# DENMARK'S NATIONAL INVENTORY REPORT 2020

## Emission Inventories 1990-2018 – Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol

Scientific Report from DCE – Danish Centre for Environment and Energy No. 372 2020

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# Data sheet

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Abstract: This report is Denmark's National Inventory Report 2020, which serves as documentation for the Danish greenhouse gas inventories submitted to the European Union and the United Nations. The report contains information on Denmark's emission inventories for all years' from 1990 to 2018 for $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs and $SF_6$.

Keywords: Emission Inventory; UNFCCC; IPCC; $CO_2$; $CH_4$; $N_2O$; HFCs; PFCs; $SF_6$

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Additional Information: Revised on 6th May. In the revised version an error was corrected related to the $CH_4$ emission from manure management. The main changes are in Chapter 5, specifically in Chapter 5.1, 5.4, 5.12 and 5.14. Additionally, the change in $CH_4$ emission from agriculture has led to updates elsewhere in the report when reference is made to shares of total emission or trends in emissions. This includes, inter alia, the summary, Chapter 1.7, Chapter 2, Chapter 9, Chapter 17, Annex 1 and Annex 3D.

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# List of abbreviations

| | |
|---|---|
| BAT | Best Available Techniques |
| $CH_4$ | Methane |
| CHP | Combined Heat and Power |
| CHR | Central Husbandry Register |
| CLRTAP | Convention on Long-Range Transboundary Air Pollution |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| COPERT | COmputer Programme to calculate Emissions from Road Transport |
| CORINAIR | CORe INventory on AIR emissions |
| CRF | Common Reporting Format |
| DAAS | Danish Agricultural Advisory Service |
| DAFA | Danish AgriFish Agency |
| DCA | Danish Centre for food and Agriculture |
| DCE | Danish Centre for Environment and energy |
| DEA | Danish Energy Agency |
| DEPA | Danish Environmental Protection Agency |
| DST | Statistics Denmark |
| EEA | European Environment Agency |
| EF | Emission Factor |
| EIONET | European Environment Information and Observation Network |
| EMEP | European Monitoring and Evaluation Programme |
| ENVS | Department of ENVironmental Science, Aarhus University |
| EU ETS | European Union Emission Trading Scheme |
| FSE | Full Scale Equivalent |
| GE | Gross Energy |
| GHG | Greenhouse gas |
| GWP | Global Warming Potential |
| HFCs | Hydrofluorocarbons |
| IDA | Integrated Database model for Agricultural emissions |
| IEF | Implied Emission Factor |
| IGN | Department of Geosciences and Natural Resource Management, Copenhagen University |
| IPCC | Intergovernmental Panel on Climate Change |
| KCA | Key Category Analysis |
| LPG | Liquefied Petroleum Gas |
| LRTAP | Long-Range Transboundary Air Pollution |
| LTO | Landing and Take Off |
| LULUCF | Land Use, Land-Use Change and Forestry |
| MCF | Methane Conversion Factor |
| MSW | Municipal Solid Waste |
| $N_2O$ | Nitrous oxide |
| $NF_3$ | Nitrogen trifluoride |
| NFI | National Forest Inventory |
| NFR | Nomenclature For Reporting |
| $NH_3$ | Ammonia |
| NIR | National Inventory Report |
| NMVOC | Non-Methane Volatile Organic Compounds |
| $NO_x$ | Nitrogen Oxides |
| PFCs | Perfluorocarbons |
| QA | Quality Assurance |

| | |
|---|---|
| QC | Quality Control |
| SCR | Selective Catalytic Reduction |
| $SF_6$ | Sulphur hexafluoride |
| SNAP | Selected Nomenclature for Air Pollution |
| $SO_2$ | Sulphur dioxide |
| SWDS | Solid Waste Disposal Sites |
| UNECE | United Nations Economic Commission for Europe |
| UNFCCC | United Nations Framework Convention on Climate Change |
| VS | Volatile Solids |
| WWTP | WasteWater Treatment Plant |

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- The European Environment Agency for granting permission for Denmark to use the CRF Aggregator tool for the submissions under the Kyoto Protocol and the UNFCCC.

# Executive summary

## ES.1 Background information on greenhouse gas inventories and climate change

### ES.1.1 Reporting

This report is Denmark's National Inventory Report (NIR) 2020 for submission to the United Nations Framework Convention on Climate Change due April 15, 2020. The report contains detailed information about Denmark's inventories for all years from 1990 to 2018. The structure of the report is in accordance with the UNFCCC reporting guidelines (UNFCCC, 2013). The main difference between Denmark's NIR 2020 report to the European Commission, due March 15, 2020, and this report to UNFCCC is reporting of territories. The NIR 2020 to the EU Commission was for Denmark, while this NIR 2020 to the UNFCCC is for Denmark, Greenland and the Faroe Islands. The report includes detailed and complete information on the inventories for all years from year 1990 to the year 2018, in order to ensure transparency.

The annual emission inventories for the years from 1990 to 2018 are reported in the Common Reporting Format (CRF). Within this submission separate CRF's are available for Denmark (EU and KP – CP2), Greenland, the Faroe Islands, for Denmark and Greenland (KP – CP1) as well as for Denmark, Greenland and the Faroe Islands (UNFCCC). The CRF spreadsheets contain data on emissions, activity data and implied emission factors for each year. Emission trends are given for each greenhouse gas and for total greenhouse gas emissions in $CO_2$ equivalents.

The issues addressed in this report are: Trends in greenhouse gas emissions, description of each emission category of the CRF, uncertainty estimates, explanations on recalculations, planned improvements and procedure for quality assurance and control. The information presented in Chapters 2-9 and Chapter 11 refers to Denmark (EU and KP – CP2) only. Specific information regarding the submission of Greenland and the Faroe Islands is included in Chapter 16 and Annex 8, respectively. Chapter 17 contains information on the aggregated submission of Denmark and Greenland under the Kyoto Protocol (e.g. on trends, uncertainties and key category analysis).

This report itself does not contain the full set of CRF tables. The full set of CRF tables is available at the EIONET, Central Data Repository, kept by the European Environmental Agency:
http://cdr.eionet.europa.eu/dk/Air_Emission_Inventories

In the report English notation is used: "." (full stop) for decimal sign and mostly space for division of thousands. The English notation for division of thousand as "," (comma) is not used due to the risk of being misinterpreted by Danish readers.

### ES.1.2 Institutions responsible

On behalf of the Ministry of the Environment and Food and the Ministry of Energy, Utilities and Climate, the Danish Centre for Environment and Energy (DCE), Aarhus University, is responsible for the calculation and reporting of the Danish national emission inventory to EU, the UNFCCC (United Nations Framework Convention on Climate Change) and the UNECE LRTAP

(Long Range Transboundary Air Pollution) conventions. Hence, DCE prepares and publishes the annual submission for Denmark to the EU and UNFCCC of the National Inventory Report and the greenhouse gas (GHG) inventories in the Common Reporting Format, in accordance with the UNFCCC guidelines. Further, DCE is responsible for reporting the national inventory for the Kingdom of Denmark to the UNFCCC. DCE is also the body designated with overall responsibility for the national inventory under the Kyoto Protocol for Greenland and Denmark. Furthermore, DCE participates when reporting issues are discussed in the regime of UNFCCC and EU (Monitoring Mechanism).

The work concerning the annual greenhouse gas emission inventory is carried out in cooperation with Danish ministries, research institutes, organisations and companies. The Government of Greenland is responsible for finalising and transferring the inventory for Greenland to DCE. The Faroe Islands Environmental Agency is responsible for finalising and transferring the inventory for the Faroe Islands to DCE.

### ES.1.3 Greenhouse gases

The greenhouse gases reported are those under the UN Climate Convention:

- Carbon dioxide $CO_2$
- Methane $CH_4$
- Nitrous oxide $N_2O$
- Hydrofluorocarbons HFCs
- Perfluorocarbons PFCs
- Sulphur hexafluoride $SF_6$
- Nitrogen trifluoride $NF_3$

The global warming potential (GWP) for various greenhouse gases has been defined as the warming effect over a given time frame of a given weight of a specific substance relative to the same weight of $CO_2$. The purpose of this measure is to be able to compare and integrate the effects of the individual greenhouse gases on the global climate. Typical lifetimes in the atmosphere of greenhouse gases are very different, e.g. approximately 9 and 130 years for $CH_4$ and $N_2O$, respectively. So the time perspective clearly plays a decisive role. The life frame chosen is typically 100 years. The effect of the various greenhouse gases can then be converted into the equivalent quantity of $CO_2$, i.e. the quantity of $CO_2$ giving the same effect in absorbing solar radiation. According to the IPCC and their Fourth Assessment Report, which UNFCCC has decided to use as reference, the global warming potentials for a 100-year time horizon are:

- Carbon dioxide ($CO_2$): 1
- Methane ($CH_4$): 25
- Nitrous oxide ($N_2O$): 298

Based on weight and a 100-year period, $CH_4$ is thus 25 times more powerful a greenhouse gas than $CO_2$ and $N_2O$ is 298 times more powerful than $CO_2$. Some of the other greenhouse gases (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) have considerably higher global warming potentials. For example, sulphur hexafluoride has a global warming potential of 22 800. The values for global warming potential used in this report are those prescribed by UNFCCC. The indirect greenhouse gases reported are nitrogen oxides ($NO_x$), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and sulphur dioxide ($SO_2$).

## ES.2 Summary of national emission and removal trends

Summary ES.2-4 refers to the inventory for Denmark only. The inventories for Greenland, Denmark and Greenland and the Faroe islands are described in Chapter 16 and 17 and Annex 8, respectively. The emissions from Greenland and the Faroe Islands are minor compared to the emissions from Denmark and shows limited fluctuations.

### ES.2.1 Greenhouse gas emissions inventory

The greenhouse gas emissions are estimated according to the IPCC guidelines and are aggregated into six main sectors. The greenhouse gases include $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$ and $NF_3$, although $NF_3$ is not occurring in Denmark. Figure 2.1 shows the estimated total greenhouse gas emissions in $CO_2$ equivalents from 1990 to 2018. The emissions are not corrected for electricity trade or temperature variations.

$CO_2$ is the most important greenhouse gas contributing in 2018 to the national total in $CO_2$ equivalents excluding LULUCF (Land Use and Land Use Change and Forestry) with 72.3 %, followed by $CH_4$ with 15.3 %, $N_2O$ with 11.3 %, and f-gases (HFCs, PFCs, $SF_6$ and $NF_3$) with 1.2 %. The energy sector and agriculture represent the largest sources, followed by industrial processes and product use and waste, see Figure 2.1. The net GHG emission by LULUCF in 2018 is 13.9 % of the total emission in $CO_2$ equivalents excl. LULUCF. The total national greenhouse gas emission in $CO_2$ equivalents excluding LULUCF and including indirect $CO_2$ has decreased by 32.1 % from 1990 to 2018, if excluding indirect $CO_2$ the emissions have decreased by 31.4 %. The decrease is mainly caused by decreasing emissions from the energy sector due to increasing production of wind power and other renewable energy. Comments on the overall trends etc. seen in Figure 2.1 are given in the sections below on the individual greenhouse gases.

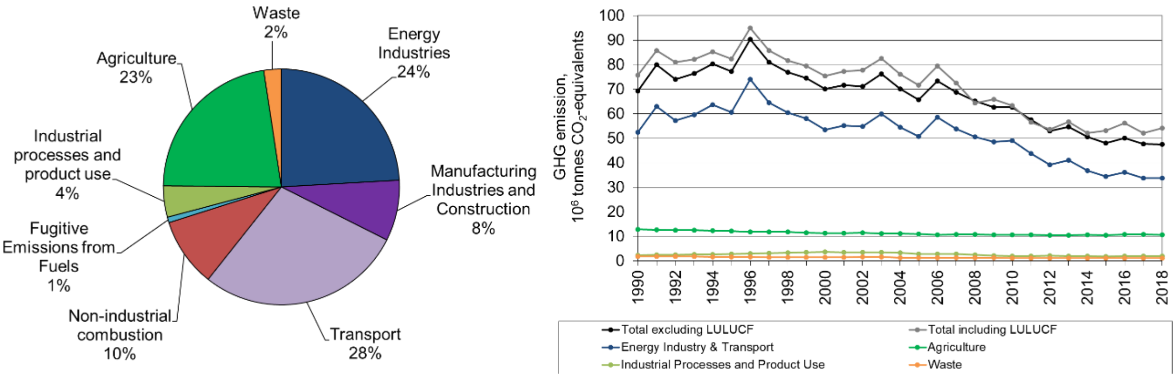



Figure 2.1 Greenhouse gas emissions in $CO_2$ equivalents distributed on main sectors for 2018 (excluding LULUCF and indirect $CO_2$) and time series for 1990 to 2018.

### ES.2.2 KP-LULUCF activities

Table ES.1 contains information on emissions/removals of greenhouse gases in 2017.

Table ES.1 Emissions and removals in 2018 for activities relating to Article 3.3 and Article 3.4.

| | Net $CO_2$ emissions/ removals | $CH_4$ | $N_2O$ | Net $CO_2$ equivalents emissions/ removals |
|---|---|---|---|---|
| | | | | kt |
| A. Article 3.3 activities | | | | -166.74 |
| A.1. Afforestation and Reforestation | -340.46 | 0.04 | 0.02 | -332.29 |
| A.2. Deforestation | 161.09 | 0.02 | 0.01 | 165.55 |
| B. Article 3.4 activities | | | | 6692.31 |
| B.1. Forest Management | 508.90 | 1.13 | 0.06 | 554.20 |
| B.2. Cropland Management | 4526.13 | 5.33 | 0.03 | 4667.32 |
| B.3. Grazing Land Management | 1389.53 | 3.20 | 0.00 | 1470.80 |
| B.4. Revegetation | NA | NA | NA | NA |
| B.5. Wetland drainage and rewetting | NA | NA | NA | NA |

## ES.3 Overview of source and sink category emission estimates and trends

### ES.3.1 Greenhouse gas emissions inventory

#### Energy

The emission from the energy sector in 2018 covers 70.3 % of the total emission in $CO_2$ equivalents (excl. LULUCF and indirect $CO_2$). The emission of $CO_2$ equivalents from Energy Industries (CRF 1A1) has decreased by 56.3 % from 1990 to 2018. The relatively large fluctuation in the emission through the time-series 1990-2018 is due to inter-country electricity trade. Thus, the high emissions in 1991, 1996, 2003 and 2006 reflect a large electricity export and the low emission in 1990, 2005, 2008, 2011 and 2012 is due to import of electricity. In general, $CO_2$ emissions are decreasing due to a lower consumption of fossil fuels.

The increasing emission of $CH_4$ is due to the increasing use of gas engines in decentralised cogeneration plants. However, in later years the $CH_4$ emission has decreased due to less use of natural gas in gas engines. The $CH_4$ emission from residential combustion (mainly wood) has increased as a result of increased use of wood. The emission of $CO_2$ equivalents from the transport sector (CRF 1A3) increased by 25.0 % from 1990 to 2018, mainly due to increasing road traffic.

#### Industrial processes and product use

The emissions from industrial processes and product use, i.e. emissions from processes other than fuel combustion, amount in 2018 to 4.3 % of the total emission in $CO_2$ equivalents (excl. LULUCF). The main sources are cement production and f-gases used in refrigeration and air conditioning.

The largest source is $CO_2$ emission from cement production, which in 2018 contributes with 1159.7 kt $CO_2$, i.e. 2.4 % of the national greenhouse gas emissions. The $CO_2$ emission from cement production has increased by 31.4 % since 1990. The second largest source is the emission from consumption of HFCs from refrigeration and air condition equipment. This source contributes with 473.8 kt $CO_2$ equivalents, i.e. 1.0 % of the national total. Historically (1990-2004), the emission of $N_2O$ from the production of nitric acid has been the second largest source (after cement), with up to 1002.5 kt $CO_2$ equivalents (1990). However, the production of nitric acid ceased in 2004, which reduced the $N_2O$ emission from industrial processes drastically.

### Agriculture

The agricultural sector contributes in 2018 with 23.0 % of the total emission in $CO_2$ equivalents (excl. LULUCF) and the major part is related to the livestock production. Since 1990, the agricultural emission has decreased 16.1 % mainly due to a decrease in the $N_2O$ emission.

In 2018, the agricultural activities accounts for 81.6 % of the total $CH_4$ emission (excl. LULUCF). Since 1990, the emission of $CH_4$ from enteric fermentation has decreased by 6.7 %, which is mainly due to the decrease in the number of dairy cattle. However, the emission from manure management has in the same period increased 19.7 %, which is mainly driven by a change from traditional housing systems towards slurry-based housing systems. In total, the $CH_4$ emission from the agriculture sector 1990 – 2018 has increased 1.6 %.

In 2018, the agricultural activities accounts for 89.0 % of the total $N_2O$ emission (excl. LULUCF). Since 1990, the $N_2O$ emission has decreased 27.7 %. A string of measures have been introduced by action plans to prevent the loss of nitro-gen from agriculture to the aquatic environment. These actions have brought a decrease in animal nitrogen excretion, improvement in use of nitrogen in manure and a fall in the use of inorganic N fertiliser, which all have consequences for a reduce of the $N_2O$ emission.

### Land Use and Land Use Change and Forestry (LULUCF)

The total sector has been estimated to be a net source of 0-14 % of the total Danish emission incl. LULUCF (average 2013-2018). The average emission in 2013-2018 has been estimated to 4312 kt $CO_2$-eq. with an emission of 6645 kt $CO_2$-eq. in 2018. Emissions/removals from the sector fluctuate based on specific conditions in the given year. In general, the forest sector has been a net sink, while Cropland and Grassland have been net sources. The latter due to a large area with drained organic soils. Emissions from drained organic agricultural soils accounts for approximately for 6-7 % of the total Danish emission incl. LULUCF in the latter years. In years where the total sector accounts to approximately zero, the forest and/or the agricultural mineral soils are net sinks. Forest has shown to be a large sink until 2014 and turned into a small net source in 2015, 2016 and 2018. In 2017, Forest was a small sink. Since 2013, Forest has been estimated to be an accumulated net sink of 4997 kt $CO_2$ equivalents. In 2018, Cropland has been estimated to be a net source of 8.5 % of the total Danish emission incl. LULUCF. This is mainly due to a large area with cultivated organic soils. Grassland is a net source contributing to 2.7 % of the total Danish emission. This is also due to a large area with drained organic soils. Emissions from Cropland have shown a continuous decrease since 1990 with 14 % and the emission from Grassland has decreased with 4 %. However, large variations occur between years, e.g. in 2018 the emissions are very high due to the unusual high temperatures during the summer accelerating the emissions.

### Waste

The waste sector contributes in 2018 to 2.4 % of the total emission in $CO_2$ equivalents (excl. LULUCF). The emission from the sector has decreased by 35.3 % since 1990. The most important activity in the sector is solid waste disposal on land with $CH_4$ emissions contributing in 2018 to 49.2 % of the sectoral total greenhouse gas emission.

The $CH_4$ emission from solid waste disposal has been decreasing since 1990 by 63.5 % due to banning of deposing organic waste and an overall decrease in waste deposited because waste has increasingly been used for power and heat production and/or recycled.

Biological treatment of solid waste (5.B) is the second largest contributor to the sectoral total greenhouse gas emission in 2018. It contributes to the sectoral total in $CO_2$ equivalents in 2018 with 38.8 %. The emissions from biological treatment of solid waste have increased by 791 % for $CH_4$ and 590 % for $N_2O$ since 1990, due to an increase in the number of biogas plants and the amount of biowaste composted in Denmark.

Wastewater handling contributes to the sectoral total in $CO_2$ equivalents in 2018 with 10.2 %. The $CH_4$ emissions from wastewater handling have increased by 23.4 % from 1990 to 2018 while the N2O emission has decreased by 40.1 %.

Since all incinerated waste (municipal, industrial, hazardous) is used for power and heat production, the emissions are included in the 1A1a category.

### ES.3.2 KP-LULUCF activities

A more detailed description is given in Chapter 10.

## ES.4 Other information

### ES.4.1 Quality assurance and quality control

A plan for Quality Assurance (QA) and Quality Control (QC) in greenhouse gas emission inventories is included in the report. The plan is in accordance with the guidelines provided by the UNFCCC (Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories and Guidelines for National Systems). ISO 9000 standards are also used as an important input for the plan.

The plan comprises a framework for documenting and reporting emissions in a way that emphasize transparency, consistency, comparability, completeness and accuracy. To fulfil these high criteria, the data structure describes the pathway, from the collection of raw data to data compilation and modelling and finally reporting.

As part of the Quality Assurance (QA) activities, emission inventory sector reports are being prepared and sent for review to national experts not involved in the inventory development. To date, the reviews have been completed for the stationary combustion plants sector, the fugitive emissions from fuels sector, the transport sector, the solvents and other product use sector and the agricultural sector. In order to evaluate the Danish emission inventories, a project where emission levels and emission factors are compared with those in other countries has been conducted.

### ES.4.2 Completeness

The Danish greenhouse gas emission inventories include all sources identified by the revised IPPC guidelines.

Please see Annex 5 for more information.

### ES.4.3 Recalculations and improvements

Recalculations and improvements are continuously made to the inventory. The sector-specific recalculations and improvements are documented in the sectoral chapters of this report (Chapter 3-7) and a general overview is provided in Chapter 9.

# Sammenfatning

## S.1 Baggrund for opgørelse af drivhusgasemissioner og klimaændringer

### S.1.1 Rapporteringen

Denne rapport er Danmarks årlige rapport – den såkaldte Nationale Inventory Report (NIR) for 2020. Rapporten beskriver drivhusgasopgørelsen som blev fremsendt til FN's konvention om klimaændringer (UNFCCC) og Kyotoprotokollen den 15. april 2020. Rapporten indeholder detaljerede informationer om Danmarks drivhusgasudslip for alle år fra 1990 til 2018. Rapportens struktur er i overensstemmelse med UNFCCC's retningslinjer for rapportering. Forskellen mellem Danmarks NIR 2020 som blev fremsendt til EU-Kommissionen den 15. marts 2020 og denne rapport til UNFCCC, vedrører det territorium rapporteringen omfatter. NIR 2020 til EU-Kommissionen omfatter Danmark, mens NIR 2020 til UNFCCC omfatter Danmark, Grønland og Færøerne. For at sikre at opgørelserne er sammenhængende og gennemskuelig, indeholder rapporten detaljerede oplysninger om opgørelsesmetoder og baggrundsdata for alle årene fra 1990 og til 2018.

Denne emissionsopgørelse for årene 1990 til 2018, er som tidligere årlige opgørelser, rapporteret i formatet Common Reporting Format (CRF) som Klimakonventionen foreskriver anvendt. Emissionsopgørelsen i CRF foreligger med denne rapportering således, at der er separate CRF for Danmark (EU og KP – CP2), Grønland, Færøerne, for Danmark og Grønland (KP – CP1) samt for Danmark, Grønland og Færøerne (Klimakonventionen). CRF-tabellerne indeholder oplysninger om emissioner, aktivitetsdata og emissionsfaktorer for hvert år, emissionsudvikling for de enkelte drivhusgasser samt den totale drivhusgasemission i $CO_2$-ækvivalenter.

Følgende emner er beskrevet i rapporten: Udviklingen i drivhusgasemissionerne, metoder mv. som anvendes til opgørelserne i de emissionskategorier som findes i CRF-formatet, usikkerheder, genberegninger, planlagte forbedringer og procedure for kvalitetssikring og –kontrol. Teksten i kapitel 2-9 og kapitel 11 omhandler kun Danmark som omfattet af EU. Oplysninger om emissionsopgørelsen for Grønland og Færøerne er inkluderet i henholdsvis kapitel 16 og anneks 8. Kapitel 17 indeholder informationer for den samlede aflevering for Danmark og Grønland under Kyotoprotokollen (f.eks. om udviklingen i emissioner over tid, usikkerheder og identifikation af nøglekategorier).

Denne rapport indeholder ikke det fulde sæt af CRF-tabeller. Det fulde sæt af CRF-tabeller er tilgængelige på EIONET, som er det Europæiske Miljøagenturs rapporterings-internetsite:
http://cdr.eionet.europa.eu/dk/Air_Emission_Inventories

Med hensyn til gengivelsen af tal i CRF-formatet, gøres opmærksom på at det er med dansk notation: "," (komma) for decimaladskillelse og "." (punktum) til adskillelse af tusinder. I rapporten er den engelske notation brugt: "." (punktum) for decimaltegn og for det meste mellemrum for adskillelse af tusinder. Den engelske notation for adskillelse af tusinder med "," (komma) er for det meste ikke brugt på grund af risikoen for fejltolkninger for danske læsere.

### S.1.2 Ansvarlige institutioner

DCE - Nationalt Center for Miljø og Energi ved Aarhus Universitet er på vegne af Miljø- og Fødevareministeriet samt Energi-, Forsynings- og Klimaministeriet ansvarlig for udregning og afrapportering af den nationale emissionsopgørelse til EU og til UNFCCC (FN's konvention om klimaændringer) såvel som til UNECE-konventionen om langtransporteret grænseoverskridende luftforurening. Som følge heraf, er DCE ansvarlig for udførelse og publicering af opgørelserne af drivhusgasemissioner og den årlige rapportering til EU og UNFCCC for Danmark. DCE er den centrale institution for Danmarks nationale system til drivhusgasopgørelser under Kyotoprotokollen. Ydermere er DCE ansvarlig for rapportering af drivhusgasemissionsopgørelser til Klimakonventionen for Kongeriget Danmark (Færøerne, Grønland og Danmark), samt Danmarks og Grønlands samlede rapportering til Kyotoprotokollen. DCE deltager desuden i arbejdet i regi af Klimakonventionen og Kyotoprotokollen, hvor retningslinjer for rapportering diskuteres og vedtages og i EU's moniteringsmekanisme for opgørelse af drivhusgasser, hvor retningslinjer for rapportering til EU reguleres.

Arbejdet med de årlige opgørelser udføres i samarbejde med andre danske ministerier, forskningsinstitutioner, organisationer og private virksomheder. Grønlands Klima- og Infrastrukturstyrelse er ansvarlig for levering af opgørelser for Grønland til DCE. Færøernes miljømyndighed (Umhvørvisstovan) er ansvarlig for de færøske opgørelser.

### S.1.3 Drivhusgasser

Til Klimakonventionen rapporteres følgende drivhusgasser:

- Kuldioxid $CO_2$
- Metan $CH_4$
- Lattergas $N_2O$
- Hydrofluorcarboner HFC'er
- Perfluorcarboner PFC'er
- Svovlhexafluorid $SF_6$
- Nitrogentrifluorid $NF_3$

Det globale opvarmningspotentiale, på engelsk Global Warming Potential (GWP), udtrykker klimapåvirkningen over en nærmere angivet tid af en vægtenhed af en given drivhusgas relativt til samme vægtenhed af $CO_2$. Drivhusgasser har forskellige karakteristiske levetider i atmosfæren, således for $CH_4$ ca. 9 år og for $N_2O$ ca. 130 år. Derfor spiller tidshorisonten en afgørende rolle for størrelsen af GWP. Typisk vælges 100 år. Herefter kan effekten af de forskellige drivhusgasser omregnes til en ækvivalent mængde $CO_2$, dvs. til den mængde $CO_2$ der vil give samme klimapåvirkning. Til rapporteringen til Klimakonventionen er vedtaget at anvende GWP-værdier for en 100-årig tidshorisont, som ifølge IPCC's fjerde vurderingsrapport er:

- Kuldioxid, $CO_2$: 1
- Metan, $CH_4$: 25
- Lattergas, $N_2O$: 298

Regnet efter vægt og over en 100-årig periode er metan således ca. 25 og lattergas ca. 298 gange så effektive drivhusgasser som kuldioxid. For andre drivhusgasser der indgår i rapporteringen, de såkaldte F-gasser (HFC, PFC, $SF_6$, $NF_3$) findes væsentlig højere GWP-værdier. Under Klimakonventionen er der ligeledes vedtaget GWP-værdier for disse baseret på IPCC's anbefalinger. Således har f.eks. $SF_6$ en GWP-værdi på 22 800. I denne rapport anvendes de GWP-værdier, som UNFCCC har vedtaget.

Endvidere rapporteres de indirekte drivhusgasser kvælstofilte ($NO_x$), kulilte (CO), ikke-metan flygtige organiske forbindelser (NMVOC) og svovldioxid ($SO_2$).

## S.2 Udviklingen i drivhusgasemissioner og optag

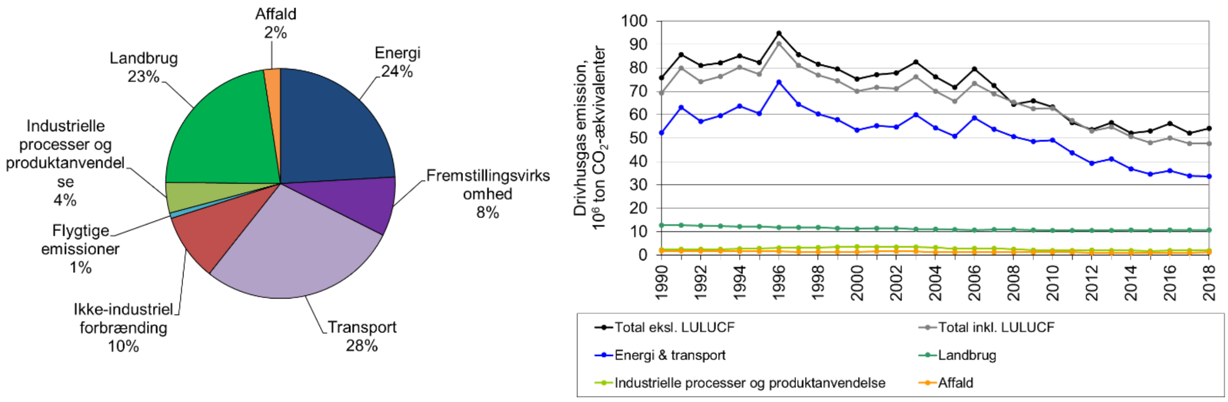
Sammenfatning S.2.-4. omhandler alene opgørelsen for Danmark. Opgørelsen for Grønland, Danmark og Grønland samt for Færøerne beskrives i kapitel 16 og 17 samt i Annex 8.

### S.2.1 Drivhusgasemissionsopgørelse

De danske opgørelser af drivhusgasemissioner følger metoderne som beskrevet i IPCC's retningslinjer. Opgørelserne er opdelt i seks overordnede sektorer, 1. energi, 2. industrielle processer og produktanvendelse, 3. landbrug, 4. arealanvendelse (Land Use Land Use Change and Forestry: LULUCF), 5. affald og 6. andet. Drivhusgasserne omfatter $CO_2$, $CH_4$, $N_2O$ og F-gasserne: HFC'er, PFC'er, $SF_6$ og $NF_3$. I Figur S.1 ses de estimerede drivhusgasemissioner for Danmark i $CO_2$-ækvivalenter for perioden 1990 til 2018. Figuren viser Danmarks totale udledning med og uden LULUCF-sektoren (Land Use and Land Use Change and Forestry). Til venstre i figur S.1 ses det relative bidrag til Danmarks totale udledning (uden LULUCF) i 2018 for sektorerne 1-3 og 5. For sektor 1. energi er transport (hovedsagelig vejtransport) vist særskilt. Sektor 4. LULUCF indgår ikke i denne figur da sektoren omfatter kilder, der bidrager med både optag og udledninger.

I overensstemmelse med retningslinjerne for opgørelserne er emissionerne ikke korrigerede for handel med elektricitet med andre lande og temperatursvingninger fra år til år.

$CO_2$ er den vigtigste drivhusgas og bidrager i 2018 med 72,3 % af den nationale totale udledning uden LULUCF-sektoren, efterfulgt af $CH_4$ med 15,3 % og $N_2O$ med 11,3 %, mens HFC'er, PFC'er og $SF_6$ kun udgør 1,2 % af de totale emissioner uden LULUCF-sektoren. Set over perioden 1990-2018, har disse procenter været stigende for $CH_4$ og F-gasser og svagt faldende for $N_2O$. For $CO_2$, har procenterne fluktueret mere gennem perioden. Netto $CO_2$-emissionen fra LULUCF er i 2018 13,9 % af den nationale totale emission eksklusiv LULUCF. Med hensyn til sektorerne (figur S.1) så bidrager energi ekskl. vejtransport (hovedsageligt stationære forbrændingsanlæg), transport og landbrug mest i 2018 (Figur S.1). De nationale totale drivhusgasemissioner i $CO_2$-ækvivalenter inklusiv indirekte $CO_2$ er faldet med 32,1 % fra 1990 til 2018, hvis nettobidraget fra skovenes og jordernes udledninger og optag af $CO_2$ (LULUCF) ikke indregnes. Eksklusiv LULUCF og indirekte $CO_2$ er emissionen faldet med 31,4.




Figur S.1 Danske drivhusgasemissioner. Bidrag til total emission fra hovedsektorer for 2018 og tidsserier i $CO_2$-ækvivalenter for 1990-2018, hvor data er angivet med og uden LULUCF.

### S.2.2 KP-LULUCF-aktiviteter

Tabel S.1 viser emissioner/optag fra LULUCF i 2018.

Tabel S.1 Emissioner og optag i 2018 for aktiviteter under Kyotoprotokollens artikel 3.3 og 3.4.

| | Netto $CO_2$ emission/ optag | $CH_4$ | $N_2O$ | Netto $CO_2$-ækvivalent emission/ optag |
|---|---|---|---|---|
| | | kt | | |
| A. Aktiviteter under artikel 3.3 | | | | -166.74 |
| A.1. Skovrejsning | -340.46 | 0.04 | 0.02 | -332.29 |
| A.2. Skovrydning | 161.09 | 0.02 | 0.01 | 165.55 |
| B. Aktiviteter under artikel 3.4 | | | | 6692.31 |
| B.1. Forvaltning af skov plantet før 1990 | 508.90 | 1.13 | 0.06 | 554.20 |
| B.2. Forvaltning af landbrugsarealer | 4526.13 | 5.33 | 0.03 | 4667.32 |
| B.3. Forvaltning af permanente græsarealer | 1389.53 | 3.20 | 0.00 | 1470.80 |
| B.4. Gentilplantning | NA | NA | NA | NA |
| B.5. Dræning og genetablering af vådom-råder | NA | NA | NA | NA |

## S.3 Oversigt over drivhusgasemissioner og optag fra sektorer

### S.3.1 Drivhusgasemissionsopgørelse

**Energi**

Emissionen fra energisektoren udgjorde i 2018 70,3 % af den samlede drivhusgasemission udtrykt i $CO_2$-ækvivalenter (ekskl. LULUCF og indirekte $CO_2$). Drivhusgasemissionen from energisektoren (CRF 1A1) er faldet med 56,3 % fra 1990 til 2018. De relativt store udsving i emissionerne fra år til år skyldes handel med elektricitet med andre lande, herunder særligt de nordiske. De høje emissioner i 1991, 1996, 2003 og 2006 er et resultat af stor eksport af elektricitet, mens de lave emissioner i 1990, 2005, 2008, 2011 og 2012 skyldes import af elektricitet. Den væsentligste årsag til den faldende tendens er faldende fossilt brændselsforbrug, hovedsageligt for kul og naturgas.

Udledningen af $CH_4$ fra energiproduktion har været stigende på grund af øget anvendelse af gasmotorer, som har en stor $CH_4$-emission i forhold til andre forbrændingsteknologier. Anvendelsen af gasmotorer er dog blevet mindre siden liberaliseringen af elmarkedet, hvilket har ført til lavere $CH_4$-emissioner fra energisektoren. $CH_4$-emissionen fra husholdninger er stegte på grund af et stigende forbrug af brænde i ovne og kedler. Transportsektorens drivhusgasemissioner er steget med 25,0 % siden 1990 hovedsagelig på grund af voksende vejtrafik.

### Industrielle processer og produktanvendelse

Emissionen fra industrielle processer og produktanvendelse – hvilket vil sige andre processer end forbrændingsprocesser – udgør i 2018 4,3 % af de totale danske drivhusgasemissioner. De vigtigste kilder er cementproduktion, og fluorerede gasser anvendt i kølesystemer.

$CO_2$-emissionen fra cementproduktion - som er den største kilde - bidrager med 1159,7 kt $CO_2$ svarende til 2,4 % af den totale emission i 2018. Emissionen fra cementproduktion er steget med 31,4 % fra 1990 til 2018. Den anden største kilde er emission af HFCs i forbindelse med køling og aircondition. Denne kilde bidrog i 2018 med 473,8 kt $CO_2$-ækvivalenter svarende til 1,0 % af den nationale total. Tidligere (1990-2004) var den andenstørste kilde $N_2O$ fra produktion af salpetersyre med op til 1002,5 kt $CO_2$-ækvivalenter (1990). Produktionen af salpetersyre stoppede i midten af 2004, hvilket betød, at $N_2O$-emissionen fra industrielle processer og produktanvendelse faldt drastisk.

### Landbrug

Landbrugssektoren bidrager i 2018 med 23,0 % til den totale drivhusgasemission i $CO_2$-ækvivalenter og er den vigtigste sektor hvad angår emissioner af $N_2O$ og $CH_4$. Siden 1990 er drivhusgasemissionen fra landbruget faldet med 16,1 %. Faldet skyldes hovedsageligt et fald i emissionen af $N_2O$.

I 2018 bidrog landbruget med 81,6 % af den totale emission af $CH_4$. Siden 1990 er emissionen af $CH_4$ fra husdyrenes fordøjelsessystem faldet med 6,7 % grundet et faldende antal kvæg. Emissionen fra gødningshåndtering er dog i samme periode steget med 19,7 %. Dette skyldes, at der er sket en overgang fra traditionelle staldsystemer med fast gødning til flere gyllebaserede staldsystemer med højere emissioner. Samlet set er $CH_4$ emissionen fra landbrug steget med 1,6 % siden 1990.

I 2018 bidrog landbruget med 89,0 % af den totale emission af $N_2O$. Siden 1990 er $N_2O$ emissionen faldet med 27,7 %, hvilket skyldes en lang række virkemidler med formål at begrænse tabet af kvælstof til vandmiljøet. Dette har medført et fald i udskillelsen af kvælstof fra husdyr, bedre udnyttelse af kvælstoffet i husdyrgødningen samt et fald i anvendelsen af handelsgødning. Disse ting har alle ført til en reduceret emission af $N_2O$.

### Arealanvendelse - skove og jorder (LULUCF)

Sektoren som helhed er estimeret til at værre en nettoudledning på mellem 0 og 14 % af den samlede danske emission inklusiv LULUCF. Den gennemsnitlige emission for perioden 2013-2018 er beregnet til 4312 kt $CO_2$-ækvivalenter med en emission på 6645 kt $CO_2$-ækvivalenter i 2018. Emissioner/optag fra sektoren fluktuerer baseret på de forhold (især klimatiske) i det enkelte år. Generelt har skov været et nettooptag, mens landbrugsjorde og græsarealer har været nettokilder. Grunden til at landbrug og græsarealer har været kilder er et betydeligt areal med drænede organiske jorde. Emissionen fra drænede organiske landbrugsjorde udgør ca. 6-7 % af den samlede drivhusgasemission i de senere år. Skove har været et stort optag indtil 2014, men blev en lille kilde i både 2015, 2016 og 2018. I 2017 var skov et lille optag. Siden 2013, har skov været et akkumuleret nettooptag på 4997 kt $CO_2$-ækvivalenter. I 2018 er landbrugsjorde opgjort til at være en kilde svarende til 8,5 % af den samlede danske drivhusgasemission. Græsarealer er opgjort til at være en kilde svarende til 2,7 % af den samlede danske drivhusgasemission. Emissioner fra landbrugsjorde og græsarealer er faldet siden 1990 med henholdsvis 14 % og 4 %. Emissionerne varierer dog meget mellem år, f.eks. er emissionen i 2018 meget høj på grund af den meget varme sommer, der medførte et stort kulstoftab.

**Affald**

Affaldssektoren bidrager i 2018 med 2,4 % af den samlede drivhusgasemission eksklusiv LULUCF. Emissionen fra sektoren er faldet med 35,3 % siden 1990. Den vigtigste aktivitet inden for sektoren er deponier, som står for 49,2 % af sektorens drivhusgasemissioner.

$CH_4$-emissionen fra deponier er faldet med 63,5 % siden 1990, hvilket skyldes et forbud mod deponering af forbrændingsegnet affald og et generelt fald i mængderne af deponeret affald pga. stigende affaldsforbrænding og genanvendelse.

Biologisk behandling af affald er den andenstørste kilde til affaldssektorens drivhusgasemissioner i 2017. Det bidrager med 38,8 % af sektorens emissioner i 2018. Emissionerne fra biologisk affaldsbehandling er steget kraftigt siden 1990 – $CH_4$ er steget med 791 % og $N_2O$ med 590 %. Dette skyldes den stigende popularitet af kompostering og biogasbehandling som affaldsbehandlingsmetoder.

Spildevandsbehandling bidrager til sektorens samlede emission med 10,2 % i 2018. $CH_4$-emissionen fra spildevandsbehandling er steget med 23,4 % siden 1990 mens $N_2O$-emissionen er faldet med 40,1 %.

Siden al affaldsforbrænding (husholdnings- og industriaffald samt farligt affald) udnyttes til produktion af varme og/eller elektricitet, så er emissionerne inkluderet under energisektoren, nærmere bestemt kategori 1A1a.

### S.3.2 KP-LULUCF-aktiviteter

En mere detaljeret redegørelse findes i kapitel 10.

## S.4 Andre informationer

### S.4.1 Kvalitetssikring og - kontrol

Rapporten indeholder en plan for kvalitetssikring og -kontrol af emissionsopgørelserne. Kvalitetsplanen bygger på IPCC’s retningslinjer og ISO 9000-standarderne. Planen skaber rammer for dokumentation og rapportering af emissionerne, så opgørelserne er gennemskuelige, konsistente, sammenlignelige, komplette og nøjagtige. For at opfylde disse kriterier, understøtter datastrukturen arbejdsgangen fra indsamling af data til sammenstilling, modellering og til sidst rapportering af data.

Som en del af kvalitetssikringen, udarbejdes der for emissionskilderne rapporter, der detaljeret beskriver og dokumenterer anvendte data og beregningsmetoder. Disse rapporter evalueres af personer uden for Aarhus Universitet, der har høj faglig ekspertise inden for det pågældende område, men som ikke direkte er involveret i arbejdet med opgørelserne. Indtil nu er rapporter for stationære forbrændingsanlæg, transport og landbrug blevet evalueret. Desuden er der gennemført et projekt, hvor de danske opgørelsesmetoder, emissionsfaktorer og usikkerheder sammenlignes med andre landes, for yderligere at verificere rigtigheden af opgørelserne.

### S.4.2 Fuldstændighed i forhold til IPCC's retningslinjer for kilder og gasser

De danske opgørelser af drivhusgasemissioner indeholder alle de kilder, der er beskrevet i IPCC's retningsliner.

I Anneks 5 er der flere informationer om fuldstændigheden af den danske drivhusgasopgørelse.

### S. 4.3 Genberegninger og forbedringer

Genberegninger og forbedringer bliver løbende udført i forbindelse med emissionsopgørelserne. De sektorspecifikke genberegninger og forbedringer er beskrevet i sektorafsnittene i denne rapport (Kapitel 3-7). Et generelt overblik er inkluderet i Kapitel 9.

# 1 Introduction

## 1.1 Background information on greenhouse gas inventories and climate change

### 1.1.1 Annual report

This report is Denmark's National Inventory Report (NIR) 2020 for submission to the United Nations Framework Convention on Climate Change due April 15, 2020. The report contains detailed information about Denmark's inventories for all years from 1990 to 2018. The structure of the report is in accordance with the UNFCCC reporting guidelines (UNFCCC, 2013). The main difference between Denmark's NIR 2020 report to the European Commission, due March 15, 2020, and this report to UNFCCC is reporting of territories. The NIR 2020 to the EU Commission was for Denmark, while this NIR 2020 to the UNFCCC is for Denmark, Greenland and the Faroe Islands. The report includes detailed and complete information on the inventories for all years from year 1990 to the year 2018, in order to ensure transparency.

The information in the sectoral chapters in this report relates to Denmark only, while information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 7. Chapter 17 contains information (e.g. on trends, uncertainties and key category analysis) on the aggregated submission of Denmark and Greenland.

The issues addressed in this report are trends in greenhouse gas emissions, a description of each IPCC category, uncertainty estimates, recalculations, planned improvements and procedures for quality assurance and control.

The annual emission inventories for the years from 1990 to 2018 are reported in the Common Reporting Format (CRF) as requested in the reporting guidelines. The CRF-spreadsheets contain data on emissions, activity data and implied emission factors for each year. Emission trends are given for each greenhouse gas and for the total greenhouse gas emissions in $CO_2$ equivalents.

According to the instrument of ratification, the Danish government has ratified the UNFCCC on behalf of Denmark, Greenland and the Faroe Islands. The Danish government has ratified the Kyoto Protocol on behalf of Denmark and Greenland. In the first commitment period under the Kyoto Protocol, Greenland had a reduction commitment. However, for the second commitment period, a territorial exemption for Greenland was made in the acceptance of the Doha Amendment; see C.N.773.2017.TREATIES-XXVII.7.c of 21 December 2017[1].

This report itself does not contain the full set of CRF Tables. The full set of CRF tables is available at the EIONET, Central Data Repository, kept by the European Environmental Agency:
http://cdr.eionet.europa.eu/dk/Air_Emission_Inventories/Submission_UNFCCC

[1] https://treaties.un.org/doc/Publication/CN/2017/CN.773.2017-Eng.pdf

### 1.1.2 Greenhouse gases

The greenhouse gases to be reported under the Climate Convention are:

- Carbon dioxide $CO_2$
- Methane $CH_4$
- Nitrous Oxide $N_2O$
- Hydrofluorocarbons HFCs
- Perfluorocarbons PFCs
- Sulphur hexafluoride $SF_6$
- Nitrogen trifluoride $NF_3$

The main greenhouse gas responsible for the anthropogenic influence on the heat balance is $CO_2$. The atmospheric concentration of $CO_2$ has increased from a pre-industrial value of about 280 ppm to about 390 ppm in 2010 (an increase of about 38 %) (IPCC, 2013), and exceeds the natural range of 180-300 ppm over the last 650 000 years as determined by ice cores. The main cause for the increase in $CO_2$ is the use of fossil fuels, but changing land use, including forest clearance, has also been a significant factor. The greenhouse gases $CH_4$ and $N_2O$ are very much linked to agricultural production; $CH_4$ has increased from a pre-industrial atmospheric concentration of about 722 ppb to 1803 ppb in 2011 (an increase of about 150 %) and $N_2O$ has increased from a pre-industrial atmospheric concentration of about 270 ppb to 324 ppb in 2011 (an increase of about 20 %) (IPCC, 2013). Changes in the concentrations of greenhouse gases are not related in simple terms to the effect on the heat balance, however. The various gases absorb radiation at different wavelengths and with different efficiency. This must be considered in assessing the effects of changes in the concentrations of various gases. Furthermore, the lifetime of the gases in the atmosphere needs to be taken into account – the longer they remain in the atmosphere, the greater the overall effect. The global warming potential (GWP) for various gases has been defined as the warming effect over a given time of a given weight of a specific substance relative to the same weight of $CO_2$. The purpose of this measure is to be able to compare and integrate the effects of individual substances on the global climate. Typical lifetimes in the atmosphere of substances are very different, e.g. 9 and 130 years approximately for $CH_4$ and $N_2O$, respectively. Therefore, the time perspective clearly plays a decisive role. The time frame chosen is typically 100 years. The effect of the various greenhouse gases can, then, be converted into the equivalent quantity of $CO_2$, i.e. the quantity of $CO_2$ giving the same effect in absorbing solar radiation. According to the IPCC and their Fourth Assessment Report (IPCC, 2007), which UNFCCC (UNFCCC, 2013) has decided to use as reference for reporting for inventory years throughout the commitment period 2013-2020, the global warming potentials for a 100-year time horizon are:

- Carbon dioxide ($CO_2$): 1
- Methane ($CH_4$): 25
- Nitrous oxide ($N_2O$): 298

Based on weight and a 100-year period, methane is thus 25 times more powerful a greenhouse gas than $CO_2$, and $N_2O$ is 298 times more powerful. Some of the other greenhouse gases (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) have considerably higher global warming potential values. For example, sulphur hexafluoride has a global warming potential of 22 800.

The indirect greenhouse gases reported are nitrogen oxides ($NO_x$), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and sulphur dioxide ($SO_2$).

### 1.1.3 The Climate Convention and the Kyoto Protocol

At the United Nations Conference on Environment and Development in Rio de Janeiro in June 1992, more than 150 countries signed the UNFCCC (the Climate Convention). On the 21st of December 1993, the Climate Convention was ratified by a sufficient number of countries, including Denmark, for it to enter into force on the 21st of March 1994. One of the provisions of the treaty was to stabilise the greenhouse gas emissions from the industrialised nations by the end of 2000. At the first conference under the UN Climate Convention in March 1995, it was decided that the stabilisation goal was inadequate. At the third conference in December 1997 in Kyoto in Japan, a legally binding agreement was reached committing the industrialised countries to reduce the six greenhouse gases by 5.2 % by 2008-2012 compared with the base year. For F-gases, the countries can choose freely between 1990 and 1995 as the base year. On May 16, 2002, the Danish parliament voted for the Danish ratification of the Kyoto Protocol. Denmark (including Greenland and excluding the Faroe Islands) is, thus, under a legal commitment to meet the requirements of the Kyoto Protocol, when it came into force on the 16th of February 2005. Hence, Denmark (including Greenland) was committed to reduce greenhouse gases with 8 %. The European Union was under the first commitment period of the Kyoto Protocol committed to reduce emissions of greenhouse gases by 8 %. However, within the EU member states have made a political agreement – the Burden Sharing Agreement – on the contributions to be made by each member state to the overall EU reduction level of 8 %.

Under the Burden Sharing Agreement, Denmark (excluding Greenland and the Faroe Islands) had to reduce emissions by an average of 21 % in the period 2008-2012 compared with the base year emission level.

For the second commitment period, the EU has a target of 20 % reduction compared to the base year. The reduction commitment within the EU distinguishes between the emissions covered by the EU Emission Trading System (ETS) and the non-ETS emissions. For the ETS there is a reduction of 24 % in allowances. For the non-ETS emissions, each Member State has a separate target set out in the Effort Sharing Decision, (ESD) (Decision No 406/2009/EC). In the ESD, Denmark has a reduction commitment of 20 % in 2020 compared to the emission level in 2005.

In accordance with the Kyoto Protocol, Denmark's base year emissions include the emissions of $CO_2$, $CH_4$ and $N_2O$ in 1990 and Denmark has chosen 1995 as the base year for the emissions of HFCs, PFCs and $SF_6$ and $NF_3$.

### 1.1.4 The role of the European Union

The European Union (EU) is a party to the UNFCCC and the Kyoto Protocol. Therefore, the EU has to submit similar datasets and reports for the collective 28 EU Member States[2]. For the commitment in the second commitment

[2] The status of the United Kingdom of Great Britain and Northern Ireland for the future greenhouse reporting is unknown at the time of writing.

period, the EU has entered into an agreement with Iceland on joint fulfilment.

The EU imposes some additional guidelines and obligations to the Member States through Regulation No. 525/2013/EU concerning a mechanism for monitoring and reporting greenhouse gas emissions and for implementing the Kyoto Protocol (EU monitoring mechanism). The Implementing Regulation detailing the reporting requirements was decided in 2014 (749/2014/EU). As mentioned above the ESD is the legal framework for Member States reduction commitments in the non-ETS sectors.

### 1.1.5 Background information on supplementary information required under KP article 7.1

For the LULUCF activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol Denmark has chosen annual accounting. Article 3.3 covers direct, human induced afforestation (A), reforestation (R) and deforestation (D) activities, and accounting of these activities is mandatory. Under Article 3.4 Denmark elected the activities Forest Management (FM), Cropland Management (CM) and Grazing Land Management (GM) for accounting in the first Commitment Period (CP) and hence these activities are mandatory for the second commitment period. No further activities were elected by Denmark for the second commitment period.

## 1.2 A description of the institutional arrangement for inventory preparation

On behalf of the Ministry of Environment and Food and the Ministry of Climate, Energy and Utilities, the Danish Centre for Environment and Energy (DCE) is responsible for the calculation and reporting of the Danish national emission inventory to the EU, the UNFCCC (United Nations Framework Convention on Climate Change) and UNECE CLRTAP (Convention on Long-Range Transboundary Air Pollution). Hence, DCE prepares and publishes the annual submission for Denmark to the EU and UNFCCC of the National Inventory Report and the GHG inventories in the Common Reporting Format, in accordance with the UNFCCC guidelines. Furthermore, DCE is responsible for reporting the national inventory for the Kingdom of Denmark to the UNFCCC. DCE is also the body (Single National Entity) designated with overall responsibility for the national inventory under the Kyoto Protocol.

The work concerning the annual greenhouse gas emission inventory is carried out in cooperation with Danish ministries, research institutes, organisations and companies. The Government of Greenland is responsible for finalising and transferring the inventory for Greenland to DCE. The environmental authority in the Faroe Islands (Umhvørvisstovan) is responsible for finalising and transferring the inventory for the Faroe Islands to DCE.

There are now data agreements in place with both Greenland and the Faroe Islands ensuring the data delivery. These agreements contain deadlines for when DCE is to receive the data and documentation.

DCE has been and is engaged in the work in connection with meetings of the Conference of the Parties (COP) to the UNFCCC, the Conference of the Parties serving as the Meeting of the Parties (CMP) to the Kyoto protocol and the Conference of the Parties serving as the Meeting of the Parties (CMA) to the Paris Agreement and the subsidiary bodies, where the reporting rules are negotiated and settled. Furthermore, DCE participates in the EU Monitoring Mechanism, Working Group 1 (WG1), where the guidelines, methodologies etc. on inventories to be prepared by the EU Member States are regulated.

The main experts responsible for the sectoral inventories and the corresponding chapters and annexes in this report are:

| **Project leader** | | **Ole-Kenneth Nielsen (okn@envs.au.dk)** |
|---|---|---|
| Sector | Sub-sector | Responsible expert(s) |
| Energy | Stationary combustion: | Malene Nielsen |
| | Transport and other mobile sources | Morten Winther |
| | Fugitive emissions: | Marlene Plejdrup |
| Industrial processes and product use | | Katja Hjelgaard |
| Agriculture | | Mette Hjorth Mikkelsen<br>Rikke Albrektsen |
| LULUCF | Forestry | Vivian Kvist Johannsen |
| | Harvested wood products | Vivian Kvist Johannsen |
| LULUCF | Cropland, grassland, wetlands, settlements | Steen Gyldenkærne |
| Waste | | Marianne Thomsen |
| Greenland | | Tuperna Maliina Olsen |
| Faroe Islands | | Maria Gunnleivsdóttir Hansen |

The work concerning the annual greenhouse emission inventory is carried out in cooperation with other Danish ministries, research institutes, organisations and companies:

<u>Danish Energy Agency, the Ministry of Climate, Energy and Utilities:</u> Annual energy statistics in a format suitable for the emission inventory work and fuel-use data for the large combustion plants. Company reports submitted under EU ETS.

<u>Danish Environmental Protection Agency, the Ministry of the Environment and Food:</u> Database on waste and emissions of F-gases.

<u>Danish Nature Agency, the Ministry of the Environment and Food:</u> Database on Danish wastewater quality parameters.

<u>Statistics Denmark, the Ministry of Social Affairs and the Interior:</u> Statistical yearbook, sales statistics for manufacturing industries and agricultural statistics.

<u>Danish Centre for Food and Agriculture (DCA), Aarhus University:</u> Data on use of mineral fertiliser, feeding stuff consumption and nitrogen turnover in animals.

<u>Department of Transport, Technical University of Denmark:</u> Number of vehicles grouped in categories corresponding to the EU classification, mileage (urban, rural, highway), trip speed (urban, rural, highway).

<u>Department of Geosciences and Natural Resource Management, University of Copenhagen:</u> Background data for Forestry and $CO_2$ uptake by forest. Re-

sponsible for preparing estimates of emissions/removals for reporting under KP article 3.3 and for reporting FM under article 3.4.

Civil Aviation Agency of Denmark, the Ministry of Transport and Housing: City-pair flight data (aircraft type and origin and destination airports) for all flights leaving major Danish airports.

Danish Railways, the Ministry of Transport and Housing: Fuel-related emission factors for diesel locomotives.

Danish companies: Audited green accounts and direct information gathered from producers and agency enterprises.

Formerly, the provision of data was strictly on a voluntary basis, but more formal agreements are now prepared. This is the case for e.g. the Danish Energy Agency, where the data agreement specifies the data needed and the deadlines for when DCE is to receive the data. Agreements are also in place with DCA, Statistics Denmark and the Ministry of Transport and Housing.

No written agreements are done with companies, but most of the information used in the inventory is based on other legal requirements under environmental law.

Additionally, DCE receives data from Greenland and the Faroe Islands in order to report for the Kingdom of Denmark. In both cases based on written data agreements.

The Ministry of Industry, Energy and Research, Government of Greenland: Complete CRF tables for Greenland and documentation for the inventory process.

The Faroe Islands Environmental Authority: Complete CRF tables for the Faroe Islands and documentation for the inventory process.

The complete emission inventories for the three different submissions (EU, Kyoto Protocol and UNFCCC) by Denmark are compiled by DCE and along with the documentation report (NIR) sent for official approval. In recent years, the responsibility for official approval has changed. Previously it was the Danish Environmental Protection Agency (Ministry of the Environment); now it is the Danish Energy Agency (Ministry of Climate, Energy and Building). This means that the emission inventory is finalised no later than March 15, whereupon the official approval is done prior to the reporting deadlines under the UNFCCC and the Kyoto Protocol.

## 1.3 Brief description of the process of inventory preparation. Data collection and processing, data storage and archiving

The background data (activity data and emission factors) for estimation of the Danish emission inventories is collected and stored in central databases located at the Department of Environmental Science (ENVS), Aarhus University. The databases are in Access format and handled with software developed by the European Environmental Agency and developed originally by the former National Environmental Research Institute (NERI), but is now maintained and further developed by ENVS. As input to the databases, various sub-models are used to estimate and aggregate the background data in order to fit the format and level in the central databases. The methodologies and data sources used for the different sectors are described in Chapter 1.4 and Chapters 3 to 9. As part of the QA/QC plan (Chapter 1.6), the data structure for data processing supports the pathway from collection of raw data to data compilation, modelling and final reporting.

For each submission, databases and additional tools and sub-models are frozen together with the resulting CRF-reporting format. This material is placed on central institutional servers, which are subject to routine back-up services. Material, which has been backed up, is archived safely. A further documentation and archiving system is the official archive for DCE. In this archiving system, correspondence, both incoming and outgoing, is registered, which in this case involves the registration of submissions and communication on inventories with the UNFCCC Secretariat, the European Commission, review teams, etc.

Figure 1.1 shows a schematic overview of the process of inventory preparation. The figure illustrates the process of inventory preparation from the first step of collecting external data to the last step, where the reporting schemes are generated for the UNFCCC and EU (in the CRF format (Common Reporting Format)) and to the United Nations Economic Commission for Europe/Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (UNECE/EMEP) (in the NFR format (Nomenclature For Reporting)). For data handling, the software tool is CollectER (Pulles et al., 1999) and for reporting the software tool is the CRF reporter tool developed by the UNFCCC Secretariat together with additional tools originally developed by NERI, but now maintained and further developed by ENVS. Data files and programme files used in the inventory preparation process are listed in Table 1.1.

Table 1.1 List of current data structure; data files and programme files in use.

| QA/QC Level | Name | Application type | Path | Type | Input sources |
|---|---|---|---|---|---|
| 4 store | CFR Submissions (UNFCCC and EU) | External report | U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_4a_Storage\ | MS Excel, xml | CRF Reporter |
| 4 store | NFR Report | External report | U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_4a_Storage\ | xls | NRF Report N8 Process |
| 3 process | CRF Reporter | Management tool | Working path: local machine Archive path: U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_3b_Processes | (exe + mdb) | National Compiler and Importer2CRF(xml) and IDAtoCRF(xml) |
| 3 process | NRF Report N8 Process | Helptool | U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_3b_Processes\NFR | Excel | NERIRep and Report Template (xls) |
| 3 process | Importer2CRF | Help tool | U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_3b_Processes | MS Access | CRF Reporter, CollectEr2CRF, and excel files |
| 3 process | CollectER2CRF | Help tool | U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_3b_Processes | MS Access | NERIRep |
| 3 proces | IDA2CRF | Help tool | U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_3b_Processes | MS Access | IDA_backend |
| 2 process 3 store | NERIRep | Help tool | Working path: I:\ROSPROJ\LUFT_EMI\DMURep | MS Access | CollectER databases; dk1972.mdb..dkxxxx.mdb and IDA_backend |
| 2 process | CollectER | Management tool | Working path: local machine Archive path: U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_2b_Processes | (exe +mdb) | Sector Expert |
| 2 store | dk1980.mdb.dkxxxx.mdb | Datastore | U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_2a_Storage | MS Access | CollectER |
| 1 process | IDA | Management | U:\ST_ENVS-Luft-Emi\Agriculture\InventoryAgricultureData | MS Access | Sector Expert |
| 1 store | IDA_Backend | Datastore | U:\ST_ENVS-Luft-Emi\Agriculture\InventoryAgricultureData | MS Access | IDA |

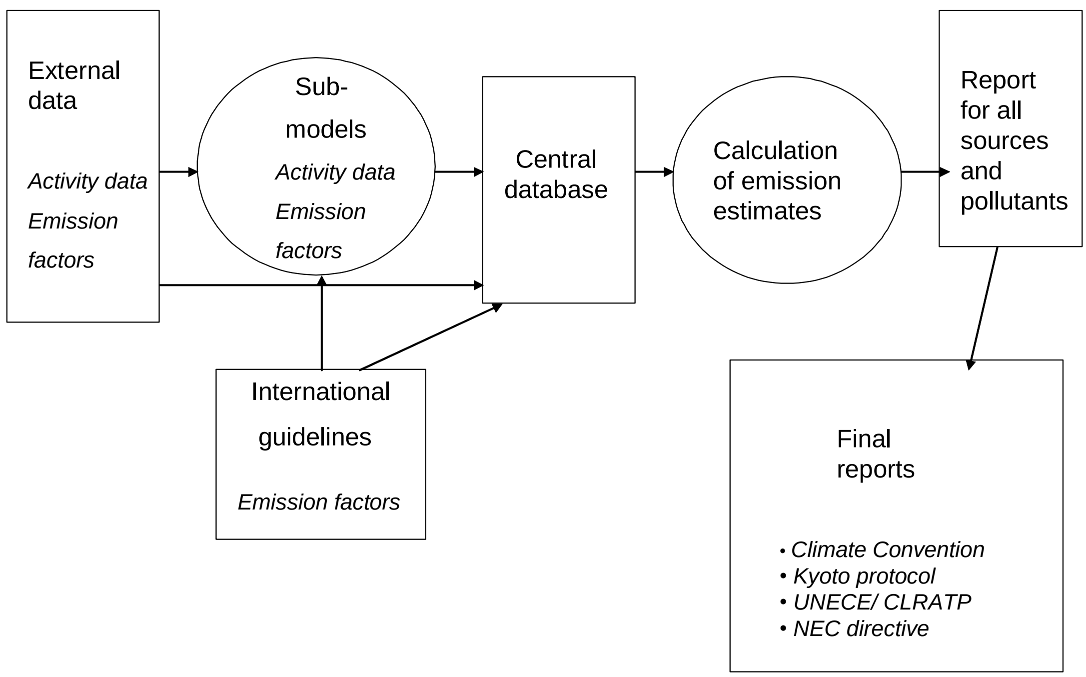



Figure 1.1 Schematic diagram of the process of inventory preparation.

Denmark has different geographical definitions for different submissions. Under the European Union, only mainland Denmark is included. For the reporting under the Kyoto Protocol, the submission includes Denmark and Greenland under the first commitment period and only Denmark for the reporting under the second commitment period. The reporting under the UNFCCC includes Denmark, Greenland and the Faroe Islands.

Due to the different geographical scopes of the Danish inventory submissions, it is necessary to operate three different versions of the CRF Reporter.

For the preparation of the Danish submission under the Kyoto Protocol, the full Danish CRF is aggregated with the Greenlandic CRF and for the UNFCCC reporting this is also aggregated with the CRF of the Faroe Islands. Under the Kyoto Protocol, Denmark now reports two submissions: one following the definition in the first commitment period and one following the definition for the second commitment period.

The process of aggregation requires additional software tools and two additional installations of CRF Reporter. The process of aggregating the KP inventory is described in Chapter 17.

## 1.4 Brief general description of methodologies and data sources used

Denmark's air emission inventories are based on the 2006 IPCC Guidelines and the CORINAIR methodology. CORINAIR (COoRdination of INformation on AIR emissions) is a European air emission inventory programme for national sector-wise emission estimations, harmonised with the IPCC guidelines. To ensure estimates are as timely, consistent, transparent, accurate and comparable as possible, the inventory programme has developed calculation methodologies for most subsectors and software for storage and further data processing (EMEP-/CORINAIR, 2007).

A thorough description of the CORINAIR inventory programme used for Danish emission estimations is given in Illerup et al. (2000). The CORINAIR calculation principle is to calculate the emissions as activities multiplied by emission factors. Activities are numbers referring to a specific process generating emissions, while an emission factor is the mass of emissions per unit activity. Information on activities to carry out the CORINAIR inventory is largely based on official statistics. The most consistent emission factors have been used either as national values or as default factors proposed by international guidelines.

A list of all subsectors at the most detailed level is given in Illerup et al. (2000) together with a translation between CORINAIR and IPCC codes for sector classifications.

### 1.4.1 Stationary Combustion Plants

Stationary combustion plants are part of the CRF emission sources *1A1 Energy Industries*, *1A2 Manufacturing Industries* and *1A4 Other sectors*.

The Danish emission inventory for stationary combustion plants is based on the CORINAIR system described in Illerup et al. (2000). The emission inventory for stationary combustion is based on activity rates from the Danish energy statistics. General emission factors for various fuels, plants and sectors have been determined. Some large plants, such as power plants, are registered individually as large point sources and plant-specific emission data are used.

The fuel consumption rates are based on the official Danish energy statistics prepared by the Danish Energy Agency (DEA). DCE aggregates fuel consumption rates to SNAP categories. The fuel consumption of the NFR category 1A4 Manufacturing industries and construction is disaggregated to subsectors according to the DEA data prepared and reported to Eurostat.

For each of the fuel and SNAP categories (sector and e.g. type of plant), a set of general emission factors has been determined. Some emission factors refer to the EMEP/EEA guidebook and some are country specific and refer to Danish legislation, Danish research reports or calculations based on emission data from a considerable number of plants.

Some of the large plants, such as e.g. power plants and municipal waste incineration plants are registered individually as large point sources and emission data from the actual plants are used. This enables use of plant specific emission factors that refer to emission measurements stated in annual environmental reports, etc. At present, the emission factors for $CH_4$ and $N_2O$ are, however, not plant-specific, whereas emission factors for $SO_2$ and $NO_X$ often are. For $CO_2$ it was possible to use data reported under the EU-ETS in the emission inventory from 2006. Therefore, it was possible to derive some plant specific $CO_2$ emission factors for coal and oil fired power plants.

The $CO_2$ from incineration of the plastic part of municipal waste is included in the Danish inventory.

Please refer to Chapter 3.2 and Annex 3A for further information on the emission inventory for stationary combustion plants.

### 1.4.2 Transport

The emissions from transport, referring to SNAP category 07 (road transport) and the sub-categories in 08 (other mobile sources), are made up in the IPCC categories: 1A2f (Industry-other), 1A3a (Civil aviation), 1A3b (road transport), 1A3c (Railways), 1A3d (Navigation), 1A4a (Commercial and Institutional), 1A4b (Residential), 1A4c (Agriculture/forestry/fisheries) and 1A5 (Other).

An internal DCE model with a structure similar to the European COPERT IV emission model (EEA, 2016) is used to calculate the Danish annual emissions for road traffic. The emissions are calculated for operationally hot engines, during cold start and fuel evaporation. The model also includes the emission effect of catalyst wear. Input data for vehicle stock and mileage is obtained from DTU Transport and Statistics Denmark, and is grouped according to average fuel consumption and emission behaviour. For each group, the emissions are estimated by combining vehicle type and annual mileage figures with hot emission factors, cold:hot ratios and evaporation factors (Tier 2 approach).

For air traffic, from 2001 onwards estimates are made on a city-pair level, using flight data provided by the Danish Civil Aviation Agency (CAA-DK) for flights between Danish airports and flights between Denmark and Greenland/Faroe Islands), and LTO and distance-related emission factors from the

CORINAIR guidelines (Tier 2 approach). For previous years, the background data consists of LTO/aircraft type statistics from Copenhagen Airport and total LTO numbers from CAA-DK. With appropriate assumptions, consistent time series of emissions are produced back to 1990, and include the findings from a Danish city-pair emission inventory in 1998.

Off-road working machines and equipment are grouped in the following sectors: inland waterways (pleasure craft), agriculture, forestry, industry, and household and gardening. The sources for stock and operational data are various branch organisations and key experts. In general, the emissions are calculated by combining information on the number of different machine types and their respective load factors, engine sizes, annual working hours and emission factors (Tier 2 approach).

The inventory for navigation consists of regional ferries, local ferries and other national sea transport (sea transport between Danish ports and between Denmark and Greenland/Faroe Islands). For regional ferries, the fuel consumption and emissions are calculated as a product of number of round trips per ferry route (Statistics Denmark), sailing time per round trip, share of round trips per ferry, engine size, engine load factor and fuel consumption/emission factor. The estimates take into account the changes in emission factors and ferry specific data during the inventory period.

For the remaining navigation categories, the emissions are calculated simply as a product of total fuel consumption and average emission factors. For each inventory year, this emission factor average comprises the emission factors for all present engine production years, according to engine life times.

Please refer to Chapter 3.3 and Annex 3B for further information on emissions from transport.

### 1.4.3 Fugitive emissions from fuels

#### Fugitive emissions from oil (1.B.2.a)

Fugitive emissions from oil are estimated according to the methodology described in the Emission Inventory Guidebook (EEA, 2016). The sources include offshore extraction of oil and gas, onshore oil tanks, onshore and offshore loading of ships, and gasoline distribution. Activity data is given in the Danish Energy Statistics by the Danish Energy Agency. The emission factors are based on the figures given in the guidebook except in the case of onshore oil tanks and gasoline distribution where national values are included.

The VOC emissions from petroleum refinery processes cover non-combustion emissions from feed stock handling/storage, petroleum products processing, and product storage/handling. $SO_2$ is also emitted from non-combustion processes and it includes emissions from product processing and sulphur-recovery plants. The emission calculations are based on information from the Danish refineries.

#### Fugitive emissions from natural gas (1.B.2.b)

Inventories of NMVOC emission from transmission and distribution of natural gas and town gas are based on annual environmental reports from the Danish gas transmission company and annual reports for the gas distribution companies. The annual gas composition is based on Energinet.dk.

#### Fugitive emissions from flaring (1.B.2.c)

Emissions from flaring offshore, in gas treatment and storage plants, and in refineries are included in the inventory. Emissions calculations are based on annual reports from the Danish Energy Agency and environmental reports from gas storage and treatment plants and the refineries. Calorific values are based on the reports for the EU ETS for offshore flaring, on annual gas quality data from Energinet.dk, and on additional data from the refineries. Emission factors are based on the Emission Inventory Guidebook (EEA, 2016).

Please refer to Chapter 3.5 for further information on fugitive emissions from fuels.

### 1.4.4 Industrial processes and product use

Energy consumption associated with industrial processes and the emissions thereof are included in the Energy sector of the inventory. This is due to the overall use of energy balance statistics for the inventory.

There is only one producer of cement in Denmark, Aalborg Portland Ltd. The activity data for the production of cement clinker is obtained from the company and the $CO_2$ emission is from the company report to EU-ETS. The methodology is approved by the Danish Energy Agency and the yearly emission estimate is in accordance with the methodology.

The reference for the activity data for production of lime, hydrated lime, expanded clay products and bricks, is the production statistics from the manufacturing industries, published by Statistics Denmark.

Limestone is used for the refining of sugar as well as for wet flue gas cleaning at power plants and waste incineration plants. The reference for the activity data is Statistics Denmark for sugar, Energinet.dk for gypsum from power plants combined with specific information on consumption of $CaCO_3$ at specific power plants and National Waste Statistics for gypsum from waste incineration. The emission factors are based on stoichiometric relations between consumption of $CaCO_3$ and gypsum generation as well as consumption of lime for sugar refining and precipitation with $CO_2$. This information is supplemented with company reports to EU-ETS.

The reference for the activity data for asphalt roofing is Statistics Denmark for consumption of roofing materials, combined with technical specifications for roofing materials produced in Denmark. The emission factors are default factors.

For road paving with asphalt, the reference for the activity data is Statistics Denmark for consumption of asphalt and cutback asphalt. The emission factors are default factors for consumption of asphalt and an estimated emission factor for cutback asphalt based on the statistics on the emission of NMVOC compiled by the industrial organisations in question.

The reference for activity data for the production of glass and glass wool are obtained from the producers published in their environmental reports. Emission factors are based on stoichiometric relations between raw materials and $CO_2$ emissions. This information is supplemented with company reports to EU-ETS.

The production of lime and yellow bricks gives rise to $CO_2$ emissions. The emission factors are based on stoichiometric relations, assumption on $CaCO_3$ content in clay as well as a default emission factor for expanded clay products. This information is supplemented with company reports to EU-ETS.

There was one producer of nitric acid in Denmark. The data in the inventory relies on information from the producer. The producer reported emissions of $NO_x$ and $NH_3$ as measured emissions and emissions of $N_2O$ for 2003 as estimated emissions. The emission of $N_2O$ in 2005 and forward is not occurring as the nitric acid production was closed down in the middle of 2004.

There is one producer of catalysts in Denmark. The data in the inventory relies on information published by the producer in environmental reports.

There was one steelwork in Denmark. The activity data as well as data on consumption of raw materials (coke) has been published by the producer in environmental reports. Emission factors are based on stoichiometric relations between raw materials and $CO_2$ emission. The electro steelwork was closed in 2005.

The inventory on F-gases (HFCs, PFCs and $SF_6$) is based on work carried out by the Danish Consultant Company "Provice". Their yearly report (DEPA, 2020) documents the inventory data up to the year 2017. The methodology is implemented for the whole time series 1990-2017, but full information on activities only exists since 1995.

This emission inventory includes $N_2O$ emissions from the use of anaesthesia for 2000 onwards. Five companies sell $N_2O$ in Denmark and only one company produces $N_2O$. Due to confidentiality, no data on produced amount are available and thus the emissions related to $N_2O$ production are unknown. An emission factor of one is assumed for all use, which equals the sold amount to the emitted amount.

Emissions from other product use such as fireworks, tobacco and charcoal for grilling are included in the inventory. Activity data on consumption of fireworks, tobacco and charcoal are obtained from Statistics Denmark. The emission factors used refer to international literature.

Please refer to Chapter 4 for further information on the emission inventory for industrial processes and product use.

### 1.4.5 Agriculture

The calculation of emissions from the agricultural sector is based on methods described in the IPCC Guidelines (IPCC, 2006). Activity data for livestock is on a one-year average basis from the agricultural statistics published by Statistics Denmark (2019). Data concerning the land use and crop yield is also from the agricultural statistics. Data concerning the feed consumption and nitrogen excretion is based on information from the Danish Centre for Food and Agriculture (Aarhus University). The $CH_4$ Implied Emission Factors for Enteric Fermentation and Manure Management are based on a Tier 2/CS approach for all animal categories except for poultry, which are based on a Tier 1 approach. All livestock categories in the Danish emission inventory are based on an average of certain subgroups separated by differences in animal breed, age and weight class. The emissions from enteric fermentation for fur farming are estimated to be not applicable.

Emission of $N_2O$ is closely related to the nitrogen balance. Thus, quite a lot of the activity data is related to the Danish calculations for ammonia emission (Albrektsen et al., 2017). National standards are used to estimate the amount of ammonia emission. When estimating the $N_2O$ emission the IPCC standard value is used for all emission sources. The emission of $CO_2$ from Agricultural Soils is included in the LULUCF sector.

A model-based system is applied for the calculation of the emissions in Denmark. This model (IDA – Integrated Database model for Agricultural emissions) is used to estimate emission from both greenhouse gases and ammonia. A more detailed description is published in Mikkelsen et al. (2011). The emissions from the agricultural sector are mainly related to livestock production. IDA works on a detailed level and includes around 38 livestock categories, and each category is subdivided according to housing type and manure type. The emissions are calculated from each subcategory and the emissions are aggregated in accordance with the livestock category given in the CRF.

To ensure data quality, both data used as activity data and background data used to estimate the emission factor are collected, and discussed in cooperation with specialists and researchers in different institutions. Thus, the emission inventory will be evaluated continuously according to the latest knowledge. Furthermore, time series of both emission factors and emissions in relation to the CRF categories are prepared. Any considerable variations in the time series are explained.

The uncertainties for assessment of emissions from enteric fermentation, manure management, agricultural soils and field burning of agricultural residue have been estimated based on a Tier 1 approach. The most significant uncertainties are related to the emissions of $N_2O$ from agricultural soils.

A more detailed description of the methodology for the agricultural sector is given in Chapter 5 and Annex 3D.

### 1.4.6 Land Use, Land Use Change and Forestry

A complete Land Use Change matrix based on satellite imaging of the entire Danish land area, together with cadastral information has been prepared for the six major area classes. This has improved the coverage and the quality of the inventory substantially.

$CO_2$ emissions from cropland and grassland are based on census data from Statistics Denmark as regards size of area and crop yield combined with GIS-analysis on land use from the EU agricultural subsidiary system. This gives a very high accuracy for land use. All applicable pools are reported for Cropland and Grassland. The emission from mineral soils for cropland is estimated with a three-pooled dynamical soil carbon model (C-TOOL). C-TOOL was initialised in 1980. The model is run for each region corresponding to former counties in Denmark. Emissions from organic soils in cropland are based on new nationally developed emission factors. For grassland IPCC Tier 1b values are used. National models have been developed for wooden perennial crops in cropland based on land use statistics from Statistic Denmark. These are of minor importance. Sinks in hedgerows are calculated based on a nationally developed model. The area with hedgerows is estimated from information on hedgerows established with financial support from the Danish Government and aerial photos. Emissions from liming are calculated from annual sales data collected by the Danish Agricultural Advisory Centre, combined with the acid neutralisation capacity for each lot produced.

For wetlands, emissions are reported from peat extraction areas. Natural wetlands are not reported. A comprehensive programme for restoration of wetlands is implemented in Denmark. Other land uses converted to wetlands is therefore reported.

For having estimates for the KP accounting other land uses converted to settlements is reported but not settlements remaining as settlements.

No estimates are made for other land remaining other land and no conversion of land to other land is occurring. For having estimates for the KP accounting estimates for living biomass are provided for land converted from other land to other land uses.

### 1.4.7 Waste

For 5.A Solid waste disposal, only managed waste disposal sites are of importance and registered; i.e. unmanaged and illegal disposal of waste is considered to play a negligible role in the context of this category. The $CH_4$ emission at the Danish SWDSs is based on a First Order Decay (FOD) model corresponding to an IPCC tier 2/3 approach (IPCC, 2006). Data on waste types and amounts deposited at solid waste disposal sites is according to the official registration collected by the Danish Environmental Protection Agency (DEPA, 2016). The model calculations are performed using landfill site characteristics and statistics on the amounts of waste fractions deposited each year. Improved documentation of the methodology, input parameter data including uncertainty analysis is described in Chapter 7.2.

Regarding 5.C Incineration and open burning of waste, all municipal, industrial, hazardous and medical waste incinerated is used for energy and heat production. This production is included in the energy statistics, hence emissions are included in the CRF under fuel combustion activities (CRF sector 1A), and more specifically waste incineration takes place in CRF sectors 1A1a, 1A2f and 1A4a. For the 2011 submission, reporting in this category covers incineration of corpses and carcasses. The activity data are obtained from the National Association of Danish Crematoria and the three facilities incinerating carcasses.

For 5.D Wastewater treatment and discharge, country-specific methodologies are used for calculating the emissions of $CH_4$ and $N_2O$ at wastewater treatment plants (WWTPs). Fugitive methane releases from the municipal and private WWTPs have been divided into contributions from 1) the sewer system, primary settling tank and biological N and P removal processes, 2) from anaerobic treatment processes in closed systems with biogas extraction and combustion for energy production and 3) septic tanks. $N_2O$ formation and releases during the treatment processes at the WWTPs and from discharged effluent wastewater are included. Documentation of the methodology, emission factors and activity data are included in Chapter 7.3.

In CRF category 5.E Other emissions from accidental fires have been reported.

Please refer to Chapter 7 and Annex 3F for further information on emission inventories for waste.

### 1.4.8 KP-LULUCF

The national system has identified land areas associated with the activities under Article 3.4 of the Kyoto Protocol in accordance with definitions, modalities, rules and guidelines relating to land use, land-use change and forestry activities under the protocol. The identification has been made using satellite monitoring, use of the EU Land Parcel Information System (LPIS), detailed crop information data on field level, soil mapping and sample plots from the National Forest Inventory (NFI). All land converted from other activities into cropland and grassland is accounted for. No land can leave elected areas under art. 3.4.

The forest definition adopted in the NFI is identical to the FAO definition (TBFRA, 2000). It includes "wooded areas larger than 0.5 ha, that are able to form a forest with a height of at least 5 m and crown cover of at least 10 %". The minimum width is 20 m. For afforestation, the carbon stock change in the period 1990 - 2011 is calculated based on the area of afforestation, the information on species composition from the Forest Census 2000 and from the NFI. In the afforestation, a steady increase in carbon stock is found. The estimates for the carbon pools in the afforestation are similar to previous estimates, with a slight increase due to the new knowledge on species composition, average carbon stock in those areas based on the NFI data and new data on the carbon stock in soils. Carbon stock change caused by deforestation is estimated based on the deforested area and the mean values of carbon stock in the total forest area. This is because no specific knowledge is available on the carbon pools of the deforested areas. For Forest Management, census and NFI data are used.

For cropland and grassland, the same methodology is used in the KP reporting as used in the Convention reporting.

Please see Chapter 10 for further details.

### 1.4.9 Use of EU Emission Trading Scheme data

In 2004, the first guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to the EU Emission Trading Scheme (ETS) Directive (2003/87/EC) were implemented (EU Commission, 2004). The guidelines were updated in 2007, 2012 and 2018 and are available from the EU Commission website (EU Commission, 2018).

The Danish emission inventory only includes data from plants using higher tier methods as defined in the EU decision establishing guidelines for monitoring and reporting (EU Commission, 2018). In the Guidelines, the specific methods for determining carbon contents, oxidation factor and calorific value are specified.

In the Danish inventory plant or activity based $CO_2$ emission factors have been derived for power plants combusting coal and oil, refinery gas and flare gas in refineries, fuel gas and flare gas at off-shore installations, cement production, production of brick and tiles and lime production. For all these sources, the EU ETS reports are only used in the Danish inventory for plants using high tier methods. The EU ETS data have been applied for the years 2006 onwards.

The EU ETS reporting guidelines emphasizes the need for a high quality reporting through ensuring completeness, consistency, accuracy, transparency and faithfulness. The quality criteria as defined under the EU ETS reporting guidelines are in complete agreement with the principles in the IPCC good practice guidance. For all activities covered by the EU ETS installations are divided into three categories (A, B and C) depending on the annual $CO_2$ emission. A category A installation has an annual emission of less than 50 kt $CO_2$, a category B installation has an annual emission of between 50 and 500 kt $CO_2$ and a category C installation has an annual emission of more than 500 kt $CO_2$. For each activity Table 1 of the EU ETS guidelines (EU Commission, 2018) specifies the minimum tier level for the different calculation parameters. An example for combustion installations is shown in Table 1.2. The full list for all activities is available in the EU ETS guidelines (EU Commission, 2018).

Table 1.2 Example of minimum requirements in EU ETS guidelines (EU Commission, 2018).

| | Activity data | | | | | | Emission factor | | | Oxidation factor | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fuel flow | | | Net calorific value | | | | | | | | |
| Activity | A | B | C | A | B | C | A | B | C | A | B | C |
| Commercial standard fuels | 2 | 2 | 2 | 2a/2b | 2a/2b | 2a/2b | 2a/2b | 2a/2b | 2a/2b | 1 | 1 | 1 |
| Other gaseous and liquid fuels | 2 | 3 | 4 | 2a/2b | 2a/2b | 3 | 2a/2b | 2a/2b | 3 | 1 | 1 | 1 |
| Solid fuels | 1 | 2 | 3 | 2a/2b | 3 | 3 | 2a/2b | 3 | 3 | 1 | 1 | 1 |

The determination of the variables needed for the emission calculation has to be done in accordance with international standards. It is not possible to list all the relevant standards here, but the principles are described in Article 42 of the EU ETS guidelines. There are also demands concerning sampling methods and frequency of analysis.

As an example the tier 3 regarding fuel flow for fuel combustion, corresponds to a determination of the fuel consumption with a maximum uncertainty of 2.5 % taking into account possible effects of stock change. Tier 4 has a maximum uncertainty of 1.5 %. These uncertainties are very low and are in line with what could be expected from a well-functioning energy statistics system. More information regarding the use of EU ETS data in the specific subsectors of the inventory is included in Chapter 3.2.5 (CHP plants), Chapter 3.5.2 (Refineries and off-shore installations) and Chapter 4.2.2 (Cement production and other mineral products).

The operators shall establish, document, implement and maintain effective data acquisition and handling activities. This means assigning responsibilities for the quality process, as well as quality assurance, reviews and validation of data. Furthermore, an independent verification ensuring that emissions have been monitored in accordance with the EU ETS guidelines and that reliable and correct emission data are reported. There are also demands that records and documentation of the control activities must be stored for at least 10 years. The demands for the QA/QC system in the EU ETS guidelines are fully comparable to the requirements in the IPCC good practice guidance. Even so, DCE also performs QC checks of the data received as part of company reporting under EU ETS. This includes comparing the reported parameters with previous years, identifying outliers etc. In case DCE detects what is considered to be outliers, DCE contacts the Danish Energy

Agency, which is the regulating authority for the EU ETS system in Denmark.

## 1.5 Brief description of key categories

The key category analysis described in this section covers only Denmark. The aggregation used for the analysis is not directly suited for emissions from Greenland. If Greenlandic emissions were included in the analysis, they would not affect the overall results of the key category analysis. For a key category analysis covering Greenland refer to Chapter 16 and for Denmark and Greenland refer to Chapter 17.

All KCA have been carried out in accordance with IPCC Guidelines (IPCC, 2006).

The KCA for Denmark includes a total of 12 different analyses:

- Base year, reporting year and trend
- Including and excluding LULUCF
- Approach 1 and approach 2

The KCA is based on 224 emission source categories including 35 LULUCF source categories.

The 12 different KCA for Denmark point out 24-55 key source categories each and a total of 75 different key source categories. The number of key categories in each of the main sectors is: energy 38, IPPU 4, agriculture 14, LULUCF 14 and waste 5.

Approach 1 point out mainly the large emission sources as key categories and thus $CO_2$ emission from stationary and mobile combustion are important key categories. Approach 2 point out some of the sources with larger uncertainty rates.

Table 1.3 shows the 74 source categories that are key categories in at least one of the six key category analysis including LULUCF. The table includes ranking in the analysis. A similar table for the KCAs excluding LULUCF is included in Annex 1.

The categorisation and detailed results of each of the KCAs are included in Annex 1.

Table 1.3 Key categories for KCAs including LULUCF. The numbers show the ranking in each of the KCAs.

| IPCC Source Categories (LULUCF included) | | GHG | Key categories with number according to ranking in analysis Identification criteria | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Level Approach 1 1990 | Level Approach 1 2018 | Trend Approach 1 1990-2018 | Level Approach 2 1990 | Level Approach 2 2018 | Trend Approach 2 1990-2018 |
| Energy | 1A Stationary combustion, Coal, ETS data, $CO_2$ | $CO_2$ | | 2 | 2 | | | 44 |
| Energy | 1A Stationary combustion, Coal, no ETS data, $CO_2$ | $CO_2$ | 1 | 35 | 1 | 14 | | 4 |
| Energy | 1A Stationary combustion, Fossil waste, ETS data, $CO_2$ | $CO_2$ | | 9 | 9 | | | 34 |
| Energy | 1A Stationary combustion, Fossil waste, no ETS data, $CO_2$ | $CO_2$ | 23 | 27 | | | | |
| Energy | 1A Stationary combustion, Petroleum coke, ETS data, $CO_2$ | $CO_2$ | | 20 | 14 | | | |
| Energy | 1A Stationary combustion, Petroleum coke, no ETS data, $CO_2$ | $CO_2$ | 29 | | 21 | | | |
| Energy | 1A Stationary combustion, Residual oil, ETS data, $CO_2$ | $CO_2$ | | 32 | 25 | | | |
| Energy | 1A Stationary combustion, Residual oil, no ETS data, $CO_2$ | $CO_2$ | 7 | | 7 | | | 40 |
| Energy | 1A Stationary combustion, Gas oil, $CO_2$ | $CO_2$ | 3 | 18 | 5 | 28 | | 24 |
| Energy | 1A Stationary combustion, Kerosene, $CO_2$ | $CO_2$ | 30 | | 23 | | | |
| Energy | 1A Stationary combustion, LPG, $CO_2$ | $CO_2$ | | 43 | | | | |
| Energy | 1A1b Stationary combustion, Petroleum refining, Refinery gas, $CO_2$ | $CO_2$ | 17 | 16 | 22 | | | |
| Energy | 1A Stationary combustion, Natural gas, onshore, $CO_2$ | $CO_2$ | 6 | 3 | 6 | | 40 | 46 |
| Energy | 1A1c_ii Stationary combustion, Oil and gas extraction, Off shore gas turbines, Natural gas, $CO_2$ | $CO_2$ | 27 | 10 | 12 | | | |
| Energy | 1A4b_i Stationary combustion, Residential wood combustion, $CH_4$ | $CH_4$ | | | | 30 | 33 | 52 |
| Energy | 1A4b_i/1A4c_i Stationary Combustion, Residen-tial and agricultural straw combustion, $CH_4$ | $CH_4$ | | | | 33 | | |
| Energy | 1A1 Stationary Combustion, Solid fuels, $N_2O$ | $N_2O$ | | | | 23 | 45 | 17 |
| Energy | 1A1 Stationary Combustion, Gaseous fuels, $N_2O$ | $N_2O$ | | | | 34 | 32 | 36 |
| Energy | 1A1 Stationary Combustion, Waste, $N_2O$ | $N_2O$ | | | | | | 42 |
| Energy | 1A1 Stationary Combustion, Biomass, $N_2O$ | $N_2O$ | | | | | 23 | 14 |
| Energy | 1A2 Stationary Combustion, Solid fuels, $N_2O$ | $N_2O$ | | | | | 34 | 23 |
| Energy | 1A2 Stationary Combustion, Liquid fuels, N2O | $N_2O$ | | | | 20 | 44 | 15 |
| Energy | 1A2 Stationary Combustion, Gaseous fuels, $N_2O$ | $N_2O$ | | | | | 42 | 51 |
| Energy | 1A4 Stationary Combustion, Liquid fuels, $N_2O$ | $N_2O$ | | | | 29 | | 28 |
| Energy | 1A4 Stationary Combustion, Gaseous fuels, $N_2O$ | $N_2O$ | | | | | 38 | 49 |
| Energy | 1A4b_i Stationary Combustion, Residential wood combustion, $N_2O$ | $N_2O$ | | | | | 17 | 8 |
| Energy | 1.A.2.g Industry (mobile) | $CO_2$ | 21 | 22 | 31 | 21 | 16 | 29 |
| Energy | 1.A.3.b Road Transport | $CO_2$ | 2 | 1 | 3 | 13 | 6 | 5 |
| Energy | 1.A.3.c Railways | $CO_2$ | 34 | 33 | | | | |
| Energy | 1.A.3.d Navigation (large vessels) | $CO_2$ | 20 | 21 | | 35 | 37 | |
| Energy | 1.A.4.c ii Agriculture (mobile) | $CO_2$ | 12 | 14 | | 18 | 15 | 48 |
| Energy | 1.A.4.c iii Fisheries | $CO_2$ | 22 | 29 | 27 | | | |
| Energy | 1.A.5.b Other (military) | $CO_2$ | | | | | | 53 |
| Energy | 1.A.2.g Industry (mobile) | $N_2O$ | | | | | 36 | 50 |
| Energy | 1.A.3.b Road Transport | $N_2O$ | | | | | 43 | 45 |
| Energy | 1.A.4.c ii Agriculture (mobile) | $N_2O$ | | | | 27 | 25 | 37 |
| Energy | 1.B.2.c.2.iii Flaring, combined | $CO_2$ | 32 | 34 | | | | |
| Energy | 1.B.2.c.2.iii Flaring, combined | $N_2O$ | | | | 12 | 13 | 35 |
| IPPU | 2A1 Cement production | $CO_2$ | 15 | 12 | 16 | | | |
| IPPU | 2B2 Nitric acid production | $N_2O$ | 13 | | 13 | 22 | | 10 |
| IPPU | 2F1 Refrigeration and air conditioning | HFCs | | 25 | 18 | | 18 | 7 |

| IPCC Source Categories (LULUCF included) | | GHG | Key categories with number according to ranking in analysis Identification criteria | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Level Approach 1 1990 | Level Approach 1 2018 | Trend Approach 1 1990-2018 | Level Approach 2 1990 | Level Approach 2 2018 | Trend Approach 2 1990-2018 |
| IPPU | 2F2 Foam blowing agents | HFCs | | | 32 | 31 | | 26 |
| Agriculture | 3A Enteric Fermentation | $CH_4$ | 5 | 4 | 11 | 6 | 4 | 12 |
| Agriculture | 3B Manure Management | $CH_4$ | 9 | 8 | 10 | 15 | 12 | 9 |
| Agriculture | 3B Manure Management | $N_2O$ | 18 | 23 | | 7 | 7 | 39 |
| Agriculture | 3B5 Atmospheric deposition | $N_2O$ | | 44 | | 24 | 27 | |
| Agriculture | 3Da1 Inorganic N fertilizer | $N_2O$ | 8 | 13 | 20 | 2 | 2 | 6 |
| Agriculture | 3Da2a Animal manure applied to soils | $N_2O$ | 14 | 15 | 19 | 4 | 3 | 3 |
| Agriculture | 3Da3 Urine and dung deposited by grazing animals | $N_2O$ | 33 | 37 | | 19 | 22 | 41 |
| Agriculture | 3Da4 Crop Residues | $N_2O$ | 24 | 26 | | 9 | 11 | 27 |
| Agriculture | 3Da5 Mineralization | $N_2O$ | | | | 25 | 24 | 47 |
| Agriculture | 3Da6 Cultivation of organic soils | $N_2O$ | 16 | 19 | | 5 | 5 | 38 |
| Agriculture | 3Db1 Atmospheric deposition | $N_2O$ | 31 | 36 | | 16 | 20 | 31 |
| Agriculture | 3Db2 Leaching | $N_2O$ | 26 | 28 | | 11 | 14 | 30 |
| Agriculture | 3G Liming | $CO_2$ | 25 | 31 | 29 | 10 | 19 | 13 |
| Agriculture | 3I Other carbon-containing fertilizers | $CO_2$ | | | | | | 54 |
| LULUCF | 4.A.1 Forest land remaining forest land, Living biomass | $CO_2$ | 19 | 7 | 8 | | 26 | 20 |
| LULUCF | 4.A.1 Forest land remaining forest land, Dead organic matter | $CO_2$ | | 6 | 4 | | 21 | 11 |
| LULUCF | 4.A.1 Forest land remaining forest land, Organic soils | $CO_2$ | | 41 | | 32 | 39 | |
| LULUCF | 4.A.2 Land converted to forest land | $CO_2$ | | 38 | 33 | | | |
| LULUCF | 4.B.1 Cropland remaining cropland, Mineral soils | $CO_2$ | 28 | 17 | 17 | 17 | 9 | 2 |
| LULUCF | 4.B.1 Cropland remaining cropland, Organic soils | $CO_2$ | 4 | 5 | 28 | 1 | 1 | 21 |
| LULUCF | 4.B.2 Forest land converted to cropland | $CO_2$ | | | | | | 43 |
| LULUCF | 4.C.1 Grassland remaining grassland, Organic soils | $CO_2$ | 11 | 11 | 26 | 8 | 8 | 19 |
| LULUCF | 4.E.2 Forest land converted to settlements | $CO_2$ | | | | | | 55 |
| LULUCF | 4.E.2 Other land uses converted to settlements | $CO_2$ | | 40 | | | 30 | 18 |
| LULUCF | 4.G Harvested wood products | $CO_2$ | | 39 | 30 | | 28 | 16 |
| LULUCF | 4(II) Cropland on organic soils | $CH_4$ | | 42 | | 26 | 29 | |
| LULUCF | 4(II) Grassland on organic soils | $CH_4$ | | | | 36 | 41 | |
| LULUCF | 4(II) Land converted to wetlands | $CH_4$ | | | | | | 33 |
| Waste | 5.A Solid waste disposal | $CH_4$ | 10 | 24 | 15 | 3 | 10 | 1 |
| Waste | 5.B.1 Composting | $CH_4$ | | | | | 31 | 22 |
| Waste | 5.B.2. Anaerobic digestion at biogas facilities | $CH_4$ | | 30 | 24 | | | 32 |
| Waste | 5.B.1 Composting | $N_2O$ | | | | | 35 | 25 |

### 1.5.1 KP-LULUCF

See Chapter 10.9.1 for discussion on the key category analysis of KP-LULUCF.

## 1.6 Information on QA/QC plan including verification and treatment of confidential issues where relevant

### 1.6.1 Introduction

This section outlines the Quality Control (QC) and Quality Assurance (QA) plan for greenhouse gas emission inventories performed by DCE (Sørensen et al., 2005; Nielsen et al., 2013; Nielsen et al., 2020). The plan is in accordance with the guidelines provided by the IPCC (IPCC, 2006. The ISO 9000 standards are also used as important input for the plan.

The QA/QC plan also covers Greenland. DCE receives the data corresponding to data processing level 3 and data storage level 4 and the data undergoes the same QA/QC procedure as the Danish data, some further QC checks are described in Chapter 17. The QA/QC specific to the Greenlandic emission inventory is described in Chapter 16.

### 1.6.2 Concepts of quality work

The quality planning is based on the following definitions as outlined by the ISO 9000 standards as well as the IPCC Guidance (IPCC, 2006):

- Quality management (*QM*) Coordinates activity to direct and control with regard to quality.
- Quality Planning (*QP*) Defines quality objectives including specification of necessary operational processes and resources to fulfil the quality objectives.
- Quality Control (*QC*) Fulfils quality requirements.
- Quality Assurance (*QA*) Provides confidence that quality requirements will be fulfilled.
- Quality Improvement (*QI*) Increases the ability to fulfil quality requirements.

The activities are considered inter-related in this report as shown in Figure 1.2.

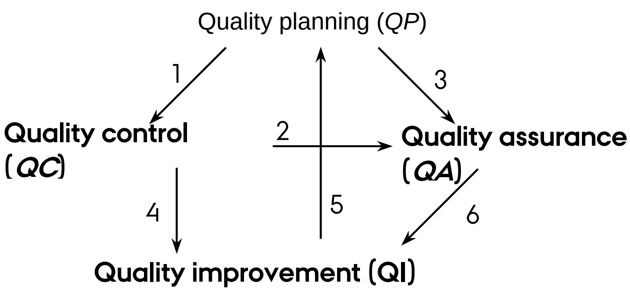



Figure 1.2 Interrelation between the activities with regard to quality. The arrows are explained in the text below this figure.
1: The *QP* sets up the objectives and, from these, measurable properties valid for the *QC*.
2: The *QC* investigates the measurable properties that are communicated to *QA* for assessment in order to ensure sufficient quality.
3. The *QP* identifies and defines measurable indicators for the fulfilment of the quality objectives. This yields the basis for the *QA* and has to be supported by the input coming from the *QC*.
4: The result from *QC* highlights the degree of fulfilment for every quality objective. It is thus a good basis for suggestions for improvements to the inventory to meet the quality objectives.
5: Suggested improvements in the quality may induce changes in the quality objectives and their measurability.
6: The evaluation carried out by external authorities is important input when improvements in quality are being considered.

### 1.6.3 Definition of quality

A solid definition of quality is essential. Without such a solid definition, the fulfilment of the objectives will never be clear and the process of quality control and assurance can easily turn out to be a fuzzy and unpleasant experience for the people involved. On the contrary, in case of a solid definition and thus a clear goal, it will be possible the make a valid statement of "good quality" and thus form constructive conditions and motivate the inventory work positively. A clear definition of quality has not been given in the UNFCCC guidelines. In the Good Practice Guidance, Chapter 8.2, however, it is mentioned that:

"Quality control requirements, improved accuracy and reduced uncertainty need to be balanced against requirements for timeliness and cost effectiveness." The statement of balancing requirements and costs is not a solid basis for QC as long as this balancing is not well defined.

The resulting standard of the inventory is defined as being composed of accuracy and regulatory usefulness. The goal is to maximise the standard of the inventory and the following statement defines the quality objective:

*The quality objective is only inadequately fulfilled if it is possible to make an inventory of a higher standard without exceeding the frame of resources*.

### 1.6.4 Definition of Critical Control Points (*CCP*)

A Critical Control Point (*CCP*) is defined in this submission as an element or an action, which needs to be taken into account in order to fulfil the quality objectives. Every *CCP* has to be necessary for the objectives and the *CCP* list needs to be extended if other factors, not defined by the *CCP* list, are needed in order to reach at least one of the quality objectives.

The objectives for the *QM*, as formulated by IPCC (2006), are to improve elements of transparency, consistency, comparability, completeness and confidence.

The objectives for the *QM* are used as *CCP*s, including the elements mentioned above. The following explanation is given by UNFCCC guidelines (UNFCCC, 2013) for each *CCP*:

*Transparency* means that the data sources, assumptions and methodologies used for an inventory should be clearly explained, in order to facilitate the replication and assessment of the inventory by users of the reported information. The transparency of inventories is fundamental to the success of the process for the communication and consideration of the information. The use of the common reporting format (CRF) tables and the preparation of a structured national inventory report (NIR) contribute to the transparency of the information and facilitate national and international reviews.

*Consistency* means that an annual GHG inventory should be internally consistent for all reported years in all its elements across sectors, categories and gases. An inventory is consistent if the same methodologies are used for the base and all subsequent years and if consistent data sets are used to estimate emissions or removals from sources or sinks. Under certain circumstances referred to in paragraphs 16 to 18 below, an inventory using different methodologies for different years can be considered to be consistent if it has been recalculated in a transparent manner, in accordance with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (hereinafter referred to as the 2006 IPCC Guidelines).

*Comparability* means that estimates of emissions and removals reported by Annex I Parties in their inventories should be comparable among Annex I Parties. For that purpose, Annex I Parties should use the methodologies and formats agreed by the COP for making estimations and reporting their inventories. The allocation of different source/sink categories should follow the CRF tables provided in annex II to decision 24/CP.19 at the level of the summary and sectoral tables.

*Completeness* means that an annual GHG inventory covers at least all sources and sinks, as well as all gases, for which methodologies are provided in the 2006 IPCC Guidelines or for which supplementary methodologies have been agreed by the COP. Completeness also means the full geographical coverage of the sources and sinks of an Annex I Party.

*Accuracy* means that emission and removal estimates should be accurate in the sense that they are systematically neither over nor under true emissions or removals, as far as can be judged, and that uncertainties are reduced as far as practicable. Appropriate methodologies should be used, in accordance with the 2006 IPCC Guidelines, to promote accuracy in inventories.

The robustness against unexpected disturbance of the inventory work has to be high in order to secure high quality, which is not covered by the *CCP*s above. The correctness of the inventory is formulated as an independent objective. This is so because the correctness of the inventory is a condition for all other objectives to be effective. A large part of the Tier 1 procedure given by the IPCC (IPCC, 2006) is actually checks for miscalculations and, thus, supports the objective of correctness. Correctness, as defined here, is not similar to accuracy, because the correctness takes into account miscalculations, while accuracy relates to minimizing the always present data-value uncertainty.

*Robustness* implies arrangement of inventory work as regards e.g. inventory experts and data sources in order to minimize the consequences of any unexpected disturbance due to external and internal conditions. A change in an external condition could be interruption of access to an external data source and an internal change could be a sudden reduction in qualified staff, where a skilled person suddenly leaves the inventory work.

*Correctness* has to be secured in order to avoid uncontrollable occurrence of uncertainty directly due to errors in the calculations.

The different *CCP*s are not independent and represent different degrees of generality. E.g., deviation from *comparability* may be accepted if a high degree of *transparency* is applied. Furthermore, there may even be a conflict between the different *CCP*s. E.g. new knowledge may suggest improvements in calculation methods for better *completeness*, but the same improvements may to some degree, violate the *consistency* and *comparability* criteria with regard to earlier years' inventories and the reporting from other nations. It is, therefore, a multi-criteria problem of optimisation to apply the set of *CCP*s in the aim for good quality.

### 1.6.5 Process-oriented QC

The strategy is based on a process-oriented principle (ISO 9000 series) and the first step is, thus, to set up a system for the process of the inventory work. The product specification for the inventory is a dataset of emission figures and the process, thereby, equates with the data flow in the preparation of the inventory.

The data flow needs to support the QC/QA in order to facilitate a cost-effective procedure. The flow of data has to take place in a transparent way by making the transformation of data detectable. It should be easy to find the original background data for any calculation and to trace the sequence of calculations from the raw data to the final emission result. Computer programming for automated calculations and checking will enhance the accuracy and minimize the number of miscalculations and flaws in input value settings. Especially manual typing of numbers needs to be minimized. This assumes, however, that the quality of the programming has been verified to ensure the correctness of the automated calculations. Automated value control is also one of the important means to secure accuracy. Realistic uncertainty estimates are necessary for securing accuracy, but they can be difficult to produce due to the uncertainty related to the uncertainty estimates themselves. It is, therefore, important to include the uncertainty calculation procedures into the data structure as far as possible. The QC/QA needs to be supported as far as possible by the data structure; otherwise, the procedures can easily become troublesome and subject to frustration.

Both data processing and data storage form the data structure. The data processing is carried out using mathematical operations or models. The models may be complicated where they concern human activity or be simple summations of lower aggregated data. The data storage includes databases and file systems of data that are calculated either using the data processing at the lower level, using input to new processing steps or even using both output and input in the data structure. The measure for quality is basically different for processing and storage, so these need to be kept separate in a well-designed quality manual. A graphical display of the data flow is seen in Figure 1.3 and explained in the following.

The data storage takes place for the following types of data:

***External Data*:** a single numerical value of a parameter coming from an external source. These data govern the calculation of *Emission calculation input.*

***Emission calculation input*:** Data for input to the final emission calculation in terms of data for release source strength and activity. The data is directly applicable for use in the standardized forms for calculation. These data are calculated using external data or represent a direct use of *External Data* when they are directly applicable for *Emission Calculations*.

***Emission Data*:** Estimated emissions based on the *emission calculation input.*

***Emission Reporting*:** Reporting of emission data in requested formats and aggregation level.

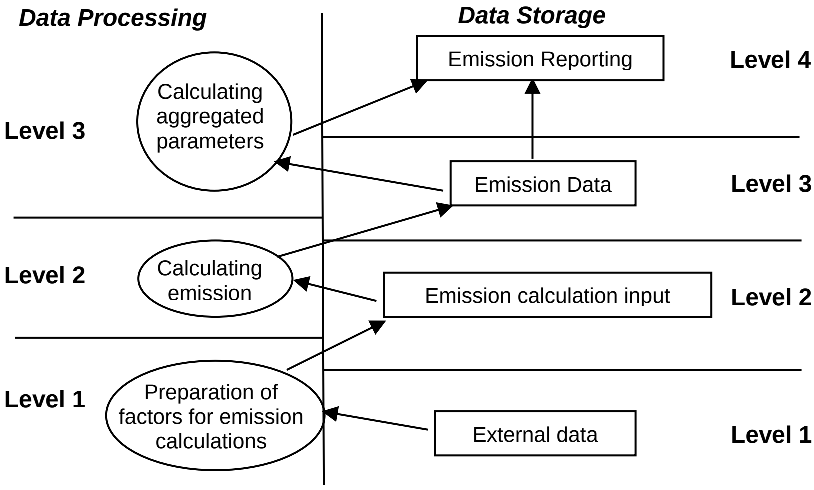



Figure 1.3 The general data structure for the emission inventory.

Key levels are defined in the data structure as:

***Data storage Level 1***, External data
Collection of external data for calculation of emission factors and activity data. The activity data are collected from different sectors and statistical surveys, typically reported on a yearly basis. The data consist of raw data, having an identical format to the data received and gathered from external sources. Level 1 data acts as a base-set, on which all subsequent calculations are based. If alterations in calculation procedures are made, they are based on the same dataset. When new data are introduced, they can be implemented in accordance with the QA/QC structure of the inventory.

***Data storage Level 2***, Data directly usable for the inventory
This level represents data that have been prepared and compiled in a form that is directly applicable for calculation of emissions. The compiled data are structured in a database for internal use as a link between more or less raw data and data that are ready for reporting. The data are compiled in a way that elucidates the different approaches in emission assessment: (1) directly on measured emission rates, especially for larger point sources, (2) based on activities and emission factors, where the value setting of these factors are stored at this level.

***Data storage Level 3***, Emission data
The emission calculations are reported by the most detailed figures and divided in sectors. The unit at this level is typically mass per year for the country. For sources included in the SNAP system, the SNAP level 3 is relevant. Internal reporting is performed at this level to feed the external communication of results.

***Data storage Level 4***, Final reports for all subcategories
The complete emission inventory is reported to UNFCCC at this level by summing up the results from every subcategory.

***Data processing Level 1*** Compilation of external data
Preparation of input data for the emission inventory based on the external data sources. Some external data may be used directly as input to the data processing at level 2, while other data needs to be interpreted using more or less complicated models, which takes place at this level. The interpretation of activity data is to be seen in connection with availability of emission fac-

tors and vice versa. These models are compiled and processed as an integrated part of the inventory preparation.

***Data processing Level 2*** Calculation of inventory figures
The emission for every subcategory is calculated, including the uncertainty for all sectors and activities. The summation of all contributions from subsources makes up the inventory.

***Data processing Level 3*** Calculation aggregated parameters
Some aggregated parameters need to be reported as part of the final reporting. This does not involve complicated calculations but important figures, e.g. implied emission factors at a higher aggregated level to be compared in time series and with other countries.

### 1.6.6 Definition of Point of Measurements (*PM*)

The *CCP*s have to be based on clear measurable factors - otherwise the *QP* will end up being just a loose declaration of intent. Thus, in the following, a series of *Points for Measuring* (*PM*) is identified as building blocks for a solid *QC*. Table 8.1 in Good Practice Guidance is a listing of such *PM*s. However, the listing in Table 1.2 is an extended and modified listing, in comparison to Table 8.1 in the Good Practice Guidance supporting all the *CCP*s. The *PM*s will be routinely checked in the QC reporting and, when external reviews take place, the reviewers will be asked to assess the fulfilment of the *PM*s using a checklist system. The list of *PM*s is continually evaluated and modified to offer the best possible support for the *CCP*s. The actual list used is seen in Table 1.4.

Table 1.4 The list of *PM*s as used.

| Level | CCP | Id | Description | |
|---|---|---|---|---|
| Data Storage level 1 | 1. Accuracy | DS.1.1.1 | General level of uncertainty for every dataset including the reasoning for the specific values | Sectoral |
| | | DS.1.1.2 | Quantification of the uncertainty level of every single data value, including the reasoning for the specific values. | Sectoral |
| | 2. Comparability | DS1.2.1 | Comparability of the data values with similar data from other countries, which are comparable with Denmark, and evaluation of the discrepancy. | Sectoral |
| | 3.Completeness | DS.1.3.1 | Documentation showing that all possible national data sources are included, by setting down the reasoning behind the selection of datasets. | Sectoral |
| | 4.Consistency | DS.1.4.1 | The origin of external data has to be preserved whenever possible without explicit arguments (referring to other PMs) | Sectoral |
| | 6.Robustness | DS.1.6.1 | Explicit agreements between the external institution holding the data and DCE about the conditions of delivery | Sectoral |
| | | DS.1.6.2 | At least two employees must have a detailed insight into the gathering of every external dataset. | General |
| | 7.Transparency | DS.1.7.1 | Summary of each dataset including the reasoning behind the selection of the specific dataset | Sectoral |
| | | DS.1.7.2 | The archiving of datasets needs to be easily accessible for any person in the emission inventory | General |
| | | DS.1.7.3 | References for citation for any external dataset have to be available for any single number in any dataset. | Sectoral |
| | | DS.1.7.4 | Listing of external contacts for every dataset | Sectoral |
| Data Processing level 1 | 1. Accuracy | DP.1.1.1 | Uncertainty assessment for every data source as input to Data Storage level 2 in relation to type of variability. (Distribution as: normal, log normal or other type of variability) | Sectoral |
| | | DP.1.1.2 | Uncertainty assessment for every data source as input to Data Storage level 2 in relation to scale of variability (size of variation intervals) | Sectoral |
| | | DP.1.1.3 | Evaluation of the methodological approach using international guidelines | Sectoral |
| | | DP.1.1.4 | Verification of calculation results using guideline values | Sectoral |
| | 2.Comparability | DP.1.2.1 | The inventory calculation has to follow the international guidelines suggested by UNFCCC and IPCC. | Sectoral |
| | 3.Completeness | DP.1.3.1 | Assessment of the most important quantitative knowledge, which is lacking. | Sectoral |
| | | DP.1.3.2 | Assessment of the most important cases where access is lacking with regard to critical data sources that could improve quantitative knowledge. | Sectoral |
| | 4.Consistency | DP.1.4.1 | In order to keep consistency at a high level, an explicit description of the activities needs to accompany any change in the calculation procedure | Sectoral |
| | | DP.1.4.2 | Identification of parameters (e.g. activity data, constants) that are common to multiple source categories and confirmation that there is consistency in the values used for these parameters in the emission calculations | General |
| | 5.Correctness | DP.1.5.1 | Shows at least once, by independent calculation, the correctness of every data manipulation | Sectoral |
| | | DP.1.5.2 | Verification of calculation results using time series | Sectoral |
| | | DP.1.5.3 | Verification of calculation results using other measures | Sectoral |
| | | DP.1.5.4 | Show one-to-one correctness between external data sources and the databases at Data Storage level 2 | Sectoral |
| | 6.Robustness | DP.1.6.1 | Any calculation must be anchored to two responsible persons who can replace each other in the technical issue of performing the calculations. | General |
| | 7.Transparency | DP.1.7.1 | The calculation principle and equations used must be described | Sectoral |
| | | DP.1.7.2 | The theoretical reasoning for all methods must be described | Sectoral |
| | | DP.1.7.3 | Explicit listing of assumptions behind all methods | Sectoral |
| | | DP.1.7.4 | Clear reference to dataset at Data Storage level 1 | Sectoral |
| | | DP.1.7.5 | A manual log to collect information about recalculations | Sectoral |
| Data Storage level 2 | 2.Comparability | DS.2.2.1 | Comparison with other countries that are closely related to Denmark and explanation of the largest discrepancies | General |

| Level | CCP | Id | Description | |
|---|---|---|---|---|
| | 5.Correctness | DS.2.5.1 | Documentation of a correct connection between all data types at level 2 to data at level 1 | Sectoral |
| | | DS.2.5.2 | Check if a correct data import to level 2 has been made | Sectoral |
| | 6.Robustness | DS.2.6.1 | All persons in the inventory work must be able to handle and understand all data at level 2. | General |
| | 7.Transparency | DS.2.7.1 | The time trend for every single parameter must be graphically available and easy to map | General |
| Data Processing level 2 | 1. Accuracy | DP.2.1.1 | Documentation of the methodological approach for the uncertainty analysis | General |
| | | DP.2.1.2 | Quantification of uncertainty | General |
| | 2.Comparability | DP.2.2.1 | The inventory calculation has to follow the international guidelines suggested by UNFCCC and IPCC | General |
| | 6.Robustness | DP.2.6.1 | Any calculation at level 4 must be anchored to two responsible persons who can replace each other in the technical issue of performing the calculations. | General |
| | 7.Transparency | DP.2.7.1 | Reporting of the calculation principle and equations used | General |
| | | DP.2.7.2 | The reasoning for the choice of methodology for uncertainty analysis needs to be written explicitly. | General |
| Data Storage level 3 | 1. Accuracy | DS.3.1.1 | Quantification of uncertainty | General |
| | 5.Correctness | DS.3.5.1 | Comparison with inventories of the previous years on the level of the categories of the CRF as well as on SNAP source categories. Any major changes are checked, verified, etc. | General |
| | | DS.3.5.2 | Total emissions, when aggregated to CRF source categories, are compared with totals based on SNAP source categories (control of data transfer). | General |
| | | DS.3.5.3 | Checking of time series of the CRF and SNAP source categories as they are found in the Corinair databases. Considerable trends and changes are checked and explained. | General |
| | 7. Transparency | DS.3.7.1 | The databases and other software used shall be clearly documented. The documentation should include a description that the appropriate data processing steps are correctly represented in the database; that data relationships are correctly represented in the database and that data fields are properly labelled and have the correct design specifications. | General |
| | | DS.3.7.2 | The documentation referred to under DS.3.7.1 should be archived at the same network folder as the program is located in. | General |
| Data Processing level 3 | 6. Robustness | DP.3.6.1 | The process of generating the official submissions must be anchored by at least two responsible persons who can replace each other in the technical issue of generating CRF tables including of the aggregation of submissions for Denmark and Greenland. | General |
| | 7. Transparency | DP.3.7.1 | The databases and other software used shall be clearly documented. The documentation should include a description that the appropriate data processing steps are correctly represented in the database; that data relationships are correctly represented in the database and that data fields are properly labelled and have the correct design specifications. | General |
| | 7. Transparency | DP.3.7.2 | The documentation referred to under DP.3.7.1 should be archived at the same network folder as the program is located in. | General |
| Data Storage level 4 | 2.Comparability | DS.4.2.1 | Description of similarities and differences in relation to other countries' inventories for the methodological approach. | General |
| | 3.Completeness | DS.4.3.1 | National and international verification including explanation of the discrepancies. | General |
| | | DS.4.3.2 | Check that the no sources where a methodology exists in the IPCC guidelines are reported as NE. | General |
| | 4.Consistency | DS.4.4.1 | The inventory reporting must follow the international guidelines suggested by UNFCCC and IPCC. | General |
| | | DS.4.4.2 | Check time series consistency of the reporting by Greenland and the Faroe Islands prior to aggregating the final submissions. | General |

| Level | CCP | Id | Description | |
|---|---|---|---|---|
| | | DS.4.4.3 | The IEFs from the CRF are checked regarding both level and trend. The level is compared to relevant emission factors to ensure correctness. Large dips/jumps in the time series are explained. | Sectoral |
| | 5.Correctness | DS.4.5.1 | Check that the aggregated submissions for Denmark under the Kyoto Protocol and the UNFCCC match the sum of the individual submissions. | General |
| | | DS.4.5.2 | Check that additional information and information related to land-use changes has been correctly aggregated compared to the individual submissions of Denmark and Greenland. | Sectoral |
| | 6. Robustness | DS.4.6.1 | The reporting to the UNFCCC must be anchored to two responsible persons who can replace each other in the technical issue of reporting to and communicating with the UNFCCC secretariat. | General |
| | 7.Transparency | DS.4.7.1 | Perform QA on the documentation report provided by the Government of Greenland. | General |

### 1.6.7 Plan for the quality work

The IPCC uses the concept of a tiered approach, i.e. a stepwise approach, where complexity, advancement and comprehensiveness increase. Generally, more detailed and advanced methods are recommended in order to give guidance to countries, which have more detailed datasets and more capacity, as well as to countries with less available data and manpower. The tiered approach helps to focus attention on the areas of the inventories that are relatively weak, rather than investing effort in irrelevant areas. Furthermore, the IPCC guidelines recommend using higher tier methods for key categories in particular. Therefore, the identification of key categories is crucial for planning quality work. However, several issues regarding the listing of priority categories exist: (1) The contribution to the total emission figure (key source listing); (2) The contribution to the total uncertainty; (3) Most critical categories in relation to implementation of new methodologies and thus highest risk for miscalculations. All the points listed are necessary for different aspects of producing high quality work. These listings will be used to secure implementation of the full quality scheme for the most relevant categories. Verification in relation to other countries has been undertaken for priority categories.

### 1.6.8 Implementation of the QA/QC plan

The PMs listed in Table 1.2 are described for each sector in the QA/QC sections of Chapters 3-8, where a status with regard to implementation is also given. Some of the PMs are the same for all sectors and a common description for these PMs is given in Section 1.6.10, below. The focus has been on level 1 for both data storage and data processing as this is the most labour-intensive part. The quality system will be evaluated and adjusted continuously.

### 1.6.9 Archiving of data and documentations

The QA/QC work is supported by an inventory file system, where all data, models and QA/QC procedures and checks are stored as files in folders (Figure 1.4).


Figure 1.4 Schematic diagram of the folder structure in the inventory file system.

The inventory file system consists of the following levels: year, sector and the level for the process of the inventory work, as illustrated in Figure 1.4. The first level in the file system is year, which here means the inventory year and not the calendar year. The sector level contains the PMs relevant for the individual sectors i.e. the first levels (DS1 and DP1) (except the PMs described in Section 1.6.10), while the rest of the PMs (DS2-4 and DP2-3), are common for all sectors.

All data, models and other QA/QC related files are stored in the inventory file system and are accessible for all staff involved in the inventory work.

### 1.6.10 Common QA/QC PMs

The following PMs are common for all the sectors:

#### Data storage Level 1

| | | | |
|---|---|---|---|
| Data Storage level 1 | 6. Robustness | DS.1.6.2 | At least two employees must have a detailed insight into the gathering of every external dataset. |

For all sectors: energy, industrial processes and product use, agriculture, LULUCF and waste, two persons have detailed insight in data gathering and processing. A strong effort is continuously made to ensure the robustness of the inventory process.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 7. Transparency | DS.1.7.2 | The archiving of datasets needs to be easily accessible for any person involved in the emission inventory. |

All data, models and other QA/QC related files are stored in the inventory file system and are accessible for all inventory staff members. Refer to Section 1.6.9.

**Data processing Level 1**

| | | | |
|---|---|---|---|
| Data Processing level 1 | 4. Consistency | DP.1.4.2 | Identification of parameters (e.g. activity data, constants) that are common to multiple source categories and confirmation that there is consistency in the values used for these parameters in the emission calculations. |

This PM is supported by the inventory file system where it is possible to compare and harmonise parameters that are common to multiple source categories.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 6.Robustness | DP.1.6.1 | Any calculation must be anchored to two responsible persons who can replace each other in the technical issue of performing the calculations. |

All data, models and other QA/QC related files are stored in the inventory file system and are accessible for all inventory staff members. Refer to Section 1.6.9.

**Data storage Level 2**

| | | | |
|---|---|---|---|
| Data Storage level 2 | 2.Comparability | DS.2.2.1 | Comparison with other countries that are closely related to Denmark and explanation of the largest discrepancies. |

Systematic inter-country comparison has only been made on data storage level 4. Refer to DS 4.3.2.

| | | | |
|---|---|---|---|
| Data Storage level 2 | 6.Robustness | DS.2.6.1 | All persons in the inventory work must be able to handle and understand all data at level 2. |

This PM is fulfilled for all sectors. The PM is supported by the inventory file system. Refer to Section 1.6.9.

| | | | |
|---|---|---|---|
| Data Storage level 2 | 7.Transparency | DS.2.7.1 | The time trend for every single parameter must be graphically available and easy to map. |

Programs exist to make time series for all parameters. A tool for graphically showing time series has not yet been developed.

**Data Processing Level 2**

| | | | |
|---|---|---|---|
| Data Processing level 2 | 1. Accuracy | DP.2.1.1 | Documentation of the methodological approach for the uncertainty analysis |

Refer to Chapter 1.7.

| | | | |
|---|---|---|---|
| Data Processing level 2 | 1. Accuracy | DP.2.1.2 | Quantification of uncertainty |

Refer to Chapter 1.7 and the uncertainty sections in the sectoral chapters (Chapter 3-7).

| | | | |
|---|---|---|---|
| Data Processing level 2 | 2.Comparability | DP.2.2.1 | The inventory calculation has to follow the international guidelines suggested by UN-FCCC and IPCC. |

The emission calculations follow the international guidelines.

| | | | |
|---|---|---|---|
| Data Processing level 2 | 6.Robustness | DS.2.6.1 | All persons in the inventory work must be able to handle and understand all data at level 2. |

At present, the emission calculations are carried out using applications developed at DCE. The software development and programme runs are anchored to two inventory staff members.

| | | | |
|---|---|---|---|
| Data Processing level 2 | 7.Transparency | DP.2.7.1 | Reporting of the calculation principle and equations used. |

Due to the uniform treatment of input data in the calculation routines used by the DCE software programmes, a central documentation of calculation principles, equations, theoretical reasoning and assumptions must be given, treating all national emission sources. This documentation remains to be made, but is planned to be carried out in the future.

| | | | |
|---|---|---|---|
| Data Processing level 2 | 7.Transparency | DP.2.7.2 | The reasoning for the choice of methodology for uncertainty analysis needs to written explicitly. |

Refer to Chapter 1.7 and the QA/QC sections in the sectoral chapters.

### Data storage Level 3

| | | | |
|---|---|---|---|
| Data Storage level 3 | 1. Accuracy | DS.3.1.1 | Quantification of uncertainty |

Refer to Chapter 1.7 and the QA/QC sections in the sector chapters.

| | | | |
|---|---|---|---|
| Data Storage level 3 | 5.Correctness | DS.3.5.1 | Comparison with inventories of the previous years on the level of the categories of the CRF as well as on SNAP source categories. Any major changes are checked, verified, etc. |

Time series is prepared and checked, any major change is closely examined with the purpose of verifying and explaining changes from earlier inventories.

| | | | |
|---|---|---|---|
| Data Storage level 3 | 5.Correctness | DS.3.5.2 | Total emissions when aggregated to CRF source categories are compared with totals based on SNAP source categories (control of data transfer). |

Total emission, when aggregated to IPCC and LRTAP reporting tables, is compared with totals based on SNAP source categories (control of data transfer).

| | | | |
|---|---|---|---|
| Data Storage level 3 | 5.Correctness | DS.3.5.3 | Checking of time series of the CRF and SNAP source categories as they are found in the Corinair databases. Considerable trends and changes are checked and explained. |

Time series are prepared and checked, any major change is closely examined with the purpose of verifying and explaining fluctuations.

| | | | |
|---|---|---|---|
| Data Storage level 3 | 7. Transparency | DS.3.7.1 | The databases and other software used shall be clearly documented. The documentation should include a description that the appropriate data processing steps are correctly represented in the database; that data relationships are correctly represented in the database and that data fields are properly labelled and have the correct design specifications. |

The databases used at data storage level 3 are documented. The documentation includes description of the queries and programming code used in the data processing. The documentation further includes information on all data fields in the database and the design specifications. Part of the detailed documentation is built into the database while the overall documentation is prepared as a separate documentation note.

| | | | |
|---|---|---|---|
| Data Storage level 3 | 7. Transparency | DS.3.7.2 | The documentation referred to under DS.3.7.1 should be archived at the same network folder as the program is located in. |

The documentation prepared as part of DS.3.7.1 is archived in the same folder as the program is stored. For information on the file structure, please see Chapter 1.6.9.

#### Data Processing Level 3

| | | | |
|---|---|---|---|
| Data Processing level 3 | 6. Robustness | DP.3.6.1 | The process of generating the official submissions must be anchored by at least two responsible persons who can replace each other in the technical issue of generating CRF tables including of the aggregation of submissions for Denmark and Greenland. |

The process of generating the official submissions including the aggregation of submissions to the UNFCCC and the Kyoto Protocol is currently anchored by two people within the team. In the future, the goal is to have three team members capable of completing this task.

| | | | |
|---|---|---|---|
| Data Processing level 3 | 7. Transparency | DP.3.7.1 | The databases and other software used shall be clearly documented. The documentation should include a description that the appropriate data processing steps are correctly represented in the database; that data relationships are correctly represented in the database and that data fields are properly labelled and have the correct design specifications. |

The databases used at data storage level 3 are documented. The documentation includes description of the queries and programming code used in the data processing. The documentation further includes information on all data fields in the database and the design specifications. Part of the detailed documentation is built into the database while the overall documentation is prepared as a separate documentation note.

| | | | |
|---|---|---|---|
| Data Processing level 3 | 7. Transparency | DP.3.7.2 | The documentation referred to under DS.3.7.1 should be archived at the same network folder as the program is located in. |

The documentation prepared as part of DS.3.7.1 is archived in the same folder as the program is stored. For information on the file structure, please see Chapter 1.6.9.

### Data Storage Level 4

| | | | |
|---|---|---|---|
| Data Storage level 4 | 2.Comparability | DS.4.2.1 | Description of similarities and differences in relation to other countries' inventories for the methodological approach |

For each key source category, a comparison has been made between Denmark and the EU-15 countries (Fauser et al., 2007 & 2013). This is performed by comparing emission density indicators, defined as emission intensity value divided by a chosen indicator. The indicators are identical to the ones identified in the Norwegian verification inventory (Holtskog et al., 2000). The correlation between emissions and an independent indicator does not necessarily imply cause and effect, but in cases where the indicator is directly associated with the emission intensity value, such as for the energy sector, the emission density indicator is a measure of the implied emission factor and a direct comparison can be made. A qualitative verification of implied emission factors can be made when a measured or theoretical value of the $CO_2$ content in the respective fuel type (or other relevant parameter) is available. For the energy sector, all countries are, in principle, comparable and inter-country deviations arise from variations in fuel purities and fuel combustion efficiencies. A comparison of national emission density indicators, analogous to the implied emission factors, will give valuable information on the quality and efficiency of the national energy sectors.

Furthermore, the inter-country comparison of emission density indicators and comparison of theoretical values gives a methodological verification of the derivation of emission intensity values, and of the correlation between emission intensity values and activity values.

When emissions are compared with non-dependent parameters, similarities with regard to geography, climate, industry structure and level of economic development may be necessary for obtaining comparable emission density indicators.

| | | | |
|---|---|---|---|
| Data Storage level 4 | 3.Completeness | DS.4.3.1 | National and international validation including explanation of the discrepancies. |

Refer to DS 4.2.1

| | | | |
|---|---|---|---|
| Data Storage level 4 | 3.Completeness | DS.4.3.2 | Check that the no sources where a methodology exists in the IPCC guidelines are reported as NE. |

It is verified both by DCE experts and by EU consistency checks that no sources where methodologies and default parameters exist have been reported as NE. If methodologies do exist efforts are made to estimate and report emissions.

| | | | |
|---|---|---|---|
| Data Storage level 4 | 4.Consistency | DS.4.4.1 | The inventory reporting must follow the international guidelines suggested by UNFCCC and IPCC. |

The inventory reporting is in accordance with the UNFCCC reporting guidelines (UNFCCC, 2013). The present report includes detailed and complete information on the inventories for all years from the base year to the year of the current annual inventory submission, in order to ensure the transparency of the inventory. The annual emission inventory for Denmark is reported in the Common Reporting Format (CRF) as requested in the reporting guidelines. The CRF-spreadsheets contain data on emissions, activity data and implied emission factors for each year. Emission trends are given for each greenhouse gas and for total greenhouse gas emissions in $CO_2$ equivalents. The link to complete sets of CRF-files and more information on the Danish emission inventories are on the ENVS homepage (http://envs.au.dk/videnudveksling/luft/emissioner/emissioninventory).

| | | | |
|---|---|---|---|
| Data Storage level 4 | 4.Consistency | DS.4.4.2 | Check time series consistency of the reporting of Greenland and the Faroe Islands prior to aggregating the final submissions |

The time series for all pollutants in the submissions from Greenland and the Faroe Islands are checked at the CRF 3 level for large variations in the time series. Any large variations are explained or corrected in cooperation with the authorities in Greenland and the Faroe Islands.

| | | | |
|---|---|---|---|
| Data Storage level 4 | 5.Correctness | DS.4.5.1 | Check that the aggregated submissions for Denmark under the Kyoto Protocol and the UNFCCC matches the sum of the individual submissions |

To ensure that the submission for Denmark under the Kyoto Protocol matches the sum of the submissions of Denmark and Greenland a spreadsheet check has been implemented to ensure complete correctness of the submitted inventory. The same procedure is followed for the submission under the UNFCCC, where it is ensured that the submitted emissions equate to the sum of Denmark, Greenland and the Faroe Islands. Special attention is paid to the additional information provided in the CRF, e.g. for the agricultural sector. Certain parameters cannot simply be added, e.g. animal weights. In these cases, a weighted average is reported in the CRF tables.

| | | | |
|---|---|---|---|
| Data Storage level 4 | 6. Robustness | DS.4.6.1 | The reporting to the UNFCCC must be anchored to two responsible persons who can replace each other in the technical issue of reporting to and communicating with the UNFCCC secretariat. |

The reporting to the UNFCCC secretariat is currently anchored by two team members. All official correspondence between the secretariat and DCE involves both the responsible team members.

| | | | |
|---|---|---|---|
| Data Storage level 4 | 7.Transparency | DS.4.7.1 | Perform QA on the documentation report provided by the Government of Greenland |

The documentation report is received by DCE from the Government of Greenland in the early spring every year. The documentation report is included in the NIR as Chapter 16. DCE experts read and provide comments on the report to the Government of Greenland, so that any questions are resolved prior to the UNFCCC reporting deadline of April 15.

## 1.7 General uncertainty evaluation, including data on the overall uncertainty for the inventory totals

### 1.7.1 Tier 1 uncertainties

The uncertainty estimates are based on the Approach 1 methodology in the 2006 IPCC Guidelines (IPCC, 2006). Uncertainty estimates for all sectors are included in the current year. The sources included in the uncertainty estimate cover 100 % of the total net Danish greenhouse gas emissions and removals.

The uncertainties for the activity rates and emission factors are shown in Table 1.5.

Table 1.5 Summary of base year and 2018 emissions in kt $CO_2$ equivalents and activity data and emission factor uncertainties. Calculated Approach 1 uncertainties for each emission source are given as percentage of the total 2018 emission. The base year for F-gases is 1995 and for all other gases, the base year is 1990.

| IPCC Source category | Gas | Base year emission kt $CO_2$ eqv. | 2018 emission kt $CO_2$ eqv. | Activity data uncertainty % | Emission factor uncertainty % | Approach 1 Combined uncertainty % of total emissions |
|---|---|---|---|---|---|---|
| 1A Stationary combustion, Coal, ETS data, $CO_2$ | $CO_2$ | 0.0 | 6107.0 | 0.5 | 0.3 | 0.583 |
| 1A Stationary combustion, Coal, no ETS data, $CO_2$ | $CO_2$ | 23826.7 | 210.9 | 1.5 | 1.0 | 1.841 |
| 1A Stationary combustion, BKB, $CO_2$ | $CO_2$ | 11.3 | 0.0 | 2.9 | 5.0 | 5.774 |
| 1A Stationary combustion, Coke oven coke, $CO_2$ | $CO_2$ | 136.5 | 43.5 | 1.5 | 5.0 | 5.224 |
| 1A Stationary combustion, Fossil waste, ETS data, $CO_2$ | $CO_2$ | 0.0 | 1340.3 | 2.0 | 3.0 | 3.606 |
| 1A Stationary combustion, Fossil waste, no ETS data, $CO_2$ | $CO_2$ | 573.5 | 431.5 | 5.0 | 10.0 | 11.180 |
| 1A Stationary combustion, Petroleum coke, ETS data, $CO_2$ | $CO_2$ | 0.0 | 631.7 | 0.5 | 0.5 | 0.707 |
| 1A Stationary combustion, Petroleum coke, no ETS data, $CO_2$ | $CO_2$ | 414.7 | 20.6 | 1.9 | 5.0 | 5.336 |
| 1A Stationary combustion, Residual oil, ETS data, $CO_2$ | $CO_2$ | 0.0 | 231.1 | 0.5 | 0.5 | 0.707 |
| 1A Stationary combustion, Residual oil, no ETS data, $CO_2$ | $CO_2$ | 2526.6 | 20.2 | 1.0 | 2.0 | 2.220 |
| 1A Stationary combustion, Gas oil, $CO_2$ | $CO_2$ | 4738.4 | 688.6 | 2.6 | 1.3 | 2.902 |
| 1A Stationary combustion, Kerosene, $CO_2$ | $CO_2$ | 367.6 | 13.2 | 2.0 | 3.0 | 3.606 |
| 1A Stationary combustion, LPG, $CO_2$ | $CO_2$ | 187.9 | 140.6 | 2.0 | 4.0 | 4.492 |
| 1A1b Stationary combustion, Petroleum refining, Refinery gas, $CO_2$ | $CO_2$ | 816.1 | 832.1 | 1.0 | 0.5 | 1.118 |
| 1A Stationary combustion, Natural gas, onshore, $CO_2$ | $CO_2$ | 3790.5 | 5194.1 | 1.3 | 0.4 | 1.358 |
| 1A1c_ii Stationary combustion, Oil and gas extraction, Off shore gas turbines, Natural gas, $CO_2$ | $CO_2$ | 544.9 | 1253.6 | 0.5 | 0.5 | 0.707 |
| 1A1 Stationary Combustion, Solid fuels, $CH_4$ | $CH_4$ | 5.3 | 1.4 | 1 | 100 | 100.005 |
| 1A1 Stationary Combustion, Liquid fuels, $CH_4$ | $CH_4$ | 0.7 | 0.5 | 1 | 100 | 100.005 |
| 1A1 Stationary Combustion, not engines, gaseous fuels, $CH_4$ | $CH_4$ | 0.8 | 1.6 | 1 | 100 | 100.005 |
| 1A1 Stationary Combustion, Waste, $CH_4$ | $CH_4$ | 0.2 | 0.3 | 3 | 100 | 100.045 |
| 1A1 Stationary Combustion, not engines, Biomass, $CH_4$ | $CH_4$ | 3.6 | 13.0 | 3 | 100 | 100.045 |
| 1A2 Stationary Combustion, solid fuels, $CH_4$ | $CH_4$ | 3.8 | 1.3 | 2 | 100 | 100.020 |
| 1A2 Stationary Combustion, Liquid fuels, $CH_4$ | $CH_4$ | 0.9 | 0.6 | 2 | 100 | 100.020 |
| 1A2 Stationary Combustion, not engines, gaseous fuels, $CH_4$ | $CH_4$ | 0.6 | 0.8 | 2 | 100 | 100.020 |
| 1A2 Stationary Combustion, Waste, $CH_4$ | $CH_4$ | 0.0 | 2.9 | 3 | 100 | 100.045 |
| 1A2 Stationary Combustion, not engines, Biomass, $CH_4$ | $CH_4$ | 1.6 | 2.3 | 3 | 100 | 100.045 |
| 1A4 Stationary Combustion, Solid fuels, $CH_4$ | $CH_4$ | 6.2 | 0.1 | 3 | 100 | 100.045 |
| 1A4 Stationary Combustion, Liquid fuels, $CH_4$ | $CH_4$ | 3.0 | 0.4 | 3 | 100 | 100.045 |
| 1A4 Stationary Combustion, not engines, gaseous fuels, $CH_4$ | $CH_4$ | 0.6 | 0.8 | 3 | 100 | 100.045 |
| 1A4 Stationary Combustion, Waste, $CH_4$ | $CH_4$ | 0.7 | 0.0 | 3 | 100 | 100.045 |
| 1A4 Stationary Combustion, not engines, not residential wood and not residential/agricultural straw, Biomass, $CH_4$ | $CH_4$ | 0.1 | 0.6 | 3 | 100 | 100.045 |
| 1A4b_i Stationary combustion, Residential wood combustion, $CH_4$ | $CH_4$ | 72.3 | 70.1 | 10 | 150 | 150.333 |
| 1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion, $CH_4$ | $CH_4$ | 63.6 | 36.9 | 10 | 150 | 150.333 |
| 1A Stationary combustion, Natural gas fuelled engines, gaseous fuels, $CH_4$ | $CH_4$ | 5.5 | 72.4 | 1 | 2 | 2.236 |
| 1A Stationary combustion, Biogas fuelled engines, | $CH_4$ | 2.2 | 57.9 | 3 | 10 | 10.440 |

| IPCC Source category | Gas | Base year emission kt $CO_2$ eqv. | 2018 emission kt $CO_2$ eqv. | Activity data uncertainty % | Emission factor uncertainty % | Approach 1 Combined uncertainty % of total emissions |
|---|---|---|---|---|---|---|
| Biomass, $CH_4$ | | | | | | |
| 1A1 Stationary Combustion, Solid fuels, $N_2O$ | $N_2O$ | 57.4 | 14.8 | 1 | 400 | 400.001 |
| 1A1 Stationary Combustion, Liquid fuels, $N_2O$ | $N_2O$ | 2.8 | 1.5 | 1 | 1000 | 1000.000 |
| 1A1 Stationary Combustion, Gaseous fuels, $N_2O$ | $N_2O$ | 11.8 | 14.3 | 1 | 750 | 750.001 |
| 1A1 Stationary Combustion, Waste, $N_2O$ | $N_2O$ | 5.2 | 13.0 | 3 | 400 | 400.011 |
| 1A1 Stationary Combustion, Biomass, $N_2O$ | $N_2O$ | 8.4 | 42.4 | 3 | 400 | 400.011 |
| 1A2 Stationary Combustion, Solid fuels, $N_2O$ | $N_2O$ | 6.7 | 24.6 | 2 | 400 | 400.005 |
| 1A2 Stationary Combustion, Liquid fuels, $N_2O$ | $N_2O$ | 28.7 | 6.2 | 2 | 1000 | 1000.002 |
| 1A2 Stationary Combustion, Gaseous fuels, $N_2O$ | $N_2O$ | 7.2 | 8.9 | 2 | 750 | 750.003 |
| 1A2 Stationary Combustion, Waste, $N_2O$ | $N_2O$ | 0.0 | 4.6 | 3 | 400 | 400.011 |
| 1A2 Stationary Combustion, Biomass, $N_2O$ | $N_2O$ | 6.9 | 10.6 | 3 | 400 | 400.011 |
| 1A4 Stationary Combustion, Solid fuels, $N_2O$ | $N_2O$ | 1.5 | 0.2 | 3 | 400 | 400.011 |
| 1A4 Stationary Combustion, Liquid fuels, $N_2O$ | $N_2O$ | 11.4 | 1.4 | 3 | 1000 | 1000.004 |
| 1A4 Stationary Combustion, Gaseous fuels, $N_2O$ | $N_2O$ | 7.7 | 9.8 | 3 | 750 | 750.006 |
| 1A4 Stationary Combustion, Waste, $N_2O$ | $N_2O$ | 1.1 | 0.0 | 3 | 400 | 400.011 |
| 1A4 Stationary Combustion, not residential wood and not residential/agricultural straw, Biomass, $N_2O$ | $N_2O$ | 0.5 | 3.8 | 3 | 400 | 400.011 |
| 1A4b_i Stationary Combustion, Residential wood combustion, $N_2O$ | $N_2O$ | 10.7 | 49.0 | 10 | 500 | 500.100 |
| 1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion, $N_2O$ | $N_2O$ | 10.1 | 5.9 | 10 | 500 | 500.100 |
| 1.A.2.g Industry (mobile) | $CO_2$ | 629.3 | 604.8 | 41 | 5 | 41.304 |
| 1.A.3.a Civil aviation | $CO_2$ | 204.8 | 133.2 | 10 | 5 | 11.180 |
| 1.A.3.b Road Transport | $CO_2$ | 9356.6 | 12306.7 | 2 | 5 | 5.385 |
| 1.A.3.c Railways | $CO_2$ | 296.7 | 224.0 | 2 | 5 | 5.385 |
| 1.A.3.d Navigation (large vessels) | $CO_2$ | 714.4 | 621.1 | 11 | 5 | 12.083 |
| 1.A.4.a Commercial/Institutional (mobile) | $CO_2$ | 44.6 | 83.0 | 35 | 5 | 35.355 |
| 1.A.4.b Residential (mobile) | $CO_2$ | 18.8 | 23.2 | 35 | 5 | 35.355 |
| 1.A.4.c ii Agriculture (mobile) | $CO_2$ | 1272.3 | 1041.7 | 24 | 5 | 24.515 |
| 1.A.4.c ii Forestry (mobile) | $CO_2$ | 35.7 | 15.3 | 30 | 5 | 30.414 |
| 1.A.4.c iii Fisheries | $CO_2$ | 619.6 | 269.2 | 2 | 5 | 5.385 |
| 1.A.5.b Other (military) | $CO_2$ | 47.9 | 97.4 | 41 | 5 | 41.304 |
| 1.A.5.b Other (small boats) | $CO_2$ | 119.0 | 117.6 | 2 | 5 | 5.385 |
| 1.A.2.g Industry (mobile) | $CH_4$ | 1.5 | 0.5 | 41 | 100 | 108.079 |
| 1.A.3.a Civil aviation | $CH_4$ | 0.1 | 0.0 | 10 | 100 | 100.499 |
| 1.A.3.b Road Transport | $CH_4$ | 78.5 | 9.3 | 2 | 40 | 40.050 |
| 1.A.3.c Railways | $CH_4$ | 0.3 | 0.1 | 2 | 100 | 100.020 |
| 1.A.3.d Navigation (large vessels) | $CH_4$ | 0.4 | 0.9 | 11 | 100 | 100.603 |
| 1.A.4.a Commercial/Institutional (mobile) | $CH_4$ | 0.6 | 0.8 | 35 | 100 | 105.948 |
| 1.A.4.b Residential (mobile) | $CH_4$ | 0.9 | 0.4 | 35 | 100 | 105.948 |
| 1.A.4.c ii Agriculture (mobile) | $CH_4$ | 2.3 | 1.4 | 24 | 100 | 102.840 |
| 1.A.4.c ii Forestry (mobile) | $CH_4$ | 4.0 | 0.4 | 30 | 100 | 104.403 |
| 1.A.4.c iii Fisheries | $CH_4$ | 0.3 | 0.2 | 2 | 100 | 100.020 |
| 1.A.5.b Other (military) | $CH_4$ | 1.9 | 0.2 | 41 | 100 | 108.079 |
| 1.A.5.b Other (small boats) | $CH_4$ | 0.1 | 0.1 | 2 | 100 | 100.020 |
| 1.A.2.g Industry (mobile) | $N_2O$ | 7.4 | 8.3 | 41 | 1000 | 1000.840 |
| 1.A.3.a Civil aviation | $N_2O$ | 2.9 | 2.0 | 10 | 1000 | 1000.050 |
| 1.A.3.b Road Transport | $N_2O$ | 87.8 | 132.5 | 2 | 50 | 50.040 |
| 1.A.3.c Railways | $N_2O$ | 2.7 | 2.0 | 2 | 1000 | 1000.002 |
| 1.A.3.d Navigation (large vessels) | $N_2O$ | 5.3 | 4.6 | 11 | 1000 | 1000.060 |
| 1.A.4.a Commercial/Institutional (mobile) | $N_2O$ | 0.4 | 0.6 | 35 | 1000 | 1000.612 |

| IPCC Source category | Gas | Base year emission kt $CO_2$ eqv. | 2018 emission kt $CO_2$ eqv. | Activity data uncertainty % | Emission factor uncertainty % | Approach 1 Combined uncertainty % of total emissions |
|---|---|---|---|---|---|---|
| 1.A.4.b Residential (mobile) | $N_2O$ | 0.1 | 0.1 | 35 | 1000 | 1000.612 |
| 1.A.4.c ii Agriculture (mobile) | $N_2O$ | 14.7 | 14.7 | 24 | 1000 | 1000.288 |
| 1.A.4.c ii Forestry (mobile) | $N_2O$ | 0.2 | 0.2 | 30 | 1000 | 1000.450 |
| 1.A.4.c iii Fisheries | $N_2O$ | 4.7 | 2.0 | 2 | 1000 | 1000.002 |
| 1.A.5.b Other (military) | $N_2O$ | 0.4 | 1.0 | 41 | 1000 | 1000.840 |
| 1.A.5.b Other (small boats) | $N_2O$ | 1.1 | 1.4 | 2 | 1000 | 1000.002 |
| 1.B.2.a.1 Exploration | $CO_2$ | 4.7 | 0.0 | 2 | 10 | 10.198 |
| 1.B.2.a.2 Production | $CO_2$ | 0.0 | 0.0 | 2 | 100 | 100.020 |
| 1.B.2.a.4 Refining/storage | $CO_2$ | 0.0 | 0.0 | 2 | 40 | 40.050 |
| 1.B.2.b.1 Exploration | $CO_2$ | 8.2 | 0.0 | 2 | 10 | 10.198 |
| 1.B.2.b.2 Production | $CO_2$ | 0.1 | 0.1 | 2 | 100 | 100.020 |
| 1.B.2.b.4 Transmission and storage | $CO_2$ | 0.0 | 0.0 | 15 | 2 | 15.133 |
| 1.B.2.b.5 Distribution | $CO_2$ | 0.0 | 0.0 | 25 | 10 | 26.926 |
| 1.B.2.c.1.ii Venting | $CO_2$ | 0.0 | 0.0 | 15 | 2 | 15.133 |
| 1.B.2.c.2.i Flaring, oil | $CO_2$ | 22.9 | 17.9 | 11 | 2 | 11.180 |
| 1.B.2.c.2.ii Flaring, gas | $CO_2$ | 2.1 | 1.4 | 7.5 | 2 | 7.762 |
| 1.B.2.c.2.iii Flaring, combined | $CO_2$ | 302.8 | 213.1 | 7.5 | 2 | 7.762 |
| 1.B.2.a.1 Exploration | $CH_4$ | 0.0 | 0.0 | 2 | 125 | 125.016 |
| 1.B.2.a.2 Production | $CH_4$ | 0.1 | 0.1 | 2 | 100 | 100.020 |
| 1.B.2.a.3 Transport | $CH_4$ | 0.8 | 1.4 | 2 | 100 | 100.020 |
| 1.B.2.a.4 Refining/storage | $CH_4$ | 30.5 | 21.4 | 1 | 200 | 200.002 |
| 1.B.2.b.1 Exploration | $CH_4$ | 0.8 | 0.0 | 2 | 125 | 125.016 |
| 1.B.2.b.2 Production | $CH_4$ | 48.8 | 38.3 | 2 | 100 | 100.020 |
| 1.B.2.b.4 Transmission and storage | $CH_4$ | 4.8 | 0.7 | 15 | 2 | 15.133 |
| 1.B.2.b.5 Distribution | $CH_4$ | 6.4 | 4.2 | 25 | 10 | 26.926 |
| 1.B.2.c.1.ii Venting | $CH_4$ | 1.5 | 0.9 | 15 | 2 | 15.133 |
| 1.B.2.c.2.i Flaring, oil | $CH_4$ | 0.2 | 0.1 | 11 | 15 | 18.601 |
| 1.B.2.c.2.ii Flaring, gas | $CH_4$ | 0.3 | 0.0 | 7.5 | 2 | 7.762 |
| 1.B.2.c.2.iii Flaring, combined | $CH_4$ | 28.6 | 22.8 | 7.5 | 125 | 125.225 |
| 1.B.2.a.1 Exploration, oil | $N_2O$ | 1.4 | 0.0 | 2 | 1000 | 1000.002 |
| 1.B.2.c.2.i Flaring, oil | $N_2O$ | 0.1 | 0.0 | 11 | 1000 | 1000.060 |
| 1.B.2.c.2.ii Flaring, gas | $N_2O$ | 0.0 | 0.0 | 7.5 | 1000 | 1000.028 |
| 1.B.2.c.2.iii Flaring, combined | $N_2O$ | 51.6 | 41.2 | 7.5 | 1000 | 1000.028 |
| 2A1 Cement production | $CO_2$ | 882.4 | 1159.7 | 2 | 2 | 2.561 |
| 2A2 Lime production | $CO_2$ | 105.4 | 36.8 | 1 | 4 | 4.228 |
| 2A3 Glass production | $CO_2$ | 16.5 | 10.4 | 1 | 2 | 2.236 |
| 2A4a Ceramics | $CO_2$ | 46.1 | 46.4 | 5 | 2 | 5.385 |
| 2A4b Other uses of soda ash | $CO_2$ | 13.8 | 18.6 | 5 | 2 | 5.385 |
| 2A4d Other process uses of carbonates | $CO_2$ | 17.5 | 26.1 | 4 | 2 | 4.472 |
| 2B10 Production of catalysts | $CO_2$ | 0.6 | 1.4 | 5 | 5 | 7.071 |
| 2C1a Steel | $CO_2$ | 30.3 | 0.0 | 5 | 10 | 11.180 |
| 2C5 Lead production | $CO_2$ | 0.2 | 0.1 | 10 | 50 | 50.990 |
| 2D1 Lubricant use | $CO_2$ | 49.7 | 31.7 | 5 | 10 | 11.180 |
| 2D2 Paraffin wax use | $CO_2$ | 21.7 | 58.5 | 10 | 20 | 22.361 |
| Paint Application | $CO_2$ | 12.9 | 5.4 | 10 | 15 | 18.028 |
| Degreasing, dry cleaning and electronics | $CO_2$ | 0.0 | 0.0 | 10 | 15 | 18.028 |
| Chemical products manufacturing or processing | $CO_2$ | 19.4 | 12.6 | 10 | 15 | 18.028 |
| Other use of solvents and related activities | $CO_2$ | 52.0 | 29.4 | 10 | 20 | 22.361 |
| Printing industry | $CO_2$ | 0.0 | 0.0 | 10 | 15 | 18.028 |
| Domestic solvent use (other than paint application) | $CO_2$ | 9.4 | 13.4 | 10 | 15 | 18.028 |
| 2D3 Road paving with asphalt | $CO_2$ | 0.6 | 0.9 | 5 | 75 | 75.166 |
| 2D3 Asphalt roofing | $CO_2$ | 0.0 | 0.0 | 5 | 75 | 75.166 |

| IPCC Source category | Gas | Base year emission<br>kt $CO_2$ eqv. | 2018 emission<br>kt $CO_2$ eqv. | Activity data uncertainty<br>% | Emission factor uncertainty<br>% | Approach 1 Combined uncertainty<br>% of total emissions |
|---|---|---|---|---|---|---|
| 2D3 Urea based catalysts | $CO_2$ | 0.0 | 8.9 | 5 | 10 | 11.180 |
| 2G4 Fireworks | $CO_2$ | 0.1 | 0.3 | 5 | 50 | 50.249 |
| 2D2 Paraffin wax use | $CH_4$ | 0.0 | 0.1 | 10 | 20 | 22.361 |
| 2D3 Road paving with asphalt | $CH_4$ | 0.3 | 0.4 | 5 | 75 | 75.166 |
| 2G4 Fireworks | $CH_4$ | 0.0 | 0.1 | 5 | 50 | 50.249 |
| 2G4 Tobacco | $CH_4$ | 1.0 | 0.5 | 5 | 50 | 50.249 |
| 2G4 Charcoal | $CH_4$ | 1.1 | 1.2 | 5 | 100 | 100.125 |
| 2B2 Nitric acid production | $N_2O$ | 1002.5 | 0.0 | 2 | 25 | 25.080 |
| 2D2 Paraffin wax use | $N_2O$ | 0.1 | 0.1 | 10 | 20 | 22.361 |
| 2G3a Medical application of $N_2O$ | $N_2O$ | 11.3 | 11.3 | 25 | 20 | 32.016 |
| 2G3b $N_2O$ as propellant for pressure and aerosol products | $N_2O$ | 5.3 | 4.9 | 100 | 150 | 180.278 |
| 2G4 Fireworks | $N_2O$ | 0.7 | 3.6 | 5 | 50 | 50.249 |
| 2G4 Tobacco | $N_2O$ | 0.3 | 0.1 | 5 | 50 | 50.249 |
| 2G4 Charcoal | $N_2O$ | 0.1 | 0.1 | 5 | 100 | 100.125 |
| 2E Electronics industry | HFCs | 0.0 | 0.0 | 0 | 0 | 0.000 |
| 2F1 Refrigeration and air conditioning | HFCs | 47.6 | 473.8 | 10 | 50 | 50.990 |
| 2F2 Foam blowing agents | HFCs | 210.3 | 0.8 | 10 | 50 | 50.990 |
| 2F4 Aerosols | HFCs | 0.0 | 12.8 | 10 | 50 | 50.990 |
| 2E Electronics industry | PFCs | 0.0 | 0.0 | 10 | 50 | 50.990 |
| 2F1 Refrigeration and air conditioning | PFCs | 0.6 | 0.0 | 10 | 50 | 50.990 |
| 2C4 Magnesium production | $SF_6$ | 34.2 | 0.0 | 10 | 30 | 31.623 |
| 2G1 Electrical equipment | $SF_6$ | 3.7 | 13.2 | 10 | 50 | 50.990 |
| 2G2 $SF_6$ and PFCs from other product use | $SF_6$ | 65.9 | 60.0 | 10 | 50 | 50.990 |
| 3A Enteric Fermentation | $CH_4$ | 4039.5 | 3767.4 | 2 | 20 | 20.100 |
| 3B Manure Management | $CH_4$ | 1853.6 | 2219.3 | 5 | 20 | 20.616 |
| 3F Field Burning of Agricultural Residues | $CH_4$ | 2.2 | 3.4 | 25 | 50 | 55.902 |
| 3B Manure Management | $N_2O$ | 780.7 | 596.7 | 25 | 100 | 103.078 |
| 3B5 Atmospheric deposition | $N_2O$ | 198.1 | 136.4 | 16 | 100 | 101.272 |
| 3Da1 Inorganic N fertilizer | $N_2O$ | 1875.0 | 1049.8 | 3 | 100 | 100.045 |
| 3Da2a Animal manure applied to soils | $N_2O$ | 991.0 | 1016.3 | 25 | 100 | 103.078 |
| 3Da2b Sewage sludge applied to soils | $N_2O$ | 14.6 | 19.0 | 15 | 100 | 101.119 |
| 3Da2c Other organic fertilizer applied to soils | $N_2O$ | 7.2 | 22.4 | 20 | 100 | 101.980 |
| 3Da3 Urine and dung deposited by grazing animals | $N_2O$ | 297.9 | 175.3 | 10 | 100 | 100.499 |
| 3Da4 Crop Residues | $N_2O$ | 569.3 | 473.4 | 25 | 100 | 103.078 |
| 3Da5 Mineralization | $N_2O$ | 147.8 | 135.1 | 50 | 100 | 111.803 |
| 3Da6 Cultivation of organic soils | $N_2O$ | 856.3 | 652.0 | 20 | 100 | 101.980 |
| 3Db1 Atmospheric deposition | $N_2O$ | 359.4 | 200.1 | 16 | 100 | 101.272 |
| 3Db2 Leaching | $N_2O$ | 549.3 | 329.5 | 20 | 100 | 101.980 |
| 3F Field Burning of Agricultural Residues | $N_2O$ | 0.7 | 1.1 | 25 | 50 | 55.902 |
| 3G Liming | $CO_2$ | 565.5 | 239.9 | 5 | 100 | 100.125 |
| 3H Urea application | $CO_2$ | 14.7 | 1.4 | 3 | 100 | 100.045 |
| 3I Other carbon-containing fertilizers | $CO_2$ | 38.4 | 2.9 | 3 | 100 | 100.045 |
| 4.A.1 Forest land remaining forest land, Living biomass | $CO_2$ | -738.3 | -2607.2 | 5 | 2 | 5.385 |
| 4.A.1 Forest land remaining forest land, Dead organic matter | $CO_2$ | -5.8 | 2977.9 | 5 | 3 | 5.983 |
| 4.A.1 Forest land remaining forest land, Mineral soils | $CO_2$ | 0.0 | 0.0 | 5 | 2 | 5.385 |
| 4.A.1 Forest land remaining forest land, Organic soils | $CO_2$ | 189.8 | 141.4 | 10 | 50 | 50.990 |
| 4.A.2 Land converted to forest land | $CO_2$ | -19.8 | -163.4 | 10 | 9 | 13.280 |
| 4.B.1 Cropland remaining cropland, Living biomass | $CO_2$ | -19.7 | 48.3 | 3 | 15 | 15.207 |
| 4.B.1 Cropland remaining cropland, Mineral soils | $CO_2$ | 460.9 | 795.6 | 3 | 75 | 75.042 |
| 4.B.1 Cropland remaining cropland, Organic soils | $CO_2$ | 4704.2 | 3525.0 | 3 | 50 | 50.109 |

| IPCC Source category | Gas | Base year emission kt $CO_2$ eqv. | 2018 emission kt $CO_2$ eqv. | Activity data uncertainty % | Emission factor uncertainty % | Approach 1 Combined uncertainty % of total emissions |
|---|---|---|---|---|---|---|
| 4.B.2 Forest land converted to cropland | $CO_2$ | 2.3 | 74.5 | 10 | 50 | 50.990 |
| 4.B.2 Other land uses converted to cropland | $CO_2$ | -1.6 | -28.0 | 10 | 50 | 50.990 |
| 4(II) Cropland on organic soils | $CO_2$ | 34.6 | 27.6 | 3 | 40 | 40.136 |
| 4.C.1 Grassland remaining grassland, Living biomass | $CO_2$ | 14.3 | 99.2 | 3 | 7 | 7.433 |
| 4.C.1 Grassland remaining grassland, Organic soils | $CO_2$ | 1420.9 | 1206.4 | 3 | 50 | 50.109 |
| 4.C.2 Forest land converted to grassland | $CO_2$ | 1.4 | 47.3 | 10 | 50 | 50.990 |
| 4.C.2 Other land uses converted to grassland | $CO_2$ | 0.9 | 24.0 | 10 | 50 | 50.990 |
| 4(II) Grassland on organic soils | $CO_2$ | 14.3 | 12.3 | 3 | 40 | 40.136 |
| 4.D.1.1 Peat extraction remaining peat extraction | $CO_2$ | 99.5 | 52.6 | 10 | 75 | 75.664 |
| 4.D.1.2 Flooded land remaining flooded land | $CO_2$ | 0.0 | 0.0 | 10 | 75 | 75.664 |
| 4.D.2. Land converted to wetlands | $CO_2$ | -1.3 | 0.0 | 10 | 75 | 75.664 |
| 4.E.2 Forest land converted to settlements | $CO_2$ | 4.8 | 35.5 | 10 | 75 | 75.664 |
| 4.E.2 Other land uses converted to settlements | $CO_2$ | 13.8 | 144.2 | 10 | 75 | 75.664 |
| 4.G Harvested wood products | $CO_2$ | -2.4 | -162.1 | 25 | 75 | 79.057 |
| 4(II) Cropland on organic soils | $CH_4$ | 162.5 | 141.0 | 10 | 90 | 90.554 |
| 4(II) Grassland on organic soils | $CH_4$ | 85.6 | 73.5 | 10 | 90 | 90.554 |
| 4(II) A. Forest land, organic soils | $CH_4$ | 4.0 | 29.4 | 10 | 90 | 90.554 |
| 4(II) Land converted to wetlands | $CH_4$ | 2.2 | 56.6 | 10 | 90 | 90.554 |
| 4(II) Peatland | $CH_4$ | 1.3 | 0.7 | 10 | 90 | 90.554 |
| 4(V) Biomass Burning | $CH_4$ | 0.7 | 0.0 | 10 | 30 | 31.623 |
| 4(III) Mineralization/immobilization, Forest land | $N_2O$ | 0.0 | 0.0 | 10 | 90 | 90.554 |
| 4(III) Mineralization/immobilization, Cropland | $N_2O$ | 0.1 | 2.0 | 10 | 90 | 90.554 |
| 4(III) Mineralization/immobilization, Grassland | $N_2O$ | 0.0 | 0.8 | 10 | 90 | 90.554 |
| 4(III) Mineralization/immobilization, Land converted to Settlements | $N_2O$ | 0.3 | 14.3 | 10 | 90 | 90.554 |
| 4(V) Biomass burning | $N_2O$ | 0.4 | 0.0 | 10 | 30 | 31.623 |
| 4(II) Drainage and rewetting, Forest soils | $N_2O$ | 26.5 | 24.0 | 10 | 50 | 50.990 |
| 4(II) Peat extraction remaining peat extraction | $N_2O$ | 0.2 | 0.1 | 10 | 50 | 50.990 |
| 5.E Accidental fires | $CO_2$ | 20.3 | 18.0 | 10 | 300 | 300.167 |
| 5.A Solid waste disposal | $CH_4$ | 1536.3 | 560.4 | 10 | 105 | 105.000 |
| 5.B.1 Composting | $CH_4$ | 34.7 | 106.8 | 20 | 100 | 101.980 |
| 5.B.2. Anaerobic digestion at biogas facilities | $CH_4$ | 5.6 | 252.1 | 5 | 20 | 20.616 |
| 5.C.1 Incineration of corpses | $CH_4$ | 0.0 | 0.0 | 1 | 150 | 150.003 |
| 5.C.2 Incineration of carcasses | $CH_4$ | 0.0 | 0.0 | 40 | 150 | 155.242 |
| 5.D.1 Domestic wastewater | $CH_4$ | 41.1 | 50.8 | 24 | 32 | 40.000 |
| 5.E Accidental fires | $CH_4$ | 2.4 | 2.1 | 10 | 500 | 500.100 |
| 5.B.1 Composting | $N_2O$ | 12.1 | 83.5 | 20 | 100 | 101.980 |
| 5.C.1 Incineration of corpses | $N_2O$ | 0.2 | 0.2 | 1 | 150 | 150.003 |
| 5.C.2 Incineration of carcasses | $N_2O$ | 0.0 | 0.1 | 40 | 150 | 155.242 |
| 5.D.1 Domestic wastewater | $N_2O$ | 61.4 | 58.5 | 30 | 50 | 58.310 |
| 5.D.2 Industrial wastewater | $N_2O$ | 47.8 | 6.9 | 30 | 50 | 58.310 |

### 1.7.2 Results of the Approach 1 uncertainty estimation

The estimated uncertainties for total GHG and for $CO_2$, $CH_4$, $N_2O$ and F-gases are shown in Table 1.6. The base year for F-gases is 1995 and for all other sources, the base year is 1990. The total Danish net GHG emission is estimated with an uncertainty of ±5.7 % and the trend in net GHG emission since the base year has been estimated to be -28.6 % ± 1.8 %-age points. The GHG uncertainty estimates do not take into account the uncertainty of the GWP factors.

The uncertainty of $N_2O$ emissions from synthetic fertiliser, animal waste applied to soil and crop residues and $CH_4$ emission from solid waste disposal, are the largest sources of uncertainty for the Danish GHG inventory (excluding LULUCF). For LULUCF the largest sources of uncertainty are organic soil emissions from cropland.

The uncertainty of the GHG emission from combustion (sector 1A) is 2.6 % and the trend uncertainty is -35.7 % ±1.5 %-age points.

Table 1.6 Uncertainties 1990-2018.

| | Uncertainty Base year [%] | Uncertainty 2018 [%] | Trend [%] | Uncertainty in trend [%-age points] |
|---|---|---|---|---|
| GHG | 5.6 | 5.7 | -28.8 | 1.8 |
| $CO_2$ | 4.5 | 5.2 | -31.5 | 1.6 |
| $CH_4$ | 22.8 | 14.3 | -6.4 | 11.7 |
| $N_2O$ | 33.4 | 36.0 | -33.5 | 9.5 |
| F-gases | 31.9 | 43.5 | 54.7 | 73.7 |
| $CO_2$ excl. LULUCF | 1.8 | 2.3 | -35.3 | 1.4 |
| GHG excl. LULUCF | 4.9 | 5.0 | -31.7 | 1.8 |

### 1.7.3 Tier 2 uncertainties

On the recommendation of the UNFCCC expert review team (ERT) in 2009 Denmark undertook a tier 2 uncertainty analysis. However, due to a reduction in resources, the tier 2 uncertainty analysis will no longer be carried out. For a description on the methodology and results of the tier 2 uncertainty estimation, please refer to Nielsen et al. (2016).

## 1.8 General assessment of the completeness

The present Danish greenhouse gas emission inventory includes all sources identified by the 2006 IPPC Guidelines. Please see Annex 5 for discussion on minor sources that are not included.

## 1.9 ETS emissions

The table below includes data for the share of national total emissions covered by the EU ETS (not including aviation) for 2013-2018. As neither Greenland nor the Faroe Islands are members of the EU, the data in Table 1.7 refer to Denmark only.

Table 1.7 Share of ETS emissions.

| | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|
| National total emission without LULUCF with indirect, kt $CO_2e$ | 55 473 | 51 246 | 48 630 | 50 664 | 48 354 | 48 224 |
| ETS emission, kt $CO_2e$ | 21 627 | 18 389 | 15 796 | 17 219 | 15 078 | 14 948 |
| Share of ETS emission, % | 39.0 | 35.9 | 32.5 | 34.0 | 31.2 | 31.0 |

## 1.10 References

Albrektsen, R., Mikkelsen, M.H. & Gyldenkærne, S. 2017. Danish emission inventories for agriculture. Inventories 1985 – 2015. Aarhus University, DCE – Danish Centre for Environment and Energy, 190 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 250. Available at: http://dce2.au.dk/pub/SR250.pdf

DEPA, 2020: The greenhouse gases HFCs, PFCs and $SF_6$. Danish consumption and emissions 2018. Tomas Sander Poulsen, Provice. In press.

DEPA, 2019: Waste Statistics 2018. Affaldsstatistik 2018. Unpublished.

EMEP/CORINAIR, 2007: EMEP/CORINAIR Atmospheric Emission Inventory Guidebook – 2007, prepared by the UNECE/EMEP Task Force on Emissions Inventories and Projections. Technical Report No 16/2007. Available at:
http://www.eea.europa.eu/publications/EMEPCORINAIR5 (27-01-2020).

EEA, 2016: EMEP/EEA air pollutant emission inventory guidebook 2016. Technical guidance to prepare national emission inventories. EEA Report 21/2016. Available at:
http://www.eea.europa.eu/publications/emep-eea-guidebook-2016 (27-01-2020).

EU Commission, 2004: COMMISSION DECISION of 29 January 2004 establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council. Available at:
http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:059:0001:0074:EN:PDF (27-01-2020).

EU Commission, 2012: COMMISSION REGULATION (EU) No 601/2012 of 21 June 2012 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0601&from=EN (27-01-2020).

EU Commission, 2018: COMMISSION IMPLEMENTING REGULATION (EU) 2018/2066 of 19 December 2018 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 601/2012. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R2066&from=EN (27-01-2020)

Fauser, P., Thomsen, M., Nielsen, O-K., Winther, M., Gyldenkærne, S., Hoffmann, L., Lyck, E. & Illerup, J.B. 2007: Verification of the Danish emission inventory data by national and international data comparisons. National Environmental Research Institute, University of Aarhus, Denmark. 53 pp. – NERI Technical Report no. 627. Available at:
http://www2.dmu.dk/pub/fr627_final.pdf

Fauser, P., Nielsen, M., Winther, M., Plejdrup, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Hoffmann, L., Thomsen, M., Hjelgaard, K. & Nielsen, O.-K., 2013: Verification of the Danish 1990, 2000 and 2010 emission inventory data. Aarhus University, DCE – Danish Centre for Environment and Energy, 85 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 79. Available at: http://dce2.au.dk/pub/SR79.pdf

Holtskog, S., Haakonsen, G., Kvingedal, E., Rypdal, K. & Tornsjø, B., 2000: Verification of the Norwegian emission inventory – Comparing emission intensity values with similar countries. The Norwegian Pollution Control Authority in cooperation with Statistics Norway. SFT report 1736/2000.

Illerup, J.B., Lyck, E., Winther, M. & Rasmussen, E. 2000: Denmark's National Inventory Report – Submitted under the United Nations Framework Convention on Climate Change. Emission Inventories. Research Notes from National Environmental Research Institute, Denmark no. 127, 326 pp. Available at:

http://www.dmu.dk/1_viden/2_Publikationer/3_arbrapporter/rapporter/ar127.pdf

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. & Tanabe K. (eds). Published: IGES, Japan. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (27-01-2020).

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp. Available at: https://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html (27-01-2020).

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp. Available at: https://www.ipcc.ch/report/ar5/wg1/ (27-01-2020).

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Gyldenkærne, S., Thomsen, M., Fauser, P., Nielsen, M. Mikkelsen, M.H., Albrektsen, R., Hjelgaard, K., Hoffmann, L. & Bruun, H.G., 2013: Quality manual for the Danish greenhouse gas inventory. Version 2. Aarhus University, DCE – Danish Centre for Environment and Energy, 44 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 47. Available at: http://www.dmu.dk/Pub/SR47.pdf

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Nielsen, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Thomsen, M., Hjelgaard, K., Fauser, P., Bruun, H.G., Johannsen, V.K., Nord-Larsen, T., Vesterdal, L., Callesen, I., Schou, E., Suadicani, K., Rasmussen, E., Petersen, S.B., Baunbæk, L. & Hansen, M.G. 2016. Denmark's National Inventory Report 2015 and 2016. Emission Inventories 1990-2014 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Aarhus University, DCE –Danish Centre for Environment and Energy, 943pp. Scientific Report from DCE – Danish Centre for Environment and Energy. Available at: http://dce2.au.dk/pub/SR189.pdf

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Gyldenkærne, S., Thomsen, M., Nielsen, M. Mikkelsen, M.H., Albrektsen, R., Hjelgaard, K. & Bruun, H.G., 2013: Quality manual for the Danish greenhouse gas inventory. Version 3. Aarhus University, DCE – Danish Centre for Environment and Energy. (In press)

Pulles, T., Mareckova, K., Svetlik, J., Linek, M., & Skakala, J. 1999: CollectER -Installation and User Guide, EEA Technical Report No 31.

Statistics Denmark, 2018: Agriculture Statistics 2017. Denmark.

Sørensen, P.B., Illerup, J.B., Nielsen, M., Lyck, E., Bruun, H.G., Winther, M., Mikkelsen, M.H. & Gyldenkærne, S. 2005: Quality manual for the greenhouse gas inventory. Version 1. National Environmental Research Institute. -

Research Notes from NERI 224: 25 pp. (electronic). Available at: http://www2.dmu.dk/1_viden/2_Publikationer/3_arbrapporter/rapporter/AR224.pdf

UNFCCC, 2013: Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention. UNFCCC Decision 24/CP.19.

# 2 Trends in greenhouse gas emissions

The trends presented in this Chapter cover the emissions from Denmark. Due to the small emissions originating from Greenland the trends are very similar in fact close to identical. A trend discussion of the aggregated greenhouse gas emissions from Denmark and Greenland is included in Chapter 17.1.

## 2.1 Description and interpretation of emission trends for aggregated greenhouse gas emissions

### 2.1.1 Greenhouse Gas Emissions

The greenhouse gas emissions are estimated according to the IPCC guidelines and are aggregated into six main sectors. The greenhouse gases include $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$ and $NF_3$, although $NF_3$ is not occurring in Denmark. Figure 2.1 shows the estimated total greenhouse gas emissions in $CO_2$ equivalents from 1990 to 2018. The emissions are not corrected for electricity trade or temperature variations.

$CO_2$ is the most important greenhouse gas contributing in 2018 to the national total in $CO_2$ equivalents excluding LULUCF (Land Use and Land Use Change and Forestry) with 72.3 %, followed by $CH_4$ with 15.3 %, $N_2O$ with 11.3 %, and f-gases (HFCs, PFCs, $SF_6$ and $NF_3$) with 1.2 %. The energy sector and agriculture represent the largest sources, followed by industrial processes and product use and waste, see Figure 2.1. The net GHG emission by LULUCF in 2018 is 13.9 % of the total emission in $CO_2$ equivalents excl. LULUCF. The total national greenhouse gas emission in $CO_2$ equivalents excluding LULUCF and including indirect $CO_2$ has decreased by 32.1 % from 1990 to 2018, if excluding indirect $CO_2$ the emissions have decreased by 31.4 %. The decrease is mainly caused by decreasing emissions from the energy sector due to increasing production of wind power and other renewable energy. Comments on the overall trends etc. seen in Figure 2.1 are given in the sections below on the individual greenhouse gases.

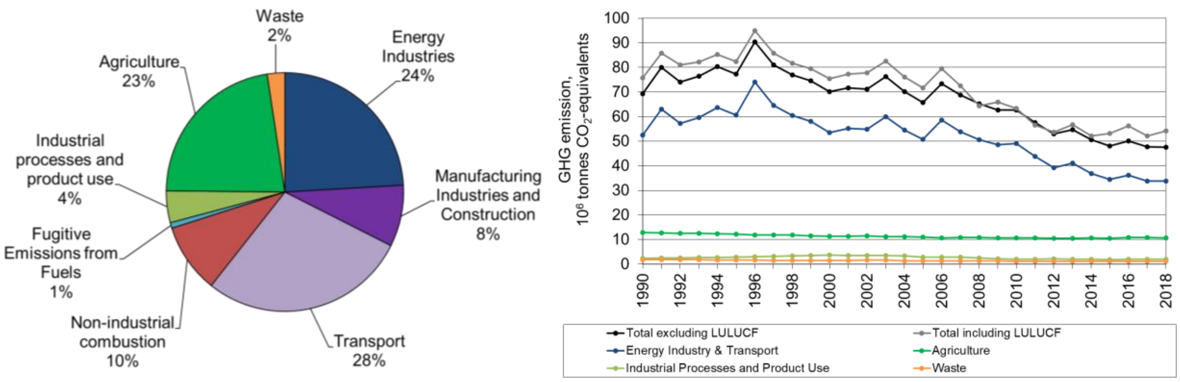



Figure 2.1 Greenhouse gas emissions in $CO_2$ equivalents distributed on main sectors for 2018 (excluding LULUCF and indirect $CO_2$) and time series for 1990 to 2018.

## 2.2 Description and interpretation of emission trends by gas

### 2.2.1 Carbon dioxide

The largest source of the emission of $CO_2$ is the energy sector, which includes the combustion of fossil fuels such as oil, coal and natural gas (Figure 2.2). Energy industries is a dominant source contributing 32.5 % of the total $CO_2$ emission, Figure 2.2. The transport sector contributes 38.3 %. The $CO_2$ emission (excl. LULUCF) decreased by 0.2 % from 2017 to 2018. The main reason for this small decrease is decreasing emissions from energy industries due to a decrease in the consumption of fossil fuels. Emissions from the transport sector increased mainly driven by increased activity in road transport. In general, $CO_2$ emissions fluctuate significantly as a result of the electricity trade with neighbouring countries. In 2018, the actual $CO_2$ emission (excl. LULUCF, incl. indirect $CO_2$) was 36.1 % less than the emission in 1990.

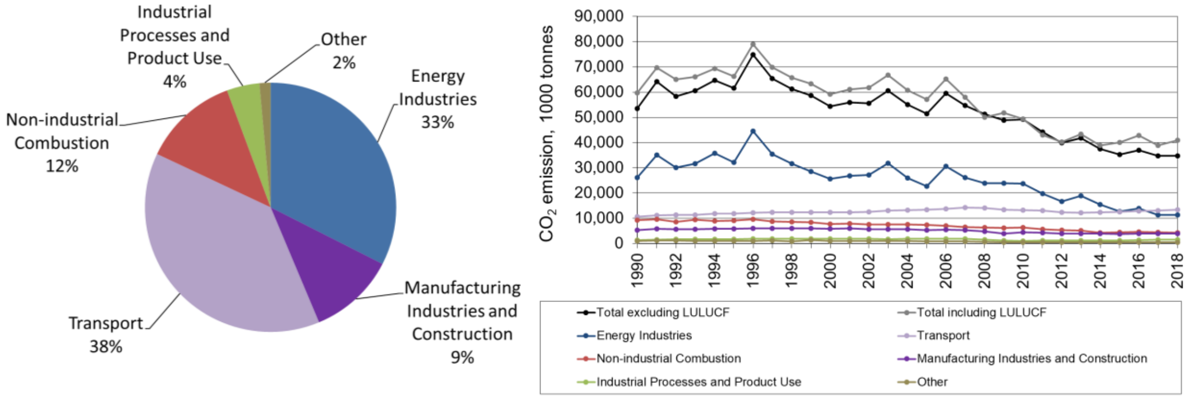



Figure 2.2 $CO_2$ emissions. Distribution according to the main sectors for 2018 and time series for 1990 to 2018.

### 2.2.2 Methane

The largest sources of anthropogenic $CH_4$ emissions are agricultural activities contributing with 81.6 % in 2018, waste (13.3 %) and the remaining emission sources covers 5.1 %, see Figure 2.3. The emission from agriculture derives from enteric fermentation (51.4 %) and management of animal manure (30.3 %).

Since 1990, the emission of $CH_4$ from enteric fermentation has decreased 6.7 %, mainly due to the decrease in the number of cattle. However, this reduction is countered by an increase of 19.7 % in emissions from manure management caused by a change in housing type towards slurry-based systems. In later years, the emission from manure management has decreased due to changes in manure management, e.g. more biogas treatment and acidification of slurry. The emission of $CH_4$ from solid waste disposal has decreased significantly (63.5 %) from 1990 to 2018 due to an increase in the incineration of waste and extensive recycling thereby causing a decrease in the waste disposal on land. The $CH_4$ emission from the energy sector increases from mid 1990ties from public power and district heating plants increases due to the increasing use of gas engines in the decentralised cogeneration plant sector. Due to the liberalisation of the electricity market the use of gas engines declined from 2005 onwards. The high emission from gas engines is caused by the fact that up to 3 % of the natural gas in the gas engines is not combusted.

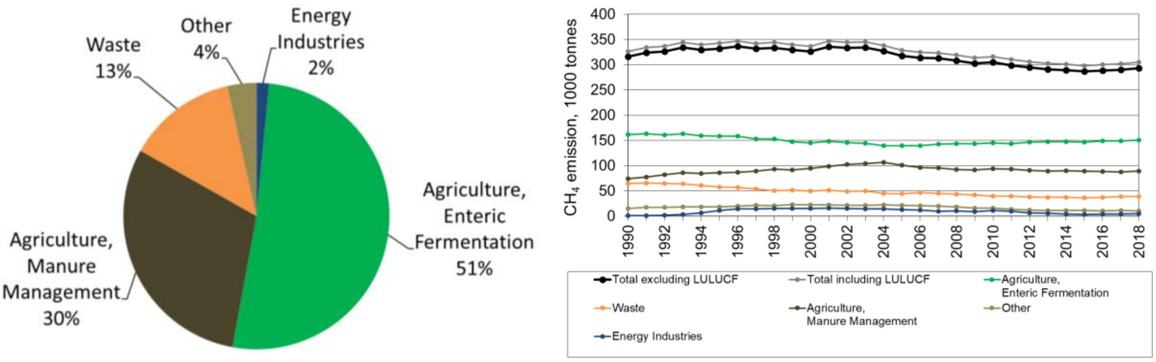



Figure 2.3 $CH_4$ emissions. Distribution according to the main sectors for 2018 and time series for 1990 to 2018.

### 2.2.3 Nitrous oxide

Agriculture is the most important $N_2O$ emission source in 2018 contributing 89.0 % (Figure 2.4) of which $N_2O$ from agricultural soils accounts for 75.4 %. $N_2O$ is emitted as a result of microbial processes in the soil. Substantial emissions also come from drainage water and coastal waters where nitrogen is converted to $N_2O$ through bacterial processes. However, the nitrogen converted in these processes originates mainly from the agricultural use of manure and nitrogen fertilisers.

The main reason for the decrease of $N_2O$ emission excluding LULUCF is due to the agricultural sector, which has decreased with 27.7 % since 1990 caused by legislation to improve the utilisation of nitrogen in manure. Combustion of fuels contributes 7.8 % to the total whereof the $N_2O$ emission from transport contributes with 2.6 % to the national total in 2018. Emission from industrial processes decreased significantly in 2004 due to the closure of the only nitric acid plant operating in Denmark and the emission from this emission source is therefore close to zero since then.

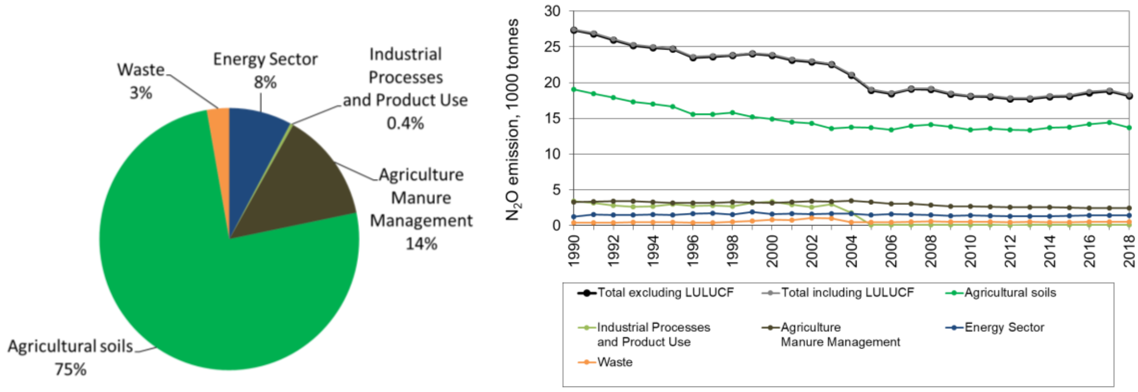



Figure 2.4 $N_2O$ emissions. Distribution according to the main sectors for 2018 and time series for 1990 to 2018.

### 2.2.4 HFCs, PFCs, $SF_6$ and $NF_3$

This part of the Danish inventory only comprises a full data set for all substances from 1995. From 1995 to 2000, there has been a continuous and substantial increase in the contribution from the range of F-gases as a whole, calculated as the sum of emissions in $CO_2$ equivalents, see Figure 2.5. This increase is simultaneous with the increase in the emission of HFCs. For the time series 2000-2009, the increase is lower than for the years 1995 to 2000 and after 2009 the emission has been decreasing. The overall increase from 1995 to 2018 for the total F-gas emission is 54.7 %, while emissions decreased from 2009 to 2018 by 46.3 % mainly due to decreasing emissions of HFCs. $SF_6$ contributed considerably to the F-gas sum in earlier years, with 28.6 % in

1995. Environmental awareness and regulation of this gas under Danish law has reduced its use in industry, see Figure 2.5. A further result is that the contribution of $SF_6$ to F-gases in 2018 was only 13.1 %. The use of HFCs has increased several folds. HFCs have, therefore, become even more dominant, comprising 71.2 % in 1995, but 86.9 % in 2017. HFCs are mainly used as a refrigerant. Danish legislation regulates the use of F-gases, e.g. since January 1, 2007, new HFC-based refrigerant stationary systems are forbidden. Refill of old systems is still allowed.

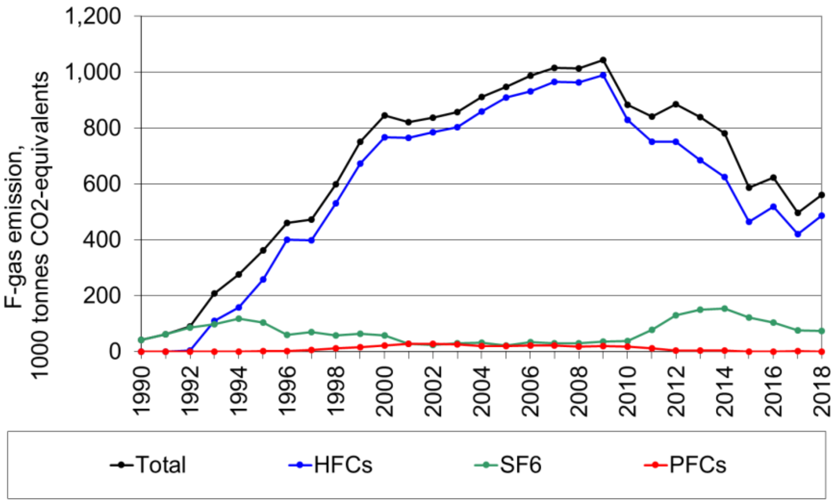



Figure 2.5 F-gas emissions. Time series for 1990 to 2018.

## 2.3 Description and interpretation of emission trends by source

### 2.3.1 Energy

The emission from the energy sector in 2018 covers 70.3 % of the total emission in $CO_2$ equivalents (excl. LULUCF and indirect $CO_2$). The emission of $CO_2$ equivalents from Energy Industries (CRF 1A1) has decreased by 56.3 % from 1990 to 2018. The relatively large fluctuation in the emission through the time-series 1990-2018 is due to inter-country electricity trade. Thus, the high emissions in 1991, 1996, 2003 and 2006 reflect a large electricity export and the low emission in 1990, 2005, 2008, 2011 and 2012 is due to import of electricity. In general, $CO_2$ emissions are decreasing due to a lower consumption of fossil fuels.

The increasing emission of $CH_4$ is due to the increasing use of gas engines in decentralised cogeneration plants. However, in later years the $CH_4$ emission has decreased due to less use of natural gas in gas engines. The $CH_4$ emission from residential combustion (mainly wood) has increased as a result of increased use of wood. The emission of $CO_2$ equivalents from the transport sector (CRF 1A3) increased by 25.0 % from 1990 to 2018, mainly due to increasing road traffic.

### 2.3.2 Industrial processes and product use

The emissions from industrial processes and product use, i.e. emissions from processes other than fuel combustion, amount in 2018 to 4.3 % of the total emission in $CO_2$ equivalents (excl. LULUCF). The main sources are cement production and f-gases used in refrigeration and air conditioning.

The largest source is $CO_2$ emission from cement production, which in 2018 contributes with 1159.7 kt $CO_2$, i.e. 2.4 % of the national greenhouse gas emissions. The $CO_2$ emission from cement production has increased by 31.4 % since 1990. The second largest source is the emission from consumption of HFCs from refrigeration and air condition equipment. This source contributes with 473.8 kt $CO_2$ equivalents, i.e. 1.0 % of the national total. Historically (1990-2004), the emission of $N_2O$ from the production of nitric acid has been the second largest source (after cement), with up to 1002.5 kt $CO_2$ equivalents (1990). However, the production of nitric acid ceased in 2004, which reduced the $N_2O$ emission from industrial processes drastically.

### 2.3.3 Agriculture

The agricultural sector contributes in 2018 with 23.0 % of the total emission in $CO_2$ equivalents (excl. LULUCF) and the major part is related to the livestock production. Since 1990, the agricultural emission has decreased 16.1 % mainly due to a decrease in the $N_2O$ emission.

In 2018, the agricultural activities accounts for 81.6 % of the total $CH_4$ emission (excl. LULUCF). Since 1990, the emission of $CH_4$ from enteric fermentation has decreased by 6.7 %, which is mainly due to the decrease in the number of dairy cattle. However, the emission from manure management has in the same period increased 19.7 %, which is mainly driven by a change from traditional housing systems towards slurry-based housing systems. In total, the $CH_4$ emission from the agriculture sector 1990 – 2018 has increased 1.6 %.

In 2018, the agricultural activities accounts for 89.0 % of the total $N_2O$ emission (excl. LULUCF). Since 1990, the $N_2O$ emission has decreased 27.7 %. A string of measures have been introduced by action plans to prevent the loss of nitro-gen from agriculture to the aquatic environment. These actions have brought a decrease in animal nitrogen excretion, improvement in use of nitrogen in manure and a fall in the use of inorganic N fertiliser, which all have consequences for a reduce of the $N_2O$ emission.

### 2.3.4 Land use, Land-use change and forestry

The total sector has been estimated to be a net source of 0-14 % of the total Danish emission incl. LULUCF. The average emission in 2013-2018 has been estimated to 4312 kt $CO_2$-eq. with an emission of 6645 kt $CO_2$-eq. in 2018. Emissions/removals from the sector fluctuate based on specific conditions in the given year. In general, the forest sector has been a net sink, while Cropland and Grassland have been net sources. The latter due to a large area with drained organic soils. Emissions from drained organic agricultural soils accounts for approximately for 6-7 % of the total Danish emission incl. LULUCF in the latter years. In years where the total sector accounts to approximately zero, the forest and/or the agricultural mineral soils are net sinks. Forest has shown to be a large sink until 2014 and turned into a small net source in 2015, 2016 and 2018. In 2017, Forest was a small sink. Since 2013, Forest has been estimated to be an accumulated net sink of 4997 kt $CO_2$ equivalents. In 2018, Cropland has been estimated to be a net source of 8.5 % of the total Danish emission incl. LULUCF. This is mainly due to a large area with cultivated organic soils. Grassland is a net source contributing to 2.7 % of the total Danish emission. This is also due to a large area with drained organic soils. Emissions from Cropland have shown a continuous decrease since 1990 with 14 % and the emission from Grassland has decreased with 4 %. However, large variations occur between years, e.g. in 2018 the emissions are very high due to the unusual high temperatures during the summer accelerating the emissions.

### 2.3.5 Waste

The waste sector contributes in 2018 to 2.4 % of the total emission in $CO_2$ equivalents (excl. LULUCF). The emission from the sector has decreased by 35.3 % since 1990. The most important activity in the sector is solid waste disposal on land with $CH_4$ emissions contributing in 2018 to 49.2 % of the sectoral total greenhouse gas emission.

The $CH_4$ emission from solid waste disposal has been decreasing since 1990 by 63.5 % due to banning of deposing organic waste and an overall decrease in waste deposited because waste has increasingly been used for power and heat production and/or recycled.

Biological treatment of solid waste (5.B) is the second largest contributor to the sectoral total greenhouse gas emission in 2018. It contributes to the sectoral total in $CO_2$ equivalents in 2018 with 38.8 %. The emissions from biological treatment of solid waste have increased by 791 % for $CH_4$ and 590 % for $N_2O$ since 1990, due to an increase in the number of biogas plants and the amount of biowaste composted in Denmark.

Wastewater handling contributes to the sectoral total in $CO_2$ equivalents in 2018 with 10.2 %. The $CH_4$ emissions from wastewater handling have increased by 23.4 % from 1990 to 2018 while the N2O emission has decreased by 40.1 %.

Since all incinerated waste (municipal, industrial, hazardous) is used for power and heat production, the emissions are included in the 1A1a category.

## 2.4 Description and interpretation of emission trends for KP-LULUCF inventory in aggregate, by activity and by gas

Coverage relating to reporting of activities under Article 3.3 and selected activities under Article 3.4 are listed in Table 2.1 for reporting concerning change in carbon pool and for greenhouse gas sources. All pools are reported. Carbon stock change in below-ground biomass for Cropland Management and Grazing Land Management under Article 3.4 are included under Above-ground biomass for the same area categories. Fertilisation of forests and other land is negligible and all fertiliser consumption is therefore reported in the agricultural sector. All liming is reported under the agriculture sector. Field burning of wooden biomass is prohibited in Denmark and therefore reported as not occurring. Wildfires are very seldom and if occurring very small in Denmark.

Table 2.1 Coverage of reporting of change of carbon pools relating to activities under Article 3.3 and elected activities under Article 3.4.

| Activity | CHANGE IN CARBON POOL REPORTED | | | | | | |
|---|---|---|---|---|---|---|---|
| | Above-ground biomass | Below-ground biomass | Litter | Dead wood | Soil | | HWP |
| | | | | | Mineral | Organic | |
| **Article 3.3 activities** | | | | | | | |
| Afforestation and reforestation | R | R | R | R | R | R | R |
| Deforestation | R | R | R | R | R | R | R |
| **Article 3.4 activities** | | | | | | | |
| Forest management | R | R | R | R | R | R | R |
| Cropland management | R | R | NO | NO | R | R | |
| Grazing land management | R | R | NO | NO | R | R | |
| Revegetation | NA | NA | NA | NA | NA | NA | |
| Wetland drainage and rewetting | NA | NA | NA | NA | | NA | |

| Activity | GREENHOUSE GAS SOURCES REPORTED | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Fertilization | Drained, rewetted and other soils | | Nitrogen mineralization in mineral soils | Indirect $N_2O$ emissions from managed soil | Biomass burning | | |
| | $N_2O$ | $CH_4$ | $N_2O$ | $N_2O$ | $N_2O$ | $CO_2$ | $CH_4$ | $N_2O$ |
| **Article 3.3 activities** | | | | | | | | |
| Afforestation and reforestation | IE | R | R | NO | R | NO | NO | NO |
| Deforestation | IE | R | R | R | IE | NO | NO | NO |
| **Article 3.4 activities** | | | | | | | | |
| Forest management | IE | R | R | NO | IE | NO | NO | NO |
| Cropland management | | R | | IE | | NO | NO | NO |
| Grazing land management | | R | | IE | | IE | R | R |
| Revegetation | NA | NA | NA | NA | NA | NA | NA | NA |
| Wetland drainage and rewetting | NA | NA | NA | | NA | NA | NA | NA |

R: reported, NR: not reported, IE: included elsewhere, NO: not occurring, NA: not applicable. Biomass burning does not occur in all years and therefore sometimes reported as NO in the CRF.

$CO_2$ is by far the most important greenhouse gas relating to activities under Article 3.3 and Article 3.4. There is however a minor contribution of $CH_4$ and $N_2O$. Large fluctuations of emissions and removals occur for the LULUCF sector, partly due to annual climatic variations, e.g. temperature and wind, but also regulations and changes in the forestry are important parameters.

### 2.4.1 Forest

The trends in emissions and removals from forests are dependent on both the current structure of the forests and the management actions in the coming years. If similar management is applied as in the previous 15 years a decline in the total carbon stock in the forest is expected. However, for some years a sink in forest is reported. For the afforested areas a steady increase in carbon stocks is expected also in the future years. The rate of increase of area will depend on both availability of land and on possible subsidies for afforestation. Deforestation occurs mainly in relation to other specific projects e.g. for nature restoration or test areas for wind turbines.

### 2.4.2 Cropland, Grassland and Wetlands

The trend for the Cropland Management and Grazing Land Management under KP-LULUCF indicates that there has been a stabilisation of the loss of carbon from agricultural soils compared to previous due to an increased input of organic matter in the soil. However, the loss depends much of the climatic conditions. As a consequence of the global warming, where most years since 1990 have been above the average for 1961-1990, it is difficult to avoid substantial losses of carbon from the agricultural soils in the future. The changes in Cropland Management since 1990 have undoubtedly prevented further losses of soil carbon. A further increase in the actual temperature will affect the ability to prevent further losses of soil carbon.

The reestablishment of wetlands on agricultural land is especially targeted towards organic soils, which leads to a decreased emission from these soils. Further reestablishments are expected to take place in the future.

# 3 Energy

## 3.1 Overview of the sector

The data presented in Chapter 3 relates to Denmark only, whereas information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 8.

The energy sector has been reported in four main chapters:

3.2 Stationary combustion plants (CRF sector 1A1, 1A2 and 1A4)
3.3 Transport and other mobile sources (CRF sector 1A2, 1A3, 1A4 and 1A5)
3.4 Additional information, fuel combustion (Reference approach, feedstocks and non-energy use of fuels)
3.5 Fugitive emissions (CRF sector 1B)

Summary tables for the energy sector are shown below.

Table 3.1.1 $CO_2$ emissions from the energy sector.

| Greenhouse gas source categories | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| | (Gg) | | | | | | | | | |
| 1. Energy | 51,635 | 62,165 | 56,332 | 58,626 | 62,586 | 59,375 | 72,627 | 63,104 | 59,049 | 56,477 |
| 1A. Fuel Combustion (Sectoral Approach) | 51,295 | 61,515 | 55,654 | 58,044 | 62,008 | 58,922 | 72,129 | 62,406 | 58,526 | 55,370 |
| 1A1. Energy Industries | 26,150 | 35,021 | 30,094 | 31,669 | 35,668 | 32,161 | 44,468 | 35,338 | 31,683 | 28,591 |
| 1A2. Manufacturing Industries and Construction | 5,362 | 5,797 | 5,658 | 5,581 | 5,723 | 5,832 | 5,977 | 6,000 | 5,967 | 6,042 |
| 1A3. Transport | 10,573 | 11,077 | 11,274 | 11,324 | 11,747 | 11,882 | 12,145 | 12,345 | 12,358 | 12,395 |
| 1A4. Other Sectors | 9,042 | 9,282 | 8,434 | 9,175 | 8,556 | 8,728 | 9,294 | 8,479 | 8,235 | 8,077 |
| 1A5. Other | 167 | 338 | 195 | 295 | 314 | 318 | 246 | 245 | 282 | 265 |
| 1B. Fugitive Emissions from Fuels | 341 | 650 | 677 | 582 | 578 | 454 | 498 | 698 | 523 | 1,107 |
| 1B1. Solid Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1B2. Oil and Natural Gas | 341 | 650 | 677 | 582 | 578 | 454 | 498 | 698 | 523 | 1,107 |

| *Continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| | (Gg) | | | | | | | | | |
| 1. Energy | 52,123 | 53,786 | 53,402 | 58,630 | 53,034 | 49,454 | 57,384 | 52,606 | 49,449 | 47,551 |
| 1A. Fuel Combustion (Sectoral Approach) | 51,399 | 53,015 | 52,728 | 57,960 | 52,282 | 48,906 | 56,852 | 52,062 | 49,062 | 47,290 |
| 1A1. Energy Industries | 25,571 | 26,855 | 27,076 | 31,819 | 25,937 | 22,735 | 30,657 | 26,032 | 23,935 | 23,882 |
| 1A2. Manufacturing Industries and Construction | 5,830 | 5,931 | 5,594 | 5,572 | 5,652 | 5,363 | 5,494 | 5,246 | 4,737 | 3,934 |
| 1A3. Transport | 12,297 | 12,356 | 12,526 | 12,991 | 13,223 | 13,439 | 13,770 | 14,312 | 14,144 | 13,381 |
| 1A4. Other Sectors | 7,505 | 7,685 | 7,348 | 7,386 | 7,127 | 6,996 | 6,703 | 6,196 | 6,038 | 5,832 |
| 1A5. Other | 197 | 188 | 184 | 191 | 343 | 374 | 228 | 276 | 208 | 260 |
| 1B. Fugitive Emissions from Fuels | 724 | 771 | 674 | 670 | 752 | 548 | 531 | 544 | 387 | 261 |
| 1B1. Solid Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1B2. Oil and Natural Gas | 724 | 771 | 674 | 670 | 752 | 548 | 531 | 544 | 387 | 261 |

| *Continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| | (Gg) | | | | | | | | |
| 1. Energy | 47,971 | 42,825 | 38,433 | 40,277 | 36,066 | 33,766 | 35,359 | 32,981 | 32,929 |
| 1A. Fuel Combustion (Sectoral Approach) | 47,618 | 42,573 | 38,216 | 40,034 | 35,816 | 33,519 | 35,085 | 32,741 | 32,696 |
| 1A1. Energy Industries | 23,717 | 19,754 | 16,656 | 18,855 | 15,366 | 12,712 | 13,866 | 11,375 | 11,264 |
| 1A2. Manufacturing Industries and Construction | 4,351 | 4,283 | 3,965 | 3,819 | 3,822 | 3,757 | 3,832 | 3,926 | 3,880 |
| 1A3. Transport | 13,254 | 12,945 | 12,374 | 12,188 | 12,302 | 12,572 | 12,846 | 13,024 | 13,285 |
| 1A4. Other Sectors | 6,090 | 5,300 | 5,008 | 4,933 | 4,096 | 4,282 | 4,336 | 4,114 | 4,052 |
| 1A5. Other | 206 | 291 | 214 | 238 | 229 | 196 | 205 | 302 | 215 |
| 1B. Fugitive Emissions from Fuels | 353 | 252 | 217 | 243 | 250 | 247 | 273 | 240 | 232 |
| 1B1. Solid Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1B2. Oil and Natural Gas | 353 | 252 | 217 | 243 | 250 | 247 | 273 | 240 | 232 |

Table 3.1.2 $CH_4$ emissions from the energy sector.

| Greenhouse gas source categories | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | (Gg) | | | | | |
| 1. Energy | 15.41 | 18.23 | 18.96 | 20.93 | 24.16 | 29.87 | 34.35 | 35.38 | 36.10 | 38.36 |
| 1A. Fuel Combustion (Sectoral Approach) | 10.50 | 11.54 | 12.13 | 14.21 | 17.24 | 22.95 | 27.02 | 26.53 | 27.74 | 27.34 |
| 1A1. Energy Industries | 0.63 | 0.97 | 1.37 | 2.99 | 6.08 | 11.42 | 14.59 | 13.91 | 15.31 | 15.40 |
| 1A2. Manufacturing Industries and Construction | 0.33 | 0.35 | 0.33 | 0.34 | 0.34 | 0.40 | 0.77 | 0.77 | 0.87 | 0.86 |
| 1A3. Transport | 3.17 | 3.29 | 3.30 | 3.25 | 3.18 | 3.02 | 2.86 | 2.72 | 2.57 | 2.38 |
| 1A4. Other Sectors | 6.29 | 6.84 | 7.04 | 7.54 | 7.54 | 8.01 | 8.71 | 9.02 | 8.89 | 8.60 |
| 1A5. Other | 0.08 | 0.09 | 0.09 | 0.09 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| 1B. Fugitive Emissions from Fuels | 4.90 | 6.69 | 6.82 | 6.73 | 6.92 | 6.92 | 7.33 | 8.85 | 8.36 | 11.01 |
| 1B1. Solid Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1B2. Oil and Natural Gas | 4.90 | 6.69 | 6.82 | 6.73 | 6.92 | 6.92 | 7.33 | 8.85 | 8.36 | 11.01 |

| *Continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | (Gg) | | | | | |
| 1. Energy | 36.56 | 37.57 | 36.41 | 35.68 | 36.08 | 33.56 | 31.73 | 29.56 | 28.39 | 24.94 |
| 1A. Fuel Combustion (Sectoral Approach) | 26.69 | 27.39 | 26.74 | 26.23 | 25.81 | 23.95 | 22.45 | 20.82 | 20.51 | 18.47 |
| 1A1. Energy Industries | 14.70 | 15.58 | 15.14 | 14.40 | 14.08 | 12.44 | 11.53 | 9.60 | 10.12 | 8.84 |
| 1A2. Manufacturing Industries and Construction | 1.07 | 1.13 | 1.03 | 1.00 | 1.01 | 0.87 | 0.73 | 0.51 | 0.55 | 0.50 |
| 1A3. Transport | 2.19 | 2.03 | 1.90 | 1.79 | 1.65 | 1.49 | 1.36 | 1.22 | 1.04 | 0.88 |
| 1A4. Other Sectors | 8.64 | 8.56 | 8.58 | 8.95 | 8.98 | 9.07 | 8.78 | 9.43 | 8.76 | 8.21 |
| 1A5. Other | 0.09 | 0.09 | 0.08 | 0.08 | 0.08 | 0.07 | 0.06 | 0.05 | 0.04 | 0.03 |
| 1B. Fugitive Emissions from Fuels | 9.87 | 10.18 | 9.68 | 9.45 | 10.27 | 9.61 | 9.29 | 8.74 | 7.88 | 6.47 |
| 1B1. Solid Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1B2. Oil and Natural Gas | 9.87 | 10.18 | 9.68 | 9.45 | 10.27 | 9.61 | 9.29 | 8.74 | 7.88 | 6.47 |

| *Continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | (Gg) | | | | |
| 1. Energy | 26.97 | 22.90 | 18.53 | 16.98 | 14.80 | 14.26 | 14.54 | 14.72 | 14.73 |
| 1A. Fuel Combustion (Sectoral Approach) | 20.67 | 17.63 | 13.90 | 12.68 | 10.51 | 10.20 | 10.56 | 10.74 | 11.13 |
| 1A1. Energy Industries | 11.01 | 9.22 | 6.39 | 5.63 | 4.04 | 3.44 | 3.95 | 4.07 | 4.46 |
| 1A2. Manufacturing Industries and Construction | 0.57 | 0.53 | 0.37 | 0.34 | 0.39 | 0.55 | 0.55 | 0.73 | 0.90 |
| 1A3. Transport | 0.81 | 0.70 | 0.61 | 0.54 | 0.50 | 0.48 | 0.46 | 0.43 | 0.41 |
| 1A4. Other Sectors | 8.26 | 7.17 | 6.51 | 6.17 | 5.56 | 5.72 | 5.59 | 5.49 | 5.35 |
| 1A5. Other | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 1B. Fugitive Emissions from Fuels | 6.31 | 5.27 | 4.63 | 4.30 | 4.29 | 4.06 | 3.98 | 3.98 | 3.60 |
| 1B1. Solid Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1B2. Oil and Natural Gas | 6.31 | 5.27 | 4.63 | 4.30 | 4.29 | 4.06 | 3.98 | 3.98 | 3.60 |

Table 3.1.3 $N_2O$ emissions from the energy sector.

| Greenhouse gas source categories | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | (Gg) | | | | |
| 1. Energy | 1.20 | 1.51 | 1.49 | 1.46 | 1.50 | 1.48 | 1.65 | 1.70 | 1.55 | 1.87 |
| 1A. Fuel Combustion (Sectoral Approach) | 1.03 | 1.15 | 1.12 | 1.15 | 1.19 | 1.24 | 1.38 | 1.31 | 1.27 | 1.25 |
| 1A1. Energy Industries | 0.29 | 0.37 | 0.34 | 0.36 | 0.39 | 0.38 | 0.51 | 0.44 | 0.42 | 0.40 |
| 1A2. Manufacturing Industries and Construction | 0.19 | 0.20 | 0.20 | 0.19 | 0.19 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 |
| 1A3. Transport | 0.33 | 0.35 | 0.36 | 0.36 | 0.38 | 0.39 | 0.40 | 0.40 | 0.40 | 0.39 |
| 1A4. Other Sectors | 0.21 | 0.22 | 0.22 | 0.23 | 0.22 | 0.22 | 0.23 | 0.22 | 0.21 | 0.21 |
| 1A5. Other | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 1B. Fugitive Emissions from Fuels | 0.18 | 0.36 | 0.37 | 0.32 | 0.31 | 0.24 | 0.27 | 0.39 | 0.28 | 0.62 |
| 1B1. Solid Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1B2. Oil and Natural Gas | 0.18 | 0.36 | 0.37 | 0.32 | 0.31 | 0.24 | 0.27 | 0.39 | 0.28 | 0.62 |

| *Continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | (Gg) | | | | |
| 1. Energy | 1.62 | 1.67 | 1.60 | 1.65 | 1.65 | 1.49 | 1.57 | 1.56 | 1.45 | 1.33 |
| 1A. Fuel Combustion (Sectoral Approach) | 1.22 | 1.24 | 1.23 | 1.28 | 1.23 | 1.19 | 1.28 | 1.26 | 1.24 | 1.19 |
| 1A1. Energy Industries | 0.38 | 0.40 | 0.40 | 0.44 | 0.39 | 0.35 | 0.42 | 0.36 | 0.35 | 0.36 |
| 1A2. Manufacturing Industries and Construction | 0.23 | 0.23 | 0.22 | 0.20 | 0.21 | 0.20 | 0.22 | 0.23 | 0.21 | 0.17 |
| 1A3. Transport | 0.39 | 0.38 | 0.38 | 0.38 | 0.38 | 0.37 | 0.36 | 0.38 | 0.39 | 0.38 |
| 1A4. Other Sectors | 0.21 | 0.22 | 0.22 | 0.24 | 0.24 | 0.26 | 0.27 | 0.29 | 0.29 | 0.28 |
| 1A5. Other | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 1B. Fugitive Emissions from Fuels | 0.40 | 0.43 | 0.37 | 0.37 | 0.42 | 0.30 | 0.29 | 0.29 | 0.21 | 0.14 |
| 1B1. Solid Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1B2. Oil and Natural Gas | 0.40 | 0.43 | 0.37 | 0.37 | 0.42 | 0.30 | 0.29 | 0.29 | 0.21 | 0.14 |

| *Continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | (Gg) | | | | |
| 1. Energy | 1.44 | 1.32 | 1.26 | 1.32 | 1.27 | 1.33 | 1.41 | 1.40 | 1.42 |
| 1A. Fuel Combustion (Sectoral Approach) | 1.25 | 1.20 | 1.15 | 1.18 | 1.14 | 1.18 | 1.25 | 1.25 | 1.28 |
| 1A1. Energy Industries | 0.38 | 0.33 | 0.31 | 0.33 | 0.29 | 0.28 | 0.30 | 0.29 | 0.29 |
| 1A2. Manufacturing Industries and Construction | 0.18 | 0.18 | 0.17 | 0.16 | 0.15 | 0.17 | 0.19 | 0.20 | 0.21 |
| 1A3. Transport | 0.38 | 0.41 | 0.41 | 0.42 | 0.43 | 0.45 | 0.46 | 0.47 | 0.47 |
| 1A4. Other Sectors | 0.30 | 0.27 | 0.26 | 0.27 | 0.25 | 0.28 | 0.29 | 0.29 | 0.29 |
| 1A5. Other | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 1B. Fugitive Emissions from Fuels | 0.19 | 0.12 | 0.11 | 0.14 | 0.14 | 0.14 | 0.16 | 0.15 | 0.14 |
| 1B1. Solid Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1B2. Oil and Natural Gas | 0.19 | 0.12 | 0.11 | 0.14 | 0.14 | 0.14 | 0.16 | 0.15 | 0.14 |

## 3.2 Stationary combustion

Stationary combustion is the largest source of $CO_2$ emission in Denmark accounting for 50 % of the 2018 national total $CO_2$ emissions excl. LULUCF or 42 % of the $CO_2$ emission including LULUCF. The $CO_2$ emission from stationary combustion has decreased by 1 % since 2017 and decreased by 55 % since 1990. The decreased emission since 1990 is a result of a change of fuels; the consumption of coal has decreased whereas the consumption of natural gas and biomass has increased since 1990. The relatively large fluctuations in the $CO_2$ emission time series from 1990 to 2018 are due to inter-country electricity trade fluctuations caused mainly by variation in hydropower generation in Norway and Sweden. The $CO_2$ emission in 2018 was 1.3 % lower than in 2017 due to a higher net electricity import in 2018 than in 2017 and to an increasing biomass share.

The methane ($CH_4$) emission from stationary combustion plants accounted for 3.6 % of the national $CH_4$ emission in 2018. The $CH_4$ emission from stationary combustion has increased by 54 % since 1990. The emission increased until 1996 and decreased after 2004. The trend is related to the considerable number of lean-burn gas engines installed in CHP plants in Denmark during the 1990s.

The $CH_4$ emission from gas engines is high compared to other plant types. The deregulation of the electricity market has made production of electricity in gas engines less favourable, therefore the fuel consumption and $CH_4$ emission has decreased since 2004. The $CH_4$ emission from residential plants has increased since 1990 due to increased combustion of biomass in residential plants. The $CH_4$ emission in 2018 was 4 % higher than in 2017 mainly due to higher fuel consumption in gas engines.

The nitrous oxide ($N_2O$) emission from stationary combustion plants accounted for 3.9 % of the national $N_2O$ emission in 2018. The $N_2O$ emission from stationary combustion was 18 % higher than in 1990, but as for $CO_2$, fluctuations in emission level due to electricity import/export are considerable. The emission in 2018 was 3 % higher than in 2017.

### 3.2.1 Source category description

#### Source category definition

Stationary combustion plants are included in the emission source subcategories:

- 1A1 Energy, Fuel combustion, Energy Industries
  - 1A1a Public electricity and heat production
  - 1A1b Petroleum refining
  - 1A1c Oil and gas extraction
- 1A2 Energy, Fuel combustion, Manufacturing Industries and Construction
  - 1A2a Iron and steel
  - 1A2b Non-ferrous metals
  - 1A2c Chemicals
  - 1A2d Pulp, Paper and Print
  - 1A2e Food processing, beverages and tobacco
  - 1A2f Non-metallic minerals
  - 1A2 g viii Other manufacturing industry
- 1A4 Energy, Fuel combustion, Other Sectors
  - 1A4a i Commercial/institutional plants.
  - 1A4b i Residential plants.
  - 1A1c i Agriculture/forestry.

The emission and fuel consumption data included in tables and figures in Chapter 3.2 only include emissions originating from stationary combustion plants of a given CRF sector. The consumption of fuel for military use in stationary combustion plants has been included in commercial/institutional plants.

In the Danish emission database all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution) according the CORINAIR system. The emission inventories are prepared from a complete emission database based on the SNAP source categories. Danish Centre for Environment and Energy, Aarhus University (DCE) has modified the SNAP categorisation to enable direct reporting of the disaggregated data for manufacturing industries and construction. Aggregation to the IPCC source category codes is based on a correspondence list enclosed in Annex 3A-1. Stationary combustion is defined as combustion activities in the SNAP sectors 01 – 03, not including SNAP 0303.

The $CO_2$ emission from calcinations is not part of the source category *Energy*. This emission is included in the source category *Industrial Processes*.

### Methodology overview, tier

The type of emission factor and the applied tier level for each emission source are shown in Table 3.2.1 below. The tier level has been determined based on the IPCC Guidelines (IPCC, 2006).

The fuel consumption data for transformation are technology specific. For end-use of fuels, the disaggregation to specific technologies is less detailed. However, for residential wood combustion the technology disaggregation is technology specific.

The distinction between tier 2 and 3 has been based on the emission factor. The tier level definitions have been interpreted as follows:

- Tier 1: The emission factor is an IPCC default tier 1 value.
- Tier 2: The emission factors are country-specific and based on a limited number of emission measurements or a technology specific IPCC tier 2 emission factor.
- Tier 3: Emission data are based on:
  - Plant specific emission measurements or
  - Technology specific fuel consumption data and country-specific emission factors based on a considerable number of emission measurements from Danish plants.

Table 3.2.1 gives an overview of the calculation methods and type of emission factor. The table also shows which of the source categories are key in any of the key category analysis[1] (including LULUCF, approach 1/approach 2, level/trend).

Four emission source categories based on tier 1 approach have been identified as key sources this year. The total emission from these emission sources adds up to 240 kton $CO_2$ equivalent or 0.4 % of the national total in 2018. In 1990, the emission from the four emission sources adds up to 630 kton or 0.8 % of national total. Additional information is included in Chapter 3.2.5.

[1] Key category according to the KCA approach 1 or approach 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990/level 2018/trend.

Table 3.2.1 Methodology and type of emission factor.

| | | Tier | EMF[1)] | Key category[2)] |
|---|---|---|---|---|
| 1A Stationary combustion, Coal, ETS data | $CO_2$ | Tier 3 | PS | Yes |
| 1A Stationary combustion, Coal, no ETS data | $CO_2$ | Tier 3 [3)] | CS | Yes |
| 1A Stationary combustion, BKB | $CO_2$ | Tier 1 | D | No |
| 1A Stationary combustion, Coke oven coke | $CO_2$ | Tier 1/Tier 3 | D/PS | No |
| 1A Stationary combustion, Fossil waste, ETS data | $CO_2$ | Tier 3 | PS | Yes |
| 1A Stationary combustion, Fossil waste, no ETS data | $CO_2$ | Tier 2 | CS | Yes |
| 1A Stationary combustion, Petroleum coke, ETS data | $CO_2$ | Tier 3 | PS | Yes |
| 1A Stationary combustion, Petroleum coke, no ETS data | $CO_2$ | Tier 2 | CS | Yes |
| 1A Stationary combustion, Residual oil, ETS data | $CO_2$ | Tier 3 | PS | Yes |
| 1A Stationary combustion, Residual oil, no ETS data | $CO_2$ | Tier 2 [4)] | CS | Yes |
| 1A Stationary combustion, Gas oil | $CO_2$ | Tier 2/Tier 3 [5)] | CS / PS | Yes |
| 1A Stationary combustion, Kerosene | $CO_2$ | Tier 1 | D | Yes |
| 1A Stationary combustion, LPG | $CO_2$ | Tier 1/Tier 3 [6)] | D / PS | Yes |
| 1A1b Stationary combustion, Petroleum refining, Refinery gas | $CO_2$ | Tier 3 | CS | Yes |
| 1A Stationary combustion, Natural gas, onshore | $CO_2$ | Tier 3 | CS | Yes |
| 1A1c_ii Stationary combustion, Oil and gas extraction, Offshore gas turbines, Natural gas | $CO_2$ | Tier 3 | CS | Yes |
| 1A1 Stationary Combustion, solid fuels | $CH_4$ | Tier 2 | D(2) | No |
| 1A1 Stationary Combustion, liquid fuels | $CH_4$ | Tier/Tier 2 | D / D(2) / CS | No |
| 1A1 Stationary Combustion, not engines, gaseous fuels | $CH_4$ | Tier 2 | CS / D(2) | No |
| 1A1 Stationary Combustion, waste | $CH_4$ | Tier 2 | CS | No |
| 1A1 Stationary Combustion, not engines, biomass | $CH_4$ | Tier 3/Tier 2/Tier 1 | CS / D(2) / D | No |
| 1A2 Stationary Combustion, solid fuels | $CH_4$ | Tier 1 | D | No |
| 1A2 Stationary Combustion, liquid fuels | $CH_4$ | Tier 1/Tier 2 | D / D(2) / CS | No |
| 1A2 Stationary Combustion, not engines, gaseous fuels | $CH_4$ | Tier 2 | CS / D(2) | No |
| 1A2 Stationary Combustion, waste | $CH_4$ | Tier 1 | D | No |
| 1A2 Stationary Combustion, not engines, biomass | $CH_4$ | Tier 2/Tier 1 | D(2) / D | No |
| 1A4 Stationary Combustion, solid fuels | $CH_4$ | Tier 1 | D | No |
| 1A4 Stationary Combustion, liquid fuels | $CH_4$ | Tier 1/Tier 2 | D / D(2) | No |
| 1A4 Stationary Combustion, not engines, gaseous fuels | $CH_4$ | Tier 2 | D(2) | No |
| 1A4 Stationary Combustion, waste | $CH_4$ | Tier 1 | D | No |
| 1A4 Stationary Combustion, not engines, not residential wood and not residential/agricultural straw, biomass | $CH_4$ | Tier 1/Tier 2 | D / D(2) / CS | No |
| 1A4b_i Stationary combustion, Residential wood combustion | $CH_4$ | Tier 2 | CS | Yes |
| 1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion | $CH_4$ | Tier 1 | D | Yes |
| 1A Stationary combustion, Natural gas fuelled engines, gaseous fuels | $CH_4$ | Tier 3 | CS | No |
| 1A Stationary combustion, Biogas fuelled engines, biomass | $CH_4$ | Tier 3 | CS | No |
| 1A1 Stationary Combustion, solid fuels | $N_2O$ | Tier 2 | CS / D(2) | Yes |
| 1A1 Stationary Combustion, liquid fuels | $N_2O$ | Tier 2/Tier 1 | D(2) / CS / D | No |
| 1A1 Stationary Combustion, gaseous fuels | $N_2O$ | Tier 3/Tier 2 | CS / D(2) | Yes |
| 1A1 Stationary Combustion, waste | $N_2O$ | Tier 2 | CS | Yes |
| 1A1 Stationary Combustion, biomass | $N_2O$ | Tier 2/Tier 1 | CS / D(2) / D | Yes |
| 1A2 Stationary Combustion, solid fuels | $N_2O$ | Tier 1/Tier 3 | D / PS | Yes |
| 1A2 Stationary Combustion, liquid fuels | $N_2O$ | Tier 2/Tier 1 | D(2) / CS / D | Yes |
| 1A2 Stationary Combustion, gaseous fuels | $N_2O$ | Tier 3/Tier 2 | CS / D(2) | Yes |
| 1A2 Stationary Combustion, waste | $N_2O$ | Tier 1 | D | No |
| 1A2 Stationary Combustion, biomass | $N_2O$ | Tier 1/Tier 2 | D / CS | No |
| 1A4 Stationary Combustion, solid fuels | $N_2O$ | Tier 1 | D | No |
| 1A4 Stationary Combustion, liquid fuels | $N_2O$ | Tier 2/Tier 1 | D(2) / CS / D | Yes |
| 1A4 Stationary Combustion, gaseous fuels | $N_2O$ | Tier 3/Tier 2 | CS / D(2) | Yes |
| 1A4 Stationary Combustion, waste | $N_2O$ | Tier 1 | D | No |
| 1A4 Stationary Combustion, not residential wood and not residential/agricultural straw, biomass | $N_2O$ | Tier 1/Tier 2 | D / CS | No |
| 1A4b_i Stationary Combustion, Residential wood combustion | $N_2O$ | Tier 1 | D | Yes |
| 1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion | $N_2O$ | Tier 1 | D | No |

1. D: IPCC (2006) default, tier 1. D(2): IPCC (2006) default, tier 2. CS: Country specific. PS: Plant specific.
2. KCA approach 1 or approach 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990 or level 2018 or trend 1990-2018.
3. Only 3.4 % of the total coal consumption is included in the non-ETS category in 2018.
4. Only 8 % of the total residual oil consumption is included in the non-ETS category in 2018.
5. Tier 3 for 0.8 % of the gas oil consumption in 2018.
6. Tier 3 for 0.1 % of the LPG consumption in 2018.

### Key Categories

Key Category Analysis (KCA) approach 1 and approach 2 for the years 1990 and 2018 and for the trend 1990-2018 for Denmark has been carried out in accordance with the IPCC Guidelines (IPCC, 2006). Table 3.2.2 shows the 26 stationary combustion key categories. The table is based on the analysis including LULUCF. Detailed key category analysis is shown in NIR Chapter 1.5 and Annex 1.

The $CO_2$ emissions from stationary combustion are key categories for all the major fuels. In addition, $CH_4$ from residential wood combustion and from straw combustion in agriculture/residential plants are key categories in the approach 2 analysis. Finally, due to the relatively high uncertainty for $N_2O$, emission factors the $N_2O$ emission from a number of emission sources are also key categories in the approach 2 analysis.

Table 3.2.2 Key categories[2], stationary combustion.

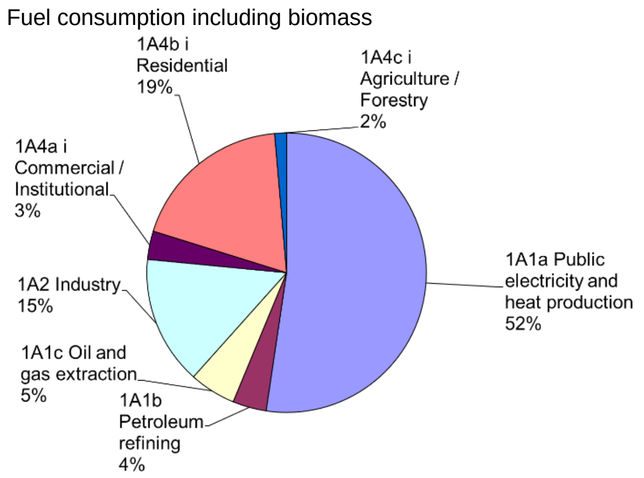
| | | | Approach 1 | | | Approach 2 | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1990 | 2018 | 1990-2018 | 1990 | 2018 | 1990-2018 |
| Energy | 1A Stationary combustion, Coal, ETS data, $CO_2$ | $CO_2$ | | Level | Trend | | | Trend |
| Energy | 1A Stationary combustion, Coal, no ETS data, $CO_2$ | $CO_2$ | Level | Level | Trend | Level | | Trend |
| Energy | 1A Stationary combustion, Fossil waste, ETS data, $CO_2$ | $CO_2$ | | Level | Trend | | | Trend |
| Energy | 1A Stationary combustion, Fossil waste, no ETS data, $CO_2$ | $CO_2$ | Level | Level | | | | |
| Energy | 1A Stationary combustion, Petroleum coke, ETS data, $CO_2$ | $CO_2$ | | Level | Trend | | | |
| Energy | 1A Stationary combustion, Petroleum coke, no ETS data, $CO_2$ | $CO_2$ | Level | | Trend | | | |
| Energy | 1A Stationary combustion, Residual oil, ETS data, $CO_2$ | $CO_2$ | | Level | Trend | | | |
| Energy | 1A Stationary combustion, Residual oil, no ETS data, $CO_2$ | $CO_2$ | Level | | Trend | | | Trend |
| Energy | 1A Stationary combustion, Gas oil, $CO_2$ | $CO_2$ | Level | Level | Trend | Level | | Trend |
| Energy | 1A Stationary combustion, Kerosene, $CO_2$ | $CO_2$ | Level | | Trend | | | |
| Energy | 1A Stationary combustion, LPG, $CO_2$ | $CO_2$ | | Level | | | | |
| Energy | 1A1b Stationary combustion, Petroleum refining, Refinery gas, $CO_2$ | $CO_2$ | Level | Level | Trend | | | |
| Energy | 1A Stationary combustion, Natural gas, onshore, $CO_2$ | $CO_2$ | Level | Level | Trend | | Level | Trend |
| Energy | 1A1c_ii Stationary combustion, Oil and gas extraction, Off shore gas turbines, Natural gas, $CO_2$ | $CO_2$ | Level | Level | Trend | | | |
| Energy | 1A4b_i Stationary combustion, Residential wood combustion, $CH_4$ | $CH_4$ | | | | Level | Level | Trend |
| Energy | 1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion, $CH_4$ | $CH_4$ | | | | Level | Level | |
| Energy | 1A1 Stationary Combustion, Solid fuels, $N_2O$ | $N_2O$ | | | | Level | Level | Trend |
| Energy | 1A1 Stationary Combustion, Gaseous fuels, $N_2O$ | $N_2O$ | | | | Level | Level | Trend |
| Energy | 1A1 Stationary Combustion, Waste, $N_2O$ | $N_2O$ | | | | | | Trend |
| Energy | 1A1 Stationary Combustion, Biomass, $N_2O$ | $N_2O$ | | | | | Level | Trend |
| Energy | 1A2 Stationary Combustion, Solid fuels, $N_2O$ | $N_2O$ | | | | | Level | Trend |
| Energy | 1A2 Stationary Combustion, Liquid fuels, $N_2O$ | $N_2O$ | | | | Level | Level | Trend |
| Energy | 1A2 Stationary Combustion, Gaseous fuels, $N_2O$ | $N_2O$ | | | | | Level | Trend |
| Energy | 1A4 Stationary Combustion, Liquid fuels, $N_2O$ | $N_2O$ | | | | Level | | Trend |
| Energy | 1A4 Stationary Combustion, Gaseous fuels, $N_2O$ | $N_2O$ | | | | | Level | Trend |
| Energy | 1A4b_i Stationary Combustion, Residential wood combustion, $N_2O$ | $N_2O$ | | | | | Level | Trend |

### 3.2.2 Fuel consumption data

In 2018, the total fuel consumption for stationary combustion plants was 407 PJ of which 236 PJ was fossil fuels and 171 PJ was biomass. Fuel consumption distributed according to the stationary combustion subcategories is shown in Figure 3.2.1 and Figure 3.2.2. The majority - 52 % - of all fuels is combusted in

[2] For Denmark, not including Greenland & Faroe Island. Based on the KCA including LULUCF.

the source category, Public electricity and heat production. Other source categories with high fuel consumption are Residential and Industry.



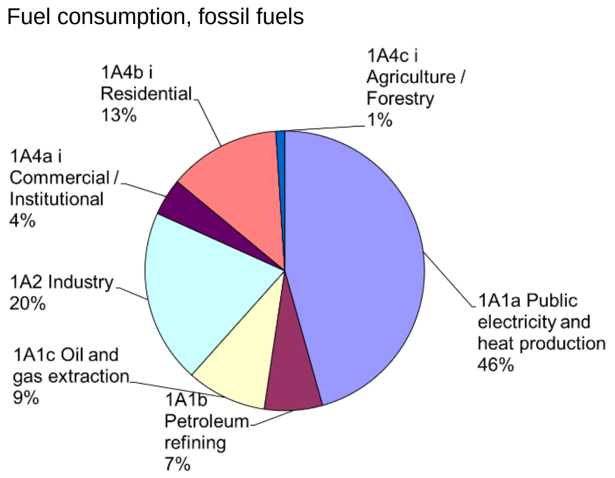




Figure 3.2.1 Fuel consumption of stationary combustion source categories, 2018. Based on DEA (2019a).

Coal, natural gas and wood are the most utilised fuels for stationary combustion plants. Coal is mainly used in power plants, natural gas is used in power plants and in decentralised combined heating and power (CHP) plants, as well as in industry, residential plants and offshore gas turbines (see Figure 3.2.2). Wood is mainly applied for public electricity and heat production and in residential plants.

Detailed fuel consumption rates are shown in Annex 3A-2.

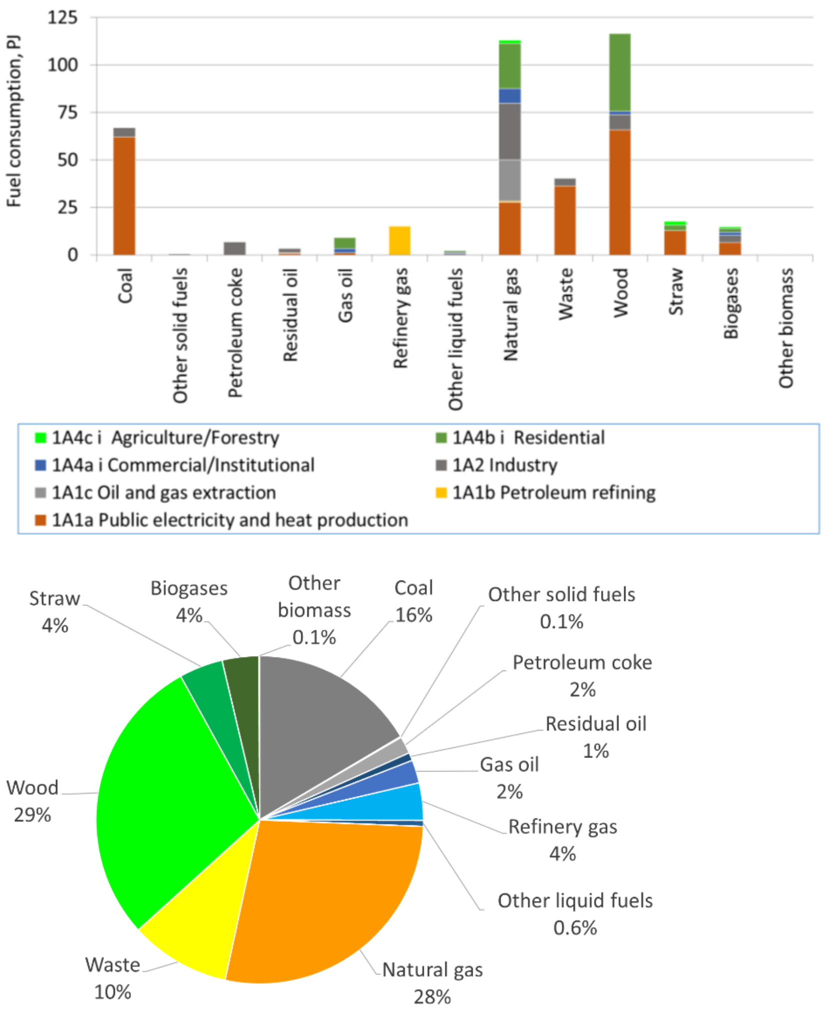



Figure 3.2.2 Fuel consumption of stationary combustion 2018, disaggregated to fuel type. Based on DEA (2019a).

Time series for fuel consumption for stationary combustion plants are presented in Figure 3.2.3. The fuel consumption for stationary combustion was 19 % lower in 2018 than in 1990, while the fossil fuel consumption was 49 % lower and the biomass fuel consumption 4.2 times the level in 1990.

The consumption of natural gas, waste and biomass has increased since 1990 whereas the consumption of coal and oil has decreased.

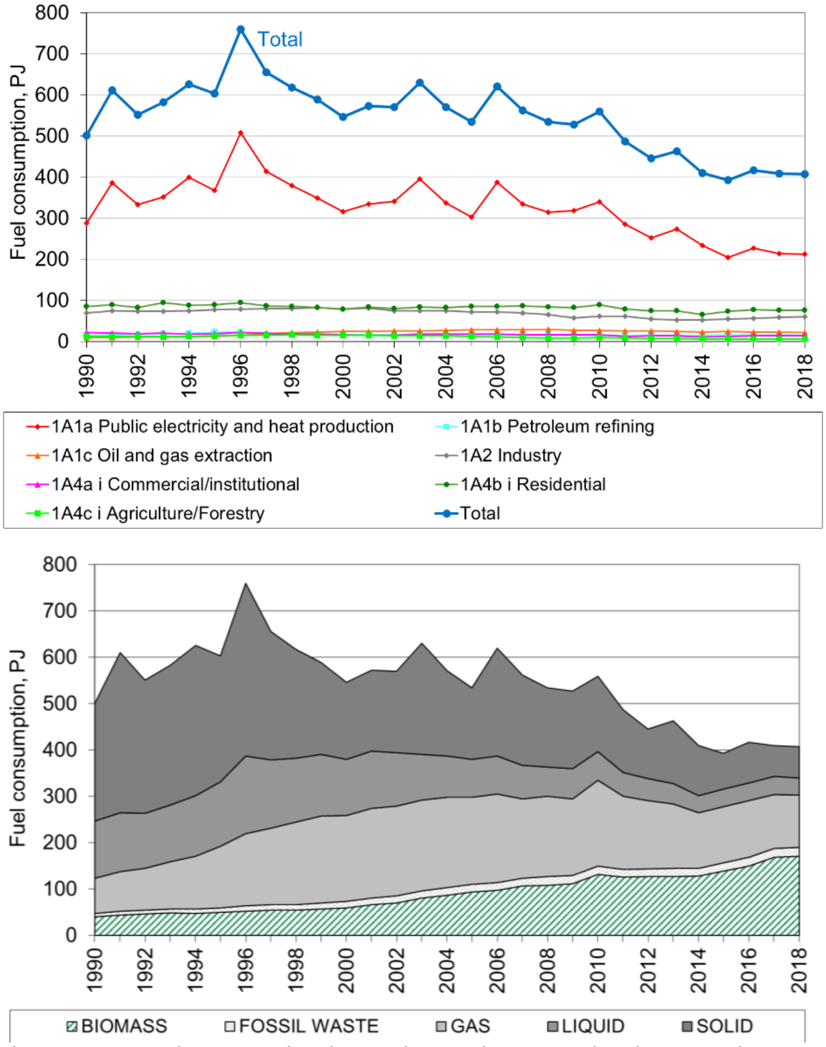



Figure 3.2.3 Fuel consumption time series, stationary combustion. Based on DEA (2019a).

The fluctuations in the time series for fuel consumption are mainly a result of electricity import/export, but also of outdoor temperature variations from year to year. This, in turn, leads to fluctuations in emission levels. The fluctuations in electricity trade, fuel consumption, $CO_2$ and $NO_x$ emission are illustrated and compared in Figure 3.2.4. In 1990, the Danish net electricity import was large causing relatively low fuel consumption, whereas the fuel consumption was high in 1996 and 2003 due to a large net electricity export. In 2018, the net electricity import was 19 PJ, whereas there was a 16 PJ net electricity import in 2017. The large net electricity export that occurs some years is a result of low rainfall in Norway and Sweden causing insufficient hydropower production in both countries.

The Danish electricity production is highly dependent on the electricity trade with especially Sweden and Norway. Denmark has a number of central coal-fuelled power plants that consists of a number of blocks. These do not under normal conditions, operate at max load, i.e. there is free capacity for peak situations. In addition, there are blocks, which are mothballed but can be reopened in situations where there is a significant increase in the electricity demand.

To be able to follow the national energy consumption, the Danish Energy Agency (DEA) produces a correction of the observed fuel consumption and $CO_2$ emission without random variations in electricity import/export and in ambient temperature. This fuel consumption trend is also illustrated in Figure 3.2.4. This fuel consumption trend is also illustrated in Figure 3.2.4. The estimates are based on DEA (2016d) and updated data (DEA, 2019d).The corrections are included here to explain the fluctuations in the time series for fuel rates and emissions.

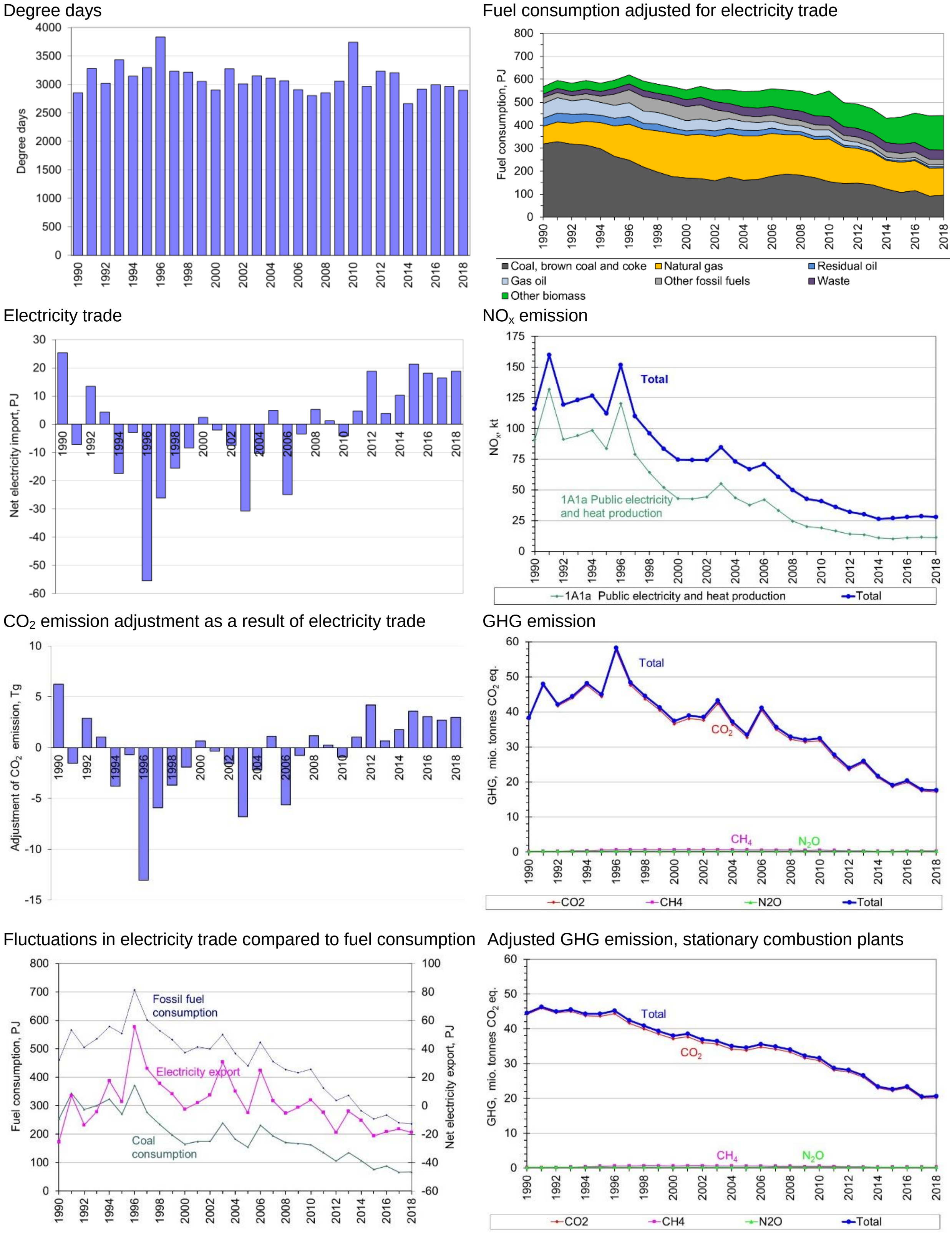



Figure 3.2.4 Comparison of time series fluctuations for net electricity import, fuel consumption, $CO_2$ emission and $NO_x$ emission. Based on DEA (2019a).

Fuel consumption time series for the subcategories to stationary combustion are shown in Figure 3.2.5, 3.2.6 and 3.2.7.

Fuel consumption for Energy Industries fluctuates due to electricity trade as discussed above. The fuel consumption in 2018 was 20 % lower than in 1990 and the fossil fuel consumption was 51 % lower. The fluctuation in electricity production is based on fossil fuel consumption in the subcategory Public electricity and Heat Production. The energy consumption in Oil and gas extraction is mainly natural gas used in gas turbines in the offshore industry. The biomass fuel consumption in Energy Industries in 2018 added up to 105 PJ, which is 6.5 times the level in 1990 and 1 % lower than in 2017.

The fuel consumption in Industry was 13 % lower in 2018 than in 1990 (Figure 3.2.6) and the fossil fuel consumption was 25 % lower. The fuel consumption in industrial plants decreased considerably after 2006 as a result of the financial crisis. The fuel consumption has increased again since 2014. The biomass fuel consumption in Industry in 2018 added up to 13 PJ, which is 2.2 times the consumption in 1990.

The fuel consumption in Other Sectors decreased 19 % since 1990 (Figure 3.2.7) and increased 0.5 % since 2017. The fossil fuel consumption decreased 57 % since 1990. The biomass fuel consumption in Other sectors in 2018 added up to 52 PJ, which is 2.8 times the consumption in 1990 and a 3 % increase since 2017. Wood consumption in residential plants in 2018 was 2.8 times the consumption in year 2000 and 4.6 times the consumption in 1990.

Time series for subcategories are shown in Chapter 3.2.4.

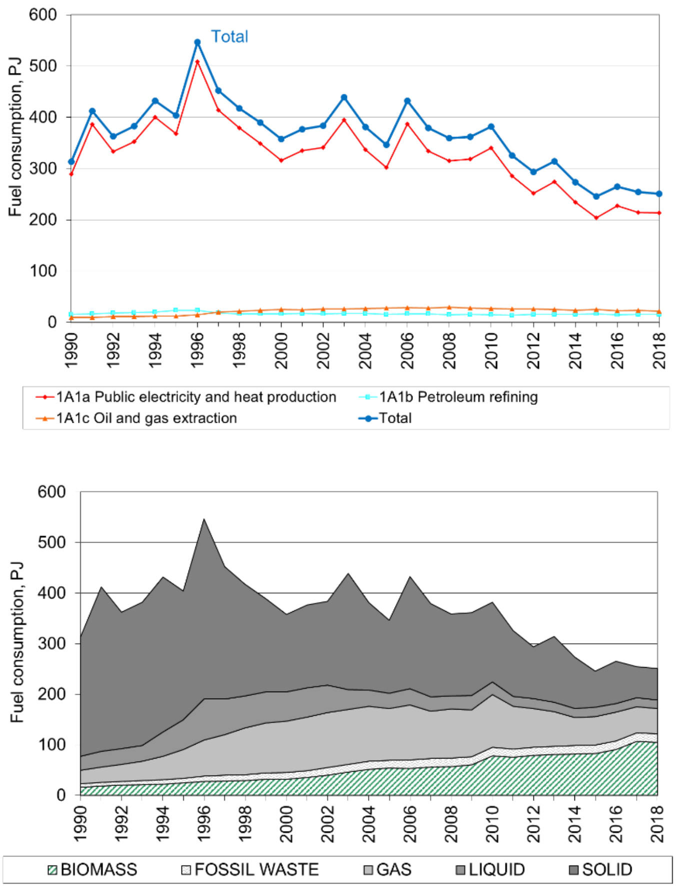



Figure 3.2.5 Fuel consumption time series for subcategories - 1A1 Energy Industries.

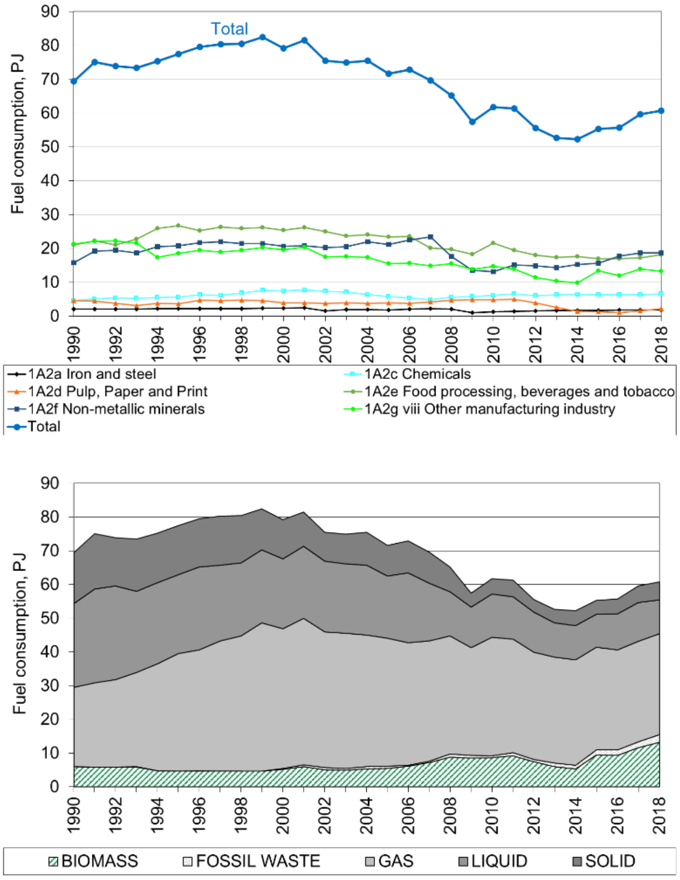



Figure 3.2.6 Fuel consumption time series for subcategories - 1A2 Industry.

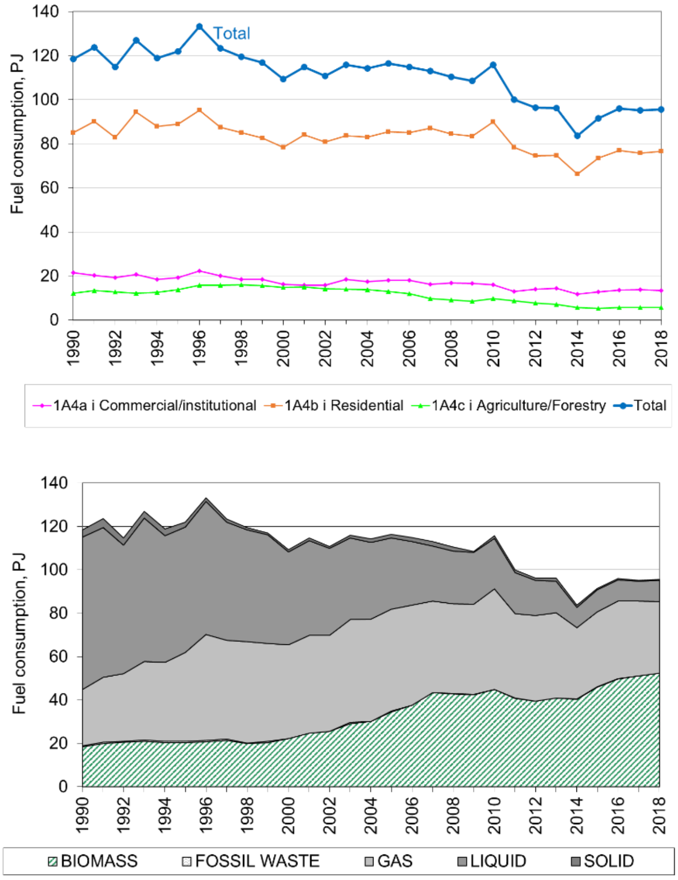



Figure 3.2.7 Fuel consumption time series for subcategories - 1A4 Other Sectors.

### 3.2.3 Emissions

#### Greenhouse gas emission

The greenhouse gas emissions from stationary combustion are listed in Table 3.2.3. The emission from stationary combustion accounted for 32.3 % of the national greenhouse gas emission (including LULUCF) in 2018.

The $CO_2$ emission from stationary combustion plants accounts for 42 % of the national $CO_2$ emission (including LULUCF). The $CH_4$ emission accounts for 3.5 % of the national $CH_4$ emission and the $N_2O$ emission for 3.9 % of the national $N_2O$ emission.

Table 3.2.3 Greenhouse gas emission, 2018 [1].

| | $CO_2$ | $CH_4$ | $N_2O$ |
|---|---|---|---|
| | kt $CO_2$ equivalent | | |
| 1A1 Fuel Combustion, Energy industries | 11264 | 112 | 86 |
| 1A2 Fuel Combustion, Manufacturing Industries and Construction[1] | 3275 | 22 | 55 |
| 1A4 Fuel Combustion, Other sectors [1] | 2620 | 130 | 70 |
| Emission from stationary combustion plants | 17159 | 264 | 211 |
| Emission share for stationary combustion (LULUCF included) | 42% | 3.5% | 3.9% |

[1] Only stationary combustion sources of the category is included.

$CO_2$ is the most important greenhouse gas accounting for 97.3 % of the greenhouse gas emission ($CO_2$ equivalents) from stationary combustion. $CH_4$ accounts for 1.5 % and $N_2O$ for 1.2 % of the greenhouse gas emission ($CO_2$ equivalents) from stationary combustion (Figure 3.2.8).

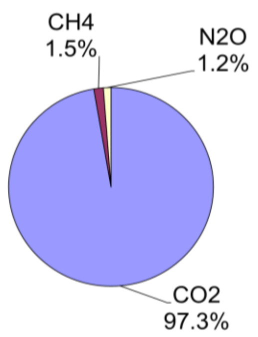



Figure 3.2.8 Greenhouse gas emission from stationary combustion ($CO_2$ equivalents), contribution from each pollutant.

Figure 3.2.9 shows the time series of greenhouse gas emissions ($CO_2$ equivalents) from stationary combustion. The development of the greenhouse gas emission follows the $CO_2$ emission development very closely. Both the $CO_2$ and the total greenhouse gas emission are lower in 2018 than in 1990, $CO_2$ is 54.8 % lower and greenhouse gas emissions are 53.9 % lower. However, fluctuations in the GHG emission level are large.

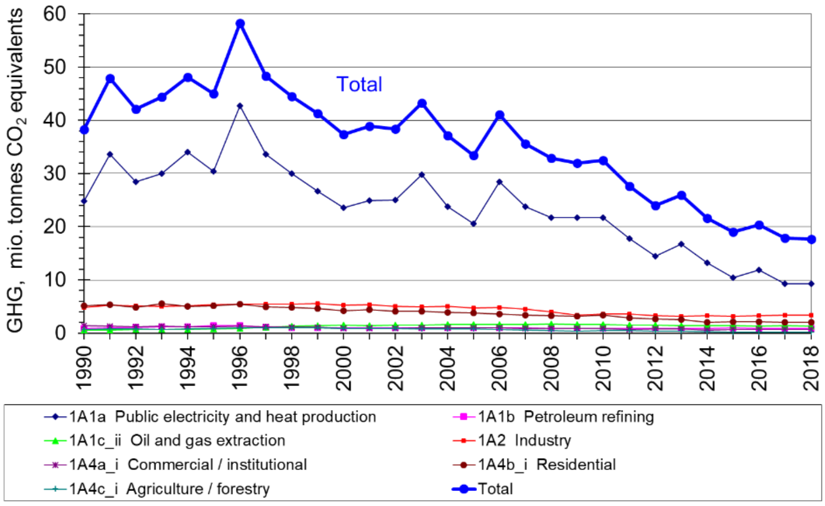



Figure 3.2.9 GHG emission time series for stationary combustion.

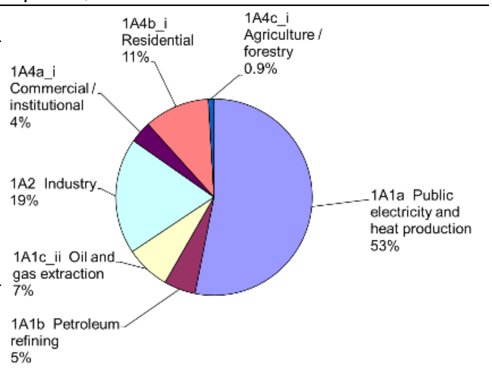
The fluctuations in the time series are largely a result of electricity import/export, but also of outdoor temperature variations from year to year. The fluctuations follow the fluctuations in fuel consumption discussed in Chapter 3.2.2. As mentioned in Chapter 3.2.2, the Danish Energy Agency estimates a correction of the observed $CO_2$ emission without random variations in electricity imports/exports and in ambient temperature. The greenhouse gas emission corrected for electricity import/export and ambient temperature has decreased by 55.6 % since 1990, and the $CO_2$ emission by 54.4 %. These data are included here to explain the fluctuations in the emission time series.

### $CO_2$

The carbon dioxide ($CO_2$) emission from stationary combustion plants is one of the most important sources of greenhouse gas emissions. Thus, the $CO_2$ emission from stationary combustion plants accounts for 42 % of the national $CO_2$ emission (LULUCF included). Table 3.2.4 lists the $CO_2$ emission inventory for stationary combustion plants for 2018. Public electricity and heat production accounts for 53 % of the $CO_2$ emission from stationary combustion. This share is somewhat higher than the fossil fuel consumption share for this category, which is 46 % (Figure 3.2.1). This is due to a large share of coal in this category. Other large $CO_2$ emission sources are Industry, Residential plants and Oil and gas extraction. These are the source categories, which also account for a considerable share of fuel consumption.

Table 3.2.4 $CO_2$ emission from stationary combustion plants, 2018[1)].

| | $CO_2$ kt |
|---|---|
| 1A1a Public electricity and heat production | 9113 |
| 1A1b Petroleum refining | 891 |
| 1A1c Oil and gas extraction | 1260 |
| 1A2 Industry | 3275 |
| 1A4a Commercial/Institutional | 615 |
| 1A4b Residential | 1849 |
| 1A4c Agriculture/Forestry | 156 |
| Total | 17159 |

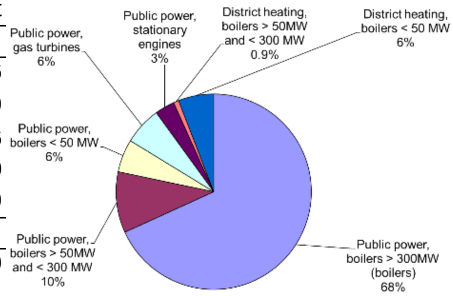



[1)] Only emissions from stationary combustion plants in the categories are included.

In the Danish inventory, the source category Public electricity and heat production is further disaggregated. The $CO_2$ emission from each of the subcategories is shown in Table 3.2.5. The largest subcategory is power plant boilers >300MW.

Table 3.2.5 $CO_2$ emission from subcategories to 1A1a Public electricity and heat production.

| SNAP | SNAP name | $CO_2$, kt |
|---|---|---|
| 0101 | Public power | |
| 010101 | Combustion plants ≥ 300MW (boilers) | 6216 |
| 010102 | Combustion plants ≥ 50MW and < 300 MW (boilers) | 919 |
| 010103 | Combustion plants <50 MW (boilers) | 496 |
| 010104 | Gas turbines | 570 |
| 010105 | Stationary engines | 299 |
| 0102 | District heating plants | |
| 010202 | Combustion plants ≥ 50MW and < 300 MW (boilers) | 80 |
| 010203 | Combustion plants <50 MW (boilers) | 534 |




$CO_2$ emission from combustion of biomass fuels is not included in the total $CO_2$ emission data, because biomass fuels are considered $CO_2$ neutral. The $CO_2$ emission from biomass combustion is reported as a memo item in the Climate Convention reporting. In 2018, the $CO_2$ emission from biomass combustion from stationary combustion was 18 408 kt.

In Figure 3.2.10, the fuel consumption share (fossil fuels) is compared to the $CO_2$ emission share disaggregated to fuel origin. Due to the higher $CO_2$ emission factor for coal than oil and gas, the $CO_2$ emission share from coal combustion is higher than the fuel consumption share. Coal accounts for 29 % of the fossil fuel consumption and for 37 % of the $CO_2$ emission. Natural gas accounts for 48 % of the fossil fuel consumption and for 38 % of the $CO_2$ emission.

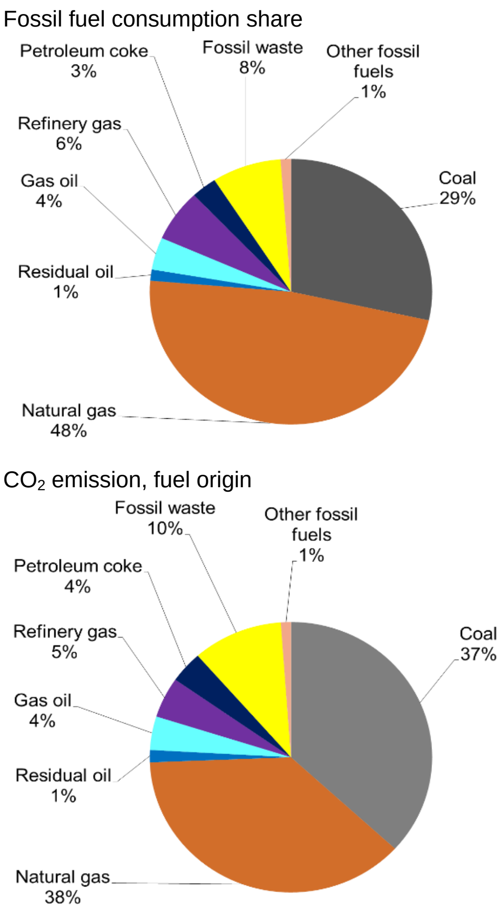



Figure 3.2.10 $CO_2$ emission, fuel origin.

The time series for $CO_2$ emission is provided in Figure 3.2.11. Despite a decrease in fuel consumption of 19 %[3] since 1990, the $CO_2$ emission from stationary combustion has decreased by 55 % because of the change of fuel type used.

The fluctuations in total $CO_2$ emission follow the fluctuations in $CO_2$ emission from Public electricity and heat production (Figure 3.2.11) and in coal consumption (Figure 3.2.4). The fluctuations are a result of electricity import/export as discussed in Chapter 3.2.2.

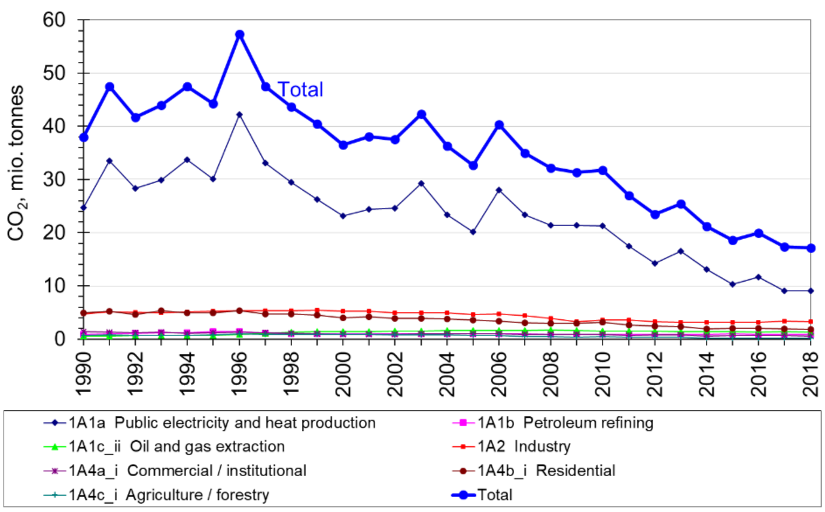



Figure 3.2.11 $CO_2$ emission time series for stationary combustion plants.

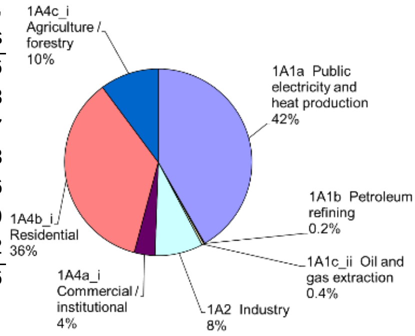
[3] The consumption of fossil fuels has decreased 49 %.

## $CH_4$

The methane ($CH_4$) emission from stationary combustion plants accounts for 3.5 % of the national $CH_4$ emission. Table 3.2.6 lists the $CH_4$ emission inventory for stationary combustion plants in 2018. Public electricity and heat production accounts for 42 % of the $CH_4$ emission from stationary combustion. The emission from residential plants adds up to 36 % of the emission.

Table 3.2.6 $CH_4$ emission from stationary combustion plants, 2018[1)].

| | $CH_4$, tonnes |
|---|---|
| 1A1a Public electricity and heat production | 4406 |
| 1A1b Petroleum refining | 18 |
| 1A1c Oil and gas extraction | 37 |
| 1A2 Industry | 878 |
| 1A4a Commercial/Institutional | 376 |
| 1A4b Residential | 3769 |
| 1A4c Agriculture/Forestry | 1072 |
| Total | 10556 |




1) Only emission from stationary combustion plants in the source categories is included.

The $CH_4$ emission factor for reciprocating gas engines is much higher than for other combustion plants due to the continuous ignition/burn-out of the gas. Lean-burn gas engines have an especially high emission factor. A considerable number of lean-burn gas engines are in operation in Denmark and in 2018, these plants accounted for 49 % of the $CH_4$ emission from stationary combustion plants (Figure 3.2.12). Most engines are installed in CHP plants and the fuel used is either natural gas or biogas. Residential wood combustion is also a large emission source accounting for 27 % of the emission in 2018.

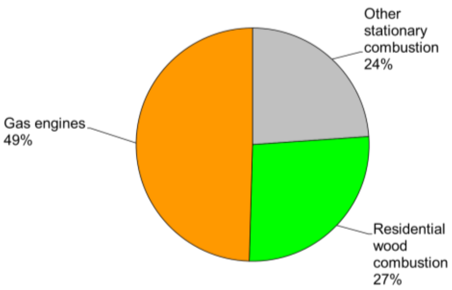



Figure 3.2.12 $CH_4$ emission share for gas engines and residential wood combustion, 2018.

Figure 3.2.13 shows the time series for $CH_4$ emission. The $CH_4$ emission from stationary combustion was 54 % higher in 2018 than in 1990. The emission increased until 1996 and decreased after 2004. This time series is related to the considerable number of lean-burn gas engines installed in CHP plants in Denmark during the 1990s. Figure 3.2.14 provides time series for the fuel consumption rate in gas engines and the corresponding increase of $CH_4$ emission. The decline in later years is due to structural changes in the Danish electricity market, which means that the fuel consumption in gas engines has been decreasing.

The $CH_4$ emission from residential plants has increased since 1990 due to increased combustion of biomass in residential plants. Combustion of wood accounted for 74 % of the $CH_4$ emission from residential plants in 2018.

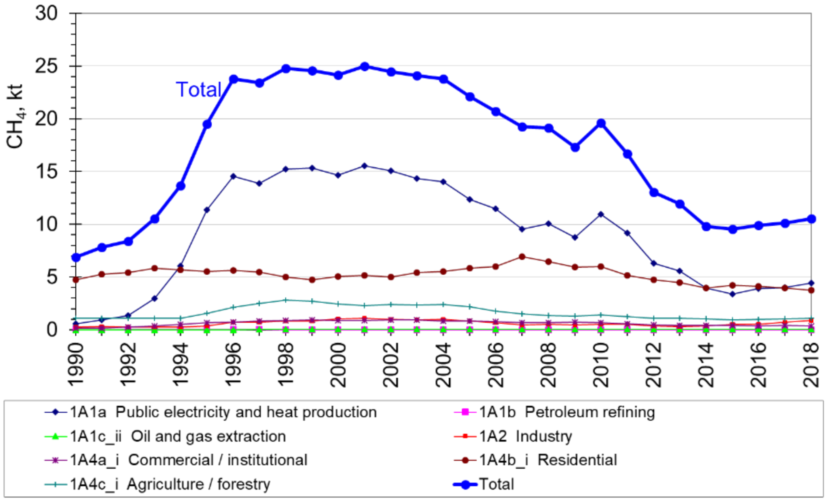



Figure 3.2.13 $CH_4$ emission time series for stationary combustion plants.

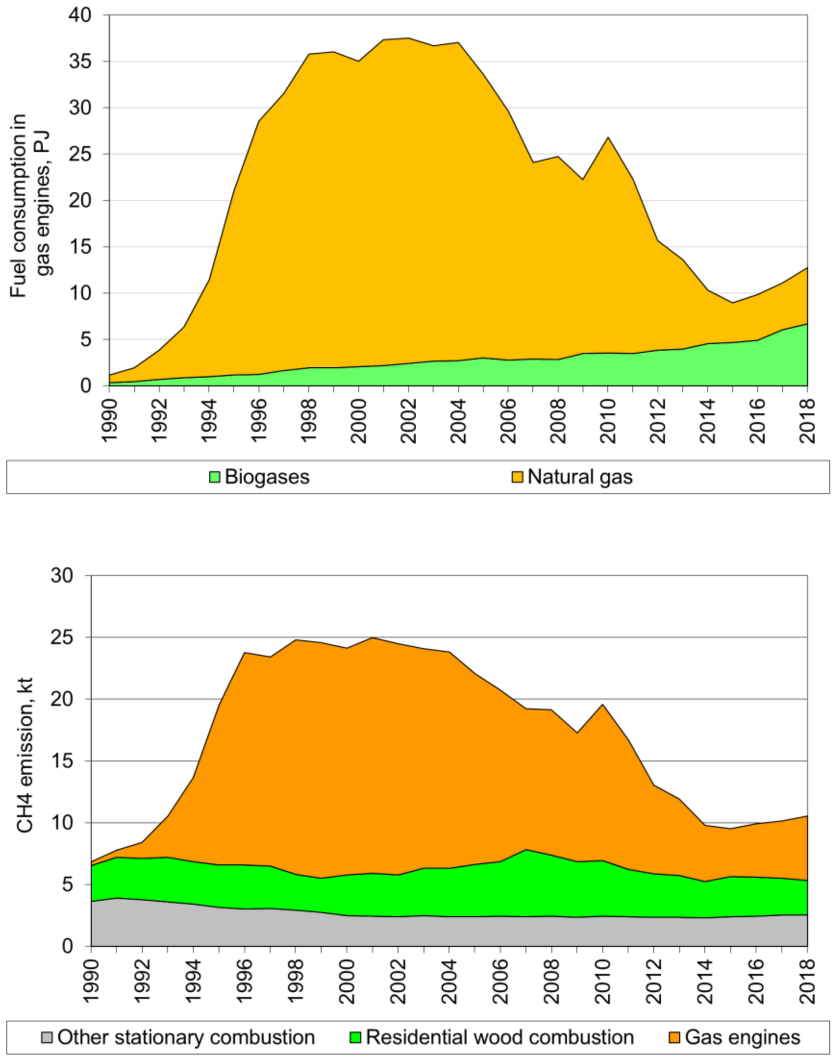


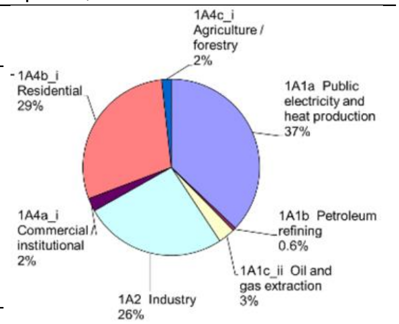

Figure 3.2.14 Time series for a) fuel consumption in gas engines and b) $CH_4$ emission from gas engines, residential wood combustion and other plants.

**$N_2O$**

The nitrous oxide ($N_2O$) emission from stationary combustion plants accounts for 3.9 % of the national $N_2O$ emission. Table 3.2.7 lists the $N_2O$ emission inventory for stationary combustion plants in the year 2018. Public electricity and heat production accounts for 37 % of the $N_2O$ emission from stationary combustion.

Table 3.2.7 $N_2O$ emission from stationary combustion plants, 2018[1].

| | $N_2O$, tonnes |
|---|---|
| 1A1a Public electricity and heat production | 263 |
| 1A1b Petroleum refining | 4 |
| 1A1c Oil and gas extraction | 22 |
| 1A2 Industry | 185 |
| 1A4a Commercial/Institutional | 17 |
| 1A4b Residential | 205 |
| 1A4c Agriculture/Forestry | 12 |
| Total | 708 |




[1] Only emission from stationary combustion plants in the source categories is included.

Figure 3.2.15 shows the time series for $N_2O$ emission. The $N_2O$ emission from stationary combustion has increased by 18% from 1990 to 2018, but again fluctuations in emission level due to electricity import/export are considerable.

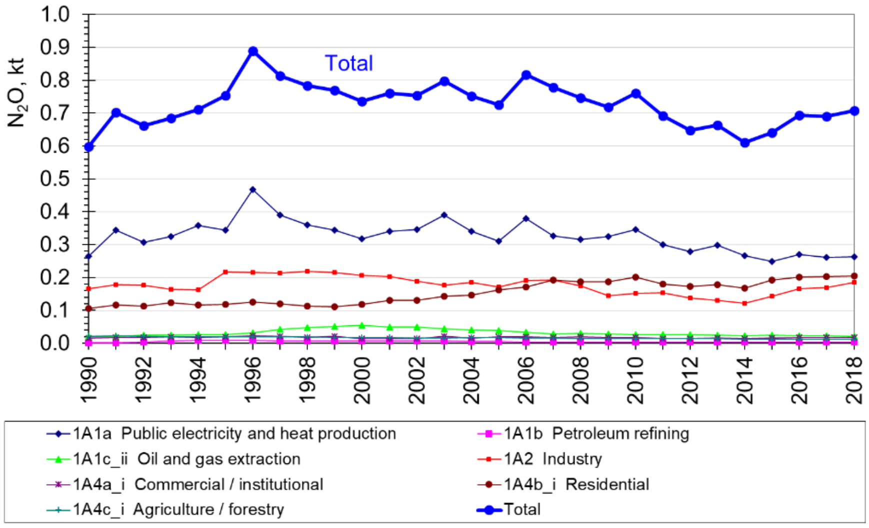



Figure 3.2.15 $N_2O$ emission time series for stationary combustion plants.

### $SO_2$, $NO_x$, NMVOC and CO

The emissions of sulphur dioxide ($SO_2$), nitrogen oxides ($NO_x$), non-volatile organic compounds (NMVOC) and carbon monoxide (CO) from Danish stationary combustion plants are included in the Danish IIR (Nielsen et al., 2019). Please refer to the Danish IIR for data presentation and references for $SO_2$, $NO_x$, NMVOC and CO.

## 3.2.4 Trend for subsectors

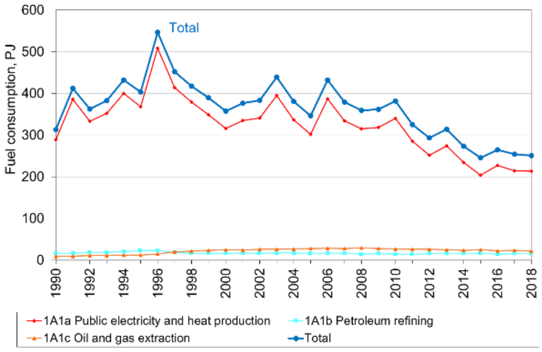
In addition to the data for stationary combustion, this chapter presents and discusses data for each of the subcategories in which stationary combustion is included. Time series are presented for fuel consumption and emissions.

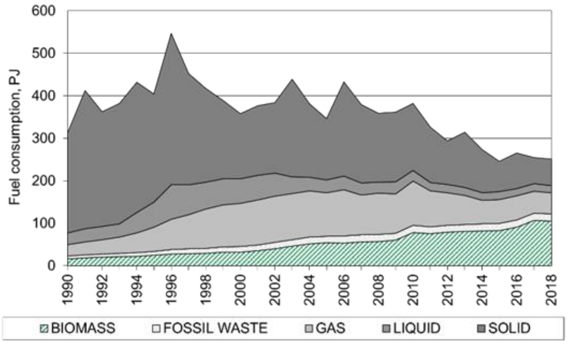
### 1A1 Energy industries

The emission source category 1A1 Energy Industries consists of the subcategories:

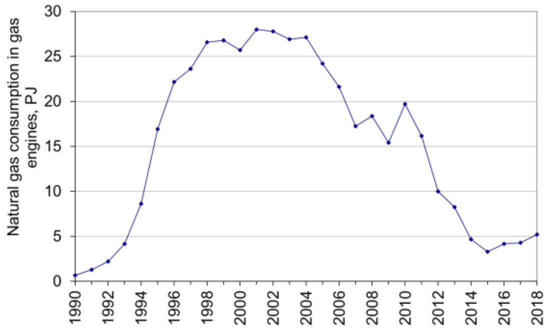
- 1A1a Public electricity and heat production
- 1A1b Petroleum refining
- 1A1c Oil and gas extraction

Figure 3.2.16 – 3.2.17 present time series for the Energy Industries. Public electricity and heat production is the largest subcategory accounting for the main part of all emissions. Time series are discussed below for each subcategory.

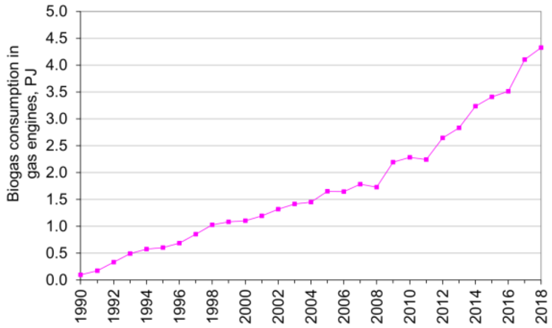



Natural gas fuelled engines




Biogas fuelled engines (biogas, bio gasification gas and bio natural gas)




Residual oil in petroleum refining

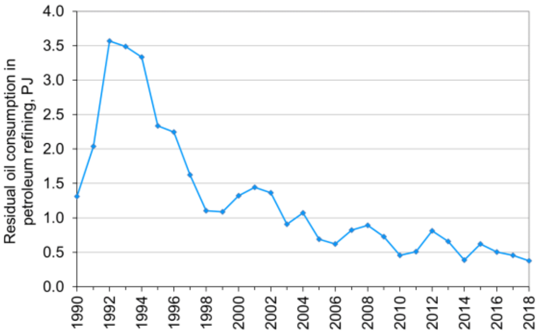



Figure 3.2.16 Time series for fuel consumption, 1A1 Energy industries.

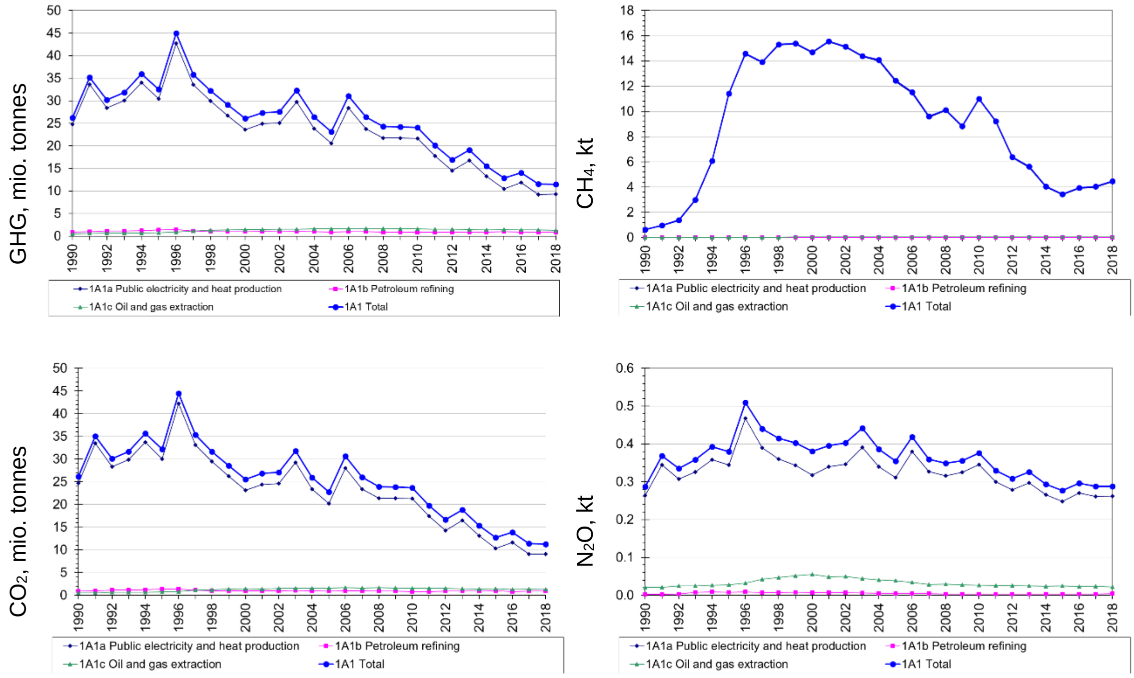



Figure 3.2.17 Time series for greenhouse gas emissions, 1A1 Energy industries.

### 1A1a Public electricity and heat production

Public electricity and heat production is the largest source category regarding both fuel consumption and greenhouse gas emissions for stationary combustion. Figure 3.2.18 shows the time series for fuel consumption and emissions.

The fuel consumption in public electricity and heat production was 26 % lower in 2018 than in 1990. In addition to fuel type changes, the total fuel consumption is also influenced by the fact that the Danish wind power production has increased.

As discussed in Chapter 3.2.2 the fuel consumption fluctuates mainly because of electricity trade. Coal is the fuel that is affected the most by the fluctuating electricity trade.

Coal is the main fuel in the source category even in years with electricity import. The coal consumption in 2018 was 74 % lower than in 1990. Natural gas is also an important fuel and the consumption of natural gas increased in 1990-2000 but has decreased since 2010. A considerable part of the natural gas is combusted in gas engines (Figure 3.2.17). The consumption of waste and biomass has increased.

The $CO_2$ emission was 63 % lower in 2018 than in 1990. This decrease – in spite of only a 26 % decrease in fuel consumption - is a result of the change of fuel types used.

The $CH_4$ emission has increase until the mid-nineties as a result of the considerable number of lean-burn gas engines installed in CHP plants in Denmark in this period. The decline after 2004 is due to structural changes in the Danish electricity market, which means that the fuel consumption in gas engines has been decreasing (Figure 3.2.17). The emission in 2018 was 7.4 times the 1990 emission level.

The $N_2O$ emission in 2018 was 1 % lower than the 1990 emission level. The emission fluctuates similar to the fuel consumption.

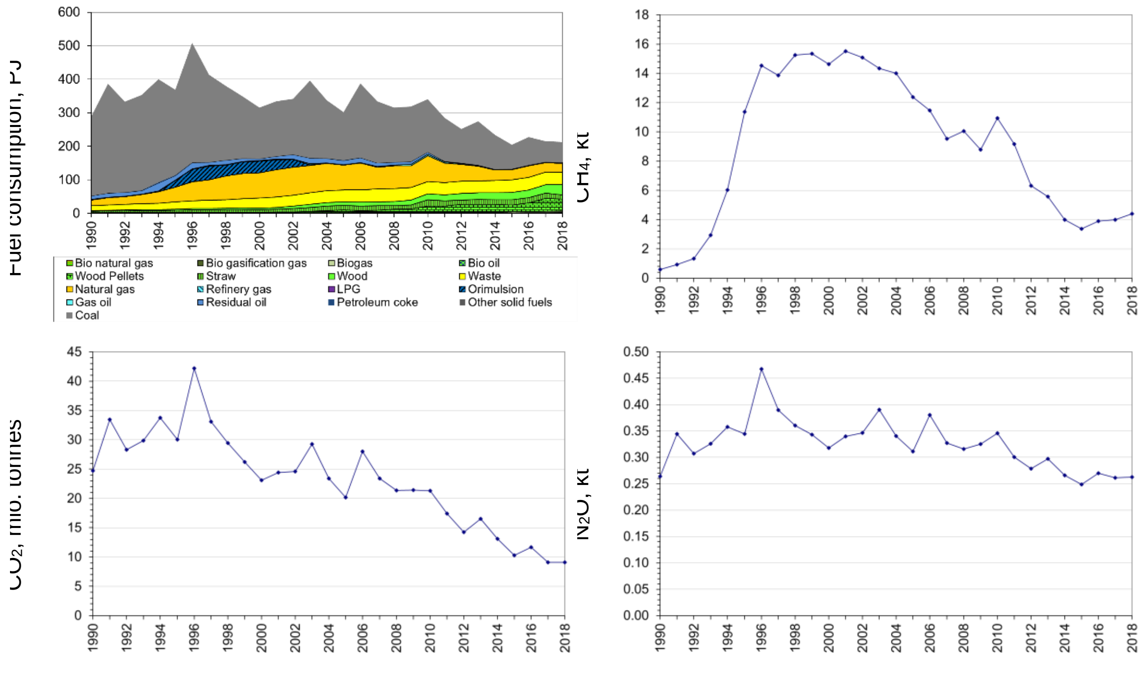



Figure 3.2.18 Time series for 1A1a Public electricity and heat production.

### 1A1b Petroleum refining

Petroleum refining is a small source category regarding both fuel consumption and emissions for stationary combustion. There are presently two refineries operating in Denmark. Figure 3.2.19 shows the time series for fuel consumption and emissions.

The significant decrease in both fuel consumption and emissions in 1996 is a result of the closure of a third refinery.

The fuel consumption has increased 4 % since 1990 and the $CO_2$ emission has decreased 2 %.

The $CH_4$ emission has increased 1 % since 1990 and decreased 1 % since 2017. The reduction in $CH_4$ emission from 1995 to 1996 is caused by the closure of a refinery.

The $N_2O$ emission was 83 % higher in 2018 than in 1990. The emission increased in 1993 as a result of the installation of a gas turbine in one of the refineries (DEA, 2019b).

The $N_2O$ emission factor for the refinery gas fuelled gas turbine has been assumed equal to the emission factor for natural gas fuelled turbines and thus the emission factor have been decreasing since 2001. The time series for the emission factor cause the decreasing $N_2O$ emission since 2001.

Emissions from refineries are further discussed in Chapter 3.5 and in Plejdrup et al. (2015).

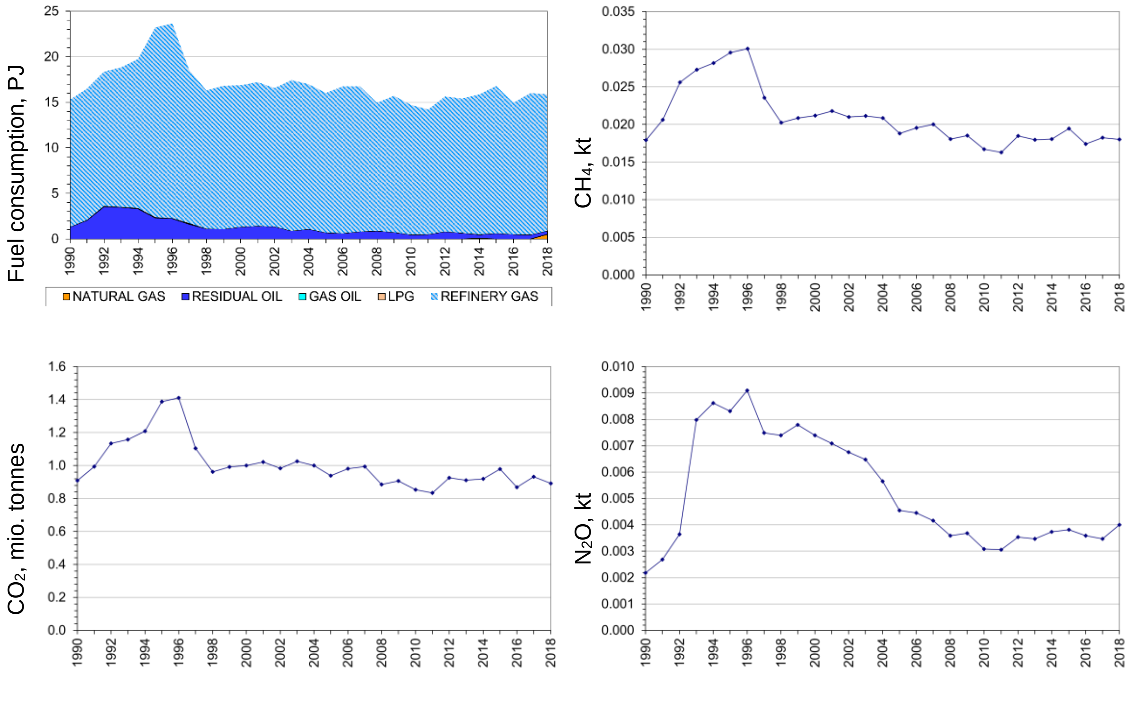



Figure 3.2.19 Time series for 1A1b Petroleum refining.

### 1A1c Oil and gas extraction

The source category Oil and gas extraction comprises natural gas consumption in the offshore industry and in addition a small consumption in the Danish gas treatment plant[4]. Gas turbines are the main plant type. Figure 3.2.20 shows the time series for fuel consumption and emissions.

The fuel consumption in 2018 was 2.3 times the consumption in 1990. The fuel consumption has decreased since 2008. The $CO_2$ emission follows the fuel consumption and the emission in 2018 was 2.3 times the emission in 1990.

The time series for $N_2O$ emission follows the decreasing emission factor for gas turbines applied in CHP plants.

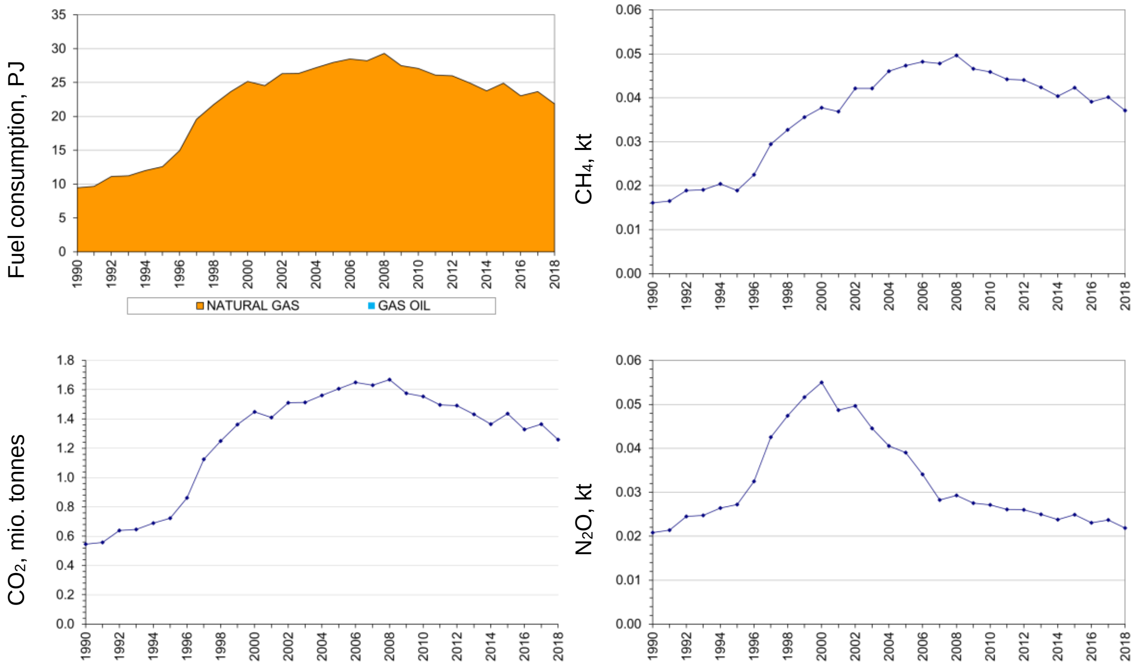



Figure 3.2.20 Time series for 1A1c Oil and gas extraction.

[4] Nybro.

### 1A2 Industry

Manufacturing industries and construction (Industry) consists of both stationary and mobile sources. In this chapter, only stationary sources are included.

The emission source category 1A2 Industry consists of the subcategories:

- 1A2a Iron and steel
- 1A2b Non-ferrous metals
- 1A2c Chemicals
- 1A2d Pulp, Paper and Print
- 1A2e Food processing, beverages and tobacco
- 1A2f Non-metallic minerals
- 1A2 g viii Other manufacturing industry

The figures 3.2.21-3.2.22 show the time series for fuel consumption and emissions. The subsectors Non-metallic minerals, Other manufacturing industry and Food processing, beverages and tobacco are the main subsectors for fuel consumption and emissions.

The total fuel consumption in industrial combustion was 13 % lower in 2018 than in 1990. The consumption of natural gas has increased since 1990 whereas the consumption of coal has decreased. The consumption of residual oil has decreased, but the consumption of petroleum coke increased. The biomass consumption in 2018 was 2.2 times the consumption in 1990.

The greenhouse gas emission and the $CO_2$ emission are both rather stable until 2006 following the small fluctuations in fuel consumption. The emission decreased in 2006-2009. Due to change of applied fuels, the greenhouse gas and $CO_2$ emissions have decreased more than the fuel consumption since 1990; The GHG emission has decreased 30 % since 1990 and the $CO_2$ emission has decreased 31%.

The $CH_4$ emission has increased from 1994-2001 and decreased again from 2001 - 2007. In 2018, the emission was 3.2 times the emission level in 1990. The $CH_4$ emission follows the consumption of natural gas and biogas in gas engines (Figure 3.2.21). Most industrial CHP plants based on gas engines came in operation in the years 1995 to 1999. The decrease after 2004 is a result of the liberalisation of the electricity market. The increased emission after 2013 is related to new biogas fuelled gas engines in the food industry.

The $N_2O$ emission has increased 11 % since 1990. The emission from mineral wood production[5] is a large emission source, and the production of mineral wool production has increased in later years (see Chapter 4.2.9). This cause the increase of the $N_2O$ emission in recent years.

The increase of $N_2O$ emission from 1994 to 1995 is related to combustion of coke oven coke in mineral wool production. Plant specific fuel consumption data are only available from 1995 onwards for the mineral wool production plants.

[5] Included in sector 1A2g viii Other manufacturing industry.

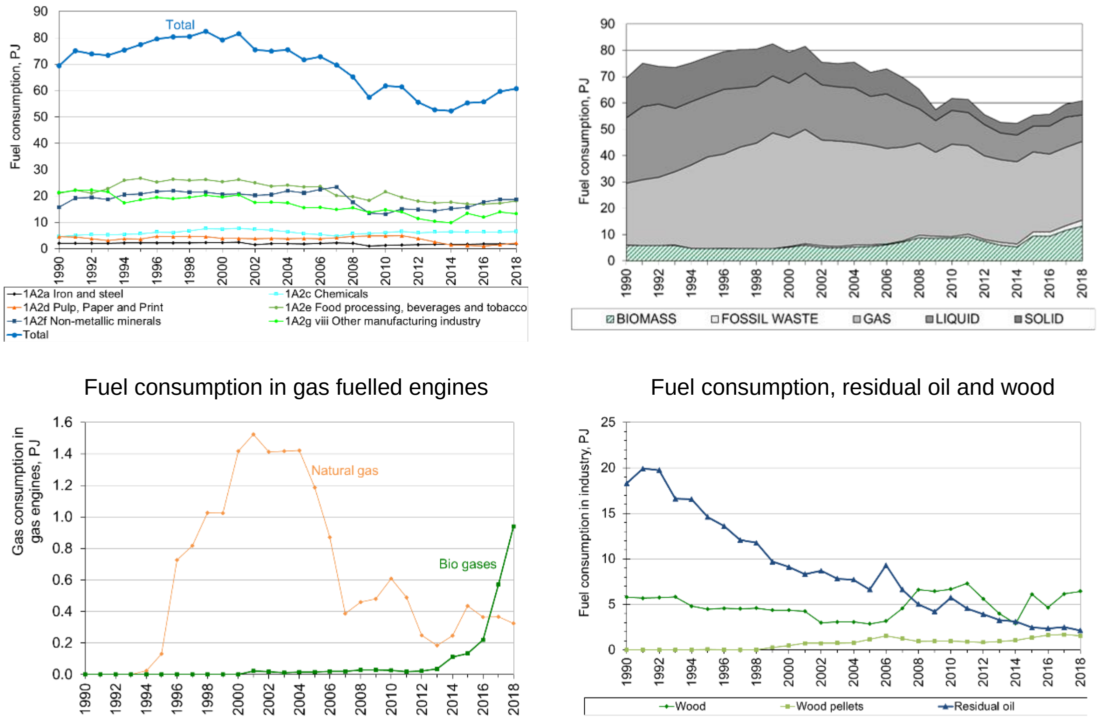



Figure 3.2.21 Time series for fuel consumption, 1A2 Industry.

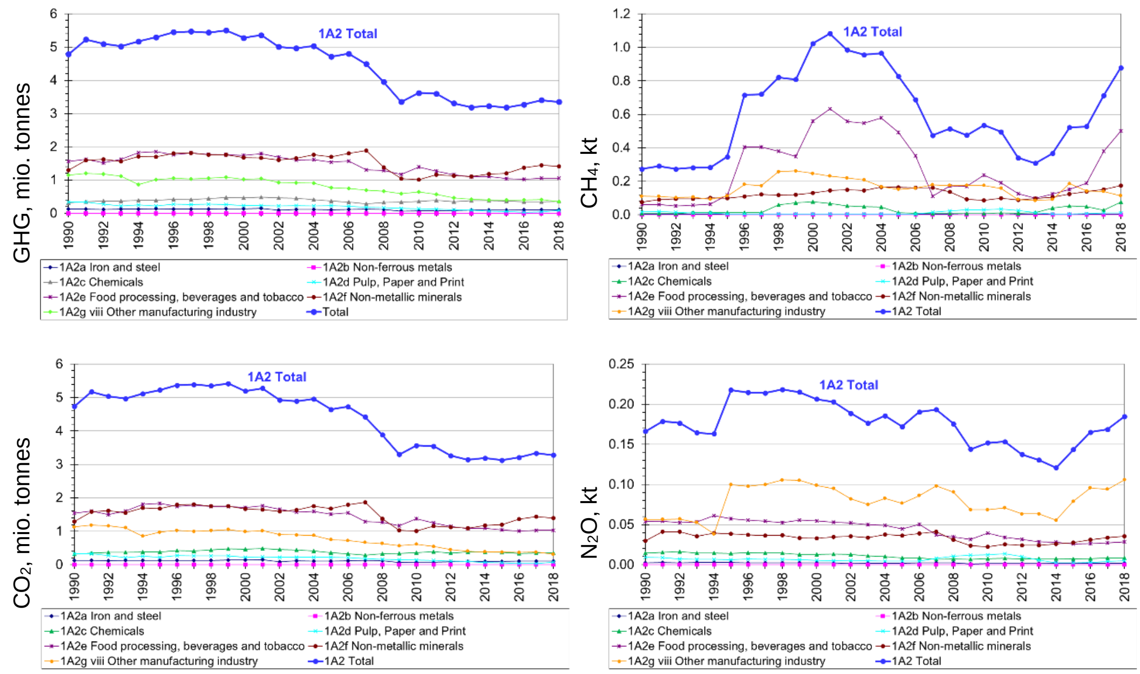



Figure 3.2.22 Time series for greenhouse gas emission, 1A2 Industry.

### 1A2a Iron and steel

*Iron and steel* is a very small emission source category. Figure 3.2.23 shows the time series for fuel consumption and emissions.

Natural gas is the main fuel in the subsector.

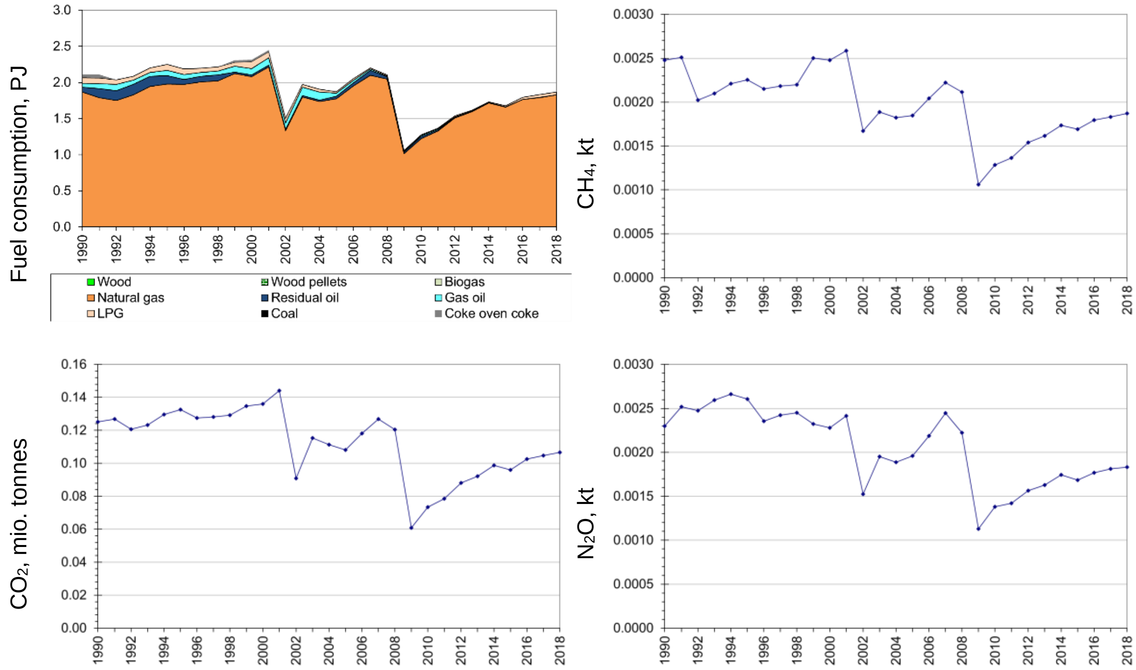



Figure 3.2.23 Time series for 1A2a Iron and steel.

### 1A2b Non-ferrous metals

The energy statistics have been recalculated and now no fuel consumption is reported for non-ferrous metals.

### 1A2c Chemicals

Chemicals is a minor emission source category. Figure 3.2.24 shows the time series for fuel consumption and emissions.

Natural gas is the main fuel in this subsector. The $CO_2$ emission time series follow the time series for fuel consumption. The time series for $CH_4$ emission 1997-2006 is related to consumption of natural gas in gas engines. The increased $CH_4$ emission in 2014 to 2018 is related to one biogas fuelled engine. The decreasing time series for $N_2O$ emission is related to the decreasing consumption of residual oil.

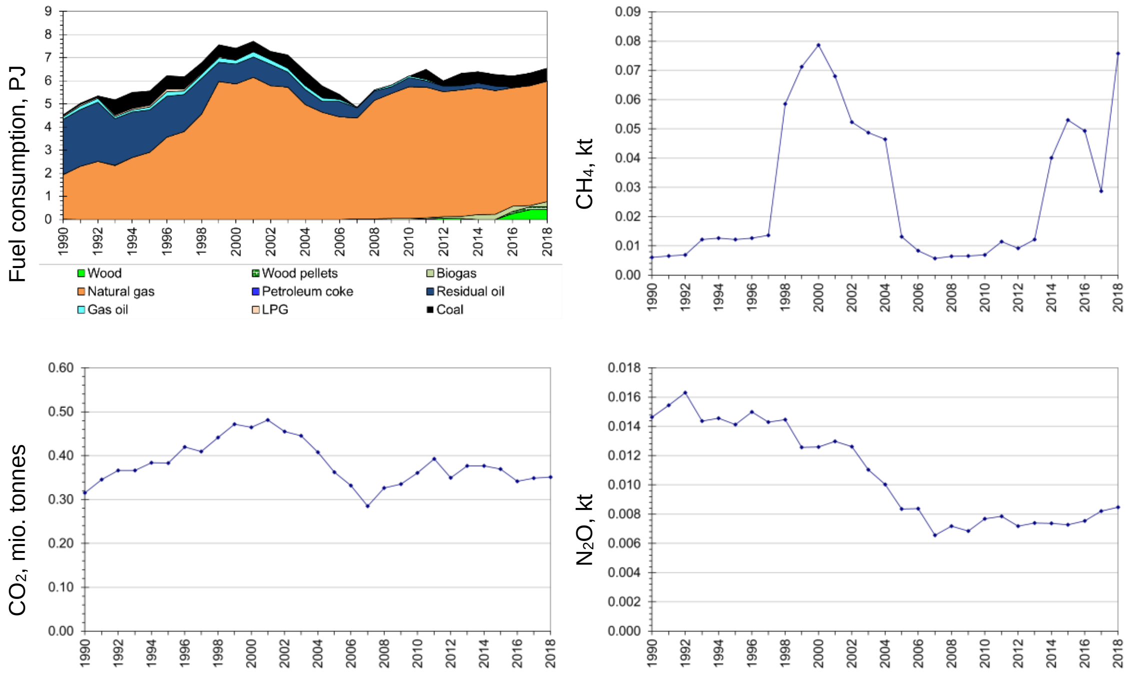



Figure 3.2.24 Time series for 1A2c Chemicals.

### 1A2d Pulp, paper and print

Pulp, paper and print is a minor emission source category. Figure 3.2.25 shows the time series for fuel consumption and emissions.

The fuel consumption decreased 51 % from 1990. The time series is related to both closure of plants and new combustion units in exiting plants. In addition, the liberalisation of the electricity market caused less operational hours of a natural gas fuelled gas turbine. Natural gas, and in 2007-2013 also wood, are the main fuels in the subsector. The increased use of wood from 2007 is reflected in the $CO_2$ emission time series.

The increased consumption of wood in 2007-2013 is also reflected in the $CH_4$ and $N_2O$ emission time series.

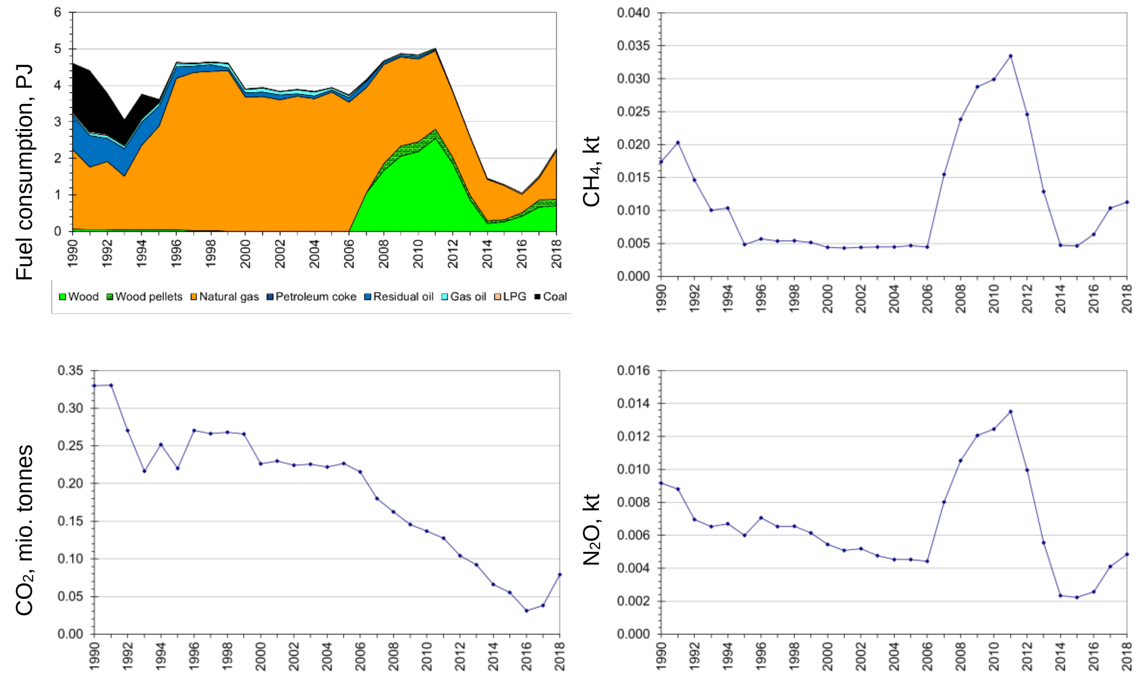



Figure 3.2.25 Time series for 1A2d Pulp, paper and print.

### 1A2e Food processing, beverages and tobacco

Food processing, beverages and tobacco is a considerable industrial subsector. Figure 3.2.26 shows the time series for fuel consumption and emissions.

Natural gas, residual oil and coal are the main fuels in the subsector. The consumption of coal and residual oil has decreased whereas the consumption of natural gas has increased.

The time series for $CH_4$ emission follows the consumption of natural gas in gas engines.

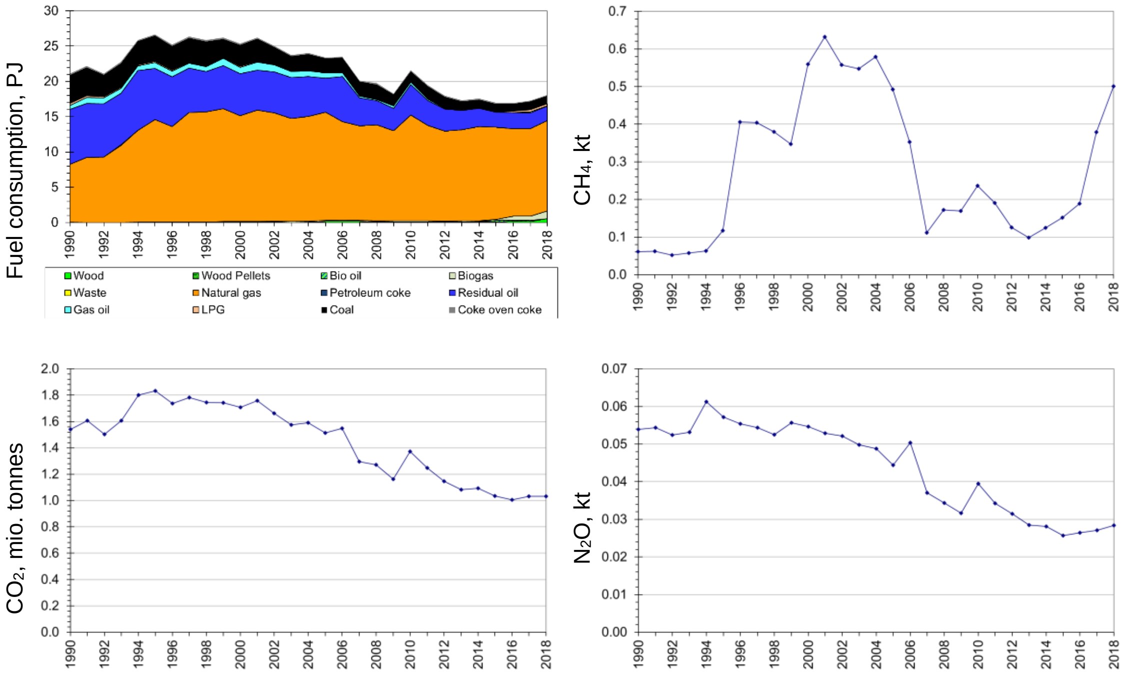



Figure 3.2.26 Time series for 1A2e Food processing, beverages and tobacco.

**1A2f Non-metallic minerals**

Non-metallic minerals is a considerable industrial subsector. The subsector includes cement production that is a major industrial emission source in Denmark. Figure 3.2.27 shows the time series for fuel consumption and emissions.

Petroleum coke, natural gas, industrial waste and coal are the main fuels in the subsector in recent years. The consumption of coal and residual oil has decreased.

Due to the global recession, cement production decreased in 2008 and 2009, but then has slightly increased since then. This is reflected in the time series.

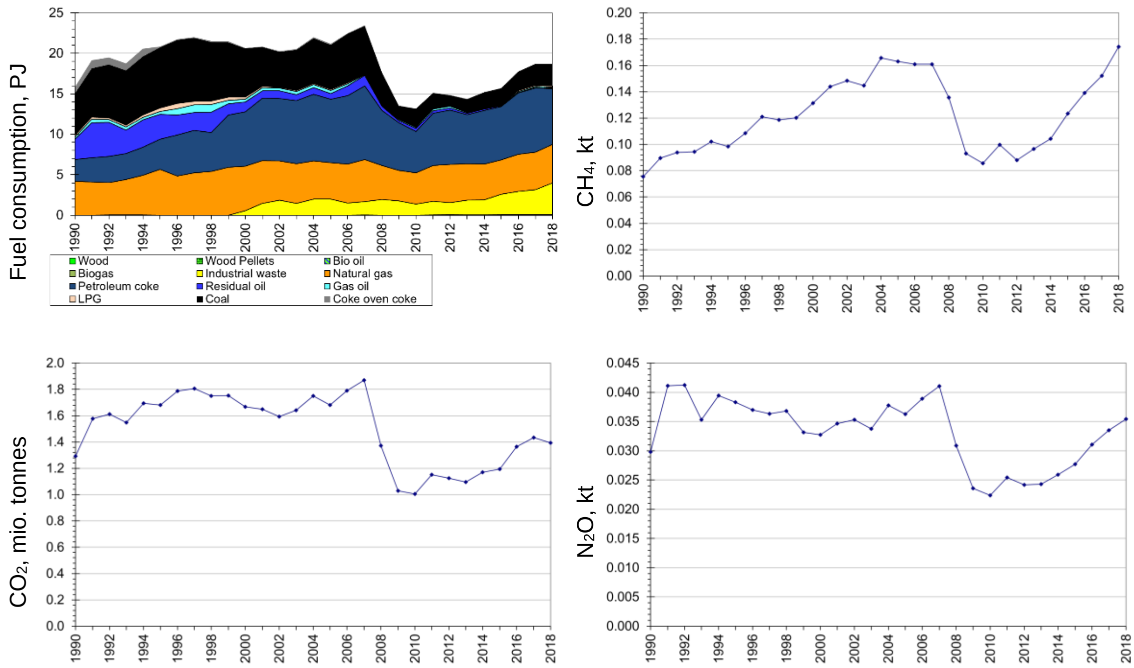



Figure 3.2.27 Time series for 1A2f Non-metallic minerals.

### 1A2g Other manufacturing industry

Other manufacturing industry is a considerable industrial subsector. Figure 3.2.28 shows the time series for fuel consumption and emissions.

Natural gas and wood are the main fuels in the subsector in recent years. The consumption of coal and residual oil has decreased.

The time series for $CH_4$ is related to the consumption of natural gas in gas engines.

Combustion of coke oven coke in mineral wood production is a large emission source for $N_2O$. Plant specific fuel consumption rates for the mineral wool production plants are available from 1995. This causes the increase in $N_2O$ emission between 1994 and 1995.

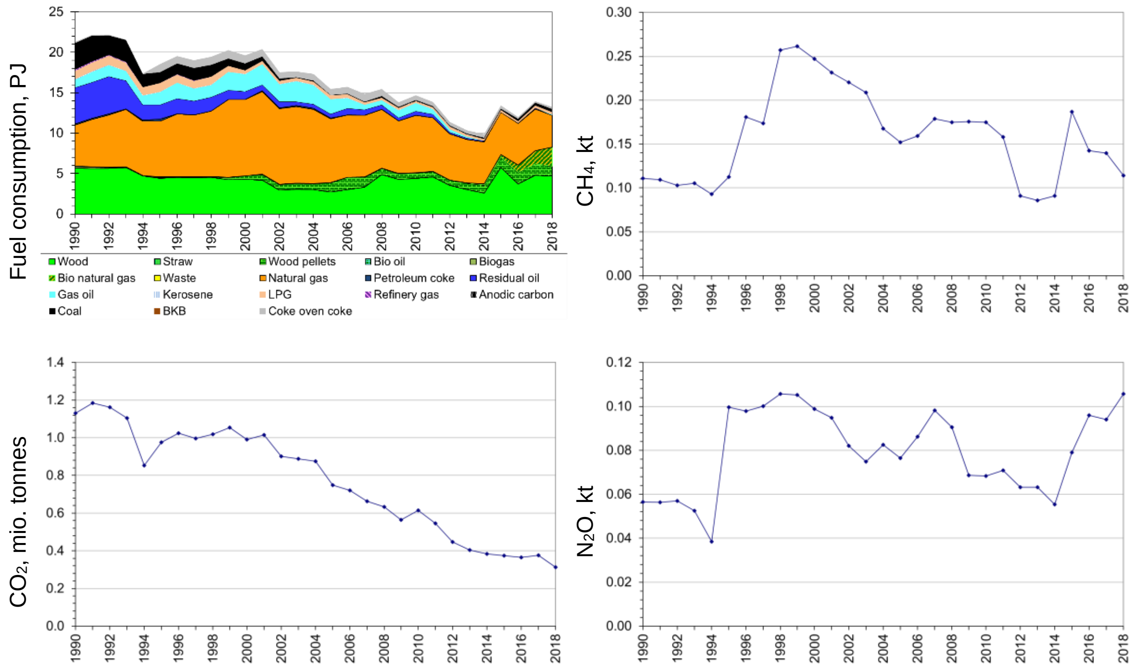



Figure 3.2.28 Time series for 1A2g Industry - other.

### 1A4 Other Sectors

The emission source category 1A4 Other Sectors consists of the subcategories:

- 1A4a Commercial/Institutional plants.
- 1A4b Residential plants.
- 1A1c Agriculture/Forestry.

The Figures 3.2.29-30 present time series for this emission source category. Residential plants are the dominant subcategory accounting for the largest part of all emissions. Time series are discussed below for each subcategory.

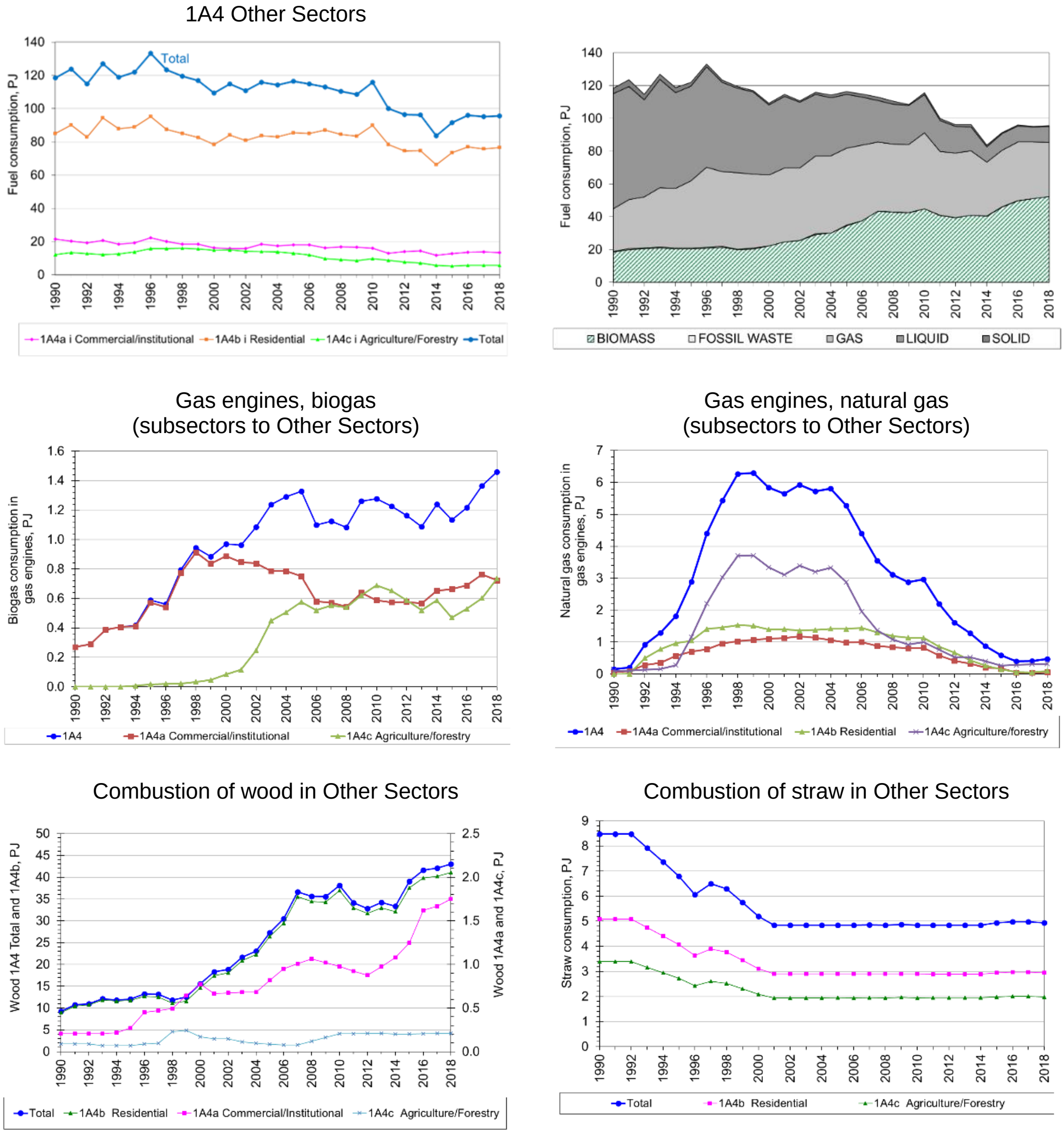



Figure 3.2.29 Time series for fuel consumption, 1A4 Other Sectors.

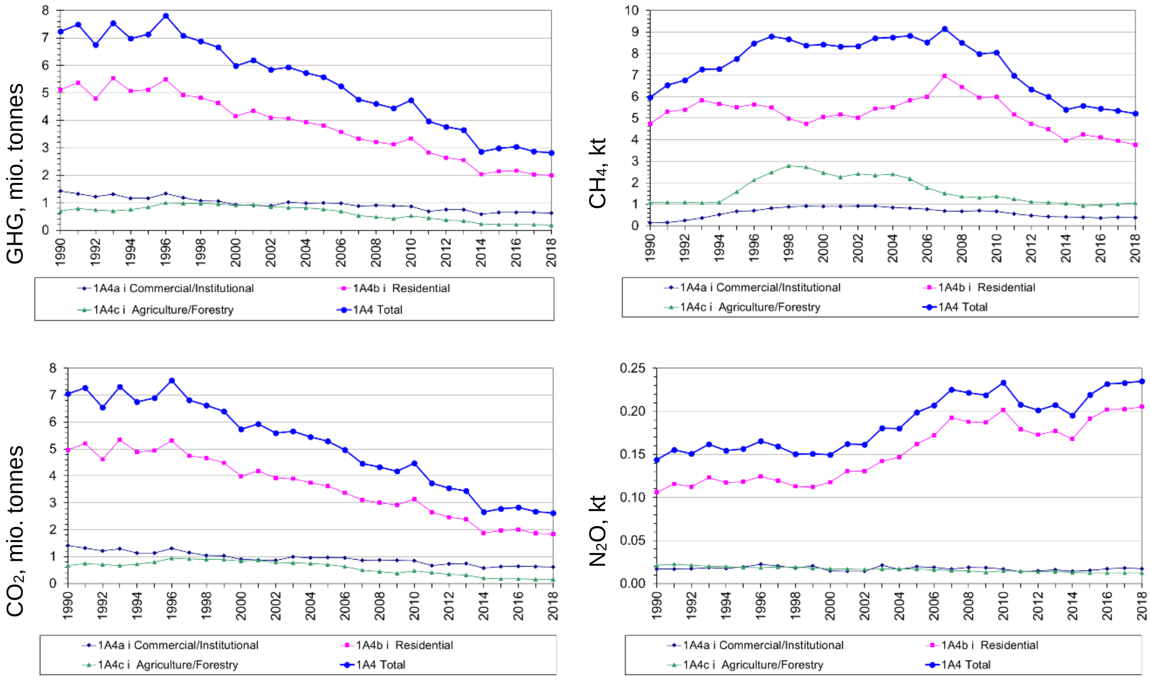



Figure 3.2.30 Time series for greenhouse gas emission, 1A4 Other Sectors.

### 1A4a Commercial and institutional plants

The subcategory Commercial and institutional plants consists of both stationary and mobile sources. In this chapter, only stationary sources are included. Figure 3.2.31 shows the time series for fuel consumption and emissions.

The subcategory Commercial and institutional plants has low fuel consumption and emissions compared to the other stationary combustion emission source categories.

The fuel consumption in commercial/institutional plants has decreased 37 % since 1990 and the fuels applied have changed. The fuel consumption consists mainly of gas oil and natural gas. The consumption of gas oil has decreased since 1990. The consumption of wood and biogas has increased. The wood consumption in 2018 was 8.6 times the consumption in 1990.

The $CO_2$ emission has decreased 57 % since 1990. Both the decrease of fuel consumption and the change of fuels contribute to the decreased $CO_2$ emission.

The $CH_4$ emission in 2018 was 2.9 times the 1990 level. The increase is mainly a result of the increased emission from natural gas fuelled engines. The emissions from biogas-fuelled engines and from combustion of wood also contribute to the increase. The time series for consumption of natural gas and biogas are shown in Figure 3.2.29.

The $N_2O$ emission in 2018 was 2 % higher than in 1990. The fluctuations of the $N_2O$ emission are mainly a result of fluctuations in consumption of natural gas and waste.

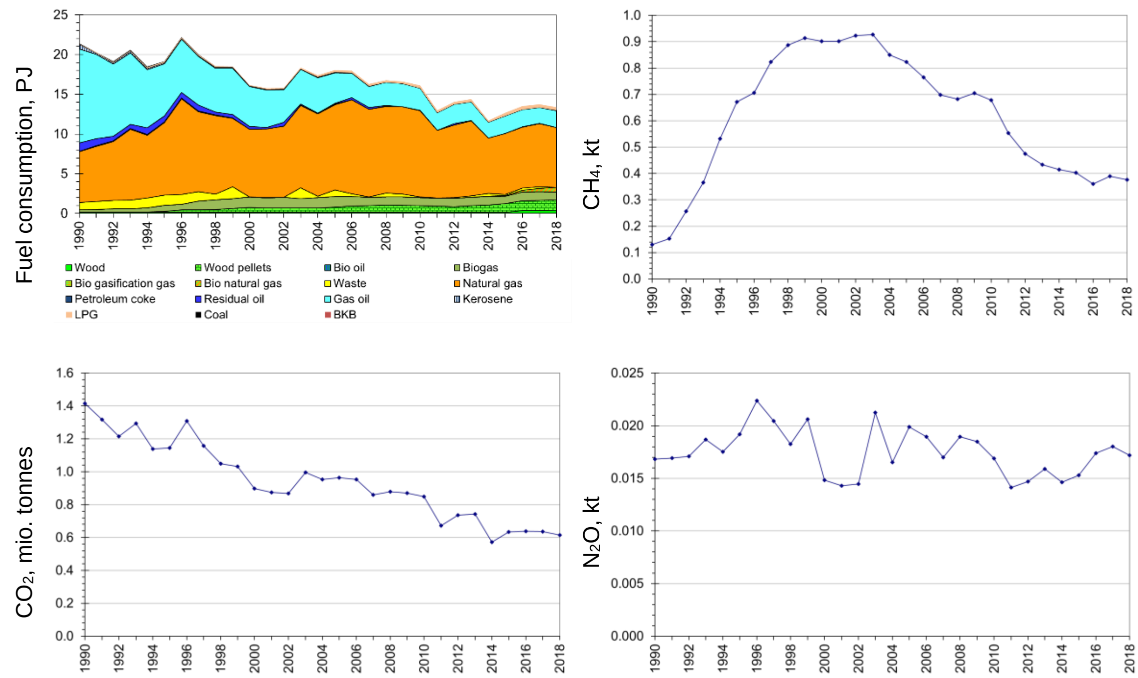



Figure 3.2.31 Time series for 1A4a Commercial /institutional.

## 1A4b Residential plants

The emission source category Residential plants consists of both stationary and mobile sources. In this chapter, only stationary sources are included. Figure 3.2.32 shows the time series for fuel consumption and emissions.

For residential plants, the total fuel consumption was 10 % lower in 2018 than in 1990. The large decrease from 2010 to 2011 was caused by high temperature in the winter season of 2011 compared to the cold winter of 2010. The consumption of gas oil has decreased since 1990 whereas the consumption of wood has increased considerably (4.6 times the 1990 level). The consumption of natural gas has also increased since 1990.

The $CO_2$ emission has decreased by 63 % since 1990. This decrease is mainly a result of the considerable change in fuels used from gas oil to wood and natural gas.

The $CH_4$ emission from residential plants was 21 % lower in 2018 than in 1990. Residential wood combustion is a large source of $CH_4$ emission and the consumption of wood has increased whereas the emission factor has decreased since 1990.

The change of fuel from gas oil to wood has resulted in a 94 % increase of $N_2O$ emission since 1990 due to a higher emission factor for wood than for gas oil.

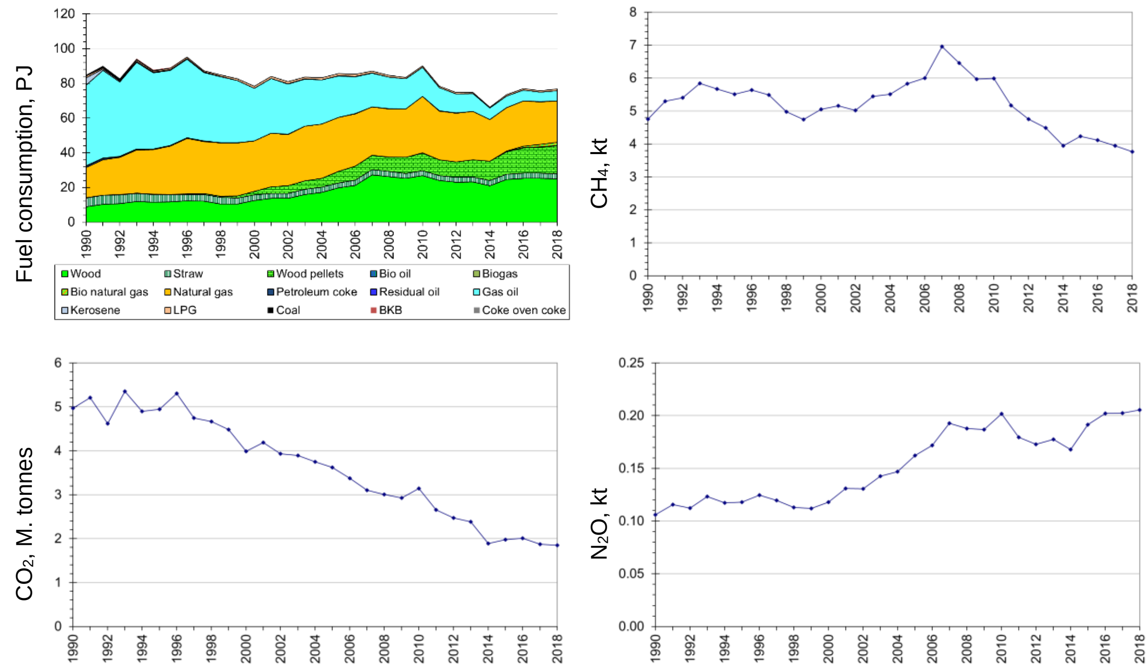



Figure 3.2.32 Time series for 1A4b Residential plants.

### 1A4c Agriculture/forestry

The emission source category Agriculture/forestry consists of both stationary and mobile sources. In this chapter, only stationary sources are included. Figure 3.2.33 shows the time series for fuel consumption and emissions.

For plants in agriculture/forestry, the fuel consumption has decreased 54 % since 1990. A remarkable decrease of fuel consumption has taken place since year 2000.

The type of fuel that has been applied has changed since 1990. In the years 1994-2004, the consumption of natural gas was high, but after 2004, the consumption decreased again. A large part of the natural gas consumption has been applied in gas engines (Figure 3.2.29). Most CHP plants in agriculture/forestry based on gas engines came in operation in 1995-1999. The decrease after 2004 is a result of the liberalisation of the electricity market.

The consumption of coal, residual oil and straw has decreased since 1990. The consumption of biogas has increased.

The $CO_2$ emission in 2018 was 77 % lower than in 1990. The $CO_2$ emission increased from 1990 to 1996 due to increased fuel consumption. Since 1996, the $CO_2$ emission has decreased in line with the decrease in fuel consumption.

The $CH_4$ emission in 2018 was 1 % lower than in 1990. The emission follows the time series for natural gas combusted in gas engines (Figure 3.2.29). The emission from combustion of straw has decreased as a result of the decreasing consumption of straw in the sector.

The emission of $N_2O$ has decreased by 42 % since 1990. The decrease is a result of the lower fuel consumption as well as the change of fuel. The decreasing consumption of straw contributes considerably to the decrease of emission.

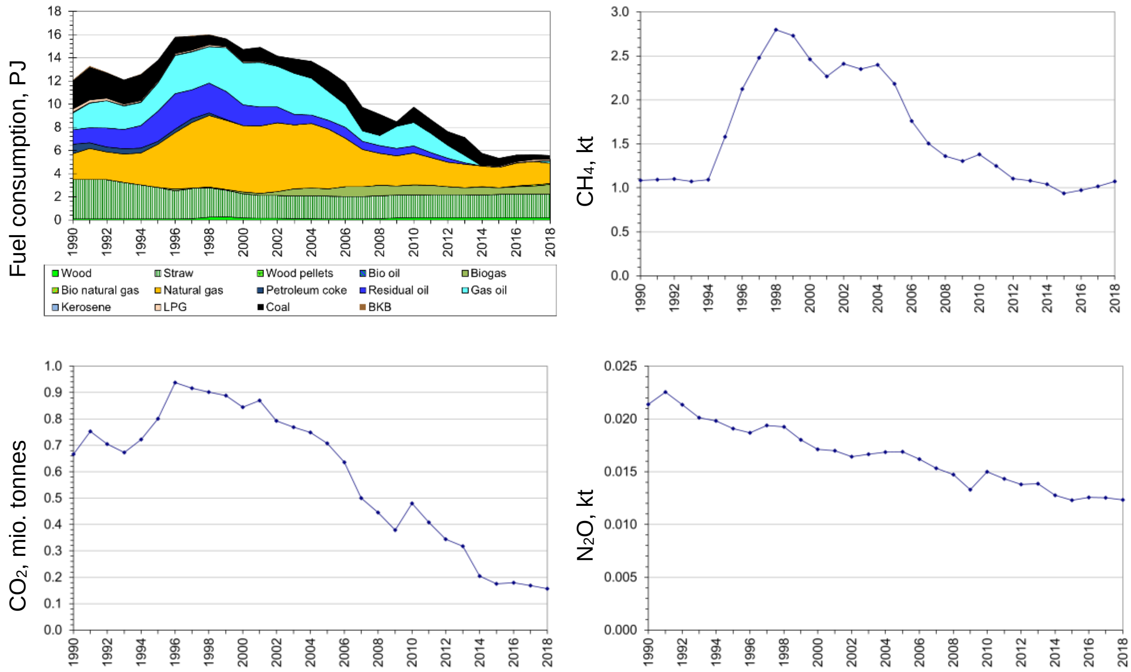



Figure 3.2.33 Time series for 1A4c Agriculture/Forestry.

### 3.2.5 Methodological issues

The Danish emission inventory is based on the CORINAIR (CORe INventory on AIR emissions) system, which is a European program for air emission inventories. CORINAIR includes methodology structure and software for inventories. The methodology is described in the EEA Guidebook (EEA, 2016). Emission data are stored in MS Access databases, from which data are transferred to the reporting formats.

In the Danish emission database all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution) according the CORINAIR system. The emission inventories are prepared from a complete emission database based on the SNAP source categories. Aggregation to the source category codes used in CRF is based on a correspondence list enclosed in Annex 3A-1.

The emission inventory for stationary combustion is based on activity rates from the Danish energy statistics. General emission factors for various fuels, plants and sectors have been determined. Some large plants, such as power plants, are registered individually as large point sources and plant-specific emission data are used.

Recalculations and improvements are shown in Chapter 3.2.8 and 3.2.9

**Tiers**

The type of GHG emission factor and the applied tier level for each emission source are shown in Table 3.2.8 below. The tier levels have been determined based on the IPCC Guidelines (IPCC, 2006). The fuel consumption data for transformation are technology specific. For end-use of fuels, the disaggregation to specific technologies is less detailed. However, for residential wood combustion technology specific fuel consumption rates have been estimated.

The tier level definitions have been interpreted as follows:

- Tier 1: The emission factor is an IPCC default tier 1 value.
- Tier 2: The emission factors are country-specific and based on a limited number of emission measurements or a technology specific IPCC tier 2 emission factor.
- Tier 3: Emission data are based on:
  - plant specific emission measurements or
  - Technology specific fuel consumption data and country-specific emission factors based on a considerable number of emission measurements from Danish plants.

Table 3.2.8 gives an overview of the calculation methods and type of emission factor. The table also shows which of the source categories are key in any of the key category analysis (including LULUCF, approach 1/approach 2, level/trend)[6].

Four emission source categories based on tier 1 approach have been identified as key sources this year. The total emission from these emission sources adds up to 240 kton $CO_2$ equivalent or 0.4 % of the national total in 2018. In 1990, the emission from the four emission sources adds up to 630 kton or 0.8 % of

[6] Key category according to the KCA approach 1 or approach 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990/ level 2018/ trend.

national total. If sufficient data are available, a tier 2 approach will be applied next year.

Table 3.2.8 Methodology and type of emission factor, 2018.

| | | Tier | EMF[1)] | Key category[2)] |
|---|---|---|---|---|
| 1A Stationary combustion, Coal, ETS data | $CO_2$ | Tier 3 | PS | Yes |
| 1A Stationary combustion, Coal, no ETS data | $CO_2$ | Tier 3 [3)] | CS | Yes |
| 1A Stationary combustion, BKB | $CO_2$ | Tier 1 | D | No |
| 1A Stationary combustion, Coke oven coke | $CO_2$ | Tier 1/Tier 3 | D/PS | No |
| 1A Stationary combustion, Fossil waste, ETS data | $CO_2$ | Tier 3 | PS | Yes |
| 1A Stationary combustion, Fossil waste, no ETS data | $CO_2$ | Tier 2 | CS | Yes |
| 1A Stationary combustion, Petroleum coke, ETS data | $CO_2$ | Tier 3 | PS | Yes |
| 1A Stationary combustion, Petroleum coke, no ETS data | $CO_2$ | Tier 2 | CS | Yes |
| 1A Stationary combustion, Residual oil, ETS data | $CO_2$ | Tier 3 | PS | Yes |
| 1A Stationary combustion, Residual oil, no ETS data | $CO_2$ | Tier 2 [4)] | CS | Yes |
| 1A Stationary combustion, Gas oil | $CO_2$ | Tier 2/Tier 3 [5)] | CS / PS | Yes |
| 1A Stationary combustion, Kerosene | $CO_2$ | Tier 1 | D | Yes |
| 1A Stationary combustion, LPG | $CO_2$ | Tier 1/Tier 3 [6)] | D / PS | Yes |
| 1A1b Stationary combustion, Petroleum refining, Refinery gas | $CO_2$ | Tier 3 | CS | Yes |
| 1A Stationary combustion, Natural gas, onshore | $CO_2$ | Tier 3 | CS | Yes |
| 1A1c_ii Stationary combustion, Oil and gas extraction, Offshore gas turbines, Natural gas | $CO_2$ | Tier 3 | CS | Yes |
| 1A1 Stationary Combustion, solid fuels | $CH_4$ | Tier 2 | D(2) | No |
| 1A1 Stationary Combustion, liquid fuels | $CH_4$ | Tier/Tier 2 | D / D(2) / CS | No |
| 1A1 Stationary Combustion, not engines, gaseous fuels | $CH_4$ | Tier 2 | CS / D(2) | No |
| 1A1 Stationary Combustion, waste | $CH_4$ | Tier 2 | CS | No |
| 1A1 Stationary Combustion, not engines, biomass | $CH_4$ | Tier 3/Tier 2/Tier 1 | CS / D(2) / D | No |
| 1A2 Stationary Combustion, solid fuels | $CH_4$ | Tier 1 | D | No |
| 1A2 Stationary Combustion, liquid fuels | $CH_4$ | Tier 1/Tier 2 | D / D(2) / CS | No |
| 1A2 Stationary Combustion, not engines, gaseous fuels | $CH_4$ | Tier 2 | CS / D(2) | No |
| 1A2 Stationary Combustion, waste | $CH_4$ | Tier 1 | D | No |
| 1A2 Stationary Combustion, not engines, biomass | $CH_4$ | Tier 2/Tier 1 | D(2) / D | No |
| 1A4 Stationary Combustion, solid fuels | $CH_4$ | Tier 1 | D | No |
| 1A4 Stationary Combustion, liquid fuels | $CH_4$ | Tier 1/Tier 2 | D / D(2) | No |
| 1A4 Stationary Combustion, not engines, gaseous fuels | $CH_4$ | Tier 2 | D(2) | No |
| 1A4 Stationary Combustion, waste | $CH_4$ | Tier 1 | D | No |
| 1A4 Stationary Combustion, not engines, not residential wood and not residential/agricultural straw, biomass | $CH_4$ | Tier 1/Tier 2 | D / D(2) / CS | No |
| 1A4b_i Stationary combustion, Residential wood combustion | $CH_4$ | Tier 2 | CS | Yes |
| 1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion | $CH_4$ | Tier 1 | D | Yes |
| 1A Stationary combustion, Natural gas fuelled engines, gaseous fuels | $CH_4$ | Tier 3 | CS | No |
| 1A Stationary combustion, Biogas fuelled engines, biomass | $CH_4$ | Tier 3 | CS | No |
| 1A1 Stationary Combustion, solid fuels | $N_2O$ | Tier 2 | CS / D(2) | Yes |
| 1A1 Stationary Combustion, liquid fuels | $N_2O$ | Tier 2/Tier 1 | D(2) / CS / D | No |
| 1A1 Stationary Combustion, gaseous fuels | $N_2O$ | Tier 3/Tier 2 | CS / D(2) | Yes |
| 1A1 Stationary Combustion, waste | $N_2O$ | Tier 2 | CS | Yes |
| 1A1 Stationary Combustion, biomass | $N_2O$ | Tier 2/Tier 1 | CS / D(2) / D | Yes |
| 1A2 Stationary Combustion, solid fuels | $N_2O$ | Tier 1/Tier 3 | D/PS | Yes |
| 1A2 Stationary Combustion, liquid fuels | $N_2O$ | Tier 2/Tier 1 | D(2) / CS / D | Yes |
| 1A2 Stationary Combustion, gaseous fuels | $N_2O$ | Tier 3/Tier 2 | CS / D(2) | Yes |
| 1A2 Stationary Combustion, waste | $N_2O$ | Tier 1 | D | No |
| 1A2 Stationary Combustion, biomass | $N_2O$ | Tier 1/Tier 2 | D / CS | No |
| 1A4 Stationary Combustion, solid fuels | $N_2O$ | Tier 1 | D | No |
| 1A4 Stationary Combustion, liquid fuels | $N_2O$ | Tier 2/Tier 1 | D(2) / CS / D | Yes |
| 1A4 Stationary Combustion, gaseous fuels | $N_2O$ | Tier 3/Tier 2 | CS / D(2) | Yes |
| 1A4 Stationary Combustion, waste | $N_2O$ | Tier 1 | D | No |
| 1A4 Stationary Combustion, not residential wood and not residential/agricultural straw, biomass | $N_2O$ | Tier 1/Tier 2 | D / CS | No |
| 1A4b_i Stationary Combustion, Residential wood combustion | $N_2O$ | Tier 1 | D | Yes |
| 1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion | $N_2O$ | Tier 1 | D | No |

1. D: IPCC (2006) default, tier 1. D(2): IPCC (2006) default, tier 2. CS: Country specific. PS: Plant specific.
2. KCA approach 1 or approach 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990 or level 2018 or trend 1990-2018.
3. Only 3.4 % of the total coal consumption is included in the non-ETS category in 2018.
4. Only 8 % of the total residual oil consumption is included in the non-ETS category in 2018.
5. Tier 3 for 0.8 % of the gas oil consumption in 2018.
6. Tier 3 for 0.1 % of the LPG consumption in 2018.

Table 3.2.9 Emission data for key sources for which the estimated emissions are based on the tier 1 approach.

| Source category | $CO_2$ emission 1990, kton $CO_2$ equivalent | $CO_2$ emission 2018, kton $CO_2$ equivalent | Key source (KCA approach) |
|---|---|---|---|
| 1A Stationary combustion, Kerosene, $CO_2$ | 368 | 13 | Level 1990 (KCA 1), Trend (KCA 1) |
| 1A Stationary combustion, LPG, $CO_2$ | 188 | 141 | Level 2018 (KCA 1) |
| 1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion, $CH_4$ | 64 | 37 | Level 1990 (KCA 2) |
| 1A4b_i Stationary Combustion, Residential wood combustion, $N_2O$ | 11 | 49 | Level 2018 (KCA 2), Trend (KCA 2) |
| Key sources for which the estimated emissions are based on the tier 1 approach, total | 630 | 240 | |

### Large point sources

Large emission sources such as power plants, industrial plants and refineries are included as large point sources in the Danish emission database. Each point source may consist of more than one part, e.g. a power plant with several units. By registering the plants as point sources in the database, it is possible to use plant-specific emission factors.

In the inventory for the year 2018, 74 stationary combustion plants are specified as large point sources. Plant specific emission data[7] are available from 62 of the plants. The point sources include:

- Power plants and decentralised CHP plants.
- Waste incineration plants.
- Large industrial combustion plants.
- Petroleum refining plants.

The criteria for selection of point sources are:

- All centralized power plants, including smaller units.
- All units with a capacity of above 25 $MW_e$.
- All district heating plants with an installed effect of 50 $MW_{th}$ or above and significant fuel consumption.
- All waste incineration plants obligated to report environmental data annually according to Danish law (DEPA, 2010b; DEPA, 2015).
- Industrial plants,
  - With an installed effect of 50 $MW_{th}$ or above and significant fuel consumption.
  - With a significant process related emission.

The fuel consumption of stationary combustion plants registered as large point sources in the 2018 inventory was 206 PJ. This corresponds to 51 % of the overall fuel consumption for stationary combustion.

A list of the large point sources for 2018 is provided in Annex 3A-5. The number of large point sources registered in the databases increased from 1990 to 2018. Aggregated fuel consumption rates for the large point sources are also shown in Annex 3A-5.

[7] For $CO_2$ or other pollutants.

The emissions from a point source are based either on plant specific emission data or, if plant specific data are not available, on fuel consumption data and the general Danish emission factors.

The plant-specific emission data from the EU ETS data represent 61 % of the total $CO_2$ emission from stationary combustion. $CO_2$ emission factors are plant specific for the major power plants, refineries, offshore gas turbines, large municipal waste incineration plants and for cement production. Plant-specific emission data are obtained from $CO_2$ data reported under the EU Emission Trading Scheme (ETS). The EU ETS data are discussed below.

Emission measurement data for $CH_4$ and $N_2O$ are applied for estimating emission factors but not implemented as plant specific data.

Annual environmental reports for the plants include a considerable number of emission data sets. In general, emission data from annual environmental reports are based on emission measurements, but some emissions have potentially been calculated from general emission factors.

If plant-specific emission factors are not available, emission factors for area sources are used.

#### Area sources

Fuels not combusted in large point sources are included as source category specific area sources in the emission database. Plants such as residential boilers, small district heating plants, small CHP plants and some industrial boilers are defined as area sources. Emissions from area sources are based on fuel consumption data and emission factors. Further information on emission factors is provided below in the chapter Emission factors.

#### Fuels used for non-energy purposes

The Danish national energy statistics includes three fuels used for non-energy purposes; bitumen, white spirit and lubricants. The total consumption for non-energy purposes is relatively low, e.g. 10.3 PJ in 2018. The use of fuels for non-energy purposes is included in the inventory in sector 2D Non-energy products from fuels and solvent use; see Chapter 4.5.3.

The non-energy use of fuels is included in the reference approach for Climate Convention reporting and appropriately corrected in line with the IPCC Guidelines (IPCC, 2006). The reference approach is included in Chapter 3.4.

#### Activity rates, fuel consumption

The fuel consumption rates are based on the official Danish energy statistics prepared by the Danish Energy Agency (DEA). DCE aggregates fuel consumption rates to SNAP categories. Some fuel types in the official Danish energy statistics are added to obtain a less detailed fuel aggregation level cf. Annex 3A-3. The calorific values on which the energy statistics are based are also enclosed in Annex 3A-3. The correspondence list between the energy statistics and SNAP categories is enclosed in Annex 4.

The fuel consumption of the CRF category Manufacturing industries and construction (corresponding to SNAP category 03) is disaggregated into industrial subsectors based on the DEA data set aggregated for the Eurostat reporting (DEA, 2019c). The fuel consumption data flow is shown in Figure 3.2.34.

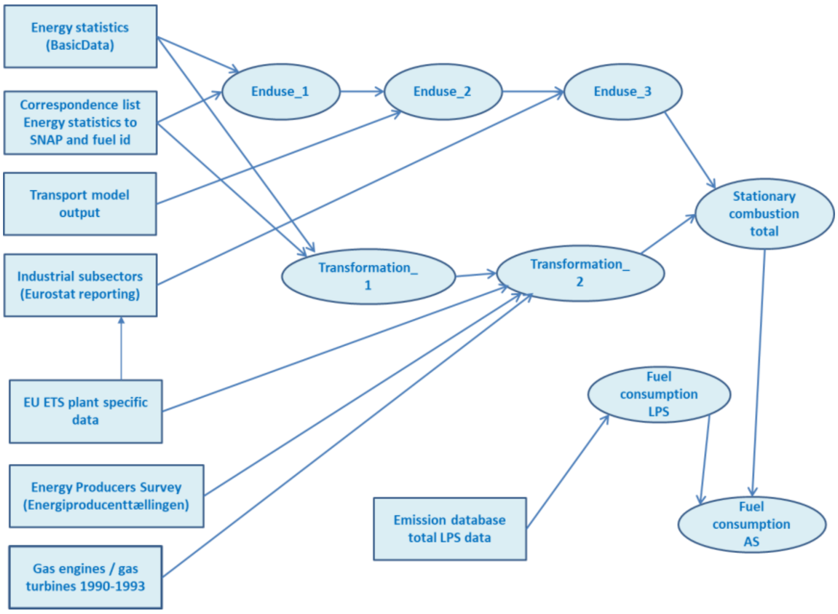



Figure 3.2.34   Fuel consumption data flow.

Both traded and non-traded fuels are included in the Danish energy statistics. Thus, for example, estimation of the annual consumption of non-traded wood is included.

Petroleum coke purchased abroad and combusted in Danish residential plants (border trade of 628 TJ in 2018) is not included in the Danish inventory. This is in agreement with the IPCC Guidelines (IPCC, 2006).

The fuel consumption data for large point sources refer to the EU Emission Trading Scheme (EU ETS) data for plants for which the $CO_2$ emission also refer to EU ETS, see page 126.

For all other large point sources, the fuel consumption refers to an annually updated DEA database; the Energy Producers Survey (DEA, 2019b). The Energy Producers Survey includes the fuel consumption of each district heating and power-producing plant, based on data reported by plant operators. The consistency between EU ETS reporting and the Energy Producers Survey database (DEA, 2019b) is checked by the DEA and discrepancies are corrected prior to the use in the emission inventory.

The fuel consumption of area sources is calculated as total fuel consumption in the energy statistics minus fuel consumption included in the emission inventory database in large point sources.

In Denmark, all waste incineration are utilised for heat and power production. Thus, incineration of waste is included as stationary combustion in the source category *Fuel combustion* (subcategories *1A1*, *1A2* and *1A4*).

Fuel consumption data are presented in Chapter 3.2.2.

#### Fuel consumption for 1A1c Oil and gas extraction

The consumption of natural gas reported in the EU ETS data are not in agreement with the energy statistics. This is because the energy statistics is based on the default net calorific value (NCV) for natural gas applied in Denmark whereas the EU ETS data are based on fuel analysis of the natural gas applied offshore at each individual platform. The total consumption of natural gas in

1A1c Oil and gas extraction applied in the emission inventories is based on the EU ETS data.

### Fuel consumption for 1A1b Petroleum refining

The EU ETS data for fuel consumption reported by the two Danish refineries are not always in agreement with the energy statistics due to the use of default values for net calorific value (NCV) in the energy statistics. The EU ETS data are based on fuel analysis. Refinery gas is only applied in the two refineries. The total consumption of refinery gas applied in the emission inventories is based on the EU ETS data.

### Upgraded biogas distributed in the natural gas grid

Biogas upgraded for distribution in the natural gas grid (bio natural gas) has been included as a separate fuel in the energy statistics and in the emission inventory

### Biogas distributed in the town gas grid

The energy statistics includes a consumption of biogas for town gas production. This biogas is distributed in the town gas grid (119 TJ in 2018). This fuel consumption has been included in the fuel category town gas in the fuel consumption data of the energy statistics. In the emission inventory biogas distributed in the town gas grid have been included in the fuel category biogas.

### Town gas

Town gas (the fossil part) has been included in the fuel category natural gas. The consumption of town gas in Denmark is very low, e.g. 0.6 PJ in 2018. In 1990, the town gas consumption was 1.6 PJ and the consumption has been steadily decreasing throughout the time series.

In Denmark, town gas is produced based on natural gas. The use of coal for town gas production ceased in the early 1980s.

An indicative composition of town gas in 2015 according to the largest supplier of town gas in Denmark is shown in Table 3.2.10 (KE, 2015).

Table 3.2.10 Composition of town gas currently used (KE, 2015).

| Component | Town gas, % (mol.) |
|---|---|
| Methane | 43.9 |
| Ethane | 2.9 |
| Propane | 1.1 |
| Butane | 0.5 |
| Carbon dioxide | 0.4 |
| Nitrogen | 40.5 |
| Oxygen | 10.7 |

The lower heating value of the town gas is 20.31 MJ per $Nm^3$ and the $CO_2$ emission factor 56.1 kg per GJ. This is very close to the emission factor used for natural gas in 2015 (57.06 kg per GJ). According to the supplier, both the composition and heating value will change during the year. It has not been possible to obtain a yearly average.

Biogas has been added to the town gas grid since 2014. This biogas distributed in the town gas grid is treated as a separate fuel in the emission inventories and thus not included in the data for town gas.

In earlier years, the composition of town gas was somewhat different. Table 3.2.11 shows data for town gas composition in 2000-2005. These data are constructed with the input from Københavns Energi (KE) (Copenhagen Energy) and Danish Gas Technology Centre (DGC), (Jeppesen, 2007; Kristensen, 2007). The data refer to three measurements performed several years apart, the first in 2000 and the latest in 2005.

Table 3.2.11 Composition of town gas, data from 2000-2005.

| Component | Town gas, % (mol.) |
|---|---|
| Methane | 22.3-27.8 |
| Ethane | 1.2-1.8 |
| Propane | 0.5-0.9 |
| Butane | 0.13-0.2 |
| Higher hydrocarbons | 0-0.6 |
| Carbon dioxide | 8-11.6 |
| Nitrogen | 15.6-20.9 |
| Oxygen | 2.3-3.2 |
| Hydrogen | 35.4-40.5 |
| Carbon monoxide | 2.6-2.8 |

The lower calorific value was been between 15.6 and 17.8 MJ per $Nm^3$. The $CO_2$ emission factors - derived from the few available measurements - are in the range of 52-57 kg per GJ.

The Danish sectoral approach includes town gas as part of the fuel category natural gas and thus indirectly assumes the same $CO_2$ emission factor. This is a conservative approach ensuring that the $CO_2$ emissions are not underestimated.

Due to the scarce data available and the very low consumption of town gas compared to consumption of natural gas (< 0.5 %), the methodology will be applied unchanged in future inventories.

### Waste

All waste incineration in Denmark is utilised for heat and/or power production and thus included in the energy sector. The waste incinerated in Denmark for energy production consists of the waste fractions shown in Figure 3.2.35. In 2017[8], 3 % of the incinerated waste was hazardous waste.

[8]Data for 2018 have not yet been published, January 2020.

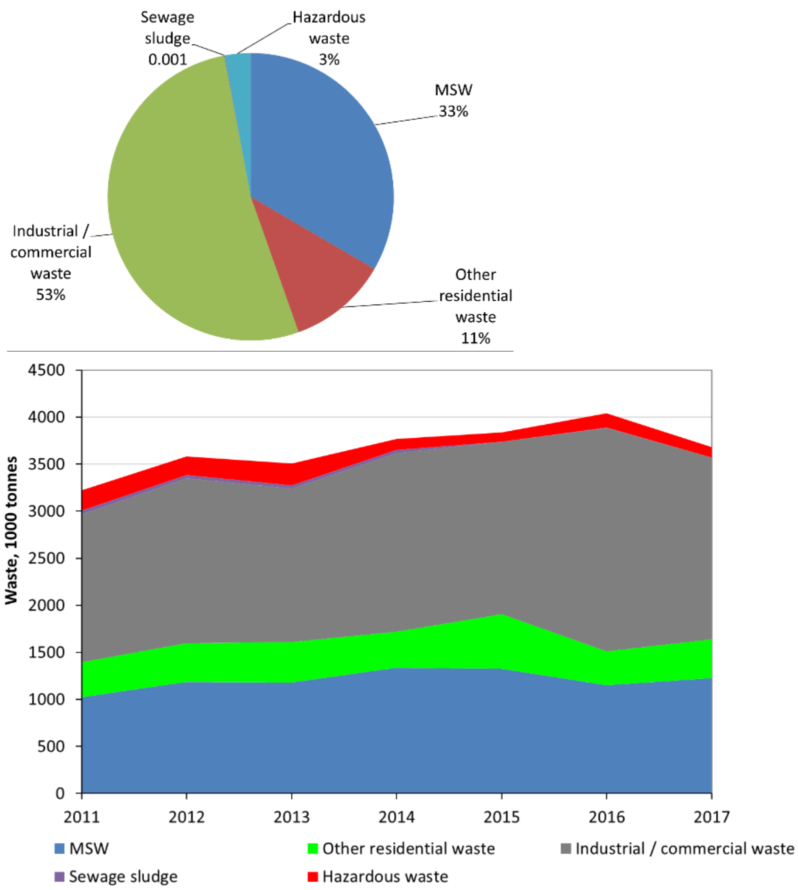



Figure 3.2.35 Waste fractions (weight) for incinerated waste in 2017 and the corresponding time series 2011-2017 (ADS, 2019)[9].

In connection to the project estimating an improved $CO_2$ emission factor for waste (Astrup et al., 2012), the fossil energy fraction was calculated. The fossil fraction was not measured or estimated as part of the project, but the flue gas measurements combined with data from Fellner & Rechberger (2010) indicated a fossil energy part of 45 %. The energy statistics also applies this fraction in the national statistics.

### Biogas

Biogas includes landfill gas, sludge gas and manure/organic waste gas[10]. The Danish energy statistics specifies production and consumption of each of the biogas types. In 2018, 91 % of the applied biogas was based on manure /organic waste. An increasing part of the biogas based on manure / organic waste is upgraded to bio natural gas.

Biogas upgraded for distribution in the natural gas grid reported as bio natural gas and is not included in the fuel category "biogas" in the rest of this report. This is also the case for bio gasification gas.

[9] Data for 2018 have not yet been published, January 2020.
[10] Based on manure with addition of other organic waste. In the Danish energy statistics this biogas is called *Biogas, other*.

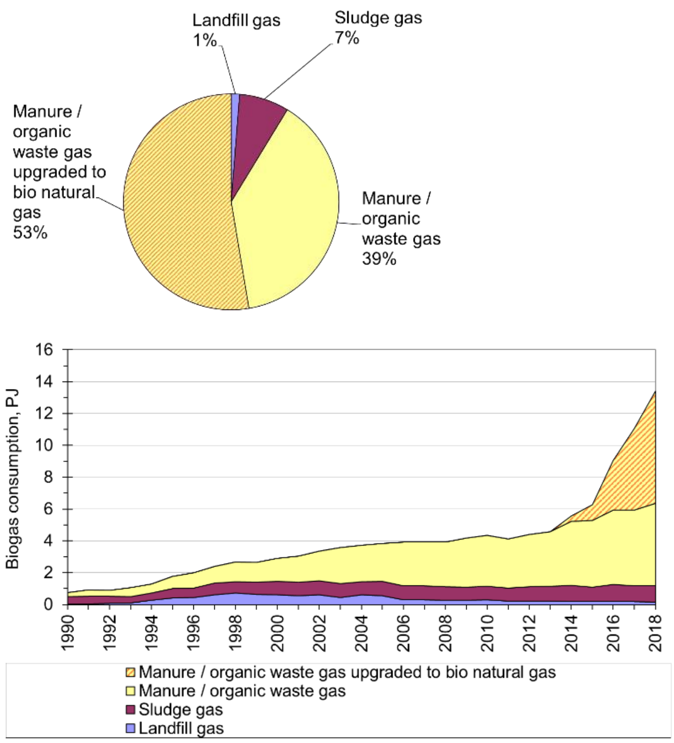



Figure 3.2.36 Biogas types (including bio natural gas) 2018 and the corresponding time series 1990-2018 (DEA, 2019a).

### Emission factors

For each fuel and SNAP category (sector and e.g. type of plant), a set of general area source emission factors has been determined. The GHG emission factors are either nationally referenced or based on the IPCC Guidelines (2006). The emission factors for other pollutants are either nationally referenced or based on the EMEP/EEA Guidebook (EEA, 2016).

An overview of the type of $CO_2$ emission factor is shown in Table 3.2.20. A complete list, of emission factors including time series and references, is provided in Annex 3A-4.

### EU ETS data for $CO_2$

The $CO_2$ emission factors for some large power plants and for combustion in the cement industry and refineries are plant specific and based on the reporting to the EU Emission Trading Scheme (EU ETS). In addition, emission factors for offshore gas turbines and refinery gas is based on EU ETS data. The EU ETS data have been applied for the years 2006 - 2018.

The EU ETS data are also applied for other source categories and are further discussed in Chapter 1.4.10.

The Danish emission inventory for stationary combustion only includes $CO_2$ emission data from plants using higher tier methods as defined in the EU decision (EU Commission, 2018), where the specific methods for determining carbon contents, oxidation factor and calorific value are specified. The EU decision includes rules for measuring, reporting and verification.

Fuel consumption data from EU ETS are included for some additional plants and fuels, e.g. biomass fuels.

For each of the plants included with plant and fuel specific $CO_2$ emission factors in the Danish inventory all applied methodologies are specified in individual monitoring plans that are approved by Danish authorities (DEA) prior to the reporting of the emissions. The plant and fuel specific $CO_2$ emission factors included in the Danish inventory are all based on fuel quality measurements[11], not default values from the Danish UNFCCC reporting. All fuel analyses are performed according to ISO 17025.

DCE performs QC checks on the reported emission data, see Chapter 1.4.10.

### EU ETS data presentation

The EU ETS data include plant specific emission factors for coal, residual oil, gas oil, natural gas, refinery gas, petroleum coke, coke oven coke and fossil waste. The EU ETS data accounted for 61 % of the $CO_2$ emission from stationary combustion in 2018.

### EU ETS data for coal

EU ETS data for 2018 were available from 18 coal fired plant (or units). The plant specific information accounts for 97 % of the Danish coal consumption and 36 % of the total fossil $CO_2$ emission from stationary combustion plants.

Data from 17 of the 18 plants have been applied for estimating an average $CO_2$ emission factor for coal[12]. The average $CO_2$ emission factor for coal for these 17 units was 94.04 kg per GJ (Table 3.2.12). The plants all apply bituminous coal.

Table 3.2.12 EU ETS data for 17 coal fired plants, 2018.

| | Average | Min | Max |
|---|---|---|---|
| Heating value, GJ per tonne | 24.3 | 23.0 | 31.3 |
| $CO_2$ implied emission factor, kg per GJ[1)] | 94.04 | 89.46 | 95.89 |
| Oxidation factor | 0.997 | 0.989 | 1.000 |

1) Including oxidation factor.

Table 3.2.13 $CO_2$ implied emission factor time series for coal fired plants based on EU ETS data.

| Year | $CO_2$ implied emission factor, kg per GJ[1)] |
|---|---|
| 2006 | 94.4 |
| 2007 | 94.3 |
| 2008 | 94.0 |
| 2009 | 93.6 |
| 2010 | 93.6 |
| 2011 | 94.7 |
| 2012 | 94.25 |
| 2013 | 93.95 |
| 2014 | 94.17 |
| 2015 | 94.46 |
| 2016 | 94.95 |
| 2017 | 94.37 |
| 2018 | 94.04 |

1) Including oxidation factor.

[11] Applying specific methods defined in the EU decision.
[12] Fuel consumption of the 17 plants adds up to more than 99.9% of the fuel consumption of the 18 plants. One plant is not considered representative for the coal consumption in Denmark.

### EU ETS data for residual oil

EU ETS data for 2018 based on higher tier methodologies were available from 10 plants (or units) combusting residual oil. The EU ETS data accounts for 92 % of the residual oil consumption in stationary combustion.

Data from 9 of the 10 plants have been applied for estimating an average $CO_2$ emission factor for residual oil[13]. Aggregated data and time series are shown in Table 3.2.14 and Table 3.2.15.

Table 3.2.14 EU ETS data for 10 plants combusting residual oil.

| | Average | Min | Max |
|---|---|---|---|
| Heating value, GJ per tonne | 40.7 | 40.5 | 40.9 |
| $CO_2$ implied emission factor, kg per GJ | 79.42 | 78.35 | 79.67 |
| Oxidation factor | 1.000 | 1.000 | 1.000 |

Table 3.2.15 $CO_2$ implied emission factor time series for residual oil fired power plant units based on EU ETS data.

| Year | $CO_2$ implied emission factor, kg per GJ[1)] |
|---|---|
| 2006 | 78.2 |
| 2007 | 78.1 |
| 2008 | 78.5 |
| 2009 | 78.9 |
| 2010 | 79.2 |
| 2011 | 79.25 |
| 2012 | 79.21 |
| 2013 | 79.28 |
| 2014 | 79.49 |
| 2015 | 79.17 |
| 2016 | 79.29 |
| 2017 | 79.19 |
| 2018 | 79.42 |

1) Including oxidation factor.

### EU ETS data for gas oil

EU ETS data for 2018 based on higher tier methodologies were included from 2 plants combusting gas oil. Aggregated data and time series are shown in Table 3.2.16 and Table 3.2.17. The EU ETS data accounts for 0.8 % of the gas oil consumption in stationary combustion.

Table 3.2.16 EU ETS data for gas oil.

| | Average | Min | Max |
|---|---|---|---|
| Heating value, GJ per tonne | 36.7 | 35.9 | 40.6 |
| $CO_2$ implied emission factor, kg per GJ | 74.25 | 73.99 | 74.31 |
| Oxidation factor | 1.000 | 1.000 | 1.000 |

[13] Fuel consumption of the 9 plants adds up to 74% of the fuel consumption of the 10 plants. The remaining plant is not considered representative for the residual oil consumption in Denmark.

Table 3.2.17 $CO_2$ implied emission factor time series for gas oil based on EU ETS data.

| Year | $CO_2$ implied emission factor, kg per GJ[1)] |
|---|---|
| 2006 | 75.1 |
| 2007 | 74.9 |
| 2008 | 73.7 |
| 2009 | 75.1 |
| 2010 | 74.8 |
| 2011 | 74.7 |
| 2012 | 73.9 |
| 2013 | 72.7 |
| 2014 | 74.2 |
| 2015 | 73.8 |
| 2016 | 74.4 |
| 2017 | 74.7 |
| 2018 | 74.2 |

1) Including oxidation factor.

### EU ETS data for waste

EU ETS data for 2018 based on higher tier methodologies were included from 18 waste incineration plants (or units). The EU ETS data for waste incineration are based on emission measurements. The average emission factor value for the plants is 43.5 kg per GJ. The emission factors are in the interval 34.9 kg per GJ to 61.2 kg per GJ. The EU ETS data accounts for 74 % of the incinerated waste.

Table 3.2.18 EU ETS data for waste incineration.

| | Average | Min | Max |
|---|---|---|---|
| Heating value, GJ per tonne | 10.7 | 10.6 | 13.7 |
| $CO_2$ implied emission factor, kg per GJ | 43.5 | 34.9 | 61.2 |
| Oxidation factor | 1.000 | 1.000 | 1.000 |

Table 3.2.19 $CO_2$ implied emission factor time series for waste incineration.

| Year | $CO_2$ implied emission factor, kg per GJ[1)] |
|---|---|
| 2013 | 43.0 |
| 2014 | 40.8 |
| 2015 | 43.3 |
| 2016 | 43.0 |
| 2017 | 41.4 |
| 2018 | 43.5 |

### EU ETS data for petroleum coke, coke oven coke, industrial waste and natural gas

The implemented EU ETS data set also includes $CO_2$ emission factors for industrial waste, petroleum coke and coke oven coke. The industrial plants with additional EU ETS data include cement industry, sugar production, glass wool production, lime production, and vegetable oil production.

### EU ETS data for natural gas applied in offshore gas turbines

EU ETS data have been applied to estimate an average $CO_2$ emission factor for natural gas combusted in offshore gas turbines, see page 134.

### EU ETS data for refinery gas

EU ETS data are also applied for the two refineries in Denmark. The emission factor for refinery gas is based on EU ETS data, see page 134.

#### $CO_2$ emission factors

The $CO_2$ emission factors that are not included in EU ETS data or that are included but based on lower tier methodologies are not plant specific in the Danish inventory. The emission factors that are not plant specific accounts for 39 % of the fossil $CO_2$ emission.

The $CO_2$ emission factors applied for 2018 are presented in Table 3.2.20. Time series have been estimated for:

- Coal
- Residual oil
- Refinery gas
- Natural gas applied in offshore gas turbines
- Natural gas, other
- Waste, fossil part
- Industrial waste, biomass part

For all other fuels, the same emission factor has been applied for 1990-2018.

In the reporting to the UNFCCC, the $CO_2$ emission is aggregated to six fuel types: solid fuels, liquid fuels, gaseous fuels, other fossil fuels, peat, and biomass. Peat is not combusted in Denmark. The correspondence list between the DCE fuel categories and the IPCC fuel categories is also provided in Table 3.2.20.

Only emissions from fossil fuels are included in the total national $CO_2$ emission. The biomass emission factors are also included in the table, because emissions from biomass are reported to the UNFCCC as a memo item.

The $CO_2$ emission from incineration of waste (42.5 + 63.3 kg per GJ) is divided into two parts: The emission from combustion of the fossil content of the waste, which is included in the national total, and the emission from combustion of the biomass part, which is reported as a memo item. In the CRF, the fuel consumption and emissions from the fossil content of the waste is reported in the fuel category Other fossil fuels.

Table 3.2.20 $CO_2$ emission factors, 2018.

| Fuel | Emission factor, kg per GJ Biomass | Fossil fuel | Reference type | IPCC fuel category |
|---|---|---|---|---|
| Coal | | 94.04 [1)] | Country specific | Solid |
| Brown coal briquettes | | 97.5 | IPCC (2006) | Solid |
| Coke oven coke | | 107 [3)] | IPCC (2006) | Solid |
| Other solid fossil fuels [6)] | | 118 [1)] | Country specific | Solid |
| Fly ash fossil (from coal) | | 94.04 | Country specific | Solid |
| Petroleum coke | | 93 [3)] | Country-specific | Liquid |
| Residual oil | | 79.42 [1)] | Country-specific | Liquid |
| Gas oil | | 74.1 [1)] | Country-specific | Liquid |
| Kerosene | | 71.9 | IPCC (2006) | Liquid |
| Orimulsion | | 80 [2)] | Country-specific | Liquid |
| LPG | | 63.1 | IPCC (2006) | Liquid |
| Refinery gas | | 56.144 | Country-specific | Liquid |
| Natural gas, offshore gas turbines | | 57.639 | Country-specific | Gas |
| Natural gas, other | | 56.89 | Country-specific | Gas |
| Waste | 63.3 [3)4)] | + 42.5[1)3)4)] | Country-specific | Biomass and Other fuels |
| Straw | 100 | | IPCC (2006) | Biomass |
| Wood | 112 | | IPCC (2006) | Biomass |
| Wood pellets | 112 | | IPCC (2006) | Biomass |
| Bio oil | 70.8 | | IPCC (2006) | Biomass |
| Biogas | 84.1 | | Country-specific | Biomass |
| Biomass gasification gas | 142.9[5)] | | Country-specific | Biomass |
| Bio natural gas | 55.55 | | Country-specific | Biomass |

1) Plant specific data from EU ETS incorporated for individual plants.
2) Not applied in 2018. Orimulsion was applied in Denmark in 1995 – 2004.
3) Plant specific data from EU ETS incorporated for cement industry and sugar, lime and mineral wool production.
4) The emission factor for waste is (42.5+63.3) kg $CO_2$ per GJ waste. The fuel consumption and the $CO_2$ emission have been disaggregated to the two IPCC fuel categories Biomass and Other fossil fuels in CRF. The corresponding IEF for $CO_2$, Other fuels is 94.44 kg $CO_2$ per GJ fossil waste (not including plant specific data).
5) Includes a high content of $CO_2$ in the gas.
6) Anodic carbon. Not applied in Denmark in 2018.

### Coal

As mentioned above, EU ETS data have been utilised for the years 2006 - 2018 in the emission inventory. The emission factor for coal is the implied emission factor for plants that report EU ETS data that are based on fuel analysis. Data for industrial plants have been included. In 2018, the implied emission factor (including oxidation factor) was 94.04 kg per GJ. The implied emission factor values were between 89.46 and 95.89 kg per GJ.

The emission factors for coal in the years 2006-2018 refer to the implied emission factors of the EU ETS data estimated for each year. For the years 1990-2005, the emission factor for coal (94 kg/GJ) refers to the average IEF for 2006-2010.

Time series for net calorific value (NCV) of coal are available in the Danish energy statistics. NCV for Electricity plant coal fluctuates in the interval 24.1-25.8 GJ per tonne.

The correlation between NCV and $CO_2$ IEF (including the oxidation factor) in the EU ETS data (2006-2009) have been analysed and the results are shown in Annex 3A-9. However, a significant correlation between NCV and IEF have not been found in the dataset and thus an emission factor time series based on the NCV time series was not relevant. In addition, the correlation of NCV and $CO_2$ emission factors has been analysed. This analysis is also shown in Annex 3A-9. As expected, the correlation was better in this dataset, but still insufficient for estimating a time series for the $CO_2$ emission factor based on the NCV time series. All coal applied in Denmark is bituminous coal (DEA, 2019c) and within the range of coal qualities applied in the plants reporting data to EU ETS a correlation could not be documented.

In 2018, the $CO_2$ emission from coal consumption was based on the emission factor (94.04 kg per GJ) for 3.4% of the coal consumption. The remaining 96.6 % was covered by EU ETS data.

Time series for the $CO_2$ emission factor are shown in Table 3.2.21.

Table 3.2.21 $CO_2$ emission factor time series for coal.

| Year | $CO_2$ emission factor kg per GJ |
|---|---|
| 1990-2005 | 94.0 |
| 2006 | 94.4 |
| 2007 | 94.3 |
| 2008 | 94.0 |
| 2009 | 93.6 |
| 2010 | 93.6 |
| 2011 | 93.73 |
| 2012 | 94.25 |
| 2013 | 93.95 |
| 2014 | 94.17 |
| 2015 | 94.46 |
| 2016 | 94.95 |
| 2017 | 94.37 |
| 2018 | 94.04 |

**Brown coal briquettes**

The emission factor for brown coal briquettes, 97.5 kg per GJ refers to the IPCC Guidelines, 2006 (IPCC, 2006). The oxidation factor has been assumed equal to 1. The same emission factor has been applied for 1990-2018.

**Coke oven coke**

The emission factor for coke oven coke, 107 kg per GJ, refers to the IPCC Guidelines 2006 (IPCC, 2006). The oxidation factor has been assumed equal to 1. The same emission factor has been applied for 1990-2018.

**Other solid fossil fuels (Anodic carbon)**

Anodic carbon was not applied in 2018. Anodic carbon has been applied in Denmark in 2009-2013 in two mineral wool production units. The emission factor 118 kg per GJ refer to EU ETS data from one of the plants in 2012.

The emission factor is not applied because plant specific data are available from the EU ETS dataset.

**Fly ash fossil (from coal)**

Fly ash from coal combustion is applied in some power plants. The emission factor have been assumed equal to the emission factor for coal.

**Petroleum coke**

The emission factor 93 kg per GJ is based on EU ETS data for 2006-2010. The data includes one power plant and the cement production plant.

Plant specific EU ETS data have been utilised for the cement production for the years 2006 - 2018.

#### Residual oil
The emission factor for residual oil is based on EU ETS data.

EU ETS data have been utilised for the 2006 - 2018 emission inventories. In 2018, the implied emission factor (including oxidation factor) for the plants combusting residual oil was 79.42 kg per GJ. The implied emission factor values were between 78.35 and 79.67 kg per GJ.

The emission factors for residual oil in the years 2006-2018 refer to the implied emission factors of the EU ETS data estimated for each year. For the years 1990-2005, the emission factor for residual oil refers to the average IEF for 2006-2010.

In 2018, 8 % of the $CO_2$ emission from residual oil consumption was based on the emission factor, whereas 92 % of the residual oil consumption was covered by EU ETS data.

Time series for the $CO_2$ emission factor are shown in Table 3.2.22.

Table 3.2.22 $CO_2$ emission factor time series for residual oil.

| Year | $CO_2$ emission factor kg per GJ |
|---|---|
| 1990-2005 | 78.7 |
| 2006 | 78.6 |
| 2007 | 78.5 |
| 2008 | 78.5 |
| 2009 | 78.9 |
| 2010 | 79.2 |
| 2011 | 79.25 |
| 2012 | 79.21 |
| 2013 | 79.28 |
| 2014 | 79.49 |
| 2015 | 79.17 |
| 2016 | 79.29 |
| 2017 | 79.19 |
| 2018 | 79.42 |

#### Gas oil
The emission factor for gas oil, 74.1 kg per GJ, is based on EU ETS data for the years 2008-2016. The emission factor is consistent with the IPCC default emission factor for gas oil (74.1 kg per GJ). The same emission factor has been applied for 1990-2018.

Plant specific EU ETS data have been utilised for a few plants each year in the 2006 - 2018 emission inventories. In 2018, the implied emission factor for the power plants using gas oil was 74.25 kg per GJ. The EU ETS $CO_2$ emission factors were in the interval 73.99 – 74.31 kg per GJ. In 2018, only 0.8 % of the $CO_2$ emission from gas oil consumption was based on EU ETS data.

#### Kerosene
The emission factor for kerosene, 71.9 kg per GJ, refers to IPCC Guidelines (IPCC, 2006). The same emission factor has been applied for 1990-2018.

#### Orimulsion
The emission factor for orimulsion, 80 kg per GJ, refers to the Danish Energy Agency (DEA, 2019a). The IPCC default emission factor is almost the same:

80.7 kg per GJ assuming full oxidation. The $CO_2$ emission factor has been confirmed by the only major power plant operator using orimulsion (Andersen, 1996). The same emission factor has been applied for all years. Orimulsion was used in Denmark in 1995-2004.

### LPG

The emission factor for LPG, 63.1 kg per GJ, refers to IPCC Guidelines (IPCC, 2006). The same emission factor has been applied for 1990-2018.

### Refinery gas

The emission factor applied for refinery gas refers to EU ETS data for the two refineries in operation in Denmark. Since 2006, implied emission factors for Denmark have been estimated annually based on the EU ETS data. The average implied emission factor for 2006-2009 (57.6 kg per GJ) have been applied for the years 1990-2005. This emission factor is consistent with the emission factor stated in the IPCC Guidelines (IPCC, 2006). The time series is shown in Table 3.2.23.

Table 3.2.23 $CO_2$ emission factors for refinery gas, time series.

| Year | $CO_2$ emission factor, kg per GJ |
|---|---|
| 1990-2005 | 57.6 |
| 2006 | 57.812 |
| 2007 | 57.848 |
| 2008 | 57.948 |
| 2009 | 56.817 |
| 2010 | 57.134 |
| 2011 | 57.861 |
| 2012 | 58.108 |
| 2013 | 58.274 |
| 2014 | 57.620 |
| 2015 | 57.508 |
| 2016 | 57.335 |
| 2017 | 57.109 |
| 2018 | 56.144 |

### Natural gas, offshore gas turbines

EU ETS data for the fuel consumption and $CO_2$ emission for offshore gas turbines are available for the years 2006-2018. Based on data for each oilfield, implied emission factors have been estimated for 2006-2018. The average value for 2006-2009 has been applied for the years 1990-2005. The time series is shown in Table 3.2.24.

Table 3.2.24 $CO_2$ emission factors for offshore gas turbines, time series.

| Year | $CO_2$ emission factor, kg per GJ |
|---|---|
| 1990-2005 | 57.469 |
| 2006 | 57.879 |
| 2007 | 57.784 |
| 2008 | 56.959 |
| 2009 | 57.254 |
| 2010 | 57.314 |
| 2011 | 57.379 |
| 2012 | 57.423 |
| 2013 | 57.295 |
| 2014 | 57.381 |
| 2015 | 57.615 |
| 2016 | 57.704 |
| 2017 | 57.628 |
| 2018 | 57.639 |

### Natural gas, other source categories

The emission factor for natural gas is estimated by the Danish gas transmission company, Energinet.dk[14]. The calculation is based on gas analysis carried out daily by Energinet.dk at Egtved.

In 2018, the natural gas import was 15 PJ, the natural gas export 58 PJ and the consumption added up to 113 PJ. Before 2010, only natural gas from the Danish gas fields was utilised in Denmark. If the import of natural gas increases further, the methodology for estimating the $CO_2$ emission factor might have to be revised in future inventories. However, Energinet.dk have stated that the difference between the emission factor for 2011 based on measurements at Egtved and the average value at Froeslev very close to the border differed less than 0.3 % for 2011 (Bruun, 2012).

Energinet.dk and the Danish Gas Technology Centre have calculated emission factors for 2000-2018. The emission factor applied for 1990-1999 refers to Fenhann & Kilde (1994). This emission factor was confirmed by the two major power plant operators in 1996 (Christiansen, 1996 and Andersen, 1996). The time series for the $CO_2$ emission factor is provided in Table 3.2.25.

Table 3.2.25 $CO_2$ emission factor time series for natural gas.

| Year | $CO_2$ emission factor, kg per GJ |
|---|---|
| 1990-1999 | 56.9 |
| 2000 | 57.1 |
| 2001 | 57.25 |
| 2002 | 57.28 |
| 2003 | 57.19 |
| 2004 | 57.12 |
| 2005 | 56.96 |
| 2006 | 56.78 |
| 2007 | 56.78 |
| 2008 | 56.77 |
| 2009 | 56.69 |
| 2010 | 56.74 |
| 2011 | 56.97 |
| 2012 | 57.03 |
| 2013 | 56.79 |
| 2014 | 56.95 |
| 2015 | 57.06 |
| 2016 | 57.01 |
| 2017 | 57.00 |
| 2018 | 56.89 |

### Waste

The $CO_2$ emission from incineration of waste is divided into two parts: The emission from combustion of the fossil content of the waste, which is included in the national total, and the emission from combustion of the rest of the waste – the biomass part, which is reported as a memo item.

The fossil $CO_2$ emission factor is based on EU ETS data for 2013-2016. The annual average emission factors for the plants that applied plant specific data are shown in Table 3.2.26 below. The emission factor applied for 2013-2018 is the average value for 2013-2016 (42.5 kg per GJ). The emission factor corresponds to 94.44 kg per GJ fossil waste.

[14] Former Gastra and before that part of DONG. Historical data refer to these companies.

As mentioned, plant specific EU ETS data have been reported by CHP plants incinerating waste for 2013-2018. In the inventory for 2018, plant specific emission factors have been implemented for 18 plants or units. In 2018, the average emission factor for 17 plants (the cement production plant not included) was 43.48 kg fossil $CO_2$ per GJ total waste. The emission factors vary between plants – 34.9 kg per GJ to 61.2 kg per GJ. The 18 plants reporting data to EU ETS represent 74 % of the incinerated waste.

The emission factor for 1990-2010 is based on the project, *Biogenic carbon in Danish combustible waste* that included emission measurements from five Danish waste incineration plants (Astrup et al., 2012). The average of the fossil emission factors for waste was estimated to be 37 kg per GJ waste and the interval for the five plants was 25 – 51 kg per GJ. The five plants represented 44 % of the incinerated waste in 2010. The emission factor 37 kg per GJ waste corresponds to 82.22 kg per GJ fossil waste.

The emission factor for biogenic $CO_2$ from waste refers to Astrup et al. (2012). The average value for five plants is 63.3 kg biogenic $CO_2$ per GJ total waste. This emission factor has been applied all years. The emission factor corresponds to 115 kg biogenic $CO_2$ per GJ biogenic waste.

The time series for the fossil $CO_2$ emission factor is shown in Table 3.2.27.

Table 3.2.26 Average fossil $CO_2$ emission factors based on EU ETS data for waste.

| Year | Fossil $CO_2$ emission factor, kg fossil $CO_2$ per GJ waste (total) |
|---|---|
| 2013 | 43.0 |
| 2014 | 40.8 |
| 2015 | 43.3 |
| 2016 | 43.0 |
| 2017 | 41.4 |
| 2018 | 43.5 |
| Average 2013-2016 | 42.5 |

Table 3.2.27 Time series for the fossil $CO_2$ emission factor for waste.

| Year | $CO_2$ emission factor, kg per GJ |
|---|---|
| 1990-2010 | 37.0 |
| 2011 | 37.5 |
| 2012 | 40.0 |
| 2013-2018 | 42.5 |

Data from the waste statistics have been analysed with the purpose to improve the time series of the fossil waste emission factor. However, the data analysis has shown that is difficult to relate the available waste fraction data and the measured fossil $CO_2$ emission. Thus, currently it is not possible to estimate an improved time series for the emission factor for the years 1990-2012.

### Wood

The emission factor for wood, 112 kg per GJ refers IPCC (2006). The same emission factor has been applied for 1990-2018.

### Straw

The emission factor for wood, 100 kg per GJ refers IPCC (2006) for other primary solid biomass. The same emission factor has been applied for 1990-2018.

#### Bio oil

The emission factor, 70.8 kg per GJ refers to the IPCC (2006). The consumption of bio oil is below 1 PJ.

#### Biogas

In Denmark, three different types of biogas are applied: Manure/organic waste based biogas, landfill based biogas and wastewater treatment biogas (sludge gas). Manure / organic waste based biogas represent 91 % of the biogas production, see page 125. Most of the biogas based on manure / organic waste is however upgraded to bio natural gas. The $CO_2$ emission factor for bio natural gas differs from the emission factor for biogas.

The emission factor for biogas, 84.1 kg per GJ refer to Kristensen (2015a) and the emission factor is based on a biogas with 65 % (vol.) $CH_4$ and 35 % (vol.) $CO_2$. Danish Gas Technology Centre has stated that this is a typical manure-based biogas as utilised in stationary combustion plants (Kristensen, 2015a). The same emission factor has been applied for 1990-2018.

#### Biomass gasification gas

Biomass gasification gas applied in Denmark is based on wood. The gas composition is known for three different plants and the applied emission factor have been estimated by Danish Gas Technology Centre (Kristensen, 2010) based on the gas composition measured on the plant with the highest consumption.

The consumption of biomass gasification gas is below 2 PJ for all years.

#### Bio natural gas

Biogas upgraded for distribution in the natural gas grid is referred to as bio natural gas in this report. Other references might refer to this fuel as bio-methane or upgraded biogas. Bio natural gas has been applied in Denmark since 2014. The emission factor is based on the gas composition of bio natural gas: 98.5 % $CH_4$ and 1.5 % $CO_2$. These data refer to Danish Gas Technology Centre (Kristensen, 2015b).

#### $CH_4$ emission factors

The $CH_4$ emission factors applied for 2018 are presented in Table 3.2.28. In general, the same emission factors have been applied for 1990-2018. However, time series have been estimated for both natural gas fuelled engines and biogas fuelled engines, residential wood combustion, natural gas fuelled gas turbines[15] and waste incineration plants.

Emission factors for CHP plants < 25 $MW_e$ refer to emission measurements carried out on Danish plants (Nielsen et al., 2010a; Nielsen & Illerup, 2003; Nielsen et al., 2008). The emission factors for residential wood combustion are based on technology dependent data.

Emission factors that are not nationally referenced all refer to the IPCC Guidelines (IPCC, 2006).

[15] A minor emission source.

Gas engines combusting natural gas or biogas accounted for 49% of the $CH_4$ emission from stationary combustion plants in 2018. The relatively high emission factor for gas engines is well documented and further discussed below.

Table 3.2.28 $CH_4$ emission factors, 2018.

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| SOLID | Coal | 1A1a | Public electricity and heat production | 0101<br>0102 | 0.9 | IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Pulverised bituminous coal combustion, Wet bottom. |
| | | 1A2 a-g | Industry | 03 | 10 | IPCC (2006), Tier 1, Table 2-3, Manufacturing industries. |
| | | 1A4b i | Residential | 0202 | 300 | IPCC (2006), Tier 1, Table 2.5, Residential, Bituminous coal. |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 10 | IPCC (2006), Tier 1, Table 2-4, Commercial, coal.[1)] |
| | BKB | 1A4b i | Residential | 0202 | 300 | IPCC (2006), Tier 1, Table 2-5, Residential, brown coal briquettes |
| | Coke oven coke | 1A2 a-g | Industry | 03 | 10 | IPCC (2006), Tier 1, Table 2-4, Commercial, coke oven coke. |
| | | 1A4b i | Residential | 0202 | 300 | IPCC (2006), Tier 1, Table 2-5, Residential, coke oven coke. |
| | Anodic carbon | 1A2 a-g | Industry | 03 | 10 | IPCC (2006), Tier 1, Table 2-3, Manufacturing industries. |
| | Fossil fly ash | 1A1a | Public electricity and heat production | 0101 | 0.9 | IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Pulverised bituminous coal combustion, Wet bottom. |
| LIQUID | Petroleum coke | 1A2 a-g | Industry | 03 | 3 | IPCC (2006), Tier 1, Table 2-3, Industry, petroleum coke. |
| | | 1A4a | Commercial/ Institutional | 0201 | 10 | IPCC (2006), Tier 1, Table 2-4, Commercial, Petroleum coke. |
| | | 1A4b | Residential | 0202 | 10 | IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, Petroleum coke. |
| | | 1A4c | Agriculture/ Forestry | 0203 | 10 | IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, Petroleum coke. |
| | Residual oil | 1A1a | Public electricity and heat production | 010101 | 0.8 | IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Residual fuel oil. |
| | | | | 010102<br>010103 | 1.3 | Nielsen et al. (2010a) |
| | | | | 010104 | 3 | IPCC (2006), Tier 1, Table 2-2, Energy industries, residual oil. |
| | | | | 010105 | 4 | IPCC (2006), Tier 3, Table 2-6, Utility, Large diesel engines |
| | | | | 010203 | 0.8 | IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Residual fuel oil. |
| | | 1A1b | Petroleum refining | 010306 | 3 | IPCC (2006), Tier 1, Table 2-2, Energy industries, residual fuel oil. |
| | | 1A2 a-g | Industry | 03 | 1.3 | Nielsen et al. (2010a) |
| | | | | Engines | 4 | IPCC (2006), Tier 3, Table 2-6, Utility, Large diesel engines |
| | | 1A4a | Commercial/ Institutional | 0201 | 1.4 | IPCC (2006), Tier 3, Table 2-10, Commercial, residual fuel oil boilers. |
| | | 1A4b | Residential | 0202 | 1.4 | IPCC (2006), Tier 3, Table 2-9, Residential, residual fuel oil. |
| | | 1A4c | Agriculture/ Forestry | 0203 | 1.4 | IPCC (2006), Tier 3, Table 2-10, Commercial, residual fuel oil boilers.[1)]. |
| | Gas oil | 1A1a | Public electricity and heat production | 010101<br>010102<br>010103 | 0.9 | IPCC (2006), Tier 3, Table 2-6, Utility, gas oil, boilers. |
| | | | | 010104 | 3 | IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil. |
| | | | | 010105 | 24 | Nielsen et al. (2010a) |
| | | | | 010202<br>010203 | 0.9 | IPCC (2006), Tier 3, Table 2-6, Utility, gas oil, boilers. |
| | | 1A1b | Petroleum refining | 010306 | 3 | IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil. |
| | | 1A1c | Oil and gas extraction | 010504 | 3 | IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil. |

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| | | 1A2 a-g | Industry | 03 | 0.2 | IPCC (2006), Tier 3, Table 2-7, Industry, gas oil, boilers. |
| | | | | Tur-bines | 3 | IPCC (2006), Tier 1, Table 2-3, Industry, gas oil. |
| | | | | Engines | 24 | Nielsen et al. (2010a) |
| | | 1A4a | Commercial/ Institu-tional | 0201 | 0.7 | IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil. |
| | | | | 020105 | 24 | Nielsen et al. (2010a) |
| | | 1A4b i | Residential | 0202 | 0.7 | IPCC (2006), Tier 3, Table 2.9, Residential, gas oil. |
| | | | | 020204 | 24 | Nielsen et al. (2010a) |
| | | 1A4c | Agriculture/ Forestry | 0203 | 0.7 | IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil[1)]. |
| | | | | 020304 | 24 | Nielsen et al. (2010a) |
| | Kerosene | 1A2 a-g | Industry | 03 | 3 | IPCC (2006), Tier 1, Table 2-3, Industry, other kerosene. |
| | | 1A4a | Commercial/ Institu-tional | 0201 | 10 | IPCC (2006), Tier 1, Table 2-4, Commercial, other kerosene. |
| | | 1A4b i | Residential | 0202 | 10 | IPCC (2006), Tier 1, Table 2-5, Residential/agricultural, other kerosene. |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 10 | IPCC (2006), Tier 1, Table 2-5, Residential/agricultural, other kerosene. |
| | LPG | 1A1a | Public electricity and heat production | 0101<br>0102 | 1 | IPCC (2006), Tier 1, Table 2-2, Energy Industries, LPG. |
| | | 1A1b | Petroleum refining | 0103 | 1 | IPCC (2006), Tier 1, Table 2-2, Energy Industries, LPG. |
| | | 1A2 a-g | Industry | 03 | 1 | IPCC (2006), Tier 1, Table 2-3, Industry, LPG |
| | | 1A4a | Commercial/ Institu-tional | 0201 | 5 | IPCC (2006), Tier 1, Table 2-4, Commercial, LPG. |
| | | 1A4b i | Residential | 0202 | 5 | IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, LPG. |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 5 | IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, LPG. |
| | Refinery gas | 1A1b | Petroleum refining | 010304 | 1.7 | Assumed equal to natural gas fuelled gas turbines. Nielsen et al. (2010a) |
| | | | | 010306 | 1 | IPCC (2006), Tier 1, Table 2-2, refinery gas. |
| GAS | Natural gas | 1A1a | Public electricity and heat production | 010101<br>010102<br>010103 | 1 | IPCC (2006), Tier 3, Table 2-6, Utility, natural gas, boilers. |
| | | | | 010104 | 1.7 | Nielsen et al. (2010a) |
| | | | | 010105 | 481 | Nielsen et al. (2010a) |
| | | | | 010202<br>010203 | 1 | IPCC (2006), Tier 3, Table 2-6, Utility, natural gas, boilers. |
| | | 1A1b | Petroleum refining | 010306 | 1 | Assumed equal to industrial boilers. |
| | | 1A1c | Oil and gas extraction | 010503 | 1 | Assumed equal to industrial boilers. |
| | | | | 010504 | 1.7 | Nielsen et al. (2010a) |
| | | 1A2 a-g | Industry | Other | 1 | IPCC (2006), Tier 3, Table 2-7, Industry, natural gas boilers. |
| | | | | Gas tur-bines | 1.7 | Nielsen et al. (2010a) |
| | | | | Engines | 481 | Nielsen et al. (2010a) |
| | | 1A4a | Commercial/ Institu-tional | 0201 | 1 | IPCC (2006), Tier 3, Table 2-10, Commer-cial, natural gas boilers. |
| | | | | 020105 | 481 | Nielsen et al. (2010a) |
| | | 1A4b i | Residential | 0202 | 1 | IPCC (2006), Tier 3, Table 2-9. Residen-tial, natural gas boilers. |
| | | | | 020204 | 481 | Nielsen et al. (2010a) |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 1 | IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers[1)]. |
| | | | | 020304 | 481 | Nielsen et al. (2010a) |
| WAST E | Waste | 1A1a | Public electricity and heat production | 0101<br>0102 | 0.34 | Nielsen et al. (2010a) |
| | | 1A2 a-g | Industry | 03 | 30 | IPCC (2006), Tier 1, Table 2-3, Industry, municipal wastes. |

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| | | 1A4a | Commercial/ Institutional | 0201 | 30 | IPCC (2006), Tier 1, Table 2-3, Industry, municipal wastes [2]. |
| | Industrial waste | 1A2f | Industry | 0316 | 30 | IPCC (2006), Tier 1, Table 2-3, Industry, industrial wastes. |
| BIO-MASS | Wood | 1A1a | Public electricity and heat production | 0101 | 3.1 | Nielsen et al. (2010a) |
| | | | | 0102 | 11 | IPCC (2006), Tier 3, Table 2-6, Utility boilers, wood |
| | | 1A2 a-g | Industry | 03 | 11 | IPCC (2006), Tier 3, Table 2-7, Industry, wood, boilers. |
| | | 1A4a | Commercial/ Institutional | 0201 | 11 | IPCC (2006), Tier 3, Table 2-10, Commercial, wood. |
| | | 1A4b i | Residential | 0202 | 110.77 | DCE estimate based on technology distribution, Nielsen et al. (2020) [3] |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 11 | IPCC (2006), Tier 3, Table 2-10, Commercial, wood.[1]. |
| | Straw | 1A1a | Public electricity and heat production | 0101 | 0.47 | Nielsen et al. (2010a) |
| | | | | 0102 | 30 | IPCC (2006), Tier 1, Table 2-2, Energy industries, other primary solid biomass |
| | | 1A4b i | Residential | 0202 | 300 | IPCC (2006), Tier 1, Table 2-5, Residential, other primary solid biomass. |
| | | 1A4c i | Agriculture/ Forestry | 020300 | 300 | IPCC (2006), Tier 1, Table 2-5, Agriculture, other primary solid biomass. |
| | | | | 020302 | 30 | IPCC (2006), Tier 1, Table 2-2, Energy industries, other primary solid biomass (large agricultural plants considered equal to this plant category) |
| | Wood pellets | 1A1a | Public electricity and heat production | 0101 | 3.1 | Nielsen et al. (2010a) |
| | | | | 0102 | 11 | IPCC (2006), Tier 3, Table 2-6, Utility boilers, wood |
| | | 1A2 a-g | Industry | 03 | 11 | IPCC (2006), Tier 3, Table 2-7, Industry, wood, boilers. |
| | | 1A4a | Commercial/ Institutional | 0201 | 11 | IPCC (2006), Tier 3, Table 2-10, Commercial, wood. |
| | | 1A4b i | Residential | 0202 | 3 | Paulrud et al. (2005) |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 11 | IPCC (2006), Tier 3, Table 2-10, Commercial, wood.[1]. |
| | Bio oil | 1A1a | Public electricity and heat production | 010102 | 3 | IPCC (2006), Tier 1, Table 2-2, Energy industries, biodiesels. |
| | | | | 010105 | 24 | Nielsen et al. (2010a) assumed same emission factor as for gas oil fuelled engines. |
| | | | | 0102 | 3 | IPCC (2006), Tier 1, Table 2-2, Energy industries, biodiesels. |
| | | 1A2 a-g | Industry | 03 | 3 | IPCC (2006), Tier 1, Table 2-3, Industry, biodiesels. |
| | | | | 030902 | 0.2 | - |
| | | 1A4b i | Residential | 0202 | 10 | IPCC (2006), Tier 1, Table 2-5, Residential, biodiesels. |
| | Biogas | 1A1a | Public electricity and heat production | 0101 | 1 | IPCC (2006), Tier 1, Table 2-2, Energy industries, other biogas. |
| | | | | 010105 | 434 | Nielsen et al. (2010a) |
| | | | | 0102 | 1 | IPCC (2006), Tier 1, Table 2-2, Energy industries, other biogas. |
| | | 1A2 a-g | Industry | 03 | 1 | IPCC (2006), Tier 1, Table 2-3, Industry, other biogas. |
| | | | | Engines | 434 | Nielsen et al. (2010a) |
| | | 1A4a | Commercial/ Institutional | 0201 | 5 | IPCC (2006), Tier 1, Table 2-4, Commercial, other biogas. |
| | | | | 020105 | 434 | Nielsen et al. (2010a) |
| | | 1A4b | Residential | 0202 | 1 | Assumed equal to natural gas. |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 5 | IPCC (2006), Tier 1, Table 2-5, Agriculture, other biogas. |
| | | | | 020304 | 434 | Nielsen et al. (2010a) |

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| | Bio gasification gas | 1A1a | Public electricity and heat production | 010101 | 1 | Assumed equal to biogas. |
| | | | | 010105 | 13 | Nielsen et al. (2010a) |
| | | 1A4a | Commercial/Institutional | 020105 | 13 | Nielsen et al. (2010a) |
| | Bio natural gas | 1A1a | Public electricity and heat production | 0101<br>0102 | 1 | Assumed equal to natural gas. |
| | | 1A2 a-g | Industry | 03 | 1 | Assumed equal to natural gas. |
| | | 1A4a | Commercial/ Institu-tional | 0201 | 1 | Assumed equal to natural gas. |
| | | 1A4b | Residential | 0202 | 1 | Assumed equal to natural gas. |
| | | 1A4c | Agriculture/ Forestry | 0203 | 1 | Assumed equal to natural gas. |

1) Assumed same emission factors as for commercial plants. Plant capacity and technology are similar for Danish plants.

2) Assumed same emission factor as for industrial plants. Plant capacity and technology is similar to industrial plants rather than to residential plants.

3) Aggregated emission factor based on the technology distribution in the sector (Nielsen et al., 2020) and technology specific emission factors that refer to Paulrud et al. (2005), Johansson et al. (2004) and Olsson & Kjällstrand (2005). The emission factor is within the IPCC (2006) interval for residential wood combustion (100-900 g per GJ).

**CHP plants**

A considerable part of the electricity production in Denmark is based on decentralised CHP plants, and well-documented emission factors for these plants are, therefore, of importance. In a project carried out for the electricity transmission company, Energinet.dk, emission factors for CHP plants <$25MW_e$ have been estimated. The work was reported in 2010 (Nielsen et al., 2010a).

The work included waste incineration plants, CHP plants combusting wood and straw, natural gas and biogas-fuelled (reciprocating) engines, natural gas fuelled gas turbines, gas oil fuelled engines, gas oil fuelled gas turbines, steam turbines fuelled by residual oil and engines fuelled by biomass gasification gas. $CH_4$ emission factors for these plants all refer to Nielsen et al. (2010a). The estimated emission factors were based on existing emission measurements as well as on emission measurements carried out within the project. The number of emission data sets was comprehensive. Emission factors for subgroups of each plant type were estimated, e.g. the $CH_4$ emission factors for different gas engine types were determined.

Time series for the $CH_4$ emission factors are based on a similar project estimating emission factors for year 2000 (Nielsen & Illerup, 2003).

**Natural gas, gas engines**

The emission factor for natural gas engines refers to the Nielsen et al. (2010a). The emission factor includes the increased emission during start/stop of the engines estimated by Nielsen et al. (2008). Emission factor time series for the years 1990-2007 have been estimated based on Nielsen & Illerup (2003). These three references are discussed below.

Nielsen et al. (2010a):

> *$CH_4$ emission factors for gas engines were estimated for 2003-2006 and for 2007-2010. The dataset was split in two, due to new emission limits for engines from October 2006. The emission factors were based on emission measurements from 366 (2003-2006) and 157 (2007-2010) engines respectively. The engines from which emission measurements were available for 2007-2010 represented 38 % of the gas consumption. The emission factors were estimated based on fuel consumption for each gas engine type and the*

*emission factor for each engine type. The majority of emission measurements that were not performed within the project related solely to the emission of total unburned hydrocarbon ($CH_4$ + NMVOC). A constant disaggregation factor was estimated based on 9 emission measurements including both $CH_4$ and NMVOC.*

Nielsen & Illerup (2003):

*The emission factor for natural gas engines was based on 291 emission measurements in 114 different plants. The plants from which emission measurements were available represented 44 % of the total gas consumption in gas engines in year 2000.*

Nielsen et al. (2008):

*This study calculated a start/stop correction factor. This factor was applied to the time series estimated in Nielsen & Illerup (2003). Further, the correction factors were applied in Nielsen et al. (2010a).*

The emission factor for lean-burn gas engines is relatively high, especially for pre-chamber engines, which account for more than half the gas consumption in Danish gas engines. However, the emission factors for different pre-chamber engine types differ considerably.

The installation of natural gas engines in decentralised CHP plants in Denmark has taken place since 1990. The first engines installed were relatively small open-chamber engines but later mainly pre-chamber engines were installed. As mentioned above, pre-chamber engines have a higher emission factor than open-chamber engines; therefore, the emission factor has increased during the period 1990-1995. After that, technical improvements of the engines have been implemented as a result of upcoming emission limits that most installed gas engines had to meet in late 2006 (DEPA, 2005).

The time series were based on:

- Full load emission factors for different engine types in year 2000 (Nielsen & Illerup, 2003), 2003-2006 and 2007-2010 (Nielsen et al., 2010a).
- Data for year of installation for each engine and fuel consumption of each engine 1994-2002 from the Danish Energy Agency (DEA, 2003).
- Research concerning the $CH_4$ emission from gas engines carried out in 1997 (Nielsen & Wit, 1997).
- Correction factors including increased emission during start/stop of the engines (Nielsen et al., 2008).

Table 3.2.29 Time series for the $CH_4$ emission factor for natural gas fuelled engines.

| Year | Emission factor, g per GJ |
|---|---|
| 1990 | 266 |
| 1991 | 309 |
| 1992 | 359 |
| 1993 | 562 |
| 1994 | 623 |
| 1995 | 632 |
| 1996 | 616 |
| 1997 | 551 |
| 1998 | 542 |
| 1999 | 541 |
| 2000 | 537 |
| 2001 | 522 |
| 2002 | 508 |
| 2003 | 494 |
| 2004 | 479 |
| 2005 | 465 |
| 2006 | 473 |
| 2007-2018 | 481 |

### Gas engines, biogas

The emission factor for biogas engines was estimated to 434 g per GJ in 2007-2018. The emission factor is lower than the factor for natural gas mainly because most biogas-fuelled engines are lean-burn open-chamber engines - not prechamber engines.

Time series for the emission factor have been estimated. The emission factors for biogas engines were based on Nielsen et al. (2010a) and Nielsen & Illerup (2003). The two references are discussed below. The time series are shown in Table 3.2.30.

Nielsen et al. (2010a):

> *$CH_4$ emission factors for gas engines were estimated for 2006 based on emission measurements performed in 2003-2010. The emission factor was based on emission measurements from 10 engines. The engines from which emission measurements were available represented 8 % of the gas consumption. The emission factor was estimated based on fuel consumption for each gas engine type and the emission factor for each engine type. The majority of emission measurements that were not performed within the project related solely to the emission of total unburned hydrocarbon ($CH_4$ + NMVOC). A constant disaggregation factor was estimated based on 3 emission measurements including both $CH_4$ and NMVOC.*

Nielsen & Illerup (2003):

> *The emission factor for natural gas engines was based on 18 emission measurements from 13 different engines. The engines from which emission measurements were available represented 18 % of the total biogas consumption in gas engines in year 2000.*

Table 3.2.30 Time series for the $CH_4$ emission factor for biogas-fuelled engines.

| Year | Emission factor, g per GJ |
|---|---|
| 1990 | 239 |
| 1991 | 251 |
| 1992 | 264 |
| 1993 | 276 |
| 1994 | 289 |
| 1995 | 301 |
| 1996 | 305 |
| 1997 | 310 |
| 1998 | 314 |
| 1999 | 318 |
| 2000 | 323 |
| 2001 | 342 |
| 2002 | 360 |
| 2003 | 379 |
| 2004 | 397 |
| 2005 | 416 |
| 2006 | 434 |
| 2007-2018 | 434 |

#### Gas turbines, natural gas

The emission factor for gas turbines was estimated to be below 1.7 g per GJ in 2005 (Nielsen et al., 2010a). The emission factor was based on emission measurements on five plants. The emission factor in year 2000 was 1.5 g per GJ (Nielsen & Illerup, 2003). A time series have been estimated.

#### CHP, wood

The emission factor for CHP plants combusting wood was estimated to be below 3.1 g per GJ (Nielsen et al., 2010a) and the emission factor 3.1 g per GJ has been applied for all years. The emission factor was based on emission measurements on two plants.

#### CHP, straw

The emission factor for CHP plants combusting straw was estimated to be below 0.47 g per GJ (Nielsen et al., 2010a) and the emission factor 0.47 g per GJ has been applied for all years. The emission factor was based on emission measurements on four plants.

#### CHP, waste

The emission factor for CHP plants combusting waste was estimated to be below 0.34 g per GJ in 2006 (Nielsen et al., 2010a) and 0.59 g per GJ in year 2000 (Nielsen & Illerup, 2003). A time series have been estimated. The emission factor was based on emission measurements on nine plants.

The emission factor has also been applied for district heating plants.

#### Residential wood combustion

The emission factor for residential wood combustion (not including wood pellets) is based on technology specific data. The emission factor time series is shown in Table 3.2.31.

Table 3.2.31 $CH_4$ emission factor time series for residential wood combustion[1)].

| Year | Emission factor, g per GJ |
|---|---|
| 1990 | 327 |
| 1991 | 321 |
| 1992 | 314 |
| 1993 | 308 |
| 1994 | 302 |
| 1995 | 296 |
| 1996 | 289 |
| 1997 | 283 |
| 1998 | 276 |
| 1999 | 270 |
| 2000 | 263 |
| 2001 | 256 |
| 2002 | 248 |
| 2003 | 240 |
| 2004 | 227 |
| 2005 | 215 |
| 2006 | 206 |
| 2007 | 197 |
| 2008 | 188 |
| 2009 | 178 |
| 2010 | 167 |
| 2011 | 160 |
| 2012 | 152 |
| 2013 | 145 |
| 2014 | 138 |
| 2015 | 131 |
| 2016 | 124 |
| 2017 | 117 |
| 2018 | 111 |

1) Wood pellets not included.

The emission factors for each technology and the corresponding reference are shown in Table 3.2.32. The emission factor time series are estimated based on time series (1990-2018) for wood consumption in each technology (Nielsen et al., 2020).

Table 3.2.32 Technology specific $CH_4$ emission factors for residential wood combustion.

| Technology | Emission factor, g per GJ | Reference |
|---|---|---|
| Stoves (-1989) | 430 | Methane emissions from residential biomass combustion, Paulrud et al. (2005) (SMED report, Sweden) |
| Stoves (1990-2007) | 215 | Assumed ½ the emission factor for old stoves. |
| Stoves (2008-2014) | 125 | Estimated based on the emission factor for new stoves and the emission factors for NMVOC. |
| Stoves (2015-2016) | 125 | Same as modern stove (2008-2015) |
| Stoves (2017-) | 125 | Same as modern stove (2008-2015) |
| Eco labelled stoves / new advanced stoves (-2014) | 2 | Low emissions from wood burning in an ecolabelled residential boiler. Olsson & Kjällstrand (2005). |
| Eco labelled stoves / new advanced stoves (2015-2016) | 2 | Same as advanced / ecolabelled stoves |
| Eco labelled stoves / new advanced stoves (2017-) | 2 | Same as advanced / ecolabelled stoves |
| Open fireplaces and similar | 430 | Assumed equal to old stove. |
| Masonry heat accumulating stoves and similar | 215 | Assumed equal to old stove. |
| Boilers with accumulation tank (-1979) | 211 | Methane emissions from residential biomass combustion, Paulrud et al 2005 (SMED report, Sweden) |
| Boilers without accumulation tank (-1979) | 256 | Methane emissions from residential biomass combustion, Paulrud et al 2005 (SMED report, Sweden) |
| Boilers with accumulation tank (1980-) | 50 | Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004) |
| Boilers without accumulation tank (1980-) | 50 | Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004) |

The time series for wood consumption in the 14 different technologies are illustrated in Figure 3.2.37. The consumption in new / ecolabelled stoves has increased. Details about disaggregation of the wood consumption between technologies are given in Nielsen et al. (2020).

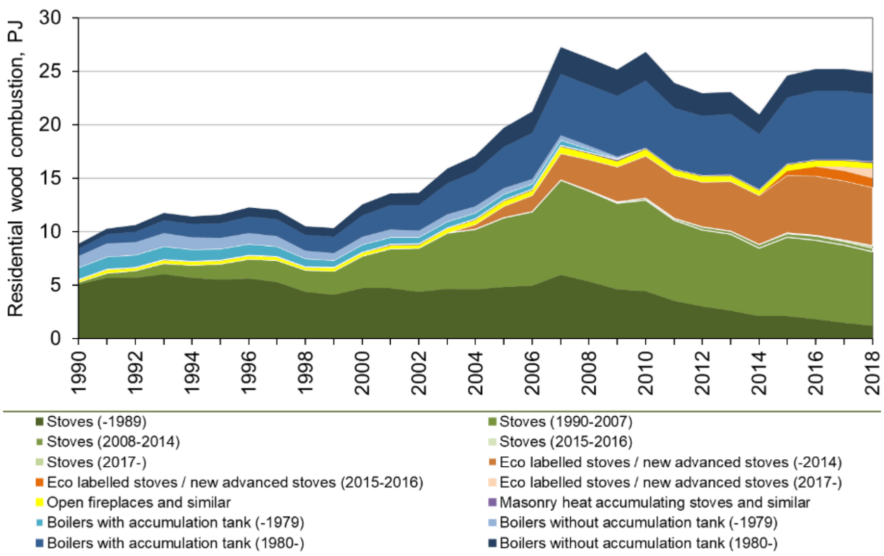



Figure 3.2.37 Technology specific wood consumption in residential plants.

## Other stationary combustion plants

Emission factors for other plants refer to the IPCC Guidelines (IPCC, 2006).

## $N_2O$ emission factors

The $N_2O$ emission factors applied for the 2018 inventory are listed in Table 3.2.33. Time series have been estimated for natural gas fuelled gas turbines and refinery gas fuelled turbines. All other emission factors have been applied unchanged for 1990-2018.

Emission factors for natural gas fuelled reciprocating engines, natural gas fuelled gas turbines, CHP plants < 300 MW combusting wood, straw or residual oil, waste incineration plants, engines fuelled by gas oil and gas engines fuelled by biomass gasification gas all refer to emission measurements carried out on Danish plants, Nielsen et al. (2010a).

The emission factor for coal-powered plants in public power plants refers to research conducted by Elsam (now part of Ørsted).

Plant specific emission factors have been included for two industrial plants.

The emission factor for offshore gas turbines has been assumed to follow the time series for natural gas fuelled gas turbines in Danish CHP plants. There is no evidence to suggest that offshore gas turbines have different emission characteristics for $N_2O$ compared to on-shore natural gas turbines and the emission factor is considered applicable.

The emission factor for natural gas fuelled gas turbines has been applied for refinery gas fuelled gas turbines. Refinery gas has similar properties as natural gas, i.e. similar nitrogen content in the fuel, which means that $N_2O$ formation will be similar under similar combustion conditions.

All emission factors that are not nationally referenced refer to the IPCC Guidelines (IPCC, 2006).

Table 3.2.33 $N_2O$ emission factors 2018.

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| SOLID | Coal | 1A1a | Public electricity and heat production | 0101 | 0.8 | Henriksen (2005) |
| | | | | 0102 | 1.4 | IPCC (2006), Tier 3, Table 2.6, Utility source, pulverised bituminous coal, wet bottom boiler. |
| | | 1A2 a-g | Industry | 03 | 1.5 | IPCC (2006), Tier 1, Table 2-3, Manufacturing industries, coal |
| | | 1A4b i | Residential | 0202 | 1.5 | IPCC (2006), Tier 1, Table 2-5, Residential, coal |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 1.5 | IPCC (2006), Tier 1, Table 2-4, Commercial, coal[1)] |
| | BKB | 1A4b i | Residential | 0202 | 1.5 | IPCC (2006), Tier 1, Table 2-5, Residential, brown coal briquettes |
| | Coke oven coke | 1A2 a-g | Industry | 03 | 1.5 | IPCC (2006), Tier 1, Table 2-3, Industry, coke oven coke |
| | | 1A4b i | Residential | 020200 | 1.5 | IPCC (2006), Tier 1, Table 2-5, Residential, coke oven coke |
| | Anodic carbon | 1A2 a-g | Industry | 03 | 1.5 | IPCC (2006), Tier 1, Table 2-3, manufacturing industries, other bituminous coal |
| | Fossil fly ash | 1A1a | Public electricity and heat production | 0101 | 0.8 | Assumed equal to coal. |
| LIQUID | Petroleum coke | 1A2 a-g | Industry – other | 03 | 0.6 | IPCC (2006), Tier 1, Table 2-3, Industry, petroleum coke |
| | | | | 031600 | 1.5 | - |
| | | 1A4a | Commercial/ Institutional | 0201 | 0.6 | IPCC (2006), Tier 1, Table 2-4, Commercial, petroleum coke |
| | | 1A4b i | Residential | 0202 | 0.6 | IPCC (2006), Tier 1, Table 2-5, Residential, petroleum coke |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 0.6 | IPCC (2006), Tier 1, Table 2-5, Residential/Agricultural, petroleum coke |
| | Residual oil | 1A1a | Public electricity and heat production | 010101 | 0.3 | IPCC (2006), Tier 3, Table 2-6, Utility, residual fuel oil |
| | | | | 010102 010103 | 5 | Nielsen et al. (2010a) |
| | | | | 010104 010105 | 0.6 | IPCC (2006), Tier 1, Table 2-2, Energy industries, residual fuel oil |
| | | | | 010203 | 0.3 | IPCC (2006), Tier 3, Table 2-6, Utility, residual fuel oil |
| | | 1A1b | Petroleum refining | 010306 | 0.6 | IPCC (2006), Tier 1, Table 2-2, Energy industries, residual fuel oil |
| | | 1A2 a-g | Industry | 03 | 5 | Nielsen et al. (2010a) |
| | | | | Engines | 0.6 | IPCC (2006), Tier 1, Table 2-3, manufacturing industries and construction, residual fuel oil. |
| | | 1A4a | Commercial/ Institutional | 0201 | 0.3 | IPCC (2006), Tier 3, Table 2-10, Commercial, fuel oil boilers |
| | | 1A4b i | Residential | 0202 | 0.6 | IPCC (2006), Tier 1, Table 2-5, Residential, residual fuel oil |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 0.3 | IPCC (2006), Tier 3, Table 2-10, Commercial, fuel oil boilers[1)] |
| | Gas oil | 1A1a | Public electricity and heat production | 010101 010102 010103 | 0.4 | IPCC (2006), Tier 3, Table 2-6, Utility, gas oil boilers |
| | | | | 010104 | 0.6 | IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil |
| | | | | 010105 | 2.1 | Nielsen et al. (2010a) |
| | | | | 0102 | 0.4 | IPCC (2006), Tier 3, Table 2-6, Utility, gas oil boilers |

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| | | 1A1b | Petroleum refining | 010306 | 0.6 | IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil |
| | | 1A1c | Oil and gas extraction | 010504 | 0.6 | IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil |
| | | 1A2 a-g | Industry | 03 | 0.4 | IPCC (2006), Tier 3, Table 2-7, Industry, gas oil boilers |
| | | | | Turbines | 0.6 | IPCC (2006), Tier 1, Table 2-3, Industry, gas oil |
| | | | | Engines | 2.1 | Nielsen et al. (2010a) |
| | | 1A4a | Commercial/ Institutional | 0201 | 0.4 | IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil boilers |
| | | | | Engines | 2.1 | Nielsen et al. (2010a) |
| | | 1A4b i | Residential | 0202 | 0.6 | IPCC (2006), Tier 1, Table 2-5, Residential, gas oil |
| | | | | Engines | 2.1 | Nielsen et al. (2010a) |
| | | 1A4c | Agriculture/ Forestry | 0203 | 0.4 | IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil boilers 1) |
| | | | | Engines | 2.1 | Nielsen et al. (2010a) |
| | Kerosene | 1A2 a-g | Industry | 03 | 0.6 | IPCC (2006), Tier 1, Table 2-3, Industry, other kerosene |
| | | 1A4a | Commercial/ Institutional | 0201 | 0.6 | IPCC (2006), Tier 1, Table 2-4, Commercial, other kerosene |
| | | 1A4b i | Residential | 0202 | 0.6 | IPCC (2006), Tier 1, Table 2-5, Residential, other kerosene |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 0.6 | IPCC (2006), Tier 1, Table 2-4, Commercial, other kerosene 1) |
| | LPG | 1A1a | Public electricity and heat production | 0101<br>0102 | 0.1 | IPCC (2006), Tier 1, Table 2-2, Energy industries, LPG |
| | | 1A1b | Petroleum refining | 010306 | 0.1 | IPCC (2006), Tier 1, Table 2-2, Energy industries, LPG |
| | | 1A2 a-g | Industry | 03 | 0.1 | IPCC (2006), Tier 1, Table 2-3, Industry, LPG |
| | | 1A4a | Commercial/ Institutional | 0201 | 0.1 | IPCC (2006), Tier 1, Table 2-4, Commercial, LPG |
| | | 1A4b i | Residential | 0202 | 0.1 | IPCC (2006), Tier 1, Table 2-5, Residential, LPG |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 0.1 | IPCC (2006), Tier 1, Table 2-5, Residential/Agricultural, LPG |
| | Refinery gas | 1A1b | Petroleum refining | 010304 | 1 | Assumed equal to natural gas fuelled turbines. Based on Nielsen et al. (2010a). |
| | | | | 010306 | 0.1 | IPCC (2006), Tier 1, Table 2-2, Energy industries, refinery gas |
| GAS | Natural gas | 1A1a | Public electricity and heat production | 010101<br>010102<br>010103 | 1 | IPCC (2006), Tier 3, Table 2-6, Natural gas, Utility, boiler |
| | | | | 010104 | 1 | Nielsen et al. (2010a) |
| | | | | 010105 | 0.58 | Nielsen et al. (2010a) |
| | | | | 0102 | 1 | IPCC (2006), Tier 3, Table 2-6, Natural gas, Utility, boiler |
| | | 1A1b | Petroleum refining | 010306 | 1 | IPCC (2006), Tier 3, Table 2-6, Natural gas, Utility, boiler |
| | | 1A1c | Oil and gas extraction | 010504 | 1 | Nielsen et al. (2010a) |
| | | 1A2 a-g | Industry | 03 | 1 | IPCC (2006), Tier 3, Table 2-7, Industry, natural gas boilers |
| | | | | Gas turbines | 1 | Nielsen et al. (2010a) |
| | | | | Engines | 0.58 | Nielsen et al. (2010a) |
| | | 1A4a | Commercial/ Institutional | 020100<br>020103 | 1 | IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers |

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| | | | | Engines | 0.58 | Nielsen et al. (2010a) |
| | | 1A4b i | Residential | 0202 | 1 | IPCC (2006), Tier 3, Table 2-9, Residential, natural gas boilers |
| | | | | Engines | 0.58 | Nielsen et al. (2010a) |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 1 | IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers [1)] |
| | | | | Engines | 0.58 | Nielsen et al. (2010a) |
| WASTE | Waste | 1A1a | Public electricity and heat production | 0101 0102 | 1.2 | Nielsen et al. (2010a) |
| | | 1A2 a-g | Industry | 03 | 4 | IPCC (2006), Tier 1, Table 2-3, Industry, wastes |
| | | 1A4a | Commercial/ Institutional | 0201 | 4 | IPCC (2006), Tier 1, Table 2-4, Commercial, municipal wastes |
| | Industrial waste | 1A2 a-g | Industry | 03 | 4 | IPCC (2006), Tier 1, Table 2-3, Industry, industrial wastes |
| BIO-MASS | Wood | 1A1a | Public electricity and heat production | 0101 | 0.8 | Nielsen et al. (2010a) |
| | | | | 0102 | 4 | IPCC (2006), Tier 1, Table 2-2, Energy industries, wood |
| | | 1A2 a-g | Industry | 03 | 4 | IPCC (2006), Tier 1, Table 2-3, Industry, wood |
| | | 1A4a | Commercial/ Institutional | 0201 | 4 | IPCC (2006), Tier 1, Table 2-4, Commercial, wood |
| | | 1A4b i | Residential | 0202 | 4 | IPCC (2006), Tier 1, Table 2-5, Residential, wood |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 4 | IPCC (2006), Tier 1, Table 2-5, Agriculture, wood |
| | Straw | 1A1a | Public electricity and heat production | 0101 | 1.1 | Nielsen et al. (2010a) |
| | | | | 0102 | 4 | IPCC (2006), Tier 1, Table 2-2, Energy industries, other primary solid bio-mass |
| | | 1A4b i | Residential | 0202 | 4 | IPCC (2006), Tier 1, Table 2-5, Residential, other primary solid biomass |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 4 | IPCC (2006), Tier 1, Table 2-5, Agriculture, other primary solid biomass |
| | Wood pellets | 1A1a | Public electricity and heat production | 0101 | 0.8 | Nielsen et al. (2010a) |
| | | | | 0102 | 4 | IPCC (2006), Tier 1, Table 2-2, Energy industries, wood |
| | | 1A2 a-g | Industry | 03 | 4 | IPCC (2006), Tier 1, Table 2-3, Industry, wood |
| | | 1A4a | Commercial/ Institutional | 0201 | 4 | IPCC (2006), Tier 1, Table 2-4, Commercial, wood |
| | | 1A4b i | Residential | 0202 | 4 | IPCC (2006), Tier 1, Table 2-5, Residential, wood |
| | Bio oil | 1A1a | Public electricity and heat production | 0101 0102 | 0.6 | IPCC (2006), Tier 3, Table 2-2, Utility, biodiesels |
| | | | | Engines | 2.1 | Assumed equal to gas oil. Based on Nielsen et al. (2010a) |
| | | 1A2 a-g | Industry | 03 | 0.4 | Assumed equal to gas oil. |
| | | 1A4b i | Residential | 0202 | 0.6 | IPCC (2006), Tier 1, Table 2-5, Residential, biodiesels |
| | Biogas | 1A1a | Public electricity and heat production | 0101 0102 | 0.1 | IPCC (2006), Tier 1, Table 2-2, Energy industries, other biogas |
| | | | | Engines | 1.6 | Nielsen et al. (2010a) |
| | | 1A2 a-g | Industry | 03 | 0.1 | IPCC (2006), Tier 1, Table 2-3, Industry, other biogas |
| | | | | Engines | 1.6 | Nielsen et al. (2010a) |

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| | | 1A4a | Commercial/ Institutional | 0201 | 0.1 | IPCC (2006), Tier 1, Table 2,4, Commercial, other biogas |
| | | | | Engines | 1.6 | Nielsen et al. (2010a) |
| | | 1A4b | Residential | 0202 | 1 | Assumed equal to natural gas. |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 0.1 | IPCC (2006), Tier 1, Table 2-5, Agriculture, other biogas |
| | | | | Engines | 1.6 | Nielsen et al. (2010a) |
| | Bio gasification gas | 1A1a | Public electricity and heat production | 010101 | 0.1 | Assumed equal to biogas. |
| | | | | 010105 | 2.7 | Nielsen et al. (2010a) |
| | | 1A4a | Commercial/ Institutional | 020105 | 2.7 | Nielsen et al. (2010a) |
| | Bio natural gas | 1A1a | Public electricity and heat production | 0101 or 0102 | 1 | Assumed equal to natural gas. |
| | | 1A2 a-g | Industry | 03 | 1 | Assumed equal to natural gas. |
| | | 1A4a | Commercial/ Institutional | 0201 | 1 | Assumed equal to natural gas. |
| | | 1A4b | Residential | 0202 | 1 | Assumed equal to natural gas. |
| | | 1A4c | Agriculture/ Forestry | 0203 | 1 | Assumed equal to natural gas. |

1) In Denmark, plants in Agriculture/Forestry are similar to Commercial plants.

### 3.2.6 Uncertainty

Uncertainty estimates include uncertainty with regard to the total emission inventory as well as uncertainty with regard to trends.

**Methodology**

The uncertainty for greenhouse gas emissions have been estimated according to the IPCC Guidelines (IPCC, 2006). This year the uncertainty has been estimated only by approach 1. Approach 1 is further described in Chapter 1.7.

Approach 1 is based on a normal distribution and a confidence interval of 95 %.

The input data for the approach 1 are:

- Emission data for the base year and the latest year.
- Uncertainties for emission factors
- Uncertainty for fuel consumption rates.

The emission source categories applied are listed in Table 3.2.34.

**Source categories**

Due to large differences in data uncertainty, some emission source categories have been further disaggregated than suggested in the IPCC Guidelines (2006):

- For five different fuels, $CO_2$ emissions based on ETS data and on non-ETS data have been considered two different emission sources.
- $CH_4$ emission from natural gas fuelled engines
- $CH_4$ emission from biogas fuelled engines
- $CH_4$ emission from residential wood combustion
- $CH_4$ emission from residential and agricultural combustion of straw
- $N_2O$ emission from residential wood combustion
- $N_2O$ emission from residential and agricultural combustion of straw

The separate uncertainty estimation for gas engine $CH_4$ emission and $CH_4$ emission from other plants is applied, because in Denmark, the $CH_4$ emission from gas engines is much larger than the emission from other stationary combustion plants, and the $CH_4$ emission factor for gas engines is estimated with a much smaller uncertainty level than for other stationary combustion plants.

The 2018 uncertainty levels have been applied in uncertainty calculation.

**Fuel**

The applied uncertainty rates for fuel consumption are shown below.

Table 3.2.34 Uncertainties for fuel consumption 2018.

| IPCC Source category | 2018 | Reference |
|---|---|---|
| 1A1, 1A2, 1A4 St. comb. Coal, ETS data, $CO_2$ | 0.5% | ETS data |
| 1A1, 1A2, 1A4 St. comb. Coal, no ETS data, $CO_2$ | 1.5% | Estimated based on IPCC (2006) values. |
| 1A1, 1A2, 1A4 St. comb., BKB, $CO_2$ | 2.9% | Estimated based on IPCC (2006) values. |
| 1A1, 1A2, 1A4 St. comb., Coke oven coke, $CO_2$ | 1.5% | Estimated based on IPCC (2006) values. |
| 1A1, 1A2, 1A4 St. comb., Fossil waste, ETS data, $CO_2$ | 2% | DCE assumption |
| 1A1, 1A2, 1A4 St. comb., Fossil waste, no ETS data, $CO_2$ | 5% | DCE assumption |
| 1A1, 1A2, 1A4 St. comb., Petroleum coke, ETS data, $CO_2$ | 0.5% | ETS data |
| 1A1, 1A2, 1A4 St. comb., Petroleum coke, no ETS data, $CO_2$ | 1.9% | Estimated based on IPCC (2006) values. |
| 1A1, 1A2, 1A4 St. comb., Residual oil, ETS data, $CO_2$ | 0.5% | ETS data |
| 1A1, 1A2, 1A4 St. comb., Residual oil, no ETS data, $CO_2$ | 1.0% | Estimated based on IPCC (2006) values. |
| 1A1, 1A2, 1A4 St. comb., Gas oil, $CO_2$ | 2.6% | Estimated based on IPCC (2006) values. |
| 1A1, 1A2, 1A4 St. comb., Kerosene, $CO_2$ | 2.0% | Estimated based on IPCC (2006) values. |
| 1A1, 1A2, 1A4 St. comb., LPG, $CO_2$ | 2.0% | Estimated based on IPCC (2006) values. |
| 1A1b,St. comb., Refinery gas, $CO_2$ | 1.0% | Estimated based on IPCC (2006) values. |
| 1A1, 1A2, 1A4, Stationary combustion, Natural gas, onshore, $CO_2$ | 1.3% | Estimated based on IPCC (2006) values. Offshore gas turbines not included in this category. |
| 1A1c Off shore gas turbines, Natural gas, $CO_2$ | 0.5% | ETS data for 2018, IPCC (2006) for 1990. |
| 1A1, Stationary Combustion, SOLID, $CH_4$ | 1.0% | IPCC (2006), less than 1% |
| 1A1, Stationary Combustion, LIQUID, $CH_4$ | 1.0% | IPCC (2006), less than 1% |
| 1A1, Stationary Combustion, not engines, GAS, $CH_4$ | 1.0% | IPCC (2006), less than 1% |
| 1A1, Stationary Combustion, WASTE, $CH_4$ | 3.0% | DCE assumption. The uncertainty for the total consumption of waste is lower than the uncertainty for the fossil part. |
| 1A1, Stationary Combustion, not engines, BIOMASS, $CH_4$ | 3.0% | DCE assumption |
| 1A2, Stationary Combustion, SOLID, $CH_4$ | 2.0% | IPCC (2006) |
| 1A2, Stationary Combustion, LIQUID, $CH_4$ | 2.0% | IPCC (2006) |
| 1A2, Stationary Combustion, not engines, GAS, $CH_4$ | 2.0% | IPCC (2006) |
| 1A2, Stationary Combustion, WASTE, $CH_4$ | 3.0% | DCE assumption. The uncertainty for the total consumption of waste is lower than the uncertainty for the fossil part. |
| 1A2, Stationary Combustion, not engines, BIOMASS, $CH_4$ | 3.0% | IPCC (2006) |
| 1A4, Stationary Combustion, SOLID, $CH_4$ | 3.0% | IPCC (2006) |
| 1A4, Stationary Combustion, LIQUID, $CH_4$ | 3.0% | IPCC (2006) |
| 1A4, Stationary Combustion, not engines, GAS, $CH_4$ | 3.0% | IPCC (2006) |
| 1A4, Stationary Combustion, WASTE, $CH_4$ | 3.0% | DCE assumption. The uncertainty for the total consumption of waste is lower than the uncertainty for the fossil part. |
| 1A4, Stationary Combustion, not engines, not residential wood and not residential/agricultural straw, BIOMASS, $CH_4$ | 3.0% | IPCC (2006) |
| 1A4, Stationary Combustion, Residential wood combustion, $CH_4$ | 10.0% | DCE assumption |
| 1A4, Stationary Combustion, Residential and agricultural straw combustion, $CH_4$ | 10.0% | DCE assumption |
| 1A1, 1A2, 1A4 Natural gas fuelled engines, GAS, $CH_4$ | 1.0% | Lindgren (2010) |
| 1A1, 1A2, 1A4 Biogas fuelled engines, GAS, $CH_4$ | 3.0% | DCE assumption |
| 1A1, Stationary Combustion, SOLID, $N_2O$ | 1.0% | IPCC (2006), less than 1% |
| 1A1, Stationary Combustion, LIQUID, $N_2O$ | 1.0% | IPCC (2006), less than 1% |

| IPCC Source category | 2018 | Reference |
|---|---|---|
| *Continued* | | |
| 1A1, Stationary Combustion, GAS, $N_2O$ | 1.0% | IPCC (2006), less than 1% |
| 1A1, Stationary Combustion, WASTE, $N_2O$ | 3.0% | DCE assumption |
| 1A1, Stationary Combustion, BIOMASS, $N_2O$ | 3.0% | DCE assumption |
| 1A2, Stationary Combustion, SOLID, $N_2O$ | 2.0% | IPCC (2006) |
| 1A2, Stationary Combustion, LIQUID, $N_2O$ | 2.0% | IPCC (2006) |
| 1A2, Stationary Combustion, GAS, $N_2O$ | 2.0% | IPCC (2006) |
| 1A2, Stationary Combustion, WASTE, $N_2O$ | 3.0% | DCE assumption |
| 1A2, Stationary Combustion, BIOMASS, $N_2O$ | 3.0% | DCE assumption |
| 1A4, Stationary Combustion, SOLID, $N_2O$ | 3.0% | IPCC (2006) |
| 1A4, Stationary Combustion, LIQUID, $N_2O$ | 3.0% | IPCC (2006) |
| 1A4, Stationary Combustion, GAS, $N_2O$ | 3.0% | IPCC (2006) |
| 1A4, Stationary Combustion, WASTE, $N_2O$ | 3.0% | DCE assumption |
| 1A4, Stationary Combustion, not residential wood and not residential/agricultural straw, BIOMASS, $N_2O$ | 3.0% | DCE assumption |
| 1A4b, Stationary Combustion, Residential wood combustion, $N_2O$ | 10.0% | DCE assumption |
| 1A4b/c, Stationary Combustion, Residential and agricultural straw combustion, $N_2O$ | 10.0% | DCE assumption |

#### Emission factors

Uncertainties for emission factors are shown in Table 3.2.35.

Table 3.2.35 Uncertainties for emission factors, 2018.

| IPCC Source category | 2018 | Reference |
|---|---|---|
| 1A1, 1A2, 1A4 St. comb. Coal, ETS data, $CO_2$ | 0.3% | ETS data, 2018 estimate |
| 1A1, 1A2, 1A4 St. comb. Coal, no ETS data, $CO_2$ | 1.0% | DCE assumption |
| 1A1, 1A2, 1A4 St. comb., BKB, $CO_2$ | 5.0% | IPCC (2000), chapter 2.1.1.6. |
| 1A1, 1A2, 1A4 St. comb., Coke oven coke, $CO_2$ | 5.0% | IPCC (2000), chapter 2.1.1.6. |
| 1A1, 1A2, 1A4 St. comb., Fossil waste, ETS data, $CO_2$ | 3.0% | ETS data, DCE estimate based on Astrup et al. (2012). |
| 1A1, 1A2, 1A4 St. comb., Fossil waste, no ETS data, $CO_2$ | 10.0% | Non-ETS data, DCE estimate based on Astrup et al. (2012). |
| 1A1, 1A2, 1A4 St. comb., Petroleum coke, ETS data, $CO_2$ | 0.5% | ETS data, 2018 estimate |
| 1A1, 1A2, 1A4 St. comb., Petroleum coke, no ETS data, $CO_2$ | 5.0% | IPCC (2000), chapter 2.1.1.6. |
| 1A1, 1A2, 1A4 St. comb., Residual oil, ETS data, $CO_2$ | 0.5% | ETS data, 2015 estimate |
| 1A1, 1A2, 1A4 St. comb., Residual oil, no ETS data, $CO_2$ | 2.0% | Jensen & Lindroth (2002). |
| 1A1, 1A2, 1A4 St. comb., Gas oil, $CO_2$ | 1.3% | DCE estimate. |
| 1A1, 1A2, 1A4 St. comb., Kerosene, $CO_2$ | 3.0% | Based on interval in IPCC (2006). |
| 1A1, 1A2, 1A4 St. comb., LPG, $CO_2$ | 4.0% | Based on interval in IPCC (2006). |
| 1A1b,St. comb., Refinery gas, $CO_2$ | 0.5% | 1990: IPCC (2000), chapter 2.1.1.6.<br>2018: DCE assumption, EU ETS data. |
| 1A1, 1A2, 1A4, Stationary combustion, Natural gas, * onshore, $CO_2$ | 0.4% | Lindgren (2010). Personal communication. |
| 1A1c Offshore gas turbines, Natural gas, $CO_2$ | 0.5% | ETS data for 2018, but not for 1990 |
| 1A1, Stationary Combustion, SOLID, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |
| 1A1, Stationary Combustion, LIQUID, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |
| 1A1, Stationary Combustion, not engines, GAS, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |
| 1A1, Stationary Combustion, WASTE, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |
| 1A1, Stationary Combustion, not engines, BIOMASS, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |
| 1A2, Stationary Combustion, SOLID, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |
| 1A2, Stationary Combustion, LIQUID, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |
| 1A2, Stationary Combustion, not engines, GAS, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |
| 1A2, Stationary Combustion, WASTE, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |
| 1A2, Stationary Combustion, not engines, BIOMASS, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |
| 1A4, Stationary Combustion, SOLID, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |
| 1A4, Stationary Combustion, LIQUID, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |
| 1A4, Stationary Combustion, not engines, GAS, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |
| 1A4, Stationary Combustion, WASTE, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |

| IPCC Source category | 2018 | Reference |
|---|---|---|
| *Continued* | | |
| 1A4, Stationary Combustion, not engines, not residential wood and not residential/agricultural straw, BIOMASS, $CH_4$ | 100% | Based on interval in IPCC (2006), table 2.12 |
| 1A4, Stationary Combustion, Residential wood combustion, $CH_4$ | 150% | Upper value in IPCC (2006), table 2.12. |
| 1A4, Stationary Combustion, Residential and agricultural straw combustion, $CH_4$ | 150% | Upper value in IPCC (2006), table 2.12. |
| 1A1, 1A2, 1A4 Natural gas fuelled engines, GAS, $CH_4$ | 2% | 1990: DCE estimate based on Nielsen et al. (2010a). 2018: Jørgensen et al. (2010). Uncertainty data for NMVOC + $CH_4$. |
| 1A1, 1A2, 1A4 Biogas fuelled engines, GAS, $CH_4$ | 10% | DCE estimate based on Nielsen et al. (2010a). |
| 1A1, Stationary Combustion, SOLID, $N_2O$ | 400% | DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark. |
| 1A1, Stationary Combustion, LIQUID, $N_2O$ | 1000% | IPCC (2000) |
| 1A1, Stationary Combustion, GAS, $N_2O$ | 750% | DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark and 1000 % if not. |
| 1A1, Stationary Combustion, WASTE, $N_2O$ | 400% | DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark. |
| 1A1, Stationary Combustion, BIOMASS, $N_2O$ | 400% | DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark. |
| 1A2, Stationary Combustion, SOLID, $N_2O$ | 400% | DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark. |
| 1A2, Stationary Combustion, LIQUID, $N_2O$ | 1000% | IPCC (2000) |
| 1A2, Stationary Combustion, GAS, $N_2O$ | 750% | DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark and 1000 % if not. |
| 1A2, Stationary Combustion, WASTE, $N_2O$ | 400% | DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark. |
| 1A2, Stationary Combustion, BIOMASS, $N_2O$ | 400% | DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark. |
| 1A4, Stationary Combustion, SOLID, $N_2O$ | 400% | DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark. |
| 1A4, Stationary Combustion, LIQUID, $N_2O$ | 1000% | IPCC (2000) |
| 1A4, Stationary Combustion, GAS, $N_2O$ | 750% | DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark and 1000 % if not. |
| 1A4, Stationary Combustion, WASTE, $N_2O$ | 400% | DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark. |
| 1A4, Stationary Combustion, not residential wood and not residential/agricultural straw, BIOMASS, $N_2O$ | 400% | DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark. |
| 1A4b, Stationary Combustion, Residential wood combustion, $N_2O$ | 500% | DCE estimate. |
| 1A4b/c, Stationary Combustion, Residential and agricultural straw combustion, $N_2O$ | 500% | DCE estimate. |

**Results**

Approach 1 uncertainty estimates for stationary combustion emission inventories are shown in Table 3.2.36. Detailed calculation sheets are provided in Annex 3A-7.

The uncertainty interval for the total greenhouse gas emission is estimated to be ±2.3 % and the trend in greenhouse gas emissions is -53.9 % ± 1.0 %-age points. The main sources of uncertainty for greenhouse gas emissions in 2018 are $N_2O$ and $CH_4$ emission from residential wood combustion, $N_2O$ emission from biomass combusted in energy industries (1A1) and $N_2O$ emission from gaseous fuels combusted in energy industries (1A1). The main sources of uncertainty in the trend in greenhouse gas emission are the $CO_2$ emission from coal and natural gas combustion, $N_2O$ emission from residential wood combustion and $N_2O$ emissions from biomass combusted in energy industries (1A1).

Table 3.2.36 Danish uncertainty estimates, Approach 1, 2018.

| Pollutant | Uncertainty Total emission, % | Trend 1990-2018, % | Uncertainty trend, %-age points |
|---|---|---|---|
| GHG | ±2.3 | -53.9 | ±1.0 |
| $CO_2$ | ±0.6 | -54.8 | ±0.4 |
| $CH_4$ | ±45 | +54 | ±65 |
| $N_2O$ | ±173 | +18.5 | ±247 |

### 3.2.7 Source specific QA/QC and verification

An updated quality manual for the Danish emission inventories has been published in 2013 (Nielsen et al., 2013a). The quality manual describes the concepts of quality work and definitions of sufficient quality, critical control points and a list of Point for Measuring (PM).

Documentation concerning verification of the Danish GHG emission inventories has been published by (Fauser et al., 2013). In addition, the IPCC reference approach for $CO_2$ emission is an important verification of the $CO_2$ emission from the energy sector. The reference approach for the energy sector is shown in Chapter 3.4.

Information on the Danish QA/QC plan is included in Chapter 1.6. Source specific QA/QC and PM's are shown below.

**National external review**

The 2004, 2006, 2009, 2014 and 2018 updates of the sector report for stationary combustion has been reviewed by external experts (Nielsen & Illerup, 2004; Nielsen & Illerup, 2006; Nielsen et al., 2009, Nielsen et al., 2014; Nielsen et al., 2018). The national external review forms a vital part of the QA activities for stationary combustion.

The 2004, 2006, 2009, 2014 and 2018 updates of this report were reviewed by Jan Erik Johnsson from the Technical University of Denmark, Bo Sander from Elsam Engineering, Annemette Geertinger from FORCE Technology, Vibeke Vestergaard Nielsen, AU DCE and energy statistics experts from the Danish Energy Agency.

**Data storage, level 1**

Table 3.2.37 lists the sector specific PM's for data storage level 1.

Table 3.2.37 List of PM, data storage level 1.

| Level | CCP | Id | Description | Sectoral/general | Stationary combustion |
|---|---|---|---|---|---|
| Data Storage level 1 | 1. Accuracy | DS.1.1.1 | General level of uncertainty for every data set including the reasoning for the specific values. | Sectoral | Uncertainties are estimated and references given in NIR chapter 3.2.6. |
| | 2. Comparability | DS1.2.1 | Comparability of the emission factors / calculation parameters with data from international guidelines, and evaluation of major discrepancies. | Sectoral | In general, if national referenced emission factors differ considerably from IPCC Guideline/EEA Guidebook values this is discussed in NIR chapter 3.2.5. This documentation is improved annually based on reviews.<br>At CRF level, a project has been carried out comparing the Danish inventories with those of other countries (Fauser et al., 2013). |
| | 3.Completeness | DS.1.3.1 | Ensuring that the best possible national data for all sources are included, by setting down the reasoning behind the selection of datasets. | Sectoral | A list of external data are shown and discussed below. |
| | 4.Consistency | DS.1.4.1 | The original external data has to be archived with proper reference. | Sectoral | It is ensured that all original external data are archived. Subsequent data processing takes place in other spreadsheets or databases. The datasets are archived annually in order to ensure that the basic data for a given report are always available in their original form. |
| | 6.Robustness | DS.1.6.1 | Explicit agreements between the external institution holding the data and DCE about the conditions of delivery | Sectoral | For stationary combustion, a data delivery agreement is made with the DEA. DCE and DEA have renewed the data delivery agreement in 2014.<br>Most of the other external data sources are available due to legislation. See Table 3.2.37. |
| | 7.Transparency | DS.1.7.1 | Listing of all archived datasets and external contacts. | Sectoral | A list of external datasets and external contacts is shown in Table 3.2.38 below. |

Table 3.2.38 List of external data sources.

| Dataset | Description | Activity data or emission factor | Reference | Contact(s) | Data agreement/ Comment |
|---|---|---|---|---|---|
| Energy Producers Survey (Energiproducenttællingen) | Energy Producers Survey. Data set for all electricity and heat producing plants. | Activity data | The Danish Energy Agency (DEA) | Kaj Stærkind | Data agreement 2014. |
| Gas consumption for gas engines and gas turbines 1990-1994 | Historical data set for gas engines and gas turbines. | Activity data | The Danish Energy Agency (DEA) | Kaj Stærkind | No data agreement. Historical data |
| Basic data (Grunddata.xls) | The Danish energy statistics. Data set applied for both the reference approach and the national approach. | Activity data | The Danish Energy Agency (DEA) | Jane Rusbjerg | Data agreement 2014. However, the data set is also published as part of national energy statistics. |
| Energy statistics for industrial subsectors | Disaggregation of the industrial fuel consumption. | Activity data | The Danish Energy Agency (DEA) | Jane Rusbjerg | Included in data delivery agreement 2014. |
| Emission factors | Emission factors refer to a large number of sources. | Emission factors | See chapter regarding emission factors | | Some of the annually updated $CO_2$ emission factors are based on EU ETS data, see below. For other emission factors no formal data delivery agreement. |
| Annual environmental reports / environmental data | Emissions from plants defined as large point sources | Emissions | Various plants | | No data agreement. Some plants are obligated by law to report data (DEPA, 2010b; DEPA, 2015) and data are published on the Danish EPA homepage. |
| EU ETS data | Plant specific $CO_2$ emission factors | Emission factors and fuel consumption | The Danish Energy Agency (DEA) | Dorte Maimann/ Rikke Brynaa Lintrup | Plants are obligated by law. The availability of detailed information is part of the data agreement with DEA (2014 update). |

**Energy Producers Survey (Energiproducenttællingen). Statistic on fuel consumption from district heating and power plants (DEA)**

The data set includes all plants producing power or district heating. The spreadsheet from DEA is listing fuel consumption of all plants included as large point sources in the emission inventory. The statistic on fuel consumption from district heating and power plants is regarded as complete and with no significant uncertainty since the plants are bound by law to report their fuel consumption and other information.

**Gas consumption for gas engines and gas turbines 1990-1994 (DEA)**

For the years 1990-1994, DEA has estimated consumption of natural gas and biogas in gas engines and gas turbines (DEA, 2003). Estimated fuel consumption data for 1990-1993 was based on engine specific data for year of installation and for fuel consumption in 1994. DCE assesses that the DEA estimate is the best available data.

**Basic data (DEA)**

The spreadsheet from the Danish energy statistics (DEA) is used for the $CO_2$ emission calculation in accordance with the IPCC reference approach and is also the first data set applied in the national approach. The data set is included in the data delivery agreement with DEA, but it is also published annually on DEA's homepage.

#### Energy statistics for industrial subsectors (DEA)

The data includes disaggregation of the fuel consumption for industrial plants. The data set is estimated for the reporting to Eurostat. The data are included in the 2014 update of the agreement with DEA.

#### Emission factors

For specific references, see the Chapter 3.2.5 regarding emission factors. Some of the annually updated $CO_2$ emission factors are based on EU ETS data, see below.

#### Annual environmental reports (DEPA)

A large number of plants are obligated by law to report annual environmental data including emission data. DCE compares the data with those from previous years and large discrepancies are checked.

#### EU ETS data (DEA)

EU ETS data includes information on fuel consumption, heating values, carbon content of fuel, oxidation factor and $CO_2$ emissions. DCE receives the verified reports for all plants, which utilises a detailed estimation methodology. DCE's QC of the received data consists of comparing to calculation using standard emission factors as well as comparing reported values with those for previous years. The data set is included in the 2014 update of the agreement with DEA.

#### Data processing, level 1

Table 3.2.39 lists the sector specific PM's for data processing level 1.

Table 3.2.39 List of PM, data processing level 1.

| Level | CCP | Id | Description | Sectoral / general | Stationary combustion |
|---|---|---|---|---|---|
| Data Processing level 1 | 1. Accuracy | DP.1.1.1 | Uncertainty assessment for every data source not part of DS.1.1.1 as input to Data Storage level 2 in relation to type and scale of variability. | Sectoral | Uncertainties are estimated and references given in NIR chapter 3.2.6. |
| | 2.Comparability | DP.1.2.1 | The methodologies have to follow the international guidelines suggested by UNFCCC and IPCC. | Sectoral | The methodological approach is consistent with international guidelines. An overview of tiers is given in NIR Chapter 3.2.5. |
| | 3.Completeness | DP.1.3.1 | Identification of data gaps with regard to data sources that could improve quantitative knowledge. | Sectoral | The energy statistics is considered complete. |
| | 4.Consistency | DP.1.4.1 | Documentation and reasoning of methodological changes during the time series and the qualitative assessment of the impact on time series consistency. | Sectoral | The two main methodological changes in the time series; implementation of Energy Producers Survey (plant specific fuel consumption data) from 1994 onwards and implementation of EU ETS data from 2006 onwards is discussed in NIR chapter 3.2.5. |
| | 5.Correctness | DP.1.5.2 | Verification of calculation results using time series | Sectoral | Time series for activity data on SNAP and CRF source category level are used to identify possible errors. Time series for emission factors and the emission from CRF subcategories are also examined. |
| | | DP.1.5.3 | Verification of calculation results using other measures | Sectoral | The IPCC reference approach validates the fuel consumption rates and $CO_2$ emission. Except for 2016, both differ less than 2.0 % in 1990-2018. The reference approach is further discussed in NIR Chapter 3.4. |
| | 7.Transparency | DP.1.7.1 | The calculation principle, the equations used and the assumptions made must be described. | Sectoral | This is included in NIR chapter 3.2.5. |
| | | DP.1.7.2 | Clear reference to dataset at Data Storage level 1 | Sectoral | This is included in NIR chapter 3.2.5. |
| | | DP.1.7.3 | A manual log to collect information about recalculations. | Sectoral | - |

### Data storage, level 2

Table 3.2.40 lists the sector specific PM's for data storage level 2.

Table 3.2.40 List of PM, data storage level 2.

| Level | CCP | Id | Description | Sectoral / general | Stationary combustion |
|---|---|---|---|---|---|
| Data Storage level 2 | 5.Correctness | DS.2.5.1 | Check if a correct data import to level 2 has been made | Sectoral | To ensure a correct connection between data on level 2 and level 1, different controls are in place, e.g. control of sums and random tests. |

### Data storage level 4

Table 3.2.41 lists the sector specific PM's for data storage level 4.

Table 3.2.41 List of PM, data storage level 4.

| Level | CCP | Id | Description | Sectoral / general | Stationary combustion |
|---|---|---|---|---|---|
| Data Storage level 4 | 4. Consistency | DS.4.4.3 | The IEFs from the CRF are checked regarding both level and trend. The level is compared to relevant emission factors to ensure correctness. Large dips/jumps in the time series are explained. | Sectoral | Large dips/jumps in time series are discussed and explained in NIR chapter 3.2.3 and 3.2.4. |

**Other QC procedures**

Some automated checks have been prepared for the emission databases:

- Check of units for fuel rate, emission factors and plant-specific emissions.
- Check of emission factors for large point sources. Emission factors for pollutants that are not plant-specific should be the same as those defined for area sources.
- Additional checks on database consistency.
- Emission factor references are included in this report (Chapter 3.2.5 and Annex 3A-4).
- Annual environmental reports are kept for subsequent control of plant-specific emission data.
- QC checks of the country-specific emission factors have not been performed, but most factors are based on input from companies that have implemented some QA/QC work. The major power plant owner/operator in Denmark, Ørsted (former DONG Energy) has obtained the ISO 14001 certification for an environmental management system. The Danish Gas Technology Centre and Force Technology both run accredited laboratories for emission measurements.
- The emission from each large point source is compared with the emission reported the previous year.

### 3.2.8 Source specific recalculations and improvements

Table 3.2.42 shows recalculations of the $CO_2$, $CH_4$ and $N_2O$ emissions. Emissions reported this year have been compared to emissions reported last year.

Sector specific recalculations for 2017 are shown in Table 3.2.43.

The main recalculations are discussed below.

Table 3.2.42 Recalculations. Emissions reported this year compared to emissions reported last year.

| GHG | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | % | % | % |
| $CO_2$ | 99.99 | 99.99 | 99.99 | 99.99 | 99.99 | 99.99 | 100.00 | 100.00 | 100.00 | 100.00 |
| $CH_4$ | 98.40 | 98.43 | 98.59 | 98.82 | 99.18 | 99.47 | 99.59 | 99.62 | 99.75 | 99.75 |
| $N_2O$ | 100.00 | 100.00 | 100.00 | 100.00 | 100.04 | 100.04 | 100.03 | 100.05 | 100.05 | 100.04 |

| GHG | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | % | % | % |
| $CO_2$ | 100.00 | 100.00 | 100.00 | 100.00 | 99.99 | 99.99 | 100.00 | 99.99 | 99.99 | 100.00 |
| $CH_4$ | 99.72 | 99.66 | 99.60 | 99.48 | 99.08 | 98.66 | 98.45 | 98.47 | 99.04 | 99.07 |
| $N_2O$ | 100.05 | 100.03 | 100.00 | 100.00 | 100.00 | 100.17 | 99.99 | 100.48 | 99.77 | 100.19 |

| GHG | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | % |
| $CO_2$ | 100.00 | 100.01 | 100.00 | 100.00 | 99.97 | 99.90 | 99.94 | 99.79 |
| $CH_4$ | 99.10 | 98.96 | 98.61 | 98.36 | 98.09 | 97.63 | 97.63 | 97.91 |
| $N_2O$ | 100.02 | 100.81 | 101.66 | 102.14 | 100.81 | 103.40 | 109.07 | 108.26 |

Table 3.2.43 Recalculations for stationary combustion, 2017.

| | $CO_2$ , kt $CO_2$ | $CH_4$, kt $CO_2$ eqv. | $N_2O$ kt $CO_2$ eqv. | $CO_2$ % | $CH_4$, % | $N_2O$ % |
|---|---|---|---|---|---|---|
| 1A1 Energy industries | -11.4 | 0.3 | 0.0 | -0.1% | 0.3% | 0.1% |
| 1A1a Public electricity and heat production | -11.4 | 0.3 | 0.0 | -0.1% | 0.3% | 0.1% |
| 1A1b Petroleum refining | 0.0 | 0.0 | 0.0 | 0.0% | 0.0% | 0.0% |
| 1A1c Oil and gas extraction | 0.0 | 0.0 | 0.0 | 0.0% | 0.0% | 0.0% |
| 1A2 Industry | -36.0 | 0.3 | 15.0 | -1.1% | 2.0% | 42.6% |
| 1A2a Iron and steel | -7.8 | 0.0 | 0.0 | -6.9% | -6.9% | -6.8% |
| 1A2b Non-ferrous metals | 0.0 | 0.0 | 0.0 | - | - | - |
| 1A2c Chemicals | -11.4 | 0.0 | 0.1 | -3.2% | 6.4% | 3.9% |
| 1A2d Pulp, paper and print | -7.1 | 0.1 | 0.5 | -15.6% | 97.0% | 77.3% |
| 1A2e Food processing, beverages and tobacco | -34.3 | 0.1 | -0.2 | -3.2% | 0.7% | -2.1% |
| 1A2f Non-metallic minerals | 3.0 | 0.1 | 0.0 | 0.2% | 1.5% | 0.2% |
| 1A2gviii Other manufacturing industry | 21.6 | 0.1 | 14.6 | 6.1% | 1.7% | 108.6% |
| 1A4 Other sectors | 10.7 | -6.1 | 0.6 | 0.4% | -4.3% | 0.9% |
| 1A4ai Commercial/institutional: Stationary | 0.5 | 0.1 | 0.1 | 0.1% | 0.8% | 1.2% |
| 1A4bi Residential: Stationary | 6.3 | -6.4 | 0.5 | 0.3% | -6.1% | 0.9% |
| 1A4ci Agriculture/Forestry/Fishing: Stationary | 3.9 | 0.2 | 0.0 | 2.4% | 0.9% | 1.0% |
| Stationary combustion | -36.6 | -5.4 | 15.7 | -0.2% | -2.1% | 8.3% |

For stationary combustion plants, the emission estimates for the years 1990-2017 have been updated according to the latest energy statistics published by the Danish Energy Agency. The update included both end use and transformation and also a source category update. The changes in the energy statistics are largest for the years 2015, 2016 and 2017.

The disaggregation to industrial subsectors has been updated to the latest data set. The largest changes are for 2017 and for waste incineration in 2011.

The $CO_2$ emission factor for coal applied in other plants than public power and district heating plants have been revised. The emission factor applied for these plants was a default emission factor from the IPCC Guidelines (2006). However, based on an analysis of EU ETS data from 2006-2018 it was concluded that a common emission factor for coal should be applied. Plant specific emission factors have been applied for large industrial plants, and thus the recalculation is small. The recalculation of $CO_2$ the emission for 1990 is -1.9 kt or -0.005 % of the $CO_2$ emission from stationary combustion. The recalculation of $CO_2$ the emission for 2017 is -0.09 kt or -0.001 % of the $CO_2$ emission from stationary combustion.

The $CO_2$ emission factor for residual oil applied in other plants than public power and district heating plants have been revised. The emission factor applied for these plants was a based on ET ETS data for 2006-2009. However, based on an analysis of EU ETS data from 2006-2018 it was concluded that a common emission factor for residual oil should be applied. Plant specific emission factors have been applied for large industrial plants, and thus the recalculation is small. The recalculation of $CO_2$ emission for 1990 is +1.4 kt or 0.004 % of the $CO_2$ emission from stationary combustion. The recalculation of $CO_2$ emission for 2017 is +0.03 kt or less than 0.001 % of the $CO_2$ emission from stationary combustion.

The disaggregation between different residential wood combustion technologies have been recalculated, and this causes minor changes in the estimated $CH_4$ emission from residential plants. The recalculation of $CH_4$ emission from residential wood combustion in 1990 is 0.11 kt or -1.6 % of the $CH_4$ emission from stationary combustion. The recalculation of $CH_4$ emission from residential wood combustion in 2017 is 0.26 kt or -2.5 % of the $CH_4$ emission from stationary combustion.

The $N_2O$ emission for 2017 has been recalculated due to improved plant specific data from two mineral wool production plants.

### 3.2.9 Response to the review process

The table below contains the recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory. The table details the status of implementation of the recommendations as well as references to where improvements have been implemented in this report.

Table 3.2.44 Response to the review process

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| 2018 submission (Review report: https://unfccc.int/sites/default/files/resource/dnk_0.pdf) | | | | |
| E.2 | 1.A.1 Energy industries – other fossil fuels – $CO_2$ | Continue the analyses with subsequent years of EU ETS EFs on how to improve earlier time series EFs and the consistency of the full time series. Addressing. Denmark revised the $CO_2$ EFs for 2011–2016 based on plant-specific EU ETS data. In Table 9.6 of the NIR Denmark indicated that the time series for earlier years will be further analysed; import of waste and the fossil energy share may be revised, if necessary, based on the ongoing analysis. | The work is ongoing. The collected data will not necessarily lead to a recalculation of the $CO_2$ emission factor time series. The ongoing work will be mentioned in NIR chapter 3.2.5, Emission factors. | NIR 3.2.5 |
| E.6 | 1. General (energy sector) | The ERT noted that in response to recommendation ID#E.4 from the ARR 2016 (see ID# E.1 in table 3), Denmark included additional information on the calculation of indirect emissions from the energy sector in section 11 of the NIR. However, in trying to replicate the estimates, the ERT arrived at results for indirect $CO_2$ and $N_2O$ emissions that differed from the values reported by the Party in CRF table 6. During the review, Denmark identified some minor errors in the estimates and indicated that the indirect $CO_2$ emissions were slightly overestimated owing to the inclusion of the sources where the default IPCC $CO_2$ EFs (i.e. the oxidation factor is 1) for kerosene, brown coal, LPG and coke were used. Moreover, the indirect $N_2O$ emissions were slightly underestimated owing to the exclusion of biomass fuels in the estimate.<br>The ERT recommends that Denmark report the correct estimates of indirect $CO_2$ emissions by excluding the sources where the default IPCC $CO_2$ EFs were used and of indirect $N_2O$ emissions by including the emissions from biomass. | The errors identified has been corrected. | CRF |
| E.7 | International bunkers and multilateral operations – liquid fuels – $CO_2$ | The ERT noted discrepancies between CRF tables 1.D. and 1.A(b) for jet kerosene reported for international aviation bunkers for the time series 1990–2000. Discrepancies also occur between CRF table 1.D and table 1.A(b) for residual fuel oil (international navigation bunkers). For example, in 2016 the value reported in CRF table 1.D is 8,933.71 TJ and the value reported in CRF table 1.A(b) is 9,162.67 TJ. During the review, Denmark explained that the discrepancies are due to an error in reported fuel values in the reference approach which will be corrected in the next submission.<br>The ERT recommends that the Party ensure consistent reporting between CRF tables 1.D and 1.A(b) for jet kerosene consumed in international aviation bunkers (1990–2000) and for residual fuel oil consumed in international navigation bunkers. | The data for international bunkers applied in the reference approach have been corrected. | NIR 3.4 |

### 3.2.10 Planned improvements

Four emission source categories based on tier 1 approach have been identified as key sources this year. If sufficient data are available, a tier 2 approach will be applied next year.

### 3.2.11 References for Chapter 3.2 and Annex 3A

Affaldsdatasystemet (ADS), 2019: Danish waste statistics for 2011-2016. Available at:
https://www.ads.mst.dk/Forms/Reports/R003_Behandlede_Maengder.aspx (2020-01-31).

Andersen, M.A. 1996: Elkraft, personal communication letter 07-05-1996.

Astrup, T., Larsen, A.W., Fuglsang, K. & Pedersen, N.H. 2012: PSO-0213, Biogenic Carbon in Danish Combustible Waste. DTU, 2012.

Bruun, J. 2012: Energinet.dk, personal communication, email 03-01-2012.

Christiansen, M., 1996: Elsam, personal communication, letter 07-05-1996.

Danish Energy Agency (DEA), 2003: Data for installation and fuel consumption for each gas engine 1994-2002. Estimated fuel consumption data for gas engines in 1990-1993. Unpublished.

Danish Energy Agency (DEA), 2016d: Notat om opdatering af elhandelskorrektion, 2016-04-04. Available at:
https://ens.dk/sites/ens.dk/files/Statistik/elhandelskorrektion.pdf (2020-01-31).

Danish Energy Agency (DEA), 2019a: The Danish energy statistics, Available at: https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics (2020-01-31).

Danish Energy Agency (DEA), 2019b: The Danish energy statistics, Energy Producers Survey (Energiproducenttællingen) 1990-2018. Unpublished.

Danish Energy Agency (DEA), 2019c: The Danish energy statistics, International reporting. Available at: https://ens.dk/service/statistik-data-noegletal-og-kort/noegletal-og-internationale-indberetninger (2020-01-31).

Danish Energy Agency (DEA), 2019d: Energy statistics data, e-mail from Ali Zarnaghi 2020-01-16.

Danish Environmental Protection Agency (DEPA), 2005: Bekendtgørelse om begrænsning af emission af nitrogenoxider, uforbrændte carbonhydrider og carbonmonooxid mv. fra motorer og turbiner. Bekendtgørelse 621 af 23/06/2005. (Danish legislation). Available at:
https://www.retsinformation.dk/Forms/R0710.aspx?id=12836&exp=1 (2020-01-31).

Danish Environmental Protection Agency (DEPA), 2010b: Bekendtgørelse om visse virksomheders afgivelse af miljøoplysninger. Bekendtgørelse 210 af 03/03/2010. (Danish legislation). Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=128761 (2020-01-31).

Danish Environmental Protection Agency (DEPA), 2015: Bekendtgørelse om et register over udledning og overførsel af forurenende stoffer (PRTR). Bekendtgørelse 1172 af 13/10/2015. (Danish legislation). Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=174453 (2020-01-31).

EU Commission, 2018: REGULATIONS, COMMISSION IMPLEMENTING REGULATION (EU) 2018/2066 of 19 December 2018 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 601/2012 Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R2066&from=EN (2020-01-31).

European Environment Agency (EEA), 2019: EMEP/EEA air pollutant emission inventory guidebook 2019. Available at: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (2020-01-31).

Fauser, P., Nielsen, M., Winther, M., Plejdrup, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Hoffmann, L., Thomsen, M., Hjelgaard, K. & Nielsen, O.-K. 2013. Verification of the Danish 1990, 2000 and 2010 emission inventory data. Aarhus University, DCE – Danish Centre for Environment and Energy, 85 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 79. V Available at: http://dce2.au.dk/pub/SR79.pdf (2020-01-31).

Fellner, J. & Rechberger, H. 2010: Biomass Content in the Waste Feed of Danish Waste-to-energy Plant, TU Wien, 2010. (Enclosed as Annex 10 in Astrup et al., 2012).

Fenhann, J. & Kilde, N.A. 1994: Inventory of Emissions to the air from Danish Sources 1972-1992, RISØ.

Henriksen, 2005: e-mail from Arne Henriksen, Elsam Engineering, 2005-08-11. Unpublished emission measurement data for $N_2O$ from 3 power plants combusting coal.

IPCC, 2000: Penman, J., Kruger, D., Galbally, I., Hiraishi, T., Nyenzi, B., Emmanuel, S., Buendia, L., Hoppaus, R., Martinsen, T., Meijer, J., Miwa, K. & Tanabe, K. (Eds). Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Published: IPCC/OECD/IEA/IGES, Hayama, Japan. Available at: http://www.ipcc-nggip.iges.or.jp/public/gp/english/index.html (2020-01-31).

IPCC, 2006: Revised 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (2020-01-31).

Jensen, B.G. & Lindroth, M. 2002: Kontrol af indberetning af $CO_2$-udledning fra el-producenter i 2001, Carl Bro for Energistyrelsens 6. Kontor (in Danish).

Jeppesen, J.S. 2007: København energi (Copenhagen Energy), Jørgen Steen Jeppesen, personal communication.

Johansson, L.S., Leckner, B., Gustavsson, L., Cooper, D., Tullin, C. & Potter, A. 2004: Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets, Atmospheric Environment 38 (2004) 4183-4195.

Jørgensen, L., Andersen, S. D., Lovett, D. M. & Kristensen, P. G., 2010: Emissionskortlægning for decentral kraftvarme 2007, Måleprogram og analyse af emissioner fra gas- og oliefyrede decentrale kraftvarmeanlæg < 25 $MW_e$. Danish Gas Technology Centre. Available at: https://www.dgc.dk/publikation/2010/emissionskortlaegning-decentral-kraftvarme-2007 (2020-01-31).

Københavns Energi (KE), 2015: Københavns energi (Copenhagen Energy) fact sheet on town gas.

Kristensen, P.G. 2007: Danish Gas Technology Centre, Per Gravers Kristensen, personal communication.

Kristensen, P.G. 2010: Danish Gas Technology Centre, Per Gravers Kristensen, email 2010-02-10.

Kristensen, P.G. 2015a: Personal communication concerning biogas, e-mail 26-03-2014, Danish Gas Technology Centre.

Kristensen, P.G. 2015b: Personal communication concerning bio natural gas, e-mail 11-11-2015, Danish Gas Technology Centre.

Lindgren, 2010: Energinet.dk, Tine Lindgren, email 2010-03-16.

Nielsen, M. & Wit, J. 1997: Emissionsforhold for gasdrevne kraftvarmeænlæg < 25$MW_e$, Miljøstyrelsen, Arbejdsrapport Nr. 17 1997 (In Danish). Available at:
http://www2.mst.dk/Udgiv/publikationer/1997/87-7810-759-8/pdf/87-7810-759-8.pdf (2020-01-31).

Nielsen, M. & Illerup, J.B. 2003: Emissionsfaktorer og emissionsopgørelse for decentral kraftvarme. Eltra PSO projekt 3141. Kortlægning af emissioner fra decentrale kraftvarmeværker. Delrapport 6. Danmarks Miljøundersøgelser. 116 s. –Faglig rapport fra DMU nr. 442. (In Danish, with an English summary). Available at:
https://www.dgc.dk/publikation/2010/emissionskortlaegning-decentral-kraftvarme-2007 (2020-01-31).

Nielsen, M. & Illerup, J.B. 2004: Danish emission inventories for stationary combustion plants. Inventories until year 2002. National Environmental Research Institute, Denmark. 127pp. – Research Notes from NERI no. 200. Available at:
http://www2.dmu.dk/1_viden/2_Publikationer/3_arbrapporter/rapporter/AR200.pdf (2020-01-31).

Nielsen, M. & Illerup, J.B. 2006: Danish emission inventories for stationary combustion plants. Inventories until year 2003. National Environmental Research Institute, Denmark. 162 pp. – Research Notes from NERI no. 229. Available at:
http://www2.dmu.dk/1_viden/2_Publikationer/3_arbrapporter/rapporter/AR229.pdf (2020-01-31).

Nielsen, O.-K., Nielsen, M. & Illerup, J.B. 2007: Danish Emission Inventories for Stationary Combustion Plants. Inventories until year 2004. National Environmental Research Institute, University of Aarhus, Denmark. 176 pp. – NERI Technical Report no. 628. Available at:
http://www2.dmu.dk/Pub/FR628_Final.pdf (2020-01-31).

Nielsen, M., Illerup, J.B. & Birr-Petersen, K., 2008: Revised emission factors for gas engines including start/stop emissions. Sub-report 3 (NERI). National Environmental Research Institute, University of Aarhus. 69 pp. - NERI Technical Report No. 672. Available at:
http://www2.dmu.dk/Pub/FR672.pdf (2020-01-31).

Nielsen, M., Nielsen, O.-K., Plejdrup, M. & Hjelgaard, K., 2009: Danish Emission Inventories for Stationary Combustion Plants. Inventories until year 2007. National Environmental Research Institute, Aarhus University, Denmark. 216 pp. – NERI Technical Report no. 744. Available at:
http://www2.dmu.dk/Pub/FR744.pdf (2020-01-31).

Nielsen, M., Nielsen, O.-K. & Thomsen, M. 2010a: Emissions from decentralised CHP plants 2007 - Energinet.dk Environmental project no. 07/1882. Project report 5 – Emission factors and emission inventory for decentralised CHP production. National Environmental Research Institute, Aarhus University. 113 pp. – NERI Technical report No. 786. Available at:
http://www.dmu.dk/Pub/FR786.pdf (2020-01-31).

Nielsen, M., Nielsen, O.-K., Plejdrup, M. & Hjelgaard, K., 2010b: Danish Emission Inventories for Stationary Combustion Plants. Inventories until 2008. National Environmental Research Institute, Aarhus University, Denmark. 236 pp. – NERI Technical Report No. 795. Available at:
http://www.dmu.dk/Pub/FR795.pdf (2020-01-31).

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Gyldenkærne, S., Thomsen, M., Fauser, P., Nielsen, M. Mikkelsen, M.H., Albrektsen, R., Hjelgaard, K., Hoffmann, L. & Bruun, H.G. 2013a. Quality manual for the Danish greenhouse gas inventory. Version 2. Aarhus University, DCE – Danish Centre for Environment and Energy, 44 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 47. Available at:
http://www.dmu.dk/Pub/SR47.pdf (2020-01-31).

Nielsen, M., Nielsen, O.-K. & Plejdrup, M., 2014: Danish Emission Inventories for Stationary Combustion Plants. Inventories until 2011. Aarhus University, DCE – Danish Centre for Environment and Energy. Available at:
http://dce2.au.dk/pub/SR102.pdf (2020-01-31).

Nielsen, M., Nielsen, O.-K. & Plejdrup, M.S. 2018. Danish emission inventories for stationary combustion plants. Inventories until 2015. Aarhus University, DCE – Danish Centre for Environment and Energy, 324 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 279 http://dce2.au.dk/pub/SR279.pdf (2020-01-31).

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Mikkelsen, M.H., Nielsen, M., Gyldenkærne, S., Fauser, P., Albrektsen, R., Hjelgaard, K., Bruun, H.G. & Thomsen, M. 2020. Annual Danish Informative Inventory Report to UNECE. Emission inventories from the base year of the protocols to year 2018. Aarhus University, DCE – Danish Centre for Environment and Energy. Scientific Report from DCE – Danish Centre for Environment and Energy. Will be available at the AU homepage in 2020.

Nielsen, O.-K., Nielsen, M. & Plejdrup, M.S., 2020: Updating the emission model for residential wood combustion. Will be available at: https://dce.au.dk/udgivelser/vr/nr-351-400/ in 2020.

Olsson, M. & Kjällstrand, J. 2005: Low emissions from wood burning in an ecolabelled residential boiler, Atmospheric Environment 40 (2006) 1148-1158.

Paulrud, S., Kindbom, K., Cooper, K. & Gustafsson, T., 2005: Methane emissions from residential biomass combustion, SMED report 2005-10-14, IVL Swedish Environmental Research Institute and SCB, Statistics Sweden SMHI. Assignment for Swedish Environmental Protection Agency.

## 3.3 Transport and other mobile sources

The emission inventory basis for mobile sources is fuel consumption information from the Danish energy statistics. In addition, background data for road transport (fleet and mileage), air traffic (aircraft type, flight numbers, origin and destination airports), national sea transport (fuel surveys, ferry technical data, number of return trips, sailing time) and non-road machinery (engine no., engine size, load factor and annual working hours) are used to make the emission estimates sufficiently detailed. Emission data mainly comes from the EMEP/EEA Air Pollutant Emission Inventory Guidebook (EMEP/EEA, 2019). However, for railways, measurements specific to Denmark are used.

In the Danish emissions database, all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution) according to the CORINAIR system. The emission inventories are prepared from a complete emission database based on the SNAP sectors. The aggregation to the sector codes used for both the UNFCCC and UNECE Conventions is based on a correspondence list between SNAP and IPCC classification codes (CRF), shown in Table 3.3.1 (mobile sources only).

Table 3.3.1 SNAP – CRF correspondence table for transport.

| SNAP classification | CRF/NFR classification |
|---|---|
| 07 Road transport | 1A3bi Road transport: Passenger cars |
| | 1A3bii Road transport:Light duty vehicles |
| | 1A3biii Road transport:Heavy duty vehicles |
| | 1A3biv Road transport: Mopeds & motorcycles |
| 0801 Military | 1A5b Other, Mobile |
| 0802 Railways | 1A3c Railways |
| 0803 Inland waterways | 1A5b Other, Mobile |
| 080402 National sea traffic | 1A3dii National navigation (Shipping) |
| 080403 National fishing | 1A4ciii Agriculture/Forestry/Fishing: National fishing |
| 080404 International sea traffic | 1A3di (i) International navigation (Shipping) |
| 080501 Dom. airport traffic (LTO < 1000 m) | 1A3aii (i) Civil aviation (Domestic, LTO |
| 080502 Int. airport traffic (LTO < 1000 m) | 1A3ai (i) Civil aviation (International, LTO) |
| 080503 Dom. cruise traffic (> 1000 m) | 1A3aii (ii) Civil aviation (Domestic, Cruise) |
| 080504 Int. cruise traffic (> 1000 m) | 1A3ai (ii) Civil aviation (International, Cruise) |
| 0806 Agriculture | 1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry |
| 0807 Forestry | 1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry |
| 0808 Industry | 1A2gvii Manufacturing industries/Construction (mobile) |
| 0809 Household and gardening | 1A4bii Residential: Household and gardening (mobile) |
| 0811 Commercial and institutional | 1A4aii Commercial/Institutional: Mobile |

Military transport activities (land and air) refer to the CRF/NFR sector Other (1A5), the latter sector also including recreational craft (SNAP code 0803).

For aviation, LTO (Landing and Take Off)[1] refers to the part of flying which is below 1000 m. This part of the aviation emissions (SNAP codes 080501 and 080502) are included in the national emissions total as prescribed by the UNECE reporting rules. According to UNFCCC, the national emissions for aviation comprise the emissions from domestic LTO (0805010) and domestic cruise (080503). The fuel consumption and emission development explained in the following are based on these latter results.

Agricultural and forestry non-road machinery (SNAP codes 0806 and 0807) is accounted for in the Agriculture/forestry (1A4cii) sector. Fishing activities (SNAP code 080403) is reported under 1A4ciii.

For mobile sources, internal database models for road transport, air traffic, sea transport and non-road machinery have been set up at DCE, Aarhus University, in order to produce the emission inventories. The output results from the DCE models are calculated in a SNAP format, as activity rates (fuel consumption) and emission factors, which are then exported directly to the central Danish CollectER database.

Apart from national inventories, the DCE models are used also as a calculation tool in research projects, environmental impact assessment studies, and to produce basic emission information, which requires various aggregation levels.

A Key Category Analysis (KCA) approach 1 and approach 2 for the years 1990 and 2017 and for the trend 1990-2017 for Denmark has been carried out in

[1]A LTO cycle consists of the flying modes approach/descent, taxiing, take off and climb out. In principle, the actual times-in-modes rely on the actual traffic circumstances, the airport configuration, and the aircraft type in question.

accordance with the IPCC Guidelines (IPCC, 2006). Table 3.3.2 shows the 12 mobile source categories. The table is based on the analysis including LULUCF. The full key category analysis for Denmark is shown in NIR Chapter 1.5 and Annex 1.

Mobile sources include quite many key categories in the case of $CO_2$. Most notably, road transport and non-road mobile machinery in industry and agriculture are key sources in 1990 and 2017 and for the emission trend in both the approach 1 and approach 2 analysis. Also large vessels in navigation are a key source in 1990 and 2017 in both approach 1 and approach 2, and for the emission trend in approach 1. $CH_4$ is not a key category in any case for mobile sources. Finally, due to the relatively high uncertainty for $N_2O$, emission factors the $N_2O$ emission from a number of emission sources are also key categories in the approach 2 analysis.

Table 3.3.2 Key category overview[2], mobile sources.

| | | Approach 1 | | | Approach 2 | | |
|---|---|---|---|---|---|---|---|
| | | 1990 | 2018 | 1990-2018 | 1990 | 2018 | 1990-2018 |
| 1.A.2.g Industry (mobile) | $CO_2$ | Level | Level | Trend | Level | Level | Trend |
| 1.A.3.a Civil aviation | $CO_2$ | | Level | | | | |
| 1.A.3.b Road Transport | $CO_2$ | Level | Level | Trend | Level | Level | Trend |
| 1.A.3.c Railways | $CO_2$ | Level | Level | | | | |
| 1.A.3.d Navigation (large vessels) | $CO_2$ | Level | Level | Trend | Level | Level | |
| 1.A.4.a Commercial/Institutional (mobile) | $CO_2$ | | | | | | |
| 1.A.4.b Residential (mobile) | $CO_2$ | | | | | | |
| 1.A.4.c ii Agriculture (mobile) | $CO_2$ | Level | Level | Trend | Level | Level | Trend |
| 1.A.4.c ii Forestry (mobile) | $CO_2$ | | | | | | |
| 1.A.4.c iii Fisheries | $CO_2$ | Level | Level | | | | |
| 1.A.5.b Other (military) | $CO_2$ | | | | | | Trend |
| 1.A.5.b Other (small boats) | $CO_2$ | | Level | | | | |
| 1.A.2.g Industry (mobile) | $CH_4$ | | | | | | |
| 1.A.3.a Civil aviation | $CH_4$ | | | | | | |
| 1.A.3.b Road Transport | $CH_4$ | | | | | | |
| 1.A.3.c Railways | $CH_4$ | | | | | | |
| 1.A.3.d Navigation (large vessels) | $CH_4$ | | | | | | |
| 1.A.4.a Commercial/Institutional (mobile) | $CH_4$ | | | | | | |
| 1.A.4.b Residential (mobile) | $CH_4$ | | | | | | |
| 1.A.4.c ii Agriculture (mobile) | $CH_4$ | | | | | | |
| 1.A.4.c ii Forestry (mobile) | $CH_4$ | | | | | | |
| 1.A.4.c iii Fisheries | $CH_4$ | | | | | | |
| 1.A.5.b Other (military) | $CH_4$ | | | | | | |
| 1.A.5.b Other (small boats) | $CH_4$ | | | | | | |
| 1.A.2.g Industry (mobile) | $N_2O$ | | | | | Level | Trend |
| 1.A.3.a Civil aviation | $N_2O$ | | | | | | |
| 1.A.3.b Road Transport | $N_2O$ | | | | | Level | Trend |
| 1.A.3.c Railways | $N_2O$ | | | | | | |
| 1.A.3.d Navigation (large vessels) | $N_2O$ | | | | | | |
| 1.A.4.a Commercial/Institutional (mobile) | $N_2O$ | | | | | | |
| 1.A.4.b Residential (mobile) | $N_2O$ | | | | | | |
| 1.A.4.c ii Agriculture (mobile) | $N_2O$ | | | | Level | Level | Trend |
| 1.A.4.c ii Forestry (mobile) | $N_2O$ | | | | | | |
| 1.A.4.c iii Fisheries | $N_2O$ | | | | | | |
| 1.A.5.b Other (military) | $N_2O$ | | | | | | |

[2] For Denmark, not including Greenland & Faroe Island. Based on the KCA including LULUCF.

### 3.3.1 Source category description

The following description of source categories explains the development in fuel consumption and emissions for road transport and other mobile sources.

#### Fuel consumption

Table 3.3.3 shows the fuel consumption for domestic transport based on DEA statistics for 2018 in CRF sectors. The fuel consumption figures in time series 1985-2018 are given in Annex 2.B.16 (CRF format) and are shown for 2018 in Annex 2.B.15 (CollectER format). Road transport has a major share of the fuel consumption for domestic transport. In 2018, this sector's fuel consumption share is 80 %, while the fuel consumption shares for Off road agriculture/forestry, Manufacturing industries (mobile) and National navigation are 7 %, 4 % and 4 %, respectively. For the remaining sectors, the total fuel consumption share is 5 %.

Table 3.3.3 Fuel consumption (PJ) for domestic transport in 2018 in CRF sectors.

| CRF ID | Fuel consumption (PJ) |
|---|---|
| Manufacturing industries/Construction (mobile) | 8.2 |
| Civil aviation (Domestic) | 1.8 |
| Road transport: Passenger cars | 96.7 |
| Road transport:Light duty vehicles | 24.4 |
| Road transport:Heavy duty vehicles | 53.9 |
| Road transport: Mopeds & motorcycles | 0.7 |
| Railways | 3.0 |
| National navigation (Shipping) | 8.3 |
| Commercial/Institutional: Mobile | 1.2 |
| Residential: Household and gardening (mobile) | 0.3 |
| Agriculture/Forestry/Fishing: Off-road agriculture/forestry | 14.3 |
| Agriculture/Forestry/Fishing: National fishing | 3.6 |
| Other. Mobile | 2.9 |
| Road transport total | 175.6 |
| Other mobile total | 43.8 |
| Domestic total | 219.4 |
| Civil aviation (International) | 42.3 |
| Navigation (international) | 22.8 |

From 1990 to 2018, diesel (sum of diesel and biodiesel) and gasoline (sum of neat gasoline and bio ethanol) fuel consumption has changed by 54 % and -17 %, respectively (Figure 3.3.1), and in 2018 the fuel consumption shares for diesel and gasoline were 71 % and 26 %, respectively (not shown). Other fuels only have a 2 % share of the domestic transport total (Figures 3.3.2). Almost all gasoline is used in road transportation vehicles. Gardening machinery and recreational craft are merely small consumers. Regarding diesel, there is considerable fuel consumption in most of the domestic transport categories, whereas a more limited use of residual oil and jet fuel is being used in the navigation sector and by aviation (civil and military flights), respectively[3].

[3] Biofuels are sold at gas filling stations and assumed used by road transport vehicles.

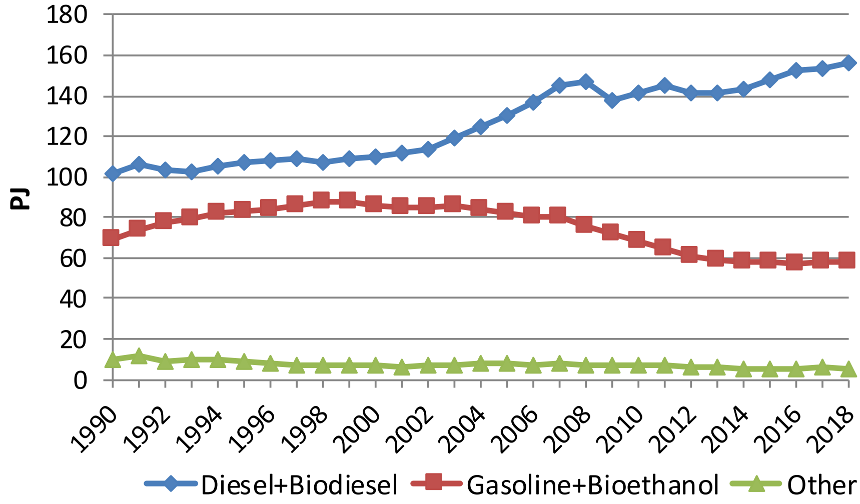



Figure 3.3.1 Fuel consumption per fuel type for domestic transport 1990-2018.

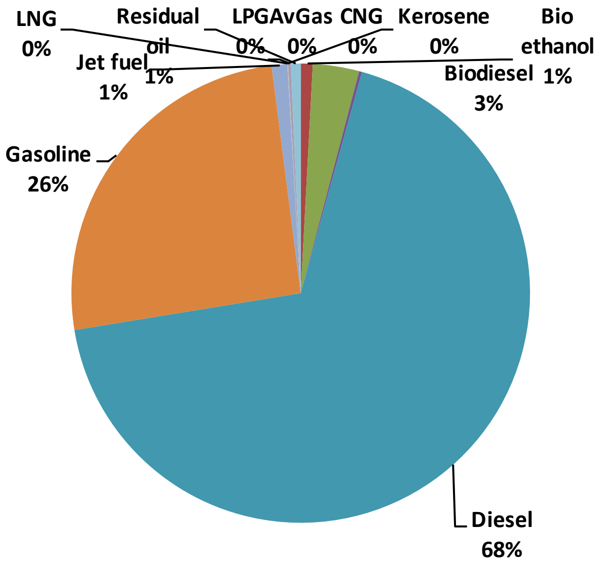



Figure 3.3.2 Fuel consumption share per fuel type for domestic transport in 2018.

**Road transport**

As shown in Figure 3.3.3, the fuel consumption for road transport[4] has generally increased until 2007, except from a small fuel consumption decline noted in 2000. The impact of the global financial crisis on fuel consumption for road transport becomes visible for 2008 and 2009. The fuel consumption development is due to a decreasing trend in the use of gasoline fuels from 1999 to 2013 combined with a steady growth in the use of diesel until 2007, and from 2014 onwards. Within sub-sectors, passenger cars represent the most fuel-consuming vehicle category, followed by heavy-duty vehicles, light duty vehicles and 2-wheelers, in decreasing order (Figure 3.3.4).

[4] The sum share of bioethanol and biodiesel in the gasoline and diesel fuel blends for road transport is 4.2 %, in 2018.

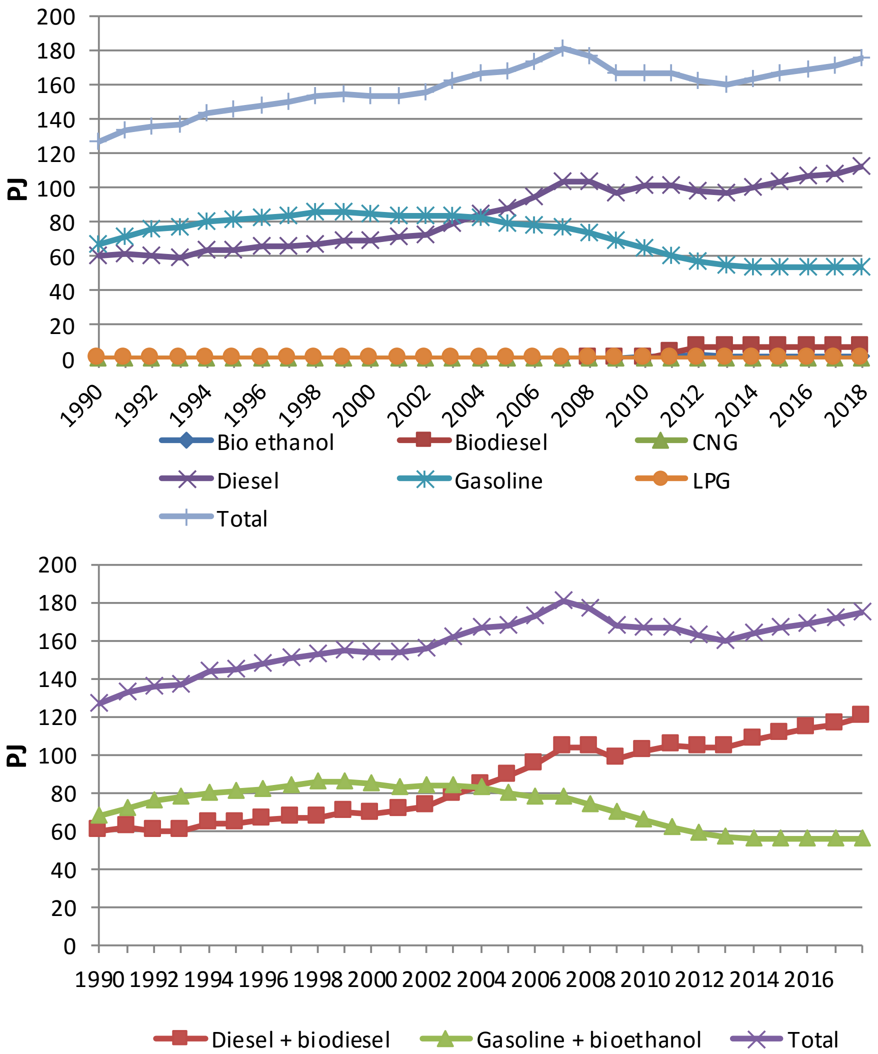



Figure 3.3.3 Fuel consumption per fuel type and as totals for road transport 1990-2018.

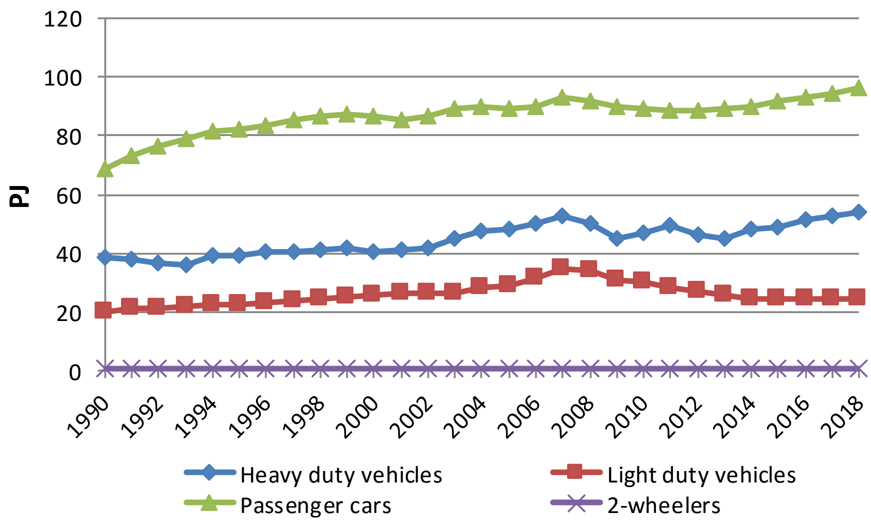



Figure 3.3.4 Total fuel consumption per vehicle type for road transport 1990-2018.

As shown in Figure 3.3.5, fuel consumption for gasoline passenger cars dominates the overall gasoline consumption trend. The development in diesel fuel consumption in recent years (Figure 3.3.6) is characterized by increasing fuel consumption for diesel passenger cars, while declines in the fuel consumption for trucks and buses (heavy-duty vehicles) and light duty vehicles are noted for 2008- 2009, 2012-2013, and 2008-2014, respectively.

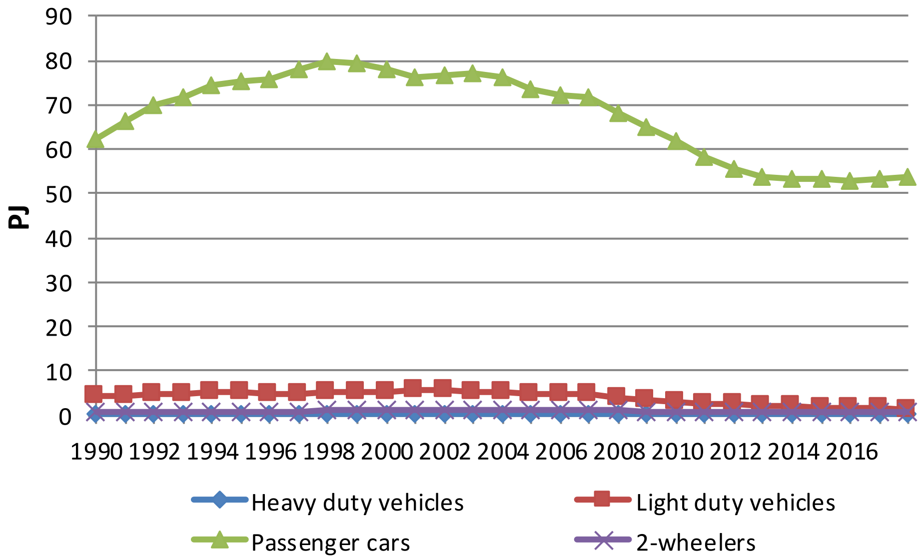



Figure 3.3.5 Gasoline fuel consumption per vehicle type for road transport 1990-2018.

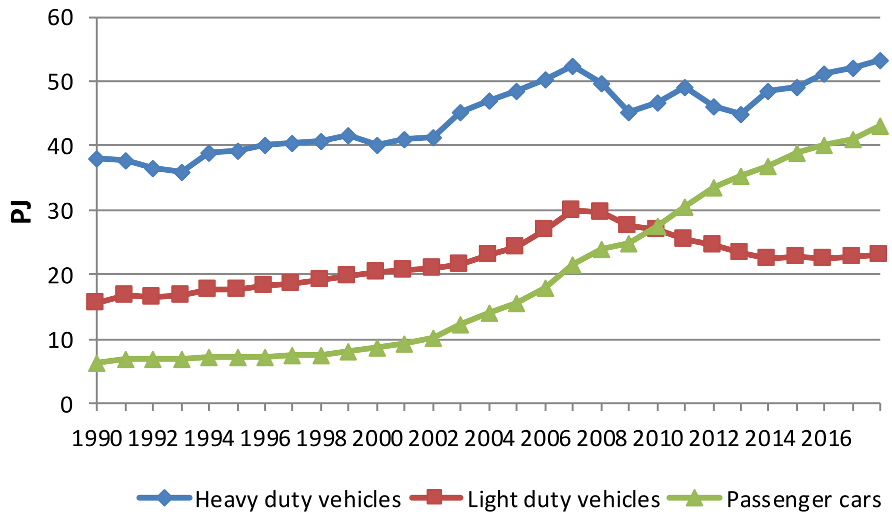



Figure 3.3.6 Diesel fuel consumption per vehicle type for road transport 1990-2018.

In 2018, fuel consumption shares for gasoline passenger cars, diesel heavy-duty vehicles, diesel passenger cars, diesel light duty vehicles and gasoline light duty vehicles were 31, 30, 25 and 13 %, respectively (Figure 3.3.7).

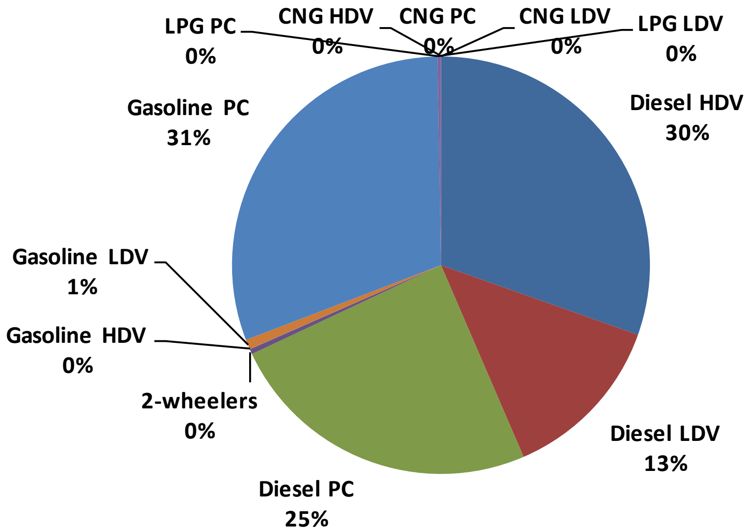



Figure 3.3.7 Fuel consumption share (PJ) per vehicle type for road transport in 2018.

### Other mobile sources

It must be noted that the fuel consumption figures behind the Danish inventory for mobile equipment in the agriculture, forestry, industry, household and gardening (residential), and inland waterways (part of navigation) sectors, are less certain than for other mobile sectors. For these types of machinery, the DEA statistical figures do not directly provide fuel consumption information, and fuel consumption totals are subsequently estimated from activity data and fuel consumption factors. For recreational craft the latest historical year is 2004.

As seen in Figure 3.3.8, classified according to CRF the most important sectors are Agriculture/forestry/fisheries (1A4c), Industry-other (mobile machinery part of 1A2g) and Navigation (1A3d). Minor fuel consuming sectors are Civil Aviation (1A3a), Railways (1A3c), Other (military mobile and recreational craft: 1A5b), Commercial/institutional (1A4a) and Residential (1A4b).

The 1990-2018 time series are shown per fuel type in Figures 3.3.9-3.3.12 for diesel, gasoline, residual oil and jet fuel, respectively.

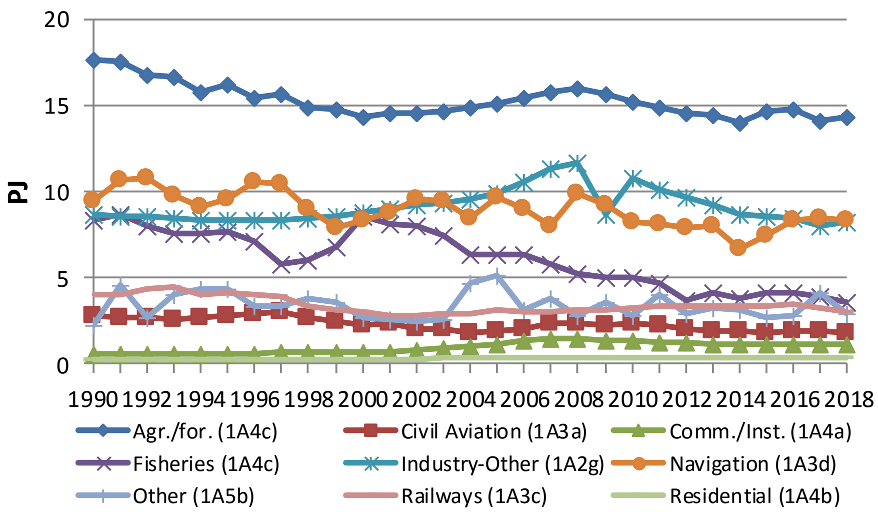



Figure 3.3.8 Total fuel consumption in CRF sectors for other mobile sources 1990-2018.

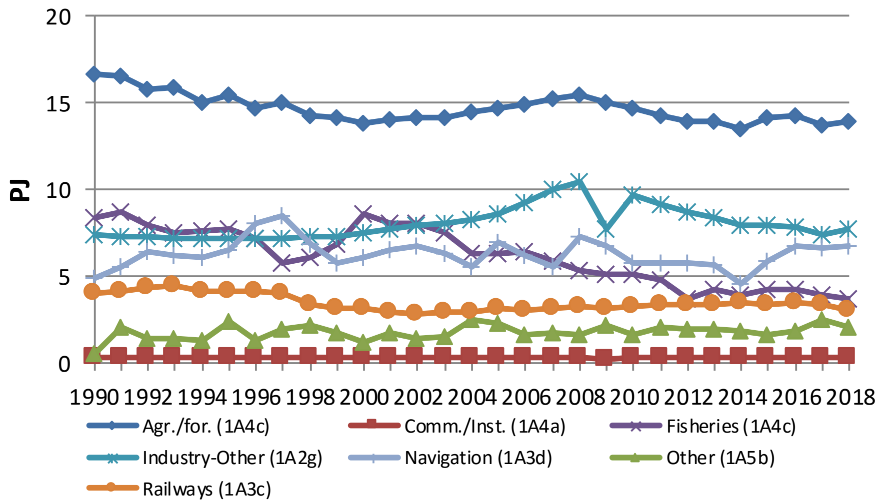



Figure 3.3.9 Diesel fuel consumption in CRF sectors for other mobile sources 1990-2018.

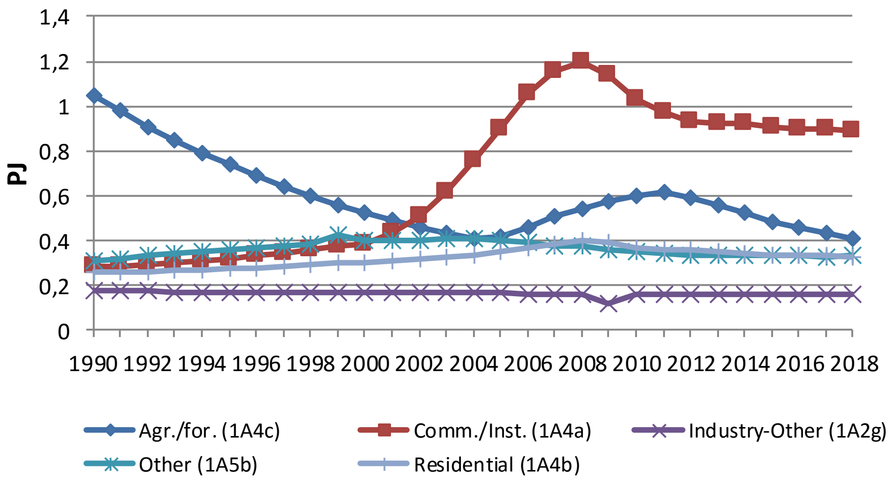



Figure 3.3.10 Gasoline fuel consumption in CRF sectors for other mobile source 1990-2018.

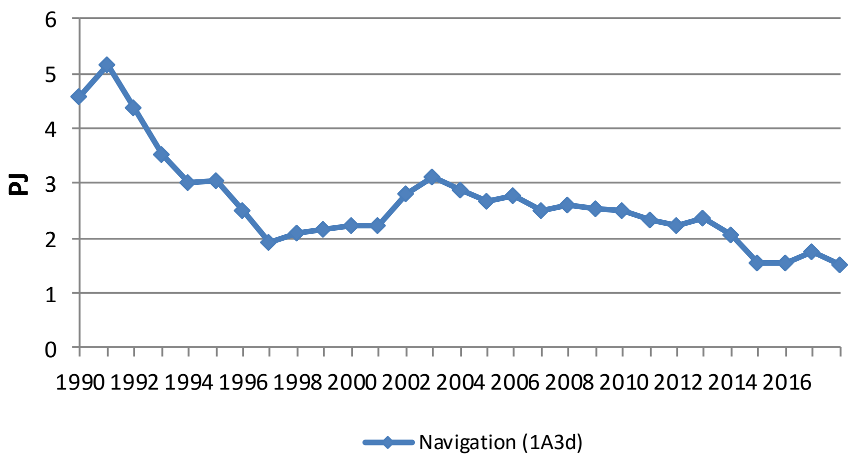



Figure 3.3.11 Residual oil fuel consumption in CRF sectors for other mobile sources 1990-2018.

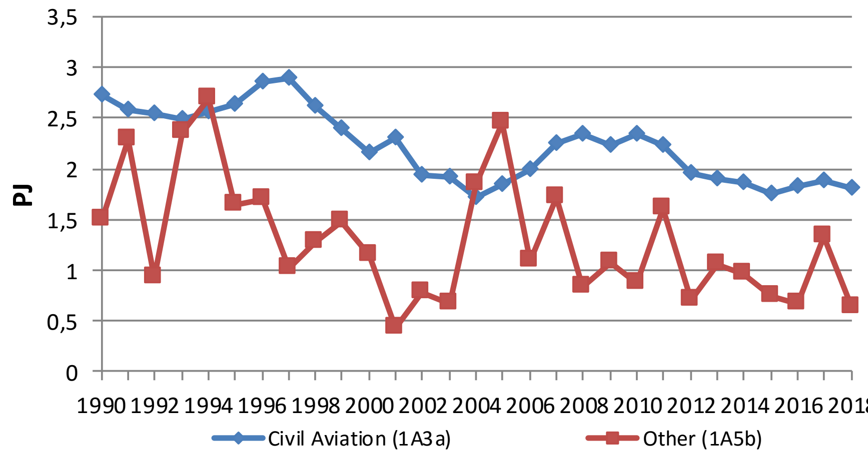



Figure 3.3.12 Jet fuel consumption in CRF sectors for other mobile sources 1990-2018.

In terms of diesel, the fuel consumption decreases for agricultural machines until 2000, due to fewer numbers of tractors and harvesters. After 2000, the increase in the engine sizes of new sold machines makes the total fuel consumption grow until 2008, whereas from 2008 to 2013 the turnover of old less fuel efficient machinery is the key factor for the total fuel consumption decrease. The fuel consumption for industry has increased from the beginning of the 1990's, due to an increase in the activities for construction machinery. The fuel consumption increase has been very pronounced in 2005-2008, for 2009; however, the global financial crisis has a significant impact on the building and construction activities. From 2009 onwards the fuel efficiency improvements for new sold vehicles is the main reason for total fuel consumption decline. For fisheries, the development in fuel consumption reflects the activities in this sector.

The Navigation sector comprises national sea transport (fuel consumption between two Danish ports including sea travel directly between Denmark and Greenland/Faroe Islands). For national sea transport, the diesel fuel consumption curve reflects the combination of traffic and ferries in use for regional ferries. In 1998 and 1999, a significant decline in fuel consumption is apparent. The most important explanation here is the closing of ferry service routes in connection with the opening of the Great Belt Bridge in 1997. For railways, the gradual shift towards electrification explains the lowering trend in diesel fuel consumption and the emissions for this transport sector. The fuel consumed (and associated emissions) to produce electricity is accounted for in the stationary combustion part of the Danish inventories.

The largest gasoline fuel consumption is calculated for the Commercial/Institutional (1A4a) sector related to the use of household and gardening machinery. For these types of machinery, a somewhat smaller gasoline fuel consumption is calculated for the Residential (1A4b) sector. For household and gardening equipment, especially from 2001-2006, a significant fuel consumption increase is apparent due to considerable growth in the machinery stock. The gasoline fuel consumption development for Agriculture/forestry/fisheries (1A4c) is due to the gradual phasing out of gasoline-fuelled agricultural tractors until 2005 and the gradual increase in the use of ATV's from the mid 2000's.

In terms of residual oil, there has been a substantial decrease in the fuel consumption for regional ferries. The fuel consumption decline is most significant from 1991-1994 and from 1995-1997.

The considerable variations from one year to another in military jet fuel consumption are due to planning and budgetary reasons, and the passing demand for flying activities. Consequently, for some years, a certain amount of jet fuel stock-building might disturb the real picture of aircraft fuel consumption. Civil aviation has decreased until 2004, since the opening of the Great Belt Bridge in 1997, both in terms of number of flights and total jet fuel consumption. From 2011 to 2012, the total consumption of jet fuel decreased significantly due to a drop in the number of domestic flights.

**Bunkers**

The residual oil and diesel oil fuel consumption fluctuations reflect the quantity of fuel sold in Denmark to international ferries, international warships, other ships with foreign destinations, tank vessels and foreign fishing boats. For jet petrol, the sudden fuel consumption drop in 2002 is explained by the recession in the air traffic sector due to the events of September 11, 2001 and structural changes in the aviation business. In 2009, the impact of the global financial crisis on flying activities becomes very visible.

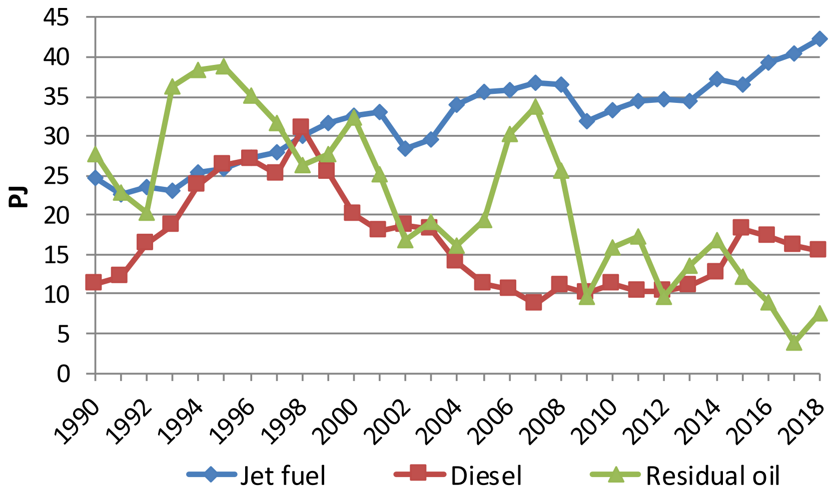



Figure 3.3.13 Bunker fuel consumption 1990-2018.

**Emissions of $CO_2$, $CH_4$ and $N_2O$**

In Table 3.3.4 the $CO_2$, $CH_4$ and $N_2O$ emissions for road transport and other mobile sources are shown for 2018 in CRF sectors. The emission figures in time series 1990-2018 are given in Annex 3.B.16 (CRF format) and are shown for 1990 and 2018 in Annex 3.B.15 (CollectER format).

From 1990 to 2018, the road transport emissions of $CO_2$ and $N_2O$ have increased by 32 and 51 %, respectively, whereas the emissions of $CH_4$ have decreased by 88 % (from Figures 3.3.14 - 3.3.16). From 1990 to 2018 the other mobile $CO_2$ emissions have decreased by 19 %, (from Figures 3.3.18 - 3.3.20).

Table 3.3.4 Emissions of $CO_2$, $CH_4$ and $N_2O$ in 2018 for road transport and other mobile sources.

| | $CO_2$ ktonnes | $CH_4$ tonnes | $N_2O$ tonnes |
|---|---|---|---|
| Manufacturing industries/Construction (mobile) | 605 | 21 | 28 |
| Civil aviation (Domestic) | 133 | 1 | 7 |
| Road transport: Passenger cars | 6798 | 226 | 159 |
| Road transport:Light duty vehicles | 1703 | 9 | 50 |
| Road transport:Heavy duty vehicles | 3756 | 58 | 235 |
| Road transport: Mopeds & motorcycles | 49 | 77 | 1 |
| Railways | 224 | 4 | 7 |
| National navigation (Shipping) | 621 | 37 | 16 |
| Commercial/Institutional: Mobile | 83 | 33 | 2 |
| Residential: Household and gardening (mobile) | 23 | 17 | 0 |
| Agriculture/Forestry/Fishing: Off-road agriculture/forestry | 1057 | 74 | 50 |
| Agriculture/Forestry/Fishing: National fishing | 269 | 7 | 7 |
| Other, Mobile | 215 | 9 | 8 |
| Road transport exhaust total | 12307 | 371 | 445 |
| Road transport non exhaust total | 0 | 0 | 0 |
| Other mobile sources total | 3230 | 202 | 124 |
| Domestic total | 15537 | 573 | 569 |
| Civil aviation (International) | 3045 | 12 | 102 |
| Navigation (International) | 1720 | 44 | 43 |

### Road transport

$CO_2$ emissions are directly fuel consumption dependent and, in this way, the development in the emission reflects the trend in fuel consumption. As shown in Figure 3.3.14, the most important emission source for road transport is passenger cars, followed by heavy-duty vehicles, light-duty vehicles and 2-wheelers in decreasing order. In 2018, the respective emission shares were 55, 31, 14 and 0 %, respectively (Figure 3.3.17).

The majority of $CH_4$ emissions from road transport come from gasoline passenger cars (Figure 3.3.15). The emission drop from 1992 onwards is explained by the penetration of catalyst cars into the Danish fleet. The 2018 emission shares for $CH_4$ were 61, 21, 16 and 2 % for passenger cars, 2-wheelers, heavy-duty vehicles and light-duty vehicles, respectively (Figure 3.3.17).

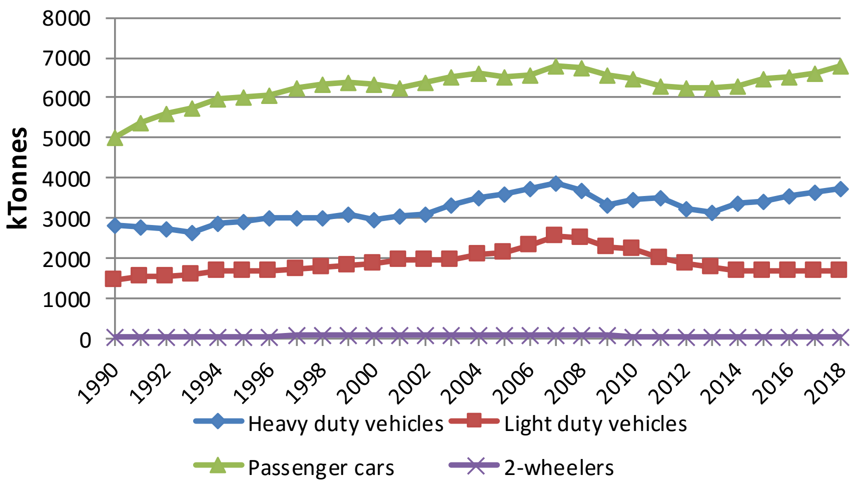



Figure 3.3.14 $CO_2$ emissions (k-tonnes) per vehicle type for road transport 1990-2018.

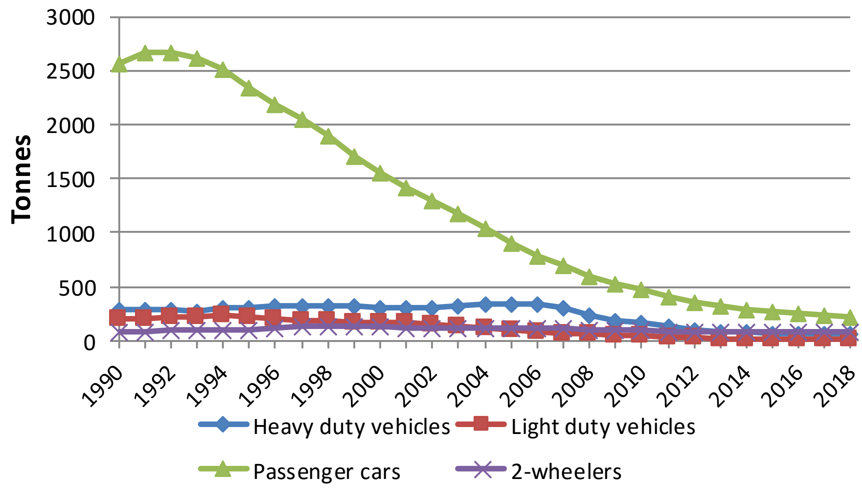



Figure 3.3.15 $CH_4$ emissions (tonnes) pr. vehicle type for road transport 1990-2018.

An undesirable environmental side effect of the introduction of catalyst cars is the increase in the emissions of $N_2O$ from the first generation of catalyst cars (Euro 1) compared to conventional cars. The emission factors for later catalytic converter technologies are considerably lower than the ones for Euro 1, thus causing the emissions to decrease from 1998 onwards (Figure 3.3.16). In 2018, emission shares for passenger cars, heavy and light-duty vehicles were 53, 36 and 11 %, of the total road transport $N_2O$, respectively (Figure 3.3.17).

Referring to the fourth IPCC assessment report, 1 g $CH_4$ and 1 g $N_2O$ has the greenhouse effect of 25 and 298 g $CO_2$, respectively. In spite of the relatively large $CH_4$ and $N_2O$ global warming potentials, the largest contribution to the total $CO_2$ emission equivalents for road transport comes from $CO_2$, and the $CO_2$ emission equivalent shares per vehicle category are almost the same as the $CO_2$ shares.

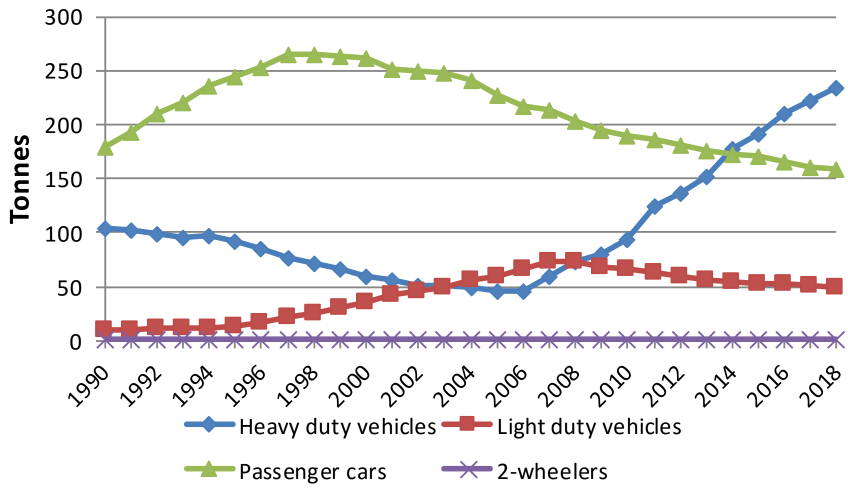



Figure 3.3.16 $N_2O$ emissions (tonnes) per vehicle type for road transport 1990-2018.

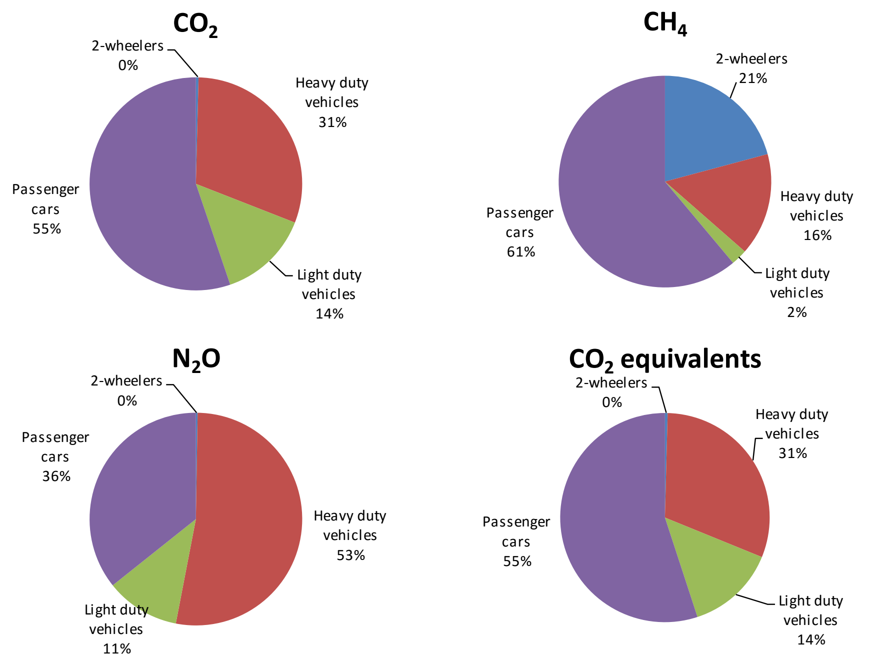



Figure 3.3.17 $CO_2$, $CH_4$ and $N_2O$ emission shares and GHG equivalent emission distribution for road transport in 2018.

### Other mobile sources

For other mobile sources, the highest $CO_2$ emissions in 2018 come from Agriculture/forestry/fisheries (1A4c), Industry-other (1A2g) and Navigation (1A3d), with shares of 41 %, 19 %, 19, respectively (Figure 3.3.21). The 1990-2018 emission trend is directly related to the fuel consumption development in the same time-period. Minor $CO_2$ emission contributors are sectors such as Commercial/Institutional (1A4a), Residential (1A4b), Railways (1A3c), Civil Aviation (1A3a) and Other (1A5).

For $CH_4$, the most important sources are Agriculture/forestry/fisheries (1A4c), Navigation (1A3d), Commercial/Institutional (1A4a), Industry-other (1A2g), and Residential (1A4b), see Figure 3.3.21. The emission shares are 40 %, 18 %, 16 %, 10 % and 9 %, respectively in 2018. For the remaining sectors the emission shares 4 % or less. The $CH_4$ emission contributions from Commercial/Institutional (1A4a) and Residential (1A4b) are quite high compared to their relative fuel consumption (and $CO_2$ emissions) contributions, due the high $CH_4$ emission factors for gasoline fueled working machinery in general.

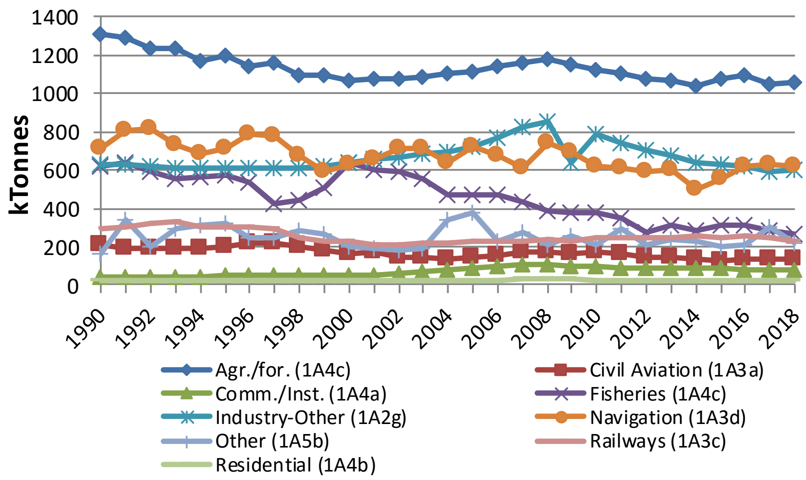



Figure 3.3.18 $CO_2$ emissions (ktonnes) in CRF sectors for other mobile sources 1990-2018.

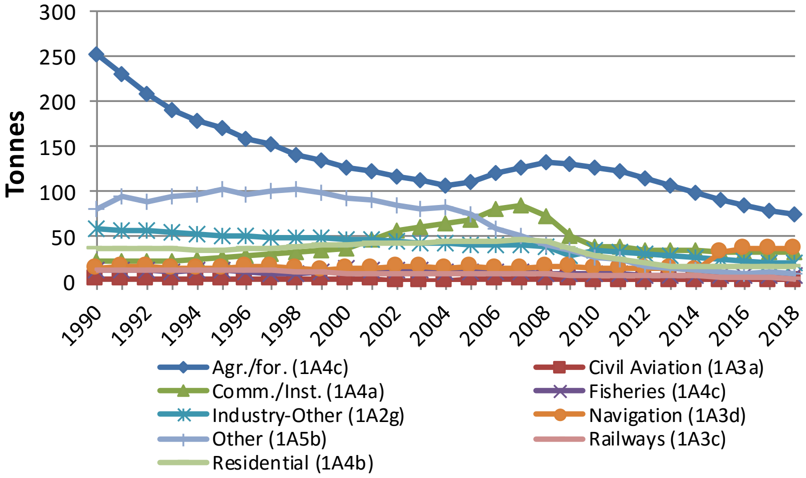



Figure 3.3.19 $CH_4$ emissions (tonnes) in CRF sectors for other mobile sources 1990-2018.

For $N_2O$, the emission trend in sub-sectors is the same as for fuel consumption and $CO_2$ emissions (Figure 3.3.20).

As for road transport, $CO_2$ alone contributes with by far the most $CO_2$ emission equivalents in the case of other mobile sources, and per sector the $CO_2$ emission equivalent shares are almost the same as those for $CO_2$, itself (Figure 3.3.21).

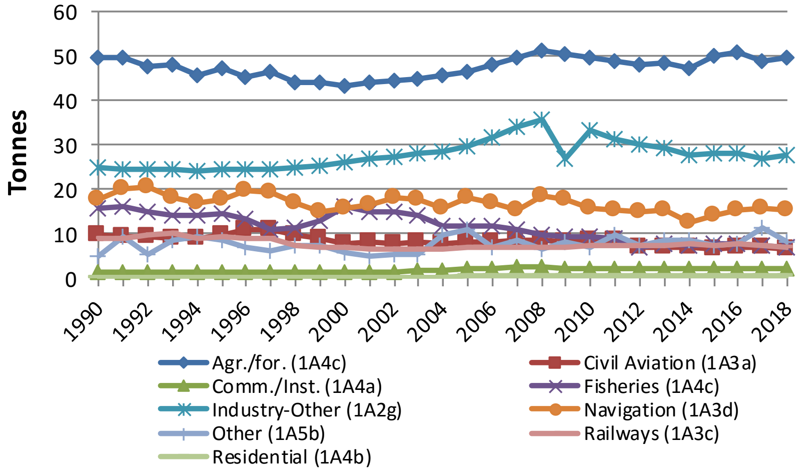



Figure 3.3.20 $N_2O$ emissions (tonnes) in CRF sectors for other mobile sources 1990-2018.

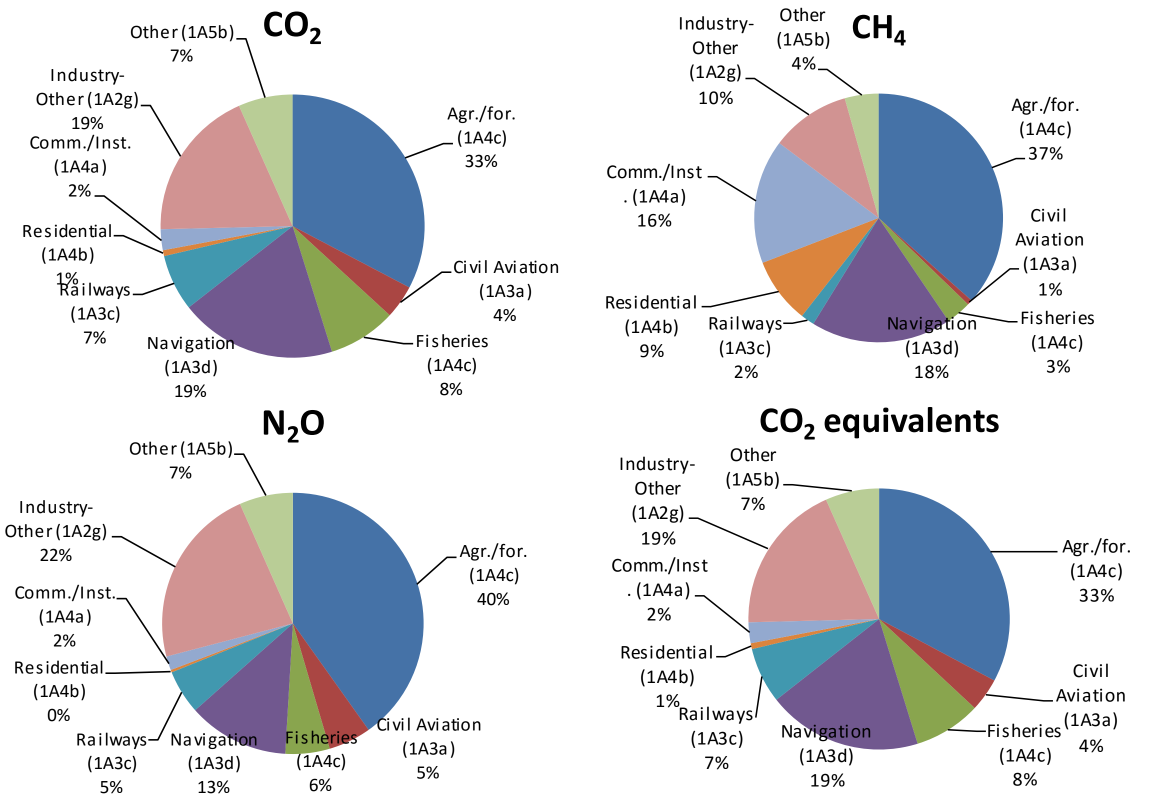



Figure 3.3.21 $CO_2$, $CH_4$ and $N_2O$ emission shares and GHG equivalent emission distribution for other mobile sources in 2018.

### Emissions of $SO_2$, $NO_X$, NMVOC and CO

For road transport and other mobile sources the emission figures of $SO_2$, $NO_X$, NMVOC and CO in the time series 1990-2018 are given in Annex 3.B.16 (CRF format) and are shown for 1990 and 2018 in Annex 3.B.15 (CollectER format). For further explanations regarding these emissions, please refer to the Danish IIR report (Nielsen et al. 2019).

### Bunkers

The most important emissions from bunker fuel consumption (fuel consumption for international transport) are $SO_2$ and $NO_X$. In terms of greenhouse gas emissions, the level of emissions from Danish bunker fuel consumption are 28 %, 8 % and 24 %, respectively, for $CO_2$, $CH_4$ and $N_2O$, compared with the emission total for mobile sources in 2018.

The bunker emission totals of $CO_2$, $CH_4$ and $N_2O$ are shown in Table 3.3.4 for 2018, split into sea transport and civil aviation. All emission figures in the 1990-2018 time series are given in Annex 3.B.16 (CRF format). In Annex 3.B.15, the emissions are also given in CollectER format for the years 1990 and 2018.

For further explanations of $SO_2$ and $NO_x$ emissions from bunkers please refer to the Danish IIR report (Nielsen et al. 2019).

The differences in $CH_4$ emissions between navigation and civil aviation are much larger than the differences in fuel consumption (and derived $CO_2$ emissions), and display a poor emission performance for international sea transport. In broad terms, the emission trends shown in Figure 3.3.22 are similar to the fuel consumption development.

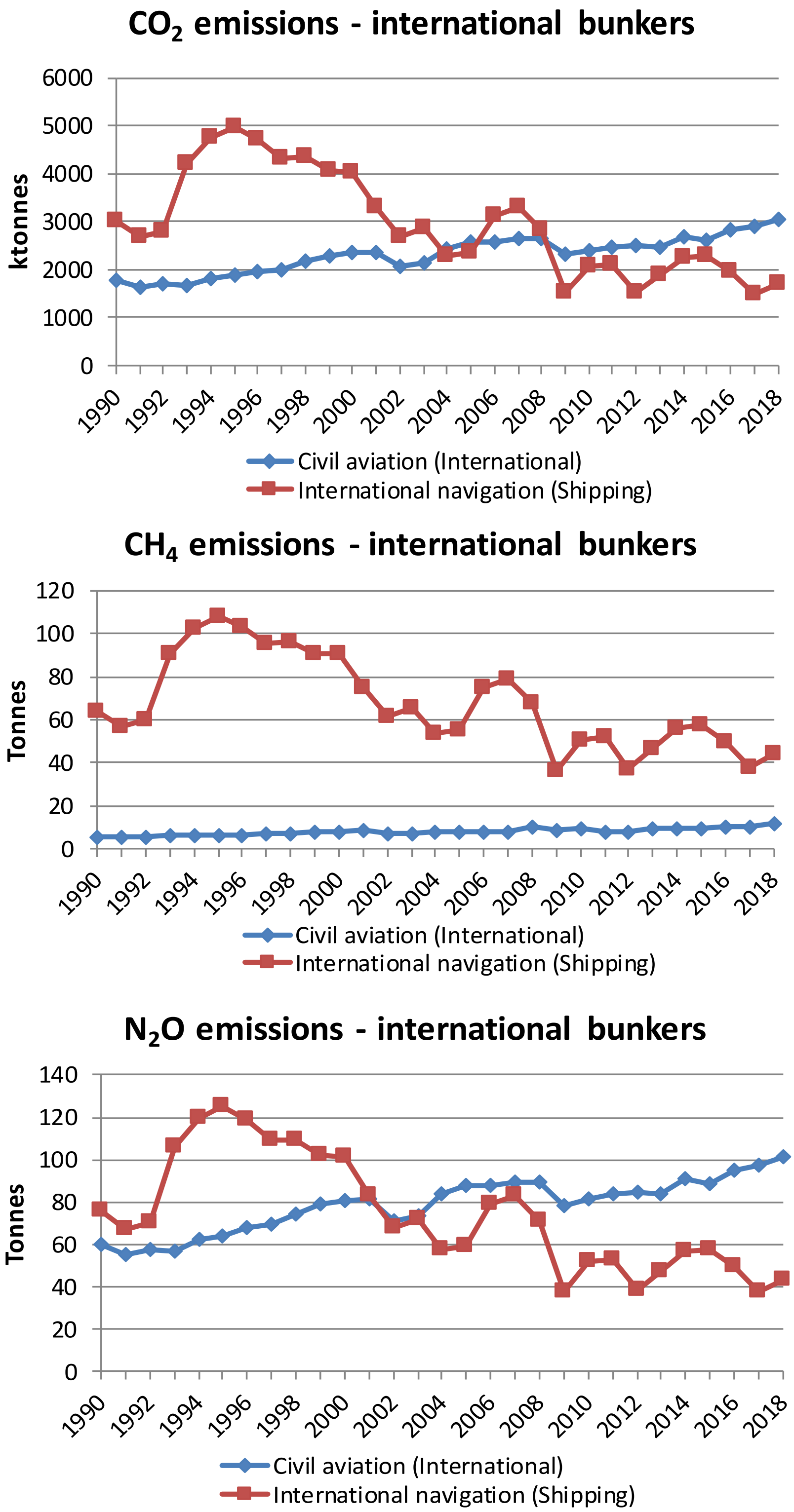



Figure 3.3.22 $CO_2$, $CH_4$ and $N_2O$ emissions for international transport 1990-2018.

### 3.3.2 Methodological issues

The description of methodologies and references for the transport part of the Danish inventory is given in two sections: one for road transport and one for the other mobile sources.

#### Methodology and references for Road Transport

For road transport, the detailed methodology (Tier 3) is used to make annual estimates of the Danish emissions, as described in the EMEP/EEA Air Pollutant Emission Inventory Guidebook (EMEP/EEA, 2019). The actual calculations are made with a model developed by ENVS, using the European COPERT 5 model methodology (EMEP/EEA, 2019). In COPERT, fuel consumption and emission simulations can be made for operationally hot engines, taking into account gradually stricter emission standards and emission degradation due to catalyst wear. Furthermore, the emission effects of cold-start and evaporation are simulated.

#### Vehicle fleet and mileage data

Corresponding to the COPERT 5 fleet classification, all present and future vehicles in the Danish fleet are grouped into vehicle classes, sub-classes and layers. The layer classification is a further division of vehicle sub-classes into groups of vehicles with the same average fuel consumption and emission behaviour, according to EU emission legislation levels. Table 3.3.5 gives an overview of the different model classes and sub-classes, and all model layers the complete list of layer level with implementation years are shown in Annex 3.B.1.

Table 3.3.5 Model vehicle classes and sub-classes and trip speeds.

| | | | Trip speed [km pr h] | | |
|---|---|---|---|---|---|
| Vehicle classes | Fuel type | Engine size/weight | Urban | Rural | Highway |
| PC | Gasoline | < 0.8 l. | 40 | 70 | 100 |
| PC | Gasoline | 0.8 - 1.4 l. | 40 | 70 | 100 |
| PC | Gasoline | 1.4 – 2 l. | 40 | 70 | 100 |
| PC | Gasoline | > 2 l. | 40 | 70 | 100 |
| PC | Diesel | < 0.8 l. | 40 | 70 | 100 |
| PC | Diesel | 0.8 - 1.4 l. | 40 | 70 | 100 |
| PC | Diesel | < 1.4 - 2 l. | 40 | 70 | 100 |
| PC | Diesel | > 2 l. | 40 | 70 | 100 |
| PC | 2-stroke | | 40 | 70 | 100 |
| PC | LPG | | 40 | 70 | 100 |
| PC | CNG | | 40 | 70 | 100 |
| PC | Plug-in hybrid | | 40 | 70 | 100 |
| LCV | Gasoline | <1305 kg | 40 | 65 | 80 |
| LCV | Gasoline | 1305-1760 kg | 40 | 65 | 80 |
| LCV | Gasoline | >1760 kg | 40 | 65 | 80 |
| LCV | Diesel | <1305 kg | 40 | 65 | 80 |
| LCV | Diesel | 1305-1760 kg | 40 | 65 | 80 |
| LCV | Diesel | >1760 kg | 40 | 65 | 80 |
| LCV | LPG | <1305 kg | 40 | 65 | 80 |
| LCV | LPG | 1305-1760 kg | 40 | 65 | 80 |
| LCV | LPG | >1760 kg | 40 | 65 | 80 |
| LCV | CNG | <1305 kg | 40 | 65 | 80 |
| LCV | CNG | 1305-1760 kg | 40 | 65 | 80 |
| LCV | CNG | >1760 kg | 40 | 65 | 80 |
| LCV | Plug-in hybrid | <1305 kg | 40 | 65 | 80 |
| LCV | Plug-in hybrid | 1305-1760 kg | 40 | 65 | 80 |
| LCV | Plug-in hybrid | >1760 kg | 40 | 65 | 80 |
| Trucks | Gasoline | | 35 | 60 | 80 |
| Trucks | Diesel/CNG | Rigid 3,5 - 7,5t | 35 | 60 | 80 |
| Trucks | Diesel/CNG | Rigid 7,5 - 12t | 35 | 60 | 80 |
| Trucks | Diesel/CNG | Rigid 12 - 14 t | 35 | 60 | 80 |
| Trucks | Diesel/CNG | Rigid 14 - 20t | 35 | 60 | 80 |
| Trucks | Diesel/CNG | Rigid 20 - 26t | 35 | 60 | 80 |
| Trucks | Diesel/CNG | Rigid 26 - 28t | 35 | 60 | 80 |
| Trucks | Diesel/CNG | Rigid 28 - 32t | 35 | 60 | 80 |
| Trucks | Diesel/CNG | Rigid >32t | 35 | 60 | 80 |
| Trucks | Diesel/CNG | TT/AT 14 - 20t | 35 | 60 | 80 |
| Trucks | Diesel/CNG | TT/AT 20 - 28t | 35 | 60 | 80 |
| Trucks | Diesel/CNG | TT/AT 28 - 34t | 35 | 60 | 80 |
| Trucks | Diesel/CNG | TT/AT 34 - 40t | 35 | 60 | 80 |
| Trucks | Diesel/CNG | TT/AT 40 - 50t | 35 | 60 | 80 |
| Trucks | Diesel/CNG | TT/AT 50 - 60t | 35 | 60 | 80 |
| Trucks | Diesel/CNG | TT/AT >60t | 35 | 60 | 80 |
| Urban buses | Gasoline | | 30 | 50 | 70 |
| Urban buses | Diesel/CNG | < 15 tonnes | 30 | 50 | 70 |
| Urban buses | Diesel/CNG | 15-18 tonnes | 30 | 50 | 70 |
| Urban buses | Diesel/CNG | > 18 tonnes | 30 | 50 | 70 |
| Coaches | Gasoline | | 35 | 60 | 80 |
| Coaches | Diesel/CNG | < 15 tonnes | 35 | 60 | 80 |
| Coaches | Diesel/CNG | 15-18 tonnes | 35 | 60 | 80 |
| Coaches | Diesel/CNG | > 18 tonnes | 35 | 60 | 80 |
| Mopeds | Gasoline | | 30 | 30 | - |
| Motorcycles | Gasoline | 2 stroke | 40 | 70 | 100 |
| Motorcycles | Gasoline | < 250 cc. | 40 | 70 | 100 |
| Motorcycles | Gasoline | 250 – 750 cc. | 40 | 70 | 100 |
| Motorcycles | Gasoline | > 750 cc. | 40 | 70 | 100 |

Fleet and annual mileage data are provided by DTU Transport for the vehicle categories present in COPERT 5 (Jensen, 2019). DTU Transport use data from the Danish vehicle register kept by Statistics Denmark. The vehicle register data consist of vehicle type (passenger cars, vans, trucks, buses, mopeds, motorcycles), fuel type, vehicle weight, gross vehicle weight, engine size (passenger cars registered from 2005+), Euro norm, NEDC type approval fuel efficiency value (passenger cars registered from 1997+) and vehicle first registration year. The Euro norm information is very complete in the Danish vehicle register for vehicle first registrations 2001 onwards for trucks and buses and 2011 onwards in the case of passenger cars and vans. For vehicles with no EU norm information, the EU norm is assigned, associated with the date for first registration (entry into service) listed in Table 3.3.6.

In order to establish engine size data for passenger cars registered before 2005, a weight class-engine size transformation key is used examined by Cowi (2008) for new Danish cars from 1998. For the years before 1998, data for 1998 is used, and for the years 1999-2004, a linear interpolation between 1998 and 2005 weight class-engine size relations is used. For trucks, truck driver registration notes gathered by Statistics Denmark are used to split the fleet figures of ordinary trucks into number of solo trucks and truck-trailer combinations. Further, the registration notes make it possible to assume the average total vehicle weight of the truck trailer combination. For articulated trucks also, the registration notes make it possible to assume the average total vehicle weight of the full articulated truck.

Danish mileage data comes from the Danish Road Directorate based on the Danish vehicle inspection program. Total mileage per year and vehicle category are derived for the years 1985-2018, together with a more detailed mileage matrix examined for the year 2008 (based on detailed vehicle inspection data analysis). The detailed mileage matrix contains annual mileage per vehicle subcategory for new vehicles and for every vintage back in time, which determines the yearly mileage reduction percentages as a function of vehicle age. In a first step, the detailed mileage matrix is combined with corresponding fleet numbers in order to estimate intermediate total mileages for each year on a detailed fleet level. Next, each year's detailed (intermediate) mileage figures are scaled according to the difference between true and intermediate total mileage per vehicle subcategory.

DTU Transport (Jensen, 2019) also provides information of the mileage split between urban, rural and highway driving based on traffic monitoring data. The respective average speeds come from The Danish Road Directorate (e.g. Winther & Ekman, 1998). Additional data for the moped fleet and motorcycle fleet disaggregation is given by The National Motorcycle Association (Markamp, 2013) and supplementary moped stock information is obtained from The Danish Bicycle Traders Association (Johnsen, 2018).

In addition, data from a survey made by the Danish Road Directorate (Hansen, 2010) has given information of the total mileage driven by foreign cars, vans, coaches and trucks on Danish roads in 2009 and a follow-up survey in 2014 has given additional information. For trucks, the mileage contribution from foreign vehicles has been added to the total mileage on Danish roads for Danish trucks > 16 tonnes of gross vehicle weight. The data has been further processed by DTU Transport; by using appropriate assumptions, the mileage have been backcasted to 1985 and forecasted to 2018.

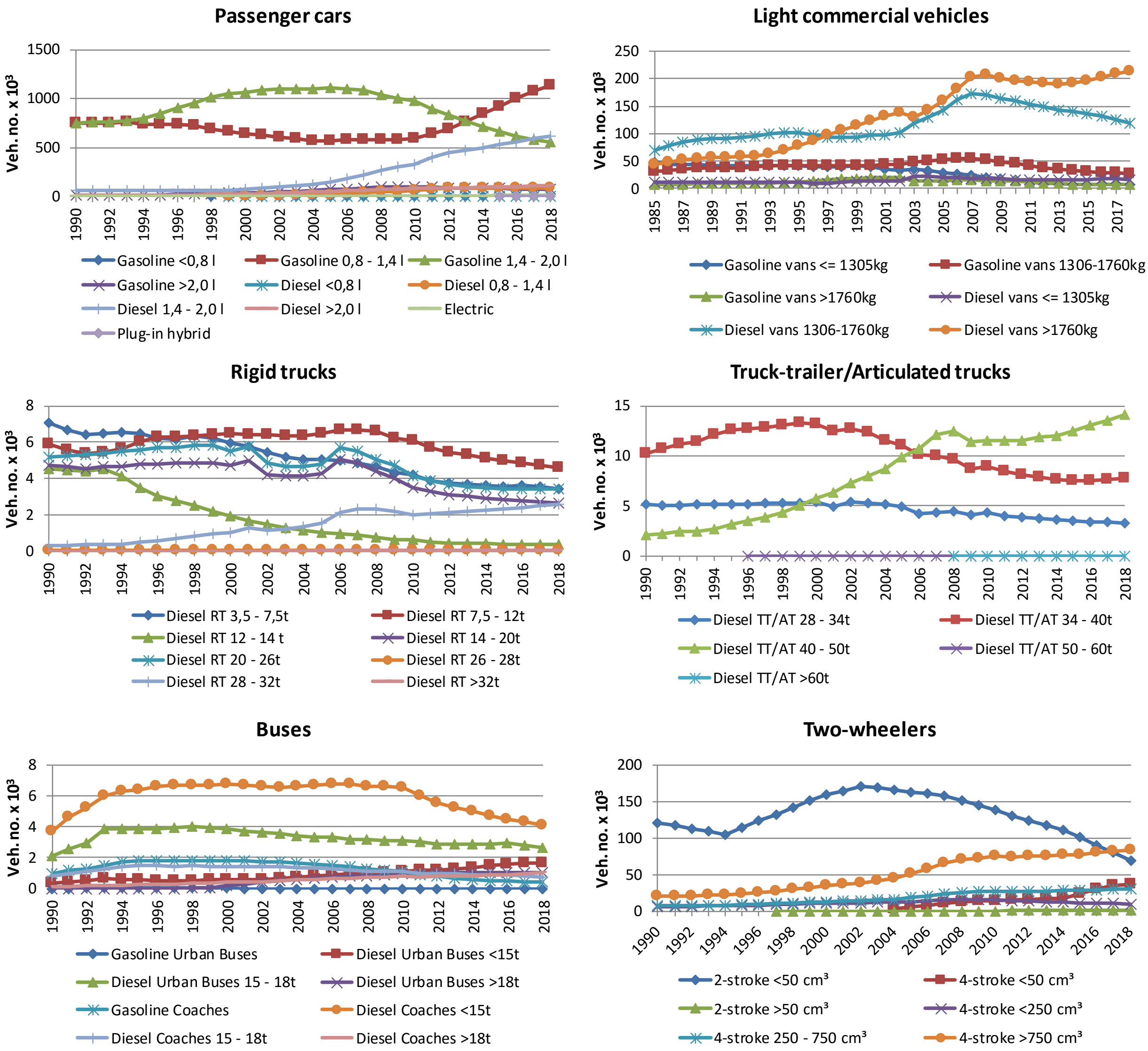



Figure 3.3.23 Number of vehicles in sub-classes in 1990-2018.

For passenger cars, the engine size differentiation is less certain for the years before 2005. The increase in the total number of passenger cars is mostly due to a growth in the number of diesel cars between 1.4 and 2 litres (from the 2000's up to now). Until 2005, there has been a decrease in the number of gasoline cars with an engine size between 0.8 and 1.4 litres. These cars, however, have also increased in numbers during the later years, while the number of 1.4-2 litres gasoline cars has decreased. Since the late 1990's small cars (< 0.8 l gasoline and <1.4 l. diesel) has slowly begun to penetrate the fleet.

There has been a considerable growth in the number of diesel light-duty vehicles from 1985 to 2006; the number of vehicles has however decreased somewhat after 2006 due to the restructuring of car taxes that made it less advantageous buying vans for private use.

For the truck-trailer and articulated truck combinations, there is a tendency towards the use of increasingly fewer but larger trucks throughout the time period. The decline in fleet numbers for many of the truck categories is due to the combined effects of the global financial crisis, the fleet shift towards fewer and larger trucks, international market competition (foreign transport companies are effectively gaining Danish market shares), and the reflagging of Danish commercial trucks to companies based in the neighbouring countries.

The sudden change in the level of urban bus and coach numbers from 1991 to 1995 is due to uncertain fleet data from Statistics Denmark.

The reason for the significant growth in the number of mopeds from 1994 to 2002 is the introduction of the so-called Moped 45 vehicle type. From 2004 onwards there is a gradual switch from 2-stroke to 4-stroke in new sales for this vehicle category. For motorcycles, the number of vehicles has grown in general throughout the entire 1985-2016 period. The increase is, however, most visible from the mid-1990s and onwards.

The vehicle numbers are summed up in EU emission layers for each year (Figure 3.3.24):

$$N_{j,y} = \sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \qquad (1)$$

Where N = number of vehicles, j = layer, y = year, i = first year of registration.

Weighted annual mileages per layer are calculated as the sum of all mileage driven per first registration year divided by the total number of vehicles in the specific layer.

$$M_{j,y} = \frac{\sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \cdot M_{i,y}}{\sum_{i=FYear(j)}^{LYear(j)} N_{i,y}} \qquad (2)$$

Since 2006, economical incitements have been given to private vehicle owners to buy Euro 5 diesel passenger cars and vans in order to bring down the particulate emissions from diesel vehicles. The estimated sales between 2006 and 2010 have been examined by the Danish EPA and are included in the fleet data behind the Danish inventory (Winther, 2011).

Vehicle numbers and weighted annual mileages per layer are shown in Annex 3.B.1 and 3.B.2 for 1990-2018. The trends in vehicle numbers per layer are also shown in Figure 3.3.24. The latter figure shows how vehicles complying with the gradually stricter EU emission levels (EURO 1-6, Euro I-VI etc.) have been introduced into the Danish motor fleet.

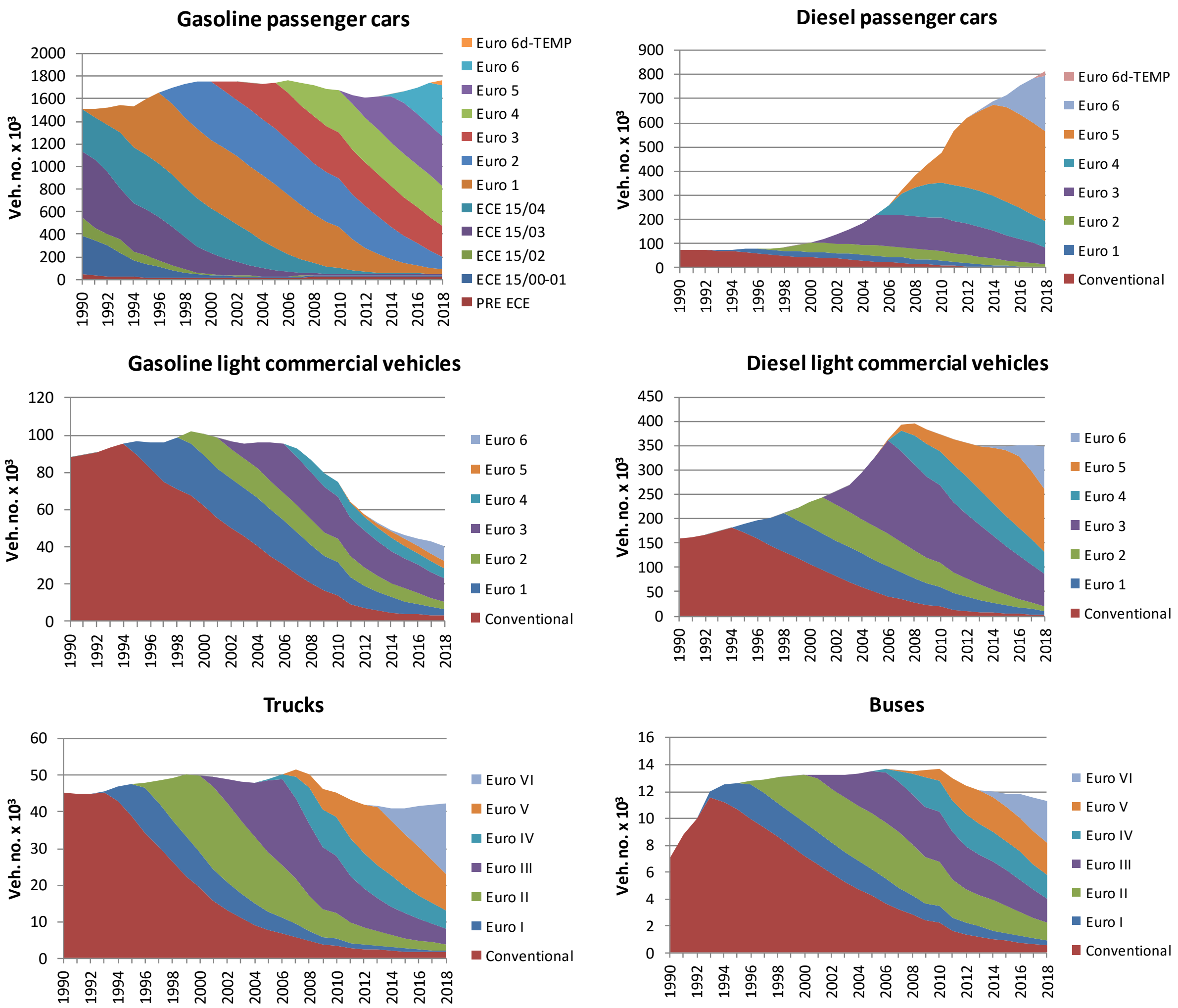



Figure 3.3.24 Layer distribution of vehicle numbers per vehicle type in 1990-2018.

### Emission legislation

The EU 443/2009 regulation sets new emission performance standards for new passenger cars as part of the Community's integrated approach to reduce $CO_2$ emissions from light-duty vehicles. Some key elements of the adopted text are as follows:

- **Limit value curve:** the fleet average to be achieved by all cars registered in the EU is 130 gram $CO_2$ per kilometre (g per km). A so-called limit value curve implies that heavier cars are allowed higher emissions than lighter cars while preserving the overall fleet average.
- **Further reduction:** a further reduction of 10 g $CO_2$ per km, or equivalent if technically necessary, will be delivered by other technological improvements and by an increased use of sustainable biofuels.
- **Phasing-in of requirements:** in 2012, 65 % of each manufacturer's newly registered cars must comply on average with the limit value curve set by the legislation. This will rise to 75 % in 2013, 80 % in 2014, and 100 % from 2015 onwards.
- **Lower penalty payments for small excess emissions until 2018:** if the average $CO_2$ emissions of a manufacturer's fleet exceed its limit value in any year from 2012, the manufacturer has to pay an excess emissions premium for each car registered. This premium amounts to €5 for the first g per km of exceedance, €15 for the second g per km, €25 for the third g per

km, and €95 for each subsequent g per km. From 2019, already the first g per km of exceedance will cost €95.

- **Long-term target:** a target of 95g $CO_2$ per km is specified for the year 2021.
- **Eco-innovations:** Manufacturers can be granted a maximum of 7g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.

The EU 510/2011 regulation sets new emission performance standards for new light commercial vehicles (vans). Some key elements of the regulation are as follows:

- **Target dates:** the EU fleet average of 175 g $CO_2$ per km will be phased in between 2014 and 2017. In 2014, an average of 70 %of each manufacturer's newly registered vans must comply with the limit value curve set by the legislation. This proportion will rise to 75 % in 2015, 80 % in 2016, and 100 % from 2017 onwards.
- **Limit value curve:** emissions limits are set according to the mass of vehicle, using a limit value curve. The curve is set in such a way that a fleet average of 175 grams of $CO_2$ per kilometre is achieved. A so-called limit value curve of 100 % implies that heavier vans are allowed higher emissions than lighter vans while preserving the overall fleet average. Only the fleet average is regulated, so manufacturers will still be able to make vehicles with emissions above the limit value curve provided these are balanced by other vehicles, which are below the curve.
- **Vehicles affected:** the vehicles affected by the legislation are vans, which account for around 12 % of the market for light-duty vehicles. This includes vehicles used to carry goods weighing up to 3.5t (vans and car-derived vans, known as N1) and which weigh less than 2610 kg when empty.
- **Long-term target:** a target of 147g $CO_2$ per km is specified for the year 2020.
- **Excess emissions premium for small excess emissions until 2018:** if the average $CO_2$ emissions of a manufacturer's fleet exceed its limit value in any year from 2014, the manufacturer has to pay an excess emissions premium for each van registered. This premium amounts to €5 for the first g per km of exceedance, €15 for the second g per km, €25 for the third g per km, and €95 for each subsequent g per km. From 2019, the first g per km of exceedance will cost €95. This value is equivalent to the premium for passenger cars.
- **Super-credits:** vehicles with extremely low emissions (below 50g per km) will be given additional incentives whereby each low-emitting van will be counted as 3.5 vehicles in 2014 and 2015, 2.5 in 2016 and 1.5 vehicles in 2017.
- **Eco-innovations:** Manufacturers can be granted a maximum of 7g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.
- **Other flexibilities:** manufacturers may group together to form a pool and act jointly in meeting the specific emissions targets. Independent manufacturers who sell fewer than 22,000 vehicles per year can also apply to the Commission for an individual target instead.

For Euro 1-6 passenger cars and vans, the chassis dynamometer test cycle used in the EU for emission approval is the NEDC (New European Driving Cycle), see e.g. www.dieselnet.com. The test cycle is also used for fuel consumption measurements. The NEDC cycle consists of two parts, the first part being a 4-time repetition (driving length: 4 km) of the ECE test cycle. The latter test cycle is the so-called urban driving cycle[5] (average speed: 19 km per h). The second part of the test is the run-through of the EUDC (Extra Urban Driving Cycle) test driving segment, simulating the fuel consumption under rural and highway driving conditions. The driving length of EUDC is 7 km at an average speed of 63 km per h. More information regarding the fuel measurement procedure can be found in the EU-directive 80/1268/EØF.

The NEDC test cycle is not adequately describing real world driving behaviour, and consequently, for diesel cars and vans, there is an increasing mismatch between the step wise lowered EU emission limits the vehicles comply with during the NEDC test cycle, and the more or less constant emissions from the same vehicles experienced during real world driving. In order to bridge this emission inconsistency gap a new test procedure, the "World-Harmonized Light-Duty Vehicles Test Procedure" (WLTP), has been developed which simulates much more closely real world driving behaviour. The WLTP test procedure gradually take effect from 2017.

For the new Euro 6 vehicles it has been decided that emission measurements must also be made with portable emission measurement systems (PEMS) during real traffic driving conditions with random acceleration and deceleration patterns. During the new Real Driving Emission (RDE) test procedure in a temporary phase, the emissions of $NO_x$ are not allowed to exceed the NEDC based Euro 6 emission limits by more than 110 % by 1/9 2017 for all new car models and by 1/9 2019 for all new cars (Euro 6d-TEMP). From 1/1 2020 in the final phase, the $NO_x$ emission not-to-exceed levels are adjusted downwards to 50 % for all new car models and by 1/1 2021 for all new cars (Euro 6d). Implementation dates for vans are one year later.

In the road transport emission model, compromise dates for enter into service of the Euro 6d-TEMP technology are set to 1/9 2018 and 1/9 2019, for diesel cars and vans, respectively. For Euro 6d, the enter into service dates are set to 1/1 2021 and 1/1 2022 for cars and vans, respectively. (pers. comm. Katja Asmussen, Danish EPA, 2018).

For NOx, VOC (NMVOC + $CH_4$), CO and PM, the emissions from road transport vehicles have to comply with the emission limit values agreed by the EU. An overview of the different emission layers in the road transport emission model and the corresponding EU emission directive numbers are given in Table 3.3.6. The specific emission limits are shown in Annex 2.B.3.

Table 3.3.6 shows the EU directive dates for new type approvals and the date for first registration (entry into service) of existing, previously type approved vehicle models. The latter date is used in the model for vehicles with no EU norm information given in the car register. In most cases the entry into service date used in the model is the same as the entry into service date specified by the EU directive.

For passenger cars and light commercial vehicles, the emission directives distinguish between three vehicle classes according to vehicle reference mass[6]: Passenger cars and light duty trucks (<1305 kg) have the same emission limits

[5] For Euro 3 and on, the emission approval test procedure was slightly changed. The 40 s engine warm up phase before start of the urban driving cycle was removed.
[6] Reference mass: net vehicle weight + mass of fuel and other liquids + 100 kg.

but different legislation dates. Light duty trucks (1305-1760 kg) and light duty trucks (>1760 kg) have the same legislation dates but different emission limits.

For heavy-duty vehicles (trucks and buses), the emission limits are given in g pr kWh and the measurements are carried out for engines in a test bench, using the ECE R-49, EU ESC (European Stationary Cycle) and ETC (European Transient Cycle) test cycles, depending on the Euro norm and exhaust gas after-treatment system installed. For Euro VI engines the WHSC (World Harmonized Stationary Cycle) and WHTC (World Harmonized Transient Cycle) test cycles are used. For a description of the test cycles, see e.g. www.dieselnet.com.

In terms of the sulphur content in the fuels used by road transportation vehicles, the EU directive 2003/17/EF describes the fuel quality standards agreed by the EU. In Denmark, the sulphur content in gasoline and diesel was reduced to 10 ppm in 2005, by means of a fuel tax reduction for fuels with 10 ppm sulphur contents.

Table 3.3.6 Overview of emission layers in the road transport emission model and the related EU emission directives.

| Vehicle category | Emission layer | EU directive | Type approval | First registration date |
|---|---|---|---|---|
| Passenger cars (gasoline) | PRE ECE | - | - | <1970- |
| | ECE 15/00-01 | 70/220 - 74/290 | 1972[a] | 1970[a] |
| | ECE 15/02 | 77/102 | 1981[b] | 1979[b] |
| | ECE 15/03 | 78/665 | 1982[c] | 1981[c] |
| | ECE 15/04 | 83/351 | 1987[d] | 1986[d] |
| Passenger cars (diesel) | Conventional | - | - | <1991- |
| Passenger cars | Euro 1 | 91/441 | 1.7.1992[e] | 1.1.1991[e] |
| | Euro 2 | 94/12 | 1.1.1996 | 1.1.1997 |
| | Euro 3 | 98/69 | 1.1.2000 | 1.1.2001 |
| | Euro 4 | 98/69 | 1.1.2005 | 1.1.2006 |
| | Euro 5 | 715/2007(692/2008) | 1.9.2009 | 1.1.2011 |
| | Euro 6 | 715/2007(692/2008) | 1.9.2014 | 1.9.2015 |
| | Euro 6d-TEMP | 2016/646 | 1.9.2017 | 1.9.2018 |
| | Euro 6d | 2016/646 | 1.1.2020 | 1.1.2021 |
| LCV < 1305 kg | Conventional | - | - | <1995 |
| | Euro 1 | 91/441 | 1.10.1994 | 1.1.1995 |
| | Euro 2 | 94/12 | 1.1.1998 | 1.1.1999 |
| | Euro 3 | 98/69 | 1.1.2001 | 1.1.2002 |
| | Euro 4 | 98/69 | 1.1.2006 | 1.1.2007 |
| | Euro 5 | 715/2007(692/2008) | 1.9.2010 | 1.1.2012 |
| | Euro 6 | 715/2007(692/2008) | 1.9.2015 | 1.9.2016 |
| | Euro 6d-TEMP | 2016/646 | 1.9.2018 | 1.9.2019 |
| | Euro 6d | 2016/646 | 1.1.2021 | 1.1.2022 |
| LCV 1305-1760 kg & > 1760 kg | Conventional | - | - | <1995 |
| | Euro 1 | 93/59 | 1.10.1994 | 1.1.1995 |
| | Euro 2 | 96/69 | 1.1.1998 | 1.1.1999 |
| | Euro 3 | 98/69 | 1.1.2001 | 1.1.2002 |
| | Euro 4 | 98/69 | 1.1.2006 | 1.1.2007 |
| | Euro 5 | 715/2007 | 1.9.2010 | 1.1.2012 |
| | Euro 6 | 715/2007 | 1.9.2015 | 1.9.2016 |
| | Euro 6d-TEMP | 2016/646 | 1.9.2018 | 1.9.2019 |
| | Euro 6d | 2016/646 | 1.1.2021 | 1.1.2022 |
| Heavy duty vehicles | Euro 0 | 88/77 | 1.10.1990 | 1.10.1990 |
| | Euro I | 91/542 | 1.10.1993 | 1.10.1993 |
| | Euro II | 91/542 | 1.10.1996 | 1.10.1996 |
| | Euro III | 1999/96 | 1.10.2000 | 1.10.2001 |
| | Euro IV | 1999/96 | 1.10.2005 | 1.10.2006 |
| | Euro V | 1999/96 | 1.10.2008 | 1.10.2009 |
| | Euro VI | 595/2009 | 1.1.2013 | 1.1.2014 |
| Mopeds | Conventional | - | - | - |
| | Euro I | 97/24 | 2000 | 2000 |
| | Euro II | 2002/51 | 2004 | 2004 |
| | Euro III | 2002/51 | 2014[f] | 2014[f] |
| | Euro IV | 168/2013 | 2017 | 2017 |
| | Euro V | 168/2013 | 2021 | 2021 |
| Motor cycles | Conventional | | 0 | 0 |
| | Euro I | 97/24 | 2000 | 2000 |
| | Euro II | 2002/51 | 2004 | 2004 |
| | Euro III | 2002/51 | 2007 | 2007 |
| | Euro IV | 168/2013 | 2017 | 2017 |
| | Euro V | 168/2013 | 2021 | 2021 |

a,b,c,d: Expert judgement suggests that Danish vehicles enter into the traffic before EU directive first registration dates. The effective inventory starting years are a: 1970; b: 1979; c: 1981; d: 1986; e: The directive came into force in Denmark 1.10.1990.

### Fuel consumption and emission factors

In practice, the emissions from vehicles in traffic are different from the legislation limit values and, therefore, the latter figures are not suited for total emission calculations. Besides difference in test versus real world driving behaviour, as discussed in the previous section, the emission limit values do not reflect the emission impact of cumulated mileage driven, and engine and exhaust after treatment maintenance levels for the vehicle fleet as a whole.

Therefore, in order to represent the Danish fleet and to support average national emission estimates, the selected emission factors must be derived from numerous emission measurements, using a broad range of real world driving patterns and a sufficient number of test vehicles. It is similarly important to have separate fuel consumption and emission data for cold-start emission calculations and gasoline evaporation (hydrocarbons).

The fuel consumption and emission factors used in the Danish inventory come from the COPERT 5 model[7]. The source for these data is various European measurement programmes. In general, the COPERT data are transformed into trip-speed dependent fuel consumption and emission factors for all vehicle categories and layers by using trip speeds as shown in Table 3.3.5. The factors are listed in Annex 2.B.4.

### Adjustment for fuel efficient vehicles

For passenger cars, COPERT 5 include measurement based fuel consumption factors until Euro 4. A calculation function is provided for newer cars that one hand compensate for the trend towards more fuel efficient vehicles being sold during the later years and on the other hand compensate for the increasing fuel gap between fuel consumption measured during vehicle type approval and real world fuel consumption.

The COPERT calculation function and supporting data material basis is, however, not able to account for the fuel gaps between fuel consumption measured during vehicle type approval and real world fuel consumption for vehicles after 2014, as monitored by e.g. the International Council on Clean Transportation (ICCT), Tietge et al. (2019).

The baseline COPERT 5 fuel consumption factors for Euro 4, Euro 5 and Euro 6 passenger cars are adjusted in the following way.

In the Danish fleet and mileage database kept by DTU Transport, the type approval fuel efficiency value based on the NEDC driving cycle ($TA_{NEDC}$) is registered for each single car. Further, DTU Transport calculates a modified fuel efficiency value ($FC_{inuse}$) with the calculation function provided by COPERT 5 that better reflects the fuel consumption in real ("inuse") traffic conditions.

The latter function uses $TA_{NEDC}$, vehicle weight, engine size and regression coefficients by first registration year, as input parameters (EMEP/EEA, 2019). For each new registration year, i, fuel type, f, and engine size, k, number based average values of $TA_{NEDC}$ and $FC_{inuse}$ are summed up and referred to as

[7] For vans, fuel consumption factors are not stratified according to vehicle weight classes in the COPERT model. For this vehicle category fuel consumption factor data are obtained from the HBEFA (Handbook of Emission Factors) model version 4.1 (e.g. Matzer et al., 2019).

$\overline{TA_{NEDC}}(i,f,k)$ and $\overline{TA_{inuse}}(i,f,k)$. For vehicle new registrations after 2014, regression coefficients are used for 2014.

The $FC_{inuse}$ function has been developed from a vehicle database consisting of new registered cars from 2006-2014 (Tietge et al. 2017). Hence, as previously mentioned, The $FC_{inuse}$ function is not able to account for the fuel gaps after 2014, between type approval and real world fuel consumption as monitored by ICCT (Tietge et al., 2019).

To obtain $\overline{FC_{inuse}}(i,f,k)$ values for vehicle new registrations 2015-2018, the $\overline{FC_{inuse}}(i,f,k)$ values for 2014 are adjusted for the years 2015-2018[8] with an index function (indexed from 2014), $C_{ICCT}$ (i, f), based on the reported ICCT fuel gap figures by fuel type for the new registration years 2014-2018.

The most recent emission projections use the assumption from The Danish Energy Agency that Danish vehicle sales meet a slightly softer national target of 95 + 1 g $CO_2$/km in 2021, instead of the EU 95 g $CO_2$/km, due to increases in new sales of electric cars and plug-in hybrids.

In order to meet the 96 g CO2/km target, the following approach is used to forecast the average $TA_{NEDC}$ values ($\overline{TA_{NEDC}}(i)$ until 2021. As a starting point, the average $CO_2$ emission factor (average from all new registrations) is calculated for the last historical year (2018) based on the registered average $TA_{NEDC}$ values from DTU Transport. Next, the average $CO_2$ emission factor (and $\overline{TA_{NEDC}}(i)$) for each future year's new sold cars is reduced with a linear function, $C_{2021}$ (i), until the emission factor reaches 96 g $CO_2$/km in 2021. For years beyond 2021 annual fuel efficiency, improvement rates are used for new cars depending on fuel type as suggested by DEA (2019).

The reduction function $C_{2021}$ (i) is then used to reduce the in use type approval fuel efficiency values, $\overline{FC_{inuse}}(i,f,k)$, for the years between last historical year and 2021, for each of the fuel type/engine size fleet segments.

Subsequently these $\overline{FC_{inuse}}(i,f,k)$ values are aggregated by mileage into layer specific values for each inventory year ($\overline{FC_{inuse}}(layer)$).

At the same time, COPERT provides fuel consumption factors for Euro 4 vehicles for a specific driving pattern composition[9] that better describes real world driving for these specific vehicles. The factors build on the actual fuel measurements for the Euro 4 sample of COPERT vehicles ($FC_{COPERT,\ sample}$), used in the development of the Euro 4 emission factors in the COPERT model.

In a final step the ratio between the layer specific fuel factors for the Danish fleet ($\overline{FC_{inuse}}(layer)$) and the COPERT Euro 4 vehicles ($FC_{COPERT,\ sample}$) are used to scale the trip speed dependent COPERT 5 fuel consumption factors for Euro 4 layers onwards.

For vans, trucks, urban buses and coaches, annual fuel efficiency improvement rates are used for future new vehicles depending on fuel type as suggested by DEA (2019).

[8] The ICCT monitoring report include new cars up to 2017. For new cars from 2018, fuel gap figures are used for cars from 2017.
[9] The factors are derived from the Common Artemis Driving Cycle (CADC), with a 1/3 weight for each of the urban, rural and highway parts of CADC.

### Adjustment for EGR, SCR and filter retrofits

In COPERT 5, emission factors are available for Euro V heavy duty vehicles using exhaust gas recirculation (EGR) and selective catalyst reduction (SCR) exhaust emission aftertreatment systems, respectively. The estimated new sales of Euro V diesel trucks equipped with EGR and SCR during the 2006-2010 time periods has been examined by Hjelgaard and Winther (2011). These inventory fleet data are used in the Danish inventory to calculate weighted emission factors for Euro V trucks in different size categories.

During the 2000's urban environmental zones have been established in Danish cities in order to bring down the particulate emissions from diesel fuelled heavy duty vehicles. Driving in these environmental zones prescribe the use of diesel particulate filters. The Danish EPA has provided the estimated number of Euro I-III urban buses and Euro II-III trucks and tourist buses, which have been retrofitted with filters during the 2000's. These retrofit data are included in the Danish inventory by assuming that particulate emissions are lowered by 80 % compared with the emissions from the same Euro technology with no filter installed (Winther, 2011).

For all vehicle categories/technology levels not represented by measurements, the emission factors are produced by using reduction factors. The latter factors are determined by assessing the EU emission limits and the relevant emission approval test conditions, for each vehicle type and Euro class.

### Deterioration factors

For three-way catalyst cars, the emissions of $NO_X$, NMVOC and CO gradually increase due to catalyst wear and are, therefore, modified as a function of total mileage by the so-called deterioration factors. Even though the emission curves may be serrated for the individual vehicles, on average, the emissions from catalyst cars stabilize after a given cut-off mileage is reached due to OBD (On Board Diagnostics) and the Danish inspection and maintenance programme.

For each year, the deterioration factors are calculated per first registration year by using deterioration coefficients and cut-off mileages, as given in EMEP/EEA (2019), for the corresponding layer. The deterioration coefficients are given for the two driving cycles: "Urban Driving Cycle" (UDF) and "Extra Urban Driving Cycle" (EUDF: urban and rural), with trip speeds of 19 and 63 km per hour, respectively.

Firstly, the deterioration factors are calculated for the corresponding trip speeds of 19 and 63 km per h in each case determined by the total cumulated mileage less than or exceeding the cut-off mileage. The Formulas 3 and 4 show the calculations for the "Urban Driving Cycle":

$$UDF = U_A \cdot MTC + U_B \text{, MTC < } U_{MAX} \quad (3)$$

$$UDF = U_A \cdot U_{MAX} + U_B \text{, MTC >= } U_{MAX} \quad (4)$$

where UDF is the urban deterioration factor, $U_A$ and $U_B$ the urban deterioration coefficients, MTC = total cumulated mileage and $U_{MAX}$ urban cut-off mileage.

In the case of trip speeds below 19 km per hour the deterioration factor, DF, equals UDF, whereas for trip speeds exceeding 63 km per hour, DF=EUDF

(Danish rural and highway trip speed; c.f. Table 3.3.5). For trip speeds between 19 and 63 km per hour (Danish urban trip speed; c.f. Table 3.3.5) the deterioration factor, DF, is found as an interpolation between UDF and EUDF. Secondly, the deterioration factors, one for each of the three road types, are aggregated into layers by taking into account vehicle numbers and annual mileage levels per first registration year:

$$DF_{j,y} = \frac{\sum_{i=FYear(j)}^{LYear(j)} DF_{i,y} \cdot N_{i,y} \cdot M_{i,y}}{\sum_{i=FYear(j)}^{LYear(j)} DF_{i,y} \cdot N_{i,y}} \qquad (5)$$

where DF is the deterioration factor.

For $N_2O$ and $NH_3$, COPERT 5 takes into account deterioration as a linear function of mileage for gasoline fuelled EURO 1-6 passenger cars and light duty vehicles. The level of emission deterioration also relies on the content of sulphur in the fuel. The deterioration coefficients are given in EMEP/EEA (2019), for the corresponding layer. A cut-off mileage of 250 000 km is behind the calculation of the modified emission factors, and for the Danish situation the low sulphur level interval is assumed to be most representative. The deterioration factors are shown in Annex 3.B.6 for 2018.

#### Emissions and fuel consumption for hot engines

Emissions and fuel consumption results for operationally hot engines are calculated for each year and for layer and road type. The procedure is to combine fuel consumption and emission factors (and deterioration factors for catalyst vehicles), number of vehicles, annual mileage levels and the relevant road-type shares given in Table 3.3.5. For non-catalyst vehicles, this yields:

$$E_{j,k,y} = EF_{j,k,y} \cdot S_k \cdot N_{j,y} \cdot M_{j,y} \qquad (6)$$

Here E = fuel consumption/emission, EF = fuel consumption/emission factor, S = road type share and k = road type.

For catalyst vehicles the calculation becomes:

$$E_{j,k,y} = DF_{j,k,y} \cdot EF_{j,k,y} \cdot S_k \cdot N_{j,y} \cdot M_{j,y} \qquad (7)$$

#### Extra emissions and fuel consumption for cold engines

Extra emissions of $NO_x$, VOC, $CH_4$, CO, PM, $N_2O$, $NH_3$ and fuel consumption from cold start are simulated separately. For $SO_2$ and $CO_2$, the extra emissions are derived from the cold start fuel consumption results.

Each trip is associated with a certain cold-start emission level and is assumed to take place under urban driving conditions. The number of trips is distributed evenly across the months. First, cold emission factors are calculated as the hot emission factor times the cold:hot emission ratio. Secondly, the extra emission factor during cold start is found by subtracting the hot emission factor from the cold emission factor. Finally, this extra factor is applied on the fraction of the total mileage driven with a cold engine (the β-factor) for all vehicles in the specific layer.

The cold:hot ratios depend on the average trip length and the monthly ambient temperature distribution. The Danish temperatures for 2018 are given in Cappelen et al. (2018). For previous years, temperature data are taken from similar reports available from The Danish Meteorological Institute (www.dmi.dk). The cold:hot ratios are equivalent for gasoline fuelled conventional passenger cars and vans, and for diesel passenger cars and vans, respectively, see EMEP/EEA (2019). For conventional gasoline and all diesel vehicles the extra emissions become:

$$CE_{j,y} = \beta \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr - 1) \quad (8)$$

Where CE is the cold extra emissions, $\beta$ = cold driven fraction, CEr = Cold:Hot ratio.

For catalyst cars, the cold:hot ratio is also trip speed dependent. The ratio is, however, unaffected by catalyst wear. The Euro I cold:hot ratio is used for all later catalyst technologies. However, in order to comply with gradually stricter emission standards, the catalyst light-off temperature must be reached in even shorter periods of time for later EURO standards. Correspondingly, the $\beta$-factor for gasoline vehicles is reduced step-wise for Euro II vehicles and their successors.

For catalyst vehicles, the cold extra emissions are found from:

$$CE_{j,y} = \beta_{red} \cdot \beta_{EUROI} \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr_{EUROI} - 1) \quad (9)$$

where $\beta_{red}$ = the $\beta$ reduction factor.

For $CH_4$, specific emission factors for cold driven vehicles are included in COPERT 5. The $\beta$ and $\beta_{red}$ factors for VOC are used to calculate the cold driven fraction for each relevant vehicle layer. The NMVOC emissions during cold start are found as the difference between the calculated results for VOC and $CH_4$.

For $N_2O$ and $NH_3$, specific cold start emission factors are also proposed by COPERT 5. For catalyst vehicles, however, just like in the case of hot emission factors, the emission factors for cold start are functions of cumulated mileage (emission deterioration). The level of emission deterioration also relies on the content of sulphur in the fuel. The deterioration coefficients are given in EMEP/EEA (2019), for the corresponding layer. For cold start, the cut-off mileage and sulphur level interval for hot engines are used, as described in the deterioration factors paragraph.

#### Evaporative emissions from gasoline vehicles

For each year, evaporative emissions of hydrocarbons are simulated in the forecast model as hot and warm running losses, hot and warm soak loss and diurnal emissions. The calculations follow the Tier 2 approach in COPERT 5. The basic emission factors are season related (predefined by four ambient temperature intervals), for Danish climate conditions the temperature intervals [-5, 10], [0, 15] and [10, 25] $^{o}$C are used. The emission factors are shown in more details in EMEP/EEA (2019).

Running loss emissions originate from vapour generated in the fuel tank while the vehicle is running. The distinction between hot and warm running loss emissions depends on engine temperature, i.e. the engine being either hot or cold. The emissions are calculated as annual mileage (broken down into cold and hot mileage totals using the β-factor) times the respective emission factors. For vehicles equipped with evaporation control (catalyst cars) only hot running loss emissions occur.

$$E^{R}_{j,y} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot ((1-\beta) \cdot HR + \beta \cdot WR) \quad (10)$$

Where $E^R$ is running loss emissions, $l_{trip}$ = the average trip length, and HR and WR are the hot and warm running loss emission factors, respectively.

Hot and warm soak emissions also occur for for carburettor vehicles (no evaporation control), whereas for catalyst cars (evaporation control) only hot soak emissions occur. The soak emissions are calculated as number of trips (broken down into cold and hot trip numbers using the β-factor) times respective emission factors:

$$E^{S}_{j,y} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot ((1-\beta) \cdot HS + \beta \cdot WS) \quad (11)$$

Where $E^S$ is the soak emission, $l_{trip}$ = the average trip length, and HS and WS are the hot and warm soak emission factors, respectively.

Average maximum and minimum temperatures pr month are used in combination with diurnal emission factors to estimate the diurnal emissions from both carburettor and catalyst vehicles $E^d$:

$$E^{D}_{j,y} = 365 \cdot N_{j,y} \cdot e^{D} \quad (12)$$

Each year's total is the sum of each layer's running loss, soak loss and diurnal emissions.

#### Fuel consumption balance

The calculated fuel consumption in COPERT 5 must equal the statistical fuel sale totals according to the UNFCCC and UNECE emissions reporting format. The statistical fuel sales for road transport are derived from the Danish Energy Authority data (see DEA, 2019).

For gasoline, the DEA data for road transport are adjusted at first, in order to account for e.g. non-road and recreational craft fuel consumption, which are not directly stated in the statistics. Please refer to paragraph 3.3.3 for further information regarding the transformation of DEA fuel data. Next, the fuel and emission results for all gasoline vehicles are scaled with the percentage difference between the adjusted bottom-up gasoline fuel consumption obtained after step one and total gasoline fuel sold.

The DEA data for diesel consist of fuel sold in Denmark and used on Danish roads and fuel sold in Denmark and used abroad. The latter diesel fuel contribution is estimated by the Danish Ministry of Taxation based on studies on fuel price differences across borders, fuel discount for haulage contractors and fuel tanking behavior of truck and bus operators as well as private cars (see e.g. the Danish Ministry of Taxation, 2015).

The amount of diesel fuel sold in Denmark and used abroad is allocated to trucks and coaches in a first step and emissions are scaled accordingly (Figure 3.3.25). Next, the percentage difference between the adjusted bottom-up diesel fuel consumption obtained after step one and total diesel fuel sold is used to scale fuel and emission results for all diesel vehicles regardless of vehicle category (Figure 3.3.26). The data behind the Figures 3.3.25 and 3.3.26 are also listed in Annex 3.B.8.

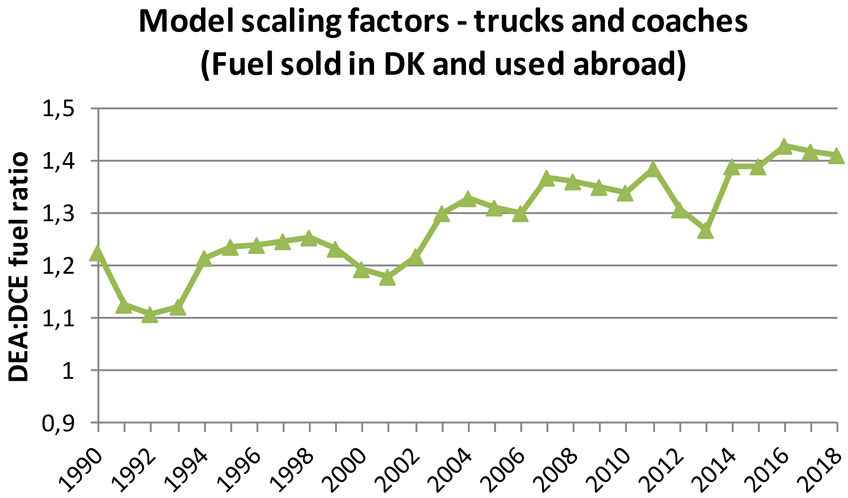



Figure 3.3.25 Fuel ratios (fuel and emission adjustment factors) for trucks and coaches: Bottom-up fuel consumption plus diesel used abroad vs bottom-up fuel consumption.

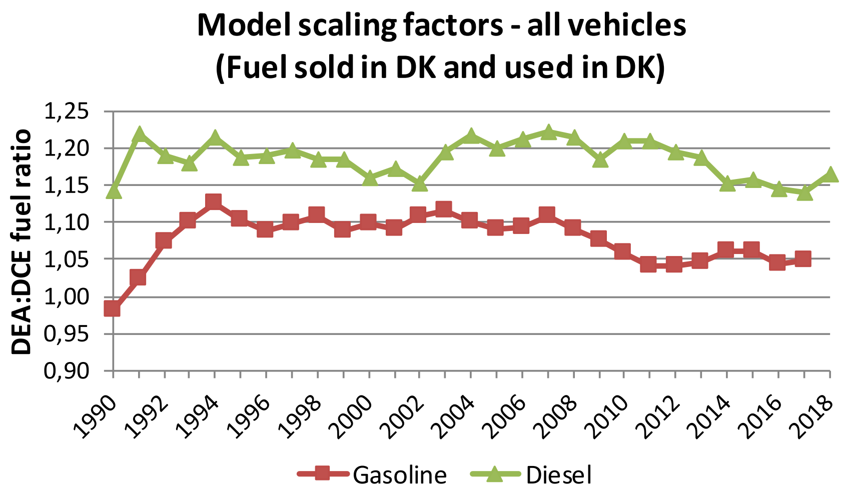



Figure 3.3.26 Gasoline and diesel fuel ratios (fuel and emission adjustment factors) regardless of vehicle category: Fuel sold and used in Denmark vs adjusted bottom-up fuel consumption.

The reasons for the differences between DEA sales figures and bottom-up fuel estimates shown in Figure 3.3.26 are mostly due to a combination of the uncertainties related to COPERT 5 fuel consumption factors, allocation of vehicle numbers in sub-categories, annual mileage, trip speeds and mileage splits for urban, rural and highway driving conditions.

The final fuel consumption and emission factors are shown in Annex 3.B.7 for 1985-2018. The total fuel consumption and emissions are shown in Annex 3.B.8, per vehicle category and as grand totals, for 1985-2018 (and CRF format in Annex 3.B.16. In Annex 3.B.15, fuel consumption and emission factors as well as total emissions are given in CollectER format for 1990 and 2018.

In the following Figures 3.3.27 - 3.3.29, the fuel and km related emission factors for $CO_2$ (km related only), $CH_4$ and $N_2O$ are shown per vehicle type for the Danish road transport (from 1990-2018).

For $CO_2$ the neat gasoline/diesel emission factors shown in Table 3.3.7 are country specific values, and come from the DEA. In 2006 and 2008, respectively, bio ethanol and biodiesel became available from a limited number of gas filling stations in Denmark, and today bio ethanol and biodiesel (FAME) is added to all fuel commercially available. Following the IPCC guideline definitions, bio fuels are in principle regarded as $CO_2$ neutral for the transport sector as such. A small part of carbon (and the associated $CO_2$ emissions) in biodiesel, however, have a fossil origin due to the use of fossil-derived methanol in the biodiesel production process. This is accounted for in the emission inventories by following the biodiesel fossil carbon content calculation methodology provided by Sempos (2019).

The sulphur content for bio ethanol/biodiesel is assumed to be zero and hence, the aggregated $CO_2$ (and $SO_2$) factors for gasoline/diesel have been adjusted, on the basis of the energy content of neat gasoline/diesel and bio ethanol/biodiesel, respectively, in the available fuels.

At present, the Danish road transport fuels only have low biofuel (BF) shares (Table 3.3.7), and hence, no thermal efficiency changes are expected for the fuels. Consequently, the energy based fuel consumption factors (MJ/km) derived from COPERT 5 are used also in this case.

As a function of the current ethanol/biodiesel energy percentage, $BF\%_E$, (Table 3.3.7) the average fuel related $CO_2$ emission factors, $emf_{CO2,E}(BF\%)$ become:

$$EF_{CO2,E}(BF\%) = EF_{CO2,E}(BF0) \cdot (100 - BF\%_E) \quad (13)$$

Where:

$EF_{CO2,E}(BF\%)$ = average fuel related $CO_2$ emission factor (g $MJ^{-1}$) for current BF%

$EF_{CO2,E}(BF0)$ = fuel related $CO_2$ emission factor (g $MJ^{-1}$) for fossil fuels

The kilometer based average $CO_2$ emission factor is subsequently calculated as the product of the fuel related $CO_2$ emission factor from equation 3 and the energy based fuel consumption factor, $FC_{CO2,E}(BF0)$, derived from COPERT 5:

$$EF_{CO2,km}(BF\%) = EF_{CO2,E}(BF\%) \cdot FC_E(BF0) \quad (14)$$

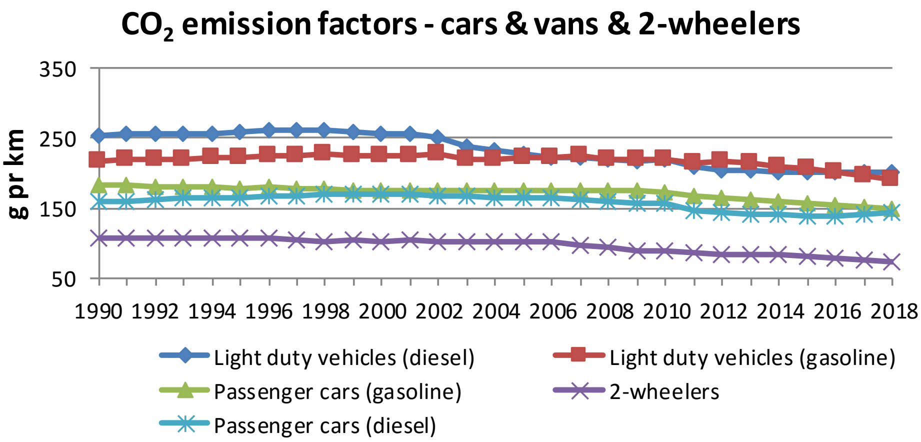
A literature review carried out in the Danish research project REBECA revealed no significant changes in emission factors between neat gasoline and E5 gasoline-ethanol blends for the combustion related emission components; $NO_x$, CO and VOC (Winther et al., 2012). Hence, due to the current low ethanol content in today's road transport gasoline, no modifications of the neat gasoline based COPERT emission factors are made in the inventories in order to account for ethanol usage.

REBECa results published by Winther (2009) have shown that the emission impact of using diesel-biodiesel blends is very small at low biodiesel blend ratios. Consequently, no bio fuel emission factor adjustments are needed for diesel vehicles as well. However, adjustment of the emission factors for diesel vehicles will be made if the biodiesel content of road transport diesel fuel increases to a more significant level in the future.

The fuel related $CO_2$ emission factors for neat gasoline/diesel, bio ethanol/biodiesel, and aggregated $CO_2$ factors are shown in Table 3.3.7. For gasoline, diesel and compressed natural gas (CNG) the $CO_2$ emission factors are country-specific. For gasoline and diesel the emission factor source is Fenhann and Kilde (1994). For CNG, the $CO_2$ emission factor is estimated by the Danish gas transmission company, Energinet.dk, based on gas analysis data. For liquefied petroleum gas (LPG), the emission factor source is EMEP/EEA (2019).

Table 3.3.7 Fuel-specific $CO_2$ emission factors and biofuel shares for road transport in Denmark.

| | Emission factors (g/MJ) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel type | 1990-2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
| Neat diesel | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 |
| Neat gasoline | 73 | 73 | 73 | 73 | 73 | 73 | 73 | 73 | 73 | 73 | 73 | 73 | 73 | 73 |
| LPG | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 |
| Biodiesel | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 |
| Bio ethanol | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Diesel avg. | 74 | 74.0 | 74.0 | 74.0 | 73.9 | 74.0 | 71.7 | 69.6 | 69.4 | 69.4 | 69.5 | 69.5 | 69.7 | 69.8 |
| Gasoline avg. | 73 | 72.9 | 72.8 | 72.8 | 72.8 | 71.8 | 70.7 | 70.5 | 70.6 | 70.6 | 70.7 | 70.7 | 70.7 | 70.7 |
| | Biofuel share (BF%) of Danish road transport fuels | | | | | | | | | | | | | |
| | 1990-2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
| | 0 | 0.08 | 0.13 | 0.12 | 0.20 | 0.65 | 3.23 | 5.26 | 5.39 | 5.42 | 5.35 | 5.33 | 5.21 | 5.06 |



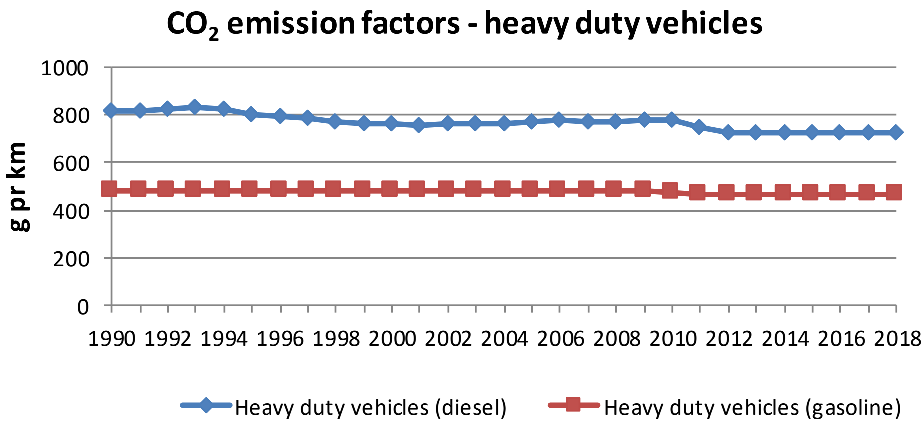
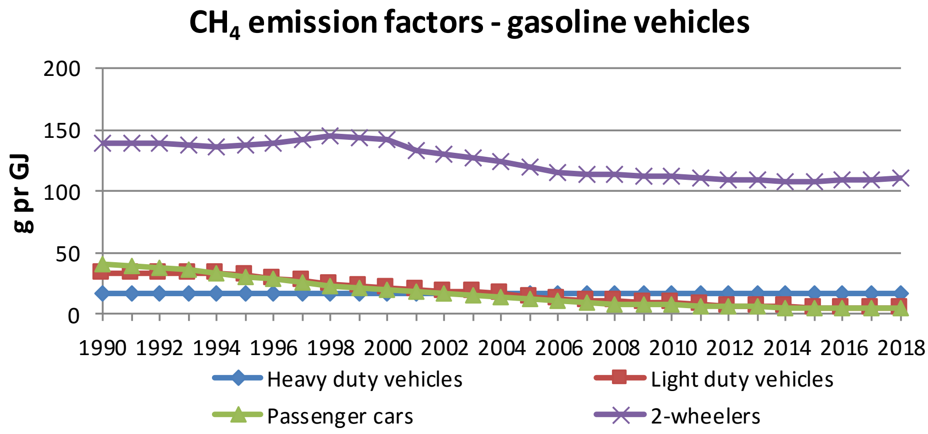
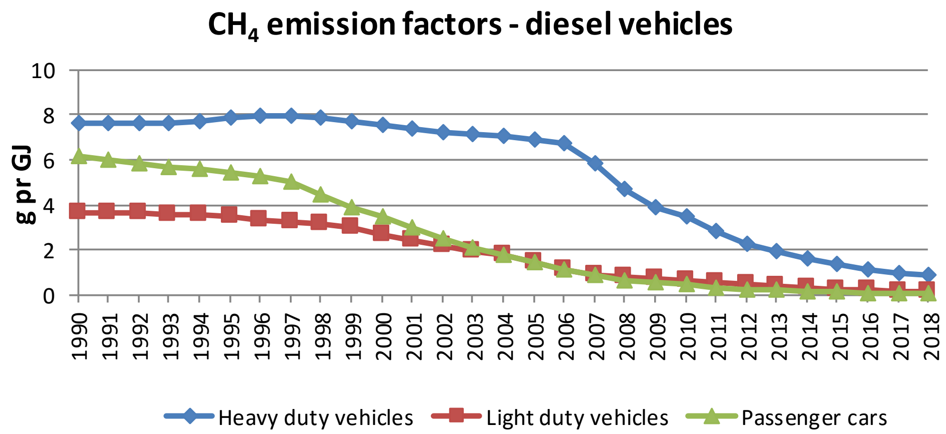
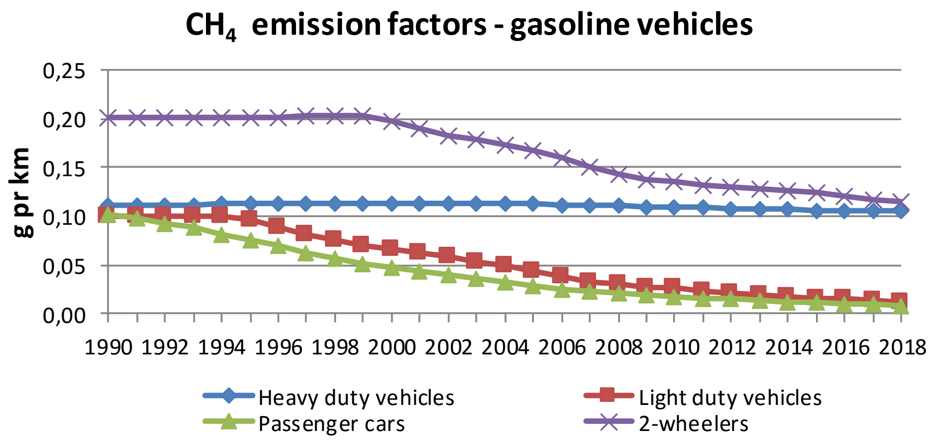



Figure 3.3.27 Km related $CO_2$ emission factors per vehicle type for Danish road transport (1990-2018).



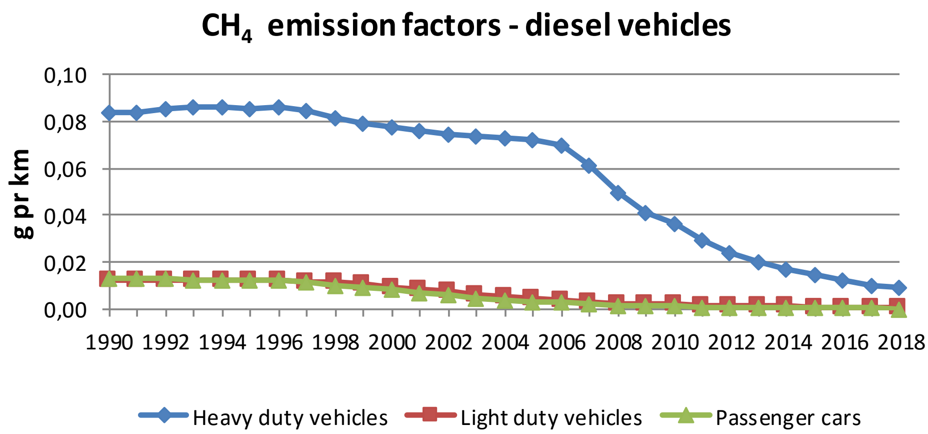
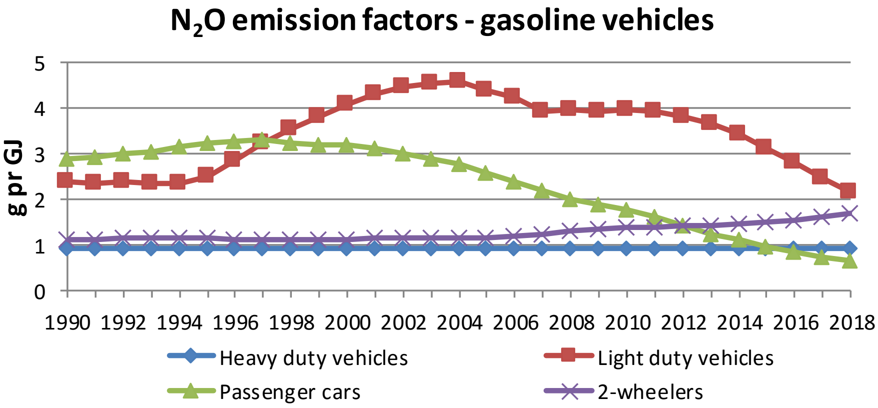
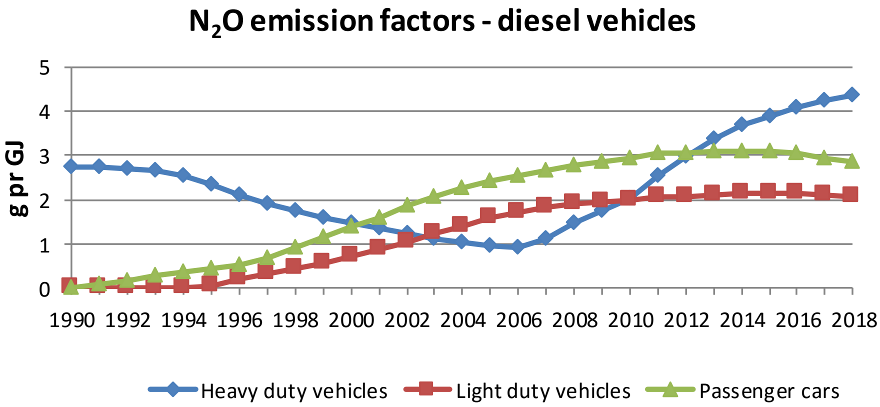



Figure 3.3.28 Fuel and km related $CH_4$ emission factors per vehicle type for Danish road transport (1990-2018).



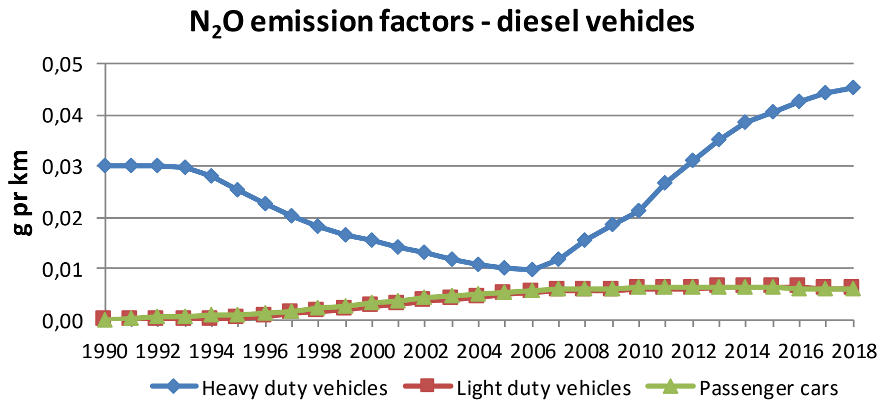




Figure 3.3.29 Fuel and km related $N_2O$ emission factors per vehicle type for Danish road transport (1990-2018).

### Methodologies and references for other mobile sources

Other mobile sources are divided into several sub-sectors: sea transport, fishery, air traffic, railways, military, and working machinery and equipment in the sectors agriculture, forestry, industry and residential. The emission calculations are made in internal DCE models using the detailed method as described in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2019) for air traffic, off-road working machinery and equipment, and ferries, while for the remaining sectors the simple method is used.

### 3.3.3 Activity data

#### Air traffic

The activity data used in the DCE emission model for aviation consists of air traffic statistics provided by the Danish Transport and Construction Agency and Copenhagen Airport. Fuel statistics for jet fuel consumption and aviation gasoline are obtained from the Danish energy statistics (DEA, 2019).

For 2001 onwards, the Danish Transport and Construction Agency provides data records per flight (city-pairs). Each flight record consists of e.g. ICAO codes for aircraft type, origin and destination airport, maximum takeoff mass (MTOM), flight call sign and aircraft registration number.

In the DCE model, each aircraft type is paired with a representative aircraft type, for which fuel consumption and emission data exist in the EMEP/EEA databank. As a basis, the type relation table is taken from the Eurocontrol AEM model, which is the primary source for the present EMEP/EEA fuel consumption and emission data. Supplementary aircraft types are assigned to representative aircraft types based on the type relation table already established in the previous version of the DCE model (e.g. Winther, 2018).

Additional aircraft types not present in the type relation table are identified by using different aircraft dictionaries and internet look-ups. In order to select the most appropriate aircraft representative type, the main selection criteria are the identified aircraft type, aircraft maximum takeoff mass, engine types, and number of engines. During this sequence, small aircraft with piston engines using aviation gasoline are excluded from the calculations.

Annex 3.B.10 shows the correspondence table between the actual aircraft type codes and representative aircraft types behind the Danish inventory. Annex 3.B.10 also show the number of LTO's per representative aircraft type for domestic and international flights starting from Copenhagen Airport and other airports, respectively[10], in a time series from 2001-2018. The airport split is necessary to make due to the differences in LTO emission factors (cf. section 3.3.4).

The same type of LTO activity data for the flights for Greenland and the Faroe Islands are shown in Annex 3.B.10 also, further detailed into an origin-destination airport matrix and having flight distances attached. This level of detail meets the demand from UNFCCC to provide precise documentation for the part of the inventory for the Kingdom of Denmark being outside the Danish mainland.

The ideal flying distance (great circle distance) between the city-pairs is calculated by DCE in a separate database. The calculation algorithm uses a global latitude/altitude coordinate table for airports. In cases when airport coordinates are not present in the DCE database, these are looked up on the internet and entered into the database accordingly.

For inventory years prior to 2001, detailed LTO/aircraft type statistics are obtained from Copenhagen Airport (for this airport only), while information of total takeoff numbers for other Danish airports is provided by the Danish

[10] Excluding flights for Greenland and the Faroe Islands. These flights are separately listed in Annex 3.B.10.

Transport and Construction Agency. The assignment of representative aircraft types for Copenhagen Airport is done as described above. For the remaining Danish airports, representative aircraft types are not directly assigned. Instead, appropriate average assumptions are made relating to the fuel consumption and emission data part.

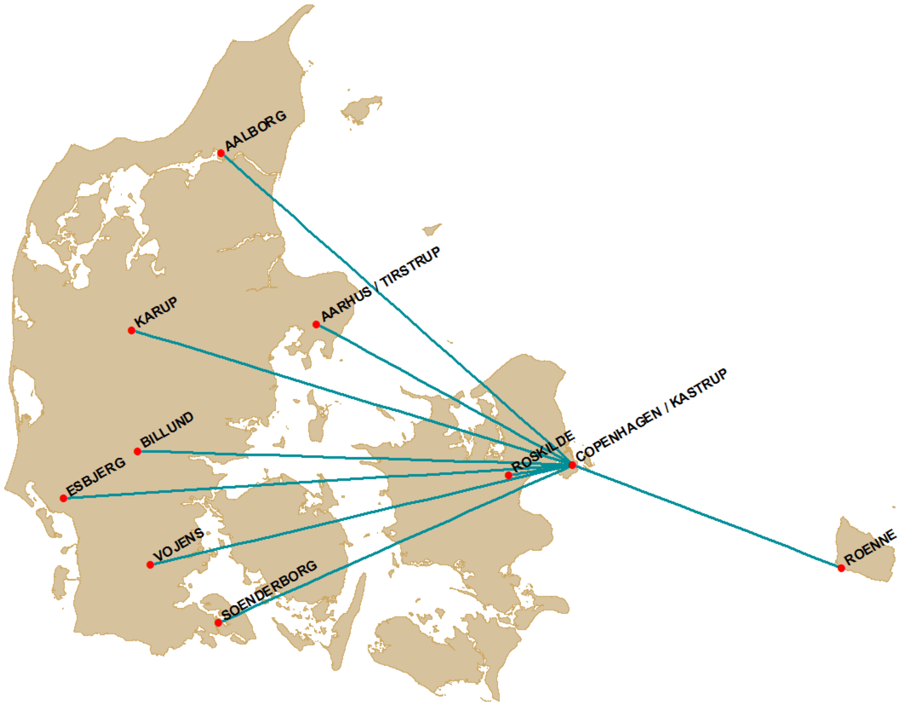



Figure 3.3.30 Most frequent domestic flying routes for large aircraft in Denmark.

Copenhagen Airport is the starting or end point for most of the domestic aviation made by large aircraft in Denmark (Figure 3.3.30; routes to Greenland/Faroe Islands are not shown). Even though many domestic flights not touching Copenhagen Airport are also reported in the flight statistics kept by the Danish Transport and Construction Agency, these flights, however, are predominantly made with small piston engine aircraft using aviation gasoline. Hence, the consumption of jet fuel by flights not using Copenhagen is merely marginal.

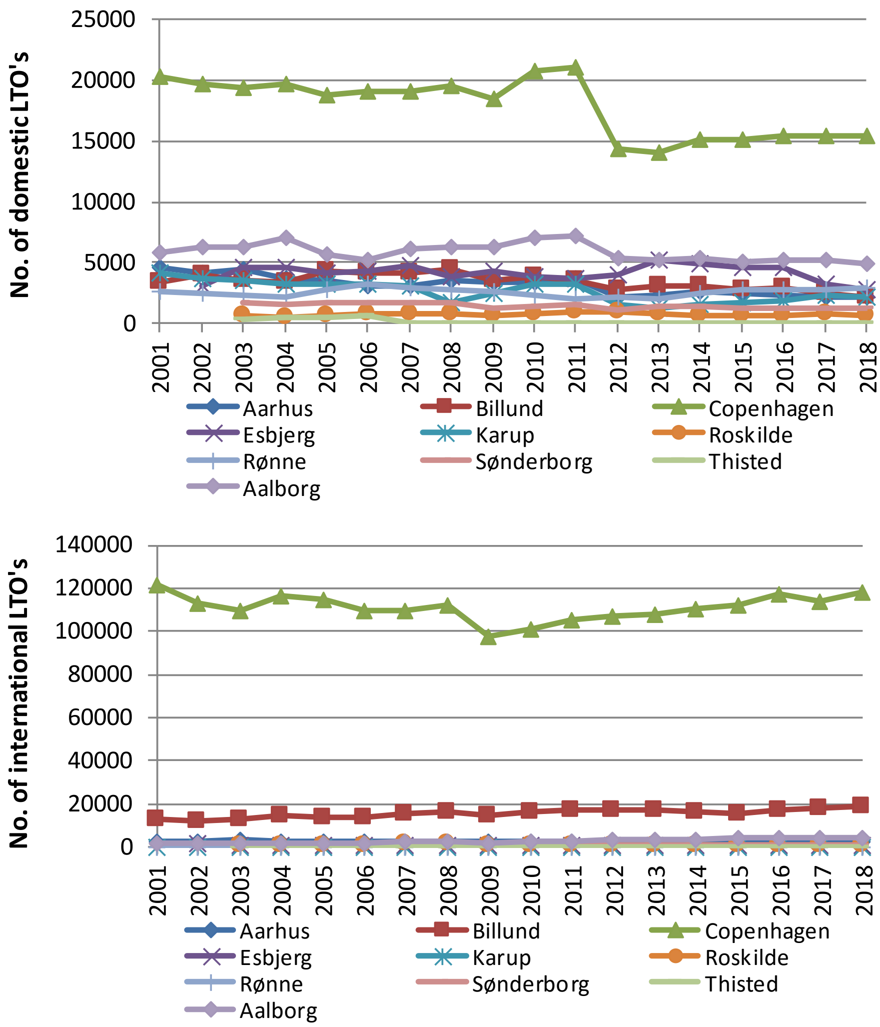



Figure 3.3.31 No. of LTO's for the most important airports in Denmark 2001-2018.

Figure 3.3.31 shows the number of domestic and international LTO's for Danish airports[11], in a time series from 2001-2018.

### Non-road working machinery and equipment

Non-road working machinery and equipment are used in agriculture, forestry and industry, for household/gardening purposes and for sailing purposes (recreational craft).

For the most important types of building and construction machinery (industrial non-road) annual new sales data for 1996 onwards has been provided by the Association of Danish Agricultural Machinery Dealers. Fork lift sales data has been provided by the Association of Producers and Distributors of Fork Lifts in Denmark for 1976 onwards. From engine manufacturers engine load factors have been provided based on electronic engine power registrations (Sjøgren 2016; Mikkelsen 2016) in the case of building and construction machinery. Further, equipment size - engine size relations, equipment scrapping curves and annual working hours as a function of machinery age has been included in the model (Sjøgren 2016; Mikkelsen 2016; Brun 2018; Christensen 2018).

[11] Flights for Greenland and the Faroe Islands are included under domestic in the figure.

For the most important household and gardening machinery types annual new sales data for 2006 onwards is provided by the Dealers Association of Electric Tools and Gardening Machinery (LTEH: Leverandørforeningen for Transportabelt Elværktøj og Havebrugsmaskiner). Further, equipment size - engine size relations, equipment scrapping curves and annual working hours as a function of machinery age has been provided by LTEH (Nielsen and Schösser, 2016).

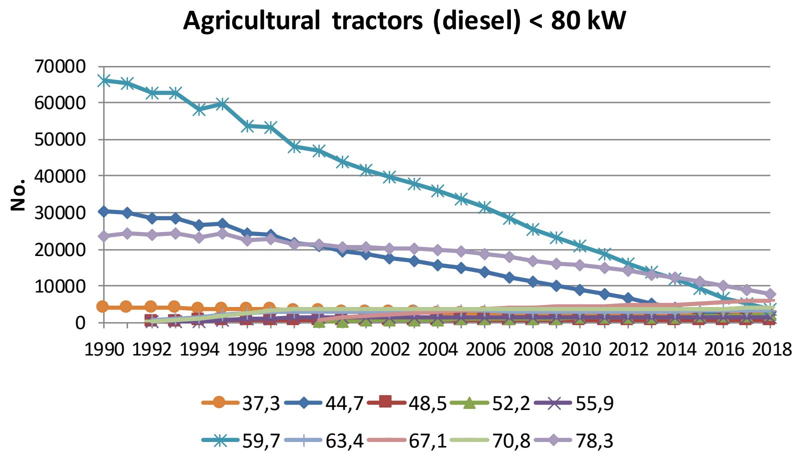
For other machinery types, information on the number of different types of machines, their respective load factors, engine sizes and annual working hours has been provided by Winther et al. (2006) for the years until 2004. For later inventory years, supplementary stock data are annually provided by the Association of Danish Agricultural Machinery Dealers.

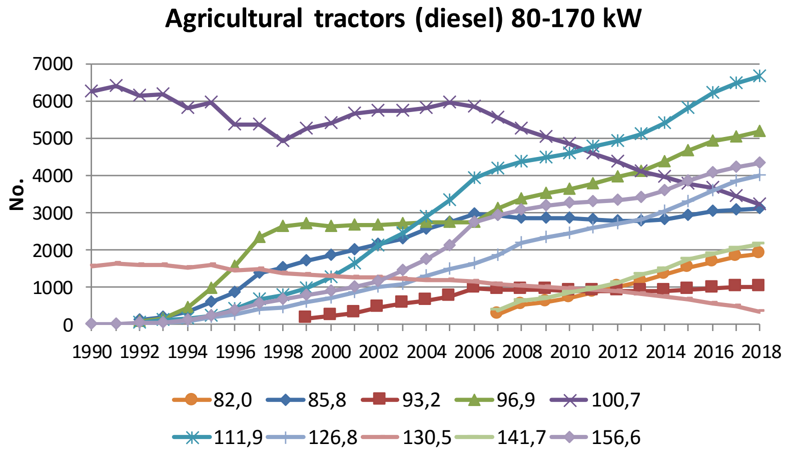
The stock development from 1990-2018 for the most important types of machinery are shown in Figures 3.3.32-3.3.39 below. The stock data are also listed in Annex 2.B.11, together with figures for load factors, engine sizes and annual working hours. As regards stock data for the remaining machinery types, please refer to (Winther et al., 2006).

It is important to note that key experts within the field of industrial non-road activities assume a significant decrease in the activities for 2009 due to the global financial crisis. This reduction is in the order of 25 % for 2009 for industrial non-road in general (pers. comm. Per Stjernqvist, Volvo Construction Equipment 2010). For fork lifts, 5 % and 20 % reductions are assumed for 2008 and 2009, respectively (pers. comm. Peter H. Møller, Rocla A/S).

For agriculture, the total number of agricultural tractors and harvesters per year are shown in the Figures 3.3.32-3.3.33, respectively. The figures clearly show a decrease in the number of small machines, these being replaced by machines in the large engine-size ranges.

The tractor and harvester developments towards fewer vehicles and larger engines, shown in Figure 3.3.34, are very clear. From 1990 to 2018, tractor and harvester numbers decrease by around 46 % and 67 %, respectively, whereas the average increase in engine size for tractors is 65 % and 278 % for harvesters, in the same time period.



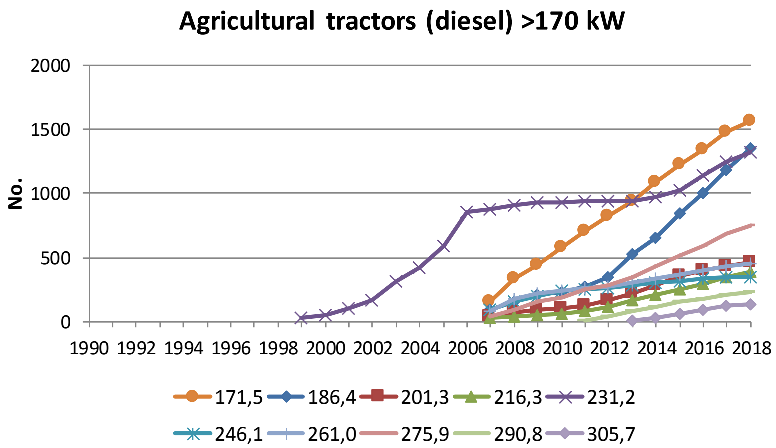
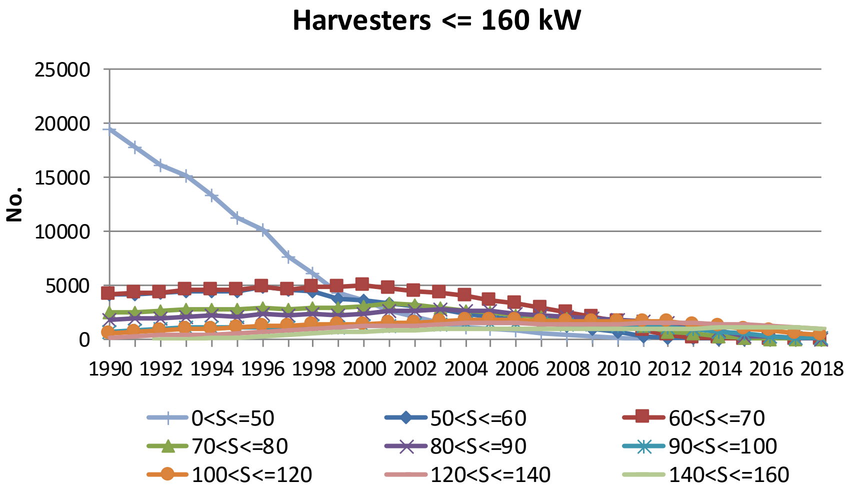




Figure 3.3.32 Total numbers in kW classes for agricultural tractors from 1990 to 2018.



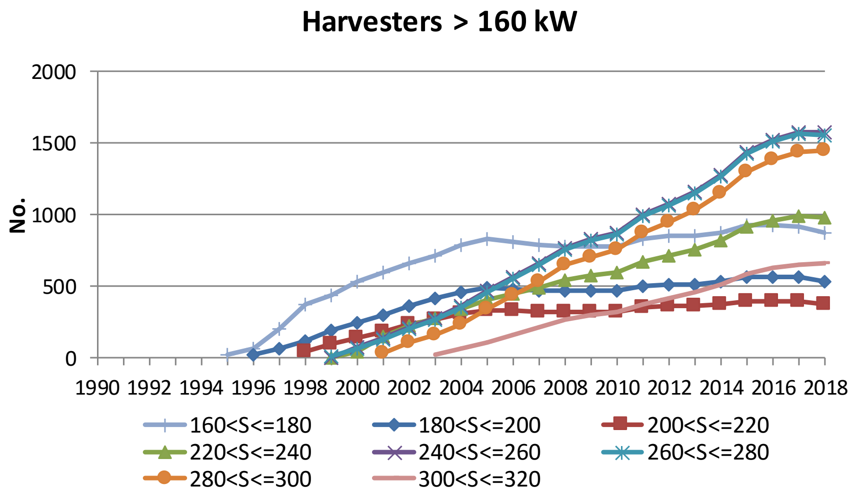




Figure 3.3.33 Total numbers in kW classes for harvesters from 1990 to 2018.

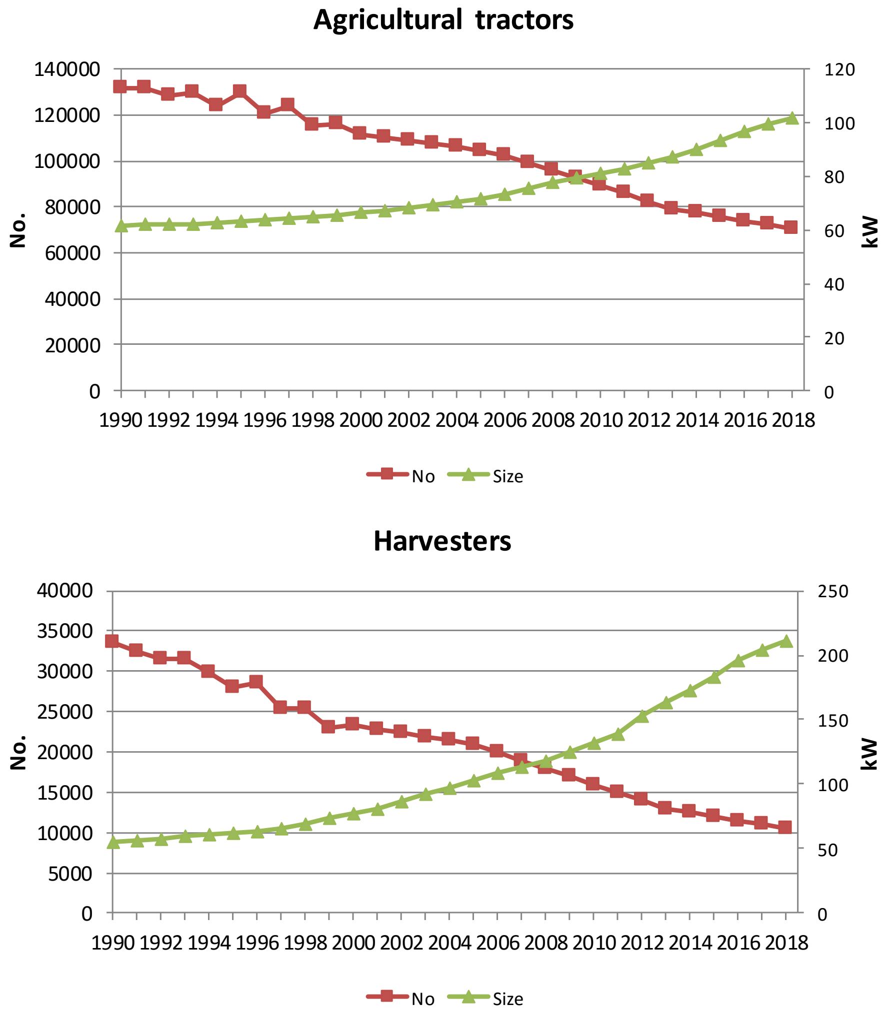



Figure 3.3.34   Total numbers and average engine size for agricultural tractors and harvesters (1990 to 2018).

The most important machinery types for industrial use are different types of construction machinery and fork lifts. The Figures 3.3.35 and 3.3.36 show the 1990-2018 stock development for specific types of construction machinery and diesel fork lifts. Due to lack of data, 1996-1999 average sales data for construction machinery is used for 1995 and back. However, it is assumed that telescopic loaders first enter into use in 1986 (Jensen, Scantruck 2016). For most of the machinery types, there is an increase in machinery numbers from 1990 onwards, due to increased construction activities.

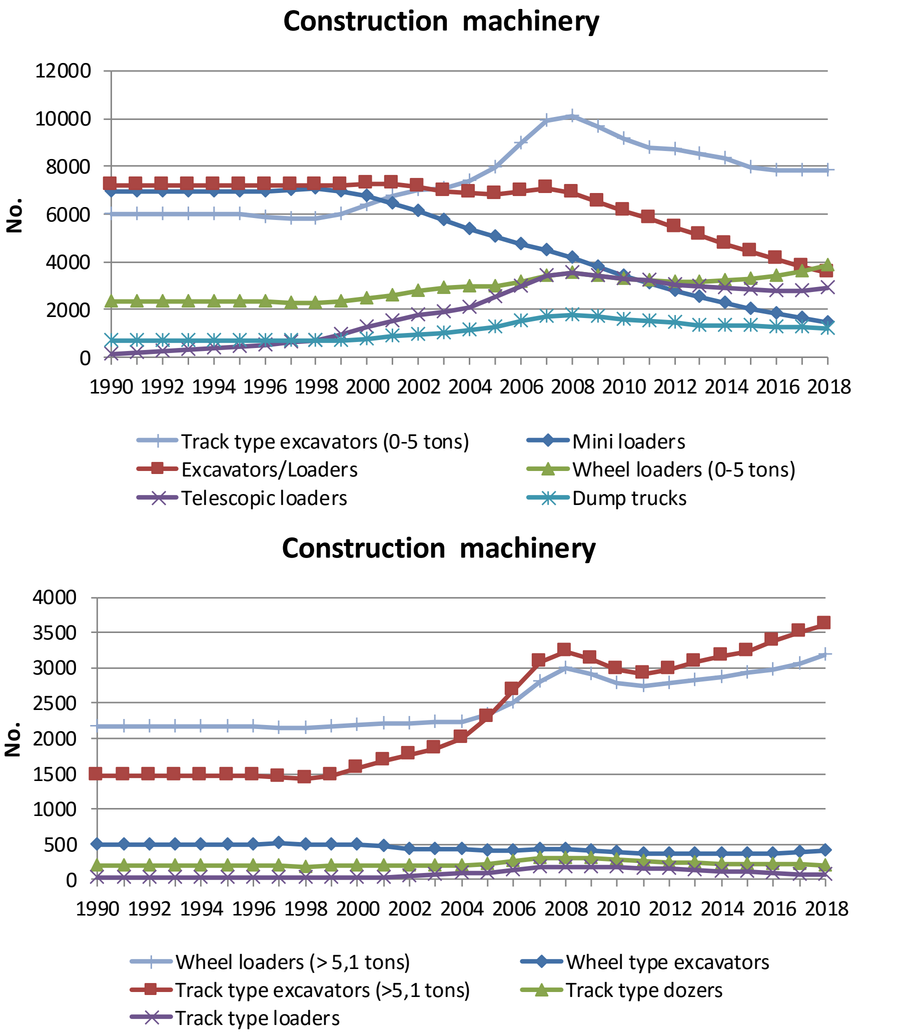



Figure 3.3.35 1990-2018 stock development for specific types of construction machinery.

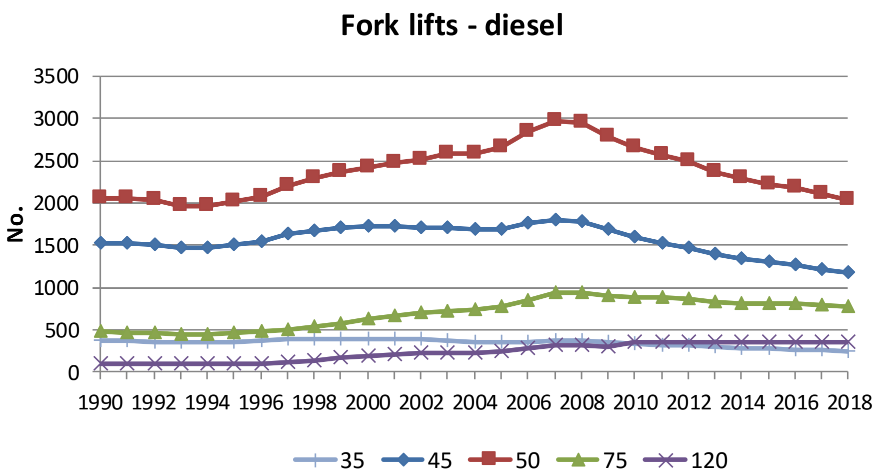
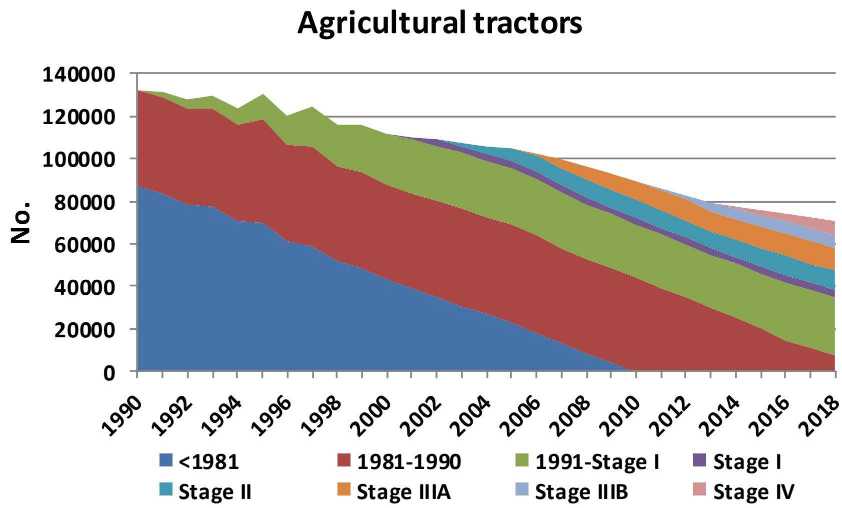


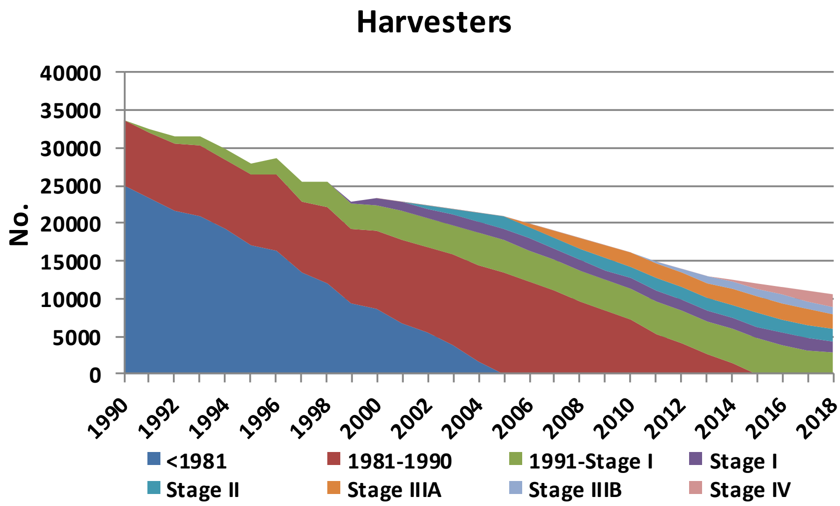

Figure 3.3.36 Total numbers of diesel fork lifts in kW classes from 1990 to 2018.

Figure 3.3.37 shows the emission layer distribution for the total stock of tractors, harvesters, construction machinery (most important types, Figure 3.3.35) and diesel fork lifts from 1990-2018.

The penetration of the different pre-Euro engine classes, and engine stages complying with the gradually stricter EU stage I-IV emission limits is very visible from Figure 3.3.37. The average lifetimes of 30 and 25 years for agricultural tractors and harvesters, and maximum life times of 24 and 20 years, respectively for fork lifts and most types of construction machinery, influence the individual engine technology turn-over speeds.

The EU emission directive stage implementation years relate to engine size, and hence, for all four machinery groups the emission level shares into specific size segments will differ slightly from the picture shown in Figure 3.3.37.

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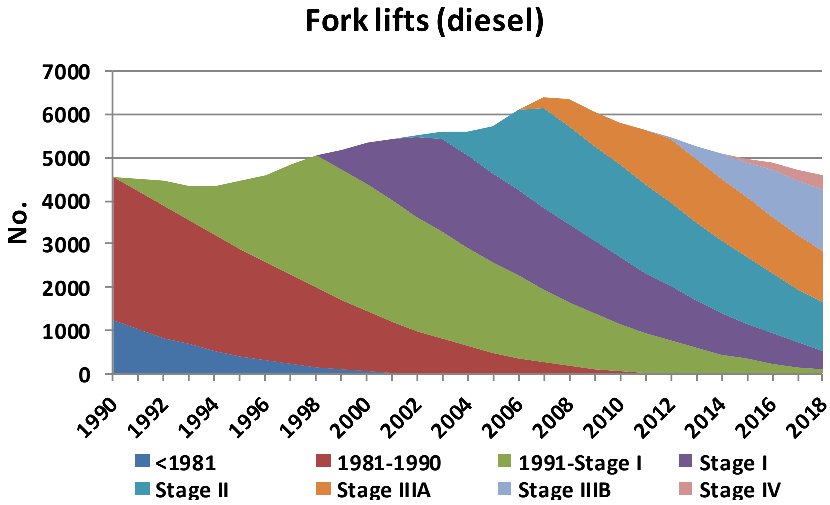


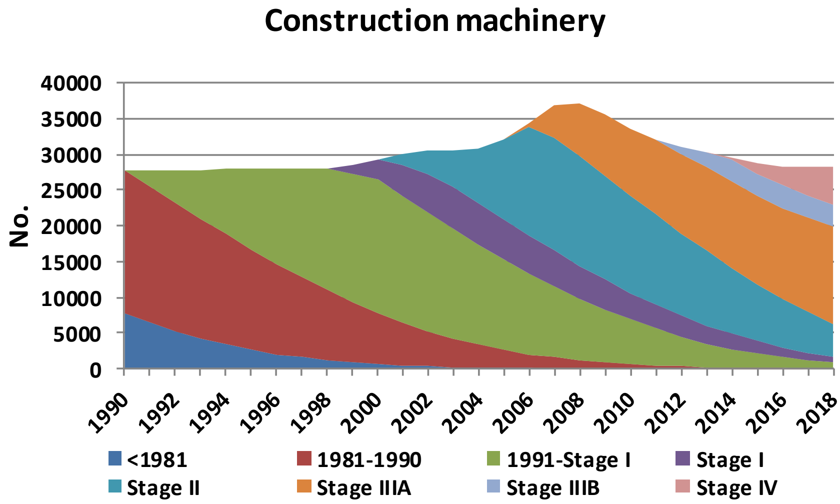


Figure 3.3.37 Layer distribution for tractors, harvesters, construction machinery and diesel fork lifts (1990 to 2018).

The 1990-2018 stock development for the most important household and gardening machinery types is shown in Figure 3.3.38. The activities made with private and professional equipment types are grouped into the Residential (1.A.4b) and Commercial/Institutional (1.A.4.a) inventory sectors, respectively.

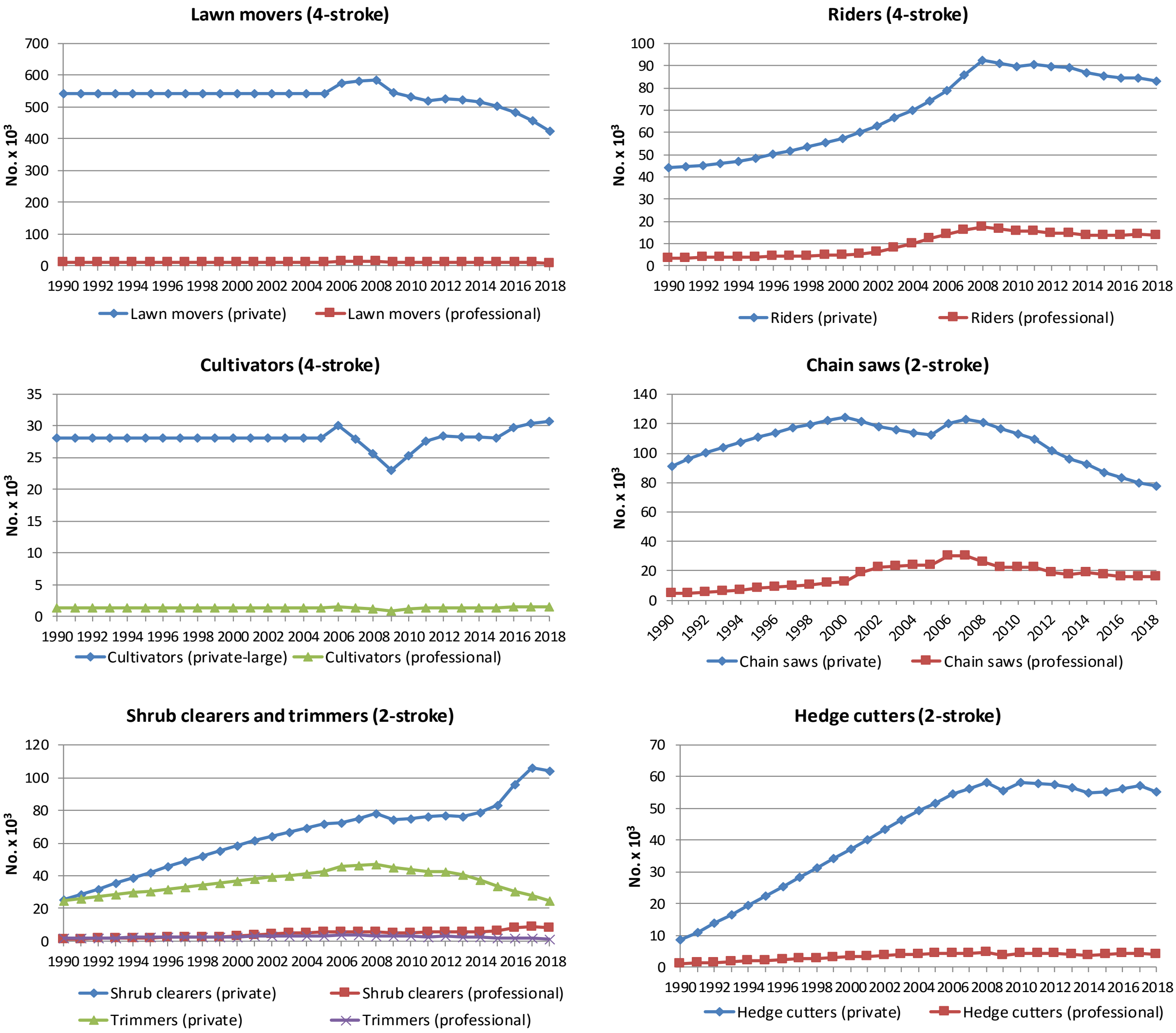


Figure 3.3.38 Stock development 1990-2018 for the most important household and gardening machinery types.

The total stock development for the most important household and gardening machinery types is shown in Figure 3.3.39 split into 2-stroke and 4-stroke machinery for Residential (1.A.4b) and Commercial/Institutional (1.A.4.a). For the same stock division, the emission layer distribution is also shown in Figure 3.3.39. The penetration of new technologies occur faster for working machinery in Commercial/Institutional (1.A.4.a) compared with Residential (1.A.4.b), due to the shorter maximum life times for the working equipment used by professionals.

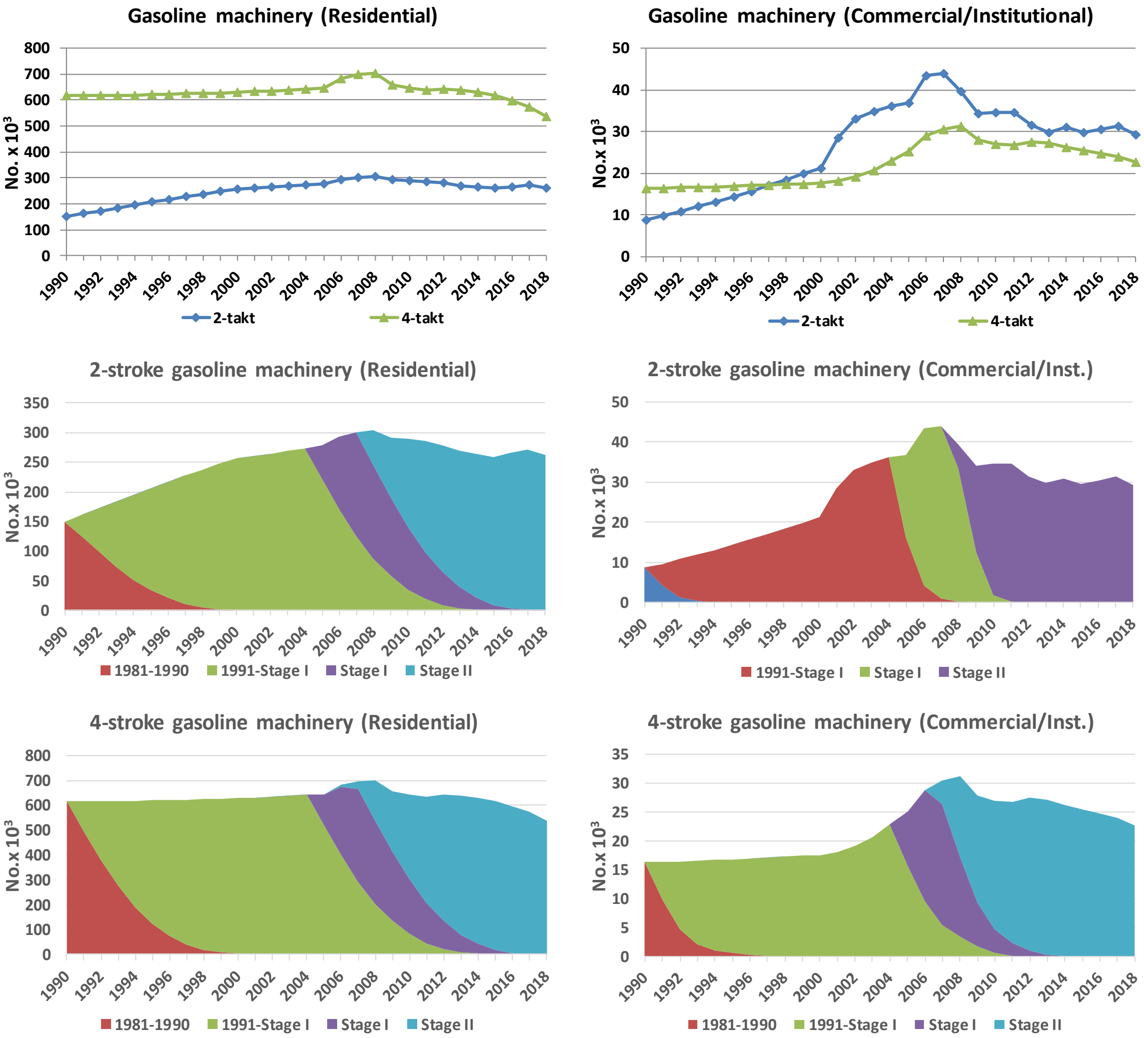


Figure 3.3.39 Layer distribution for the most important household and gardening machinery types split into residential and commercial/institutional (1990-2018).

Figure 3.3.40 shows the development in numbers of different recreational craft from 1990-2018. The 2004 stock data for recreational craft are repeated for 2005+, due to lack of data from the Danish Sailing Association.

For diesel boats, increases in stock and engine size are expected during the whole period, except for the number of motor boats (< 27 ft.) and the engine sizes for sailing boats (<26 ft.), where the figures remain unchanged. A decrease in the total stock of sailing boats (<26 ft.) by 21 % and increases in the total stock of yawls/cabin boats and other boats (<20 ft.) by around 25 % are expected. Due to a lack of information specific to Denmark, the shifting rate from 2-stroke to 4-stroke gasoline engines is based on a German non-road study (IFEU, 2004).

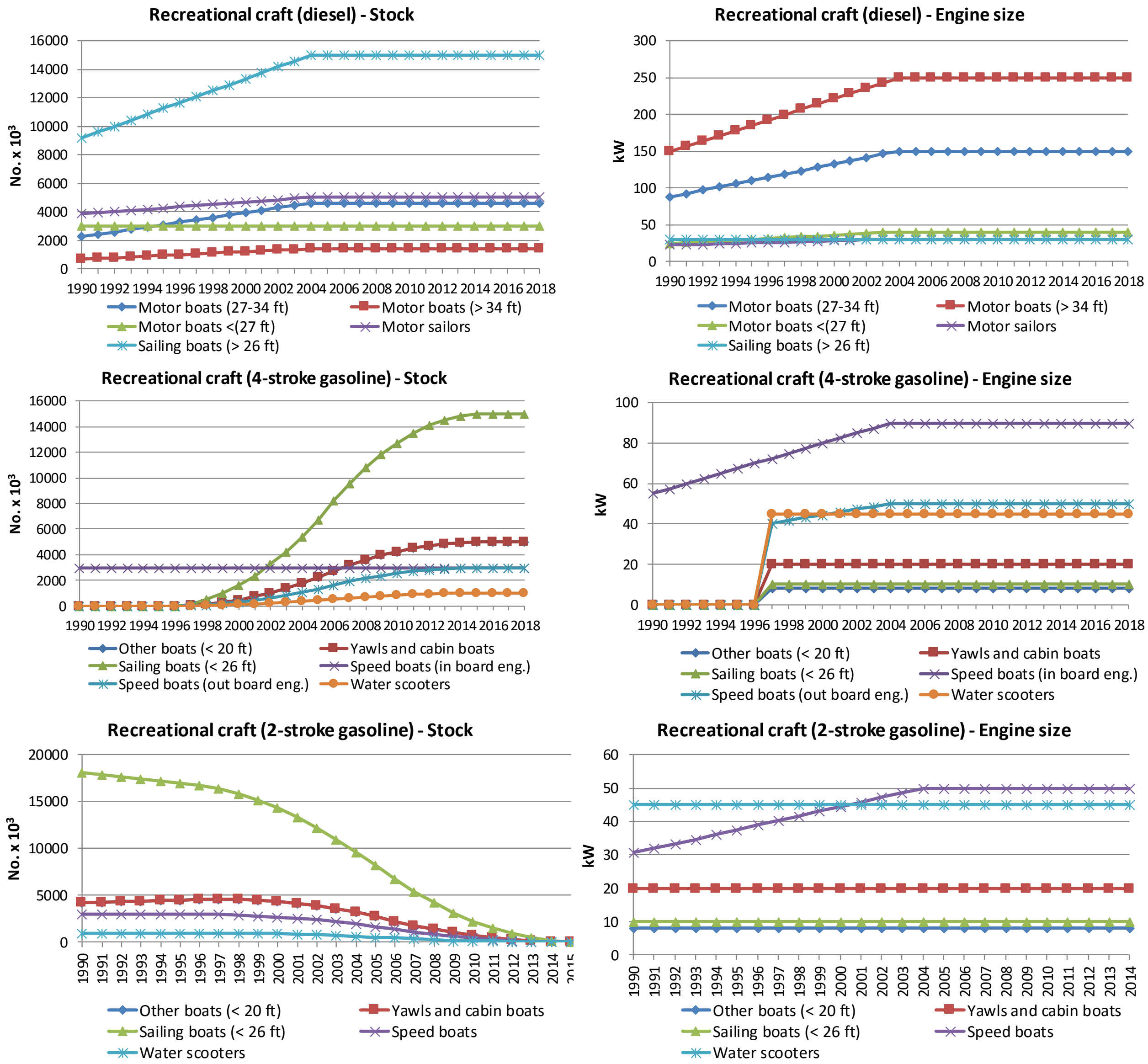


Figure 3.3.40 1990-2018 Stock and engine size development for recreational craft.

## National sea transport

Table 3.3.8 lists the most important domestic ferry routes (regional ferries) in Denmark in the period 1990-2018. For these ferry routes and the years 1990-2005, the following detailed traffic and technical data have been gathered by Winther (2008): Ferry name, year of service, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size and sailing time (single trip).

For 2006-2018, the above mentioned traffic and technical data for specific ferries have been provided by Nielsen (2019) in the case of Mols-Linien (Sjællands Odde-Ebeltoft, Sjællands Odde-Århus, Kalundborg-Århus, Køge-Rønne), by Jørgensen (2017) for Færgen A/S (Køge-Rønne, Tårs-Spodsbjerg, Kalundborg-Samsø), by Kruse (2015) for Samsø Rederi (Hou-Sælvig), by Mortensen (2015) for Færgeselskabet Læsø (Frederikshavn-Læsø) and by Eriksen (2017) for Ærøfærgerne (Svendborg-Ærøskøbing). For Esbjerg/Hanstholm/Hirtshals-Torshavn traffic and technical data have been provided by Dávastovu (2010).

Table 3.3.8 Regional ferry routes comprised in the Danish inventory.

| Ferry service | Service period |
|---|---|
| Esbjerg-Torshavn | 1990-1995, 2009+ |
| Halsskov-Knudshoved | 1990-1999 |
| Hanstholm-Torshavn | 1991-1992, 1999+ |
| Hirtshals-Torshavn | 2010 |
| Hou-Sælvig | 1990+ |
| Hundested-Grenaa | 1990-1996 |
| Frederikshavn-Læsø | 1990+ |
| Kalundborg-Juelsminde | 1990-1996 |
| Kalundborg-Samsø | 1990+ |
| Kalundborg-Århus | 1990+ |
| Korsør-Nyborg, DSB | 1990-1997 |
| Korsør-Nyborg, Vognmandsruten | 1990-1999 |
| København-Rønne | 1990-2004 |
| Køge-Rønne | 2004+ |
| Sjællands Odde-Ebeltoft | 1990+ |
| Sjællands Odde-Århus | 1999+ |
| Svendborg-Ærøskøbing | 1990+ |
| Tårs-Spodsbjerg | 1990+ |

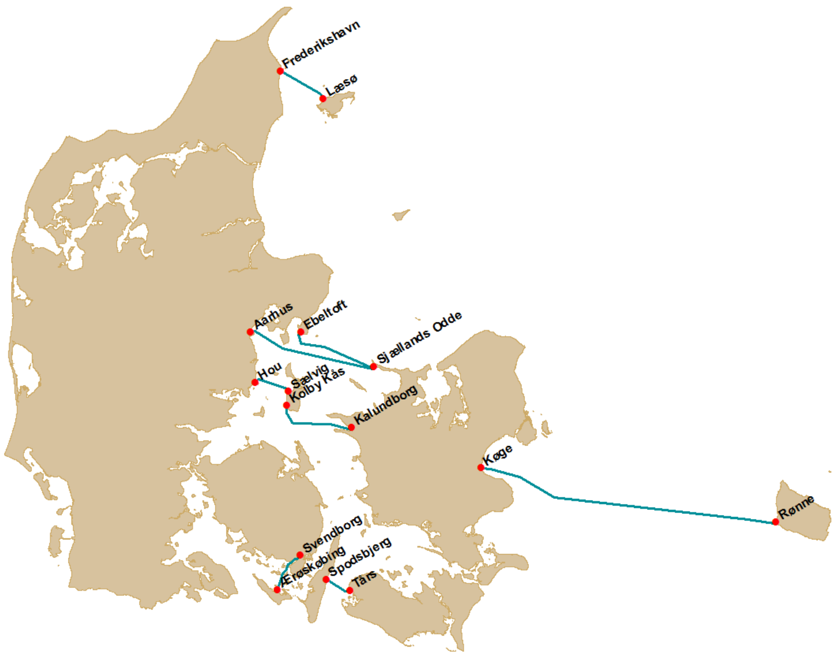


Figure 3.3.41 Regional ferry routes in Denmark (2018).

Table 3.3.9 lists the small ferry routes (island and short cut ferries) included in the Danish inventory for the period 1990-2018. For these ferry routes and the years 1990-2018, the following detailed traffic and technical data have been gathered by Rasmussen (2017) and Andersen (2019): Ferry name, year of service, engine size (MCR), engine year, and sailing time (single trip). Supplementary data for engine type, fuel type and average load factor is provided by Kristensen (2017).

Table 3.3.9 Small ferry routes comprised in the Danish inventory.

| Ferry service | Service period |
|---|---|
| Assens-Baagø | 1990+ |
| Ballebro-Hardeshøj | 1990+ |
| Bandholm-Askø | 1990+ |
| Branden-Fur | 1990+ |
| Bøjden-Fynshav | 1990+ |
| Esbjerg-Fanø | 1990+ |
| Feggesund overfart | 1990+ |
| Fejø-Kragenæs | 1990+ |
| Femø-Kragenæs | 1990+ |
| Frederikssund-Roskilde | 1999-2000 |
| Fåborg-Avernakø-Lyø | 1990+ |
| Fåborg-Søby | 1990+ |
| Grenaa-Anholt | 1990+ |
| Gudhjem-Christiansø | 2015+ |
| Hals-Egense | 1994+ |
| Havnsø-Sejerø | 1990+ |
| Holbæk-Orø | 1990+ |
| Horsens-Endelave | 1990+ |
| Hov-Tunø | 1990+ |
| Hundested-Rørvig | 1990+ |
| Hvalpsund-Sundsøre | 1990+ |
| Kastrup-Rønne | 1990 |
| Kleppen-Venø | 1990+ |
| Korsør-Lohals | 1990+ |
| København-Århus | 1992-1993 |
| Næssund overfart | 1990+ |
| Rudkøbing-Marstal | -2013 |
| Rudkøbing-Strynø | 1990+ |
| Stigsnæs-Agersø | 1990+ |
| Stigsnæs-Omø | 1990+ |
| Stubbekøbing-Bogø | 1990+ |
| Svendborg-Skarø-Drejø | 1990+ |
| Søby-Fynshav | 2009+ |
| Søby-Mommark | -2009 |
| Thyborøn-Agger | 1990+ |
| Aarø-Aarøsund | 1990+ |

The number of round trips per ferry route from 1990 to 2018 is provided by Statistics Denmark (2019). Figure 3.3.41 show the regional ferry routes in 2018 (Esbjerg/Hanstholm/Hirtshals-Torshavn not shown). The ferry traffic data are also listed in Annex 3.B.12, together with different ferry specific technical and operational data.

For each ferry, Annex 3.B.12 lists the relevant information as regards ferry route, name, year of service, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size and sailing time (single trip). There is a lack of historical traffic data for 1985-1989, and hence, data for 1990 are used for these years, to support the fuel consumption and emission calculations.

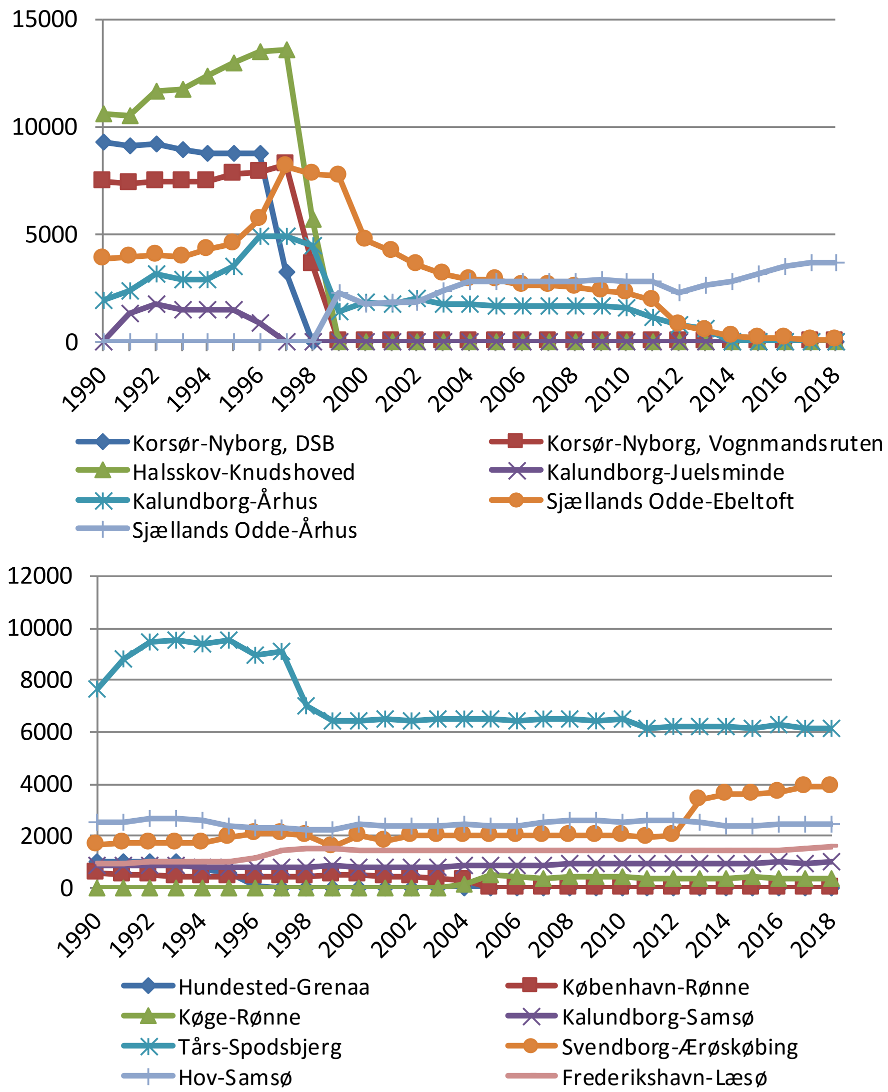

Figure 3.3.42 No. of round trips for the most important ferry routes in Denmark 1990-2018.

It is seen from Table 3.3.8 (and Figure 3.3.42) that several ferry routes were closed in the time period from 1996-1998, mainly due to the opening of the Great Belt Bridge (connecting Zealand and Funen) in 1997. Hundested-Grenaa and Kalundborg-Juelsminde was closed in 1996, Korsør-Nyborg (DSB) closed in 1997, and Halsskov-Knudshoved and Korsør-Nyborg (Vognmandsruten) was closed in 1998. The ferry line København-Rønne was replaced by Køge-Rønne in 2004 and from 1999, a new ferry connection was opened between Sjællands Odde and Århus.

The fuel sold for freight transport by Royal Arctic Line between Aalborg (Denmark) and Greenland is included under other national sea transport in the Danish inventories. In this case all fuel is being bought in Denmark (Rasmussen, 2019). The fuel used by freight transport between Denmark and the Faroe Islands (Eimskip) is bought outside Denmark. Hence, this fuel consumption is not included in the Danish inventories at all.

Fuel used for the remaining part of the traffic between two Danish ports, other national sea transport, is taken as the difference between DEA national fuel sales for national sea transport and the bottom-up calculated fuel consumption for Danish ferries. For years when the fuel estimates for ferries (not including the ferry to the Faroe Islands) are higher than DEA reported fuel sold for national sea transport, fuel is taken from fisheries in the case of marine diesel (1985-1999). For heavy fuel oil, the missing fuel amount is taken from stationary sources (1985-1986, 1988, 1994-1996) and international sea transport (2015 onwards).

In national sea transport, LNG fuel has been calculated for Danish ferries since 2015. However, in DEA fuel statistics, the consumption of LNG for national sea transport is included under diesel instead of being reported as LNG. In the Danish emission model for ships, the bottom up estimated consumption of LNG by mass is converted to energy units by using the calorific value 47.9 MJ/kg. The LNG energy use is reported under national sea transport in the inventories, and the amount of diesel (by energy unit) reported for national sea transport is subsequently being reduced by the same number.

#### Other sectors

The activity data for military, railways, international sea transport and fishery consists of fuel consumption information from DEA (2019).

For international sea transport, the basis is in principle fuel sold in Danish ports for vessels with a foreign destination (i.e. outside the Kingdom of Denmark), as prescribed by the IPCC guidelines. However, it must be noted that fuel sold for sailing activities between Denmark and Greenland/Faroe Islands are reported as international in the DEA energy statistics. Hence, for inventory purposes in order to follow the IPCC guidelines, the bottom-up fuel estimates for the ferry routes Esbjerg/Hanstholm/Hirtshals-Torshavn, and fuel buy reports from Royal Arctic Line is transferred from international sea transport to national sea transport in fuel sales, prior to inventory fuel input.

For fisheries, the calculation methodology is fuel activity based and input fuel data is in principle the diesel fuel sold for fisheries reported by DEA. For years when bottom up diesel estimates for national sea transport are higher than DEA reported fuel sold for national sea transport, diesel is transferred from fisheries to national sea transport in the inventories. Also, the bottom up diesel estimate for recreational craft is subtracted from fisheries and grouped in the "Other" inventory category together with military activities.

Summarized up per fuel type, the above described fuel transferals involving the sectors national and international sea transport, fisheries and stationary industrial sources becomes zero, thus leaving the national energy balance unchanged.

For all sectors, fuel consumption figures are given in Annex 3.B.15 for the years 1990 and 2018 in CollectER format, and fuel consumption time series are given in Annex 3.B.16 in NFR format.

#### Emission legislation

For other modes of transport and non-road machinery, the engines have to comply with the emission legislation limits agreed by the EU and different UN organisations in terms of $NO_x$, CO, VOC and TSP emissions and fuel sulphur content. In terms of greenhouse gases, the emission legislation requirements for VOC influence the emissions of $CH_4$, the latter emission component forming a part of total VOC. Only for ships, legislative limits for specific fuel consumption have been internationally agreed in order to reduce the emissions of $CO_2$.

For non-road working machinery and equipment, and recreational craft and railway locomotives/motor cars, the emission directives list specific emission limit values (g per kWh) for CO, VOC, $NO_x$ (or VOC + $NO_x$) and TSP, depending on engine size (kW for diesel, ccm for gasoline) and date of implementation (referring to engine market date).

For diesel, the directives 97/68 and 2004/26 (Table 3.3.10) relate to Stage I-IV non-road machinery other than agricultural and forestry tractors and the directives have different implementation dates for machinery operating under transient and constant loads. The latter directive also comprises emission limits for Stage IIIA and IIIB railways machinery (Table 3.3.14). For Stage I-IV tractors the relevant directives are 2000/25 and 2005/13 (Table 3.3.10).

For emission approval of the EU Stage I, II and IIIA engine technologies, emissions (and fuel consumption) measurements are made using the steady state test cycle ISO 8178 C1, referred to as the Non-Road Steady Cycle (NRSC), see e.g. www.dieselnet.com. In addition to the NRSC test, the newer Stage IIIB and IV (and optionally Stage IIIA) engine technologies are tested under more realistic operational conditions using the new Non-Road Transient Cycle (NRTC).

For gasoline, the directive 2002/88 distinguishes between Stage I and II hand-held (SH) and not hand-held (NS) types of machinery (Table 3.3.11). Emissions are tested using one of the specific constant load ISO 8178 test cycles (D2, G1, G2, G3) depending on the type of machinery.

For Stage V machinery, EU directive 2016/1628 relate to non-road machinery other than agricultural tractors and railways machinery (Table 3.3.10) and non-road gasoline machinery (Table 3.3.11). EU directive 167/2013 relate to Stage V agricultural and forestry tractors (Table 3.3.10). The Stage V emission limits are also shown in Annex 3.B.11.

Table 3.3.10 Overview of EU emission directives relevant for diesel fueled non-road machinery.

| Stage | Engine size | CO | VOC | $NO_x$ | VOC+$NO_x$ | PM | Diesel machinery | | | Tractors | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Implement. date | | EU | Implement. |
| | [kW] | [g/kWh] | | | | | EU Directive | Transient | Constant | Directive | Date |
| Stage I | | | | | | | | | | | |
| A | 130<=P<560 | 5 | 1.3 | 9.2 | - | 0.54 | 97/68 | 1/1 1999 | - | 2000/25 | 1/7 2001 |
| B | 75<=P<130 | 5 | 1.3 | 9.2 | - | 0.7 | | 1/1 1999 | - | | 1/7 2001 |
| C | 37<=P<75 | 6.5 | 1.3 | 9.2 | - | 0.85 | | 1/4 1999 | - | | 1/7 2001 |
| Stage II | | | | | | | | | | | |
| E | 130<=P<560 | 3.5 | 1 | 6 | - | 0.2 | 97/68 | 1/1 2002 | 1/1 2007 | 2000/25 | 1/7 2002 |
| F | 75<=P<130 | 5 | 1 | 6 | - | 0.3 | | 1/1 2003 | 1/1 2007 | | 1/7 2003 |
| G | 37<=P<75 | 5 | 1.3 | 7 | - | 0.4 | | 1/1 2004 | 1/1 2007 | | 1/1 2004 |
| D | 18<=P<37 | 5.5 | 1.5 | 8 | - | 0.8 | | 1/1 2001 | 1/1 2007 | | 1/1 2002 |
| Stage IIIA | | | | | | | | | | | |
| H | 130<=P<560 | 3.5 | - | - | 4 | 0.2 | 2004/26 | 1/1 2006 | 1/1 2011 | 2005/13 | 1/1 2006 |
| I | 75<=P<130 | 5 | - | - | 4 | 0.3 | | 1/1 2007 | 1/1 2011 | | 1/1 2007 |
| J | 37<=P<75 | 5 | - | - | 4.7 | 0.4 | | 1/1 2008 | 1/1 2012 | | 1/1 2008 |
| K | 19<=P<37 | 5.5 | - | - | 7.5 | 0.6 | | 1/1 2007 | 1/1 2011 | | 1/1 2007 |
| Stage IIIB | | | | | | | | | | | |
| L | 130<=P<560 | 3.5 | 0.19 | 2 | - | 0.025 | 2004/26 | 1/1 2011 | - | 2005/13 | 1/1 2011 |
| M | 75<=P<130 | 5 | 0.19 | 3.3 | - | 0.025 | | 1/1 2012 | - | | 1/1 2012 |
| N | 56<=P<75 | 5 | 0.19 | 3.3 | - | 0.025 | | 1/1 2012 | - | | 1/1 2012 |
| P | 37<=P<56 | 5 | - | - | 4.7 | 0.025 | | 1/1 2013 | - | | 1/1 2013 |
| Stage IV | | | | | | | | | | | |
| Q | 130<=P<560 | 3.5 | 0.19 | 0.4 | - | 0.025 | 2004/26 | 1/1 2014 | 1/1 2014 | 2005/13 | 1/1 2014 |
| R | 56<=P<130 | 5 | 0.19 | 0.4 | - | 0.025 | | 1/10 2014 | 1/10 2014 | | 1/10 2014 |
| Stage V[A] | | | | | | | | | | | |
| NRE-v/c-7 | P>560 | 3.5 | 0.19 | 3.5 | | 0.045 | 2016/1628 | | 2019 | 167/2013[B] | 2019 |
| NRE-v/c-6 | 130≤P≤560 | 3.5 | 0.19 | 0.4 | | 0.015 | | | 2019 | | 2019 |
| NRE-v/c-5 | 56≤P<130 | 5.0 | 0.19 | 0.4 | | 0.015 | | | 2020 | | 2020 |
| NRE-v/c-4 | 37≤P<56 | 5.0 | | | 4.7 | 0.015 | | | 2019 | | 2019 |
| NRE-v/c-3 | 19≤P<37 | 5.0 | | | 4.7 | 0.015 | | | 2019 | | 2019 |
| NRE-v/c-2 | 8≤P<19 | 6.6 | | | 7.5 | 0.4 | | | 2019 | | 2019 |
| NRE-v/c-1 | P<8 | 8.0 | | | 7.5 | 0.4 | | | 2019 | | 2019 |
| Generators | P>560 | 0.67 | 0.19 | 3.5 | | 0.035 | | | 2019 | | 2019 |

A = For selected machinery types, Stage V includes emission limit values for particle number.

B = Article 63 in 2016/1628 revise Article 19 in 167/2013 to include Stage V limits as described in 2016/1628.

Table 3.3.11 Overview of the EU Emission Directives relevant for gasoline fueled non-road machinery.

| | Category | Engine size [ccm] | CO [g pr kWh] | HC [g pr kWh] | $NO_X$ [g pr kWh] | $HC+NO_X$ [g pr kWh] | Implement. date |
|---|---|---|---|---|---|---|---|
| EU Directive 2002/88 | Stage I | | | | | | |
| Hand held | SH1 | S<20 | 805 | 295 | 5.36 | - | 1/2 2005 |
| | SH2 | 20≤S<50 | 805 | 241 | 5.36 | - | 1/2 2005 |
| | SH3 | 50≤S | 603 | 161 | 5.36 | - | 1/2 2005 |
| Not hand held | SN3 | 100≤S<225 | 519 | - | - | 16.1 | 1/2 2005 |
| | SN4 | 225≤S | 519 | - | - | 13.4 | 1/2 2005 |
| | Stage II | | | | | | |
| Hand held | SH1 | S<20 | 805 | - | - | 50 | 1/2 2008 |
| | SH2 | 20≤S<50 | 805 | - | - | 50 | 1/2 2008 |
| | SH3 | 50≤S | 603 | - | - | 72 | 1/2 2009 |
| Not hand held | SN1 | S<66 | 610 | - | - | 50 | 1/2 2005 |
| | SN2 | 66≤S<100 | 610 | - | - | 40 | 1/2 2005 |
| | SN3 | 100≤S<225 | 610 | - | - | 16.1 | 1/2 2008 |
| | SN4 | 225≤S | 610 | - | - | 12.1 | 1/2 2007 |
| EU Directive 2016/1628 | Stage V | | | | | | |
| Hand held (<19 kW) | NRSh-v-1a | S<50 | 805 | - | - | 50 | 2019 |
| | NRSh-v-1b | 50≤S | 805 | - | - | 72 | 2019 |
| Not hand held (P<19 kW) | NRS-vr/vi-1a | 80≤S<225 | 610 | - | - | 10 | 2019 |
| | NRS-vr/vi-1b | S≥225 | 610 | - | - | 8 | 2019 |
| Not hand held (19=<P<30 kW) | NRS-v-2a | S≤1000 | 610 | - | - | 8 | 2019 |
| | NRS-v-2b | S>1000 | 4.40* | - | - | 2.70* | 2019 |
| Not hand held (30=<P<56 kW) | NRS-v-3 | any | 4.40* | - | - | 2.70* | 2019 |

* Or any combination of values satisfying the equation $(HC+NO_x) \times CO^{0.784} \leq 8.57$ and the conditions $CO \leq 20.6$ g/kWh and $(HC+NO_x) \leq 2.7$ g/kWh.

For recreational craft, Directive 2003/44 comprises the Stage 1 emission legislation limits for diesel engines, and for 2-stroke and 4-stroke gasoline engines, respectively. The CO and VOC emission limits depend on engine size (kW) and the inserted parameters presented in the calculation formulas in Table 3.3.12. For $NO_X$, a constant limit value is given for each of the three engine types. For TSP, the constant emission limit regards diesel engines only.

In Table 3.3.13, the Stage II emission limits are shown for recreational craft. CO and $HC+NO_x$ limits are provided for gasoline engines depending on the rated engine power and the engine type (stern-drive vs. outboard) while CO, $HC+NO_x$, and particulate emission limits are defined for Compression Ignition (CI) engines depending on the rated engine power and the swept volume.

Table 3.3.12 Overview of the EU Emission Directive 2003/44 for recreational craft.

| Engine type | Impl. date | $CO=A+B/P^n$ | | | $HC=A+B/P^n$ | | | $NO_X$ | TSP |
|---|---|---|---|---|---|---|---|---|---|
| | | A | B | n | A | B | n | | |
| 2-stroke gasoline | 1/1 2007 | 150.0 | 600.0 | 1.0 | 30.0 | 100.0 | 0.75 | 10.0 | - |
| 4-stroke gasoline | 1/1 2006 | 150.0 | 600.0 | 1.0 | 6.0 | 50.0 | 0.75 | 15.0 | - |
| Diesel | 1/1 2006 | 5.0 | 0.0 | 0 | 1.5 | 2.0 | 0.5 | 9.8 | 1.0 |

Table 3.3.13 Overview of the EU Emission Directive 2013/53 for recreational craft.

| Diesel engines | | | | | |
|---|---|---|---|---|---|
| Swept Volume, SV l/cyl. | Rated Engine Power, $P_N$ kW | Impl. Date | CO g/kWh | HC + $NO_x$ g/kWh | PM g/kWh |
| SV < 0.9 | $P_N$ < 37 | | | | |
| | 37 <= $P_N$ < 75 (*) | 18/1 2017 | 5 | 4.7 | 0.30 |
| | 75 <= $P_N$ < 3 700 | 18/1 2017 | 5 | 5.8 | 0.15 |
| 0.9 <= SV < 1.2 | $P_N$ < 3 700 | 18/1 2017 | 5 | 5.8 | 0.14 |
| 1.2 <= SV < 2.5 | | 18/1 2017 | 5 | 5.8 | 0.12 |
| 2.5 <= SV < 3.5 | | 18/1 2017 | 5 | 5.8 | 0.12 |
| 3.5 <= SV < 7.0 | | 18/1 2017 | 5 | 5.8 | 0.11 |
| **Gasoline engines** | | | | | |
| Engine type | Rated Engine Power, $P_N$ kW | | CO g/kWh | HC + $NO_x$ g/kWh | PM g/kWh |
| Stern-drive and inboard engines | $P_N$ <= 373 | 18/1 2017 | 75 | 5 | - |
| | 373 <= $P_N$ <= 485 | 18/1 2017 | 350 | 16 | - |
| | $P_N$ > 485 | 18/1 2017 | 350 | 22 | - |
| Outboard engines and PWC engines (**) | $P_N$ <= 4.3 | 18/1 2017 | 500 – (5.0 x $P_N$) | 15.7 + ($50/PN^{0.9}$) | - |
| | 4.3 <= $P_N$ <= 40 | 18/1 2017 | 500 – (5.0 x $P_N$) | 15.7 + ($50/PN^{0.9}$) | - |
| | $P_N$ > 40 | 18/1 2017 | 300 | | - |

(*) Alternatively, this engine segment shall not exceed a PM limit of 0.2 g/kWh and a combined HC + $NO_x$ limit of 5.8 g/kWh.
(**) Small and medium size manufacturers making outboard engines <= 15 kW have until 18/1 2020 to comply.

Table 3.3.14 Overview of the EU Emission Directives relevant for railway locomotives and motorcars.

| | EU directive | Engine size [kW] | | CO | HC | $NO_x$ | HC+$NO_x$ | PM | Imp. date |
|---|---|---|---|---|---|---|---|---|---|
| | | | | g/kWh | | | | | |
| Locomotives | 2004/26 | Stage IIIA | | | | | | | |
| | | 130<=P<560 | RL A | 3.5 | - | - | 4 | 0.2 | 1/1 2007 |
| | | 560<P | RH A | 3.5 | 0.5 | 6 | - | 0.2 | 1/1 2009 |
| | | 2000<=P and piston displacement >= 5 l/cyl. | RH A | 3.5 | 0.4 | 7.4 | - | 0.2 | 1/1 2009 |
| | 2004/26 | Stage IIIB | RB | 3.5 | - | - | 4 | 0.025 | 1/1 2012 |
| | 2016/1628 | Stage V | | | | | | | |
| | | 0<P | RLL-v/c-1 | 3.5 | - | - | 4 | 0.025 | 2021 |
| Motor cars | 2004/26 | Stage IIIA | | | | | | | |
| | | 130<P | RC A | 3.5 | - | - | 4 | 0.2 | 1/1 2006 |
| | 2004/26 | Stage IIIB | | | | | | | |
| | | 130<P | RC B | 3.5 | 0.19 | 2 | - | 0.025 | 1/1 2012 |
| | 2016/1628 | Stage V | | | | | | | |
| | | 0<P | RLR-v/c-1 | 3.5 | 0.19 | 2 | - | 0.015 | 2021 |

Aircraft engine emissions of $NO_x$, CO, VOC and smoke are regulated by ICAO (International Civil Aviation Organization). The engine emission certification standards are contained in Annex 16 — Environmental Protection, Volume II — to the Convention on International Civil Aviation (ICAO Annex 16, 2008, plus amendments). The emission standards relate to the total emissions (in grams) from the so-called LTO (Landing and Take Off) cycle divided by the rated engine thrust (kN). The ICAO LTO cycle contains the idealised aircraft movements below 3000 ft (915 m) during approach, landing, airport taxiing, take off and climb out.

For smoke, all aircraft engines manufactured from 1 January 1983 have to meet the emission limits agreed by ICAO. For $NO_x$, CO, VOC The emission legislation is relevant for aircraft engines with a rated engine thrust larger than 26.7 kN. In the case of CO and VOC, the ICAO regulations apply for engines manufactured from 1 January 1983.

For $NO_x$, the emission regulations fall in five categories

- For engines of a type or model for which the date of manufacture of the first individual production model was before 1 January 1996, and for which the production date of the individual engine was before 1 January 2000.
- For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 1996, or for individual engines with a production date on or after 1 January 2000.
- For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2004.
- For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2008, or for individual engines with a production date on or after 1 January 2013.
- For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2014.

The regulations published by ICAO are given in the form of the total quantity of pollutants ($D_p$) emitted in the LTO cycle divided by the maximum sea level thrust ($F_{oo}$) and plotted against engine pressure ratio at maximum sea level thrust.

The limit values for $NO_x$ are given by the formulae in Table 3.3.15.

Table 3.3.15 Current certification limits for $NO_x$ for turbo jet and turbo fan engines.

| | Engines first produced before 1.1.1996 & for engines manufactured before 1.1.2000 | Engines first produced on or after 1.1.1996 & for engines manufactured on or after 1.1.2000 | Engines for which the date of manufacture of the first individual production model was on or after 1 January 2004 | Engines first produced on or after 1.1.2047 & for engines manufactured on or after 1.1.2013 | Engines for which the date of manufacture of the first individual production model was on or after 1.1.2014 |
|---|---|---|---|---|---|
| Applies to engines >26.7 kN | $Dp/F_{oo} = 40 + 2\pi_{oo}$ | $Dp/F_{oo} = 32 + 1.6\pi_{oo}$ | | | |
| Engines of pressure ratio less than 30 | | | | | |
| Thrust more than 89 kN | | | $Dp/F_{oo} = 19 + 1.6\pi_{oo}$ | $Dp/F_{oo} = 16.72 + 1.4080\pi_{oo}$ | $7.88 + 1.4080\pi_{oo}$ |
| Thrust between 26.7 kN and not more than 89 kN | | | $Dp/F_{oo} = 37.572 + 1.6\pi_{oo} - 0.208F_{oo}$ | $Dp/F_{oo} = 38.54862 + (1.6823\pi_{oo}) – (0.2453F_{oo}) – (0.00308\pi_{oo}F_{oo})$ | $Dp/F_{oo} = 40.052 + 1.5681\pi_{oo} - 0.3615F_{oo} - 0.0018 \pi_{oo} \times F_{oo}$ |
| Engines of pressure ratio more than 30 and less than 62.5 (104.7) | | | | | |
| Thrust more than 89 kN | | | $Dp/F_{oo} = 7+2.0\pi_{oo}$ | $Dp/F_{oo} = -1.04+ (2.0*\pi_{oo})$ | |
| Thrust between 26.7 kN and not more than 89 kN | | | $Dp/F_{oo} = 42.71 +1.4286\pi_{oo} - 0.4013F_{oo} +0.00642\pi_{oo}F_{oo}$ | $Dp/F_{oo} = 46.1600 + (1.4286\pi_{oo}) – (0.5303F_{oo}) – (0.00642\pi_{oo}F_{oo})$ | |
| Engines with pressure ratio 62.5 or more | | | | | |
| Engines with pressure ratio 82.6 or more | | | $Dp/F_{oo} = 32+1.6\pi_{oo}$ | $Dp/F_{oo} = 32+1.6\pi_{oo}$ | |
| Engines of pressure ratio more than 30 and less than (104.7) | | | | | |
| Thrust more than 89 kN | | | | | $Dp/F_{oo} = -9.88 + 2.0\pi_{oo}$ |
| Thrust between 26.7 kN and not more than 89 kN | | | | | $Dp/F_{oo} = 41.9435 + 1.505\pi_{oo} - 0.5823F_{oo} + 0.005562\pi_{oo} \times F_{oo}$ |
| Engines with pressure ratio 104.7 or more | | | | | $Dp/F_{oo} = 32 + 1.6\pi_{oo}$ |

Source: International Standards and Recommended Practices, Environmental Protection, ICAO Annex 16 Volume II 3rd edition July 2008, plus amendments: Amendment 7 (17 November 2011), Amendment 8 (July 2014),
where:
$D_p$ = the sum of emissions in the LTO cycle in g.
$F_{oo}$ = thrust at sea level take-off (100 %).
$\pi_{oo}$ = pressure ratio at sea level take-off thrust point (100 %).

The equivalent limits for HC and CO are $D_p/F_{oo}$ = 19.6 for HC and $D_p/F_{oo}$ = 118 for CO (ICAO Annex 16 Vol. II paragraph 2.2.2). Smoke is limited to a regulatory smoke number = 83 $(F_{oo})^{-0.274}$ or a value of 50, whichever is the lower.

A further description of the technical definitions in relation to engine certification as well as actual engine exhaust emission measurement data can be found in the ICAO Engine Exhaust Emission Database. The latter database is accessible from "http://www.easa.europa.eu" hosted by the European Aviation Safety Agency (EASA).

On 8 February 2016, at the tenth meeting of the International Civil Aviation Organization (ICAO) Committee for Environmental Protection (CAEP) a performance standard was agreed for new aircraft that will mandate improvements in fuel efficiency and reductions in carbon dioxide ($CO_2$) emissions. The standards will on average require a 4 % reduction in the cruise fuel consumption of new aircraft starting in 2028 compared to 2015 deliveries, with the actual reductions ranging from 0 to 11 %, depending on the maximum takeoff mass (MTOM) of the aircraft (ICCT, 2017).

The $CO_2$ certification standards are contained in a new Volume III - $CO_2$ Certification Requirement - to Annex 16 of the Convention on civil aviation (ICAO, 2017).

Embedded applicability dates are:

- **Subsonic jet aeroplanes**, including their derived versions, of greater than 5 700 kg maximum take-off mass for which the application for a type certificate was submitted on or after 1 January 2020, except for those aeroplanes of less than or equal to 60 000 kg maximum take-off mass with a maximum passenger seating capacity of 19 seats or less;
- **Subsonic jet aeroplanes**, including their derived versions, of greater than 5 700 kg and less than or equal to 60 000 kg maximum take-off mass with a maximum passenger seating capacity of 19 seats or less, for which the application for a type certificate was submitted on or after 1 January 2023;
- **All propeller-driven aeroplanes**, including their derived versions, of greater than 8 618 kg maximum take-off mass, for which the application for a type certificate was submitted on or after 1 January 2020;
- **Derived versions of non-$CO_2$-certified subsonic jet aeroplanes** of greater than 5 700 kg maximum certificated take-off mass for which the application for certification of the change in type design was submitted on or after 1 January 2023;
- **Derived versions of non-$CO_2$ certified propeller-driven aeroplanes** of greater than 8 618 kg maximum certificated take-off mass for which the application for certification of the change in type design was submitted on or after 1 January 2023;
- **Individual non-$CO_2$-certified subsonic jet aeroplanes** of greater than 5 700 kg maximum certificated take-off mass for which a certificate of airworthiness was first issued on or after 1 January 2028; and
- **Individual non-$CO_2$-certified propeller-driven aeroplanes** of greater than 8 618 kg maximum certificated take-off mass for which a certificate of airworthiness was first issued on or after 1 January 2028.

Marpol 73/78 Annex VI agreed by IMO (International Maritime Organisation) concerns the control of $NO_x$ emissions (Regulation 13 plus amendments) and $SO_x$ and particulate emissions (Regulation 14 plus amendments) from ships (DNV, 2009). Recently the so called Energy Efficiency Design Index (EEDI) fuel efficiency regulations for new built ships was included in Chapter 4 of Annex VI in the Marpol convention for the purpose of controlling the $CO_2$ emissions from ships (Lloyd's Register, 2012).

The baseline $NO_x$ emission regulation of Annex VI apply for diesel engines with a power output higher than 130 kW, which are installed on a ship constructed on or after 1 January 2000 and diesel engines with a power output higher than 130 kW which undergo major conversion on or after 1 January 2000.

The baseline $NO_x$ emission limits for ship engines in relation to their rated engine speed (n) given in RPM (Revolutions Per Minute) are the following:

- 17 g pr kWh, $n < 130$ RPM
- 45 x n-0.2 g pr kWh, $130 \le n < 2000$ RPM
- 9.8 g pr kWh, $n \ge 2000$ RPM

The further amendment of Annex VI Regulation 13 contains a three tiered approach in order to strengthen the emission standards for $NO_x$. The three tier approach comprises the following:

- Tier I: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2000 and prior to 1 January 2011 (initial regulation).
- Tier II: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2011.
- Tier III[12]: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2016 operating in the North American ECA or the United States Caribbean Sea ECA and diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2021 operating in the Baltic Sea and North Sea ECA.

The three tier $NO_x$ emission limit functions are shown in Table 3.3.16.

Table 3.3.16 Tier I-III $NO_x$ emission limits for ship engines in MARPOL Annex VI.

| | $NO_x$ limit | RPM (n) |
|---|---|---|
| Tier I | 17 g pr kWh | n < 130 |
| | 45 · n-0.2 g pr kWh | 130 ≤ n < 2000 |
| | 9,8 g pr kWh | n ≥ 2000 |
| Tier II | 14.4 g pr kWh | n < 130 |
| | 44 · n-0.23 g pr kWh | 130 ≤ n < 2000 |
| | 7.7 g pr kWh | n ≥ 2000 |
| Tier III | 3.4 g pr kWh | n < 130 |
| | 9 · n-0.2 g pr kWh | 130 ≤ n < 2000 |
| | 2 g pr kWh | n ≥ 2000 |

Further, the $NO_x$ Tier I limits are to be applied for existing engines with a power output higher than 5000 kW and a displacement per cylinder at or above 90 litres, installed on a ship constructed on or after 1 January 1990 but prior to 1 January 2000.

In relation to the sulphur content in heavy fuel and marine gas oil used by ship engines, Table 3.3.17 shows the EU and IMO (Regulation 14 plus amendments) legislation in force for SECA (Sulphur Emission Control Area) areas and outside SECA's.

[12] For ships operating in a designated Emission Control Area. Outside a designated Emission Control Area, Tier II limits apply.

Table 3.3.17 Current legislation in relation to marine fuel quality.

| Legislation | | Heavy fuel oil S- % | Heavy fuel oil Implement. date (day/month/year) | Gas oil S- % | Gas oil Implement. date (day/month/year) |
|---|---|---|---|---|---|
| EU-directive 93/12 | | None | | 0.2[1] | 01.10.1994 |
| EU-directive 1999/32 | | None | | 0.2 | 01.01.2000 |
| EU-directive 2005/33[2] | SECA - Baltic sea | 1.5 | 11.08.2006 | 0.1 | 01.01.2008 |
| | SECA - North sea | 1.5 | 11.08.2007 | 0.1 | 01.01.2008 |
| | Outside SECA's | None | | 0.1 | 01.01.2008 |
| MARPOL Annex VI | SECA – Baltic sea | 1.5 | 19.05.2006 | | |
| | SECA – North sea | 1.5 | 21.11.2007 | | |
| | Outside SECA | 4.5 | 19.05.2006 | | |
| MARPOL Annex VI amendments | SECA's | 1 | 01.03.2010 | | |
| | SECA's | 0.1 | 01.01.2015 | | |
| | Outside SECA's | 3.5 | 01.01.2012 | | |
| | Outside SECA's | 0.5 | 01.01.2020 | | |

[1] Sulphur content limit for fuel sold inside EU.
[2] From 1.1.2010 fuel with a sulphur content higher than 0.1 % must not be used in EU ports for ships at berth exceeding two hours.

In Marpol 83/78 Annex VI (Chapter 4) the EEDI fuel efficiency regulations are mandatory from 1st January 2013 for new built ships larger than 400 GT.

EEDI is a design index value that expresses how much $CO_2$ is produced per work done (g $CO_2$/tonnes.nm). At present, the IMO EEDI scheme comprises the following ship types; bulk carriers, gas carriers, tankers, container ships, general cargo ships, refrigerated and combination cargo carriers.

The EEDI percentage reductions that need to be achieved for new built ships relative to existing ships, are shown in Table 3.3.18 stratified according to ship type and dead weight tonnes (DWT) in the temporal phases (new built year in brackets); 0 (2013-14), 1 (2015-19), 2 (2020-24) and 3 (2025+).

Table 3.3.18 EEDI percentage reductions for new built ships relative to existing ships.

| Ship type | Size | Phase 0 1-Jan-2013 to 31-Dec-2014 | Phase 1 1-Jan-2015 to 31-Dec-2019 | Phase 2 1-Jan-2020 to 31-Dec-2024 | Phase 3 1-Jan-2025 onwards |
|---|---|---|---|---|---|
| Bulk carrier | 20,000 DWT and above | 0 | 10 | 20 | 30 |
| | 10,000 – 20,000 DWT | n/a | 0-10* | 0-20* | 0-30* |
| Gas carrier | 10,000 DWT and above | 0 | 10 | 20 | 30 |
| | 2,000 – 10,000 DWT | n/a | 0-10* | 0-20* | 0-30* |
| Tanker | 20,000 DWT and above | 0 | 10 | 20 | 30 |
| | 4,000 – 20,000 DWT | n/a | 0-10* | 0-20* | 0-30* |
| Container ship | 15,000 DWT and above | 0 | 10 | 20 | 30 |
| | 10,000 – 15,000 DWT | n/a | 0-10* | 0-20* | 0-30* |
| General cargo ship | 15,000 DWT and above | 0 | 10 | 15 | 30 |
| | 3,000 – 15,000 DWT | n/a | 0-10* | 0-15* | 0-30* |
| Refrigerated cargo carrier | 5,000 DWT and above | 0 | 10 | 15 | 30 |
| | 3,000 – 5,000 DWT | n/a | 0-10* | 0-15* | 0-30* |
| Combination carrier | 20,000 DWT and above | 0 | 10 | 20 | 30 |
| | 4,000 – 20,000 DWT | n/a | 0-10* | 0-20* | 0-30* |

It is envisaged that also Ro-ro cargo, ro-ro passenger and cruise passenger ships will be included in the EEDI scheme in the near future.

For non-road machinery, the EU directive 2003/17/EC gives a limit value of 10 ppm sulphur in diesel (from 2011).

### Emission factors

The $CO_2$ emission factors are country-specific and come from Fenhann and Kilde (1994). For LNG, however, the $CO_2$ emission factor is estimated by the Danish gas transmission company, Energinet.dk, based on gas analysis data. For LPG, the emission factor source is EMEP/EEA (2019).

The $N_2O$ emission factors are taken from the EMEP/EEA guidebook; EMEP/EEA (2019) for road transport and non-road machinery, and IPCC (2006) for national sea transport and fisheries as well as aviation.

In the case of military ground equipment, due to lack of fleet/activity and emission data, aggregated $CH_4$ emission factors for gasoline and diesel are derived from total road traffic emission results. For piston engine aircraft using aviation gasoline, the $CH_4$ emission factors are derived from VOC factors from EMEP/EEA (2019) and a NMVOC/$CH_4$ split, based on expert judgement.

The $CH_4$ emission factors for railways are derived from specific Danish VOC measurements from the Danish State Railways (Mølgård, 2019) and a NMVOC/$CH_4$ split, based on expert judgement.

For agriculture, forestry, industry, household gardening and recreational craft, the VOC emission factors are derived from various European measurement programmes; see IFEU (2004, 1999) and Winther et al. (2006). The NMVOC/$CH_4$ split is taken from IFEU (1999).

For national sea transport and fisheries, the VOC emission factors come from Trafikministeriet (2010). Specifically for the ferries used by Mols Linjen, VOC emission factors are provided by Kristensen (2008), originating from engine measurements (Hansen et al., 2004; Wismann, 1999; PHP, 1996). Complimentary VOC emission factor data for new ferries is provided by Kristensen (2013) and engine load specific VOC emission data is provided by Nielsen (2019).

For the LNG fueled ferry in service on the Hou-Sælvig route $CH_4$ and NMVOC emission factors are taken from Bengtsson et al. (2011).

For ship diesel and residual oil fuelled engines VOC/$CH_4$ splits are taken from EMEP/EEA (2019), and all emission factors are shown in Annex 3.B.13.

The source for aviation (jet fuel) $CH_4$ emission factors is the EMEP/EEA guidebook (EMEP/EEA, 2019). For a number of different representative aircraft types, the EMEP/EEA guidebook comprises fuel flow and $NO_x$, CO and VOC emission indices for the four LTO modes and distance based emission factors for cruise. For auxiliary power units (APU), ICAO (2011) is the data source for APU load specific $NO_x$, CO and VOC emission factors for different APU aircraft groups to be linked with the different representative aircraft types. VOC/$CH_4$ splits for aviation are taken from EMEP/EEA (2019).

Annex 3.B.14 list the lower heating values (LHV) for the inventory fuel types together with their references. The LHV's are used to transform emission factors from g/kg fuel into g/MJ or fuel results from kg into MJ if needed in the inventories.

For all sectors, emission factors for the years 1990 and 2018 are given in CollectER format in Annex 3.B.15.

Table 3.3.19 shows the aggregated emission factors for $CO_2$, $CH_4$ and $N_2O$ in 2018 used to calculate the emissions from other mobile sources in Denmark.

Table 3.3.19 The aggregated emission factors for $CO_2$, $CH_4$ and $N_2O$ in 2018 used to calculate the emissions from other mobile sources in Denmark.

| | | | | | Emission factors[13] | | |
|---|---|---|---|---|---|---|---|
| | | | | $CH_4$ % of | $CH_4$ | $CO_2$ | $N_2O$ |
| SNAP ID | Category | Fuel type | Tier level | VOC | g pr GJ | g pr GJ | g pr GJ |
| 080100 | Military | Diesel | Tier 1 | 9.4 | 0.42 | 74.00 | 3.38 |
| 080100 | Military | Gasoline | Tier 1 | 5.0 | 5.52 | 73.00 | 0.72 |
| 080100 | Military | Jet fuel | Tier 1 | 9.6 | 2.65 | 72.00 | 2.30 |
| 080200 | Railways | Diesel | Tier 1 | 3.7 | 1.18 | 74.00 | 2.24 |
| 080300 | Recreational craft | Bio ethanol | Tier 3 | 2.8 | 12.26 | 0.00 | 1.61 |
| 080300 | Recreational craft | Diesel | Tier 3 | 2.4 | 2.78 | 74.00 | 2.97 |
| 080300 | Recreational craft | Gasoline | Tier 3 | 2.8 | 12.26 | 73.00 | 1.61 |
| 080402 | National sea traffic | Diesel | Tier 3 | 3.0 | 1.83 | 74.00 | 1.87 |
| 080402 | National sea traffic | LNG | Tier 3 | 74.0 | 263.14 | 56.80 | 0.00 |
| 080402 | National sea traffic | Residual oil | Tier 3 | 3.0 | 1.98 | 78.00 | 1.95 |
| 080403 | Fishing | Diesel | Tier 1 | 3.0 | 1.82 | 74.00 | 1.87 |
| 080404 | International sea traffic | Diesel | Tier 1 | 3.0 | 1.86 | 74.00 | 1.87 |
| 080404 | International sea traffic | Residual oil | Tier 1 | 3.0 | 2.05 | 78.00 | 1.96 |
| 080501 | Air traffic. Dom. < 3000 ft. | AvGas | Tier 1 | 2.0 | 8.62 | 73.00 | 2.00 |
| 080501 | Air traffic. Dom. < 3000 ft. | Jet fuel | Tier 3 | 10.0 | 1.75 | 72.00 | 8.92 |
| 080502 | Air traffic. Int. < 3000 ft. | Jet fuel | Tier 3 | 10.0 | 2.43 | 72.00 | 4.95 |
| 080503 | Air traffic. Dom. > 3000 ft. | Jet fuel | Tier 3 | 0.0 | 0.00 | 72.00 | 2.30 |
| 080504 | Air traffic. Int. > 3000 ft. | Jet fuel | Tier 3 | 0.0 | 0.00 | 72.00 | 2.30 |
| 080600 | Agriculture | Bio ethanol | Tier 3 | 11.1 | 135.12 | 0.00 | 1.63 |
| 080600 | Agriculture | Diesel | Tier 3 | 2.4 | 0.84 | 74.00 | 3.55 |
| 080600 | Agriculture | Gasoline | Tier 3 | 11.1 | 135.12 | 73.00 | 1.63 |
| 080700 | Forestry | Bio ethanol | Tier 3 | 6.0 | 240.84 | 0.00 | 0.46 |
| 080700 | Forestry | Diesel | Tier 3 | 2.4 | 0.43 | 74.00 | 3.64 |
| 080700 | Forestry | Gasoline | Tier 3 | 6.0 | 240.84 | 73.00 | 0.46 |
| 080800 | Industry | Bio ethanol | Tier 3 | 3.7 | 59.54 | 0.00 | 1.49 |
| 080800 | Industry | Diesel | Tier 3 | 2.4 | 1.08 | 74.00 | 3.42 |
| 080800 | Industry | Gasoline | Tier 3 | 3.7 | 59.54 | 73.00 | 1.49 |
| 080800 | Industry | LPG | Tier 3 | 5.0 | 7.69 | 63.10 | 3.50 |
| 080900 | Household and gardening | Bio ethanol | Tier 3 | 1.9 | 52.88 | 0.00 | 1.16 |
| 080900 | Household and gardening | Gasoline | Tier 3 | 1.9 | 52.88 | 73.00 | 1.16 |
| 081100 | Commercial and institutional | Bio ethanol | Tier 3 | 3.9 | 36.49 | 0.00 | 1.31 |
| 081100 | Commercial and institutional | Diesel | Tier 3 | 2.4 | 0.46 | 74.00 | 3.67 |
| 081100 | Commercial and institutional | Gasoline | Tier 3 | 3.9 | 36.49 | 73.00 | 1.31 |
| 080501 | Air traffic. Dom. < 3000 ft., CPH | AvGas | Tier 1 | 2.0 | 8.62 | 73.00 | 2.00 |
| 080501 | Air traffic. Dom. < 3000 ft., CPH | Jet fuel | Tier 3 | 10.0 | 1.96 | 72.00 | 5.44 |
| 080502 | Air traffic. Int. < 3000 ft., CPH | Jet fuel | Tier 3 | 10.0 | 2.51 | 72.00 | 3.02 |
| 080503 | Air traffic. Dom. > 3000 ft., CPH | Jet fuel | Tier 3 | 0.0 | 0.00 | 72.00 | 2.30 |
| 080504 | Air traffic. Int. > 3000 ft., CPH | Jet fuel | Tier 3 | 0.0 | 0.00 | 72.00 | 2.30 |

[13] References. $CO_2$: Country-specific, Energinet.dk (LNG), EMEP/EEA (LPG). $N_2O$: EMEP/EEA. $CH_4$: Railways: Danish State Railways, DCE; Agriculture/Forestry/Industry/Household-Gardening: IFEU (2004, 1999, 2014); National sea traffic/Fishing/International sea traffic: Trafikministeriet (2010), specific data from Mols Linjen, Bengtsson et al. (2011), EMEP/EEA; domestic and international aviation: EMEP/EEA.

**Factors for deterioration, transient loads and gasoline evaporation for non-road machinery**

The emission effects of engine wear are taken into account for diesel and gasoline engines by using the so-called deterioration factors. For diesel engines alone, transient factors are used in the calculations, to account for the emission changes caused by varying engine loads. The evaporative emissions of NMVOC are estimated for gasoline fuelling and tank evaporation. The factors for deterioration, transient loads and gasoline evaporation are taken from IFEU (2004, 1999, 2014), and are shown in Annex 3.B.10. For more details regarding the use of these factors, please refer to paragraph 3.3.4 or Winther et al. (2006).

**Engine load adjustment factors for ship engines**

For ship engines, specific fuel consumption (sfc) and emission factors are found to vary with engine load, and hence engine load adjustment factors, LAF, are used in the fleet activity calculations for ferries to account for these engine load changes. For sfc and $NO_x$, $N_2O$, CO, VOC and PM, engine load adjustment functions are provided by IMO (2015) based on Starcrest (2013). For practical purposes only sfc is adjusted in the calculations, due to the actual engine load levels for ferries in the Danish inventories. The load adjustment factors are shown in Annex 3.B.12.

For a few ferries operated by Mols Linjen actual engine loads and engine load specific emission data provided by Nielsen (2019) is used to calculate precise sfc and emission factors of $NO_x$, CO and VOC.

### 3.3.4 Calculation method

**Air traffic**

For aviation, the domestic and international estimates are made separately for landing and takeoff (LTOs < 3000 ft), and cruising (> 3000 ft).

By using the LTO mode specific fuel flow and emission indices from EMEP/EEA (2019), the fuel consumption and emission factors for the full LTO cycle are estimated for each of the representative aircraft types used in the Danish inventory.

The fuel consumption for one LTO cycle is calculated according to the following sum formula:

$$FC^{a}_{LTO} = \sum_{m=1}^{5} t_m \cdot ff_{a,m} \quad (15)$$

Where FC = fuel consumption (kg), m = LTO mode (approach/landing, taxi in, taxi out, take off, climb out), t = times in mode (s), ff = fuel flow (kg per s), a = representative aircraft type.

The emissions for one LTO cycle are estimated as follows:

$$E^{a}_{LTO} = \sum_{m=1}^{5} FC_{a,m} \cdot EI_{a,m} \quad (16)$$

Where EI = emission index (g per kg fuel). Due to lack of specific airport data for approach/descent, take off and climb out, standardised times-in-modes of 4, 0.7 and 2.2 minutes are used as defined by ICAO (ICAO, 1995). For taxi in and taxi out, specific times-in-modes data are provided by Eurocontrol for the airports present in the Danish inventory. The taxi times-in-modes data are shown in Annex 3.B.10 for the years 2001-2018.

The fuel consumption and emissions for aircraft auxiliary power units (APU's) are calculated with the same method used to estimate LTO fuel consumption and emissions for aircraft main engines (formulas 15 and 16). ICAO (2011) is the data source for APU load specific fuel flows (kg per s) and emission rates (g per kg fuel) for different APU aircraft groups (characterised by seating capacity and age). APU times-in-modes for arrival, start-up, boarding and main engine start are also provided by ICAO (2011), whereas push back time intervals are taken from an emission study made in Copenhagen Airport (Ellermann et al., 2011; Winther et al., 2015).

For each representative aircraft type, the calculated fuel consumption and emission factors per LTO are shown in Annex 3.B.10 for Copenhagen Airport and other airports (aggregated) for 2018. APU data for fuel flows, emission rates and times-in-modes are also shown in Annex 3.B.10, together with the correspondence table for APU group-representative aircraft type.

The calculations for cruise use the distance specific fuel consumption and emissions given by EMEP/EEA (2019) per representative aircraft type. Data interpolations or extrapolations are made – in each case determined by the great circle distance between the origin and the destination airports.

If the great circle distance, y, is smaller than the maximum distance for which fuel consumption and emission data are given in the EMEP/EEA data bank the fuel consumption or emission E (y) becomes:

$$E(y) = E_{x_i} + \frac{(y - x_i)}{x_{i+1} - x_i} \cdot (E_{x_{i+1}} - E_{x_i}) \quad y<x_{max},\ i = 0,1,2\ldots max-1 \qquad (17)$$

In (17) $x_i$ and $x_{max}$ denominate the separate distances and the maximum distance, respectively, with known fuel consumption and emissions. If the flight distance y exceeds $x_{max}$ the maximum figures for fuel consumption and emissions must be extrapolated and the equation then becomes:

$$E(y) = E_{x_{max}} + \frac{(y - x_{max})}{x_{max} - x_{max-1}} \cdot (E_{x_{max}} - E_{x_{max-1}}) \quad y>x_{max} \qquad (18)$$

Total results are summed up and categorised according to each flight's destination airport code in order to distinguish between domestic and international flights.

Annex 3.B.10 shows the average fuel consumption and emission factors per representative aircraft type for cruise flying, as well as total distance flown, for 2018[14]. The factors are split between Copenhagen Airport and other airports and distinguish between domestic and international flights.

Specifically for flights between Denmark and Greenland or the Faroe Islands, for each representative aircraft type, the flight distances are directly shown in Annex 3.B.10, which go into the cruise calculation expressions 17 and 18.

The overall fuel precision (fuel balance) in the model is 0.94 in 2018, derived as the fuel ratio between model estimates and statistical sales. The fuel difference is accounted for by adjusting cruising fuel consumption and emissions in the model according to domestic and international cruising fuel shares.

For inventory years before 2001, the calculation procedure is to estimate each year's fuel consumption and emissions for LTO based on LTO/aircraft type statistics from Copenhagen Airport, and total take off numbers for other airports provided by the Danish Transport and Construction Agency. Due to lack of aircraft type specific LTO data, fuel consumption and emission factors derived for domestic LTO's in Copenhagen Airport is used for all LTO's in other airports. In a next step, the total fuel consumption for cruise (true cruise fuel consumption) is found year by year as the statistical fuel consumption total minus the calculated fuel consumption for LTO.

For each inventory year, intermediate cruise fuel consumption figures split into four parts (Copenhagen/Other airports; domestic/international) are found as proportional values between part specific LTO fuel consumption values estimated as described previously, and part specific cruise:LTO fuel consumption ratios for 2001 derived from the detailed city-pair emission inventory.

Each inventory year's true cruise fuel consumption is finally split into four parts by using the intermediate cruise fuel consumption values as a distribution key. As emission factor input data for cruise, aggregated fuel related emission factors for 2001 are derived from the detailed city-pair emission inventory.

### Non-road working machinery and recreational craft

Prior to adjustments for deterioration effects and transient engine operations, the fuel consumption and emissions in year X, for a given machinery type, engine size and engine age, are calculated as:

$$E_{Basis}(X)_{i,j,k} = N_{i,j,k} \cdot HRS_{i,j,k} \cdot P \cdot LF_i \cdot EF_{y,z} \quad (19)$$

where $E_{Basis}$ = fuel consumption/emissions in the basic situation, N = number of engines, HRS = annual working hours, P = average rated engine size in kW, LF = load factor, EF = fuel consumption/emission factor in g pr kWh, i = machinery type, j = engine size, k = engine age, y = engine-size class and z = emission level. The basic fuel consumption and emission factors are shown in Annex 3.B.11.

The deterioration factor for a given machinery type, engine size and engine age in year X depends on the engine-size class (only for gasoline), y, and the

[14] Excluding flights for Greenland and the Faroe Islands.

emission level, z. The deterioration factors for diesel and gasoline 2-stroke engines are found from:

$$DF_{i,j,k}(X) = \frac{K_{i,j,k}}{LT_i} \cdot DF_{y,z} \quad (20)$$

where DF = deterioration factor, K = engine age, LT = lifetime, i = machinery type, j = engine size, k = engine age, y = engine-size class and z = emission level.

For gasoline 4-stroke engines the deterioration factors are calculated as:

$$DF_{i,j,k}(X) = \sqrt{\frac{K_{i,j,k}}{LT_i}} \cdot DF_{y,z} \quad (21)$$

The deterioration factors inserted in (20) and (21) are shown in Annex 3.B.11. No deterioration is assumed for fuel consumption (all fuel types) or for LPG engine emissions and, hence, DF = 1 in these situations.

The transient factor for any given machinery type, engine size and engine age in year X, relies only on emission level and load factor, and is denominated as:

$$TF_{i,j,k}(X) = TF_z \quad (22)$$

Where i = machinery type, j = engine size, k = engine age and z = emission level.

The transient factors inserted in (22) are shown in Annex 3.B.11. No transient corrections are made for gasoline and LPG engines and, hence, $TF_z$ = 1 for these fuel types.

The final calculation of fuel consumption and emissions in year X for a given machinery type, engine size and engine age, is the product of the expressions 19-22:

$$E(X)_{i,j,k} = E_{Basis}(X)_{i,j,k} \cdot TF(X)_{i,j,k} \cdot (1 + DF(X)_{i,j,k}) \quad (23)$$

The evaporative hydrocarbon emissions from fuelling are calculated as:

$$E_{Evap,fueling,i} = FC_i \cdot EF_{Evap,fueling} \quad (24)$$

Where $E_{Evap,fueling}$, = hydrocarbon emissions from fuelling, i = machinery type, FC = fuel consumption in kg, $EF_{Evap,fueling}$ = emission factor in g NMVOC pr kg fuel.

For tank evaporation, the hydrocarbon emissions are found from:

$$E_{Evap,\tan k,i} = N_i \cdot EF_{Evap,\tan k,i} \quad (25)$$

Where $E_{Evap,tank,i}$ = hydrocarbon emissions from tank evaporation, N = number of engines, i = machinery type and $EF_{Evap,fueling}$ = emission factor in g NMVOC pr year.

#### Ferries, other national sea transport, fisheries and international sea transport

The fuel consumption and emissions in year X, for ferries are calculated as:

$$E(X) = \sum_i N_i \cdot T_i \cdot S_{i,j} \cdot P_i \cdot LF_j \cdot LAF_j \cdot EF_{k,l,y} \quad (26)$$

Where E = fuel consumption/emissions, N = number of round trips, T = sailing time pr round trip in hours, S = ferry share of ferry service round trips, P = engine size in kW, LF = engine load factor, LAF = engine load adjustment factor, EF = fuel consumption/emission factor in g pr kWh, i = ferry service, j = ferry, k = fuel type, l = engine type, y = engine year.

For the remaining navigation categories, the emissions are calculated using a simplified approach:

$$E(X) = \sum_i EC_{i,k} EF_{k,l,y} \quad (27)$$

Where E = fuel consumption/emissions, EC = energy consumption, EF = fuel consumption/emission factor in g per kg fuel, i = category (other national sea, fishery, international sea), k = fuel type, l = engine type, y = average engine year.

The emission factor inserted in (27) is found as an average of the emission factors representing the engine ages which are comprised by the average lifetime in a given calculation year, X:

$$EF_{k,l,y} = \frac{\sum_{year=X}^{year=X-LT} EF_{k,l}}{LT_{k,l}} \quad (28)$$

#### Other sectors

For military and railways, the emissions are estimated with the simple method using fuel-related emission factors and fuel consumption from the DEA:

$$E = FC \cdot EF \quad (29)$$

where E = emission, FC = fuel consumption and EF = emission factor. The calculated emissions for other mobile sources are shown in CollectER format in Annex 3.B.16 for the years 1990 and 2018 and as time series 1990-2018 in Annex 3.B.15 (CRF format).

#### Fuel balance between DEA statistics and inventory estimates

Following convention rules, the DEA statistical fuel sales figures are the basis for the full Danish inventory. However, in some cases for mobile sources the DEA statistical sectors do not fully match the inventory sectors.

In the following, the transferal of fuel consumption data from DEA statistics into inventory relevant categories is explained for national sea transport and fisheries, non-road machinery and recreational craft, and road transport. A full list of all fuel consumption data, DEA figures as well as intermediate fuel consumption data, and final inventory input figures is shown in Annex 3.B.14.

**National sea transport and fisheries**

For years when the fuel estimates for ferries (not including the ferry to the Faroe Islands) are higher than DEA reported fuel sold for national sea transport, fuel is taken from fisheries in the case of marine diesel (1985-1999). For heavy fuel oil, the missing fuel amount is taken from stationary sources (1985-1986, 1988, 1994-1996) and international sea transport (2015 onwards).

In national sea transport, LNG fuel has been calculated for Danish ferries since 2015. However, in DEA fuel statistics, the consumption of LNG for national sea transport is included under diesel instead of being reported as LNG. In the Danish emission model for ships, the bottom up estimated consumption of LNG by mass is converted to energy units by using the calorific value 47.9 MJ/kg. The LNG energy use is reported under national sea transport in the inventories, and the amount of diesel (by energy unit) reported for national sea transport is subsequently being reduced by the same number.

For fisheries, the calculation methodology is fuel activity based and input fuel data is in principle the diesel fuel sold for fisheries reported by DEA. For years when bottom up diesel estimates for national sea transport are higher than DEA reported fuel sold for national sea transport, diesel is transferred from fisheries to national sea transport in the inventories. In addition, the bottom up diesel estimate for recreational craft is subtracted from fisheries and grouped in the "Other" inventory category together with military activities. Incorrectly reported gasoline and heavy fuel oil for fisheries is transferred to recreational craft (reported under "Other") and national sea transport, respectively.

According to the DEA, in some cases inaccurate costumer specifications are made by the oil suppliers, which result in sector misallocation in the sales statistics between national sea transport and fisheries for diesel oil and between national sea transport and industry for heavy fuel oil (Peter Dal, DEA, personal communication, 2007). Further, fuel sold for vessels sailing between Denmark and Greenland/Faroe Islands are reported as international in the DEA statistics, and this fuel categorisation is different from the IPCC guideline definitions (see following paragraph "Bunkers").

Inaccurate fuel sale specifications is also the reason for heavy fuel oil being reported for fisheries in the DEA statistics. No engines installed in fishing vessels use heavy fuel oil, even though a certain amount of heavy fuel oil is listed in the DEA numbers for some statistical years (H. Amdissen, Danish Fishermen's Association, personal communication, 2006).

**Non-road machinery and recreational craft**

In 2014, 2015 and 2017, the bottom up estimate for diesel in the DCE non-road emission model exceed the diesel fuel sales reported by the DEA under the categories: agriculture and forestry, market gardening, building and construction, industry, and the residual part of diesel not being used for heating in private houses (as estimated by DCE). For these years, the fuel consumption and emission estimates for diesel machinery in the Danish non-road model (agriculture, forestry, industry, commercial/institutional) are scaled down accordingly, to keep the national fuel balance.

For gasoline, the DEA residential sector, together with the DEA sectors mentioned for diesel and LPG, contribute to the non-road fuel consumption total. In addition, a certain amount of fuel from road transport is needed to reach the fuel consumption goal.

The amount of diesel (2014, 2015, 2017) and LPG in DEA industry not being used by non-road machinery is included in the sectors, "Combustion in manufacturing industry" (0301) and "Non-industrial combustion plants" (0203) in the Danish emission inventory.

For recreational craft, the calculated fuel consumption totals for diesel and gasoline are subsequently subtracted from the DEA fishery sector. For gasoline, the DEA reported fuel consumption for fisheries is far too small to fill the fuel gap, and hence the missing fuel amount is taken from the DEA road transport sector.

#### Road transport

For natural gas and LPG, the difference between fuel reported in DEA statistics and bottom-up estimates for road transport is outbalanced with fuel totals from "non-industrial combustion plants" (020200) in order to obtain a fuel balance.

#### Bunkers

The distinction between domestic and international fuel consumption and emissions from aviation and navigation for Denmark should be in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. For the national emission inventory, this, in principle, means that fuel sold (and associated emissions) for flights/sea transportation starting from a seaport/airport in the Kingdom of Denmark, with destinations inside or outside the Kingdom of Denmark, are regarded as domestic or international, respectively.

#### Aviation

As prescribed by the IPCC guidelines, for aviation, the fuel consumption and emissions associated with flights inside the Kingdom of Denmark are counted as domestic.

This report includes flights from airports in Denmark and associated jet fuel sales. Hence, the flights between airports in Denmark and flights from Denmark to Greenland and the Faroe Islands are classified as domestic and flights from Danish airports with destinations outside the Kingdom of Denmark are classified as international flights.

In Greenland and in the Faroe Islands, the jet fuel sold is treated as domestic. This decision becomes reasonable when considering that almost no fuel is bunkered in Greenland/the Faroe Islands by flights other than those going to Denmark.

#### Navigation

In DEA statistics, the domestic fuel total consists of fuel sold to Danish ferries and other ships sailing between two Danish ports. The DEA international fuel total consists of the fuel sold in Denmark to international ferries, international warships, other ships with foreign destinations, transport to Greenland and the Faroe Islands, tank vessels and foreign fishing boats.

In order to follow the IPCC guidelines the bottom-up fuel estimates for the ferry routes between Denmark and the Faroe Islands, and fuel sold in Denmark to vessels engaged in freight transportation between Denmark and Greenland/Faroe Islands are being subtracted from the fuel sales figures for international sea transport prior to inventory fuel input.

In Greenland, all marine fuel sales are treated as domestic. In the Faroe Islands, fuel sold in Faroese ports for Faroese fishing vessels and other Faroese ships is treated as domestic. The fuel sold to Faroese ships bunkering outside Faroese waters and the fuel sold to foreign ships in Faroese ports or outside Faroese waters is classified as international (Lastein and Winther, 2003).

Conclusively, the domestic/international fuel split (and associated emissions) for navigation is not determined with the same precision as for aviation. It is considered, however, that the potential of incorrectly allocated fuel quantities is only a small part of the total fuel sold for navigational purposes in the Kingdom of Denmark.

### 3.3.5 Uncertainties and time series consistency

Tier 1 uncertainty estimates for greenhouse gases, are made for road transport and other mobile sources using the guidelines formulated in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). For road transport, railways and fisheries, these guidelines provide uncertainty factors for activity data that are used in the Danish situation. For other sectors, the factors reflect specific national knowledge (Winther et al., 2006 and Winther, 2008). These sectors are (SNAP categories): Inland Waterways (a part of 1A3d: Navigation), Agriculture and Forestry (parts of 1A4c: Agriculture-/forestry/fisheries), Industry (mobile part of (1A2f: Industry-other), Residential (1A4b) and National sea transport (a part of 1A3d: Navigation).

The activity data uncertainty factor for civil aviation is based on expert judgement.

The calculations for Tier 1 are shown in Annex 3.B.17 for all emission components.

Table 3.3.20 Tier 1 Uncertainties for activity data, emission factors and total emissions in 2018 and as a trend.

| Category | Activity data | $CO_2$ | $CH_4$ | $N_2O$ |
|---|---|---|---|---|
| | | % | | |
| Road transport | 2 | 5 | 40 | 50 |
| Military | 2 | 5 | 100 | 1000 |
| Railways | 2 | 5 | 100 | 1000 |
| Navigation (small boats) | 41 | 5 | 100 | 1000 |
| Navigation (large vessels) | 11 | 5 | 100 | 1000 |
| Fisheries | 2 | 5 | 100 | 1000 |
| Agriculture | 24 | 5 | 100 | 1000 |
| Forestry | 30 | 5 | 100 | 1000 |
| Industry (mobile) | 41 | 5 | 100 | 1000 |
| Residential | 35 | 5 | 100 | 1000 |
| Commercial/Institutional | 35 | 5 | 100 | 1000 |
| Civil aviation | 10 | 5 | 100 | 1000 |
| Overall uncertainty in 2018 | | 4.9 | 29.9 | 112.9 |
| Trend uncertainty | | 4.7 | 2.4 | 58.7 |

As regards time series consistency, background flight data cannot be made available on a city-pair level prior to 2000. However, aided by LTO/aircraft statistics for these years and the use of proper assumptions, a good level of consistency is in any case, obtained for this part of the transport inventory.

The time series of emissions for mobile machinery in the agriculture, forestry, industry, household and gardening (residential) and inland waterways (part of navigation) sectors are less certain than time series for other sectors, since DEA statistical figures do not explicitly provide fuel consumption information for working equipment and machinery.

### 3.3.6 Quality assurance/quality control (QA/QC)

The intention is to publish every second year a sector report for road transport and other mobile sources. The last sector report prepared concerned the 2016 inventory (Winther, 2018).

The QA/QC descriptions of the Danish emission inventories for transport follow the general QA/QC description for DCE in Section 1.6, based on the prescriptions given in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000). A general QA/QC plan for the Danish greenhouse gas inventory has been elaborated by Nielsen et al. (2012).

An overview diagram of the Danish emission inventory system is presented in Figure 1.2 (Data storage and processing levels), and the exact definitions of Critical Control Points (CCP) and Points of Measurements (PM) are given in Section 1.6. The status for the PMs relevant for the mobile sector are given in the following text and the result of this investigation indicates a need for future QA/QC activities in order to fulfil the QA/QC requirements from the IPCC GPG.

*Data storage level 1*

| | | | |
|---|---|---|---|
| Data Storage level 1 | 3.Completeness | DS.1.3.1 | Documentation showing that all possible national data sources are included by setting down the reasoning behind the selection of datasets. |

The following external data sources are used in the mobile part of the Danish emission inventories for activity data and supplementary information:

- Danish Energy Agency: Official Danish energy statistics.
- National sea transport (Royal Arctic Line, Eim Skip): Annual fuel consumption data.
- DTU Transport: Road traffic vehicle fleet and mileage data.
- Danish Transport and Construction Agency: Flight statistics.
- Non-road machinery: Information from statistical sources, research organisations, different professional organisations and machinery manufacturers.
- Ferries (Statistics Denmark): Data for annual return trips for Danish ferry routes.
- Ferries (Danish Ferry Historical Society): Detailed technical and operational data for specific ferries.

- Ferries (Mols Linjen, Bornholmstrafikken, Langelandstrafikken, Færgeselskabet Læsø, Samsø Rederi, Ærøfærgerne A/S, Smyril Line): Detailed technical and operational data for specific ferries.
- Danish Meteorological Institute (DMI): Temperature data.
- The National Motorcycle Association: 2-wheeler data.

The emission factors come from various sources:

- Danish Energy Agency: $CO_2$ emission factors and lower heating values (all fuel types).
- COPERT 5: Road transport (all exhaust components, except $CO_2$, $SO_2$).
- Handbook of Emission Factors (fuel consumption factors for vans)
- Danish State Railways: Diesel locomotives ($NO_X$, VOC, CO and TSP).
- EMEP/EEA guidebook: Civil aviation and supplementary.
- ICAO: Civil aviation auxiliary power units.
- Non-road machinery: References given in NERI reports.
- National sea transport and fisheries: TEMA2015 ($NO_X$, VOC, CO and TSP), IMO (TSP), MAN Energy Solutions (sfc, $NO_X$), specific data from Mols Linjen ($NO_x$, CO, NMVOC, TSP) and LNG emission factors ($NO_x$, CO, NMVOC, TSP) from Bengtsson et al. (2011).

Table 3.3.21 to follow contains Id, File/Directory/Report name, Description, Reference and Contacts. As regards File/Directory/Report name, this field refers to a file name for Id when all external data (time series for the existing inventory) are stored in one file. In other cases, a computer directory name is given when the external data used are stored in several files, e.g. each file contains one inventory year's external data or each file contains time series of external data for sub-categories of machinery. A third situation occurs when the external data are published in publicly available reports; here the aim is to obtain electronic copies for internal archiving.

Table 3.3.21 Overview table of external data and contact persons for transport.

| Id no | File/-Directory/-Report name | Description | Activity data or emission factor | Reference | Contacts | Data agreement |
|---|---|---|---|---|---|---|
| T1 | Transport energy[1] | Dataset for all transport energy use | Activity data | The Danish Energy Agency (DEA) | Jane Rusbjerg | Yes |
| T2 | Fleet and mileage data[2] | Road transport fleet and mileage data | Activity data | DTU Transport | Thomas Jensen | Yes |
| T3 | Flight statistics[2] | Data records for all flights | Activity data | Danish Transport and Construction Agency | Michael Weber | Yes |
| T4 | Non-road machinery[2] | Stock and operational data for non-road machinery | Activity data | Non-road Documentation report | | No |
| T5 | Emissions from ships[3] | Data for ferry traffic | Activity data | Statistics Denmark | Heidi Sørensen | No |
| T6 | Emissions from ships[3] | Technical and operational data for Danish ferries | Activity data | Navigation emission documentation report | Hans Otto Kristensen | No |
| T7 | Temperature data[3] | Monthly average of daily max/min temperatures | Other data | Danish Meteorological Institute | Danish Meteorological Institute | No |
| T8 | Fleet and mileage data[1] | Stock data for mopeds and motorcycles | Activity data | The National Motorcycle Association | Henrik Markamp | No |
| T9 | $CO_2$ emission factors[1] | DEA $CO_2$ emission factors (all fuel types) | Emission factor | The Danish Energy Agency (DEA) | Jane Rusbjerg | No |
| T10 | COPERT 5 emission factors[2] | Road transport emission factors | Emission factor | Laboratory of applied thermodynamics Aristotle University Thessaloniki | Leonidas Ntziachristos | No |
| T11 | Railways emission factors[1] | Emission factors for diesel locomotives | Emission factor | Danish State Railways | Jesper Mølgård | Yes |
| T12 | EMEP/EEA guidebook[3] | Emission factors for navigation, civil aviation and supplementary | Emission factor | European Environment Agency | European Environment Agency | No |
| T13 | Non-road emission factors[3] | Emission factors for agriculture, forestry, industry and household/gardening | Emission factor | Non-road Documentation report | | No |
| T14 | Emissions from ships[3] | Emission factors for national sea transport and fisheries | Emission factor | Navigation emission documentation report | | No |

1) File name;

2) Directory in the DCE data library structure; 3) Reports available on the internet.

### Danish Energy Agency (energy statistics)

The official Danish energy statistics are provided by the Danish Energy Agency (DEA) and are regarded as complete on a national level. For most transport sectors, the DEA subsector classifications fit the SNAP classifications used by DCE.

For non-road machinery, this is however not the case, since DEA do not distinguish between mobile and stationary fuel consumption in the subsectors relevant for non-road mobile fuel consumption.

In this case, DCE calculates a bottom-up non-road fuel consumption estimate and for diesel (land-based machinery only) and LPG, the residual fuel quantities are allocated to stationary consumption. For years when bottom up diesel exceed total DEA fuel sales in the relevant DEA fuel categories, the bottom up estimates are adjusted downwards in order to account for fuel sold. For gasoline (land-based machinery) the relevant fuel consumption quantities for the DEA are smaller than the DCE estimates, and the amount of fuel consumption missing is subtracted from the DEA road transport total to account for all fuel sold. For recreational craft, no specific DEA category exists and, in this case, the gasoline and diesel fuel consumption is taken from road transport and fisheries, respectively.

For years when the fuel estimates for national sea transport are higher than DEA reported fuel sold for national sea transport, fuel is taken from fisheries in the case of marine diesel (1985-1999). For heavy fuel oil, the missing fuel amount is taken from stationary sources (1985-1986, 1988, 1994-1996) and international sea transport (2015 onwards). In DEA fuel statistics, the consumption of LNG for national sea transport is included under diesel instead of being reported as LNG. In the Danish emission model for ships, the bottom up estimated consumption of LNG by mass is converted to energy units by using the calorific value 47.9 MJ/kg. The LNG energy use is reported under national sea transport in the inventories, and the amount of diesel (by energy unit) reported for national sea transport is subsequently being reduced by the same number.

In order to maintain the national energy balance, the changes in the fuel consumption time series for national sea transport lead, in turn, to changes in the fuel activity data for fisheries (diesel oil), industry and international sea transport (heavy fuel oil).

The DCE fuel modifications, thus, give DEA-SNAP differences for road transport, national sea transport and fisheries.

A special note must be made for the DEA civil aviation statistical figures. The domestic/international fuel consumption division derives from bottom-up fuel consumption calculations made by DCE.

#### DTU Transport

Figures for fleet numbers and mileage data are provided by DTU Transport on behalf of the Danish Ministry of Transport. Following the data deliverance contract between DCE and the Danish Ministry of Transport, it is a basic task for DTU Transport to possess comprehensive information on Danish road traffic. The fleet figures are based on data from the Car Register, kept by Statistics Denmark and are, therefore, regarded as very precise. Annual mileage information is obtained by DTU Transport from the Danish Vehicle Inspection and Maintenance Programme.

#### Danish Transport and Construction Agency (Civil Aviation Agency of Denmark)

The Danish Transport and Construction Agency monitors all aircraft movements in Danish airspace and, in this connection, possesses data records for all take-offs and landings at Danish airports. The dataset from 2001 onwards, among others consisting of aircraft type and origin and destination airports for all flights leaving major Danish airports, are, therefore, regarded as very complete. For inventory years before 2001, the most accurate data contain Transport Authority total movements from major Danish airports and detailed aircraft type distributions for aircraft using Copenhagen Airport, provided by the airport itself.

#### Non-road machinery (stock and operational data)

A great deal of stock and operational data for non-road machinery was obtained in a research project carried out by Winther et al. (2006) for the 2004 inventory. In 2016, a comprehensive data update were made for the most important building and construction machinery concerning engine load factors, equipment size - engine size relations, equipment scrapping curves and annual working hours as a function of engine age. In 2017, a comprehensive data update were made for the most important household and gardening machinery types concerning new sales data, equipment size - engine size relations, equipment scrapping curves and annual working hours as a function of machinery age, with sales figures validated through discussions with KVL.

The source for the agricultural machinery stock of tractors and harvesters is Statistics Denmark. Sales figures for tractors, harvesters and construction machinery, together with operational data and supplementary information, are obtained from The Association of Danish Agricultural Machinery Dealers and key experts from the most important engine manufacturers. IFAG (The Association of Producers and Distributors of Fork Lifts in Denmark) provides for lift sale figures. Stock information disaggregated into vessel types for recreational craft was obtained from the Danish Sailing Association. A certain part of the operational data comes from previous Danish non-road research projects (Dansk Teknologisk Institut, 1992 and 1993; Bak et al., 2003).

No statistical register exists for non-road machinery types and this affects the accuracy of stock and operational data. For tractors and harvesters, Statistics Denmark provide total stock data based on information from questionnaires and the registers of crop subsidy applications kept by the Ministry of Environment and Food of Denmark. In combination with new sales figures pr engine size from The Association of Danish Agricultural Machinery Dealers, the best available stock data are obtained. In addition, using the data sources for construction machinery, gasoline fueled gardening machinery and fork lift sale figures are regarded as the only realistic approach for consolidated stock information for these machinery types.

Total stock estimates and engine lifetime assumptions are used to disaggregate the stock into layers in the case of machinery types (rare types of diesel and gasoline non-road equipment, recreational craft) where data is even scarcer.

To support the 2017 inventory, new 2017 stock data for tractors, harvesters, fork lifts and construction machinery was obtained from the same sources as in Winther et al. (2006). For non-road machinery in general, it is, however, uncertain if data in such a level can be provided annually in the future.

#### Ferries (Statistics Denmark)

Statistics Denmark provides information of annual return trips for all Danish ferry routes from 1990 onwards. The data are based on monthly reports from passenger and ferry shipping companies in terms of transported vehicles passengers and goods. Thus, the data from Statistics Denmark are regarded as complete. Most likely, the data can be provided annually in the future.

#### Ferries (Danish Ferry Historical Society, DFS)

No central registration of technical and operational data for Danish ferries and ferry routes is available from official statistics. However, one valuable reference to obtain data and facts about construction and operation of Danish ferries, especially in the recent 20 - 30 years is the archives of Danish Ferry Historical Society. Pure technical data has not only been obtained from this society´s archives, but some of the knowledge has been obtained through the personal insight about ferries from some of the members of the society, which have been directly involved in the ferry business for example consultants, naval architects, marine engineers, captains and superintendents. However, until recently no documentation of the detailed DFS knowledge was established in terms of written reports or a central database system.

To make use of all the ferry specific data for the Danish inventories, DSF made a data documentation for the years 1990-2005 as a specific task of the research project carried out by Winther (2008).

#### Ferries (Mols Linjen, Bornholmstrafikken, Langelandstrafikken, Færgeselskabet Læsø, Samsø Rederi, Ærøfærgerne A/S, Smyril Line)

For the years 2006+, the major Danish ferry companies are contacted each year in order to obtain ferry technical data, relating to specific ferries in service, annual share of total round trips and other technical information. The relevant annual information is given as personal communication, a method, which can be repeated in the future.

#### National sea transport (Royal Arctic Line, Eim Skip)

For the years 2006+, the major shipping companies with frequent sailing activities between Denmark and Greenland/Faroe Islands are contacted each year in order to obtain data for fuel sold in Denmark used for these vessel activities. The relevant annual information is given as personal communication, a method, which can be repeated in the future.

#### Danish Meteorological Institute

The monthly average max/min temperature for Denmark comes from DMI. This source is self-explanatory in terms of meteorological data. Data are publicly available for each year on the internet.

#### The National Motorcycle Association

Road transport: 2-wheeler stock information (The National Motorcycle Association). Given that no consistent national data are available for mopeds in terms of fleet numbers and distributions according to new sales per year, The National Motorcycle Association is considered the professional organisation, where most expert knowledge is available. The relevant annual information is given as personal communication, a method, which can be repeated in the future.

#### Danish Energy Agency ($CO_2$ emission factors and lower heating values)

The $CO_2$ emission factors and net calorific values (NCV) are fuel-specific constants. The country-specific values from the DEA are used for all inventory years.

#### COPERT 5

COPERT 5 provides factors for fuel consumption and for all exhaust emission components, which are included in the national inventory. For several reasons, COPERT 5 is regarded as the most appropriate source of road traffic fuel consumption and emission factors. First of all, very few Danish emission measurements exist, so data are too scarce to support emission calculations on a national level. Secondly, most of the fuel consumption and emission information behind the COPERT model are derived from different large European research activities, and the formulation of fuel consumption and emission factors for all single vehicle categories has been made by a group of road traffic emission experts. A large degree of internal consistency is, therefore, achieved. Finally, the COPERT model is regularly updated with new experimental findings from European research programs and, apart from updated fuel consumption and emission factors, the use of COPERT 5 by many European countries ensures a large degree of cross-national consistency in reported emission results.

#### The Handbook of Emission Factors

The Handbook of Emission Factors is a comprehensive road transport emission model developed by a consortium of research institutes in Germany, Austria, Switzerland, France, Sweden and Norway. A large corporation exist and data exchange activities takes place between Handbook, COPERT 5 and other European emission modelers, with the aims of sharing basis emission and fuel consumption measurement data as basis input for the different emission models. The most recent version of the Handbook is in a few cases more updated in terms of vehicle size-technology splits compared to COPERT 5. This is the case for light commercial vehicles, in which case the Handbook provides the necessary fuel consumption data split into the three vehicle size classes for all relevant fuel types and Euro levels.

#### Danish State Railways

Aggregated emission factors of $NO_x$, VOC, CO and TSP for diesel locomotives are provided annually by the Danish State Railways. Taking into account available time resources for subsector emission calculations, the use of data from Danish State Railways is sensible. This operator accounts for around 90 % of all diesel fuel consumed by railway locomotives in Denmark and the remaining diesel fuel is used by various private railways companies. Setting up contacts with the private transport operators is considered a rather time consuming experience taking time away from inventory work in areas of greater emission importance.

#### EMEP/EEA guidebook

Fuel consumption and emission data from the EMEP/EEA guidebook is the prime and basic source for the aviation and navigation part of the Danish emission inventories. For aviation, the guidebook contains the most comprehensive list of representative aircraft types available for city-pair fuel consumption and emission calculations. The data have been provided by Eurocontrol (the European aviation safety organization) specifically for detailed national inventory use and was evaluated by the transport expert panel in the TFEIP (Task Force for Emission Inventories and Projections) under UNECE CLRTAP.

In addition, the EMEP/EEA guidebook is the source of non-exhaust TSP, $PM_{10}$, $PM_{2.5}$ and BC emission factors for road transport, and the primary source of emission factors for some emission components – typically $N_2O$, $NH_3$ and PAH – for other mobile sources.

#### Non-road machinery (fuel consumption and emission factors)

The references for non-road machinery fuel consumption and emission factors are listed in Winther (2018) and in the present report. The fuel consumption and emission data is regarded as one of the most comprehensive data collections on a European level, having been thoroughly evaluated by German emission measurement and non-road experts within the framework of a German non-road inventory project.

**National sea transport and fisheries**

Emission factors for $NO_X$, VOC and CO are taken from the TEMA2015 model developed for the Ministry of Transport. To a large extent, the emission factors originate from the exhaust emission measurement programme carried out by Lloyd's (1995). For TSP, IMO (2015) is the source for the emission factors. For $NO_X$, additional information of emission factors for engine manufacturing years going back to 1949, as well as $NO_X$, VOC and CO emission factors for engines built after 2010, was provided by the engine manufacturer MAN Energy Solutions. $PM_{10}$ and $PM_{2.5}$ fractions of total TSP were also provided by the latter source.

Specifically for the ferries used by Mols Linjen new $NO_x$, VOC and CO emission factors are provided by Kristensen (2008), originating from measurement results by Hansen et al. (2004), Wismann (1999) and PHP (1996). Kristensen (2013) has provided complimentary emission factor data for new ferries.

The experimental work by Lloyd's is still regarded as the most comprehensive measurement campaign with results publicly available. The additional $NO_X$ and $PM_{10}/PM_{2.5}$ information comes from the world's largest ship engine manufacturer and data from this source is consistent with data from Lloyd's. Consequently, the data used in the Danish inventories for national sea transport is regarded as the best available for emission calculations.

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| Data Storage level 1 | 1. Accuracy | DS.1.1.1 | General level of uncertainty for every dataset, including the reasoning for the specific values |

The uncertainty involved in the DEA fuel consumption information (except civil aviation) and the Danish Transport and Construction Agency flight statistics is negligible, as such, and this is also true for DMI temperature data. For civil aviation, some uncertainty prevails, since the domestic fuel consumption figures originate from a division of total jet-fuel sales figures into domestic and international fuel quantities, derived from bottom-up calculations. A part of the fuel consumption uncertainties for non-road machines is due to the varying levels of stock and operational data uncertainties, as explained in DS 1.3.1.

As regards emission factors, the $CO_2$ factors (and NCVs) from the DEA are considered very precise, since they relate only to fuel. For the remaining emission factor sources, the $SO_2$ (based on fuel sulphur content), $NO_X$, NMVOC, $CH_4$, CO, TSP, $PM_{10}$ and $PM_{2.5}$ emission factors are less accurate. Though many measurements have been made, the experimental data rely on the individual measurement and combustion conditions. The uncertainties for $N_2O$ and $NH_3$ emission factors increase even further due to the small number of measurements available. For heavy metals and PAH, experimental data are so scarce that uncertainty becomes very high.

A special note, however, must be made for energy. The uncertainties due to the subsequent treatment of DEA data for road transport, national sea transport, fisheries and the non-road relevant sectors, explained in DS 1.3.1, trigger some uncertainties in the fuel consumption figures for these sectors. This point is, though, more relevant for QA/QC description for data processing, Level 1.

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| Data Storage level 1 | 2.Comparability | DS.1.2.1 | Comparability of the emission factors/calculation parameters with data from international guidelines, and evaluation of major discrepancies. |

Work has been carried out to compare Danish figures with corresponding data from other countries in order to evaluate discrepancies. The comparisons have been made on a CRF level, mostly for implied emission factors (Fauser et al., 2007, 2013).

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| Data Storage level 1 | 4.Consistency | DS.1.4.1 | The origin of external data has to be archived with proper reference. |

It is ensured that the original files from external data sources are archived internally at DCE. Subsequent raw data processing is carried out either in the DCE database models or in spreadsheets (data processing level 1).

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| Data Storage level 1 | 6.Robustness | DS.1.6.1 | Explicit agreements between the external institution holding the data and DCE about the condition of delivery |

For transport, DCE has made formal agreements with regard to external data deliverance with (Table 3.3.21 external data source Id's in brackets): DEA (T1), the Danish Transport and Construction Agency (T3), Danish State Railways (T9) and DTU Transport (T2).

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| Data Storage level 1 | 7. Transparency | DS.1.7.1 | Listing of all archived datasets and external contacts |

The listing of all archived datasets and external contact persons are given in Table 3.3.21.

*Data Processing Level 1*

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|---|---|---|---|
| Data Processing level 1 | 1. Accuracy | DP.1.1.1 | Uncertainty assessment for every data source not part of DS.1.1.1 as input to Data Storage level 2 in relation to type and scale of variability. |

The general uncertainties of the DEA fuel consumption information, DMI temperature data, road transport stock totals and the Danish Transport and Construction Agency flight statistics are zero. For domestic aviation fuel consumption, the uncertainty is based on own judgement. For road transport, military and railways the fuel consumption uncertainties are taken from the IPCC Good Practice Guidance manual. It is noted that for road transport, it is not possible to quantify in-depth the uncertainties (1) of stock distribution into COPERT 5 relevant vehicle subsectors and (2) of the national mileage figures, as such.

In the mobile part of the Danish emission inventories, uncertainty assessments are made at Data Processing Level 1 for non-road machinery, recreational craft and national sea transport. For these types of mobile machinery, the stock and operational data variations are assumed to be normally distributed (Winther et al., 2006; Winther, 2008). Tier 1 uncertainty calculations produce final fuel consumption uncertainties ready for Data Storage Level 2 (SNAP level 2: Inland waterways, agriculture, forestry, industry and household-gardening). The sizes of the variation intervals are given for activity data and emission factors in the present report.

For non-road machinery stock and operational data, the uncertainty figures are given in Winther et al. (2006). For navigation, the uncertainty figures are given in Winther (2008).

For emission factors, the uncertainties for mobile sources are determined as suggested in the IPCC and UNECE guidelines. The uncertainty figures are listed in Paragraph 1.1.5 for greenhouse gases, and in Winther et al. (2006) and Winther (2008, 2015) for the remaining emission components.

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| Data Processing level 1 | 1. Accuracy | DP.1.2.1 | The methodologies have to follow the international guidelines suggested by UNFCCC and IPCC. |

An evaluation of the methodological inventory approach has been made, which proves that the emission inventories for transport are made according to the IPCC guidelines (IPCC, 2006). Further, the Danish inventories are reviewed annually by the UNFCCC.

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| Data Processing level 1 | 1. Accuracy | DP.1.1.4 | Verification of calculation results using guideline values |

It has been checked that the greenhouse gas emission factors used in the Danish inventory are within margin of the IPCC guideline values.

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| Data Processing level 1 | 3.Completeness | DP.1.3.1 | Identification of data gaps with regard to data sources that could improve quantitative knowledge. |

No important areas can be identified.

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| Data Processing level 1 | 4.Consistency | DP.1.4.1 | Documentation and reasoning of methodological changes during the time series and the qualitative assessment of the impact on time series consistency. |

See DP 1.7.5.

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| Data Processing level 1 | 5.Correctness | DP.1.5.2 | Verification of calculation results using time series |

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| Data Processing level 1 | 5.Correctness | DP.1.5.3 | Verification of calculation results using other measures |

For road transport, aviation, navigation and non-road machinery, whether all external data are correctly put into the DCE transport models is checked. This is facilitated by the use of sum queries, which sum up stock data (and mileages for road transport) to input aggregation levels. However, spreadsheet or database manipulations of external data are, in some cases, included in a step prior to this check.

This is carried out in order to produce homogenous input tables for the DCE transport models (road, civil aviation, non-road machinery/recreational craft, navigation/fisheries). The sub-routines perform operations, such as the aggregation/disaggregation of data into first sales year (Examples: Fleet numbers and mileage for road transport, stock numbers for tractors, harvesters and fork lifts) or simple lists of total stock per year (per machinery type for e.g. household equipment and for recreational craft). For civil aviation, additional databases control the allocation of representative aircraft to real aircraft types and the cruise distance between airports. A more formal description of the sub-routines will be made.

Regarding fuel data, it is checked for road transport and civil aviation that DEA totals (modified for road) match the input values in the DCE models. For the transport modes military and railways, the DEA fuel consumption figures go directly into Data Storage Level 2. This is also the case for the railway emission factors obtained from Danish State Railways and, generally, for the emission factors, which are kept constant over the years.

The DCE model simulations of fuel consumption and emission factors for road transport, civil aviation and non-road machinery refer to Data Processing Level 1.

When DCE transport model changes are made relating to fuel consumption, it is checked that the calculated fuel consumption sums correspond to the expected fuel consumption levels in the time series. The fuel consumption check also includes a time series comparison with fuel consumption totals calculated in the previous model version. The checks are performed on a SNAP level and, if appropriate, detailed checks are made for vehicle/-machinery technology splits.

As regards model changes in relation to derived emission factors (and calculated emissions), the time series of emission factors (and emissions) are compared to previous model figures. A part of this evaluation includes an assessment, if the development corresponds to the underlying assumptions given by detailed input parameters. Among other things, the latter parameters depend on emission legislation, new technology phase-in, deterioration factors, engine operational conditions/driving modes, gasoline evaporation (hydrocarbons) and cold starts. For methodological issues, please refer to Section 3.3.2.

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| Data Processing level 1 | 7.Transparency | DP.1.7.1 | The calculation principle, the equations used and the assumptions made must be described |

The DCE model calculation principles and basic equations are thoroughly described in the present report, together with the theoretical model reasoning and assumptions. Documentation is also given e.g. in Winther (2001a, 2001b, 2008, 2018) and Winther et al. (2006). Further formal descriptions of DCE model sub routines are given in internal notes, and flow maps show the interrelations between tables and calculation queries in the models.

During model development, it has been checked that all mathematical model relations give exactly the same results as independent calculations.

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| Data Processing level 1 | 7.Transparency | DP.1.7.2 | Clear reference to dataset at Data Storage level 1 |

In the different documentation reports for transport in the Danish emission inventories, there are explicit references for the different external data used.

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| Data Processing level 1 | 7.Transparency | DP.1.7.3 | A manual log to collect information about recalculations |

Recalculation changes in the emission inventories are described in the NIR and IIR reports as a standard. These descriptions take into account changes in emission factors, activity data and calculation methods.

*Data Storage Level 2*

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| Data Storage level 2 | 5.Correctness | DS.2.5.1 | Check if a correct data import to level 2 has been made |

At present, a DCE software programme imports data from prepared input data tables (SNAP fuel consumption figures and emission factors) into the CollectER database.

Tables for CollectER fuel consumption and emission results are prepared by a special DCE database (NERIrep.mdb). The results relevant for mobile sources are copied into a database containing all the official inventory results for mobile sources (Data2018 NIR-UNECE.mdb). By the use of database queries, the results from this latter database are aggregated into the same formats as being used by the relevant DCE transport models in their results calculation part. The final comparison between CollectER and DCE transport model results are set up in a spreadsheet.

*Data Storage Level 4*

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| Data Storage level 4 | 4.Consistency | DS.4.4.3 | The IEFs from the CRF are checked regarding both level and trend. The level is compared to relevant emission factors to ensure correctness. Large dips/jumps in the time series are explained |

A spreadsheet "Check CRF 2018.xls" has been set up to check that the fuel consumption and emission totals from CollectER imported in Data2018 NIR-UNECE.mdb are identical to the fuel consumption and emission totals from the CRF.

### 3.3.7 Recalculations and improvements

The following recalculations and improvements of the emission inventories have been made since the emission reporting in 2018.

**Civil aviation**

The source of emission factors for piston engine aircraft using aviation gasoline has been changed to EMEP/EEA (2019). Previously was used fuel related factors derived for conventional gasoline cars from the road transport emission model simulations.

The following largest percentage differences (in brackets) for civil aviation are noted for $CO_2$ (-0.8 %), $CH_4$ (-45.5 %) and $N_2O$ (-0.3 %).

### Road transport

For road transport the following changes have been made.

Fuel consumption factors for vans are now further split into vehicle weight classes based on fuel consumption factor data from the European model Handbook of Emission Factors (Matzer et al., 2019).

The $CO_2$ emission factor for biodiesel has been slightly changed to accommodate for the fact that a small part of the carbon (and the associated $CO_2$ emissions) in biodiesel, has a fossil origin due to the use of fossil-derived methanol in the biodiesel production process (Sempos (2019). The update in the $CO_2$ emission factor for biodiesel brings small increases in the total $CO_2$ emissions for road transport from 2008-2017.

The percentage emission change interval and year of largest percentage differences (low %; high %, year) for the different emission components are: $CO_2$ (0.00 %, 0.26 %, 2017), $CH_4$ (-0.48 %; 0.74 %, 2011) and $N_2O$ (-0.81 %; 0.75 %, 2000).

### Railways

No changes have been made.

### Navigation

A few inventory updates has been made for the ferries operated by Mols Linjen in terms of engine load factors in 2016 and 2017, round trip distribution for ferries in 2017, and updated emission factors as a function of engine load.

An error has been corrected in the inventories as regards the fuel used by freight transport between Denmark and the Faroe Islands (Eimskip). This fuel is not bought in Denmark (as previously believed), and hence this fuel should not be included in the Danish inventories. This update cause emission decreases for all pollutants for the years 2008-2017.

The following largest emission differences (ktonnes; % difference) for domestic navigation are noted in 2017 for: $CO_2$ (-37,4 ktonnes; -5.6 %), $CH_4$ (-0.9 tonnes; -2.3 %) and $N_2O$ (0.9 tonnes; -5.4 %).

### Industry

Minor updates in 2016 and 2017 sales figures for building and construction machinery has been included in the emission inventories.

The following largest percentage differences (in brackets) for mobile industry are noted for: $CO_2$ (-0.3 %), $CH_4$ (0.0 % and $N_2O$ (-0.4 %).

### Commercial and institutional

No changes have been made.

### Residential

No changes have been made.

### Agriculture/forestry

Minor updates in 2017 sales figures for ATV's has been included in the emission inventories.

The following largest percentage differences (in brackets) for agriculture/forestry are noted for: $CO_2$ (0.0 %), $CH_4$ (-5.3 % and $N_2O$ (0.1 %).

### Fishing

No changes have been made.

### Other (Military and recreational craft

Updated emission factors derived from the road transport model in the case of military equipment (1985-2017), and the changes in emission factors for piston engine aircraft (see description for civil aviation) have caused a few $CH_4$ and $N_2O$ emission changes from 1985-2017.

The following largest percentage differences (in brackets) for the Other category are noted for: $CH_4$ (-0.65 %) and $N_2O$ (-1.1 %).

## 3.3.8 Planned improvements

No planned improvements are envisaged to be made.

### QA/QC

Future improvements regarding this issue are dealt with in Section 3.1.4.

## 3.3.9 References for Chapter 3.3

Andersen, C., 2019: Unpublished data material for small ferries.

Bengtsson, S., Andersson, K. & Fridell, E. 2011: A comparative life cycle assessment of marine fuels: liquefied natural gas and three other fossil fuels, 14 pp., Proc. IMechE Vol. 225 Part M: J. Engineering for the Maritime Environment (DOI: 10.1177/1475090211402136).

Brun, I. 2018: Unpublished data material from Toyota Material Handling Danmark A/S.

Cappelen, J. 2019: The Climate of Denmark 2018 - with English summary, Technical report No 19-01, pp. 91, Danish Meteorological Institute.

Christensen, A. 2018: Personal communication, Allan Christensen, N.C. Nielsen A/S.

Cowi, 2008: Model til beregning af vej og banetransportens $CO_2$-ævivalent emissioner, Technical note, pp. 42, Ministry of Transport (in Danish).

Dávastovu, J. 2010: Unpublished data material from Smyril Line.

DEA, 2019: The Danish energy statistics, Available at: https://ens.dk/sites/ens.dk/files/Analyser/energistatistik_2018.pdf (18-12-2019).

DEA, 2019: Future fuel efficiency improvement rates for passenger cars, vans and trucks provided by the Danish Energy Agency.

Danish Ministry of Taxation, 2015: Status over grænsehandel 2014, pp. 112.

DNV, 2009: Marpol 73/78 Annex VI Regulations for the Prevention of Air Pollution from Ships - Technical and Operational implications, 32 pp.

Ellermann, T., Massling, A., Løfstrøm, P., Winther, M., Nøjgaard, J.K. & Ketzel, M., 2011: Investigation of Air Pollution at the Apron at Copenhagen Airport in Relation to Working Environment (Danish with English summary). DCE e Danish Centre for Environment and Energy, Aarhus University, p. 148. DCE report no. 5. Available at: http://www.dmu.dk/Pub/TR5.pdf

EMEP/EEA, 2019: Air Pollutant Emission Inventory Guidebook, prepared by the UNECE/EMEP Task Force on Emissions Inventories and Projections (TFEIP). Available at: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (09-12-2019).

Eriksen, J., 2017: Unpublished data material from Ærøfærgerne A/S.

Fauser, P., Thomsen, M., Nielsen, O.K., Winther, M., Gyldenkærne, S., Hoffmann, L., Lyck, E. & Illerup, J.B. 2007: Verification of the Danish emission inventory data by national and international data comparisons. National Environmental Research Institute, University of Aarhus. - NERI Technical Report 627: 53 pp. (electronic). Available at:
http://www2.dmu.dk/Pub/FR627_Final.pdf

Fauser, P., Nielsen, M., Winther, M., Plejdrup, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Hoffmann, L., Thomsen, M., Hjelgaard, K. & Nielsen, O.-K. 2013: Verification of the Danish 1990, 2000 and 2010 emission inventory data. Aarhus University, DCE – Danish Centre for Environment and Energy, 85 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 79. Available at: http://dce2.au.dk/pub/SR79.pdf

Fenhann, J. & Kilde, N.A. 1994: Inventory of Emissions to the air from Danish Sources 1972-1992, 111 pp., ISBN 87-550-1943-9, RISØ National Laboratory.

Hansen, C.O. 2010: Estimation af udenlandske bilers trafikarbejde i Danmark i 2009, Notat nr. 12032-005, 12 pp. Danish Road Directorate, 2010.

Hansen, K.F. & Jensen, M.G. 2004: MÅLING AF EMISSIONER FRA FREMDRIVNINGSANLÆG PÅ MADS MOLS. Ruston 20RK270, Sagsnr.: 1076868, Documentation note, 5 pp. (in Danish).

Hjelgaard, K. & Winther, M. 2011: The estimated new sales of Euro V diesel trucks equipped with EGR and SCR during the 2006-2010 time periods. Internal DCE note (unpublished). 2 pp. (in Danish).

ICAO, 2008: ICAO Annex 16 "International standards and recommended practices, Environmental protection", Volume II "Aircraft engine emissions", 3rd ed. (2008) plus amendments, 108 pp., International Civil Aviation Organization, ISBN 978-92-9231-123-0.

ICAO, 2017: ICAO Annex 16 "International standards and recommended practices, Environmental protection", Volume III "Aeroplane $CO_2$ emissions", 28 pp., International Civil Aviation Organization.

ICAO, 2011: Airport Air Quality Manual (doc. 9889), first ed. International Civil Aviation Organization. ISBN 978-92-9231-862-8.

ICCT, 2017: International Civil Aviation Organization's $CO_2$ standard for new aircraft, ICCT Policy update, 8 pp., International Council on Clean Transportation, 2017.

IFEU, 2004: Entwicklung eines Modells zur Berechnung der Luftschadstoffemissionen und des Kraftstoffverbrauchs von Verbrennungsmotoren in mobilen Geräten und Maschinen - Endbericht, UFOPLAN Nr. 299 45 113, pp. 122, Heidelberg.

IFEU 2009: Aktualisierung des Modells TREMOD - Mobile Machinery (TREMOD-MM), Endbericht; Institut für Energie- und Umweltforschung, pp. 48, Heidelberg.

IFEU 2014: Erarbeitung eines Konzepts zur Minderung der Umweltbelastung aus NRMM (non-road mobile machinery) unter Berücksichtigung aktueller Emissionsfaktoren und Emissionsverminderungsoptionen für den Bestand, ISSN 1862-4804, Texte 24/2014, pp. 99, Heidelberg.

IMO, 2015: Third IMO GHG Study 2014, Smith, T.W.P., Jalkanen, J.P., Anderson, B.A., Corbett, J.J., Faber, J., Hanayama, S., O'Keeffe, E., Parker, S., Johansson, L., Aldous, L., Raucci, C., Traut, M., Ettinger, S., Nelissen, D., Lee, D.S., Ng, S., Agrawal, A., Winebrake, J.J., Hoen, M., Chesworth, S. & Pandey, A., 2015: International Maritime Organization, (IMO) London, UK, April 2015. Available at: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. & Tanabe K. (eds). Published: IGES, Japan. Available at:
http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (21-02-2014).

Jensen, T.C. 2019: Dokumentation af konvertering af trafiktal til emissionsopgørelser, arbejdsnotat 35187, 30 pp. DTU Transport, 2019.

Johnsen, T. 2018: Personal communication, Thomas Johnsen, The Danish Bicycle Traders Association.

Jørgensen, H. 2017: Unpublished data material from Færgen A/S.

Kristensen, F. 2008: Unpublished data material from Mols-Linjen.

Kristensen, F. 2013: Unpublished data material from Mols-Linjen.

Kristensen, F. 2015: Unpublished data material from Mols-Linjen.

Kristensen, H.O. 2017: Unpublished data material for small ferries provided by Naval Engineer Hans Otto Holmegaard Kristensen.

Kruse, C. 2015: Unpublished data material from Samsø Rederi.

Lastein, L. & Winther, M. 2003: Emission of greenhouse gases and long-range transboundary air pollutants in the Faroe Islands 1990-2001. National Environmental Research Institute. - NERI Technical Report 477: 62 pp. (electronic). Available at:
http://www2.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR477.pdf

Lloyd's Register, 2012: Implementing the Energy Efficiency Design Index Version 3.0, December 2012, pp. 22.

Markamp, H. 2013: Personal communication, Henrik Markamp, The National Motorcycle Association.

Matzer C., Weller K., Dippold M., Lipp S., Röck M., Rexeis M., Hausberger S. 2019: Update of emission factors for HBEFA Version 4.1; Final report, I-05/19/CM EM-I-16/26/679 from 09.09.2019, TU Graz.

Mikkelsen, B. 2016: Unpublished data material from Pon equipment.

Ministry of Transport, 2015: TEMA2015 - et værktøj til at beregne transporters energiforbrug og emissioner i Danmark (TEMA2015 - a calculation tool for transport related fuel use and emissions in Denmark). Technical report. 126 pp.

Mortensen, L. 2015: Unpublished data material from Færgeselskabet Læsø.

Mølgård, J. 2018: Unpublished data material from the Danish State Railways.

Møller, K. 2015: Unpublished data material from Ærøfærgerne A/S.

Nielsen, D. 2019: Unpublished data material from Mols-Linjen.

Nielsen, M. & Schösser, M., 2016: Unpublished data material from LTEH (Dealers Association of Electric Tools and Gardening Machinery (In Danish: Leverandørforeningen for Transportabelt Elværktøj og Havebrugsmaskiner).

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Gyldenkærne, S., Thomsen, M., Fauser, P., Nielsen, M., Mikkelsen, M.H., Albrektsen, R., Hjelgaard, K., Hoffmann, L. & Bruun, H.G. 2012. Quality manual for the Danish greenhouse gas inventory. Version 2. Aarhus University, DCE – Danish Centre for Environment and Energy, 44 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 47. Available at:
http://www2.dmu.dk/Pub/SR47.pdf

Nielsen, O-K., Plejdrup, M.S., Winther, M., Mikkelsen, M.H., Nielsen, M., Gyldenkærne, S., Fauser, P., Albrektsen, R., Hjelgaard, K.H., Bruun, H.G. & Thomsen, M. 2018. Annual Danish Informative Inventory Report to UNECE. Emission inventories from the base year of the protocols to year 2016. Aarhus University, DCE – Danish Centre for Environment and Energy, 495 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 267. Available at: http://dce2.au.dk/pub/SR267.pdf

PHP, 1996: Research Report – Emission tests at Alpha, Mols 2 and Mols 4, 9L25MC mk6 engines #35031 and #35033, 22-23/10 1995 and 16/1 1996, DOK, PHP Basic Research, October 1996, 20 pp.

Rasmussen, T., 2017: Unpublished data material for small ferries.

Rasmussen, H. 2018: Unpublished data material from Royal Arctic Line.

Sempos (2019): Note on fossil carbon content in biofuels, pp. 13.

Sjøgren, P. 2016: Unpublished data material from Volvo Construction Equipment.

Starcrest, 2013: Port of Los Angeles Inventory of Air Emissions – 2012. Available at: http://www.portoflosangeles.org/pdf/2012_Air_Emissions_Inventory.pdf

Statistics Denmark, 2019: Data from Statbank Denmark. Available at: http://www.statistikbanken.dk/statbank5a/default.asp?w=1364

Thorarensen, B. 2019: Unpublished data material from Eim Skip.

Tietge, U., Mock, P., Franco, V. & Zacharof, N. 2017: From laboratory to road: Modeling the divergence between official and realworld fuel consumption and $CO_2$ emission values in the German passenger car market for the years 2001–2014, Energy Policy 103 (2017) 212–222. Available at: http://dx.doi.org/10.1016/j.enpol.2017.01.021

Tietge, U., Díaz, S., Mock, P., Bandivadekar, Dornoff, J., A., Ligterink, N., 2019: From laboratory to road. A 2018 update of official and "real world" fuel consumption and $CO_2$ values for passenger cars in Europe, ICCT White paper, 56 pp., International Council on Clean Transportation, 2019.

Winther, M. & Ekman, B. 1998: Emissioner fra vejtrafikken i Danmark 1980-2010. Danmarks Miljøundersøgelser, Aarhus Universitet, 1998. 73 s. (Faglig rapport fra DMU, Vol. 256).

Winther, M. 2001a: 1998 Fuel Use and Emissions for Danish IFR Flights. Environmental Project no. 628, 2001. 112 pp. Danish EPA. Prepared by the National Environmental Research Institute, Denmark. Available at: http://www.mst.dk/udgiv/Publications/2001/87-7944-661-2/html/

Winther, M. 2001b: Improving fuel statistics for Danish aviation. National Environmental Research Institute, Denmark. 56 pp. – NERI Technical Report No. 387. Available at: http://www2.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR387.pdf

Winther, M. & Nielsen, O.K. 2006: Fuel use and emissions from non-road machinery in Denmark from 1985–2004 – and projections from 2005-2030. The Danish Environmental Protection Agency. - Environmental Project 1092: 238 pp.

Winther, M. 2008: Fuel consumption and emissions from navigation in Denmark from 1990-2005 - and projections from 2006-2030. Technical Report from NERI no. 650. 109 pp. Available at: http://www2.dmu.dk/Pub/FR650.pdf

Winther, M. 2009: Emission Differences between Petroleum based Diesel and different Biodiesel Blend Ratios for Road Transport Vehicles. / Winther, Morten. 2009. Transport and Air Pollution Symposium - 3rd Environment and Transport Symposium, no. 17, Toulouse, France, 2-4 June 2009.

Winther, M. 2011: Ændring i partikelemission som følge af fremskyndet salg af Euro 5 biler og retrofit af filtre på tunge køretøjer. Internal DCE note (unpublished). 2 p. (in Danish).

Winther, M., Møller, F. & Jensen, T.C. 2012: Emission consequences of introducing bio ethanol as a fuel for gasoline cars, Atmospheric Environment 55 (2012) 144-153.

Winther, M. 2018: Danish emission inventories for road transport and other mobile sources. Inventories until the year 2016. Aarhus University, DCE – Danish Centre for Environment and Energy, 127pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 277. Available at: http://dce2.au.dk/pub/SR277.pdf

Winther, M., Kousgaard, U., Ellermann, T., Massling, A., Nøjgaard, J.K. & Ketzel, M. 2015: Emissions of $NO_x$, particle mass and particle numbers from aircraft main engines, APU's and handling equipment at Copenhagen Airport, Atmospheric Environment 100 (2015) 218-229.

Wismann, T. 1999: MOLS-LINIEN, Mai Mols - Måling af emissioner fra hovedturbiner, dk-RAPPORT 14.901, 9 pages (in Danish).

## 3.4 Additional information, CRF sector 1A Fuel combustion

### 3.4.1 Reference approach, feedstocks and non-energy use of fuels

In addition to the sector specific $CO_2$ emission inventories (the sectoral approach - SA), the $CO_2$ emission is also estimated using the reference approach (RA) described in the IPCC Guidelines (IPCC, 2006). The reference approach is based on data for fuel production, import, export and stock change. The $CO_2$ emission inventory based on the reference approach is reported to the Climate Convention and used for verification of the sectoral approach.

Data for import, export and stock change used in the reference approach originate from the annual “basic data” table prepared by the Danish Energy Agency (DEA) and published on their home page (DEA, 2019a). The fraction of carbon oxidised has been assumed 1.00.

The applied carbon emission factors are equal to the emission factors also applied in the sectoral approach and thus include nationally referenced emission factors. This is in agreement with the 2006 IPCC Guidelines.

The Climate Convention reporting tables include a comparison of the sectoral approach and the reference approach estimates.

The consumption for non-energy purposes is subtracted in the reference approach, because non-energy use of fuels is included in other sectors (Industrial processes and Solvent use) in the Danish sectoral approach. Three fuels are used for non-energy purposes: lubricants, bitumen and white spirit. The total consumption for non-energy purposes is relatively low – 10.3 PJ in 2018.

The $CO_2$ emission from oxidation of lube oil during use was 31.7 Gg in 2018 and this emission is reported in the sector industrial processes and product use (sector 2.D). The reported emission corresponds to 20 % of the $CO_2$ emission from lube oil consumption assuming full oxidation. This is in agreement with the methodology for lube oil emissions in the 2006 IPCC Guidelines (IPCC, 2006). Methodology and emission data for lube oil are shown in NIR Chapter 4.5.3.

For white spirit, the $CO_2$ emission is indirect as the emissions occur as NMVOC emissions from the use of white spirit as a solvent. The indirect $CO_2$ emission from solvent use was 60.7 Gg in 2018. The methodology and emission data for white spirit are included in NIR Chapter 4.5.4.

The $CO_2$ emission from bitumen is included in sector 2.D.3, Road paving with asphalt and Asphalt roofing. The total $CO_2$ emissions for these sectors are 0.96 Gg in 2018. Methodology and emission data for non-energy use of bitumen are shown in NIR Chapter 4.5.6.

**Results**

The sectoral approach and the reference approach have been compared and the differences between the two approaches are shown in Table 3.4.1 below.

Table 3.4.1 Difference between sectoral approach and reference approach.

| Year | Difference Energy consumption [%] | Difference $CO_2$ emission [%] |
|---|---|---|
| 1990 | 0.28 | -0.32 |
| 1991 | -0.55 | -0.96 |
| 1992 | -0.02 | -0.63 |
| 1993 | -0.40 | -1.01 |
| 1994 | -0.31 | -0.89 |
| 1995 | -0.56 | -0.94 |
| 1996 | -0.49 | -0.76 |
| 1997 | -0.03 | -0.12 |
| 1998 | 1.50 | 1.33 |
| 1999 | -0.58 | -0.88 |
| 2000 | 0.27 | 0.06 |
| 2001 | 0.75 | 0.62 |
| 2002 | 0.05 | -0.15 |
| 2003 | 0.10 | -0.07 |
| 2004 | 0.00 | -0.18 |
| 2005 | -0.88 | -0.93 |
| 2006 | -0.64 | -0.87 |
| 2007 | -0.91 | -1.02 |
| 2008 | -0.22 | -0.35 |
| 2009 | -1.69 | -1.75 |
| 2010 | 0.12 | -0.21 |
| 2011 | -0.99 | -1.08 |
| 2012 | -1.54 | -1.88 |
| 2013 | -0.79 | -1.08 |
| 2014 | -1.39 | -1.58 |
| 2015 | -1.51 | -1.73 |
| 2016 | -2.79 | -3.28 |
| 2017 | -0.75 | -0.87 |
| 2018 | -1.44 | -1.58 |

The comparison of the sectoral approach and the reference approach is illustrated in Figure 3.4.1. In 2018, the fuel consumption rates in the two approaches differ by 1.4 % and the $CO_2$ emission differs by 1.6 %. Both the fuel consumption and the $CO_2$ emission differ by less than 2 % for all years except 2016.

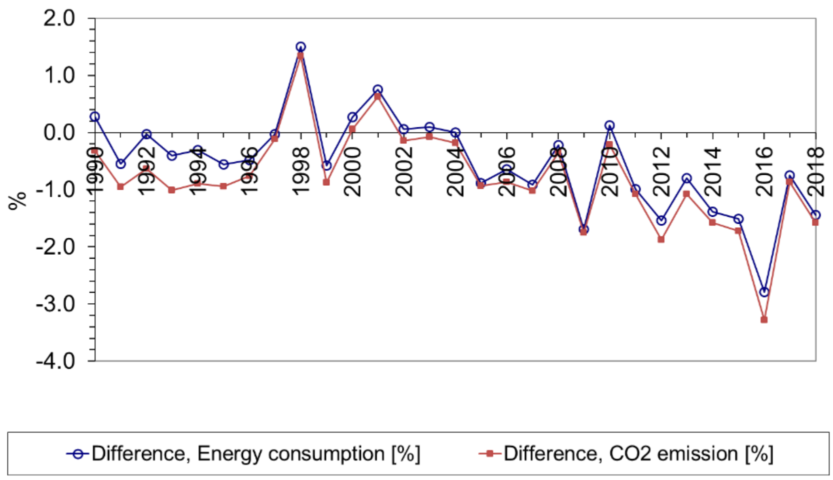


Figure 3.4.1 Comparison of the reference approach and the sectoral approach.

The fluctuations in Figure 3.4.1 follow the fluctuations of the statistical difference in the Danish energy statistics shown in Figure 3.4.2. The large differences in certain years, e.g. in 1998, 2009, 2012 and 2016, are due to high statistical differences in the Danish energy statistics in these years.

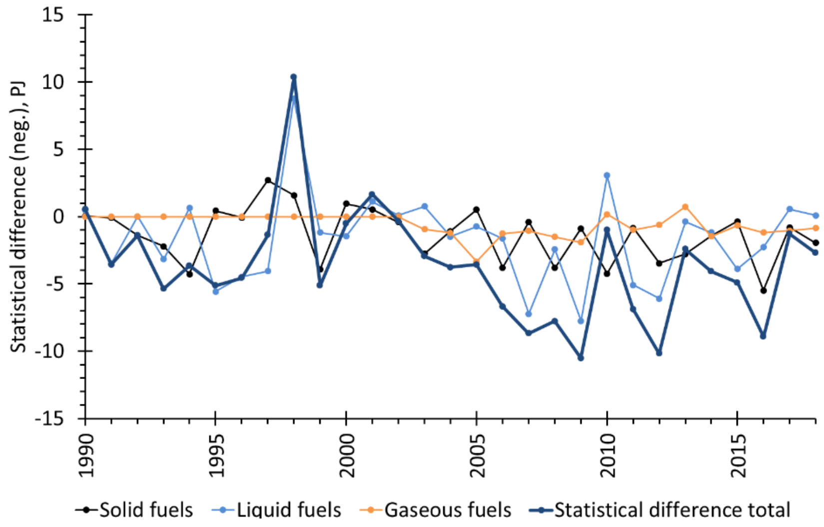


Figure 3.4.2 Statistical difference in the Danish energy statistics (DEA, 2019a).

The difference between SA and RA is above 2 % in 2016 and the reason for this difference have been further analysed.

The large difference between RA and SA in 2016 is mainly related to fuel consumption data. The fuel consumption applied in the SA was higher than in the RA for all fuel categories for 2016.

**Differences between the sectoral approach and the reference approach**

The difference between the sectoral approach and the reference approach is above 2 % in 2016 and thus the sources causing this difference have been analysed for each of the fossil fuel categories.

### Solid fuels

The difference for solid fuels is 6.2 % or 5.5 PJ. The statistical difference for solid fuels in the Danish energy statistics is 5.5 PJ for 2016. This difference mainly relates to coal (5.5 PJ). Thus, the difference between approaches is a result of the statistical difference. A time series for the difference of solid fuel consumption is shown in Figure 3.4.3.

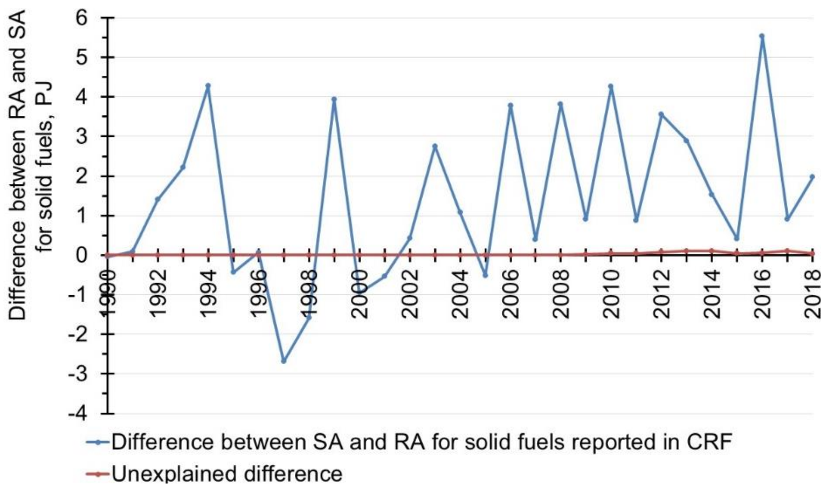


Figure 3.4.3 Difference between RA and SA for solid fuels reported in CRF and the difference not explained by statistical difference of the Danish energy statistics.

### Liquid fuels

The difference for liquid fuels in 2016 is 1.7 % or 4.1 PJ. This difference have been further analysed and several sources identified.

- The statistical difference for liquid fuels in the Danish energy statistics is 2.3 PJ for 2016. This difference mainly relates to crude oil (3.7 PJ).
- The Danish energy statistics includes data for net input of blends. In 2016, the net input was 0.2 PJ.
- In the Danish energy statistics, the fuel input to refineries is not equal to the fuel output added to fuel consumption. In 2016, the difference was 2.7 PJ.
- For refinery gas, the fuel consumption applied in the SA is based on EU ETS data rather than the energy statistics (see NIR Chapter 3.2.5). For 2016, the fuel consumption in EU ETS that are applied in SA is 0.5 TJ *lower* than the data from the energy statistics.

The explained differences for liquid fuels in 2016 add up to 5.2 PJ. Thus, only the remaining 1.1 PJ is not explained. The time series for reported difference for liquid fuels between SA and RA for 1990-2018 is shown in Figure 3.4.4 below. In the figure, the estimated difference taking into account the four known sources explained above is also shown.

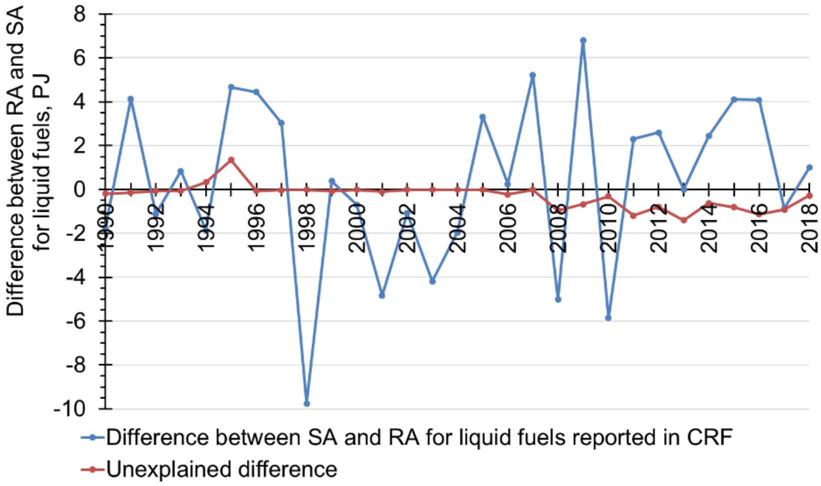


Figure 3.4.4 Difference between RA and SA for liquid fuels reported in CRF and the difference not explained by four known sources.

### Gaseous fuels

For 2016, the difference for gaseous fuels is 1.8 % or 2.2 PJ. The statistical difference for gaseous fuels in the Danish energy statistics is 1.2 PJ for 2016. For off shore gas turbines the fuel consumption applied in the sectoral approach is based on EU ETS data rather than the energy statistics (see NIR Chapter 3.2.5). For 2016, the consumption in EU ETS that are applied in SA was 1.0 PJ higher than the data from the energy statistics. Thus, the statistical difference and the different data sets applied for off shore gas turbines cause the difference between the two approaches for gaseous fuels.

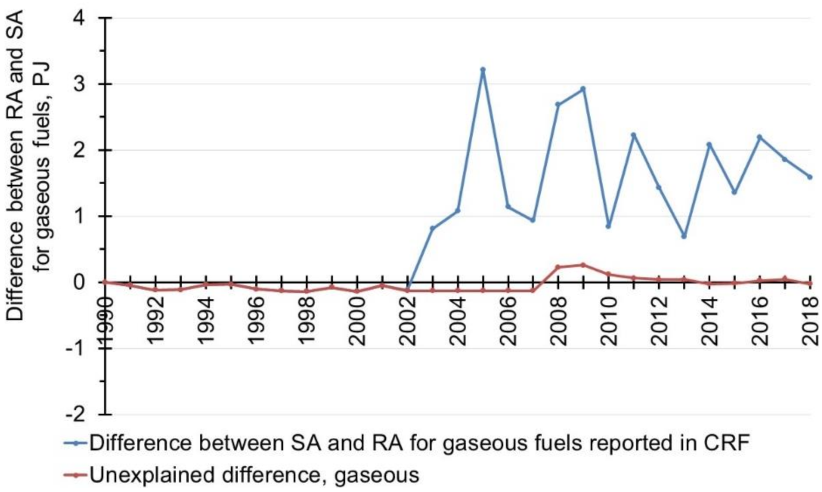


Figure 3.4.5 Difference between RA and SA for gaseous fuels reported in CRF and the difference not explained by two known sources.

### Other fossil fuels

For 2016, the difference for other fossil fuels (fossil waste) is 7.2 % or 1.4 PJ.

The statistical difference for fossil waste in the Danish energy statistics is 0.0 PJ for 2016. The fossil part of waste applied in the Danish cement production plant is higher than for other waste applied in Danish incineration plants. The higher fossil part of waste applied in the cement production plant have been implemented in the SA but not in the RA. For 2016, this corresponds to a 0.5 PJ difference. In addition, the combustion of waste in individual plants implemented in the SA for 2016 added up to a higher total than included in the energy statistics. This difference corresponds to a difference of 0.5 PJ fossil waste. Finally, the fossil part of biodiesel reported in SA sector 1A3 is included in the fuel category other fossil fuels. This fuel consumption is included in biomass in RA. In 2016, the fossil part of biodiesel added up to 0.5 PJ.

The reason for the higher total waste consumption based on the plant specific data than in the energy statistics will be further analysed. The recent implementation of EU ETS data as a data source for the industrial subsectors has improved transparency.

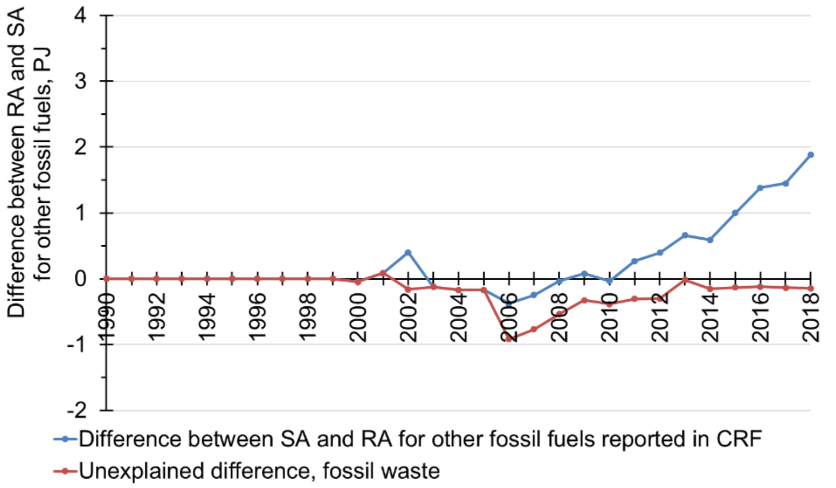

Figure 3.4.6 Difference between RA and SA for other fossil fuels reported in CRF and the difference not explained by four known sources.

#### Recalculations and improvements
Data for both reference approach and national approach have been updated according to the latest energy statistics.

#### Planned improvements
The differences mentioned above are part of the ongoing dialogue with the Danish Energy Agency.

### 3.4.2 References for Chapter 3.4


Danish Energy Agency (DEA), 2019a: The Danish energy statistics, Available at:
https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics (2020-01-10).

IPCC, 2006: Revised 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at:
http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (2020-01-10).


## 3.5 Fugitive emissions (CRF sector 1B)

### 3.5.1 Overview of sector

Fugitive emissions from fuels include emissions from production, storage, refining, transport, venting and flaring of oil and natural gas. Denmark has no production of solid fuels, and accordingly greenhouse gas emissions from solid fuels are not occurring. The fugitive sector consists of the following CRF categories:

- 1B2a Oil
- 1B2b Natural gas
- 1B2c Venting and flaring

Most fugitive emission sources are of minor importance compared to the total Danish emissions. Fugitive and national total emissions are given in Table 3.5.1. Note that the data presented in Chapter 3 relate to Denmark only, whereas information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 7.

Table 3.5.1 National and fugitive emissions of $CO_2$, $CH_4$ $N_2O$ and GHG in 2018, and the fugitive emissions share of national total emissions.

| | National emission | Fugitive emission | Fugitive/national emission |
|---|---|---|---|
| | kt $CO_2$ eqv. | kt $CO_2$ eqv. | % |
| $CO_2$ | 34 651 | 232 | 0.7 |
| $CH_4$ | 7 333 | 90 | 1.2 |
| $N_2O$ | 5 398 | 41 | 0.8 |
| GHG | 47 943 | 364 | 0.8 |

Table 3.5.2 list the results from the key category analysis for approach 1 and approach 2 for fugitive emission sources.

Table 3.5.2 Key categories in the fugitive emission sector.

| CRF table | Pollutant | Key category identification | |
|---|---|---|---|
| | | Approach 1 | Approach 2 |
| 1.B.2.a.1 Exploration, oil | $CO_2$ | - | - |
| 1.B.2.a.2 Production, oil | $CO_2$ | - | - |
| 1.B.2.a.4 Refining/storage | $CO_2$ | - | - |
| 1.B.2.b.1 Exploration, gas | $CO_2$ | - | - |
| 1.B.2.b.2 Production, gas | $CO_2$ | - | - |
| 1.B.2.b.4 Transmission and storage, gas | $CO_2$ | - | - |
| 1.B.2.b.5 Distribution, gas | $CO_2$ | - | - |
| 1.B.2.c.1.ii Venting, gas | $CO_2$ | - | - |
| 1.B.2.c.2.i Flaring, oil | $CO_2$ | - | - |
| 1.B.2.c.2.ii Flaring, gas | $CO_2$ | - | - |
| 1.B.2.c.2.iii Flaring, combined | $CO_2$ | Level (1990 & 2018) | - |
| 1.B.2.a.1 Exploration, oil | $CH_4$ | - | - |
| 1.B.2.a.2 Production, oil | $CH_4$ | - | - |
| 1.B.2.a.3 Transport, oil | $CH_4$ | - | - |
| 1.B.2.a.4 Refining/storage | $CH_4$ | - | - |
| 1.B.2.b.1 Exploration, gas | $CH_4$ | - | - |
| 1.B.2.b.2 Production, gas | $CH_4$ | - | - |
| 1.B.2.b.4 Transmission and storage, gas | $CH_4$ | - | - |
| 1.B.2.b.5 Distribution, gas | $CH_4$ | - | - |
| 1.B.2.c.1.ii Venting, gas | $CH_4$ | - | - |
| 1.B.2.c.2.i Flaring, oil | $CH_4$ | - | - |
| 1.B.2.c.2.ii Flaring, gas | $CH_4$ | - | - |
| 1.B.2.c.2.iii Flaring, combined | $CH_4$ | - | - |
| 1.B.2.a.1 Exploration, oil | $N_2O$ | - | - |
| 1.B.2.c.2.i Flaring, oil | $N_2O$ | - | - |
| 1.B.2.c.2.ii Flaring, gas | $N_2O$ | - | - |
| 1.B.2.c.2.iii Flaring, combined | $N_2O$ | - | - |

Calculations of fugitive emissions are to the highest degree possible, based on Tier 2 and Tier 3 methodologies. The methodological Tiers and the level of detail for the applied emission factors in are listed in (Table 3.5.3).

Table 3.5.3 Applied methodology for fugitive emission sources.

| CRF | Source | Pollutant | Method | Emission factor |
|---|---|---|---|---|
| 1 B 2 a i | Exploration of oil | $CO_2$ | Tier 3 | PS |
| | | $CH_4$ | Tier 3 | CS |
| | | $N_2O$ | Tier 3 | D |
| 1 B 2 a ii | Production of oil | $CO_2$ | Tier 3 | D |
| | | $CH_4$ | Tier 3 | D |
| 1 B 2 a iii | Transport | $CH_4$ | Tier 2 | OTH (EMEP/EEA 2019) |
| 1 B 2 a iv | Refining/storage | $CH_4$ | Tier 3 | PS, CS |
| 1 B 2 b i | Exploration of gas | $CO_2$ | Tier 3 | PS |
| | | $CH_4$ | Tier 3 | CS |
| | | $N_2O$ | Tier 3 | D |
| 1 B 2 b ii | Production of gas, Offshore activities | $CO_2$ | Tier 3 | D |
| | | $CH_4$ | Tier 3 | D |
| 1 B 2 b iv | Transmissions and storage | $CO_2$ | Tier 2 | CS |
| | | $CH_4$ | Tier 2 | CS |
| 1 B 2 b v | Distribution | $CO_2$ | Tier 2 | CS |
| | | $CH_4$ | Tier 2 | CS |
| 1 B 2 c 1 ii | Venting in gas storage | $CO_2$ | Tier 3 | CS(1990-1994), PS(1995 onwards) |
| | | $CH_4$ | Tier 3 | D |
| 1 B 2 c 2 i | Flaring in oil refinery | $CO_2$ | Tier 3 | CS(1990-2006), PS(2007 onwards) |
| | | $CH_4$ | Tier 3 | D |
| | | $N_2O$ | Tier 3 | D |
| 1 B 2 c 2 ii | Flaring in gas storage, transmission and distribution | $CO_2$ | Tier 3 | CS(1990-2006), PS(2007 onwards) |
| | | $CH_4$ | Tier 3 | D |
| | | $N_2O$ | Tier 3 | D |
| 1 B 2 c 2 iii | Flaring in oil and gas extraction | $CO_2$ | Tier 3 | CS(1990-2007), PS(2008 onwards) |
| | | $CH_4$ | Tier 3 | CS |
| | | $N_2O$ | Tier 3 | D |

Note: PS: plant specific. CS: country specific, D: default (IPCC, 2006), OTH: other.

### 3.5.2 Source category description

According to the IPCC sector definitions the category *fugitive emissions from fuels* is a sub-category under the main-category Energy (Sector 1). The category *fugitive emissions from fuels* (Sector 1B) is segmented into sub-categories covering emissions from solid fuels *(coal mining and handling (1B1a), solid fuel transformation (1B1b) and other (1B1c))*, oil *(oil (1B2a)*, natural gas *(1B2b)*, venting and flaring *(1B2c)* and other *(1B2d)*. The sub-categories relevant for the Danish emission inventory are shortly described below according to Danish conditions:

- 1B1a: Fugitive emission from solid fuels: Coal mining and solid fuel transformation are not occurring in Denmark. Accordingly, greenhouse gas emissions from solid fuels are not occurring in Denmark.
- 1B2a: Fugitive emissions from oil include emissions from exploration, production, storage, and transmission of crude oil, distribution of oil products and fugitive emissions from refining.
- 1B2b: Fugitive emissions from natural gas include emissions from exploration, production, transmission of natural gas and distribution of natural gas and town gas.
- 1B2c: Venting and flaring include activities onshore and offshore. Flaring occur both offshore in upstream oil and gas production, and onshore in gas treatment and storage facilities, in refineries and in natural gas transmission and distribution. Venting occurs in gas storage facilities. Venting

of gas is assumed to be negligible in oil and gas production and in refineries as controlled venting enters the gas flare system.

Table 3.5.4 summarizes the Danish fugitive greenhouse gas emissions in 2018. Information on other pollutants are included in the Informative Inventory Reports (IIR) reported annually to UNECE CLRTAP (Nielsen et al., 2020b).

Table 3.5.4 Summary of the Danish fugitive emissions 2018. P refers to point source and A to area source.

| IPCC code | Source | Type* | Pollutant | Emission | Unit | Share of total fugitive |
|---|---|---|---|---|---|---|
| 1.B.2.a.1 | Exploration of oil | A | $CH_4$ | <0.001 | t | <0.01% |
| 1.B.2.a.1 | Exploration of oil | A | $CO_2$ | <0.001 | kt | <0.01% |
| 1.B.2.a.1 | Exploration of oil | A | $N_2O$ | <0.001 | t | <0.01% |
| 1.B.2.a.2 | Production of oil | A | $CH_4$ | 4 | t | 0.1% |
| 1.B.2.a.2 | Production of oil | A | $CO_2$ | <0.001 | kt | <0.01% |
| 1.B.2.a.3 | Offshore loading of oil | A | $CH_4$ | 39 | t | 1.1% |
| 1.B.2.a.3 | Onshore loading of oil | A | $CH_4$ | 16 | t | 0.4% |
| 1.B.2.a.4 | Petroleum products processing | P | $CH_4$ | 583 | t | 16.2% |
| 1.B.2.a.4 | Storage of crude oil | A | $CH_4$ | 271 | t | 7.5% |
| 1.B.2.a.4 | Storage of crude oil | A | $CO_2$ | 0 | kt | <0.01% |
| 1.B.2.b.1 | Exploration of gas | A | $CH_4$ | <0.001 | t | <0.01% |
| 1.B.2.b.1 | Exploration of gas | A | $CO_2$ | <0.001 | kt | <0.01% |
| 1.B.2.b.1 | Exploration of gas | A | $N_2O$ | <0.001 | t | <0.01% |
| 1.B.2.b.2 | Production of gas | A | $CH_4$ | 1532 | t | 42.6% |
| 1.B.2.b.2 | Production of gas | A | $CO_2$ | 0.06 | kt | <0.01% |
| 1.B.2.b.4 | Natural gas transmission | A | $CH_4$ | 27 | t | 0.8% |
| 1.B.2.b.4 | Natural gas transmission | A | $CO_2$ | <0.001 | kt | <0.01% |
| 1.B.2.b.5 | Natural gas distribution | A | $CH_4$ | 110 | t | 3.1% |
| 1.B.2.b.5 | Natural gas distribution | A | $CO_2$ | 0 | kt | <0.01% |
| 1.B.2.b.5 | Town gas distribution | A | $CH_4$ | 58 | t | 1.6% |
| 1.B.2.b.5 | Town gas distribution | A | $CO_2$ | 0 | kt | <0.01% |
| 1.B.2.c.1.ii | Venting in gas storage | A | $CO_2$ | <0.001 | kt | <0.01% |
| 1.B.2.c.1.ii | Venting in gas storage | P | $CH_4$ | 37 | t | 1.0% |
| 1.B.2.c.1.ii | Venting in gas storage | P | $CO_2$ | 0 | kt | <0.01% |
| 1.B.2.c.2.i | Flaring in oil refinery | P | $CH_4$ | 6 | t | 0.2% |
| 1.B.2.c.2.i | Flaring in oil refinery | P | $CO_2$ | 18 | kt | 7.7% |
| 1.B.2.c.2.i | Flaring in oil refinery | P | $N_2O$ | 0.15 | t | 0.1% |
| 1.B.2.c.2.ii | Flaring in gas storage | P | $CH_4$ | 0.47 | t | <0.01% |
| 1.B.2.c.2.ii | Flaring in gas storage | P | $CO_2$ | 1 | kt | 0.6% |
| 1.B.2.c.2.ii | Flaring in gas storage | P | $N_2O$ | <0.001 | t | <0.01% |
| 1.B.2.c.2.ii | Flaring in gas transmission and distribution | A | $CH_4$ | 0.21 | t | <0.01% |
| 1.B.2.c.2.ii | Flaring in gas transmission and distribution | A | $CO_2$ | 0.04 | kt | <0.01% |
| 1.B.2.c.2.ii | Flaring in gas transmission and distribution | A | $N_2O$ | <0.001 | t | <0.01% |
| 1.B.2.c.2.iii | Flaring in gas and oil extraction | A | $CH_4$ | 913 | t | 25.4% |
| 1.B.2.c.2.iii | Flaring in gas and oil extraction | A | $CO_2$ | 213 | kt | 91.7% |
| 1.B.2.c.2.iii | Flaring in gas and oil extraction | A | $N_2O$ | 138 | t | 99.9% |

* A: area source, P: point source.

### 3.5.3 Use of EU ETS data

Reporting to the European Union Emission Trading Scheme (EU ETS) are available in the annual EU ETS reports for refineries, upstream oil and gas extraction facilities and the natural gas treatment plant, concerning fugitive emissions. EU ETS data are only included in the national emission inventory if higher tier methodologies are applied, which is the case for the EU ETS reports regarding fugitive emission sources. The EU ETS data used are fully in line with the requirements in the IPCC Guidelines and are considered the best data source on $CO_2$ emission factors due to the legal obligation for the relevant companies to make the accounting following the specified EU decisions. The EU ETS data are thereby a source of consistent data with low uncertainties. For further information on EU ETS please refer to the section "*Use of EU Emission Trading Scheme data*" in Chapter 1. Unfortunately, corresponding data do not exist before the commencement of EU ETS in 2006 and therefore it is not possible to set up time series based on EU ETS. In these cases, appropriate methods from the IPCC Guidelines have been selected to ensure time series consistency. This is described in the specific sections.

**EU ETS reports for refineries**

Activity data are measured with flow meters and rates are reported with high accuracy using the Tier 4 methodology (uncertainty ±1.5 %) for large sources and Tier 3 (uncertainty ±2.5 %) or Tier 2 (uncertainty ±5 %) for small sources. The oxidation factor is set to 1, corresponding the Tier 1 methodology. $CO_2$ emission factors are calculated according to the relevant Tier given in the EU Commission Implementing Regulation of 19 December 2018 (EU Commission, 2018). The Tier 2b methodology based on yearly density and calorific values is applied, while the activity specific Tier 3 methodology is applied for diesel. $CO_2$ emissions factors for flaring are calculated using the Tier 3 methodology based on the measured carbon contents.

**EU ETS reports for offshore installations**

Activity data are measured with flow meters and rates are reported with high accuracy. For combustion, the Tier 4 methodology (uncertainty ±1.5 %) is used for large sources and Tier 3 (uncertainty ±2.5 %) or Tier 2 (uncertainty ±5 %) for small sources. For flaring, mainly the Tier 3 or the Tier 2 methodology is used (uncertainty ±7.5 % or ±12.5 %) is used. The oxidation factor is set to 1, corresponding the Tier 1 methodology. $CO_2$ emission factors are calculated according to the relevant Tier given in the EU Commission Implementing Regulation of 19 December 2018 (EU Commission, 2018). For combustion of fuel gas the Tier 3 methodology, which is activity specific, is applied, while the country specific Tier 3 methodology is applied for diesel. $CO_2$ emissions factors for flaring are calculated using the Tier 2b methodology.

### 3.5.4 Activity data, emission factors and emissions for fugitive sources

The following paragraphs describe the methodology for emission calculation for fugitive sources, including activity data, emission factors and annual emissions. The order follow the IPCC structure (1B2a Oil, 1B2b Natural gas, 1B2c Venting and flaring), with the exception that exploration and production of gas are include in the paragraphs for exploration and production of oil, due to similar methodologies and data providers.

**Fugitive emissions from oil (1B2a)**

The emissions from oil derive from exploration, production, onshore and offshore loading of ships, onshore oil tanks, service stations and refineries. Exploration and production of both oil and gas are described in this paragraph.

***Exploration (1B2a1, 1B2b1)***

Activity data

Activity data for oil and gas exploration are provided annually by the Danish Energy Agency (Erichsen, 2019). Data for exploration of oil and gas are given separately for each exploration drilling, and fluctuate significantly over the time series. The largest oil rates are seen for 1990, 2002 and 2005, while relatively large gas rates are seen for more years of the time series. There was no exploration activity in 2018. Explored rates are shown in Figure 3.5.1.

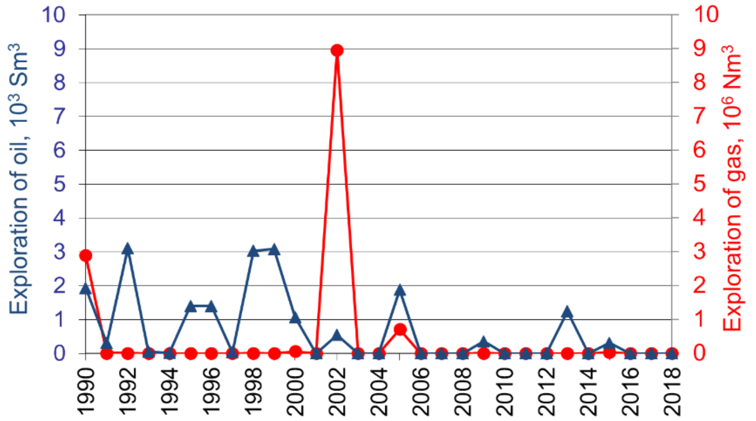


Figure 3.5.1 Exploration of oil and gas.

Emission factors

Annual $CO_2$ emission factors are based on composition data, calorific values and densities for explored oil and gas provided by the Danish Energy Agency. Composition data are available for the exploration and appraisal wells (E/A wells) separately, except for a few E/A wells, for which the compositions for the previous E/A well are used for emission calculation. As calorific values and densities are not available per drilling, data from a gas test in 1992 are used. $CO_2$ emission factors are listed in Table 3.5.5. The emission factors used to calculate emissions from offshore flaring in upstream oil and gas production are applied for the remaining pollutants (refer to the Section *Fugitive emissions from venting and flaring (1B2c)* below).

Table 3.5.5 Annual $CO_2$ emission factors for selected years for exploration of oil and gas.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| EF($CO_2$), exploration of oil, kg/Sm3 | 2433 | 2449 | 2449 | 2444 | NO | 2449 | NO | 2449 | NO | NO | NO |
| EF($CO_2$), exploration of gas, kg/Nm3 | 2.85 | 2.94 | 2.94 | 2.89 | NO | 2.82 | NO | 2.82 | NO | NO | NO |

Emissions

Calculated $CH_4$ emissions for exploration of oil and gas are shown in Figure 3.5.2. There is no correlation between emissions from oil and gas, as the individual exploration drillings have different ratios between oil and gas rates.

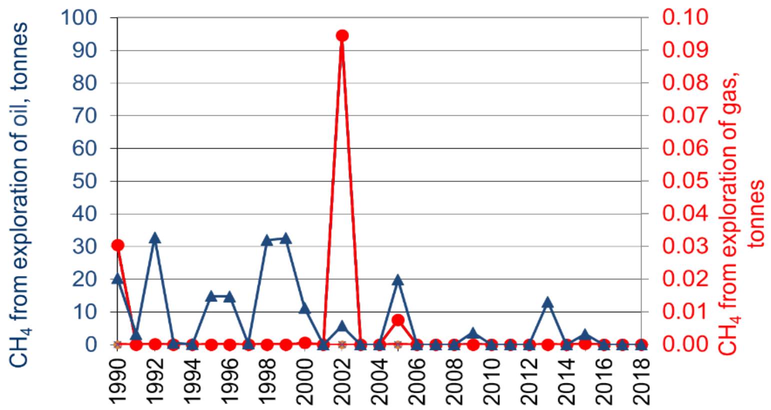

Figure 3.5.2 $CH_4$ emissions from exploration of oil and gas.

***Production (1B2a2, 1B2b2)***

Activity data

Activity data used for oil and gas production are provided by the Danish Energy Agency (DEA 2019a). As seen in Figure 3.5.3 the production of oil and gas in the North Sea has generally increased in the years 1990-2004, and since 2004 the production has decreased. Five major platforms were completed in 1997-1999, which is the main reason for the great increase in the oil production in the years 1998-2000.

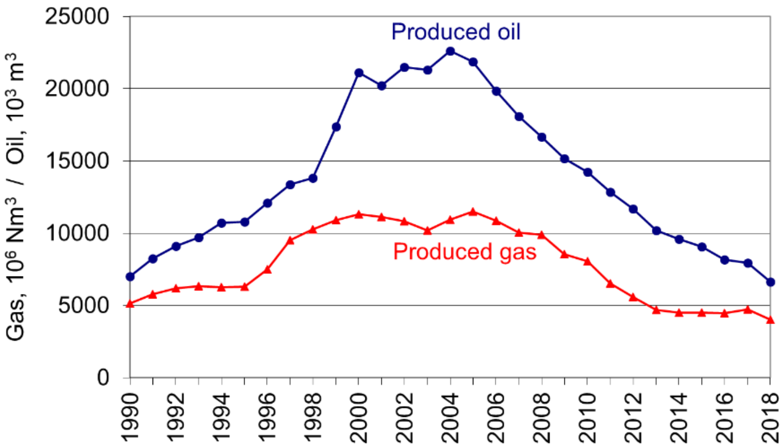


Figure 3.5.3 Production of oil and gas.

Emission factors

Standard emission factors from the 2006 IPCC Guidelines (IPCC, 2006) are used to calculate emissions from production of oil and gas (see Table 3.5.6).

Table 3.5.6 Emission factors for exploration of oil and gas.

| | $CO_2$ | $CH_4$ | Reference |
|---|---|---|---|
| Production of oil, kt/1000m$^3$ | 4.30E-08 | 5.90E-07 | IPCC 2006 |
| Production of gas, kt/Mm3 | 1.40E-05 | 3.80E-04 | IPCC 2006 |

Emissions

Calculated $CH_4$ emissions from oil and gas production are shown in Figure 3.5.4. The annual variations follow the production rates.

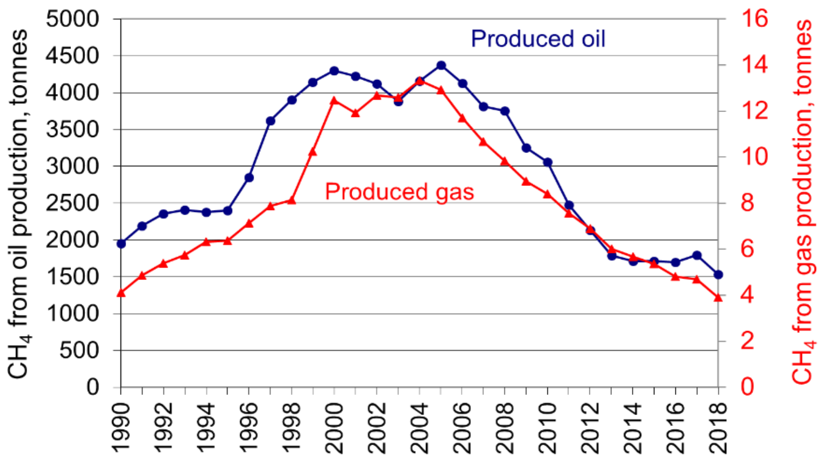


Figure 3.5.4 $CH_4$ emissions from production of oil and gas.

***Transport (1B2a3)***

Activity data

Fugitive emissions of oil transport include loading of ships from storage tanks or directly from the wells. Activity data for loading offshore and onshore are provided by the Danish Energy Agency (DEA 2019a) and from the annual self-regulating reports from Danish Oil Pipe A/S (Kold-Christensen; 2019), respectively.

The rates of oil loaded on ships roughly follow the trend of the oil production (see Figure 3.5.5). Offshore loading of ships was introduced in 1999. In earlier years, the produced oil was transported to land via pipeline.

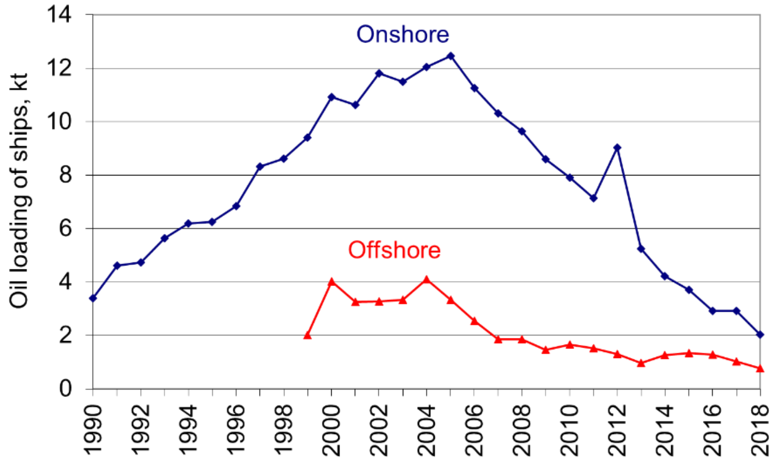


Figure 3.5.5 Onshore and offshore loading of ships.

Emission factors

The EMEP/EEA Guidebook provide standard emission factors for loading of ships onshore and offshore for different countries (EMEP/EEA, 2019). In the Danish inventory, the Norwegian emission factors are used for estimation of fugitive emissions from loading of ships onshore and offshore for the years 1990-2009. During 2009 new emission reducing technologies (degassing unit) were installed at the crude oil terminal. Measurements were carried out at the terminal before and after installation show a decrease of 21 % of the $CH_4$ emission from loading of ships (Miljøcenter Odense, 2010). The reduced emission factors used for 2010 onwards are included in Table 3.5.7.

Table 3.5.7 Emission factors for the oil terminal and for onshore and offshore loading of ships.

| Source | Pollutant | Unit | Emission factor 1990-2009 | Emission factor 2010 onwards |
|---|---|---|---|---|
| Oil terminal | $CO_2$ | kt/1000m$^3$ oil transported by pipeline | 4.9E-07 | 4.9E-07 |
| Offshore loading of ships | $CH_4$ | fraction of loaded | 5E-05 | 5E-05 |
| Onshore loading of ships | $CH_4$ | fraction of loaded | 1E-05 | 7.9E-06 |

Emissions

$CH_4$ emissions from transport of oil are shown in Figure 3.5.6.

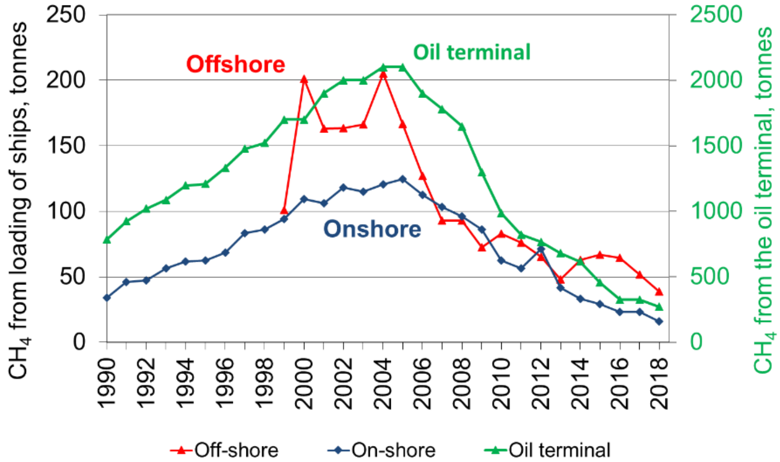


Figure 3.5.6 $CH_4$ emissions from storage at the raw oil terminal and from onshore and offshore loading of ships.

***Refining/storage (1B2a4)***

Activity data

Refining/storage include emissions from storage and handling at the oil terminal and emissions from oil refinery processes, including non-combustion emissions from handling and storage of feedstock (raw oil), from the petroleum product processing and from handling and storage of products. Emissions from flaring in refineries are included in the Section *Fugitive emissions from venting and flaring (1B2c)*. Emissions related to process furnaces in refineries are included in stationary combustion.

Annual emissions from storage and handling at the oil terminal is provided in the annual self-regulating reports from Danish Oil Pipe A/S (Kold-Christensen; 2019).

Rates of crude oil processed in the two Danish refineries are given in their annual environmental report (A/S Dansk Shell, 2019 and Equinor Refining Denmark A/S, 2019). Until 1996 a third refinery was in operation, leading to a decrease in the crude oil rate from 1996 to 1997. Activity data are shown in Figure 3.5.7.

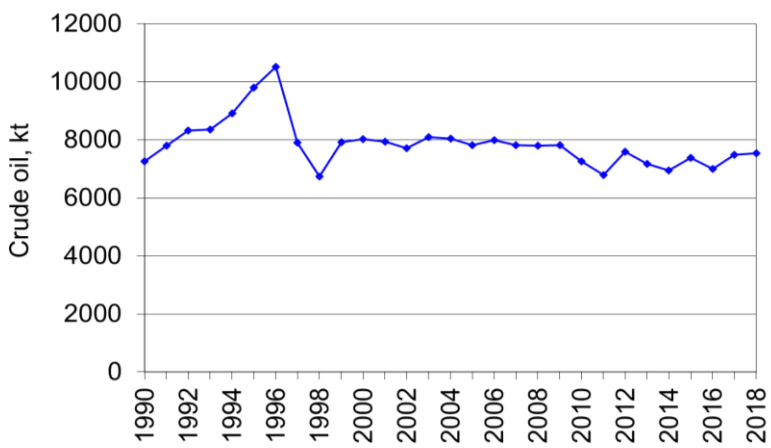


Figure 3.5.7 Crude oil processed in Danish refineries.

Emission factors

The standard $CO_2$ emission factor for oil transport from the 2006 IPCC Guidelines (IPCC, 2006) is used to calculate emissions from storage and handling at the oil terminal (Table 3.5.7).

VOC emissions are provided by the refineries. Only one of the two refineries has made a split between NMVOC and $CH_4$. For the other refinery, it is assumed that 10 % of the VOC emission is $CH_4$ (Hjerrild & Rasmussen, 2014).

Both the non-combustion processes including product processing and sulphur recovery plants emit $SO_2$. For descriptions regarding fugitive emissions of $SO_2$ and other pollutants from refining, please refer to the Danish Informative Inventory Report (Nielsen et al., 2020b).

Emissions

$CH_4$ emissions from storage at the raw oil terminal is shown in Figure 3.5.6.

Figure 3.5.8 shows $CH_4$ emissions from the Danish refineries for selected years in the time series. The increase from 2005 to 2006 owes a new measurement campaign at one refinery, which showed larger emissions than the previous. According to the environmental department at the refinery, fugitive emissions from oil processing in refineries are not correlated to any measured parameters, but are expected to follow a more random pattern. The refinery has chosen to report the latest measured emission for the years between measurement campaigns, and as no better methodology are available, the same approach is used in the national emission inventories.

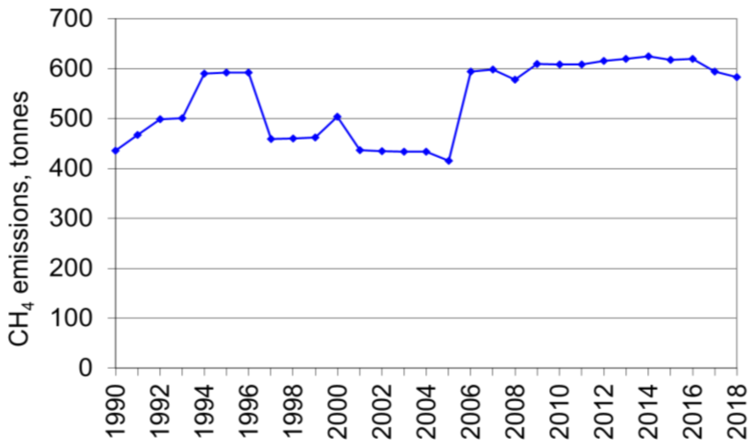


Figure 3.5.8 $CH_4$ emissions from crude oil processing in Danish refineries.

**Service stations (1B2a5)**

Fugitive emissions from service stations cover only NMVOC. For a description on methodology and data basis, please refer to the Danish Informative Inventory Report (Nielsen et al., 2020b).

**Fugitive emissions from natural gas (1B2b)**

The emissions from natural gas derive from exploration, transmission, storage and distribution. Descriptions of exploration and production of natural gas are included in the sections covering exploration and production of oil *Exploration (1B2a1, 1B2b1)* and *Production (1B2a2, 1B2b2)*.

***Exploration (1B2b1)***

See Section *Exploration (1B2a1, 1B2b1)*.

***Production (1B2b2)***

See Section *Production (1B2a2, 1B2b2)*.

#### *Transmission and storage (1B2b4)*

Activity data

The fugitive emissions from transmission and storage of natural gas are based on information from the gas transmission companies, which provide data on transported rate, pipeline losses, and length and material of the pipeline systems. The length of the transmission pipelines is approximately 900 km.

The activity data used in the calculation of the emissions from transmission of natural gas are shown in Figure 3.5.9. Transmission rates for 1990-1998 refer to annual environmental reports of DONG Energy. In 1999-2006, transmission rates refer to the Danish Gas Technology Centre (Karll 2002, Karll 2003, Karll 2004, Karll 2005, Oertenblad 2006, Oertenblad 2007). From 2008 onwards, transmission rates refer to Energinet.dk (2019b). Transmission losses for 1991-1999 are based on annual environmental report of DONG Energy. The average for 1991-1995 is applied for 1990. From 2005 onwards, transmission losses are given by Energinet.dk. The average for 2005-2010 is applied for the years 2000-2004.

The variation over the time series owes mainly to variations in the winter temperature and to the variation of import/export of electricity from Norway and Sweden. The transmission rate is less than the production rate, as part of the produced natural gas is exported through the NOGAT pipeline system.

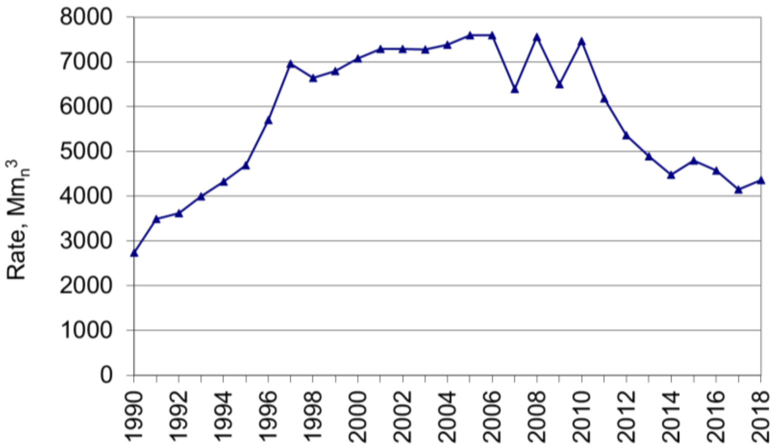


Figure 3.5.9 Rates for transmission of natural gas.

Emission factors

The fugitive emissions from transmission and storage of natural gas are based on data on gas losses from the companies and on the average annual natural gas composition given by Energinet.dk (2019c) (Table 3.5.8).

Table 3.5.8 Annual gas composition, lower heating value and density for Danish natural gas.

| | | Unit | 1990 | 2000 | 2005 | 2010 | 2015 | 2018 |
|---|---|---|---|---|---|---|---|---|
| Methane | $CH_4$ | molar-% | 90.92 | 86.97 | 88.97 | 89.95 | 88.80 | 89.59 |
| Ethane | $C_2H_6$ | molar-% | 5.08 | 6.88 | 6.14 | 5.71 | 6.08 | 5.67 |
| Propane | $C_3H_8$ | molar-% | 1.89 | 3.17 | 2.50 | 2.19 | 2.47 | 2.29 |
| i-Butane | i-$C_4H_{10}$ | molar-% | 0.36 | 0.43 | 0.40 | 0.37 | 0.39 | 0.4 |
| n-Butane | n-$C_4H_{10}$ | molar-% | 0.50 | 0.61 | 0.55 | 0.54 | 0.59 | 0.61 |
| i-Petane | i-$C_5H_{12}$ | molar-% | 0.14 | 0.11 | 0.11 | 0.13 | 0.13 | 0.15 |
| n-Petane | n-$C_5H_{12}$ | molar-% | 0.10 | 0.08 | 0.08 | 0.08 | 0.10 | 0.11 |
| n-Hexane and heavier hydrocarbons | $C^{6+}$ | molar-% | 0.09 | 0.06 | 0.05 | 0.06 | 0.05 | 0.06 |
| Nitrogen | $N_2$ | molar-% | 0.31 | 0.34 | 0.29 | 0.31 | 0.32 | 0.29 |
| Carbon dioxide | $CO_2$ | molar-% | 0.60 | 1.35 | 0.90 | 0.66 | 1.07 | 0.83 |
| Lower heating value | $H_n$ | $MJ/m^3_n$ | 39.176 | 40.154 | 39.671 | 39.461 | 39.635 | 39.586 |
| Density | ρ | $kg/m^3_n$ | 0.808 | 0.846 | 0.825 | 0.816 | 0.828 | 0.822 |

Emissions

The gas transmission company reports emissions of $CH_4$ for the years 1999 and onwards, based on registered loss in the transmission grid and the emission from the natural gas consumption in the pressure regulating stations. For the years 1991-1998, the $CH_4$ emissions for transmission are estimated based on the registered loss provided by the transmission company and the annual composition of Danish natural gas given by Energinet.dk. Transmission loss is not available for 1990, why the average for 1991-1995 is applied.

As the pipelines in Denmark are relatively new and made of plastic, most emissions are due to leaks during construction and maintenance. This leads to large annual fluctuations in emissions, which are not correlated to the transmission rates. E.g. the large emission in 1995 owe to a large construction work covering four different locations. The increase in 2011 owe to venting for drainage of the pipes in preparation for construction work on a new compressor station, and the increase in 2014 owe to the construction of a new major railway line.

Emissions of $CH_4$ from transmission of natural gas are shown in Figure 3.5.10. Emissions of $CO_2$ from transmission and storage are very limited and not included in the figure. For information on emissions of NMVOC, please refer to Chapter 3.4 in the Danish Informative Inventory Report (Nielsen et al., 2020b).

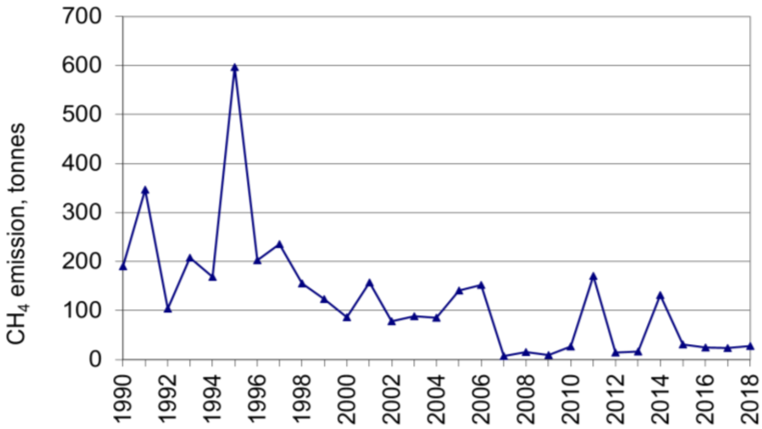


Figure 3.5.10 $CH_4$ emissions from transmission of natural gas.

### *Distribution (1B2b5)*

Activity data

Distribution rates for 1990-1998 are estimated from the Danish energy statistics. Distribution rates are assumed to equal total Danish consumption rate minus the consumption rates of sectors that receive the gas at high pressure. The following consumers are assumed to receive high-pressure gas: town gas production companies, production platforms and power plants. In 1999-2006 distribution rates refer to DONG Energy/Danish Gas Technology Centre/Danish gas distribution companies (Karll, 2002; Karll, 2003; Karll, 2004; Karll, 2005; Oertenblad, 2006; Oertenblad, 2007). Since 2007, the distribution rates are given by the companies. The fugitive losses from distribution of natural gas are only given for some companies. The average of the available "loss/distribution"-ratios is used for the remaining companies too.

Activity data for distribution of town gas are rather scarce, and calculations are based on the available data from the town gas distribution companies on losses from the pipelines. At present, there are two areas with town gas distribution and correspondingly two distribution companies. Two other companies in other areas were closed in 2004 and 2006, and it have not been possible to collect data for all years in the time series. The emissions have been calculated for the years with available data and the distribution loss for the first year with data has been applied for the previous years in the time series. Data is missing for the later years (1996-2003) for one of the distribution companies. The distribution rate is assumed to decrease linearly to cero over these years, and the share ("distribution loss/distribution rate") is assumed equal to the value for 1995.

Data on the distribution network are given by Energinet.dk, DGC and the distribution companies concerning length and material. The length of the distribution network is around 20.000 km. Because the distribution network in Denmark is relatively new, most of the pipelines are made of plastic (approximately 90 %). For this reason, the fugitive emission is negligible under normal operating conditions as the distribution system is basically tight with no fugitive losses. However, the plastic pipes are vulnerable and therefore most of the fugitive emissions from the pipes are caused by losses due to excavation damages, and construction and maintenance activities performed by the gas companies. These losses are either measured or estimated by calculation in each case by the gas companies. About 5 % of the distribution network is used for town gas. This part of the network is older and the fugitive losses are larger. The fugitive losses from this network are associated with more uncertainty as it is estimated as a percentage (15 %) of the meter differential. This assumption is based on expert judgement from one of the town gas companies (Jensen, 2008). Distribution rates are shown in Figure 3.5.11.

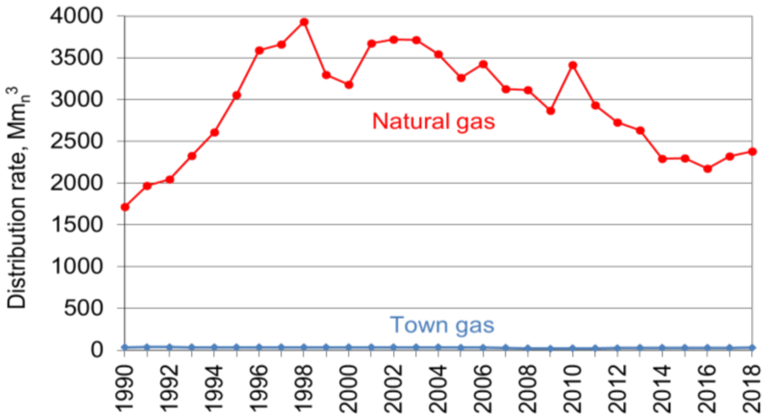


Figure 3.5.11 Distribution rates of natural gas and town gas.

Emission factors

Emissions from natural gas distribution are calculated from the fugitive losses from pipelines and the gas quality measured by Energinet.dk (see Table 3.5.8). The same approach is used for town gas, which is natural gas admixed ~ 50 % ambient air. From 2014, one town gas distribution company has started to admix biogas. In 2014, the share of biogas is 10.1 %, which is expected to increase in the coming years. The admixed biogas has not been upgraded as tests of different appliances have shown that up to 40 % non-upgraded biogas can be added to the town gas without causing problems with the appliances' combustion. The composition of biogas is given in Table 3.5.9.

Table 3.5.9 Composition of biogas admixed to town gas (Jeppesen, 2014; Ea Energianalyse, 2014).

| | | | |
|---|---|---|---|
| Methane | $CH_4$ | molar-% | 60.98 |
| Nitrogen | $N_2$ | molar-% | 0.001 |
| Carbon dioxide | $CO_2$ | molar-% | 39.02 |
| Lower heating value | $H_n$ | MJ/m$^3_n$ | 21.53 |
| Density | ρ | kg/m$^3_n$ | 0.808 |

The distribution companies provide emissions of $CH_4$ for 1997 and onwards. For the years 1995-1996, $CH_4$ emissions are calculated from the registered loss from distribution and the annual composition of Danish natural gas given by Energinet.dk. As distribution losses are not available for the years 1990-1994, the percentage loss for 1995 is used.

Emissions

Emissions of $CH_4$ from distribution of natural gas and town gas are shown in Figure 3.5.12. Emissions of $CO_2$ are very limited and not included in the figure. For information on emissions of NMVOC, please refer to Chapter 3.4 in the Danish Informative Inventory Report (Nielsen et al., 2020b).

Emissions from the natural gas network are variable and are associated with renovation to the network and excavation damages.

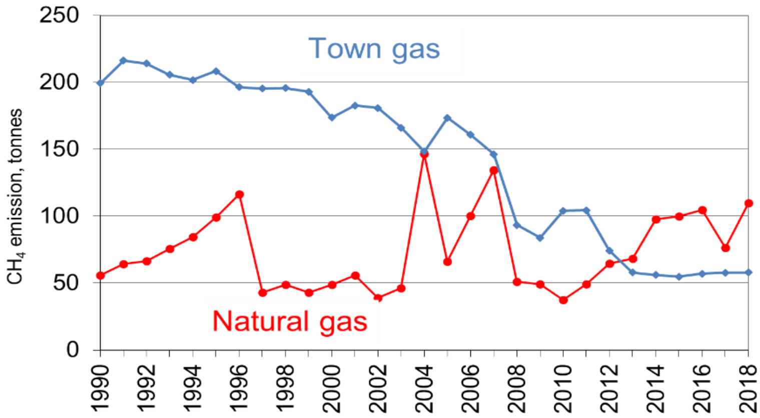

Figure 3.5.12 $CH_4$ emissions from transmission of natural gas.

**Fugitive emissions from venting and flaring (1B2c)**

Venting occur in the two Danish natural gas storage facilities. Flaring occurs in oil and gas production, in gas treatment and storage facilities, in refineries, and in gas transmission and distribution.

***Venting***

Activity data

The natural gas storage facilities are obligated to make environmental reports on an annual basis, including data on venting. Venting of gas is assumed to be not occurring in extraction and in refineries, as controlled venting enters the gas flare system. Venting rates in gas storage facilities are shown in Figure 3.4.13. Data are not available for the years 1990-1994 for the one gas storage facility that was in operation over the entire time series, and the average for 1995-1998 is applied. The second gas storage facility was opened in 1994, leading to increasing venting rates.

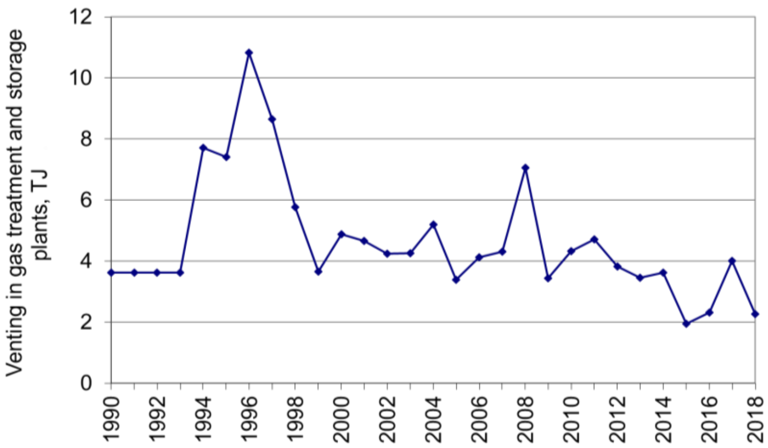

Figure 3.5.13 Venting rates in gas storage facilities.

Emission factors

Emissions of $CH_4$ and NMVOC from venting are given in the environmental reports for the gas storage facilities (Energinet.dk, 2019a; Energinet.dk, 2019a). $CO_2$ emissions from venting are calculated from country specific emission factors based on annual natural gas composition published by Energinet.dk.

Emissions

Venting is limited to the gas storage facilities and the emissions are of minor importance to the total fugitive emissions. Venting emissions are included in Figure 3.5.17.

### *Flaring*

#### Flaring in refineries

Activity data

Flaring rates for the two Danish refineries are given in their environmental reports and in additional data provided by the refineries directly to DCE. From 2006, flaring rates are given in the EU ETS reporting. Data are not available for the years 1990-1993, why the flaring rate for 1994 has been adopted for the previous years. Flaring rates are shown in Figure 3.5.14.

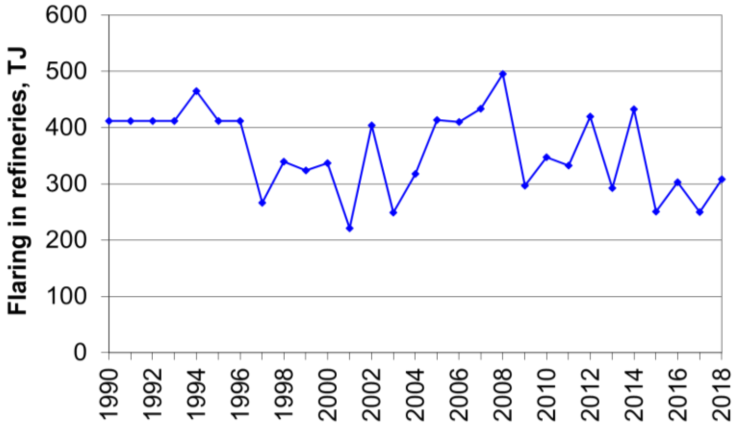


Figure 3.5.14 Flaring rates in refineries.

Emission factors

The composition of refinery gas is given for 2008 by one of the two refineries. As the composition for refinery gas is very different from the composition of natural gas, the 2008 refinery gas composition is used in calculations for both Danish refineries. The $CH_4$ and NMVOC emission factors based on the 2008 refinery gas composition are applied for both refineries for the entire time series. The $CO_2$ emission factor is based on the refineries reporting to the EU ETS from the years 2006 and onwards. Before 2006, corresponding data are not available, and the average of $CO_2$ emission factors for 2007-2011 for each refinery is applied. The emission factor applied for $N_2O$ is based on OLF (1993) for flaring in oil and gas extraction, as no value are given for flaring in refineries. The emission factors are listed in Table 3.5.10. For information on emissions of other pollutants, please refer to Chapter 3.4 in the Danish Informative Inventory Report (Nielsen et al., 2020b).

Table 3.5.10 Emission factors for flaring in refineries for 2018.

| Pollutant | Emission factor | Unit |
|---|---|---|
| $CH_4$ | 18.1 | g per GJ |
| $CO_2$ * | 58.16 / 57.20 | kg per GJ |
| $N_2O$ | 0.47 | g per GJ |

** The $CO_2$ emission factors are based on the refineries reports for EU ETS and are plant specific.

Emissions

Emissions of $CH_4$ and $CO_2$ are shown in Figure 3.5.15. The variation over the time series follow the flaring rates, with small variations for $CO_2$ from 2006 onwards, when annual plant specific $CO_2$ emission factors became available in EU ETS reporting.

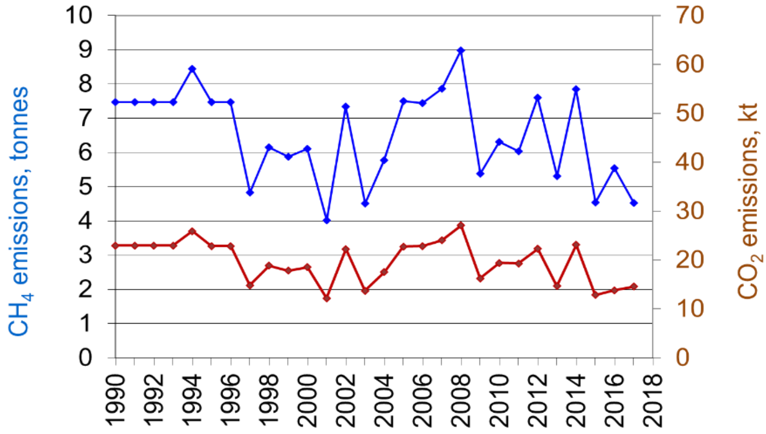


Figure 3.5.15 $CH_4$ and $CO_2$ emissions from flaring in refineries.

**Flaring in upstream oil and gas production**

Activity data

From 2006, data on flaring in upstream oil and gas production is given in the reports submitted under the EU ETS and thereby emission calculation can be made for the individual production units. Before 2006 only the total flared amount is available in the annual report Denmark's oil and gas production (Danish Energy Agency, 2019a). Flaring rates (and $CO_2$ emissions) are shown in Figure 3.5.16. Flaring rates in upstream oil and gas production have been decreasing over the last 10 years period in accordance with the decrease in production as seen in Figure 3.5.3. Further, there is focus on reducing the amount being flared for environmental reasons.

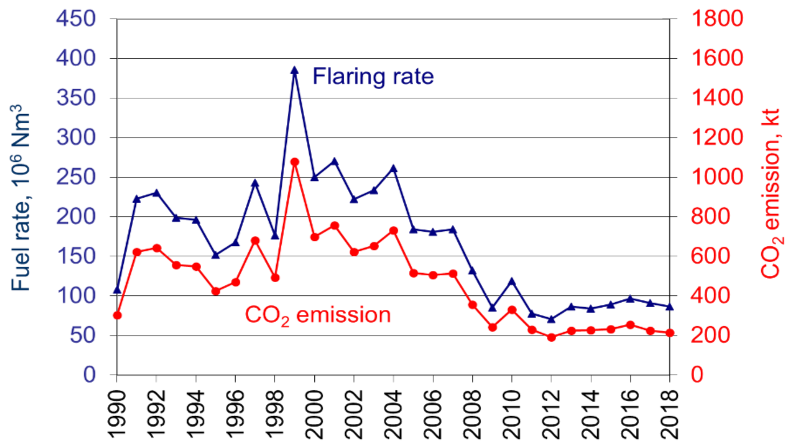


Figure 3.5.16 Fuel rate and $CO_2$ emission from flaring in upstream oil and gas production.

Emission factors

The emission factors for flaring in upstream oil and gas production are shown in Table 3.5.11. Since 2006, the $CO_2$ emission factor is calculated according to the reporting for EU ETS. As corresponding data are not available for earlier years, the average $CO_2$ EF for the years 2008-2012 is applied for the years 1990-2007. The emission factor for $CH_4$ is estimated from flare gas quality data for one offshore production platform, assuming a flare efficiency of 98 % in agreement with IPCC (2006) and API (2009). Emission factors for $N_2O$ are based on IPCC (2006). For information on emissions of other pollutants, please refer to Chapter 3.4 in the Danish Informative Inventory Report (Nielsen et al., 2020b).

Table 3.5.11 Emission factors for flaring in upstream oil and gas production for 2018.

| Pollutant | Emission factor | Unit |
|---|---|---|
| $CH_4$ | 10.56 | g per $Nm^3$ |
| $CO_2$ | 2.47 | kg per $Nm^3$ |
| $N_2O$ | 1.6 | g per $Nm^3$ |

Emissions

The time series for the emission of $CO_2$ from flaring in upstream oil and gas production fluctuates due to the fluctuations in the fuel rate and to a minor degree due to the $CO_2$ emission factor. As shown in Figure 3.5.16, there was a marked increase in the rate of flaring in upstream oil and gas production in 1997 and especially in 1999. The increase in 1997 was due to the new Dan field and the completion of the Harald field. The increase in 1999 was due to the opening of the three new fields Halfdan, Siri and Syd Arne. The $CH_4$ and $N_2O$ emissions from flaring in upstream oil and gas production are estimated from the same emission factors for all years and the variations reflect only the variations in the flared amounts. Emissions of $CH_4$ from flaring are shown in Figure 3.5.17.

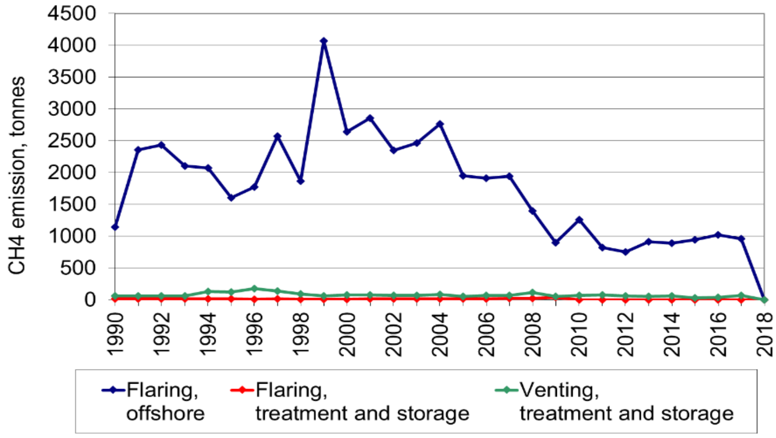


Figure 3.5.17 $CH_4$ emissions from flaring in upstream oil and gas production.

**Flaring in gas treatment and storage facilities**

Activity data

Activity data for flaring in gas treatment and storage facilities are given in DONG Energy's environmental reports (Dong Energy, 2019; Energinet.dk, 2019a). Flaring rates in gas treatment and gas storage facilities are not available before 1994. The mean value for 1994-1998 has been adopted as basis for the emission calculation for the years 1990-1993. Note that one of the two gas storage facilities was not opened before 1994. The large amount of gas flared in 2007 owe to a larger maintenance work at the gas treatment plant.

Emission factors

Emissions from flaring in gas treatment and storage facilities are calculated from the same emission factors, which are used for flaring in upstream oil and gas production, except for $CO_2$. The natural gas flared in the treatment and storage facilities are natural gas with the same composition as natural gas distributed in Denmark, and the $CO_2$ emission factors are based on the gas composition given by Energinet.dk.

Emissions

Emissions from flaring in gas treatment and storage facilities are of minor importance to the total fugitive emissions. Emissions from gas treatment and storage facilities have decreased from 2009 to 2010 due to a change from continuous to regulating power operation of the power producing gas turbine at the gas storage plant. $CH_4$ emissions are included in Figure 3.5.18. The increase in 2017 owe to increased flaring amount at the gas treatment plant.

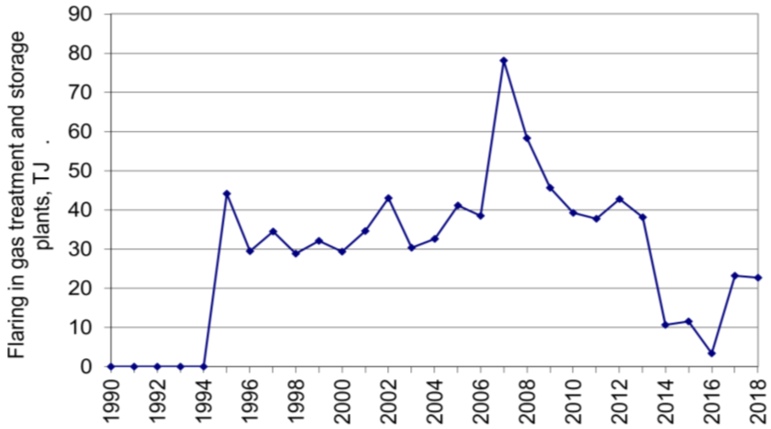


Figure 3.5.18 Flaring in gas treatment and storage facilities.

### 3.5.5 Uncertainties and time series consistency

Until 2016, two sets of uncertainty estimates were made for the Danish emission inventory for greenhouse gases based on Approach 1 and Approach 2, respectively. The uncertainty models follow the methodology in the 2006 IPCC Guidelines (IPCC, 2006). Approach 1 is based on the simplified uncertainty analysis (error propagation method) and Approach 2 is based on Monte Carlo simulations. From the 2017 submission, the Approach 2 uncertainty estimation has not been carried out due to a lack of resources.

Uncertainty estimates are made for total emissions in the latest inventory year and for the emission trend for the corresponding time series. Uncertainty estimates are made for the $CO_2$, $CH_4$ and $N_2O$ separately and summarized.

#### Input data

The Approach 1 uncertainty model is based on emission data, uncertainty levels for activity data and uncertainty levels for emission factors for base year and latest inventory year. Emission data, activity data and emission factors are described in Section *3.5.4 Activity data, emission factors and emissions for fugitive sources*.

The uncertainty levels used in the uncertainty models are based on different sources, e.g. the 2006 IPCC Guidelines, EMEP/EEA Guidebook and reports under the EU ETS. Further, a number of the uncertainty levels are given as DCE assumptions. DCE assumptions are based on source and/or plant specific uncertainty levels for part of the SNAP category and assumptions for the remaining sources and/or plants in the category.

Input data are aggregated on SNAP level. Estimates are made for the greenhouse gases $CO_2$, $CH_4$ and $N_2O$ both separately and summarized (GHG). Uncertainty levels for activity data and emission factors are listed in Table 3.5.12. Uncertainty levels are given in percentage related.

Table 3.5.12 Uncertainty levels for activity rates and emission factors.

| Pollutant | CRF category | Source | Activity data uncertainty level, % | | Emission factor uncertainty level, % | |
|---|---|---|---|---|---|---|
| $CO_2$ | 1.B.2.a.1 | Exploration | 2 | A | 10 | A |
| $CO_2$ | 1.B.2.a.2 | Production | 2 | A | 100 | I |
| $CO_2$ | 1.B.2.a.4 | Refining/storage | 2 | A | 40 | S |
| $CO_2$ | 1.B.2.b.1 | Exploration | 2 | A | 10 | A |
| $CO_2$ | 1.B.2.b.2 | Production | 2 | A | 100 | I |
| $CO_2$ | 1.B.2.b.4 | Transmission and storage | 15 | G | 2 | Q |
| $CO_2$ | 1.B.2.b.5 | Distribution | 25 | G, A | 10 | Q, A |
| $CO_2$ | 1.B.2.c.1.ii | Venting | 15 | G, A | 2 | Q |
| $CO_2$ | 1.B.2.c.2.i | Flaring, oil | 11 | E | 2 | E |
| $CO_2$ | 1.B.2.c.2.ii | Flaring, gas | 7.5 | E | 2 | E |
| $CO_2$ | 1.B.2.c.2.iii | Flaring, combined | 7.5 | E | 2 | E |
| $CH_4$ | 1.B.2.a.1 | Exploration | 2 | A | 125 | A |
| $CH_4$ | 1.B.2.a.2 | Production | 2 | A | 100 | I |
| $CH_4$ | 1.B.2.a.3 | Transport | 2 | A | 100 | I |
| $CH_4$ | 1.B.2.a.4 | Refining/storage | 1 | E, A | 200 | A |
| $CH_4$ | 1.B.2.b.1 | Exploration | 2 | A | 125 | A |
| $CH_4$ | 1.B.2.b.2 | Production | 2 | A | 100 | I |
| $CH_4$ | 1.B.2.b.4 | Transmission and storage | 15 | G | 2 | Q |
| $CH_4$ | 1.B.2.b.5 | Distribution | 25 | G, A | 10 | Q, A |
| $CH_4$ | 1.B.2.c.1.ii | Venting | 15 | G, A | 2 | Q |
| $CH_4$ | 1.B.2.c.2.i | Flaring, oil | 11 | E | 15 | H, A |
| $CH_4$ | 1.B.2.c.2.ii | Flaring, gas | 7.5 | E | 2 | A |
| $CH_4$ | 1.B.2.c.2.iii | Flaring, combined | 7.5 | E | 125 | I |
| $N_2O$ | 1.B.2.a.1 | Exploration, oil | 2 | A | 1000 | A |
| $N_2O$ | 1.B.2.c.2.i | Flaring, oil | 11 | E | 1000 | I |
| $N_2O$ | 1.B.2.c.2.ii | Flaring, gas | 7.5 | E | 1000 | I |
| $N_2O$ | 1.B.2.c.2.iii | Flaring, combined | 7.5 | E | 1000 | I |

A: DCE assumption.
I: IPCC 2006 Guidelines (default value).
S: Statistisk Sentralbyrå, Statistics Norway, 2008.
E: EU Emission Trading Scheme (EU ETS).
H: Holst, 2009 and Statoil A/S, 2010.
Q: Annual gas quality, Energinet.dk.

The $CO_2$ emission factors for flaring in upstream oil and gas production and in refineries and the $CO_2$ and $CH_4$ emission factors for natural gas transmission, distribution and venting, are the most accurate as they are calculated on basis of gas composition measurements. Emissions factors for flare gas are available in the EU ETS reporting while emissions factors for natural gas are published by Energinet.dk.

The calculation of $CO_2$ emissions from exploration of oil and gas is based on information on oil and gas quality for most drillings. As the uncertainty levels of the measurements are not available, the double of the uncertainty for flaring in oil and gas extraction (before EU ETS standards) has been used.

The $CO_2$ emission factor for extraction of oil and gas is based on standard emission factors from IPCC (2006) and the corresponding uncertainties of 100 % are applied in the uncertainty analysis.

The uncertainty level for the emission factor for fugitive $CH_4$ emissions from refineries is dominated by a large uncertainty for one refinery. Further, measurements of fugitive emissions from the refineries are only available for one and two years, respectively, and these measurements indicate larger emissions than earlier estimates. As more measurements become available, the uncertainty level is expected to decrease.

The emission factors for loading of ships are given as quality C in EMEP/EEA (2019), corresponding an uncertainty level of 50-200 %. The lower level is assumed the most plausible for Danish conditions.

For onshore activities, the emission factor uncertainty corresponds to the uncertainty for onshore loading by Statistics Norway (2008), and the same uncertainty level is assumed for the $CH_4$ emission factor for onshore activities.

According to IPCC (2006) the emission factor for $N_2O$ is the least reliable, and the uncertainty interval for the $N_2O$ emission factors given for flaring in oil and gas production is -10 % to +1 000 %. An uncertainty level of 1 000 % is adopted in the Danish uncertainty model for all fugitive sources in the Danish inventory (exploration and flaring of oil and gas).

**Results**

The results of the Approach 1 uncertainty model for 2018 are shown in Table 3.5.13. $N_2O$ has the largest uncertainty for both the total emission and the trend followed by $CH_4$ and $CO_2$. The estimated uncertainty for the total GHG emission is 117 % and the GHG emission trend is -31 % ±12 %-point.

Table 3.5.13 Uncertainty estimates for total emissions and emission trends from the Approach 1 uncertainty model.

| | 1990 emission, kt $CO_2$ eqv | 2017 emission, kt $CO_2$ eqv | Uncertainty, % lower and upper (±) | Trend 1990-2017, % | Uncertainty, % lower and upper (±) |
|---|---|---|---|---|---|
| $CO_2$ | 341 | 232 | 7 | -32 | 7 |
| $CH_4$ | 123 | 90 | 71 | -27 | 4 |
| $N_2O$ | 53 | 41 | 999 | -22 | 30 |
| GHG | 517 | 364 | 115 | -30 | 11 |

### 3.5.6 Source specific QA/QC and verification

The elaboration of a formal QA/QC plan started in 2004 and was updated in 2013 (Nielsen et al., 2013) and latest in 2020 (Nielsen et al., 2020a). The plan describes the concepts of quality work and definitions of sufficient quality, Critical Control Points (CCP) and a list of Points of Measuring (PM) (Figure 3.5.20). Please refer to the general Section *1.6 Information on QA/QC plan including verification and treatment of confidential issues where relevant* for further information.

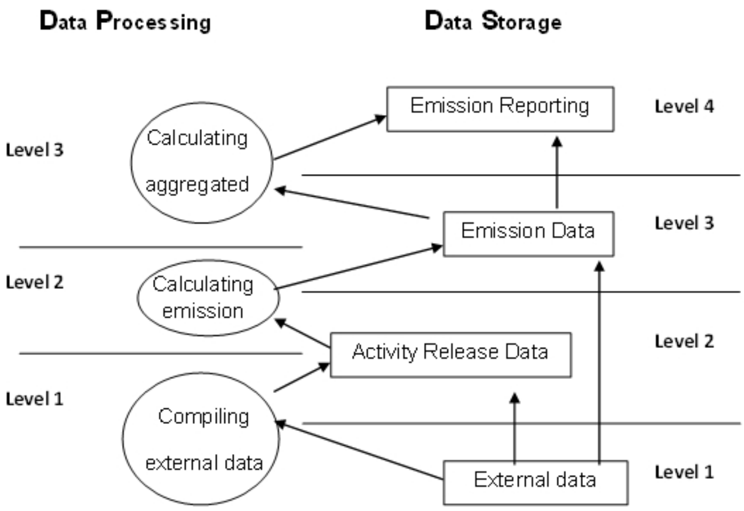


Figure 3.5.20 The general data structure for the Danish emission inventory (Nielsen et al., 2013).

### Data storage level 1

Data storage level 1 refers to the data collected by DCE before any processing or preparing. Table 3.5.15 lists the external data deliveries used for the inventory of fugitive emissions. Further, the table holds information on the contacts at the data delivery companies.

Table 3.5.15 List of external data sources.

| Category | Data description | Activity data, emission factors or emissions | Reference | Contact(s) | Data agreement /comment |
|---|---|---|---|---|---|
| Exploration of oil and gas | Dataset for exploration of oil and gas, including rates and composition. | Activity data | The Danish Energy Agency | Kirsten Lundt Erichsen | Data agreement |
| Production of oil and gas | Gas and oil production. Dataset, including rates of offshore loading of ships. | Activity data | The Danish Energy Agency | Kirsten Lundt Erichsen | Not necessary due to obligation by law |
| Offshore flaring | Flaring in upstream oil and gas production (EU ETS data) | Activity data | The Danish Energy Agency | Dorte Maimann | Data agreement |
| Service stations | Data on gasoline sales from the Danish energy statistics. | Activity data | The Danish Energy Agency | Jane Rusbjerg | Data agreement |
| Gas transmission | Natural gas transmission rates from the transmission company, sales and losses. | Activity data | Energinet.dk | Tine Lindgren | Not necessary due to obligation by law |
| Onshore activities | Rates of oil transport in pipeline and onshore loading to ships. Emissions from storage of raw oil in the terminal. | Activity data and emission data | Ørsted | Mette Kold-Christensen | No formal data agreement. |
| Gas distribution | Natural gas and town gas distribution rates from the distribution company, sales and losses (meter differences) | Activity data | Dong Energy / Dansk gasdistribution | Marianne Ødum | No formal data agreement. |
| Emissions from refinery | Fuel consumption and emission data. | Activity data and emission data | Equinor Refining Denmark A/S,<br><br>A/S Danish Shell | Anette Holst,<br><br>Trine Bjerre Kristiansen | No formal data agreement. |
| Treatment and storage of gas | Environmental reports from plants defined as large point sources (Lille Torup, Stenlille, Nybro) | Activity data | Various plants | | Not necessary due to obligation by law |
| $CO_2$ emission factors for different sources | Reports according to the $CO_2$ emission trading scheme (EU ETS) | Activity data | Various plants | | Not necessary due to obligation by law |
| Emission factors | Emission factors origin from a large number of sources | Emission factors | See Section *3.5.4 Activity data, emission factors and emissions for fugitive sources* regarding emission factors | | |

The following lists the CCPs and the PMs in the Danish QA/QC plan, relevant for the emission inventory for the fugitive sector.

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Storage level 1 | 1. Accuracy | DS.1.1.1 | General level of uncertainty for every dataset including the reasoning for the specific values. |

The uncertainty for every dataset included in the inventory of fugitive emissions are evaluated and included in the Tier 1 uncertainty calculations with short descriptions of the reasoning behind the specific values. The general levels of uncertainty are relatively low. The largest uncertainties are expected for emissions from refineries and distribution of town gas, the latter being of minor importance to the total fugitive emissions. For further comments regarding uncertainties, see Section *3.5.5 Uncertainties and time series consistency*.

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Storage level 1 | 2.Comparability | DS.1.2.1 | Comparability of the emission factors/calculation parameters with data from international guidelines, and evaluation of major discrepancies. |

Systematic inter-country comparison has only been made on Data Storage Level 4. Refer to DS.4.3.2 in Section *1.6 Information on QA/QC plan including verification and treatment of confidential issues where relevant*.

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Storage level 1 | 3.Completeness | DS.1.3.1 | Ensuring that the best possible national data for all sources are included, by setting down the reasoning behind the selection of datasets. |

External data include energy statistics from the Danish Energy Agency, EU ETS reports and annual environmental reports from a number of plants and companies. Further, supplementary information are gathered annually from some companies. Only one national data set is found for most fugitive sources, and all data sets are expected to be complete and include all activities/emissions form the sources. Data on flaring in upstream oil and gas production, in refineries and in gas treatment and storage facilities are available both in annual environmental reports and in EU ETS reports. Data are compared and if any differences occur, this is checked with the data suppliers. Minor differences may owe to the allocation of fuels, e.g. if pilot gas are included in the flare gas or the fuel gas rate.

Energy statistics

The Danish Energy Agency reports fuel consumption statistics on the SNAP level based on a correspondence table developed in co-operation with DCE. Both traded and non-traded fuels are included in the Danish energy statistics. Data on production and flaring in upstream oil and gas production, and gasoline sales are used for estimation of fugitive emissions.

Environmental reports

A large number of plants are obligated by law to publish an environmental report annually with information on e.g. fuel consumption and emissions. DCE compares data with those from previous years, discrepancies are checked, and large fluctuations are verified.

Annual reports

The gas distribution companies and the raw oil terminal are not obligated to publish environmental reports. Instead, the self-regulation reports, annual reports and/or additional information are used. All information is compared with data for previous years.

Reports for the European Union Greenhouse Gas Emission Trading System (EU ETS)

$CO_2$ emission factors for offshore in upstream oil and gas production and in refineries are taken from the EU ETS reports since 2006, when the EU ETS reports became available. EU ETS reports are available individually for the Danish oil/gas production fields and refineries.

Emission factors from a wide range of sources

For specific references, see Section *3.5.4 Activity data, emission factors and emissions for fugitive sources*.

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Storage level 1 | 4.Consistency | DS.1.4.1 | The original external data has to be archived with proper reference. |

All external data are stored in the inventory file system and are accessible for all inventory staff members. Data processing is carried out in separate spread sheets to ensure that the external data are always available in the original form. Data sources are referenced in the spread sheets. Refer to Section *1.3. Brief description of the process of inventory preparation. Data collection and processing, data storage and Archiving*.

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Storage level 1 | 6.Robustness | DS.1.6.1 | Explicit agreements between the external institution holding the data and DCE about the conditions of delivery |

Formal agreements are made with the Danish Energy Agency. Annual environmental reports are available due to legal requirements. The remaining data are published or delivered by the companies on voluntary basis. See Table. 3.5.15.

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Storage level 1 | 7.Transparency | DS.1.7.1 | Listing of all archived datasets and external contacts. |

See DS 1.3.1 and Table 3.5.15.

### Data Processing Level 1

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Processing level 1 | 1. Accuracy | DP.1.1.1 | Uncertainty assessment for every data source not part of DS.1.1.1 as input to Data Storage level 2 in relation to type and scale of variability. |

Refer to Section *1.7 General uncertainty evaluation, including data on the overall uncertainty for the inventory totals* in the Danish NIR and Section *3.5.6 Source specific QA/QC and verification*.

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Processing level 1 | 2.Comparability | DP.1.2.1 | The methodologies have to follow the international guidelines suggested by UNFCCC and IPCC. |

The methodologies in the inventory follow the principles in international guidelines by UNFCCC and IPCC.

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Processing level 1 | 3.Completeness | DP.1.3.1 | Identification of data gaps with regard to data sources that could improve quantitative knowledge. |

Data gaps are found for distribution of town gas, as more companies are closed before this source was included in the Danish inventory. Emissions, which account for only a limited part of the total fugitive emissions, are calculated on a scarce data foundation. Also further information regarding VOC emissions from refineries would be preferred, but are not available. DCE continue the collaboration with the refineries update the methodology and emission estimates if new information become available.

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Processing level 1 | 4.Consistency | DP.1.4.1 | Documentation and reasoning of methodological changes during the time series and the qualitative assessment of the impact on time series consistency. |

Since 2006, the EU ETS data have been available for a number of sources. In all cases, the new data replace use of data assumed to be less accurate. Therefore, the $CO_2$ emission factors have been updated for all years, and no methodological change occur in the time series.

A change in the calculating procedure would entail elaboration of an updated description in Section *3.5.4 Activity data, emission factors and emissions for fugitive sources*.

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Processing level 1 | 5.Correctness | DP.1.5.2 | Verification of calculation results using time series |

Time series for activity data, emission factors and/or emissions on SNAP level are used to identify possible errors in the calculation procedure.

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Processing level 1 | 5.Correctness | DP.1.5.3 | Verification of calculation results using other measures |

For fugitive sources, only one data set is available for calculation, and no verification using other measures are possible. For sources where activity data is available in more data sources (e.g. in both EU ETS and annual reports), data are compared and reasons for any differences are clarified.

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Processing level 1 | 7.Transparency | DP.1.7.1 | The calculation principle, the equations used and the assumptions made must be described. |

Descriptions are included in the NIR in Section *3.5.4 Activity data, emission factors and emissions for fugitive sources*.

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Processing level 1 | 7.Transparency | DP.1.7.2 | Clear reference to dataset at Data Storage level 1 |

Notes on data sources are included in the calculation files for all input data.

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Processing level 1 | 7.Transparency | DP.1.7.3 | A manual log to collect information about recalculations. |

A log holding information on recalculations are included in the national inventory system. Further, a log is prepared annually holding information on status of the inventory work and recalculations for each source in the fugitive sector.

### Data storage level 2

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Storage level 2 | 5.Correctness | DS.2.5.1 | Check if a correct data import to level 2 has been made |

To ensure a correct connection between data on level 2 to data on level 1, different controls are in place, e.g. control of sums and random tests.

### Data storage level 4

| Level | CCP | PM | Description |
|---|---|---|---|
| Data Storage level 4 | 4.Consistency | DS.4.4.3 | The IEFs from the CRF are checked both regarding level and trend. The level is compared to relevant emission factors to ensure correctness. Large dips/jumps in the time series are explained. |

Time series for IEFs are checked to identify large fluctuations, which are afterwards investigated and explained. The level of the IEFs are compared to other relevant EFs, e.g. in standard EFs in guidebooks and guidelines.

### Other QC procedures

A list of QA/QC tasks are performed directly in relation to the fugitive emission part of the Danish emission inventories. The following procedures are carried out to ensure the data quality:

- The emission from the large point sources (refineries, gas treatment and gas storage facilities) is compared with the emission reported the previous year.
- Annual environmental reports are kept for subsequent control of plant-specific emission data.
- Checks of data transfer are incorporated in the fugitive emission models, e.g. sum checks.
- Verification of activity data from external data when data are available through more data sources (production and flaring rates in upstream oil and gas production).
- Data sources are incorporated in the fugitive emission models
- A manual log table in the emission databases is applied to collect information about recalculations.
- Comparison with the inventory of the previous year. Any major changes are verified.
- Total emission, when aggregated to reporting tables, is compared with totals based on SNAP source categories (control of data transfer).
- Checking of time series in the CRF and SNAP source categories. Significant dips and jumps are controlled and explained.

#### *External review*

In 2015, a documentation report for the sector “Fugitive emissions from fuels” was published, including detailed information on the methodology used in the emission inventories for greenhouse gases and air pollution (Plejdrup et al., 2015). The report was reviewed by Glen Thistlethwaite from Ricardo Energy & Environment, Oxfordshire, UK

### 3.5.7 Recalculations

No recalculations have been made for the fugitive sector that influence the greenhouse emissions for the time series.

### 3.5.8 Source specific planned improvements

Measurements of emissions from onshore loading of ships at the oil terminal/Shell harbour terminal was planned in 2018, but was postponed due to problems getting all four pumps to work properly and simultaneously. The measurements were carried out in 2019 but the results were not available for DCE in due time for the 2020 reporting. DCE – Aarhus University will assess the results when available to verify and, if necessary, to update the emission factors for onshore loading. Further, it will be evaluated if the allocation between raw oil terminal, the harbour terminal, and the refinery is accurate or if new information and measurements give rise to modify the emission estimations.

DCE – Aarhus University has continually been in dialogue with the operator and the regulatory authority to obtain further information. However, it is more complicated as the measurements originally were carried out with the specific purpose of establishing the efficiency of abatement. A further challenge is to ensure correct allocation of emissions between the raw oil terminal, the harbour terminal and the Shell refinery, as they are all located in the same area, and as Shell operates the harbour terminal from which raw oil is loaded to ships.

### 3.5.9 References

A/S Dansk Shell, 2019: Annual environmental report.

API, 2009: Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry. American Petroleum Institute.

Danish Energy Agency, 2019a: Data for oil and gas production in Denmark. Reports for earlier years available at: https://ens.dk/en/our-responsibilities/oil-gas/reports-oil-and-gas-activities (07-01-2020).

Danish Energy Agency, 2019b: The Danish energy statistics (Energistatistik) (in Danish). Available at: https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics (07-01-2020).

DONG Energy, 2019: Annual environmental reports from DONG Energy for Nybro gas treatment plant (in Danish).

Ea Energianalyse, 2014: Anvendelse af biogas i naturgas i København (in Danish).

EMEP/EEA, 2019: Air emission inventory guidebook, prepared by the UNECE/EMEP Task Force on Emission Inventories and Projections, 2016 update. Available at:
https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (07-01-2020).

Energinet.dk, 2019a: Data for Lille Torup and Stenlille gas storage facilities. Personal communication with Christian Guldager Corydon (25/9 2019).

Energinet.dk, 2019b: Data for gas loss and flaring in gas transmission. Personal communication with Tine Lindgren (11/10 2019).

Energinet.dk, 2019c: Annual gas quality. Available at:
https://en.energinet.dk/Gas/Gas-Quality/Yearly-Average-Gas-Quality (07-01-2020).

Equinor Refining Denmark A/S, 2018: Sustainability report (in Danish). Available at: https://www.equinor.com/en/how-and-why/sustainability/sustainability-reports.html (07-01-2020).

Erichsen, 2019: Personal communication, e-mail correspondence 31/10 2019, Danish Energy Agency.

EU Commission, 2018: COMMISSION IMPLEMENTING REGULATION on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 601/2012. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R2066&from=EN

Fenhann, J. & Kilde, N.A. 1994: Inventory of Emissions to the Air from Danish Sources 1972-1992. Risø National Laboratory, Roskilde, Denmark.

Hjerrild and Rasmussen, 2014: Fugitive VOC from refineries.

Holst, A. 2009: Personal communication, e-mail 18-11-2009, Statoil A/S.

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at:
http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (07-01-2020).

Jensen, 2008: Town gas distribution loss. Documentation for expert judgement.

Jeppesen, 2014: Biogas i bygas – biogasrense- og bygasproduktionsanlæg. Presentation at Gastekniske data 14/05/2014 (in Danish).

Karll, B. 2002: Personal communication, e-mail 2002, Danish Gas Technology Centre.

Karll, B. 2003: Personal communication, e-mail 2003, Danish Gas Technology Centre.

Karll, B. 2004: Personal communication, e-mail 2004, Danish Gas Technology Centre.

Karll, B. 2005: Personal communication, e-mail 2005, Danish Gas Technology Centre.

Kold-Christensen, 2019: Personal communication, e-mail correspondence 28/10 2019, Orsted.

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Gyldenkærne, S., Thomsen, M., Nielsen, M. Mikkelsen, M.H., Albrektsen, R., Hjelgaard, K., & Bruun, H.G. 2020a. Quality manual for the Danish greenhouse gas inventory. Version 3. Aarhus University, DCE – Danish Centre for Environment and Energy. (In press).

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Mikkelsen, M.H., Nielsen, M., Gyldenkærne, S., Fauser, P., Albrektsen, R., Hjelgaard, K., Bruun, H.G. & Thomsen, M. 2020b. Annual Danish Informative Inventory Report to UNECE. Emission inventories from the base year of the protocols to year 2019. Aarhus University, DCE – Danish Centre for Environment and Energy. (In press)

Oertenblad, M. 2006: Personal communication, e-mail 2006, Danish Gas Technology Centre.

Oertenblad, M. 2007: Personal communication, e-mail 2007, Danish Gas Technology Centre.

Statistisk Sentralbyrå, Statistics Norway, 2008: The Norwegian Emission Inventory 2008. Documentation of methodologies for estimating emissions of greenhouse gases and long-range transboundary air pollutants. 252 pp. Reports 2008/48. Available at:
http://www.ssb.no/english/subjects/01/sa_nrm/nrm2008/sa109.pdf
(07-01-2020).

Statoil A/S, 2010: Ubestemtheden på massestrømmen ved blændemåling og ultralyd. Report in Danish.

The Norwegian Oil industry Association, OLF environmental program. Phase II. Summary report. 1993.

# 4 Industrial Processes and Product Use

## 4.1 Overview of the sector

The *Industrial Processes and Product Use* (IPPU) sector covers greenhouse gases (GHG) from industrial processes not related to generation of energy along with emissions from product use. The IPPU sector consists of the following CRF source categories:

- 2A Mineral Industry
- 2B Chemical Industry
- 2C Metal Industry
- 2D Non-Energy Products from Fuels and Solvent Use
- 2E Electronics Industry
- 2F Product Uses as Substitutes for Ozone Depleting Substances (ODS)
- 2G Other Product Manufacture and Use

The data presented in Chapter 4 relate to Denmark only, whereas information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 7.

For a more detailed description of the methods used and the verifications performed, please refer to the sectoral method report Hjelgaard & Nielsen (2018).

### 4.1.1 Methodology overview

Table 4.1.1 gives a brief overview over methodologies applied for the IPPU sector. Further description of the applied methodologies can be found in the following chapters.

Table 4.1.1 Overview of methodologies used for the 2018 data (or the latest active year for activities that have ceased).

| IPCC code | Process | Substance | Tier | EF | Key category 1990/2018/ trend |
|---|---|---|---|---|---|
| 2A1 | Cement production* | $CO_2$ | T3 | PS | Yes/Yes/Yes |
| 2A2 | Lime production | $CO_2$ | T2 | PS/CS | No/No/No |
| 2A3 | Glass production | $CO_2$ | T3 | PS | No/No/No |
| 2A4a | Ceramics | $CO_2$ | T3 | CS | No/No/No |
| 2A4b | Other uses of soda ash | $CO_2$ | T3 | D | No/No/No |
| 2A4d | Other process uses of carbonates | $CO_2$ | CS/T3 | D | No/No/No |
| 2B2 | Nitric acid production | $N_2O$ | T2 | PS | Yes/No/Yes |
| 2B10 | Catalyst production | $CO_2$ | T2 | PS | No/No/No |
| 2C1 | Iron and steel production* | $CO_2$ | T1 | CS, D | No/No/No |
| 2C4 | Magnesium production | $SF_6$ | T2 | D | No/No/No |
| 2C5 | Secondary lead production | $CO_2$ | T1 | D | No/No/No |
| 2D1 | Lubricant use | $CO_2$ | T1 | D | No/No/No |
| 2D2 | Paraffin wax use | $CO_2$, $N_2O$, $CH_4$ | T2 | OTH/D | No/No/No |
| 2D3 | Paint application | $CO_2$ | CS/T2 | CS | No/No/No |
| 2D3 | Degreasing, dry cleaning and electronics | $CO_2$ | CS/T2 | CS | No/No/No |
| 2D3 | Chemical products manufacturing or processing | $CO_2$ | CS/T2 | CS | No/No/No |
| 2D3 | Other use of solvents and related activities | $CO_2$ | CS/T2 | CS | No/No/No |
| 2D3 | Road paving with asphalt | $CO_2$, $CH_4$ | T2 | OTH | No/No/No |
| 2D3 | Asphalt roofing | $CO_2$ | T2 | OTH | No/No/No |
| 2D3 | Urea-based catalysts | $CO_2$ | T3 | D | No/No/No |
| 2E5 | Other electronics industry | HFCs, PCFs | T2 | D | No/No/No |
| 2F1 | Refrigeration and air conditioning | HFCs, PFCs | T2 | D/CS | No/Yes/Yes |
| 2F2 | Foam blowing agents | HFCs | T2 | D | Yes/No/Yes |
| 2F4 | Aerosols | HFCs | T2 | D | No/No/No |
| 2F5 | Solvents | PFCs | T2 | D | No/No/No |
| 2G1 | Electrical equipment | $SF_6$ | T3 | D | No/No/No |
| 2G2 | $SF_6$ and PFCs from other product use | $SF_6$ | T2 | D | No/No/No |
| 2G3a | Medical application | $N_2O$ | T1 | D | No/No/No |
| 2G3b | Propellant for pressure and aerosol products | $N_2O$ | T1 | D | No/No/No |
| 2G4 | Other product uses | $CO_2$, $CH_4$, $N_2O$ | T2 | D/CS/OTH | No/No/No |

* The methodology used for this category varies over the time series, see Table 4.1.2.

Table 4.1.2 Overview of implemented methodologies for categories where the methodology varies over the time series.

| Process | Years | Available activity data | Available emission factors | Resulting methodology |
|---|---|---|---|---|
| 2A1 Cement production | 1990-1997 | Production of white cement and production of three types of grey clinker. | Plant specific factors for the three individual grey clinker types and for white cement. | Tier 1/PS |
| | 1998-2018 | Consumption of raw materials. | Plant specific measured carbonate content of raw materials. | Tier 3/PS |
| 2A4a Ceramics | 1990-2005 | Estimated $CaCO_3$ eqv data based on national statistics | Country specific | Tier 2/CS |
| | 2006-2018 | Plant specific data on carbonate consumption | Country specific | Tier 3/CS |
| 2A4d Other process uses of carbonates | 1990-2005 | Estimated $CaCO_3$ data based on total produced flue gas cleaning residue | Default | Tier 2/D |
| | 2006-2018 | Plant specific data on carbonate consumption | Default | Tier 3/D |
| 2C1 Iron and steel production | 1990-1992, 2005 | Extrapolation, interpolation, expert judgement | Expert judgement | Tier 1/CS,D |
| | 1993-2001 | Environmental reports | Environmental reports | Tier 2/CS,D |

### 4.1.2 Key categories

A Key Category Analysis (KCA) for the years 1990 and 2018 as well as for the trend has been carried out. The result for the IPPU sector is shown in Table 4.1.3. A detailed KCA is presented in Chapter 1.5 and Annex 1. The calculations are based on national emissions including LULUCF but excluding Greenland and the Faroe Islands.

The analysis is carried out using both Approach 1 and Approach 2 methods. Four categories are identified as key categories in IPPU in this submission, all four for both level and trend.

Table 4.1.3 Key Category Analysis for Industrial Processes and Product Use.

| IPCC code | Process | Substance | Approach 1 1990 | Approach 1 2018 | Approach 1 1990-2018 | Approach 2 1990 | Approach 2 2018 | Approach 2 1990-2018 |
|---|---|---|---|---|---|---|---|---|
| 2A1 | Cement production | $CO_2$ | Level | Level | Trend | | | |
| 2B2 | Nitric acid production | $N_2O$ | Level | | Trend | Level | | Trend |
| 2F1 | Refrigeration and air conditioning | HFCs | | Level | Trend | | Level | Trend |
| 2F2 | Foam blowing agents | HFCs | | | Trend | Level | | Trend |

Only source categories identified as key categories are presented in Table 4.1.3, for a full overview of the source categories included in this inventory please refer to Table 4.1.1.

### 4.1.3 Emission overview

An overview of the five most significant sources in 2018 is presented in Table 4.1.4; these five source categories comprise more than 90 % of emissions in $CO_2$ equivalents ($CO_2$ eqv) from IPPU. The table below also gives an indication of the contribution to the total emission of greenhouse gases in 2018 in the IPPU sector.

Table 4.1.4 Overview of the largest sources to greenhouse gas emissions in the IPPU sector in 2018.

| Process | IPCC Code | Substance | Emission kt $CO_2$ eqv | %* |
|---|---|---|---|---|
| Cement production | 2A1 | $CO_2$ | 1160 | 56.7 |
| Refrigeration and air conditioning | 2F1 | HFCs, PFCs | 474 | 23.2 |
| Other uses of carbonates | 2A4 | $CO_2$ | 91 | 4.5 |
| Solvent use | 2D3 | $CO_2$, $CH_4$ | 71 | 3.5 |
| $SF_6$ from other product uses | 2G2 | $SF_6$ | 60 | 2.9 |
| Total of five largest sources | | | 1856 | 90.8 |

*of total $CO_2$ equivalent emissions from the IPPU sector.

For 2018, the subsector Mineral Industry (2A) constitutes 64 % of the GHG emissions from the IPPU sector and Product Uses as Substitutes for ODS (2F) constitutes 24 %. Non-Energy Products from Fuels and Solvent Use (2D) and Other Product Manufacture and Use (2G) constitutes 8 and 5 % respectively, while Chemical Industry (2B), Metal production (2C) and Electronics Industry (2E) together constitutes below 0.1 %. The total emission of greenhouse gases (excl. LULUCF) in Denmark in 2018 is estimated to 47.6 Mt $CO_2$ equivalents of which IPPU contribute with 2.0 Mt $CO_2$ equivalents (4.3 %). The emissions of GHG from IPPU from 1990-2018 are presented in Figure 4.1.1.

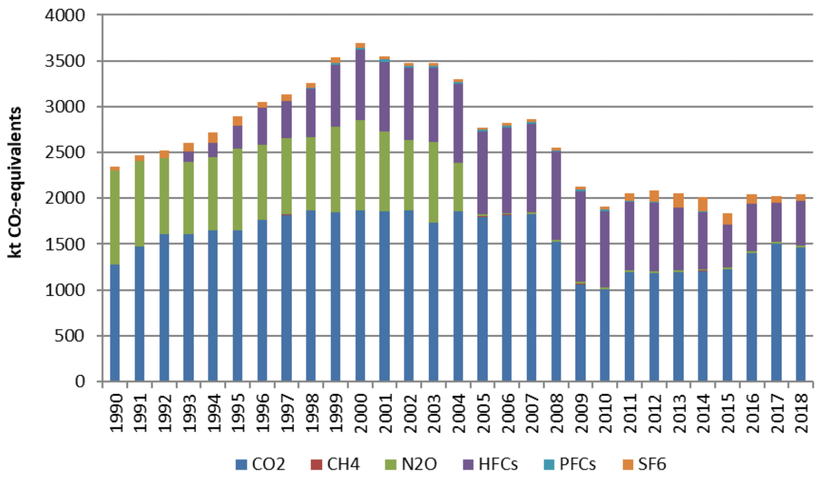


Figure 4.1.1 Emission of individual- and total greenhouse gases from IPPU (CRF Sector 2) from 1990-2018.

The majority of $CO_2$ emissions in the IPPU sector are emitted from the cement production, the small drop in $CO_2$ emissions in 2003 and the larger decrease in 2008-2010 are caused by a lower production of cement for these years. The production of nitric acid closed down during 2004 causing the $N_2O$ emission to drop drastically; from 764-1020 kt $CO_2$ equivalents in 1990-2003 to 16-22 kt $CO_2$ equivalents in 2005-2018. The use of HFCs in mainly refrigeration and air conditioning has increased significantly during the time series but is decreasing in recent years. HFC emissions peaked in 2009 with 989 kt $CO_2$ equivalents, but has decreased to 487 kt $CO_2$ equivalents in 2018.

### 4.1.4 EU-ETS (EU Emission Trading Scheme)

Guidelines for calculating company specific $CO_2$ emissions are developed by the EU (EU Commission, 2018). The guidelines present standard methods for minor companies and methods for developing individual plans for major companies. The standard methods include default emission factors similar to the default emission factors presented by IPCC (e.g. for limestone), whereas, the major companies have to use individual methods to determine the actual composition of raw materials (e.g. purity of limestone or Ca per tonne ratio in dolomite) or the actual $CO_2$ emission from the specific process. Where data from the EU-ETS are used more detail is provided on the specific methodologies used in the specific chapter. This is the case in the following categories:

- Cement production
- Lime production
- Glass production
- Ceramics
- Flue gas desulphurisation
- Stone wool production

## 4.2 Mineral Industry

### 4.2.1 Source category description

The sector *Mineral Industry* (CRF 2A) covers the following industries relevant for the Danish air emission inventory:

- 2A1 Cement production (SNAP 040612); see section 4.2.3.
- 2A2 Lime production (SNAP 040614); see section 4.2.4.

- 2A3 Glass production (SNAP 040613); see section 4.2.5.
- 2A4a Ceramics (SNAP 040691, 040692); see section 4.2.6.
- 2A4b Other uses of soda ash (SNAP 040619); see section 4.2.7.
- 2A4d Flue gas desulphurisation (SNAP 040618); see section 4.2.8.
- 2A4d Stone wool production (SNAP 040618); see section 4.2.9.

Cement production is identified as key category according to Approach 1 for level in 1990 and 2018 and for trend; see *Annex 1: Key Category Analyses*.

### 4.2.2 Emissions

Total greenhouse gas emissions from the Mineral Industry sector are available in the CRF Table 10. The emission time series for the source categories within *Mineral Industry* (2A) are presented in Figure 4.2.1 and individually in the sub-sections below (Sections 4.2.3 – 4.2.9). The following figure gives an overview of how much the individual source categories contribute throughout the time series.

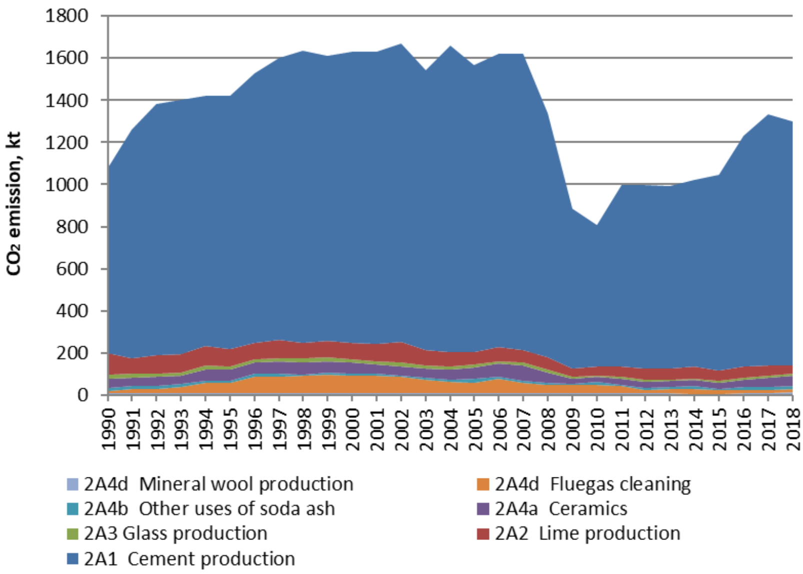


Figure 4.2.1 Emission of $CO_2$ from the individual source categories compiling *2A Mineral Industry*, kt.

Greenhouse gas emissions from *Mineral Industry* are made up mostly by $CO_2$ emissions from the production of cement; min. 82 % (1990) to max. 90 % (2017).

Emissions from *Mineral Industry* increased with 54 % from 1990 to the time series peak in 2002 (2002 emission: 1670 kt $CO_2$). The overall development in the $CO_2$ emission for 1990 to 2018 shows an increase from 1082 kt $CO_2$ to 1298 kt $CO_2$, i.e. 20 %.

The increase from 1990 to 1997 can be explained by the increase in the annual cement production. The emission factor has only changed slightly as the distribution between types of cement especially grey/white cement has been almost constant from 1990-1997. The increase in emissions from 2010-2017 may be explained by an increase in the construction activity after the financial crisis in 2008-2010.

### 4.2.3 Cement production

The production of cement in Denmark is concentrated at one company: Aalborg Portland A/S situated in Aalborg. The following SNAP-code is covered:

- 04 06 12 Cement (decarbonising)

Emissions associated with fuel combustion in cement kilns are estimated and reported in the energy sector. Only emissions related to the calcination of non-fuel feedstock to cement kilns are reported under category 2A.

#### Methodology

Process emissions are released from the calcination of raw materials (primarily chalk and sand). The overall process for calcination is:

$$CaCO_3 \rightarrow CaO + CO_2$$

The primary raw materials are sand, chalk and water and the main products are grey cement, white cement and cement clinker for sale.

Aalborg Portland uses a semi-dry process. The first step is production of raw meal. The chalk slurry and the grounded sand are mixed as slurry that is injected into a drier crusher. The raw materials are converted into raw meal that releases carbon dioxide ($CO_2$) in the calciner.

In a rotary kiln the material is burned to clinker that afterwards is grounded to cement in the cement mill. During the process, cement kiln dust is recirculated.

The emission of $CO_2$ depends on the ratio: white/grey cement and the ratio between the three types of clinker used for grey cement: GKL-clinker/FKH-clinker/SKL-RKL-clinker.

For 1990-1997, the ratio white/grey cement and the ratio GKL-clinker/FKH-clinker/SKL-RKL-clinker is known. White cement peaked in 1990 and decreased thereafter. The production of SKL/RKL-clinker peaks in 1991 and decreases hereafter. FKH-clinker is introduced in 1992 and increases to a share of 35 % in 1997. The $CO_2$ emission is calculated according to the following equation:

$$M_{CO_2} = M_{grey} * \frac{M_{GLK} * EF_{GLK} + M_{FKH} * EF_{FKH} + M_{SKL/RKL} * EF_{SKL/RKL}}{M_{GLK} + M_{FKH} + M_{SKL/RKL}} + M_{white} * EF_{white}$$

| | | |
|---|---|---|
| $M_{grey}$ | Grey cement | t |
| $M_{white}$ | White cement | t |
| $M_{GLK}$ | GKL clinker (rapid cement) | t |
| $M_{FKH}$ | FKH clinker (basis cement) | t |
| $M_{SKL/RKL}$ | SKL/RKL clinker (low alkali cement) | t |
| $EF_{white}$ | $CO_2$ emission factor | t/t white cement |
| $EF_{GLK}$ | $CO_2$ emission factor | t/t GLK clinker |
| $EF_{FKH}$ | $CO_2$ emission factor | t/t FKH clinker |
| $EF_{SKL/RKL}$ | $CO_2$ emission factor | t/t SKL/RKL clinker |

The company has at the same time stated that data until 1997 cannot be improved as there are no further information available. Data for white cement is therefore used as an estimate for white clinker making the methodology used for the years 1990-1997 a Tier 1.

From 1998-2004 carbonate content of the raw materials has been determined by loss on ignition methodology. Determination of loss on ignition takes into account all the potential raw materials leading to release of $CO_2$ based on full oxidation and omits the Ca-sources leading to generation of CaO in cement clinker without $CO_2$ release. The applied methodology is in accordance with EU guidelines on calculation of $CO_2$ emissions (Aalborg Portland, 2008). Clinker data are available.

From the year 2005 the $CO_2$ emission determined by Aalborg Portland, independently verified and reported under the EU-ETS (EU Emission Trading Scheme) is used in the inventory (Aalborg Portland, 2019a). The reporting to EU-ETS also provides detailed information of alternative fuels used in the production of clinker and the amount of clinker produced.

#### EU-ETS data for cement production

Cement production applies the Tier 3 methodology for calculating the $CO_2$ emission for 1998-2018.

The implied $CO_2$ emission factor for Aalborg Portland is plant specific and based on the reporting to the EU-ETS. The EU-ETS data have been applied for the years 2006 – 2018.

The $CO_2$ emission for cement production is based on measurements of the consumption of calcium carbonate to the calcination process. These measurements fulfil a Tier 3 methodology (± 1.6 %) as defined in the EU decision (EU Commission, 2018). The emission factor is based on continuous measurements with flow meters, density meters, X-ray and CaO analysis. (Aalborg Portland, 2013b).

#### Activity data

Activity data for cement (measured in total cement equivalents (TCE)) and clinker production are presented in Table 4.2.1 and Annex 3C-1. Emissions are based on clinker production alone, cement production data are used for verification.

Table 4.2.1 Production statistics for cement and clinker production, kt (Aalborg Portland, 2008, 2013a, 2019a, b).

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| kt TCE | 1620 | 2274 | 2613 | 2706 | 1454 | 1902 | 2202 | 2416 | 2360 |
| kt clinker[1] | 1406 | 2353 | 2452 | 2521 | 1314 | 1715 | 1973 | 2170 | 2141 |

[1] 1990-1997: Clinker production is estimated as grey clinker plus white cement (Aalborg Portland, 2008).

#### Emission factors

The calculated implied emission factors (IEF) for cement production are presented in Table 4.2.2 and Annex 3C-2.

Table 4.2.2 Implied emission factors for $CO_2$ for cement production.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| IEF t $CO_2$ per t TCE[1,2,3] | 0.545 | 0.529 | 0.530 | 0.504 | 0.462 | 0.490 | 0.497 | 0.494 | 0.491 |
| IEF t $CO_2$ per t clinker[3,4] | 0.628 | 0.512 | 0.565 | 0.541 | 0.512 | 0.543 | 0.555 | 0.550 | 0.542 |

[1] 1990-1997: IEF based on information provided by Aalborg Portland (2005).

[2] 1998-2004: IEF based on information provided by Aalborg Portland (2008).

[3] 2005-2018: IEF based on emissions reported to EU-ETS (Aalborg Portland, 2019a).

[4] 1998-2018: IEF based on clinker production statistics provided by Aalborg Portland (2019b).

The IEF for $CO_2$ from the calcination process is expressed per tonne of cement or clinker and depends on the actual input of chalk/limestone in the process. The IEF will therefore vary as the allocation of different cement/clinker types produced varies. When the implied $CO_2$ emission factor in 1990 is markedly higher than for the remaining time series it is because the production of white cement was higher in 1990 than for the following years, leading the ratio white/grey cement to be higher for 1990. The share of white cement decreases significantly through the early part of the 1990s causing the IEF to decrease as well. In 1990, 25 % of all cement produced was white cement; in 1991-1997 that same share fluctuates around 21 % (20 % in 1992 to 22 % in 1995). As presented in Table 4.2.3, emission factors are higher for white cement than for grey cement products resulting in a higher IEF for 1990.

Table 4.2.3 Emission factors used for 1990-1997 (Aalborg Portland, 2008).

| Product | Value | Unit |
|---|---|---|
| White cement | 0.669 | t $CO_2$/t white cement |
| GLK clinker | 0.477 | t $CO_2$/t GLK grey clinker |
| FKH clinker | 0.459 | t $CO_2$/t FKH grey clinker |
| SKL/RKL clinker | 0.610 | t $CO_2$/t SKL/RKL grey clinker |

For the entire time series, the emission factor (carbon content) has been estimated from the loss on ignition determined for the different kinds of clinkers produced (1990-1997) or different raw materials used (1998-2018). Determination of loss on ignition means that there is no need to consider uncalcined cement kiln dust (CKD) not recycled to the kiln; further detail is given above under methodology.

The company reporting to the EU-ETS applies the following emission factors for the most important raw materials used in 2018, similar data are available back to 2006 (Aalborg Portland 2019a) and to a less detailed degree back to 1998 (Aalborg Portland, 2019b).

Table 4.2.4 Emission factors for some of the raw materials used in 2018 (Aalborg Portland, 2019a).

| Raw material | t $CO_2$ per t raw material |
|---|---|
| Limestone | 0.44 |
| Magnesium carbonate | 0.522 |
| Sand | 0.007-0.030 |
| Fly ash | 0.145 |
| Oxiton | 0.027 |
| CKD | 0.05-0.33 |

The emission factors for limestone and magnesium carbonate are in accordance with the stoichiometric factors and the emission factors for the remaining raw materials and CKD are determined by individual yearly analysis.

**Emission trends**

The emission trend for the $CO_2$ emission from cement production is available in Annex 3C-3 and is also presented in Figure 4.2.2 below.

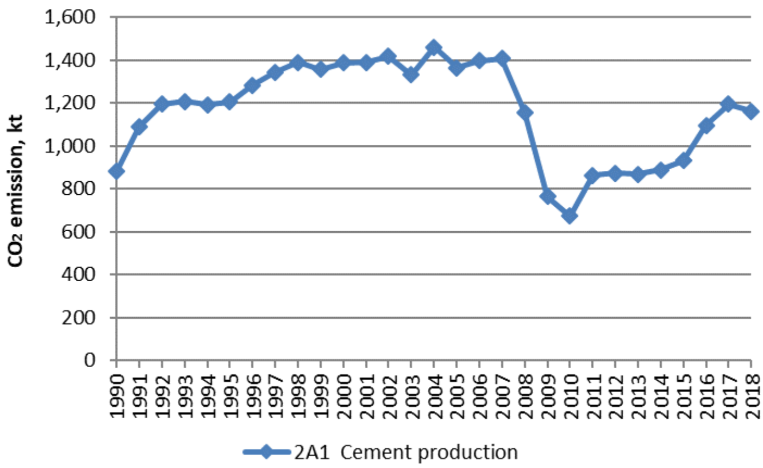

Figure 4.2.2 Emission of $CO_2$ from cement production.

The increase in $CO_2$ emission from the production of cement from 1990 to 1997 can be explained by the increase in the annual cement production. The most significant change to occur in the time series is the significant decline in emission from 2007-2010, the decrease is due to reduced production resulting from the economic recession caused by the global financial crisis. The emissions increased 78 % in 2010-2017, but the emissions are still below the pre-recession levels. However, the overall development in the $CO_2$ emission from 1990 to 2018 is an increase from 882 to 1160 kt $CO_2$, i.e. by 31.4 %. The maximum emission occurred in 2004 and constituted 1 459 kt $CO_2$.

**Time series consistency and completeness**

Since Denmark only has one cement factory, all data collected from the production are plant specific data.

For 1990-1997, activity data for grey cement production fulfil the Tier 2 methodology while activity data for white cement (20-25 % of mass produced) only fulfil the Tier 1 methodology (IPCC, 2006). The company has informed that data until 1997 cannot be improved as there is no further information available. Since 1998, the determination of activity data for cement production has met the requirements of the Tier 3 methodology.

Emission factors have for the entire time series been determined by analysed loss on ignition which fulfil the requirements of the Tier 3 methodology.

Due to extensive verification, the methodology is believed to be consistent. For the various verifications performed, please refer to the IPPU sector report Hjelgaard & Nielsen (2018).

The inventory on cement production is considered complete in accordance with IPCC (2006) as the sole producer of cement in Denmark is fully included.

### 4.2.4 Lime production

The production of limestone ($CaCO_3$) and lime/burned lime/quicklime (CaO) is located at a few localities: Faxe Kalk (Lhoist group) situated in Faxe, Scandinavian Calcium Oxide ApS situated in Støvring, Dankalk A/S situated in Løgstør with limestone quarries/limeworks in Aggersund, Mjels, Poulstrup and Batum. In addition to the marketed lime production is the lime production related to production of sugar. Sugar production is concentrated at one company: Nordic Sugar (previously Danisco Sugar A/S) located in Assens (closed since 2007), Nakskov and Nykøbing Falster. The following SNAP-code is covered:

- 04 06 14 Lime (decarbonising)

Emissions associated with the fuel use are estimated and reported in the energy sector.

#### Methodology

Calculation of $CO_2$ emissions from oxidation of carbonates follows the general process:

$$CaCO_3 + heat \rightarrow CaO + CO_2$$

The emission of $CO_2$ results from heating of the carbonates in the lime-kiln. The lime-kilns can be located either at the location for limestone extraction or at the location for use of burned lime.

The $CO_2$ emission from the production of marketed burnt lime has been estimated from the annual production figures registered by Statistics Denmark, and emission factors. Since 2006, point source data for Faxe Kalk have been applied, but the total production always sums up to the national statistics. Plant specific activity data for marketed lime from Faxe Kalk are available from EU-ETS since 2006. Faxe Kalk constitutes 36-83% (59 % in average) of the Danish activity in 2006-2018. The plant specific activity data are available back to 1995 from the environmental reports but these are not applied as a point source. Different smaller productions account for the remaining production of marketed lime in Denmark.

Since 2006, process $CO_2$ emissions from Faxe Kalk have been calculated by the company and reported to EU-ETS and since 2008 Faxe Kalk has measured and included the content of tonnes $CO_3$ in the process emissions reported to EU-ETS. For the sake of consistency, the same method has been applied for the entire time series and for all producers, i.e. assuming the same $CaCO_3/MgCO_3$ ratio as the measured average from Faxe Kalk in 2007-2013.

Limestone consumption data for production of sugar are available from the company's environmental reports (Nordic Sugar, 2019; Nordic Sugar Nykøbing, 2010; Nordic Sugar Nakskov, 2012; Danisco Sugar Assens, 2007) back to 1996 and sugar sales statistics are available from Statistics Denmark (2019) for the entire time series. Limestone consumption data are used when available and national sugar sales statistics are used as surrogate data for the remaining years (1990-1995). Raw material consumption data are for 1990-2006 only given in amount of limestone, these data and calculated into amount of burnt lime (CaO) equivalents using the stoichiometric relation between $CaCO_3/CaO$ and the 2007-2013 average measured $CaCO_3$ content in limestone of 11.62 % (Nordic Sugar Nakskov, 2012 and Nordic Sugar, 2019).

#### EU-ETS data for lime production

The applied methodology for Faxe Kalk is specified in the individual monitoring plan that is approved by Danish authorities (DEA) prior to the reporting of the emissions. Lime production applies the Tier 2 methodology for the activity data (uncertainty ± 1.0 %) and Tier 3 for the emission factor.

The implied $CO_2$ emission factor for Faxe Kalk is plant specific and based on the reporting to the EU Emission Trading Scheme (EU-ETS). The EU-ETS data have been applied for the years 2006 – 2018.

The $CO_2$ emission for lime production is based on sales (± 1.0 %) and measurements of the CaO and MgO contents in the product (annual averages of weekly measurements) (Faxe Kalk, 2013a).

### Activity data

The production data for burnt lime are presented in Table 4.2.5 and Annex 3C-4.

Table 4.2.5 Production of burnt lime, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| From Faxe Kalk[1] | - | 46.3 | 62.5 | 57.3 | 25.6 | 30.1 | 37.7 | 31.3 | 29.3 |
| From other producers[2] | - | 54.4 | 29.5 | 13.9 | 24.8 | 33.4 | 31.1 | 31.1 | 15.8 |
| From sugar production[3] | 5.8 | 5.1 | 5.8 | 4.7 | 2.0 | 0.7 | 1.5 | 1.9 | 1.3 |
| Total lime production | 133.8 | 105.9 | 97.8 | 75.9 | 52.4 | 64.2 | 70.4 | 64.2 | 46.4 |

[1] Faxe Kalk (2013b and 2019).
[2] Non-ETS producers of marketed lime, calculated as national statistics data minus Faxe Kalk.
[3] Data from the sugar factories.

### Emission factors

The emission factor for calcination of both marketed and non-marketed calcium carbonate is based on measurements from Faxe Kalk in 2008-2012; the emission factor applied is 0.788 kg $CO_2$ per kg CaO, Faxe Kalk (2019). These measurements include a small impurity of MgO. It is assumed that the degree of calcination is 100 % and that no lime kiln dust (LKD) emits from the process.

The total implied emission factor will vary as the measured emission factor for Faxe Kalk fluctuates between 0.787 kg $CO_2$ per kg CaO (2017) and 0.796 kg $CO_2$ per kg CaO (2018).

### Emission trends

The trend for the $CO_2$ emission from lime production, including sugar production; is available in Annex 3C-5 and Figure 4.2.3.

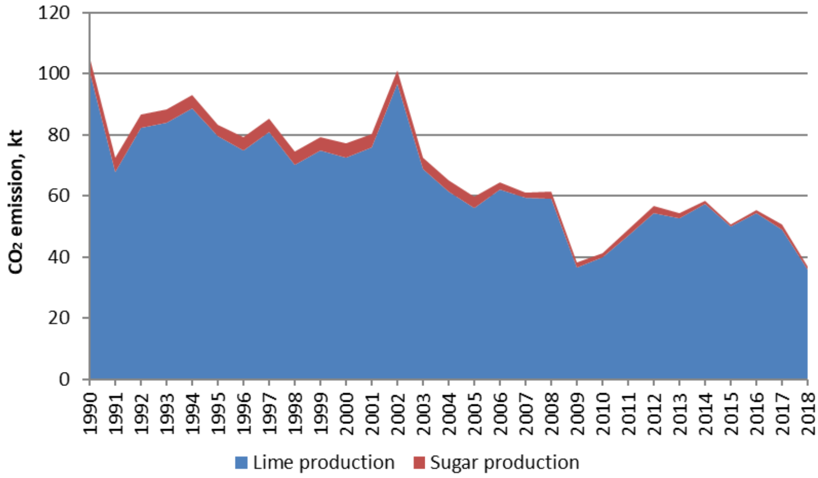


Figure 4.2.3 Emission of $CO_2$ from lime production.

The emission from sugar production only comprise 1 % (2015) to 6 % (1991) of the total $CO_2$ emission from lime production; 4 % in average over the time series.

The activity data are based on the official statistics from Statistics Denmark and there is no immediate explanation to the peak in 2002. There are very few producers in Denmark and therefore it will not be possible to obtain more detailed information from Statistics Denmark.

#### Time series consistency and completeness

The chosen methodology, activity data and emission factor for calculation of $CO_2$ emissions from marketed lime are consistent throughout the time series.

All though the activity data for non-marketed lime production at the sugar factories are based on actual carbonate consumption from 1996 onward and on estimated consumptions for 1990-1995, the methodology and applied emission factor are both considered to be consistent.

With regards to completeness concerning production of other lime products than burnt lime, dolomitic lime is not produced in Denmark and the production of hydrated lime (slaked lime) from burnt lime does not emit any greenhouse gasses. All burnt lime that is later slaked is included in the statistical data on which the calculations are based, and adding the production of slaked lime to the activity data would therefore result in double counting.

Other industries that typically use lime as an intermediate product are chemical-, metal-, production for emissions abatement etc., these industries have been investigated with respect to completing this source but nothing was found. Regarding industries producing lime as intermediate products only one was identified (i.e. Nordic Sugar). Denmark has virtually no chemical or metal industry, so the need for lime in the Danish industry is non-existing with the exception of the sources listed, and the sector must therefore be complete.

For verification, please refer to Hjelgaard & Nielsen (2018).

### 4.2.5 Glass production

Glass production in Denmark includes production of:

- Container glass
- Industrial art glass
- Glass wool

The production of container glass for packaging is concentrated at one company; Ardagh Glass Holmegaard A/S (previously Rexam Glass Holmegaard A/S), and the production of art industrial glass products is concentrated at Holmegaard A/S, both companies are situated in Fensmark, Næstved. Saint-Gobain Isover situated in Vamdrup is the only Danish producer of glass wool. The following SNAP-code is covered:

- 04 06 13 Glass (decarbonising)

Emissions associated with the fuel use are estimated and reported in the energy sector.

#### Methodology

For the production of both container glass, art glass and glass wool, the main raw materials are soda ash ($Na_2CO_3$), dolomite ($CaMg(CO_3)_2$), limestone

($CaCO_3$) and recycled glass (cullets). Emissions are calculated for each carbonate raw material individually.

Information on consumption of carbon containing raw materials in container- and art glass production is available from the environmental reports for 1997-2013 (Ardagh, 2014) and from EU-ETS since 2006 (Ardagh, 2019). For the years prior to 1997 the production of glass is based on information contained in Illerup et al. (1999). Only one industrial art glass producer with virgin glass production exists in Denmark; Holmegaard A/S. Emissions from this production is included in the data on container glass.

Information on consumption of carbon containing raw materials in glass wool production is available from the environmental reports of the plant for 1996-2014 (Saint-Gobain Isover, 2015) and from EU-ETS since 2006 (Saint-Gobain Isover, 2019). For the years prior to 1996 the production of glass wool and consumption of carbonates are estimated.

#### EU-ETS data for glass production

The applied methodologies for Ardagh Glass Holmegaard and Saint-Gobain Isover are specified in the individual monitoring plan that is approved by Danish authorities (DEA) prior to the reporting of the emissions.

Glass production applies the Tier 3 for both methodology and emission factors as the calculations are based on individual carbonates used as raw materials.

The $CO_2$ emission from container/art glass production is based on consumption of carbonate raw materials (based on invoices and corrected for changes in inventory by measures on the storage silos; Tier 2: 1.10-1.37% depending on the silo) and standard emission factors except for dolomite where Ca/Mg analysis are performed for each new batch (Ardagh, 2012).

The $CO_2$ emission from glass wool production is based on weight measures of carbonate raw materials (Tier 1: ±2.5%) and standard emission factors (Saint-Gobain Isover, 2012).

#### Activity data

The activity data for container/art glass production are presented in Table 4.2.6 and Annex 3C-6.

Table 4.2.6 Production of container/art glass, activity data, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Production of glass[1, 2] | 164.0 | 140.0 | 183.3 | 168.2 | 172.9 | 155.7 | 167.1 | 149.5 | 156.2 |
| Consumption of soda ash[3, 4] | 17.8 | 15.2 | 16.4 | 13.0 | c | c | c | c | c |
| Consumption of limestone[3,4] | 14.4 | 12.3 | 7.7 | 5.7 | c | c | c | c | c |
| Consumption of dolomite[3,4] | 1.0 | 0.8 | 9.1 | 6.1 | c | c | c | c | c |

[1] 1990-1997: Illerup et al. (1999).
[2] 1998-2016: Estimated based on Illerup et al. (1999) and consumption of raw materials.
[3] 1990-1996: Estimated based on Illerup et al. (1999) and the consumption of raw materials in 1997.
[4] 1997-2017: Environmental reports and EU-ETS data; Ardagh (2014, 2019).
c Confidential: data from EU-ETS (Ardagh, 2019).

The activity data for glass wool production are presented in Table 4.2.7 and Annex 3C-7.

Table 4.2.7 Production of glass wool, activity data, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Production of glass wool[1] | 35.6 | 35.6 | 39.7 | 37.3 | 24.9 | 33.0 | 35.5 | 38.3 | 43.5 |
| Consumption of soda ash[2, 4] | 3.6 | 3.6 | 3.0 | 3.6 | c | c | c | c | c |
| Consumption of limestone[2, 4] | 0.8 | 0.8 | 0.2 | 0.6 | c | c | c | c | c |
| Consumption of dolomite[3] | 1.0 | 1.0 | 1.0 | 1.0 | c | c | c | c | c |

[1] 1990-1996: Estimated: Assumed constant on the average production from 1997-1999.
[2] 1990-1995: Estimated: Assumed constant on the average consumption from 1996-1998.
[3] 1990-2005: Estimated: Assumed constant on the average consumption from 2006-2008.
[4] 1996-2005: Environmental reports (Saint-Gobain Isover, 2015).
c Confidential: data from EU-ETS (Saint-Gobain Isover, 2019).

### Emission factors

The $CO_2$ emission factors from using soda ash and other carbonate containing raw materials in production of virgin glass and glass wool, based on stoichiometric relationships, are:

- 0.41492 t $CO_2$/t $Na_2CO_3$
- 0.43971 t $CO_2$/t $CaCO_3$
- 0.473-0.517 t $CO_2$/t $CaMg(CO_3)_2$

The emission factor for dolomite is 0.478 tonnes $CO_2$ per tonne for glass wool production and 0.506 tonnes $CO_2$ per tonne for container/art glass production in 2018. The average emission factor for dolomite in container glass production is 0.495 tonnes $CO_2$ per tonne dolomite for 2008-2018. The calcination of all carbonates in all years is assumed to be 100 %.

From 2006 onward the $CO_2$ emissions are calculated by the companies and reported to EU-ETS (Ardagh, 2019; Saint-Gobain Isover, 2019), but the applied emission factors remain the same for the entire time series.

### Emission trends

For the years from 2006 onward, where EU-ETS data are applied, information is confidential and therefore not presented individually for container/art glass and glass wool production.

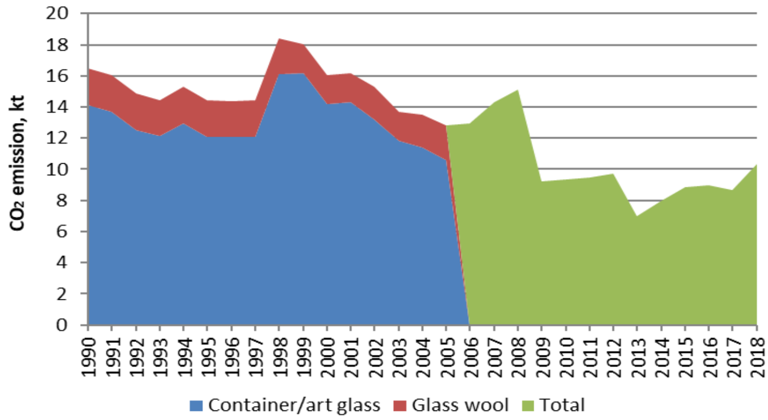


Figure 4.2.4 $CO_2$ emissions from glass and glass wool production.

### Time series consistency and completeness

$CO_2$ emissions from container/art glass and glass wool production are calculated based on consumption of carbonates and stoichiometric emission factors for the entire time series, the time series is therefore consistent.

In relation to completeness, the production of flat glass (SNAP 03 03 14 Flat glass) does not occur in Denmark. The processes in Denmark are limited to mounting of sealed glazing units. The mounting process does not contribute to greenhouse gas emissions in Denmark.

An effort has been made to ensure that all glass producers are included in the inventory. Smaller facilities producing art glass do exist in Denmark, but none of these were found to produce their own virgin glass. The source category of glass production is therefore considered to be complete.

For verification, please refer to Hjelgaard & Nielsen (2018).

### 4.2.6 Ceramics

This section covers production of bricks, tiles (aggregates or bricks/blocks for construction) and expanded clay products for different purposes (aggregates as absorbent for chemicals, cat litter, and for other miscellaneous purposes). The following SNAP codes are covered:

- 04 06 91 Production of bricks
- 04 06 92 Production of expanded clay products

The production of bricks (and tiles) is found all over the country, where clay is available. Producers of expanded clay products are located in the northern part of Jutland.

Emissions associated with the fuel use are estimated and reported in the energy sector.

#### Methodology

Emission of $CO_2$ is related to the content of carbon bearing material in the clay. The emission estimation is based on the total carbon content of the raw material. Since 2006, the producers of ceramics have measured and reported process $CO_2$ emissions to EU-ETS and production statistics are known from Statistics Denmark (2019) for the entire time series. From these two datasets, implied emission factors are calculated for 2006-2013 and emissions are calculated for the years back to 1990.

#### EU-ETS data for ceramics

The applied methodologies for brickworks and expanded clay producers are specified in the individual monitoring plans that are approved by Danish authorities (DEA) prior to the reporting of the emissions. The production of ceramics applies the ETS Tier 2 methodology for calculating the $CO_2$ emission.

The $CO_2$ emission for ceramics production is based on measured carbonate content in all raw materials and consumption of the individual carbonate containing raw materials (Tier 2; ± 5.0 %). The implied $CO_2$ emission factors for the production facilities are based on stoichiometry and 100 % calcination is assumed.

#### Activity data

National statistics on bricks, tiles and expanded clay contain a broad range of different products, most of them in units of numbers (no.). The consumption of limestone is therefore used as activity data for these source categories; available for 2006-2018 and calculated for 1990-2005. The national statistics are used as surrogate data; available for 1985-2018. Data on consumption of lime and produced amounts of ceramics are presented in Table 4.2.8 and Annex 3C-8.

Table 4.2.8 Statistics for production of bricks/tiles and expanded clay products.

| | | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Bricks and tiles** | | | | | | | | | | |
| Produced[1] | million pieces | 315.2 | 385.6 | 436.3 | 426.5 | 223.0 | 226.7 | 250.7 | 280.9 | 286.8 |
| Consumed lime[2] | kt $CaCO_3$ | 58.6 | 71.7 | 81.1 | 79.2 | 35.1 | 46.2 | 53.3 | 63.3 | 67.0 |
| **Expanded clay products** | | | | | | | | | | |
| Produced[1] | kt | 331.8 | 340.9 | 316.2 | 310.9 | 157.4 | 155.0 | 145.7 | 183.0 | 185.7 |
| Consumed lime[2] | kt $CaCO_3$ eqv | 46.2 | 47.5 | 44.0 | 43.3 | 19.1 | 19.5 | 25.4 | 32.0 | 38.4 |

[1] Statistics Denmark (2019).

[2] 1990-2005: Calculated from production data and the average implied emission factor for 2006-2013.

Both the brickworks and expanded clay productions displays a significant decrease from 2007 to 2009 that can be explained by the global financial crises. The decreases correspond to 59 % and 78 % respectively for brickworks and expanded clay production. Two brickworks closed down in 2008, and further two in 2009.

### Emission factors

The emission factor for lime is 0.43971 kg $CO_2$ per kg $CaCO_3$. The calcination factor is assumed to be 100 % for all years and all producers.

Since 2006, $CO_2$ emissions are reported by the brickworks to EU-ETS (confidential reports). The number of brickworks are decreasing; in 2006 19 brickworks reported to EU-ETS, in 2018 this number had decreased to 13. The reported emissions are calculated from measured lime contents of the raw materials and the stoichiometric emission factor 0.43971 kg $CO_2$ per kg $CaCO_3$.

Producers of expanded clay products also report $CO_2$ emissions to EU-ETS for the years since 2006 (Imerys, 2019; Leca, 2019). The reported emissions are calculated from the difference in C contents measured in the raw materials and products and the stoichiometric emission factor 3.664 kg $CO_2$ per kg C. The reported emissions are recalculated to match the activity data for brickworks using the stoichiometric factors.

### Emission trends

The emission trends for the $CO_2$ emission from production of bricks/tiles and expanded clay products are available in Annex 3C-9 but is also presented in Figure 4.2.5.

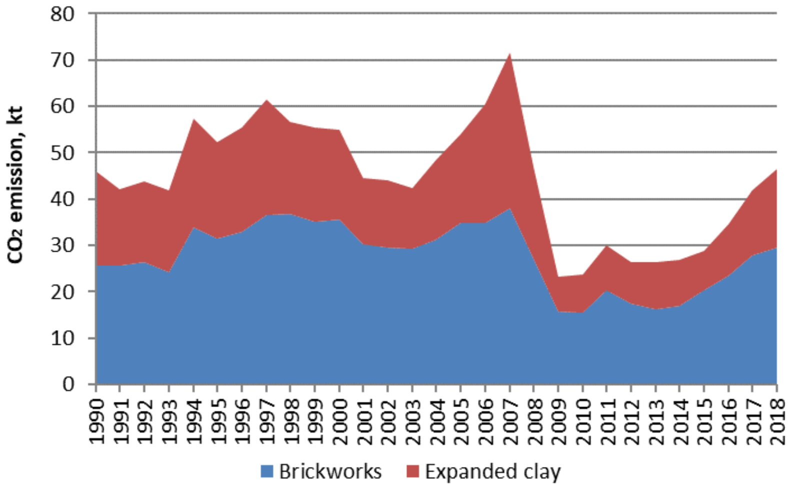


Figure 4.2.5 $CO_2$ emissions from the production of ceramics.

Emissions from this source category are very dependent on new houses being built as well as old ones being renovated. The significant decline in emissions from 2007-2009 was caused by a reduced production resulting from the economic recession caused by the global financial crisis.

#### Time series consistency and completeness

Emissions from 2006 onwards are known from the EU-ETS reports and emissions for 1990-2005 are estimated. However, due to the various performed verifications (Hjelgaard & Nielsen, 2018), the ceramics source category is considered to be consistent.

The inventory is based on companies reporting to EU-ETS and national sales statistics, but clay is also burned in minor scale e.g. ceramic art workshops and school art classes. These miniscule sources are however negligible and the source category of ceramics is considered to be complete.

### 4.2.7 Other uses of soda ash

This section covers the use of soda ash not related to glass production. The following SNAP code is covered:

- 04 06 19 Other uses of soda ash

#### Methodology

Emissions from other uses of soda ash ($Na_2CO_3$) are calculated based on national statistics on import/export (subtracted the amount used in the glass industry) and the stoichiometric emission factor. No information is available on the end uses of soda ash and therefore all use is considered to be emissive.

#### Activity data

National statistics on import/export and the calculated activity data (supply) are presented in Table 4.2.9 and Annex 3C-10.

Table 4.2.9 Statistics for other uses of soda ash, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Import | 54.6 | 47.6 | 42.0 | 59.5 | 36.5 | 26.3 | 35.2 | 47.5 | 50.4 |
| Export | 0.09 | 2.13 | 0.31 | 0.01 | 0.06 | 0.07 | 0.11 | 0.17 | 0.14 |
| Glass production | 21.4 | 18.8 | 19.4 | 16.6 | 10.7 | 8.6 | 8.9 | 8.9 | 10.9 |
| Supply | 33.2 | 26.7 | 22.3 | 42.9 | 25.7 | 17.6 | 26.2 | 38.4 | 39.3 |

#### Emission factors

The applied emission factor for other uses of soda ash is 414.92 kg $CO_2$ per tonne $Na_2CO_3$. The calculation assumes a calcination factor of 100 %.

#### Emission trends

The emission trend for the $CO_2$ emission from other uses of soda ash is available in Figure 4.2.6 and Annex 3C-11.

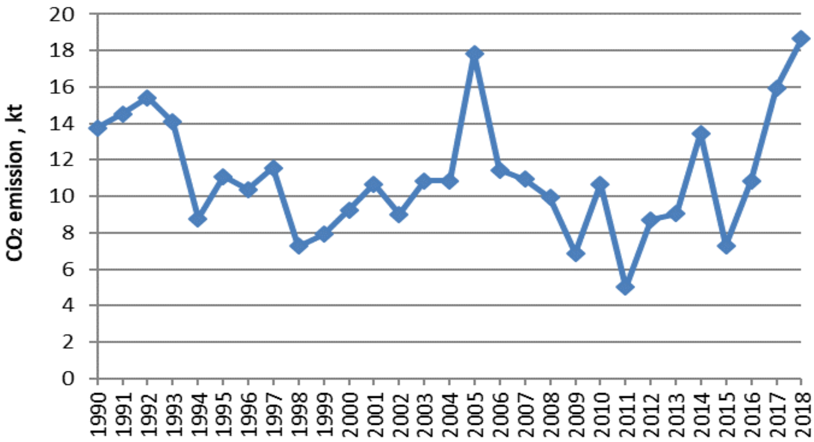


Figure 4.2.6 $CO_2$ emissions from other uses of soda ash.

Information on the uses of soda ash outside the glass industry is scarce, and descriptions of the trend development are therefore not available.

**Time series consistency and completeness**

The same methodology is used for calculating emissions for the entire time series, the emissions from other uses of soda ash are therefore consistent. Calculations are based on national import/export statistics and are therefore also complete as there is no production of soda ash in Denmark.

For verification, please refer to Hjelgaard & Nielsen (2018).

### 4.2.8 Flue gas desulphurisation

Flue gas cleaning systems utilising different technologies are primarily present at major combustion plants i.e. power plants, combined heat and power plants as well as waste incineration plants. The following SNAP code is covered:

- 04 06 18 Limestone and dolomite use - Flue gas cleaning, wet, power plants and waste incineration plants

**Methodology**

The emission of $CO_2$ from wet flue gas desulphurisation can be calculated from the following equation:

$$SO_2\ (g) + \tfrac{1}{2}O_2\ (g) + CaCO_3\ (s) + 2H_2O\ (l) \rightarrow CaSO_4{,}2H_2O\ (s) + CO_2\ (g)$$

The consumed amount of limestone ($CaCO_3$) is used as activity data. Information on limestone consumption is available from EU-ETS for 2006 forward.

Energinet.dk compile environmental information related to energy transformation and distribution. Since the waste incineration plants with desulphurisation are all power producers, these plants are also included in the data from Energinet.dk (2019). Statistics on the generation of gypsum are available from Energinet.dk (2019) for 1990-2018. However, for 2006-2018 information on consumption of limestone at the relevant power plants and waste incineration plants has been compiled from EU-ETS and used in the calculation of $CO_2$ emission from flue gas cleaning. For 1990-2005, the generation of gypsum data have been used as surrogate data.

The consumption of other carbonates than limestone (e.g. TASP[1]) is measured by the individual power plants and is added to the limestone consumption in $CaCO_3$ equivalents.

### EU-ETS data for flue gas desulphurisation

The applied methodologies for flue gas desulphurisation are specified in the individual monitoring plans that are approved by Danish authorities (DEA) prior to the reporting of the emissions. The flue gas desulphurisation applies the Tier 1-2 methodology for calculating the $CO_2$ emission depending on the individual units.

The $CO_2$ emission for flue gas desulphurisation is based on measured lime consumption (± 1.5 % to ± 7.5 %). The implied $CO_2$ emission factors for the production facilities are based on stoichiometry.

Since 2013, seven of the 12 waste incineration plants operating wet flue gas cleaning, have applied a reporting method based on measurements. This means that these plants now estimate the total emissions (process and energy related as one), and that process emissions from these plants are therefore reported under the energy sector.

### Activity data

During the time series this source has increased due to more plants being fitted with desulphurisation (1990-1999). However, since the main use is in coal fired plants, flue gas desulphurisation is decreasing as some of the coal fired power plants are rebuilt to combust biomass and the need for flue gas desulphurisation ceases. Since 2006, three of the nine coal fired power plants have changed to alternative fuels and desulphurisation has ceased from these plants.

The Danish waste incineration plants are in general smaller than the coal combustion facilities and owned by smaller companies. Of the approximately 30 waste incineration plants with flue gas desulphurisation only one third uses wet flue gas cleaning.

The activity data are presented in Table 4.2.10, Figure 4.2.7 and Annex 3C-12.

Table 4.2.10 Activity data for flue gas desulphurisation, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Gypsum production[1] | 41.6 | 211.5 | 354.3 | 220.4 | 179.7 | 91.7 | 98.8 | 76.6 | NAV |
| $CaCO_3$ consumption[2, 3] | 22.0 | 111.8 | 187.3 | 116.6 | 95.6 | 35.3 | 40.9 | 33.0 | 34.4 |

[1] Energinet.dk (2018).
[2] 1990-2005: Estimated from surrogate data and stoichiometric relations.
[3] 2006-2018: EU-ETS of the individual plants.
NAV: Not Available.

[1] "Tørt AfSvovlingsProdukt" (Dry desulphurisation product), the by-product from dry flue gas desulphurisation processes.

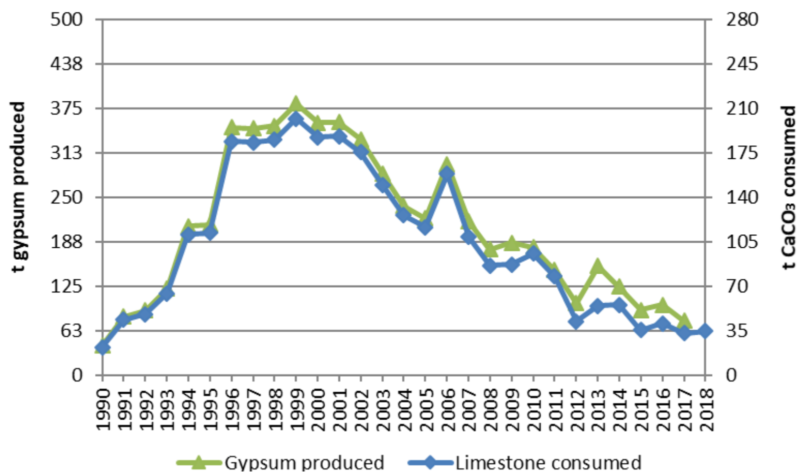


Figure 4.2.7 Activity data for flue gas desulphurisation.

The activity data level varies with the coal consumption that again varies greatly with electricity import/export.

### Emission factors

The emission factor applied to the limestone consumption is the stoichiometric emission factor 0.43971 tonnes $CO_2$ per tonne $CaCO_3$.

### Emission trends

The emission trend for the $CO_2$ emission from flue gas desulphurisation is available in Table 4.2.11 and Annex 3C-13.

Table 4.2.11 $CO_2$ emissions from flue gas desulphurisation, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Flue gas desulphurisation | 9.7 | 49.2 | 82.4 | 51.2 | 42.0 | 15.5 | 18.0 | 14.5 | 15.1 |

### Time series consistency and completeness

The methodology for calculating emission from flue gas desulphurisation consistent in spite of varying methods; please refer to the verification presented in Hjelgaard & Nielsen (2018). The source category is considered to be complete.

## 4.2.9 Stone wool production

Only one company produces stone wool in Denmark, Rockwool situated at three localities: Hedehusene[2], Vamdrup and Øster Doense. The following SNAP-code is covered:

- 04 06 18 Limestone and dolomite use – Stone wool production

Emissions associated with the fuel use are estimated and reported in the energy sector.

### Methodology

Stone wool is produced from mineral fibres and a binder. The raw materials are melted in a cupola fired by coke and natural gas, several raw materials contribute to the process $CO_2$ emission e.g. bottom ash, limestone, dolomite, binder etc.. The consumption of raw material as well as amount of produced stone wool is confidential.

[2] The melting of minerals (cupola) has closed down in 2002.

Information on emissions from 2006-2010 has in combination with yearly total raw material consumption been used to extrapolate the emissions back to 1995. The data have been extracted from company reports (Rockwool, 2014a) and EU-ETS (Rockwool, 2019). $CO_2$ process emissions are available for the years 2006-2018 (EU-ETS) and the consumption of raw materials for 1995-2013 (environmental reports). Emissions for 1990-1994 are estimated as the constant average of 1995-1999.

Calculations are performed for the three factories individually.

**EU-ETS data for stone wool production**

Stone wool production applies the ETS Tier 3 methodology for calculating the $CO_2$ process emission for 2006 onwards.

The implied $CO_2$ emission factor for Rockwool is plant specific and based on the reporting to the EU-ETS. The EU-ETS data have been applied for the years 2006 onwards.

The $CO_2$ emission for stone wool production is based on measurements of the consumption of carbonates. These measurements fulfil an ETS Tier 1 or Tier 3 methodology (± 1.6 - 5.0 %) depending on the carbonate. The emission factors are based on carbon content measurements for each carbonate (ETS Tier 2-3). (Rockwool, 2014b).

**Activity data**

The consumption of limestone equivalents are presented in Table 4.2.12 and Annex 3C-14.

Table 4.2.12 Activity data for stone wool production, kt $CaCO_3$ equivalents.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Carbonate consumption | 17.9 | 18.0 | 17.3 | 18.0 | 17.1 | 13.5 | 17.0 | 18.2 | 25.0 |

**Emission factors**

The applied emission factor for stone wool production is the stoichiometric factor 0.43971 tonnes $CO_2$ per tonne $CaCO_3$.

**Emission trends**

The emission trend for the $CO_2$ emission from stone wool production is presented in Figure 4.2.8 below and Annex 3C-15.

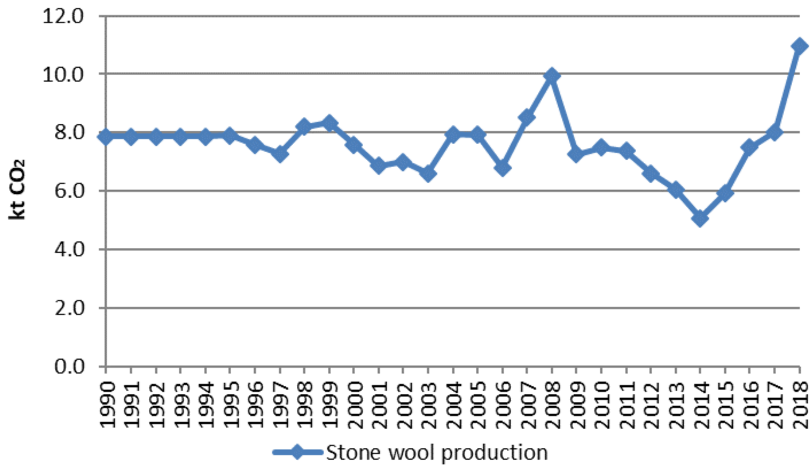


Figure 4.2.8 $CO_2$ emissions from stone wool production.

**Time series consistency and completeness**

The source category of stone wool production is complete. Emissions for 2006 onward are known (EU-ETS) but emissions for 1990-2005 are estimated via surrogate data, in spite of this change in method the source category is considered to be consistent.

## 4.3 Chemical Industry

### 4.3.1 Source category description

The sector *Chemical industry* (2B) covers the following industries relevant for the Danish air emission inventory:

- 2B2 Nitric acid production (SNAP 040402); see section 4.4.3.
- 2B10 Catalyst production (SNAP 040416); see section 4.4.4.

Nitric acid production is identified as a key category in 1990 according to both Approach 1 and Approach 2. The trend is also identified as key category according to both Approach 1 and Approach 2, however this is due to the closing of the lone plant producing nitric acid in Denmark in 2004.

### 4.3.2 Emissions

Total greenhouse gas emissions from the Chemical Industry sector are available in the CRF Table 10. The emission time series for the source categories within *Chemical Industry* (2B) are presented in Figure 4.3.1 and individually in the subsections below (Sections 4.4.3 – 4.2.4). The following figure gives an overview of which source categories contribute the most throughout the time series.

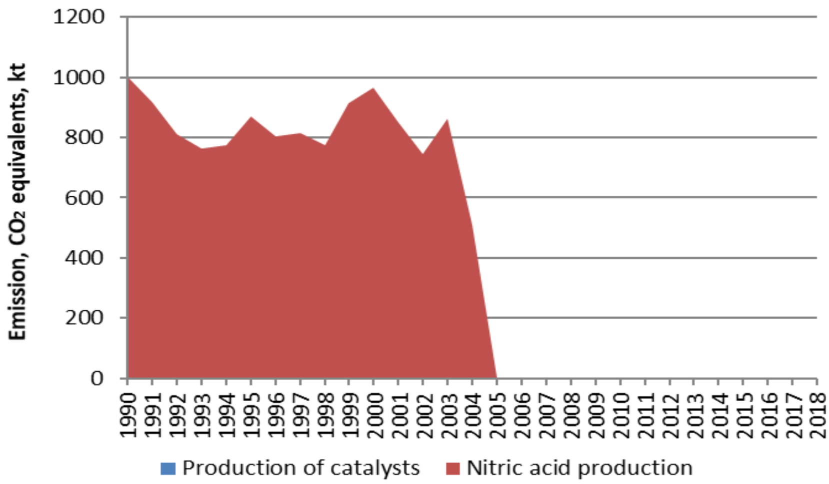


Figure 4.3.1 Emission of $CO_2$ equivalents from the individual source categories compiling *2B Chemical Industry*, kt.

Greenhouse gas emissions from *Chemical Industry* are made up almost entirely by $N_2O$ emissions from the production of nitric acid; only 0.1 % (1990-2003) to 0.2 % (2004) stems from the production of catalysts, making the emission invisible in the figure above. The production of nitric acid ceased in the middle of 2004.

### 4.3.3 Nitric acid production

The production of nitric acid as well as NPK fertilisers has been concentrated at one company: Kemira GrowHow A/S situated in Fredericia. The production ceased in the summer of 2004. The following SNAP code is covered:

- 04 04 02 Nitric acid

### Methodology

The information on the $N_2O$ emissions from the production of nitric acid/fertiliser is obtained from environmental reports (Kemira GrowHow, 2005), contact to the company as well as information from the county. Information on emissions of $N_2O$ is available for 2002. For the remaining years the $N_2O$ emission has been estimated from annual production statistics from the company and an implied emission factor based on 2002.

Specific information on applied technology is not available; however, the emission factor measured by the Danish nitric acid plant is comparable with the default emission factor for a medium pressure plant (IPCC, 2006).

The production of nitric acid in Denmark ceased in the middle of 2004 and the company relocated the production to a more modern facility in another country.

### Activity data

The applied activity data for production of nitric acid are presented in Table 4.3.1 and Annex 3C-16.

Table 4.3.1 Production of nitric acid, kt.

| | 1990 | 1995 | 2000 | 2004 |
|---|---|---|---|---|
| Nitric acid | 450 | 390 | 433 | 229 |

In the time series, the production of nitric acid peaked in 1990 with 450 kt (and 807 kt fertiliser) and then fluctuated around the average of 375 kt nitric acid (694 kt fertiliser) from 1990-2003 until the factory closed down in the summer of 2004; 2004 production of 229 kt nitric acid and 395 kt fertiliser (Kemira GrowHow, 2005).

### Emission factors

Default emission factors given by IPCC (2006[3]) are presented in Table 4.3.2 together with the Danish value.

Table 4.3.2 Emission factors for production of nitric acid in Denmark compared with default emission factors (IPCC, 2006) (kg per t nitric acid).

| | Danish IEF 2002 | Default EF |
|---|---|---|
| $N_2O$ | 7.476 | 2-2.5[1] |
| | | 5[2] |
| | | 7[3] |
| | | 9[4] |

[1] Modern, NSCR, process-integrated or tailgas $N_2O$ destruction.
[2] Atmospheric pressure plant (low pressure).
[3] Medium pressure combustion plants.
[4] High pressure plants.

### Emission trends

The emission trend for the $N_2O$ emission from nitric acid production is available in Figure 4.3.1 and Annex 3C-17.

The trend for $N_2O$ emission from 1990 to 2003 shows a decrease from 3.4 to 2.9 kt, i.e. 14 %, and a 41 % decrease from 2003 to 2004. However, the activity

[3] Volume 3 Chemical Industry, Chapter 3.3.2.2 page 3.23 (Table 3.3).

and the corresponding emission show considerable fluctuations in the period considered and the decrease from 2003 to 2004 can be explained by the closing of the plant in the middle of 2004.

#### Time series consistency and completeness

The applied methodology regarding $N_2O$ is consistent. The activity data are based on information from the specific company/plant. The emission factor applied has been constant for the whole time series and is based on measurements performed in 2002. The production equipment has not been changed during the period. The source category of nitric acid production is complete.

### 4.3.4 Catalyst production

Production of a wide range of catalysts and potassium nitrate (fertiliser) is concentrated at one company: Haldor Topsøe A/S situated in Frede-rikssund. The following SNAP code is covered:

- 04 04 16 Other: catalysts

#### Methodology

The processes involve carbonate compounds i.e. the process leads to emissions of $CO_2$. The company has estimated the emission of $CO_2$ from known emission factors for incineration of natural gas and LPG and from information on the raw materials containing carbonate. The contribution from carbonate compounds is estimated to be the difference between the total $CO_2$ emission reported in the environmental reports and PRTR (Haldor Topsøe, 2013 and 2019b) and the $CO_2$ emission from energy consumption reported in the environmental reports and to EU-ETS (Haldor Topsøe, 2013 and 2019a). An average implied emission factor (IEF) was calculated for 2003-2009 using this method, this IEF was used for the entire time series. For the years 1990-1995, the production (activity data) is estimated using linear regression on the years 1997-2012.

#### Activity data

Table 4.3.3 Source of activity data.

| Years | Determined by |
|---|---|
| 1990-1995 | Linear regression of 1997-2012 |
| 1996 | Total production is available, the average split between the two products from 1997-2001 is applied for estimating the individual productions |
| 1997-2012 | Information from the company (environmental reports) |
| 2013-2014 | Estimated using the consumption of raw materials as surrogate data |
| 2015-2018 | Estimated using the fuel consumption as surrogate data and the average produced fraction of each product in relation to total production for 2003-2012 |

The activity data regarding production of catalysts and fertiliser are obtained through environmental reports from Haldor Topsøe (2013) where these are available (2007-2012). For years where environmental reports are not available, production data are estimated using the drivers mentioned in Table 4.3.3. Production data are presented in Table 4.3.4 and Annex 3C-18, the annex also includes the applied surrogate data.

Table 4.3.4 Production of catalysts and potassium nitrate, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Catalysts produced | - | - | 17.2 | 23.2 | 20.5 | 27.2 | 23.3 | 27.2 | 29.7 |
| Potassium nitrate produced | - | - | 19.2 | 23.3 | 25.9 | 35.2 | 34.4 | 29.6 | 29.6 |
| Total produced | 23.7 | 30.5 | 36.4 | 46.5 | 46.4 | 62.4 | 57.7 | 56.8 | 59.3 |

#### Emission factors

The average calculated implied emission factor for 2003-2009 is 0.0241 tonnes $CO_2$ per tonne product; this factor is applied for the entire time series.

#### Emission trends

From 1990 to 2018, the emission of $CO_2$ from the production of catalysts/fertilisers has increased from 0.6 to 1.4 kt (151 %) with maximum in 2015 (1.5 kt), due to an increase in the production as well as changes in raw material consumption.

The trend for the $CO_2$ emission from the production of catalysts and fertilisers is presented in Annex 3C-19 and in Figure 4.3.2.

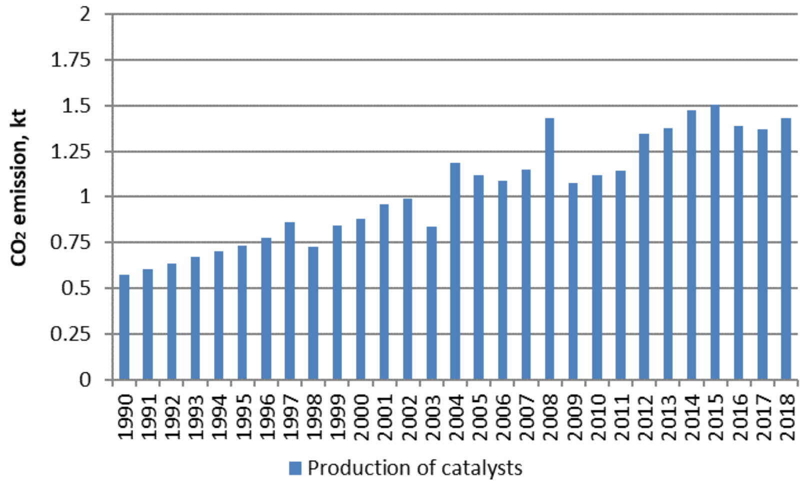


Figure 4.3.2 Emission of $CO_2$ from catalyst/fertiliser production, kt.

#### Time series consistency and completeness

There is a change in the applied methodology from 1990-1995 and 1996-onward. Linear regression is used to estimate emissions for 1990-1995, while $CO_2$ emissions have been provided from the company since 1996. However, the source category is considered to be consistent.

The source category of catalyst production is complete.

## 4.4 Metal industry

### 4.4.1 Source category description

The sector *Metal Industry* (CRF 2C) covers the following industries relevant for the Danish air emission inventory:

- 2C1 Iron and steel production (SNAP 040207, 040208); see section 4.4.3
- 2C4 Magnesium production (SNAP 040304); see section 4.4.4
- 2C5 Secondary lead production (SNAP 030307); see section 4.4.5

### 4.4.2 Emissions

The time series for emission of greenhouse gasses from *Metal Industry* (2C) is presented in the CRF tables and in Figure 4.4.1 below.

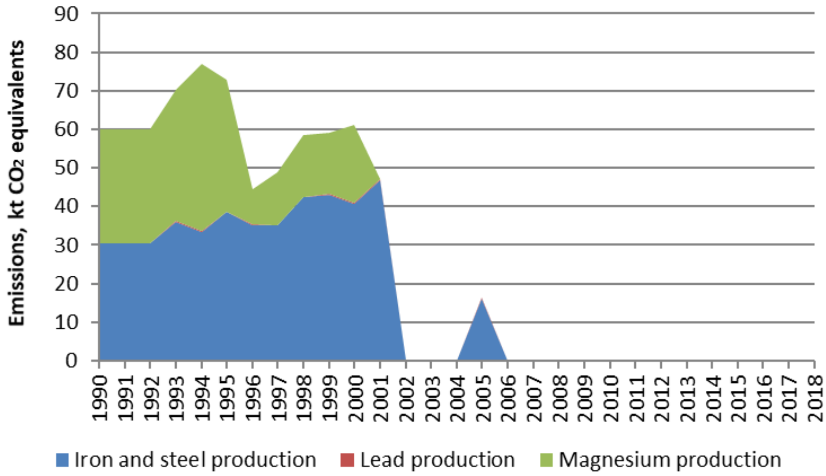


Figure 4.4.1 Emission of greenhouse gasses from the individual source categories compiling *2C Metal Industry*, kt $CO_2$ equivalents.

From 1990 to 2001, the $CO_2$ emission from the electro-steelwork increased by 55 % whiles the $SF_6$ emission from magnesium production decreased with 31 % (1990-2000). The changes in the greenhouse gas emission is similar to the increase and decrease in the activity as the consumption of metallurgical coke per amount of steel sheets and bars produced has almost been constant during the period and the emission factor for magnesium production is constant throughout the time series.

Emissions from secondary lead production are miniscule (0.3 % of $CO_2$ equivalent emissions for 1990-2000), but are the only emissions in the *Metal Industry* sector that occur for the entire time series.

The electro-steelwork was shut down in January 2002 and reopened and closed down again in 2005. In 2000, the $SF_6$ emission from the magnesium production ceased.

Grey iron foundries are active for the entire time series. But this production does not result in any greenhouse gas emissions

### 4.4.3 Iron and steel production

The production of semi-manufactured steel products (e.g. steel sheets/plates and bars) was concentrated at one company: Det Danske Stålvalseværk A/S situated in Frederiksværk. After the closure of the electro steelwork in 2002 the two rolling mills were divided in two companies called DanSteel and Duferco, these are both still in operation but are not included here, as they do not emit process greenhouse gas emissions. The following SNAP code is covered:

- 04 02 07 Electric furnace steel plant

The steelwork was closed down in January 2002 and then partly reopened in November 2002. The production of steel sheets/plates was reopened by DanSteel in 2003, the production of steel bars was reopened by DanScan Metal in March 2004, and the electro steelwork was reopened by DanScan Steel in January 2005. The production at DanScan Metal and Steel ceased in the last part of 2005 and in June 2006 DanScan Metal was taken over by Duferco; the electro steelwork (DanScan Steel) has still not been in operation since 2005. The timeline is presented in Figure 4.4.2.

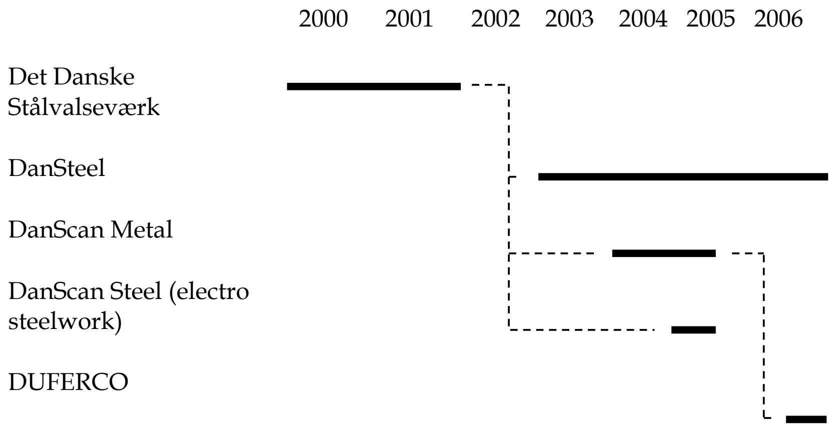


Figure 4.4.2 Timeline for production at the Danish steelwork.

### Methodology

Metallurgical coke is used in the melting process to reduce iron oxides and to remove impurities. The overall process is:

$$C + O_2 \rightarrow CO_2$$

The $CO_2$ emission from the consumption of metallurgical coke at steelworks has been estimated from the annual production of steel sheets and steel bars combined with the consumption of metallurgical coke per produced amount (Stålvalseværket, 2002). The carbon source is assumed to be coke and all the carbon is assumed to be converted to $CO_2$ as the carbon content in the products is assumed to be the same as in the iron scrap. The emission factor (consumption of metallurgical coke per tonne of product) has been almost constant from 1993 to 2001; steel sheets: 0.012-0.018 tonnes metallurgical coke per tonne and steel bars: 0.011-0.017 tonnes metallurgical coke per tonne.

Production data for 1990-1991 and for 1993 have been determined with extrapolation and interpolation, respectively and data on the consumption of metallurgical coke for 1990-1992 have been extrapolated.

### Activity data

Statistical data on steel production activities, i.e. amount of steel sheets and bars produced as well as consumption of metallurgical coke are available in environmental reports from the single Danish steel plant (Stålvalseværket, 2002) supplemented with other literature. In 2002, production stopped. For 2005 the production has been assumed to be one third of the production in 2001 as the steelwork was operating between 4 and 6 months in 2005. The activity data are presented in Table 4.4.1 and Annex 3C-20.

Table 4.4.1 Overall mass flow for Danish steel production, kt.

| | | 1990 | 1995 | 2000 | 2005 |
|---|---|---|---|---|---|
| Det Danske Stålvalseværk | | | | | |
| Raw material | Iron and steel scrap | - | 657 | 731 | - |
| Intermediate product | Steel slabs etc. | - | 654 | 803 | - |
| Product | Steel sheets | 444[1] | 478 | 380 | - |
| | Steel bars | 170[1] | 239 | 251 | - |
| | Products, total | 614[1] | 717 | 631 | 250[2] |
| Raw material | Metallurgical coke | 8.3 | 10.5 | 11.1 | 4.4 |

[1]Extrapolation, [2]Assumed.

The mass balances/flow sheets presented in the annual environmental reports do not for all years tell about the changes in the stock and therefore the balance cannot be completed.

### Emission factors

The emission factors for carbon dioxide from using metallurgical coke in manufacturing of iron and steel from scrap is the stoichiometric ratio 3.667 tonnes $CO_2$ per tonne C.

### Emission trends

The greenhouse gas emissions from the steel production are presented in Figure 4.4.3 and Annex 3C-21. The production ceased in 2001 and reopened and closed again in 2005; see Figure 4.4.2.

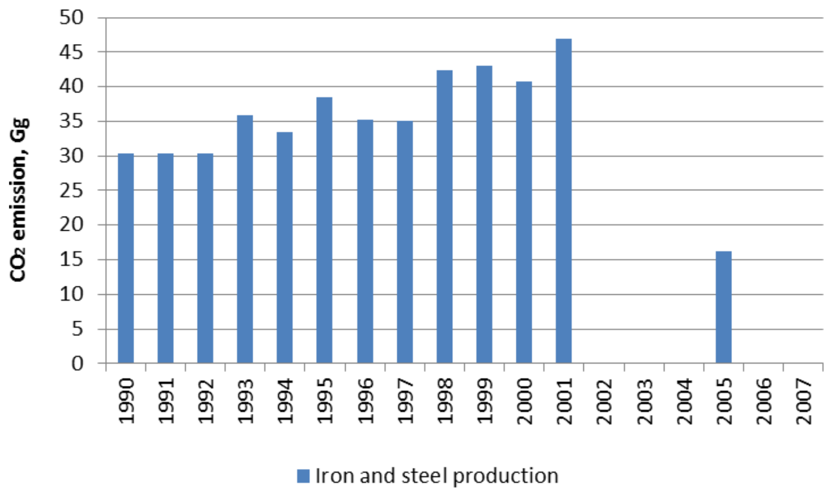


Figure 4.4.3 Emission of greenhouse gasses from the production of steel from scrap.

### Time series consistency and completeness

The time series for secondary steel production is consistent as the same methodology has been applied for the whole period. The time series is also considered to be complete.

There is no metallurgical coke production in Denmark.

## 4.4.4 Magnesium production

For the production of magnesium in Denmark the following SNAP-code is covered:

- 04 03 04 Consumption of $SF_6$ in magnesium foundries

#### Methodology
The consumption of $SF_6$ in the magnesium production is known from information directly from the industry (Poulsen, 2020). The emission can be calculated from the $SF_6$ consumption and the default Tier 1 emission factor, which is a release of 100 %.

#### Activity data
Table 4.4.2 presents the activity data.

Table 4.4.2 Production of magnesium, tonnes.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Magnesium produced | 1300 | 1300 | 1300 | 1500 | 1900 | 1500 | 400 | 600 | 700 | 700 | 891 |

#### Emission factors
The applied emission factor is 1, i.e. 100 % release of $SF_6$ used.

#### Emission trends
The greenhouse gas emissions from the production of magnesium are presented in Figure 4.4.4 below. The consumption of $SF_6$ ceased in 2000.

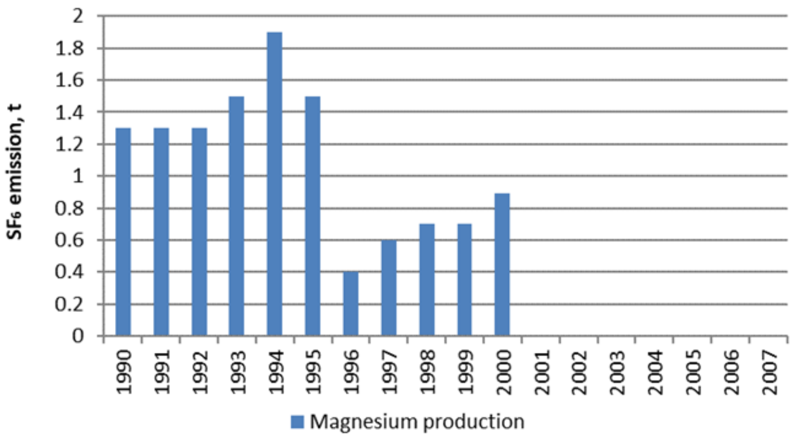


Figure 4.4.4 Emission of greenhouse gasses from the production of magnesium.

#### Time series consistency and completeness
The time series for magnesium production is considered to be both consistent and complete.

### 4.4.5 Secondary lead production

One Danish company producing secondary lead has been identified; Hals Metal. The following SNAP code is covered:

- 03 03 07 Secondary lead production

#### Methodology
Only one Danish company; Hals Metal, has been identified as producing secondary lead from scrap metal. In addition to Hals metal, old lead tiles from castles, churches etc. are melted and recast on site during preservation of the many historical buildings in Denmark.

#### Activity data
Activity data from Hals Metal are provided by the company (Hals Metal, 2019). A clause affected in 2002 meant that Hals Metal could no longer burn cables containing lead. The processing of cables was therefore stopped and

the company's activity changed to smelting. This transition resulted in a low activity in 2003.

The activity of recasting lead tiles is not easily found because it is spread out on many craftsmen and poorly regulated. However, an estimate by Lassen et al. (2004) states that 200-300 tonnes lead tiles were recast in 2000. Since the building stock worthy of preservation is constant, it is assumed that the activity of recasting of lead tiles is constant.

Activity data for secondary lead production are shown in Table 4.4.3 and Annex 3C-22.

Table 4.4.3 Activity data for secondary lead production, tonnes.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Hals metal | 540 | 750 | 540 | 691 | 635 | 745 | 475 | 605 | 348 |
| Lead tiles | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 |
| Total | 790 | 1000 | 790 | 941 | 885 | 995 | 725 | 855 | 598 |

#### Emission factors

The applied $CO_2$ emission factor for secondary lead production is the default Tier 1 factor of IPCC (2006)[4]; 0.2 tonnes per tonne product.

#### Emission trends

The greenhouse gas emissions from the production of secondary lead are presented in Figure 4.4.5 below and Annex 3C-23.

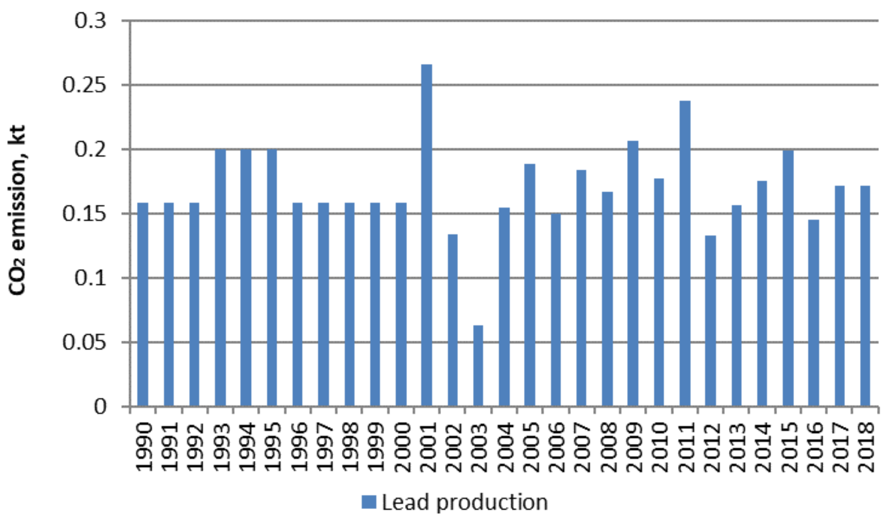


Figure 4.4.5 Emission of greenhouse gasses from secondary lead production.

#### Time series consistency and completeness

The time series for secondary lead production is considered to be both consistent and complete.

## 4.5 Non-Energy Products from Fuels and Solvent Use

### 4.5.1 Source category description

*Non-Energy Products from Fuels and Solvent Use* (CRF 2D) covers the following categories relevant for the Danish air emission inventory:

[4] Volume 3: Industrial Processes and Product Use, Chapter 4.6.2.2: Choice of emission factors, Table 4.21, page 4.73.

- 2D1 Lubricant use ( SNAP 060604); see section 4.5.3
- 2D2 Paraffin wax use ( SNAP 060606); see section 4.5.4
- 2D3 Solvent use (SNAP 0601, 0602, 0603, 0604); see section 4.5.5
- 2D3 Road paving with asphalt (SNAP 040611); see section 4.5.6
- 2D3 Asphalt roofing (SNAP 040610); see section 4.5.7
- 2D3 Urea-based catalysts (SNAP 060607); see section 4.5.8

### 4.5.2 Emissions

The time series for emission of greenhouse gasses from *Non-Energy Products from Fuels and Solvent Use* (2D) is presented in the CRF tables and in Figure 4.5.1 below.

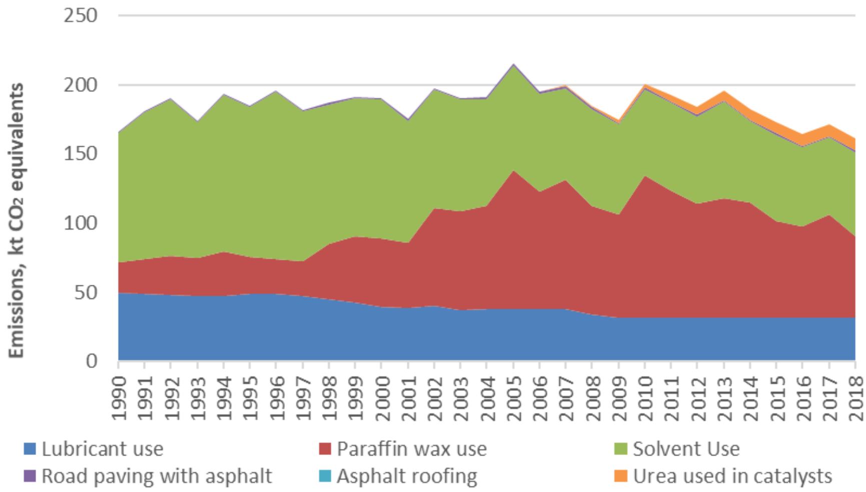


Figure 4.5.1 Emission of greenhouse gasses from the individual source categories compiling *2D Non-Energy Products from Fuels and Solvent Use*, kt $CO_2$ eqv.

The largest source of greenhouse gas emissions from *Non-Energy Products from Fuels and Solvent Use* is for 1990-2004 the use of solvents. As the use of solvents decrease (35 % decrease from 2000-2007) and the use of candles (i.e. paraffin wax use) increases (111 % increase from 2001-2005), the use of candles becomes the largest source of greenhouse gas emissions for 2005-2017. Since the peak in emissions from the use of candles in 2005, emissions have decreased with 42 % (2005-2018). Since emissions from solvent use have found a more stable level since 2007, solvent use is from 2018 again the largest contributing source of greenhouse gas emissions from *Non-Energy Products from Fuels and Solvent Use*.

### 4.5.3 Lubricant use

The category Lubricant use (CRF 2D1) covers the following process/SNAP code:

- 06 06 04 Oxidation of lubricants during use

Lubricants consumed in machinery (i.e. that is combusted during use) is included in this section. Collection of waste lubricants with subsequent combustion is reported in the energy sector.

#### Methodology

The emission of $CO_2$ from oxidation of lubricants during use is calculated according to the equation (IPCC, 2006):

$$E_{CO2} = LC \bullet CC_{\text{lub}\,ricant} \bullet ODU_{\text{lub}\,ricant} \bullet 44/12 \qquad \text{(Eq. 4.5.1)}$$

Where $E_{CO2}$ is the $CO_2$ emission, LC is the consumption of lubricants, $CC_{lubricant}$ is the carbon content factor, $ODU_{lubricant}$ is the Oxidised During Use factor and 44/12 is the mass ratio of $CO_2$/C.

Equation 4.5.1 represents a Tier 1 approach where LC is the total amount of lubricant consumed in Denmark with no differentiation between greases and oils.

**Activity data**

The time series for consumption of lubricant oil in TJ is obtained from the Danish Energy Agency (2019) along with the calorific value of 41.9 GJ per tonne. The consumption has been reported as constant by the DEA since 2010. The consumption is presented in Table 4.5.1 and the complete time series in Annex 3C-24.

Table 4.5.1 Consumption of lubricant oil, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Lubricants | 80.5 | 79.1 | 64.3 | 60.9 | 51.3 | 51.3 | 51.3 | 51.3 | 51.3 |

**Emission factors**

Table 4.5.2 Factors for calculation of the lubricant use emission factor.

| Factor | Description | Source | Value | Unit |
|---|---|---|---|---|
| $CC_{lubricant}$ | The default carbon content factor | IPCC (2006), page 5.9 | 20.1 | kg C/GJ |
| $ODU_{lubricant}$ | The oxidised during use factor for grease | IPCC (2006), Table 5.2 page 5.9 | 0.2 | - |
| $CO_2$/C | Mass ratio, 44/12 | IPCC 2006, page 5.5 | 3.7 | kg $CO_2$/kg C |

The emission factor is calculated as the product: $CC_{lubricant} \cdot ODU_{lubricant} \cdot 44/12$ in Eq 4.5.1, and yields an emission factor of 14.7 kg $CO_2$ per TJ or 0.617 tonnes $CO_2$ per tonne lubricant used. This is constant for the entire time series.

**Emission trends**

The time series for $CO_2$ emission from oxidation of lubricants during use is presented in Table 4.5.3 and Annex 3C-25.

Table 4.5.3 Emissions from oxidation of lubricants during use, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Lubricants | 49.7 | 48.8 | 39.7 | 37.6 | 31.7 | 31.7 | 31.7 | 31.7 | 31.7 |

**Time series consistency and completeness**

The applied methodology has been the same for all years in the time series, with activity data based on information from the Danish Energy Agency and using the same emission factor. The emission time series is therefore consistent. Since activity data are available from the energy statistics (Danish Energy Agency, 2019), the time series is also considered to be complete.

### 4.5.4 Paraffin wax use

The category Paraffin wax use (CRF 2D2) covers the following activity:

- 06 06 06 Combustion of paraffin wax candles

Paraffin waxes are used in applications such as candles, corrugated boxes, paper coating, board sizing, adhesives, food production, packaging, wax polishes, surfactants (used in detergents or in wastewater treatment), and many others. Emissions from the use of paraffin waxes occur primarily when they are combusted during use, e.g. candles, or when incinerated or used in waste water treatment. The latter cases should be reported in the energy or waste sectors, respectively (IPCC, 2006).

#### Methodology

In the Danish inventory, greenhouse gas emissions ($CO_2$, $N_2O$ and $CH_4$) are only included from the main emission source: Combustion of paraffin wax candles. The methodology corresponds to a Tier 2 (IPCC, 2006), and assumes an oxidation factor of 100 %.

#### Activity data

Activity data are derived from import, export and production data for candles from Statistics Denmark (2019). The activity data are presented in Table 4.5.4 and in Annex 3C-26.

Table 4.5.4 Use of paraffin wax candles, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Paraffin wax use | 7.4 | 9.1 | 16.9 | 34.4 | 35.2 | 24.0 | 22.5 | 25.6 | 20.1 |

#### Emission factors

The emission factors presented in Table 4.5.5 are constant for the entire time series and are compiled from the scientific literature. The IPCC (2006) $CO_2$ emission factor is valid for shale oil and is therefore not used.

Table 4.5.5 Emission factors for use of paraffin wax candles.

| Pollutant | Unit | Value | Source |
|---|---|---|---|
| $CO_2$ | kt/kt | 2.91 | Shires et al. (2004) |
| $N_2O$ | t/kt | 0.024 | Shires et al. (2009) |
| $CH_4$ | t/kt | 0.121 | Shires et al. (2009) |

#### Emission trends

The time series for greenhouse gas emissions from paraffin wax use is shown in Table 4.5.6 and Annex 3C-27.

Table 4.5.6 Emissions from the use of paraffin wax candles.

| | Unit | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ | kt | 21.7 | 26.5 | 49.3 | 100.2 | 102.3 | 70.0 | 65.4 | 74.5 | 58.5 |
| $CH_4$ | t | 0.9 | 1.1 | 2.0 | 4.2 | 4.3 | 2.9 | 2.7 | 3.1 | 2.4 |
| $N_2O$ | t | 0.2 | 0.2 | 0.4 | 0.8 | 0.8 | 0.6 | 0.5 | 0.6 | 0.5 |
| $CO_2$ eqv | kt | 21.7 | 26.6 | 49.4 | 100.6 | 102.7 | 70.2 | 65.6 | 74.8 | 58.7 |

Since the emission factors are constant throughout the time series, any increase or decrease in emissions are caused by an equal development in activity. Emissions increased with 363 % from 1990 to 2005, after which they started decreasing (-42 % from 2005-2018). The overall development from 1990 to 2018 in an increase of 170 %.

The decrease in the later years is believed to be caused by an increased awareness on indoor climate/pollution and an increased sale of LED candles.

#### Time series consistency and completeness

The time series is both consistent and complete.

### 4.5.5 Solvent use

The category Solvent use (CRF 2D3 Other) is aggregated according to the following categories, which correspond to the grouping in IPCC (2006):

- 06 01 00 Paint application
- 06 02 02 Degreasing, dry cleaning and electronics
- 06 03 00 Chemical products manufacturing or processing
- 06 04 00 Other use of solvents and related activities
- 06 04 03 Printing industry
- 06 04 08 Domestic solvent use (other than paint application)

Only NMVOC, which is subsequently oxidised to $CO_2$ in the atmosphere, is relevant for these categories. To be consistent with the reporting during the first commitment period of the Kyoto Protocol, Denmark has continued to report these indirect $CO_2$ emissions under sector 2D rather than reporting them separately under indirect $CO_2$.

#### Methodology

NMVOC emissions from solvent use are estimated using emission modelling of solvents by estimating the amount of (pure) solvents consumed, thus representing a chemicals approach, where each pollutant is estimated separately. All relevant solvents must be estimated, or at least those together representing more than 90 % of the total pollutant emission. These emissions are summed up to one national total $CO_2$ (NMVOC) emissions from solvent use.

The method is mainly based on the detailed approach and methodology described in EMEP/EEA (2016) and emissions are calculated for industrial sectors, households and for individual pollutants.

#### Activity data

Description of compilation of activity data can be found in Nielsen et al. (2019) Chapter 4.5.2. Activity data for solvent use is presented in Table 4.5.7 and Annex 3C-28.

Table 4.5.7 Solvent consumption activity data, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Paint application | 83.5 | 91.0 | 104.3 | 74.2 | 44.4 | 43.0 | 41.4 | 38.5 | 37.7 |
| Degreasing, dry cleaning and electronics | 1.4 | 1.5 | 0.6 | 0.4 | 0.2 | 0.2 | 0.1 | 0.2 | 0.3 |
| Chemical products manufacturing or processing | 406.9 | 503.6 | 564.0 | 740.1 | 647.8 | 511.7 | 479.9 | 531.2 | 518.6 |
| Other use of solvents and related activities | 176.4 | 212.0 | 198.3 | 177.4 | 145.9 | 144.0 | 133.4 | 133.1 | 130.6 |
| Printing industry | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 |
| Domestic solvent use (other than paint application) | 29.1 | 43.9 | 41.1 | 35.5 | 26.1 | 39.1 | 33.9 | 28.9 | 41.8 |

#### Emission factors

Emission factors are calculated for a complete conversion to $CO_2$ of each NMVOC molecule in units g $CO_2$ per g NMVOC from:

$$n \cdot 12 \frac{g}{mol} \Big/ (molecular\ weight\ NMVOC) \cdot 3.667 \frac{g\ CO_2}{g\ C}$$

where $n$ is the number of carbon atoms in the NMVOC molecule. Further description of the methodology for derivation of emission factors in categories can be found in Nielsen et al. (2019) Chapter 4.5.2. The implied emission factors are presented in Table 4.5.8 and Annex 3C-29.

Table 4.5.8 $CO_2$ emission factors for solvent use.

| | Unit | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| Paint application | t/kt | 154.4 | 160.3 | 151.7 | 138.6 | 146.5 | 145.0 | 151.4 | 141.9 | 142.2 |
| Degreasing, dry cleaning and electronics | t/kt | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Chemical prod. manufacturing/processing | t/kt | 47.8 | 43.6 | 30.0 | 21.1 | 19.2 | 23.2 | 22.7 | 22.0 | 24.3 |
| Other use of solvents and related activities | t/kt | 294.9 | 271.3 | 273.4 | 217.7 | 250.1 | 219.2 | 225.5 | 221.7 | 224.9 |
| Printing industry | t/kt | 81.1 | 86.4 | 80.0 | 70.3 | 77.9 | 75.5 | 77.0 | 75.5 | 75.8 |
| Domestic solvent use (not paint application) | t/kt | 321.1 | 331.3 | 328.1 | 315.8 | 269.6 | 308.8 | 299.4 | 294.7 | 319.4 |

**Emission trends**

Table 4.5.9, Figure 4.5.2 and Annex 3C-30 show the emissions of $CO_2$ from solvent use. The general decrease from 1997 to present is an indication of increased implementation of NMVOC emission reducing measures in production facilities, and a general shift to water soluble and high solid products, in e.g. the graphics-, paint-, plastic- and auto paint and repair industries. Further information can be found in Nielsen et al. (2019) Chapter 4.5.2.

Table 4.5.9 $CO_2$ emissions from solvent use.

| | Unit | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| Paint application | kt | 12.9 | 14.6 | 15.8 | 10.3 | 6.5 | 6.2 | 6.3 | 5.5 | 5.4 |
| Degreasing, dry cleaning and electronics | kg | 37.4 | 40.6 | 15.1 | 9.7 | 5.5 | 4.1 | 1.4 | 6.6 | 7.1 |
| Chemical products manufacturing or processing | kt | 19.4 | 22.0 | 16.9 | 15.6 | 12.4 | 11.9 | 10.9 | 11.7 | 12.6 |
| Other use of solvents and related activities | kt | 52.0 | 57.5 | 54.2 | 38.6 | 36.5 | 31.6 | 30.1 | 29.5 | 29.4 |
| Printing industry | t | 16.2 | 19.8 | 14.9 | 13.3 | 19.8 | 18.1 | 16.1 | 18.2 | 17.4 |
| Domestic solvent use (not paint application) | kt | 9.4 | 14.6 | 13.5 | 11.2 | 7.0 | 12.1 | 10.2 | 8.5 | 13.4 |
| Total $CO_2$ | kt | 93.7 | 108.6 | 100.4 | 75.7 | 62.5 | 61.8 | 57.4 | 55.2 | 60.7 |

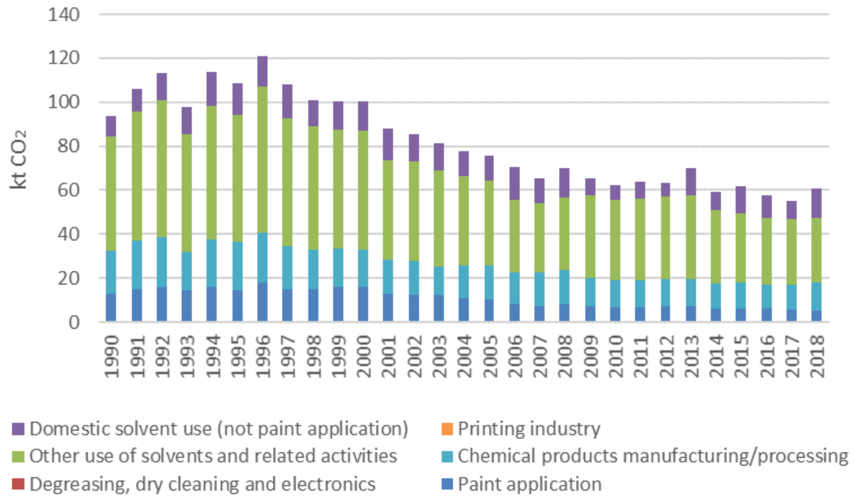


Figure 4.5.2 $CO_2$ emissions from solvent use, kt.

**Time series consistency and completeness**

The time series is considered to be both consistent and complete. For verification, please refer to Hjelgaard & Nielsen (2018).

### 4.5.6 Road paving with asphalt

The category Road paving with asphalt (CRF 2D3 Other) covers the following activity:

- 04 06 11 Road paving with asphalt

### Methodology

Road paving with asphalt is an activity that can be found all over the country and especially in relation to establishing new traffic facilities. The raw materials for construction of transport facilities are prepared on one of the plants located near the locality of application to limit the transport distance. The asphalt concrete is mixed and brought to the locality of application on a truck.

Transport facilities are constructed by a number of different layers:

- a load bearing layer (e.g. course gravel)
- an adhesive layer (liquefied asphalt e.g. "cutback" asphalt or asphalt emulsion)
- a wearing coarse (e.g. hot mix asphalt concrete).

Different qualities of "cutback" asphalt (e.g. asphalt dissolved in organic solvents/petroleum distillates) and asphalt emulsion contains different kinds and amounts of solvent. Cutback asphalt contains 25-45%v/v solvent e.g. heavy residual oil, kerosene-type solvent, naphtha or gasoline solvent. Approximately 500.000 liter solvent evaporates annually from the use of "cutback" asphalt (Asfaltindustrien, 2003). This amount of solvent, which is added to the asphalt, is comprised in the category 2D3 Other: Solvent use, described above with an emission factor of approximately unity. This means that NMVOC emissions from "cutback" asphalt in Road paving only include emissions from the asphalt fraction, which is included in Table 4.5.10.

Indirect $CO_2$ emissions are calculated from NMVOC, $CH_4$ and CO emissions. To be consistent with the reporting during the first commitment period of the Kyoto Protocol, Denmark has continued to report indirect $CO_2$ emissions from road paving with asphalt under category 2D rather than separately under indirect $CO_2$.

### Activity data

The used amounts of asphalt for road paving have been compiled from production, import and export statistics of asphalt products in Statistics Denmark (2019) and are presented in Table 4.5.10 and Annex 3C-31.

Table 4.5.10 Activity data for asphalt in road paving, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Road paving with asphalt | 2535 | 3144 | 2933 | 3879 | 3005 | 3440 | 3600 | 3662 | 4089 |

### Emission factors

Emission factors are available in Table 4.5.11 below.

Table 4.5.11 Emission factors for road paving with asphalt incl. cutback.

| Pollutant | Unit | Emission factor value | Source |
|---|---|---|---|
| $CO_2$ | kg/t | 0.23 | Calculated emission factor: Indirect $CO_2$ from NMVOC, $CH_4$ and CO |
| $CH_4$ | g/t | 4.4 | US EPA (2004) |
| NMVOC | g/t | 16.0 | EMEP/EEA (2016) |
| CO | g/t | 120.2 | US EPA (2004) |

### Emission trends

Greenhouse gas emissions from road paving with asphalt are presented in Table 4.5.12 and Annex 3C-32.

Table 4.5.12 Emissions from road paving with asphalt, t.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ | 583 | 723 | 675 | 892 | 691 | 791 | 828 | 842 | 940 |
| $CH_4$ | 11 | 14 | 13 | 17 | 13 | 15 | 16 | 16 | 18 |

#### Time series consistency and completeness

The time series is considered to be both consistent and complete.

### 4.5.7 Asphalt roofing

The source category Asphalt roofing (CRF 2D3 Other) covers the following activity:

- 04 06 10 Asphalt roofing

#### Methodology

The asphalt industry produces a number of products, e.g. roofing and siding shingles, for use in roofing. Key steps in the total production and roofing process include asphalt storage, asphalt blowing, felt saturation, coating and mineral surfacing.

Asphalt blowing is the process of polymerising and stabilising asphalt to improve its weathering characteristics, and it may take place in an asphalt processing or roofing plant, or in a refinery. Only asphalt blowing is covered in IPCC (2006) and in the Danish inventory, as it leads to the highest emissions of NMVOC and CO in the total production and roofing process.

Indirect $CO_2$ emissions from NMVOC and CO emissions from asphalt blowing in asphalt roofing are included. To be consistent with the reporting during the first commitment period of the Kyoto Protocol, Denmark has continued to report indirect $CO_2$ emissions from asphalt roofing under category 2D rather than separately under indirect $CO_2$.

#### Activity data

The use amounts of asphalt for roofing have been compiled from production, import and export statistics of asphalt products in Statistics Denmark (2019). Activity data are presented in Table 4.5.13 and Annex 3C-33.

Table 4.5.13 Activity data for asphalt roofing, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Asphalt roofing | 56.1 | 57.0 | 88.5 | 69.6 | 43.9 | 47.0 | 49.5 | 54.8 | 58.8 |

#### Emission factors

Emission factors are available in Table 4.5.14 below.

Table 4.5.14 Emission factors for asphalt roofing (asphalt blowing).

| Pollutant | Unit | Emission factor value | Source |
|---|---|---|---|
| $CO_2$ | kg/t | 0.40 | Calculated emission factor: Indirect $CO_2$ from NMVOC and CO |
| NMVOC | g/t | 130 | EMEP/EEA (2016) |
| CO | g/t | 9.5 | EMEP/EEA (2016) |

#### Emission trends

Greenhouse gas emission from asphalt roofing are presented in Table 4.5.15 and Annex 3C-34.

Table 4.5.15 Emissions from asphalt roofing, t.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ | 22.4 | 22.8 | 35.4 | 27.8 | 17.6 | 18.8 | 19.8 | 21.9 | 23.5 |

#### Time series consistency and completeness

The time series is considered to be both consistent and complete.

### 4.5.8 Urea-based catalysts

#### Methodology

The category Urea-based catalysts (CRF 2D3 Other) covers $CO_2$ emissions from urea-based additives used in catalytic converters in heavy duty vehicles to bring down $NO_x$ emissions:

- 06 06 07 Urea-based catalysts

The consumption of urea by SCR catalysts for heavy duty vehicles is estimated with the DCE emission model for road transport by using fuel consumption totals and urea consumption rates for relevant engine technologies. The DCE model uses the COPERT 5 detailed methodology as explained in Chapter 3.3. SCR catalysts are used by Euro V and VI trucks and to a smaller extent by Euro IV trucks as an emission abatement technology in order to bring down $NO_x$ emissions.

#### Activity data

According to COPERT 5, the consumption of urea is 5-7 % by volume of fuel for Euro IV/V heavy duty vehicles (6 % is used) and 3-4 % for Euro VI heavy duty vehicles (3.5 % is used). Activity data for the use of urea is presented in Table 4.5.16 and Annex 3C-35.

Table 4.5.16 Activity data for use of urea in catalysts, kt.

| | 2001 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|
| Urea | 0.002 | 0.040 | 10.5 | 33.8 | 35.5 | 36.9 | 37.5 |

#### Emission factors

For each vehicle layer, the emissions of $CO_2$ are subsequently estimated as the product of urea consumption and a $CO_2$ emission factor of 0.26 kg $CO_2$ per l urea (EMEP/EEA, 2019).

#### Emission trends

$CO_2$ emissions from the use of urea in catalysts are presented in Table 4.5.17 and Annex 3C-36.

Table 4.5.17 $CO_2$ emissions from the use of urea in catalysts, kt.

| | 2001 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 0.001 | 0.009 | 2.5 | 8.1 | 8.5 | 8.8 | 8.9 |

#### Time series consistency and completeness

The time series is considered to be both consistent and complete.

## 4.6 Electronics Industry

### 4.6.1 Source category description

The sector *Electronic Industry* (CRF 2E) covers the use of HFCs and PFCs in the production of fibre optics. There is no production of semiconductors, TFT flat panels or photovoltaics with use of F-gases in Denmark. No use of HFCs or PFCs as heat transfer fluids occur in Denmark.

As a result the only relevant category is:

- 2E5 Other: HFC-23, PFC-14 ($CF_4$) and PFC-318 ($c\text{-}CF_4F_8$) from fibre optics

The description of consumption and emission of F-gases given below is based on an inventory by Poulsen (2019 and 2020). For further details refer to these reports.

### 4.6.2 Emissions

The use of F-gases in the production of fibre optics did not start until 2001 and hence the time series covers the years 2001-2018. The emission time series for *Electronics Industry* (2E) is available in the CRF tables but is also presented in Figure 4.6.1.

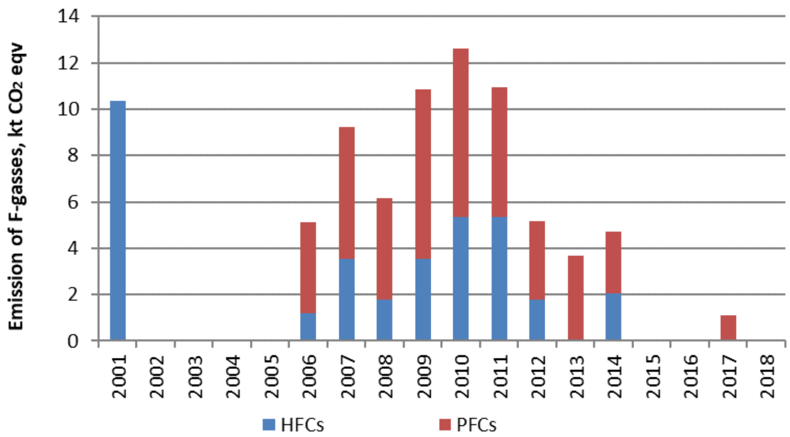

Figure 4.6.1 Emissions of HFCs and PFCs from *Electronics Industry.*

### 4.6.3 Other electronics industry

As mentioned above, optic fibre production is the only source category relevant for the Danish inventory on electronic industries.

#### Methodology

Both HFCs (HFC-23) and PFCs (PFC-14 and PFC-318) are used for technical purposes in Danish optics fibre production for protection and as cleaning gases in the production process. Information on consumption of HFCs and PFCs in production of fibre optics is derived from annual importers' sales report with specific information on the amount used for production of fibre optics. This is believed to represent 100% of the Danish consumption of F-gases for that purpose. The emission factor is 1, i.e. 100 % release in the production year (i.e. year of consumption). The methodology corresponds to the IPCC Tier 2 method.

#### Activity data

There has been no use of F-gasses in 2002-2005, 2015-2016 or 2018. The consumption data are provided in Figure 4.6.2 below and Annex 3C-37.

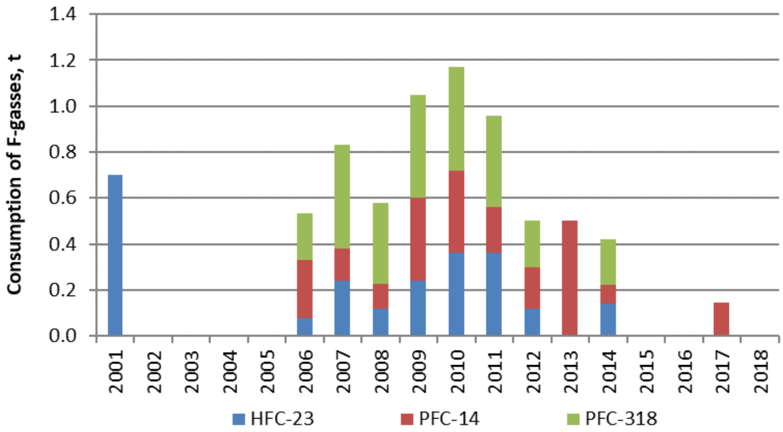


Figure 4.6.2 Consumption of F-gases in production of fibre optics, t.

#### Emission factors

Since HFC-23 and the PFCs are used as protection and cleaning gases as well as for etching in optics fibre production, the emission factor is defined as 100 % release during production.

#### Emission trends

Emission trends are presented in Figure 4.6.3 below and Annex 3C-38.

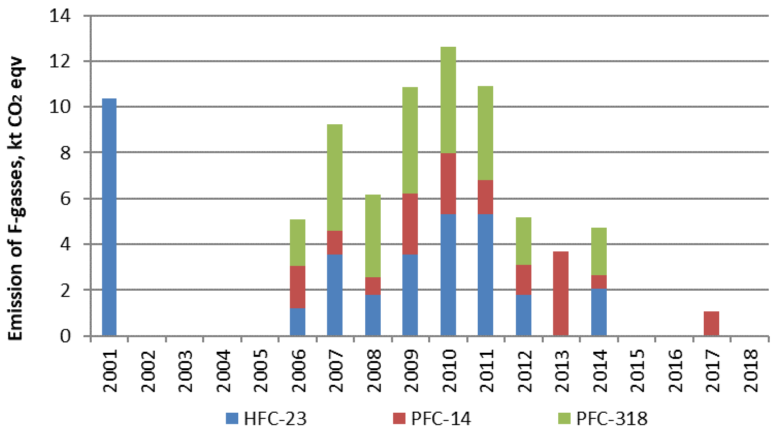


Figure 4.6.3 Emissions from Electronic industry, kt $CO_2$ eqv.

#### Time series consistency and completeness

The estimates are based on information directly from the importer supplying this sector in Denmark. As Denmark is a small country with a limited consumption of F-gasses, there are only few importers. Data collection for the F-gas report (Poulsen, 2019 and 2020) is done in close corporation with the industry associations enabling inclusion of any new importers of F-gases or F-gas containing products. The time series is therefore considered both complete and consistent.

## 4.7 Product Uses as Substitutes for Ozone Depleting Substances (ODS)

### 4.7.1 Source category description

The sub-sector *Product uses as substitutes for ODS* (2F) includes the following source categories and the following F-gases of relevance for Danish emissions:

- 2F1: Refrigeration and air conditioning: HFC-32, -125, -134a, -143a, -152a, unspecified mix of HFCs, PFC-218 and PFC-14

- 2F2: Foam blowing agents: HFC-134a, -152a
- 2F4: Aerosols: HFC-134a
- 2F5: Solvents: PFC-218

It must be noted that the inventories for the years 1990-1994 might not cover emissions of these gases in full. The choice of base-year for these gases under the Kyoto Protocol is 1995 for Denmark.

Two key categories were identified for the emission of HFCs in the sub-sector *Product uses as substitutes for ODS* (2F); refrigeration and air conditioning for level in 2018 and for trend (both Approach 1 and Approach 2) and foam blowing agents for level in the base year (Approach 2) and for trend (Approach 1 and Approach 2).

The description of consumption and emission of F-gases given below is based on an inventory by Poulsen (2019 and 2020). For further details, refer to these reports.

### 4.7.2 Emissions

The emission time series for *Product uses as substitutes for ODS* (2F) are presented in Figure 4.7.1 and Figure 4.7.2 below.

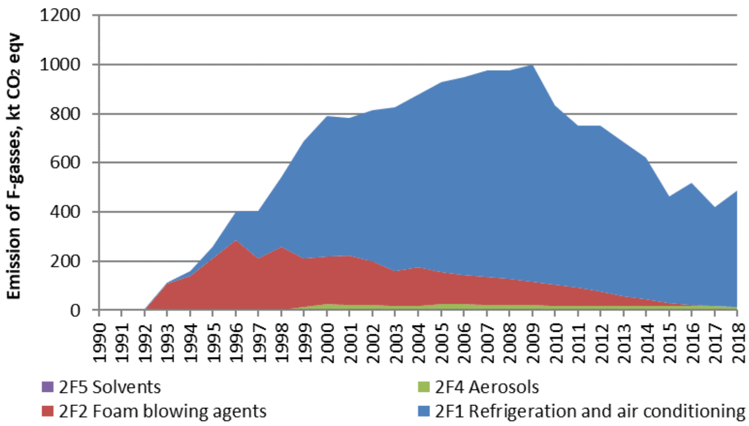


Figure 4.7.1 Emission of F-gases from the individual source categories within *2F Product uses as substitutes for ODS*, kt $CO_2$ eqv.

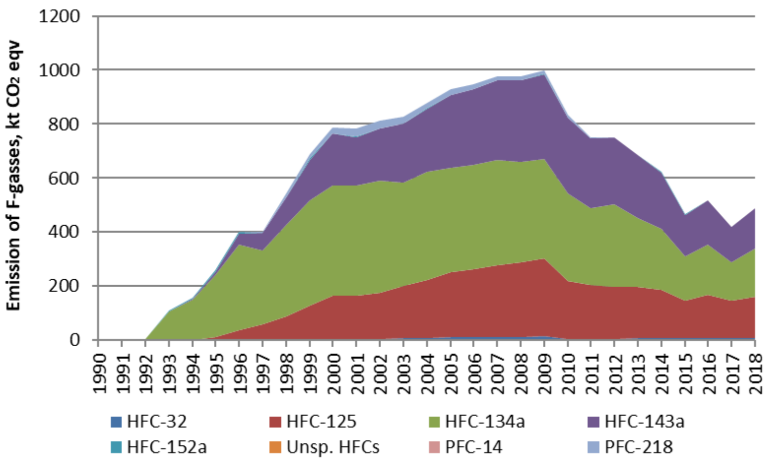


Figure 4.7.2 Emission of F-gases from the individual gases within 2F Product uses as substitutes for ODS, kt $CO_2$ eqv.

The emission of HFCs increased rapidly in the 1990s and, thereafter, increased more modestly due to a moderate increase in the use of HFCs as a refrigerant and a decrease in foam blowing. The F-gases have been regulated in two ways since 1 March 2001. For some types of use there is a ban on use of the gases in new installations and for other types of use, taxation is in place. These regulations seem to have influenced emissions so that since 2009, an overall decreasing trend can be observed.

#### General trends

The phase out of F-gases has in particular been effective within the foam blowing sector and refrigeration and air conditioning installations. Regarding foam blowing, there was a stepwise phase-out of HFC-134a used for foam blowing in closed cell and open cell foam production, during the period 2001-2004. Especially the phase-out of HFCs in open cell foam is significant for the emission in this period.

Since the introduction of taxes on HFCs in 2001, the consumption from foams has seen a steady decrease and is almost entirely gone in 2018. But the emission of HFCs for refrigeration continued to increase until 2009, especially HFC-404a and HFC-134a increased. This increase is explained with other initiatives in Danish legislation, where new refrigeration systems containing HCFC-22 (ODS) was banned from 2001. It caused a boom in refrigeration systems using HFCs during 2002-2004, because the HFC technology was cheap and well proven. The consumption of HFCs for refrigeration changed significantly after 1 January 2007, where new larger HFC installations with charges exceeding 10 kg were banned. The emission of HFC-134a peaked in 2007, but the peak for HFC-125 and HFC-143a is not seen until 2009. Alternative refrigeration technologies based on $CO_2$, propane/butane and ammonia are now introduced and available for customers.

The import of PFC-218 ($C_3F_8$) has been very low since 2008, and as expected, this refrigerant has been phased out of the marked. Emissions have been decreasing since 2002, and no emissions of PFC-218 are reported after 2014. The use of PFC-218 ($C_3F_8$) as a solvent only occurred from 2000 to 2003.

A quantitative overview is given below (Figure 4.7.3 – Figure 4.7.6) for each of the four source categories, showing their emissions in tonnes of $CO_2$ equivalents through the times series.

### 4.7.3 General methodology

The data for emissions of HFCs and PFCs have been obtained in continuation of the work on previous inventories. The determination includes the quantification and determination of any import and export of HFCs and PFCs contained in products and substances in stock form. This is in accordance with the IPCC guidelines (IPCC, 2006).

For the Danish inventories of F-gases, a Tier 2 bottom-up approach is basically used. In Annex 3 to the F-gas inventory report (Poulsen, 2019 and 2020), there is a specification of the approach applied for each sub-source category.

The following sources of information have been used:

- Importers, agency enterprises, wholesalers and suppliers
- Consuming enterprises, and trade and industry associations
- Danish Environmental Protection Agency

- Recycling enterprises and chemical waste recycling plants
- Statistics Denmark
- Danish Refrigeration Installers' Environmental Scheme (KMO)
- Previous evaluations of HFCs, PFCs and $SF_6$

Suppliers and/or producers provide consumption data of F-gases. Emission factors are primarily defaults from the IPCC guidelines, which are assessed to be applicable in a national context. In the case of commercial refrigerants and Mobile Air Conditioning (MAC), information from Danish suppliers has been used. The actual amount of F-gas used for refilling is used as an estimate on the actual emission.

Import/export data for sub-source categories where import/export is relevant (e.g. MAC and fridges/freezers for households) are quantified on estimates from import/export statistics of products + default values of the amount of gas in the product. The estimates are transparent and described in Appendix 3 of Poulsen (2020).

The Tier 2 bottom-up analysis used for determination of emissions from HFCs, PFCs and $SF_6$ covers the following activities:

- Screening of the market for products in which F-gases are used
- Determination of averages for the content of F-gases per product unit
- Determination of emissions during the lifetime of products and disposal Identification of technological development trends that have significance for the emission of F-gases
- Calculation of import and export is based on defined key figures, and information from Statistics Denmark on foreign trade and industry information

The determination of emissions of F-gases is based on a calculation of the actual emission. The actual emission is the emission in the evaluation year, accounting for the time lapse between consumption and emission. The actual emission includes Danish emissions from production, from products during their lifetimes and from disposal.

Whenever possible, consumption and emissions of F-gases are determined for individual substances, even though the consumption of certain HFCs has been very limited. This has been carried out to ensure transparency of evaluation in the determination of GWP values. However, the continued use of a category for *Unspecified mix of HFCs* has to a small extent been necessary since not all importers and suppliers have specified records of sales for individual substances.

The substances have been accounted for in the annual survey according to their trade names, which are mixtures of HFCs used in the CRF, etc. In the transfer to the "pure" substances used in the CRF reporting tables, the ratios provided in Table 4.7.1 have been used.

Table 4.7.1 Content (w/w%)[1] of "pure" HFC in HFC-mixtures, used as trade names.

| HFC mixtures | HFC-32 | HFC-125 | HFC-134a | HFC-143a | HFC-152a | HFC-227ea |
|---|---|---|---|---|---|---|
| | % | % | % | % | % | % |
| HFC-365 | | | | | | 8 |
| HFC-401a | | | | | 13 | |
| HFC-402a | | 60 | | | | |
| HFC-404a | | 44 | 4 | 52 | | |
| HFC-407c | 23 | 25 | 52 | | | |
| HFC-410a | 50 | 50 | | | | |
| HFC-507a | | 50 | | 50 | | |

[1]The mixtures also contain substances that do not have GWP values and therefore, the substances do not sum up to 100 %.

The national inventories for F-gases are provided and documented in an annual report (Poulsen, 2019 and 2020). Furthermore, detailed data and calculations are available and archived in an electronic version. The report contains summaries of methods used and information on sources as well as further details on methodologies.

### 4.7.4 Refrigeration and air conditioning

2F1 Refrigeration and air conditioning consists of the following subcategories:

- 2F1a Commercial refrigeration
- 2F1b Domestic refrigeration
- 2F1c Industrial refrigeration (included under commercial)
- 2F1d Transport refrigeration
- 2F1e Mobile air-conditioning
- 2F1f Stationary air-conditioning

The use of HFCs in industrial refrigeration was previously surveyed and the conclusion was that large-scale industrial refrigeration e.g. slaughterhouses, fish factories and medico companies use ammonia based refrigeration units. This is particularly caused by the tax on HFCs in Denmark that makes HFC based refrigeration units with large charges too expensive and furthermore the ban from 2007. Smaller HFC based units will occur in industry, but is then similar to commercial refrigeration units. Since it is not possible to separate small-scale industrial and commercial refrigeration units, all consumption and emissions are reported under commercial refrigeration.

#### Methodology

For refrigeration and air-conditioning, Denmark uses mainly the Tier 2 top-down approach (Tier 2b). However, for Domestic Refrigeration the methodology is a combination of Tier 2a and 2b. For more information on the applied methodology please refer to Poulsen (2019 and 2020).

According to Danish law, refrigerators and air-conditioning equipment must be emptied before decommissioning by recovery, reuse or destruction of the remaining gases. It is reasonable to assume that this law is upheld in Denmark since waste collection is mandatory and there are no extra charges for e.g. getting rid of a used refrigerator. In addition, to recycling plants where companies and individuals can deliver their waste there is also a collection scheme, where e.g. used refrigerators are collected at the sidewalks and disposed of. Due to this there is no reason why people would chose to illegally dispose of an appliance when the legal disposal is both free and easy. The notation key

”Not occurring” (NO) is therefore used in the CRF for the amounts of HFCs remaining in products at decommissioning.

**Activity data**

The data collection is described in the Chapter 4.7.3 General methodology.

The activity data expressed as total amount of HFCs and PFCs filled into new products, present in operating systems and remaining in products at decommissioning are included in the CRF tables and are not repeated here.

Heat pumps are part of category 2.F.1.f Stationary air-conditioning. There is however no production of heat pumps in Denmark and the stock of HFC-32, HFC-125, HFC-134a and unspecified HFCs in heat pumps therefore increases without any emissions from manufacture.

**Emission factors**

The applied emission factors are presented in Table 4.7.2.

Table 4.7.2 Applied emission factors for refrigeration and air-condition systems.

| | | Assembly, % | Stock, % per annum | Lifetime, years | Recovery, % |
|---|---|---|---|---|---|
| 2.F.1.a | Commercial and industrial refrigerators[1] | 0.5-1.5 | 3-10 | 15 | 88.5-100 |
| 2.F.1.b | Household fridges and freezers | 2 | 1 | 15 | 100 |
| 2.F.1.d | Transport refrigeration | 0.5 | 17 | 7 | 88.5 |
| 2.F.1.e | Mobile air conditioning systems[2] | 4.5 | 30 | 3-15 | 88.5-100 |
| 2.F.1.f | Stationary air-conditioning[3] | 0.5-1.5 | 3-10 | 15 | 88.5 |
| | - Heat pumps[4] | 0.2 | 3 | 10 | 80 |

[1] For HFC-449a EFs change from 2010, from 1.5 % to 0.5 % for assembly and from 10 % to 3 % for stock, for PFC-218 recovery is 100 %.
[2] For pure HFC-134a, EFs are 15 years and 88.5 % recovery, for HFC-404a, EFs are 3 years and 100 % recovery.
[3] For all HFCs except pure HFC-134a EFs change from 2010, from 1.5 % to 0.5 % for assembly, for all HCFs EFs change from 10 % to 3 % for stock from 2010.
[4] EFs for heat pumps are mentioned separately from the remaining 2.F.1.f category.

The reduction in emission factor from 10% leakage rate to 3% leakage rate from 2010 is implemented based on an expert judgement of when the technologies improved and next generation units were introduced to the market (Poulsen, 2019 and 2020).

Detailed information on the amount of HFCs used for refilling of mobile A/C has been available and applied for the years 2009 - 2011, and therefore, a new approach has been implemented in the calculation of emissions from these years onward. HFCs for mobile A/C are only used for refilling, and therefore the amount used for mobile A/C is assumed to be the same as the amount emitted during use (Poulsen, 2019):

Consumption of HFC for MAC = refilled stock = emission

**Emission trends**

Figure 4.7.3 present the emissions of F-gases from consumption of HFCs and PFCs in the individual sub-categories of refrigeration and air-conditioning systems.

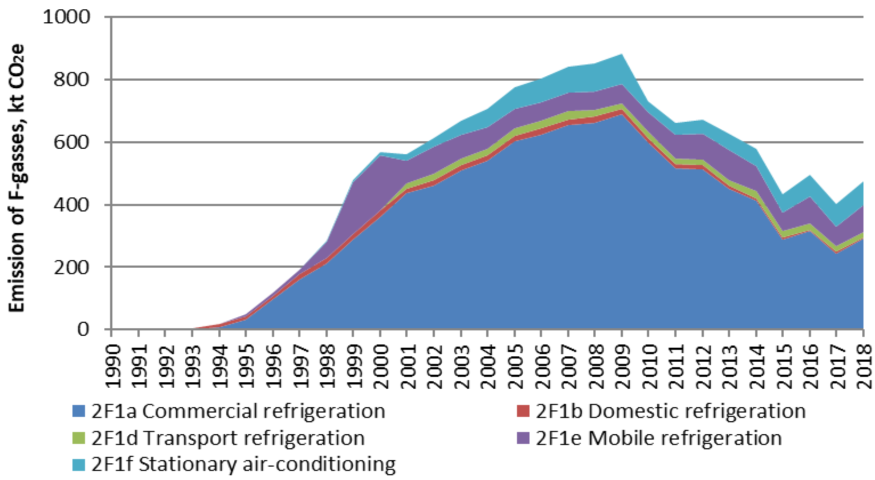


Figure 4.7.3 Emissions from refrigeration and air-conditioning.

F-gas emissions from commercial refrigeration are dominating the overall emissions from this source. Hence, the increasing trend from the mid-1990s to 2008 and the subsequent decrease in emissions are explained in Chapter 4.7.2 Emissions.

EU F-gas Regulation 517/2014, Annex III entered into force on 1 January 2015 placing a ban on sale/installation of domestic refrigeration appliances containing F-gases with a GWP>150. However, for 2015-2018 amounts of HFC 125 (GWP 3500), HFC-134a (GWP 1430) and HFC 143a (GWP 4470) are reported as "filled into new manufactured products" in the domestic refrigeration subcategory. The single producer responsible for this consumption confirms the consumption of HFC 134a and HFC-404a for domestic appliances and biomedical coolers and freezers. The producer was at the time of contact not aware of the ban but is now informed of the regulation and expected to take the necessary actions.

### 4.7.5 Foam blowing agents

2F2 Foam blowing agents consists of the following processes:

- Closed cells (hard foam)
- Open cells (soft foam)

In Denmark, five specific processes have occurred during the time series, i.e. foam in household fridges and freezers (closed cell), soft foam (open cell), joint filler (open cell), foaming of polyether for shoe soles (closed cell) and system foam for panels, insulation etc. (closed cell)

#### Methodology

The methodology used varies between the different processes. For all processes the methodology corresponds to the Tier 2 level of IPCC (2006). For some processes a bottom-up methodology is applied while for others a top-down approach or a combination of top-down and bottom-up is used. For more information on the details of the applied methodology, please refer to Poulsen (2019 and 2020).

#### Activity data

The data collection is described in the Chapter 4.7.3 General methodology.

There is no longer production of HFC-based hard PUR insulation foam in Denmark. This production has been banned in statutory order since 1. January 2006 (MIM, 2002)

### Emission factors

The applied emission factors for foam blowing agents are presented in Table 4.7.3 (Poulsen, 2020 – Appendix 3).

Table 4.7.3 Applied emission factors for foam blowing agents (2F2).

| | Consumption | Stock | Lifetime |
|---|---|---|---|
| | % | % | years |
| Foam in household fridges and freezers (closed cell) | 10[4] | 4.5[4] | 15[5] |
| Soft foam (open cell)[1] | 100[4] | | |
| Joint filler (open cell)[1] | 100[4] | | |
| Foaming of polyether for shoe soles (closed cell) | 15[5] | 4.5[5] | 3[5] |
| System foam (for panels, insulation, etc.) | 0[2] | -[3] | |

[1] 100 % emission during the first year after production. [2] HFC is used as a component in semi-manufactured goods and emissions first occur when the goods are put into use. [3] System foam is only produced for export. [4] IPCC (2006) default, [5] Danish default.

System foam is produced in a closed environment and is only produced for export. Therefore, the consumption of HFCs does not contribute to the Danish stock.

The emission factors for foam in fridges and freezers, soft foam and joint filler are default values from (IPCC, 2006[5]). The emission factors for foaming of polyether are country-specific (Poulsen, 2019 and 2020).

The F-gases remaining in products at decommissioning (closed cell products) are destroyed by incineration and hence there are no F-gas emissions related to disposal of these products.

### Emission trends

Figure 4.7.4 presents the emissions of F-gases from consumption of HFCs in foam blowing agents.

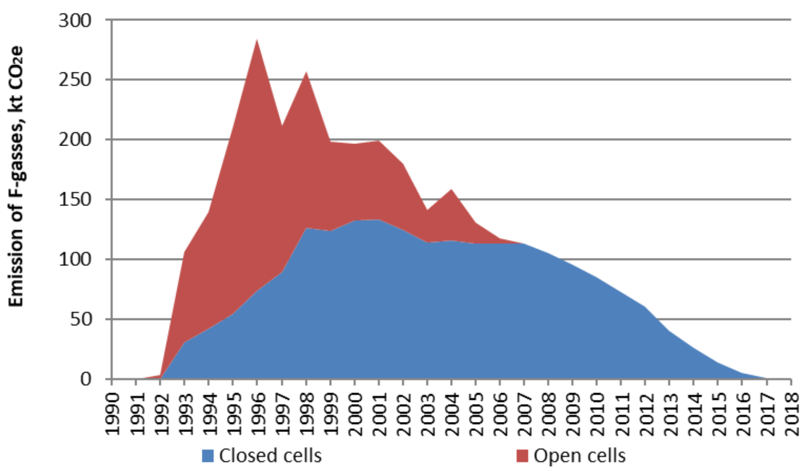


Figure 4.7.4 Emissions from foam blowing agents.

[5] Volume 3: Industrial Processes and Product Use, Chapter 7.4.2.1: Foam blowing agents, Choice of method, Table 7.5, page 7.35 and Chapter 7.4.2.3: Foam blowing agents, Choice of activity data, page 7.38.

The sharp fluctuations in the time series are caused by fluctuations in the consumption of HFCs in production of open cell foam, with an emission factor of a 100 % in the given year. For the later part of the time series the trend reflects the limited use of HFCs and reflects the emission from the stock of previous use of HFCs.

### 4.7.6 Fire protection

No HFCs or PFCs are used in fire protection in Denmark. The use of halogen substituted hydrocarbons has been banned since 1977 (MIM, 1977), this ban is still in place (MIM, 2015).

Halon-1301 has been used in planes, in the military, in server rooms and on ships. New fire protection systems use other technologies, e.g. early fire detection, inert gases or gas mixtures (argon, nitrogen and $CO_2$) or water vapour. For mobile systems halon-1211 has been replaced with $CO_2$ or foam fire extinguishers.

### 4.7.7 Aerosols

2F4 Aerosols consist of HFCs used for:

- Propellant in aerosols
- Metered dose inhalers

#### Methodology

For HFC use as propellant in aerosol cans the IPCC (2006) Tier 2a default methodology is used. A default emission factor of 50 % of the initial charge per year is used for aerosols. For metered dose inhalers (MDI) a Tier 2 bottom-up approach is used and an emission factor of 100 % of the initial charge per year is applied.

As all F-gasses are assumed to be released during the product lifetime for all aerosols, there are no F-gasses remaining in products at decommissioning and therefore no emission from decommissioning and no recovery of F-gasses. The notation key used for these is therefore "NO" (not occurring).

#### Activity data

The general data collection process is described in the section 4.7.3 General methodology.

Information on propellant consumption is derived from reports on consumption from the only major producers of HFC-containing aerosol sprays in Denmark. The import and export are estimated by the producer.

Information on consumption of F-gasses in MDIs is based on data from the national medical trade statistic and information on product content of HFCs from the producers.

#### Emission factors

The applied emission factors are presented in Table 4.7.4 (Poulsen et al., 2020).

Table 4.7.4 Applied emission factors for aerosols/medical dose inhalers.

| | Consumption/filling | Stock | Lifetime |
|---|---|---|---|
| Aerosols | 0 % | 50 % first year<br>50 % second year | 2 years |
| Medical dose inhalers | 0 % | 100 % in year of application | 1 year |

#### Emission trends

Figure 4.7.5 presents the emissions of F-gases from consumption of HFCs in aerosols.

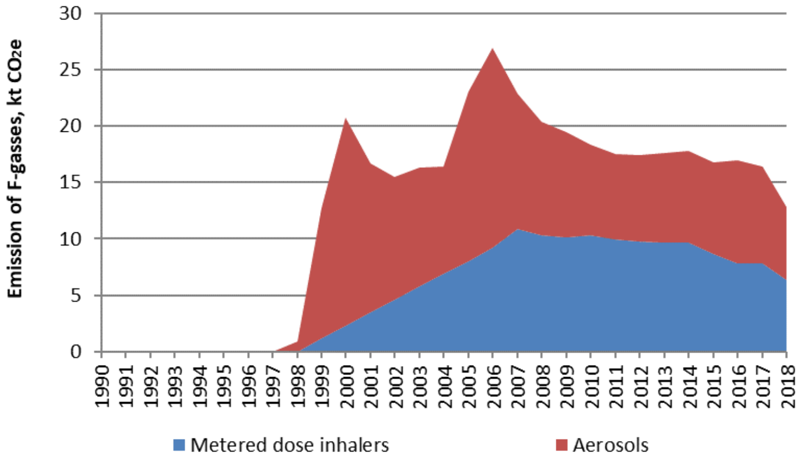


Figure 4.7.5 Emissions from aerosols.

Due to the methodology used, the fluctuations in the time series are a result of changes in import, production and export. Baring these fluctuations in mind the emission level has been rather constant at a level between 15 and 20 kt $CO_2$ equivalents in 2000-2017.

### 4.7.8 Solvents

$C_3F_8$ was used as cleaner from 2000 to 2002 (emissions in 2000-2003) and the use then ceased following the ban in accordance with the Executive Order (MIM, 2002).

#### Methodology

The methodology used is the IPCC (2006) default and the fraction of chemical emitted from solvents in the year of initial use is assumed to be 50 % in line with good practice. The other 50 % is assumed to be emitted in the second year and hence there is no subtraction of any destruction of solvents.

#### Activity data

The general data collection process is described in the section 4.7.3 General methodology.

Information on consumption of PFCs in liquid cleaners is derived from two importers' sales reports. This is representing 100% of the Danish consumption.

### Emission factors

In accordance with IPCC (2006)[6], the emission factor is 50 % in year 1 and 50 % in year 2.

### Emission trends

Figure 4.7.6 presents the emissions of F-gases from consumption of PFCs used as solvents.

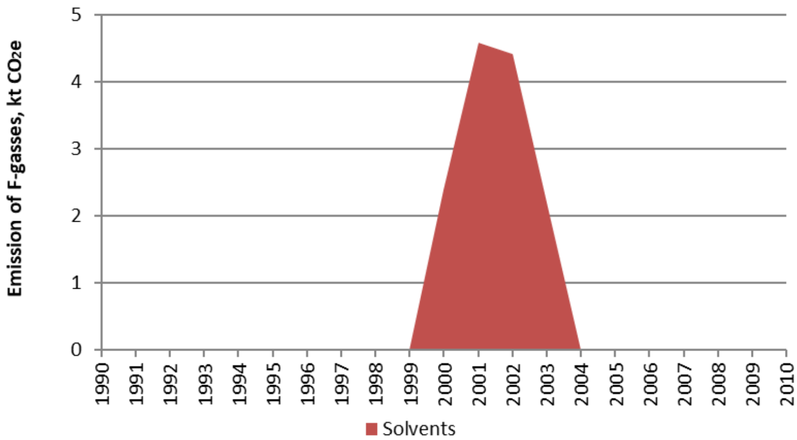


Figure 4.7.6 Emissions from PFCs used as solvents.

As mentioned the use of PFCs as solvent only occurred from 2000 to 2002 and hence emissions only occurred from 2000 to 2003.

## 4.8 Other Product Manufacture and Use

### 4.8.1 Source category description

The sector *Other Product Manufacture and Use* (CRF 2G) covers the following processes relevant for the Danish air emission inventory:

- 2G1 Electrical equipment (SNAP 060507); see section 4.8.3
- 2G2 $SF_6$ from other product uses (SNAP 060508); see section 4.8.4
- 2G3a Medical applications (SNAP 060501); see section 4.8.5
- 2G3b $N_2O$ used as propellant for pressure and aerosol products (SNAP 060506); see section 4.8.6
- 2G4 Other product uses (SNAP 060601, 060602, 060605); see section 4.8.7

### 4.8.2 Emissions

Total greenhouse gas emissions from the *Other Product Manufacture and Use* (2G) sector are available in the CRF Table 10. The emission time series for the source categories within 2G are presented in Figure 4.8.1 and individually in the subsections below (Sections 4.8.3 – 4.8.7). The following figure gives an overview of which source categories contribute the most throughout the time series.

[6] Volume 3: Industrial Processes and Product Use, Chapter 7.2.2.1: Solvents (non-aerosol), Choice of method, Equation 7.5, page 7.23 and Chapter 7.2.2.2: Solvents (non-aerosol), Choice of activity data, page 7.24.

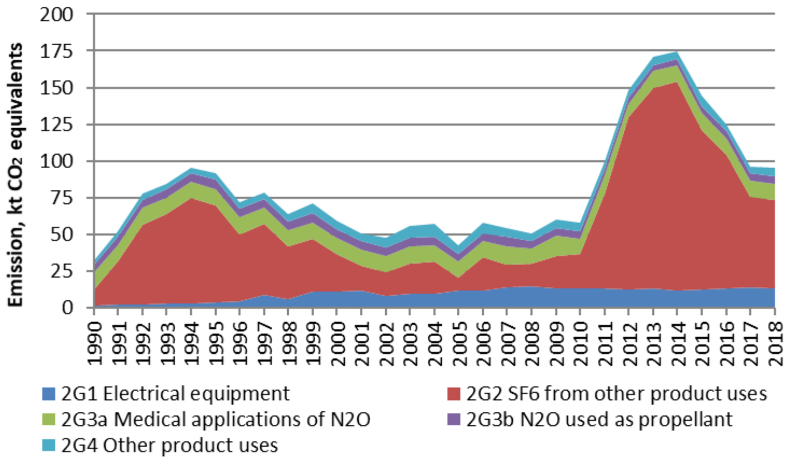


Figure 4.8.1 Emission of $CO_2$ equivalents from the individual source categories compiling *2G Other Product Manufacture and Use*.

### 4.8.3 Electrical equipment

Use of electrical equipment (2G1b) is the only source relevant for the Danish inventories in the sub sector of 2G1 *Electrical equipment*.

#### Methodology

High voltage power switches are filled or refilled with $SF_6$, either for new installation or during service and repair. Filling is usually carried out on new installations and a smaller proportion of the consumption of $SF_6$ is due to refilling.

The methodology uses annual data from importers' statistics with detailed information on the use of the gas. This corresponds to the country-level mass-balance Tier 3c methodology of IPCC (2006).

No emissions are assumed to result from disposal since the used $SF_6$ is drawn off from the power switches and re-used internally by the sole Danish supplier (Siemens) or appropriately disposed of through waste collection schemes. The notation key used for the activity data for the amount of $SF_6$ remaining in products at decommissioning of electrical equipment in the CRF is therefore "not occurring" (NO).

#### Activity data

The data collection is described in the Chapter 4.7.3 General methodology.

Information on consumption of $SF_6$ in high-voltage power switches is derived from importers' sales reports (gas or gas-containing products). The importers account for 100% of the Danish sales of $SF_6$ for this purpose.

The electricity sector also provides information on the installation of new plants and thus whether the stock is increasing.

#### Emission factors

The applied emission factors are presented in Table 4.8.1. Special attention has been given to use of $SF_6$ as insulation in high-voltage plants (Poulsen, 2001; ELTRA, 2004).

Table 4.8.1 Applied emission factors for other processes (Poulsen, 2020).

| | Consumption/ filling | Stock, per annum | Disposal | Lifetime |
|---|---|---|---|---|
| Insulation gas in high voltage switches | 5 % | 0.5 % | 0 % | -[1] |

[1] Lifetime unknown.

**Emission trends**

Figure 4.8.2 presents the emissions of $SF_6$ from electrical equipment.

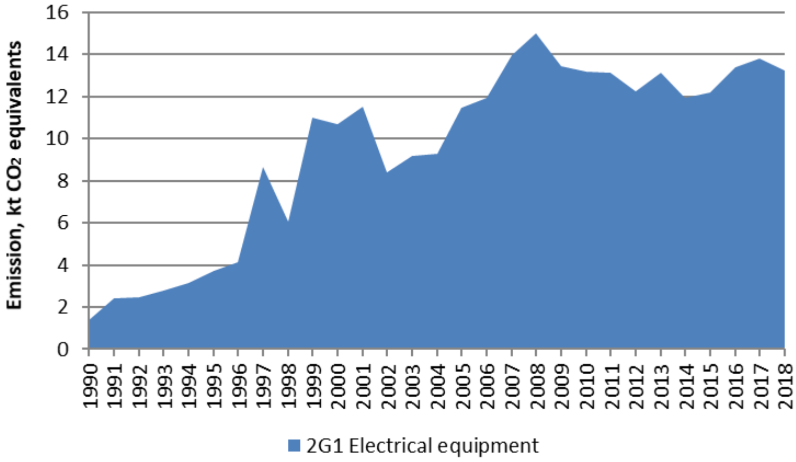


Figure 4.8.2 Emissions from $SF_6$ from electrical equipment.

The trend in emissions from use of $SF_6$ in electrical equipment has been increasing. However, significant inter-annual variations occur depending on the specific activity level in a given year.

### 4.8.4 $SF_6$ from other product use

2G2 $SF_6$ from other product use consists of the following subcategories:

- Consumption of $SF_6$ in running shoes
- Consumption of $SF_6$ in laboratories
- Consumption of $SF_6$ in double glazed windows

An overview of when emissions from these three sources occurred are available in Table 4.8.2 below.

Table 4.8.2 Occurrence of emissions from the sources compiling 2G2.

| | From manufacture | From stocks | From disposal |
|---|---|---|---|
| Running shoes | - | - | 1995-2003 |
| Laboratories | 1990-1997, 2001-2014, 2006-2018 | - | - |
| Windows | 1991-2001 | 1991-2018 | 2011-2018 |

**Methodology**

A mass balance approach is used for laboratory use of $SF_6$. For double glazed windows the default Tier 2 IPCC methodology is used with country-specific emission factor. For more information, please refer to Poulsen (2019 and 2020).

Consumption of $SF_6$ in laboratories includes consumption for a particle accelerator, a radiotherapy device and electron microscopes. Importers/suppliers of $SF_6$ have been questioned with regard to their knowledge of $SF_6$ consumption in laboratories, but no further details could be obtained. The yearly consumption reached a maximum of 1.1 tonnes of $SF_6$ in 2013 and is below 0.8

tonnes for all other years in the time series. It is therefore not considered relevant to introduce national emission factors for e.g. particle accelerators. As soon as individual emission factors are available in the Guidelines, Denmark will include these in the submission. But for now, consumption of $SF_6$ for these special purposes are reported as part of the consumption in laboratories.

### Activity data

The data collection is described in the Chapter 4.7.3 General methodology.

Information on consumption of $SF_6$ in double glazing is derived from importers' sales reports to the application area. The importers account for 100% of the Danish sales of $SF_6$ for double glazing. In addition, the largest producer of windows in Denmark has provided consumption data, with which import information is verified.

Importers have estimated imports to Denmark of $SF_6$ in training footwear.

### Emission factors

The applied emission factors are presented in Table 4.8.3.

Table 4.8.3 Applied emission factors for $SF_6$ from other product use (Poulsen, 2020).

| | Consumption | Stock | Lifetime |
|---|---|---|---|
| Laboratories | 100 % | | |
| Insulation gas in double glazed windows | 15 % | 1 % annual | 20 years |
| Shock-absorbing in Nike Air training footwear | -[1] | -[2] | 5 years |

[1] No emission from production in Denmark.
[2] Yearly emissions have been estimated to 0.11 t in 1995-2003.

80 % of the content filled into new manufactured double glazed windows is assumed to be disposed at decommissioning.

### Emission trends

Figure 4.8.3 presents the emissions of $SF_6$ from shoes, double glazed windows and other uses (laboratories etc.).

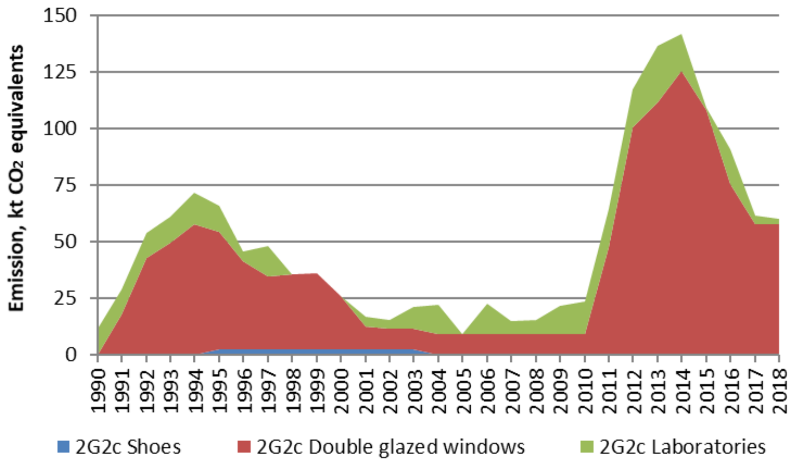


Figure 4.8.3 Emissions from $SF_6$ from other product uses.

Double-glazed windows using $SF_6$ was introduced in 1991 and ceased 10 years later. While there is annual emissions, the lifetime is assumed to be 20 years meaning that all remaining $SF_6$ contained in the windows is assumed to be emitted 20 years after the last production, i.e. starting from 2011. Emissions of $SF_6$ from this source is therefore high from 2011 (where the first windows are scrapped) and the following 10 years. However, since the use of $SF_6$ in double glazed windows was banned in 2002, by 2021 all emissions are assumed to have taken place.

### 4.8.5 Medical applications of $N_2O$

The category *Medical applications* of $N_2O$ (CRF 2G3a) covers the following SNAP-code:

- 06 05 01 Anaesthesia

#### Methodology

$N_2O$ has been used as anaesthetics for more than a hundred years but has also had other smaller applications in newer times. $N_2O$ in this source category is predominantly used as anaesthesia and a small amount is used as fuel in race cars and in chemical laboratories.

In the mid-1990s, introduction of air quality limit values for $N_2O$ together with requirements of expensive extraction systems reduced the application of $N_2O$ for anaesthetics at smaller facilities like dentists.

Five companies sell $N_2O$ in Denmark and only one company produces $N_2O$. $N_2O$ is primarily used in anaesthesia by hospitals, dentists and veterinarians and in minor use in laboratories, racing cars and in the production of electronics. Due to confidentiality, no data on produced amount are available and thus the emissions related to $N_2O$ production are unknown. For 2005-2012, sold amounts are obtained from the respective distributors and the produced amount is estimated from communication with the company. For the remaining years, data are estimated.

#### Activity data

Data on total sold and estimated produced $N_2O$ for sale in Denmark is only available for the years 2005-2012, activity data for the years 1990-2004 and 2013-2018 have therefore been estimated as the average value of 2005-2012. Activity data for the time series are presented in Table 4.8.4.

Table 4.8.4 Activity data for $N_2O$ mainly used for medical applications, t.

| | 1990-2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013-2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| $N_2O$ consumption | 38[1] | 37 | 38 | 43 | 33 | 46 | 34 | 42 | 30 | 38[1] |

[1)] Calculated: average 2005-2012.

#### Emission factors

An emission factor of 1 is assumed for all uses.

#### Emission trends

The emission trend for the $N_2O$ emission from medical applications is presented in Figure 4.8.4 below.

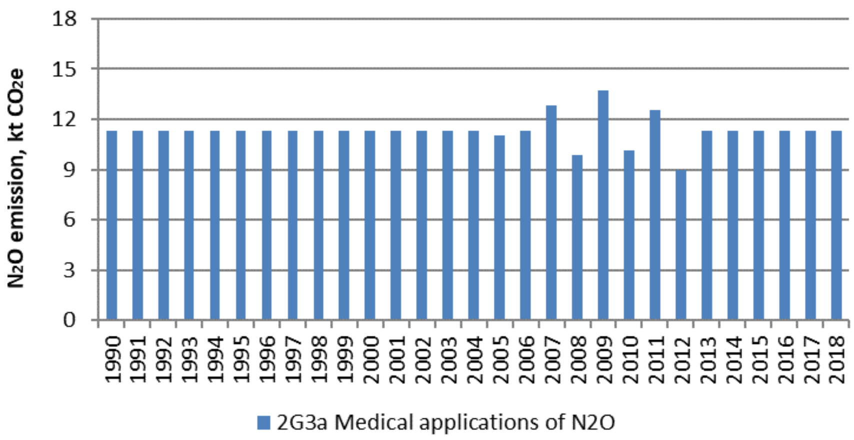


Figure 4.8.4 $N_2O$ emissions from the use of anaesthetics.

**Time series consistency and completeness**

The methodology is consistent throughout the time series. It is not possible to obtain reliable data prior to 2005, but the source category is considered to be complete although uncertainties going back from 2005 and forth from 2012 are increasing.

### 4.8.6 $N_2O$ used as propellant for pressure and aerosol products

The category *$N_2O$ used as propellant for pressure and aerosol products* (CRF 2G3b) covers the following SNAP-code:

- 06 05 06 Aerosol cans

**Methodology**

There is a strong tradition of fresh dairy products in Danish culture and while canned whipped cream is used for e.g. hot beverages in the winter months this product is not widely used.

There are no statistics on production, import/export and/or sales of canned whipped cream in Denmark and the content of propellant is confidential. The consumption of canned whipped cream is therefore estimated as 1 % of the regular cream sale. Further assumptions made include 5 mass% propellant in a can, 250 ml (250 g) cream per can and 95 % release of $N_2O$.

**Activity data**

Data on total sold cream and the estimated sale of canned cream are presented in Table 4.8.5 and in Annex 3C-39.

Table 4.8.5 Consumption of cream in Denmark, t.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Cream[1] | 37378 | 46279 | 39380 | 37333 | 34835 | 31772 | 32275 | 35373 | 34682 |
| Canned cream | 374 | 463 | 394 | 373 | 348 | 318 | 323 | 354 | 347 |

[1]Statistics Denmark (2019).

**Emission factors**

The applied emission factor is 0.0475 tonnes $N_2O$ per tonne canned cream sold; 5 % propellant and 95 % release.

**Emission trends**

The emission trend for the $N_2O$ used as propellant is available in Annex 3C-40 but is also presented in Figure 4.8.5 below.

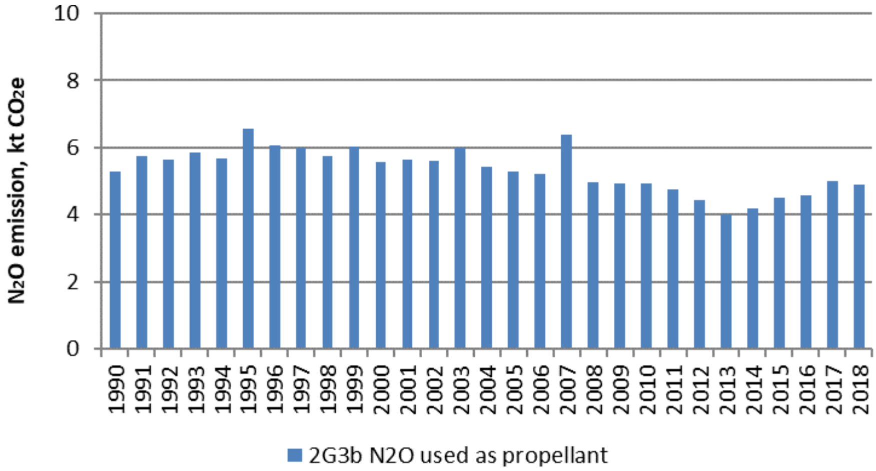

Figure 4.8.5 $N_2O$ emissions from the use of canned whipped cream.

#### Time series consistency and completeness

The methodology is consistent throughout the time series. The estimate is considered too rough to be certain of completeness. For verification, please refer to Hjelgaard & Nielsen (2018).

### 4.8.7 Other product uses

The category *Other Product Uses* (CRF 2G4) covers the following SNAP-codes:

- Use of fireworks (SNAP 060601): $CO_2$, $N_2O$ and $CH_4$
- Use of tobacco (SNAP 060602): $N_2O$ and $CH_4$
- Use of charcoal for barbequing (SNAP 060605): $N_2O$ and $CH_4$

#### Methodology

Methane and nitrous oxide emissions are calculated for all three product uses but carbon dioxide is only relevant for fireworks since $CO_2$ emissions from the two remaining product uses are biogenic.

The applied methodology follows a Tier 2 technology-specific approach from EMEP/EEA (2016)[7] for calculating emissions from fireworks, tobacco and charcoal for barbeques (BBQ).

#### Activity data

Activity data are derived from import, export and production data from Statistics Denmark (2019) and are available in Table 4.8.6 and Annex 3C-41.

Table 4.8.6 Activity data for other product uses, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Fireworks | 1.3 | 3.0 | 4.9 | 3.7 | 5.4 | 5.8 | 4.5 | 4.1 | 6.2 |
| Tobacco | 13.1 | 11.7 | 11.4 | 10.5 | 9.5 | 7.3 | 7.1 | 7.4 | 6.2 |
| Charcoal for BBQ | 7.2 | 7.9 | 13.4 | 14.9 | 7.8 | 16.3 | 7.1 | 7.7 | 8.0 |

The assumption of the weight of cigarettes and cigars of 1 g and 5 g respectively was made to derive the activity data from Table 4.8.6.

[7] 2.D.3.i, 2.G Other solvent and product use, Chapter 3.3 Tier 2 technology-specific approach.

### Emission factors

Emission factors for use of fireworks, tobacco and charcoal for BBQ are found through literature studies and are presented in Table 4.8.7.

Table 4.8.7 Emission factors for other product uses.

| | Unit | Fireworks[1] | Tobacco[2] | BBQ[3] |
|---|---|---|---|---|
| $CO_2$ | kg/t | 43.3 | NA | NA |
| $N_2O$ | kg/t | 1.94 | 0.06 | 0.03 |
| $CH_4$ | kg/t | 0.83 | 3.2 | 5.9 |

[1] Netherlands National Water Board (2008).
[2] Emission factors for wood (111A) in residential plants (1A4b i), SNAP 020200, the energy content used in the calculation is the average of wood pills and wood waste (16.1 GJ/t).
[3] IPCC (2006), calculated using default EFs[8] a net calorific value[9].

### Emission trends

The emission trend for the greenhouse gases from other product uses is available in Annex 3C-42 and in Figure 4.8.6 below.

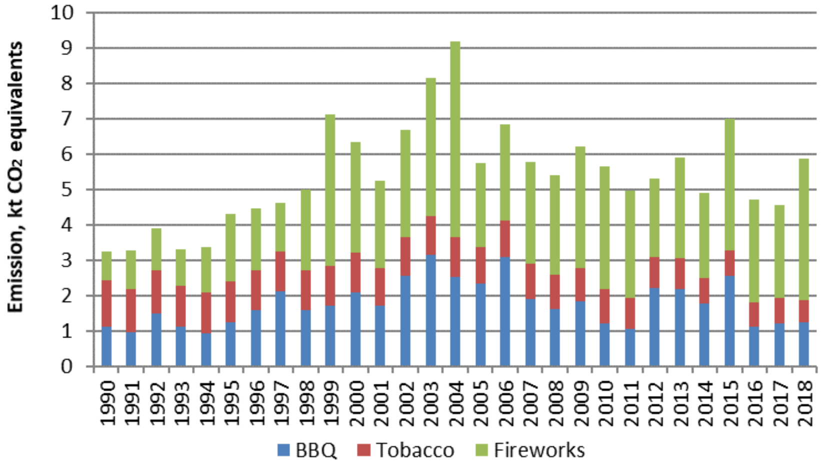


Figure 4.8.6 Greenhouse gas emissions from other product uses.

The consumption of charcoal for BBQs is highly influenced by the summer season weather and the number of smokers has been decreasing throughout the time series.

For fireworks, two peaks are visible in the time series, the peak in 1999 is caused by the celebration of the new millennia and the peak in 2004 by the Seest incident where 284 t net explosive mass (NEM) corresponding to a gross weight of about 1,500 t of fireworks exploded (Report Seest, 2005). From 2005, the new restrictions put on fireworks meant a lower general consumption than before 2004, but the increasing trend continued.

### Time series consistency and completeness

Activity data for fireworks are based on import/export data. There is no firework production industry in Denmark and the use of illegal products is assumed negligible. Cross-border shopping of fireworks is also considered negligible since most fireworks from e.g. Germany is illegal in Denmark due to the strict Danish laws on the content of net explosive mass (NEM).

[8] Volume 2: Energy, Chapter 2.3.2.1 Stationary combustion, Tier 1, Table 2.4, page 2.21, solid biofuels, charcoal.
[9] Volume 2: Energy, Chapter 1.4.1.3 Introduction, Activity data sources, Table 1.2, page 1.19, solid biofuels, charcoal.

Activity data for tobacco includes cross-border shopping. Data for cross-border shopping is known for 2000-2016 and estimated for the remaining years of the time series. From 2000 to 2016 the cross-border shopping of tobacco decreased from 14 % of retail sale to 8 % in 2016. Cross-border shopping is highly influenced by regulations in the Danish tax system.

The activity data for charcoal for barbeques are determined from import/export data and includes:

- Charcoal, including coal of nutshells or nuts, also agglomerated
- Bamboo, including coal of nutshells or nuts, also agglomerated (except for medical use, charcoal mixed with incense, activated charcoal and charcoal for drawing)
- Charcoal, including coal of nutshells or nuts, also agglomerated (except bamboo, charcoal dosed or packaged as medicines, charcoal mixed with incense, activated charcoal and charcoal for drawing).

The product called Heat Beads® BBQ briquettes consist of a certain blend of hardwood charcoal and mineral carbon made by carbonising brown coal and is therefore emitting some non-biogenic $CO_2$. Due to confidentiality it is not possible to determine neither the market share of this product nor the share of non-biogenic $CO_2$ emitted from the product. The amount of non-biogenic $CO_2$ from barbequing is assumed to be negligible. It is further more assumed that the cross-border shopping of charcoal is negligible.

The time series is considered to be complete for the included sources, the time series is also considered consistent all though some data (e.g. cross-border shopping of tobacco) is estimated for some historical years.

## 4.9 Uncertainty

### 4.9.1 Uncertainty input

The source specific uncertainties for industrial processes and product uses are presented in Table 4.9.1. The uncertainties are based on IPCC (2006) combined with assessment of the individual processes.

#### Mineral Industry

The single Danish producer of cement has delivered the activity data for production as well as calculated the emission factor based on quality measurements. For activity data, there is a shift in methodology from 1997 to 1998. Prior to 1998 activity data are derived by the Tier 2 (1-2 % uncertainty) methodology for grey cement production and the Tier 1 (<35 % uncertainty) for white cement production (20-25 % of total production). Activity data have fulfilled the Tier 3 methodology since 1998 and is assumed to have an uncertainty of 1 %. Since uncertainties cannot vary over time in Approach 1 uncertainty calculations, the activity data uncertainty is assumed to be 2 % for the entire time series. The estimation of emission factors fulfils the Tier 3 methodology for the entire time series and uncertainties are therefore assumed to be 2 %.

The activity data for production of lime, including non-marketed lime in the sugar production, are based on information compiled by Statistics Denmark. The uncertainty for the entire time series is assumed to be 1 % for activity data. The emission factor for marketed lime production cover many producers and a variety of high calcium products, assumptions that influence the uncertainty includes the assumptions of no impurities, 100 % calcination and for sugar production also the assumptions on the lime consumption and sugar content in beets. Since 2006 and the introduction of EU-ETS data, the uncertainty decreased as many of the mentioned assumptions were no longer needed, the combined uncertainty for emission factors are estimated to be 4 %.

The activity data uncertainty associated with glass production (including glass wool production) are low for recent years (EU-ETS data) but higher for historic years (carbonate data were not available for 1990-1996 and were therefore estimated for these years), since uncertainties cannot vary over time in Approach 1 calculations, activity data uncertainties are assumed to be 1 % for the entire time series. Uncertainties associated with the emission factors from glass production are low. Denmark uses the Tier 3 methodology and therefore stoichiometric $CO_2$ factors, some uncertainty is however connected to assuming a calcination factor of 1, and the overall emission factor uncertainty is therefore estimated to be 2 %.

The activity data for production of ceramics are based on information compiled by Statistics Denmark and EU-ETS and the uncertainty is assumed to be 5 % (Tier 2). The emission factor is based on stoichiometric relations and the assumption of full calcination; the uncertainty is assumed to be 2 %.

The $CO_2$ emission from other uses of soda ash is calculated based on national statistics and the stoichiometric emission factor for soda ash ($Na_2CO_3$) assuming the calcination factor of 1. Uncertainties are assumed to be 5 % and 2 % for activity data and emission factor respectively.

The category “Other Process Uses of Carbonates” in the Danish inventory includes flue gas desulphurisation and stone wool production. The activity data uncertainty for flue gas desulphurisation is assumed to be 10 %. For stone wool the activity data uncertainty is low for recent years (EU-ETS data) but higher for historic years (calculated/estimated), the uncertainties are assumed to be 2% and 15 % respectively. The overall activity data uncertainties for other process uses of carbonates are assumed to be 4 %. The uncertainty of the stoichiometric emission factors for both source categories is assumed to be 2 %.

#### Chemical Industry

The producers have registered the production of nitric acid during many years and, therefore, the activity data uncertainty is assumed to be 2 %. The measurement of $N_2O$ is problematic and is only carried out for one year. Therefore, the emission factor uncertainty is assumed to be 25 %.

The uncertainty for the activity data as well as for the emission factor is assumed to be 5 % for production of catalysts/fertilisers.

#### Metal Industry

The uncertainty for the activity data and emission factor is assumed to be 5 % and 10 % respectively for production of secondary steel.

The uncertainty for the activity data and emission factor is assumed to be 10 % and 30 % respectively for production of magnesium ($SF_6$) and 10 % and 50 % respectively for lead production.

### Non-Energy Products from Fuels and Solvent Use

Emissions from consumption of lubricant oil is derived from the energy statistics and standard emission factors. Uncertainties are assumed to be 5 % and 10 % respectively for activity data and emission factors.

For paraffin wax use the activity data are known for the entire time series (Statistics Denmark) and emission factors from literature. The fraction of candles made from beeswax is unknown, beeswax candles emit biogenic $CO_2$. Candles produced and sold at e.g. souvenir shops (less than 10 employees) are not included in the activity data from Statistics Denmark. Uncertainties are assumed to be 10 % and 20 % respectively for the two data sets.

Important uncertainty issues related to the mass-balance approach used for solvent use are: (i) Identification of pollutants that qualify as NMVOCs (The definition in Directive (1999) is used) as it is possible that relevant pollutants are not included, e.g. pollutants that are not listed with their name in Statistics Denmark but as a product. (ii) Distribution of solvent consumption between appliances. Although the total consumption is set, a change in distribution of consumption between industrial sectors and households will affect the total emissions, as different emission factors are applied in industry and households, respectively. Uncertainties are assumed to be 10 % for activity data and 15 % for emission factors, except for "other use of solvents and related activities" where the emission factor uncertainty is set at 20 %.

While the activity data for the use of asphalt products are known for the entire time series from Statistics Denmark (uncertainty set at 5 %), the emission factors are calculated using a number of assumptions (uncertainty set at 75 %).

Activity data for urea based catalysts are calculated by the COPERT 5 model. The emission factor includes a number of assumptions. Uncertainties are assumed to be 5 % and 10 % for activity data and emission factors respectively.

### Product Uses as Substitutes for Ozone depleting Substances

The emission of F-gases is dominated by emissions from refrigeration equipment and therefore, the uncertainties assumed for this sector will be used for all the F-gases. The IPCC propose an uncertainty at 30-40 % for regional estimates. However, Danish statistics have been developed over many years and, therefore the uncertainty on activity data is assumed to be 10 %. The uncertainty on the emission factor is assumed to be 50 %. The base year for F-gases for Denmark is 1995.

### Other Product Manufacture and Use

The uncertainty of $N_2O$ used for medical applications is assumed to be 25 % for activity data and 20 % for the emission factor.

The uncertainty of $N_2O$ used as propellant for pressure and aerosol products is estimated to be 100 % for activity data and 150 % for the emission factor.

The main issues leading to uncertainties for activity data for "Other Product Use" are collection of data for quantifying production, import and export of products. Some data, like private import (cross-border shopping) of fireworks, are not available. Other missing data like the composition of mineral containing charcoal for barbequing are unobtainable due to confidentiality. The uncertainty for activity data for all three product uses (fireworks, tobacco and BBQs) is estimated to be 5 %. Reliable emission factors are difficult to obtain for the other product use categories. Some chosen emission factors apply to countries that are not directly comparable to Denmark, and hereby is introduced an increased uncertainty. The uncertainties for emission factors are estimated to be 50 % for fireworks, 50 % for tobacco and 100 % for barbeques.

### 4.9.2 Approach 1 uncertainty

All uncertainty input values are discussed in Section 4.9.1 above. Table 4.9.1 presents the uncertainty inputs for activity data and emission factors and the calculated total emission and uncertainty for Approach 1 for the individual pollutants. The total $CO_2$ equivalent greenhouse gas emission from the IPPU sector in 2018 is 2044 kt $CO_2$ equivalents and the calculated Approach 1 uncertainty for the year is 12.0 %. The trend decreases with 23.3 % during the time series and the trend uncertainty is 11.7 %.

Table 4.9.1 Input uncertainties and calculated Approach 1 emission and uncertainties.

| CRF | Category | Activity data uncertainty | Emission factor uncertainty | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $CO_2$ | $CH_4$ | $N_2O$ | HFCs[2] | PFCs[2] | $SF_6$[2] |
| | | % | % | % | % | % | % | % |
| 2A1 | Cement production | 2 | 2 | | | | | |
| 2A2 | Lime production | 1 | 4 | | | | | |
| 2A3 | Glass production | 1 | 2 | | | | | |
| 2A4a | Ceramics | 5 | 2 | | | | | |
| 2A4b | Other uses of soda ash | 5 | 2 | | | | | |
| 2A4d | Other process uses of carbonates | 4 | 2 | | | | | |
| 2B2 | Nitric acid production[1] | 2 | | | 25 | | | |
| 2B10 | Catalysts/fertiliser production | 5 | 5 | | | | | |
| 2C1 | Iron and steel production | 5 | 10 | | | | | |
| 2C4 | Magnesium production | 10 | | | | | | 30 |
| 2C5 | Secondary lead production | 10 | 50 | | | | | |
| 2D1 | Lubricant use | 5 | 10 | | | | | |
| 2D2 | Paraffin wax use | 10 | 20 | 20 | 20 | | | |
| 2D3 | Paint application | 10 | 15 | | | | | |
| 2D3 | Degreasing, dry cleaning and electronics | 10 | 15 | | | | | |
| 2D3 | Chemical products manufacturing or processing | 10 | 15 | | | | | |
| 2D3 | Other use of solvents and related activities | 10 | 20 | | | | | |
| 2D3 | Printing industry | 10 | 15 | | | | | |
| 2D3 | Domestic solvent use (other than paint applicat.) | 10 | 15 | | | | | |
| 2D3 | Road paving with asphalt | 5 | 75 | 75 | | | | |
| 2D3 | Asphalt roofing | 5 | 75 | | | | | |
| 2D3 | Urea from fuel consumption | 5 | 10 | | | | | |
| 2E5 | Other electronics industry[3] | - | | | | | | |
| 2F1 | Refrigeration and air conditioning | 10 | | | | 50 | 50 | |
| 2F2 | Foam blowing agents | 10 | | | | 50 | | |
| 2F4 | Aerosols | 10 | | | | 50 | | |
| 2F5 | Solvents[3] | - | | | | | | |
| 2G1 | Electrical equipment | 10 | | | | | | 50 |
| 2G2 | $SF_6$ from other product use | 10 | | | | | | 50 |
| 2G3a | Medical application | 25 | | | 20 | | | |
| 2G3b | Propellant for pressure and aerosol products | 100 | | | 150 | | | |
| 2G4 | Fireworks | 5 | 50 | 50 | 50 | | | |
| 2G4 | Tobacco | 5 | | 50 | 50 | | | |
| 2G4 | Barbeques | 5 | | 100 | 100 | | | |
| Emission 2018, kt | | | 1461 | 0.1 | 0.1 | 487[4] | 0.01[4] | 73.2[4] |
| Overall uncertainty in 2018, % | | | 2.3 | 54.2 | 48.3 | 49.6 | 51.0 | 42.8 |
| Trend 1990-2018 (1995-2018), % | | | 14.2 | -4.8 | -98.0 | 89.0 | -98.8 | -29.5 |
| Trend uncertainty, % | | | 2.4 | 14.4 | 1.2 | 109.6 | 0.2 | 13.7 |

[1] The production closed down in the middle of 2004.
[2] The base year for F-gases is for Denmark 1995.
[3] Uncertainties are not calculated for this source category because the activity occurs in neither 1990 nor 2018.
[4] $CO_2$ equivalents.

## 4.10 Quality assurance/quality control (QA/QC)

### 4.10.1 Internal QA/QC

The approach used for quality assurance/quality control (QA/QC) is presented in Chapter 1.6; see also Nielsen et al. (2012). The present chapter presents QA/QC considerations for industrial processes and product use based on a series of Points of Measuring (PMs); see Chapter 1.6.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 1. Accuracy | DS.1.1.1 | General level of uncertainty for every dataset including the reasoning for the specific values. |

The uncertainty assessment has been performed on Approach 1 level by using default and country specific uncertainty factors. The applied uncertainty factors are presented in Chapter 4.9.

The sources of data described in the methodology sections and in DS.1.2.1 and DS.1.3.1 are used. It is the accuracy of these data that define the uncertainty of the inventory calculations. Any data value obtained from Statistics Denmark and SPIN are given as a single point estimate and no probability range or uncertainty is associated with this value. Information from reports is sometimes given in ranges. Uncertainties are therefore assessed from DCE judgement and guidebook estimates.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 2.Comparability | DS.1.2.1 | Comparability of the emission factors/calculation parameters with data from international guidelines, and evaluation of major discrepancies. |

Comparability of the data has not been performed at "Data Storage level 1". However, investigation of comparability at CRF level is in progress and is described in verification sections under each source category in Hjelgaard & Nielsen (2018) as they are performed.

The applied data sets are presented in Table 4.9.1.

Production and import/export data from Statistics Denmark for single products/chemicals can be directly compared with data from Eurostat for other countries. This has been done for a few chosen products/chemicals and countries. Furthermore, chosen Danish data from Eurostat have been validated with data from Statistics Denmark in order to check the consistency in data transfer from national to international databases.

Use categories for chemicals in products are found from the Nordic SPIN database. Data for all Nordic countries are available and reported uniformly. For chosen chemicals a comparison of chemical amounts and use has been made between countries.

Regarding Non-energy products from fuels and solvent use, a joint Nordic project funded by the Nordic Council of Ministers has been used on methodological issues and for emission factors (Fauser et al., 2009).

| | | | |
|---|---|---|---|
| Data Storage level 1 | 3.Completeness | DS.1.3.1 | Ensuring that the best possible national data for all sources are included, by setting down the reasoning behind the selection of datasets. |

The data sources - in general - can be grouped as follows:

- Company specific environmental reports.
- Personal communication with individual companies.
- Company specific information compiled by Danish Energy Agency in relation to the EU-ETS.
- Industrial organisations.
- Statistics Denmark.
- SPIN database.
- Secondary literature.
- IPCC guidelines.

The environmental reports contribute with company-specific emission factors, technical information and, in some cases, activity data. The environmental reports are primarily used for large companies and, for some companies, are supplemented with information from personal contacts, especially for completion of the time series for the years before the legal requirement to prepare environmental reports (i.e. prior to 1996) and after the removal of the requirement (i.e. after 2014).

For reports from and personal contacts with industrial branches it is fundamental to have information from the industrial branches that have direct contact with the activities, e.g. chemicals and products of interest. The information can be in the form of personal communication, but also reported surveys are of great importance. In contrast to the more generic approach of collecting information from large databases, the expert information from industries may give valuable information on specific production processes, chemicals and/or products and industrial activities. By considering both sources a verification as well as optimum reliability and accuracy is obtained.

Statistics Denmark is used as source for activity data as they are able to provide consistent data for the entire time series. In the cases where the statistics do not contain transparent data, statistics from industrial organisations are used to generate the required activity data. Statistics Denmark is used as the main database for collecting data on production, import and export of products, single chemicals, chemical groups and in some cases surrogate data. In order to obtain a uniform and unique set of data, it is important that the data for e.g. production of single chemicals is in the same reporting format and from the same source. The amount of data is very comprehensive and is linked with the data present in Eurostat whenever possible. The database covers all sectors and is regarded as complete on a national level.

Nordic SPIN database provides data on the use of chemicals in Norway, Sweden, Denmark and Finland. It is financed by the Nordic Council of Ministers, Chemical group, and the data is supplied by the product registries of the contributing countries. The Danish product register (PROBAS) is a joint register for the WEA and the EPA and comprises a large number of chemicals and products. The information is obtained from registration according to the EPA rules and from scientific studies and surveys and other relevant sources. The product register is the most comprehensive collection of chemical data in products for Denmark and with the availability of data from the other Nordic countries it enables an inter-country comparison. For each chemical the data is reported in a uniform way, which enhances comparability, transparency and consistency.

For some of the processes, the default emission factors are based on chemical equations (stoichiometric) and are, therefore, the best choice. In some cases, the default emission factor has been modified in order to reflect local conditions.

Secondary literature may be used in the interpretation or in disaggregation of the public statistics.

Regarding Non-energy products from fuels and solvent use, the present inventory procedure builds partly on information from the previous Danish solvent emission inventory, which is based on questionnaires to industrial branches. Furthermore, a joint Nordic collaboration on solvent inventories has given important information on methods and data.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 4.Consistency | DS.1.4.1 | The original external data has to be archived with proper reference. |

The original data files are archived in the following folder:

O:\ST_ENVS-Luft-Emi\Inventory\2018\2_IPPU\Level_1a_Storage.

All data extracted from the internet (e.g. Statistics Denmark, SPIN, online PRTR) are saved as original copies in their original form. Specific information from industries and experts are saved as e-mails and reports.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 6.Robustness | DS.1.6.1 | Explicit agreements between the external institution holding the data and NERI about the condition of delivery. |

An agreement regarding inclusion of information - compiled by Danish Energy Agency for EU-ETS - in the Danish greenhouse gas inventory has been signed. The implementation of this information has been introduced for production of cement, lime production, glass production, glass wool production, bricks, expanded clay products, flue gas desulphurisation and stone wool production.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 7.Transparency | DS.1.7.1 | Listing of all archived datasets and external contacts. |

The datasets applied are presented in Table 4.10.1. For the reasoning behind their selection, see DS.1.3.1.

Table 4.10.1 Applied datasets (archived in: O:\ST_ENVS-Luft-Emi\Inventory\2018\2_IPPU\Level_1a_Storage).

| | |
|---|---|
| \Grønne regnskaber\ | Ardagh Glass Holmegaard GR 2013 |
| | Danisco Assens GR 2007 |
| | Faxe Kalk GR 2013 |
| | Haldor Topsøe GR 2012 |
| | Haldor Topsøe 2018 PRTR |
| | Kemira GR 2005 |
| | Nordic Sugar Nakskov Miljøberetning 2012 |
| | Nordic Sugar Nykøbing GR 2009 |
| | Rockwool Miljøredegørelse 2013 |
| | Saint-Gobain Isover GR 2014 |
| | Stålvalseværket GR 2000 |
| | Aalborg Portland 2018 Miljøredegørelse |
| \$CO_2$ kvote indberetninger\ | Ceramics (folder with 16 files) |
| | Ardagh Glass Holmegaard 2018 EU-ETS |
| | Faxe Kalk 2018 EU-ETS |
| | Haldor Topsøe 2018 EU-ETS |
| | Isover 2018 EU-ETS |
| | Nordic Sugar Nakskov 2018 EU-ETS |
| | Rockwool Doense 2018 EU-ETS |
| | Rockwool Vamdrup 2018 EU-ETS |
| | Aalborg Portland 2018 EU-ETS |
| \Danmarks Statistik\ | Afgrøder |
| | Asphalt |
| | BBQ |
| | Beverages |
| | Bread |
| | Bricks and tiles |
| | Building stock |
| | Cast iron |
| | Catalysts |
| | Chemical ingredients |
| | Coffee |
| | Construction, road |
| | Construction, rådata |
| | Dolomite and soda ash |
| | Expanded clay |
| | Fats |
| | Fireworks |
| | Fløde |
| | Folketal |
| | Meat |
| | Paraffin wax |
| | Rødgods |
| | Slaughterhouse waste |
| | Soda ash |
| | Solvents |
| | Stenbrud og minedrift |
| | Sugar production |
| | Tobacco |

| | | | |
|---|---|---|---|
| Data Processing level 1 | 1. Accuracy | DP.1.1.1 | Uncertainty assessment for every data source not part of DS.1.1.1 as input to Data Storage level 2 in relation to type and scale of variability. |

The uncertainty assessment has been performed on Approach 1 level, assuming a normal distribution of activity data as well as emission data, by application of default uncertainty factors. Therefore, no considerations regarding distribution or type of variability have been performed.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 2.Comparability | DP.1.2.1 | The methodologies have to follow the international guidelines suggested by UNFCCC and IPCC. |

All methodologies follow UNFCCC and IPCC unless better national methodologies have been identified.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 3.Completeness | DP.1.3.1 | Identification of data gaps with regard to data sources that could improve quantitative knowledge. |

This is discussed for each source category individually in the "Time series consistency and completeness" chapters.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 4.Consistency | DP.1.4.1 | Documentation and reasoning of methodological changes during the time series and the qualitative assessment of the impact on time series consistency. |

Recalculations are described in the chapter 4.11. A manual log is included in the tool used for data processing at Data Processing level 2. This log also includes changes on Data Processing level 1.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 5.Correctness | DP.1.5.2 | Verification of calculation results using time series. |

The calculations are verified by checking the time series.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 5.Correctness | DP.1.5.3 | Verification of calculation results using other measures. |

The calculation of results is verified using other measures where other measurements are available. Some are presented in the "Verification" sections, in the sector report (Hjelgaard & Nielsen, 2018) and some are only used internally.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 7.Transparency | DP.1.7.1 | The calculation principle, the equations used and the assumptions made must be described. |

The calculation principles and equations are based on the methodology presented by the IPCC. A detailed description can be found in the sector report for industrial processes and product use (Hjelgaard & Nielsen, 2018).

| | | | |
|---|---|---|---|
| Data Processing level 1 | 7.Transparency | DP.1.7.2 | Clear reference to dataset at Data Storage level 1 |

The calculation files contain links to the original data files.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 7.Transparency | DP.1.7.3 | A manual log to collect information about recalculations. |

A log on information about recalculation is included in CollectER.

| | | | |
|---|---|---|---|
| Data Processing level 2 | 5.Correctness | DS.2.5.1 | Check if a correct data import to level 2 has been made |

The sector report for industrial processes and product use (Hjelgaard & Nielsen, 2018) presents the connection between the datasets on Data Storage level 1 and Data Processing level 2. Individual calculations are used to check the output of the data processing tool used at Data Processing level 2.

| | | | |
|---|---|---|---|
| Data Storage level 4 | 4. Consistency | DS.4.4.3 | The IEFs from the CRF are checked regarding both level and trend. The level is compared to relevant emission factors to ensure correctness. Large dips/jumps in the time series are explained. |

The implied emission factors (IEFs) are checked by using a tool developed especially for that purpose and outliers are explained.

| | | | |
|---|---|---|---|
| Data Storage level 4 | 4. Correctness | DS.4.5.2 | Check that additional information and information related to land-use changes has been correctly aggregated compared to the individual submissions of Denmark and Greenland. |

The aggregated submission for Denmark and Greenland is checked against the individual submissions for Denmark and Greenland.

### 4.10.2 External QA/QC

External QA/QC is described for one source: cement production.

**Cement production**

Aalborg Portland has an environmental management system that meets the requirements in DS/ISO 14001, EMAS etc. (Aalborg Portland, 2013b). The environmental management system is part of an integrated process management system. The system is certified according to the standards by the accredited body: Danish Standards. Information on raw material consumption as well as internal recycling is compiled in an environmental database. Some pollutants ($NO_x$, $SO_2$, CO and TSP) are measured continuously. Emission of $CO_2$ is calculated based on (fuel and) raw material consumption and raw material flow according to an approved $CO_2$ emission plan (EU-ETS). The $CO_2$ emission plan has to fulfil the requirements in the guidelines developed by EU (EU Commission, 2018).

## 4.11 Recalculations

Table 4.11.1 shows recalculations of the $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs and $SF_6$ emissions. Emissions reported this year have been compared to emissions reported last year.

Table 4.11.1 Recalculations, %.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|
| $CO_2$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| $CH_4$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.9 | 0.0 |
| $N_2O$ | 0.0 | 0.0 | 0.0 | -1.4 | -1.4 | -1.2 | -1.2 | -1.4 |
| HFCs | | 0.0 | 0.0 | 0.6 | 0.1 | 0.6 | 2.9 | 3.5 |
| PFCs | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| $SF_6$ | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| GHG | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.2 | 0.7 | 0.7 |

Sector specific recalculations for 2017 are shown in Table 4.11.2, subcategories with no recalculations are not displayed in the table, e.g. 2A1 Cement production. The main recalculations are discussed for each sub-sector below.

Table 4.11.2 Recalculations for industrial processes and product use, 2017.

| | | $CO_2$, kt $CO_2$ | $CH_4$, t $CO_2$ eqv | $N_2O$ t $CO_2$ eqv | F-gas t $CO_2$ eqv | $CO_2$ % | $CH_4$, % | $N_2O$ % | F-gas % |
|---|---|---|---|---|---|---|---|---|---|
| 2A | Mineral industry | 0.81 | | | | 0.06 | | | |
| 3 | Glass production | -0.001 | | | | -0.01 | | | |
| 4a | Ceramics | -0.26 | | | | -0.61 | | | |
| 4b | Other uses of soda ash | -0.01 | | | | -0.07 | | | |
| 4c | Other | 1.08 | | | | 5.04 | | | |
| 2B | Chemical industry | No RC | | | | No RC | | | |
| 2C | Metal industry | No RC | | | | No RC | | | |
| 2D | Non-energy products from fuels and solvent use | -0.65 | -0.05 | -0.01 | | -0.38 | -0.23 | -1.44 | |
| 2 | Paraffin wax use | -1.09 | -0.05 | -0.01 | | -1.44 | -1.44 | -1.44 | |
| 3 | Solvent use | 0.42 | | | | 0.76 | | | |
| 3 | Asphalt roofing | 0.005 | | | | 27.1 | | | |
| 3 | Urea used in catalysts | 0.02 | | | | 0.17 | | | |
| 2E | Electronics industry | | | | No RC | | | | No RC |
| 2F | Product Uses as Substitutes for ODS | | | | 14.01 | | | | 3.46 |
| 1 | Refrigeration and air conditioning | | | | 14.01 | | | | 3.61 |
| 2G | Other product manufacture and use | -0.0003 | 0.05 | -0.90 | No RC | -0.15 | 0.06 | -1.39 | No RC |
| 3b | $N_2O$ used as propellant | | | -0.89 | | | | -5.00 | |
| 4 | Charcoal | | 0.05 | 0.0003 | | | 0.11 | 0.11 | |
| 4 | Fireworks | -0.0003 | -0.01 | -0.01 | | -0.15 | -0.15 | -0.15 | |

No RC: No recalculations

### 4.11.1 Mineral industry

The overall recalculations for mineral industry are between -0.2 kt $CO_2$ in 2012 (-0.02 %) and +0.8 kt $CO_2$ in 2017 (0.06 %).

The measured carbon content of dolomite used for production of container glass is now included for 2016 and 2017. This change results in a recalculation of 1 tonne for both years (-0.01% in 2017).

$CO_2$ emissions from production of expanded clay products from Imerys were recalculated for the entire time series based on collaboration with the company. This is the only recalculation for the years 1990-2015 and the recalculation results in both increases and decreases; from -0.3 kt $CO_2$ (2017) to +0.2 kt $CO_2$ (2010).

An update of the activity data for other uses of soda ash from Statistics Denmark has led to a decrease in $CO_2$ emissions in 2016-2017 of between -0.01 kt (2017) and -0.07 kt (2016).

An increase in emissions of 1.1 kt $CO_2$ (i.e. 5.0 %) for fluegas desulphurisation in 2017, is caused by inclusion of data from one plant that were missing in last submission.

### 4.11.2 Non-energy products from fuels and solvent use

The vast majority of recalculations made in this category are made for "Paraffin wax use" and "Solvent use".

Activity data for paraffin wax use are available from Statistics Denmark. For this year's submission, Statistics Denmark updated the import and export data for 2016-2017. As a result, greenhouse gas emissions decreased with between -2.1 kt $CO_2$ equivalents (2016) and -4.9 kt $CO_2$ equivalents (2017).

The recalculations for solvent use include, (i) An update of activity data from Statistics Denmark, (ii) Addition of an ethanol category in Statistics Denmark throughout the time series, which account for less than 2% of the ethanol emissions, (iii) Adjustments of the reallocation of solvent use categories, which results in minor changes in total emissions throughout the time series. The overall recalculation for solvent use, is between -1.5 kt $CO_2$ (-1.7 %) in 2002 and +0.8 kt $CO_2$ (+1.2 %) in 2008.

For this year's submission, Statistics Denmark updated their data for asphalt roofing. This change resulted in an increase in $CO_2$ emissions for the entire time series of between 0.004 kt (2002) to 0.009 kt (2000). As $CO_2$ emissions from this source category are low (0.02-0.04 kt), this increase amounts to 23%-36% from the asphalt roofing source category.

Recalculations of $CO_2$ emissions from urea based catalysts are caused by a change in road work (total km driven) for heavy duty vehicles equipped with SCR catalysts. This change affects emissions for 2006-2017 with up to +0.66 kt $CO_2$ (+9.3 %) in 2014.

### 4.11.3 Electronic industry

The only recalculation in emissions from "Electronic industry" is the introduction of a HFC-23 emission of 0.7 tonnes in 2001; this equals an increase of 10.4 kt $CO_2$ equivalents. The subsector of *Electronic industry* is not presented in Table 4.9.1 and Table 4.11.2, as no emissions occur in 1995 or 2017.

### 4.11.4 Product Uses as Substitutes for ODS

Some recalculations were made for HFCs used in refrigeration and air conditioning (2F1) in this year's submission. Recalculations result in increased emissions for the years 1995-2017 with up to 14.8 kt $CO_2$ equivalents (3 %) in 2016.

### 4.11.5 Other product manufacture and use

One recalculation is performed for $N_2O$ used as propellant for pressure and aerosol cans. Instead of 100 % release, it is now assumed that 5% of $N_2O$ remains in the can and is destroyed in waste handling. This results in a 0.7-1.2 tonnes decrease in $N_2O$ (5%) for the entire time series.

Recalculations were also made due to updated activity data published by Statistics Denmark for 2016-2017 concerning the use of fireworks and charcoal for barbequing. All of the recalculations are minor (maximum 0.02 kt $CO_2$ equivalents per category per year). The resulting overall recalculations for other product manufacture and use - other (2G4) are -0.003 kt $CO_2$ equivalents (2017) to +0.04 kt $CO_2$ equivalents (2016).

## 4.12 Improvements

### 4.12.1 Responses to the review process

The table below contains the recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory. The table details the status of implementation of the recommendations as well as references to where improvements have been implemented in this report.

| Table 4.11.3 Recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory. | | | | |
|---|---|---|---|---|
| Para. | CRF | ERT Comment | Denmark's response | Reference |
| **2018 submission (Review report: https://unfccc.int/sites/default/files/resource/dnk_0.pdf)** | | | | |
| I.6 | 2.F. Product uses as substitutes for ozone depleting substances – HFCs and $SF_6$ | Provide a transparent explanation in the NIR regarding the use of the notation key "NO" for the AD for the amounts of HFCs remaining in products at decommissioning for refrigeration and air conditioning and aerosols and the amount of SF6 remaining in products at decommissioning of electrical equipment.<br>Not resolved. There is not sufficient information in the NIR explaining why some subcategories in the CRF tables include amounts in products at decommissioning and some are reported as "NO" when there is an amount of HFCs in stock | This has been included | The "Methodology" sections under chapters 4.8.3 Electrical equipment, 4.7.4 Refrigeration and air conditioning and 4.7.7 Aerosols |
| I.11 | 2. General (IPPU) | The ERT noted that Denmark implemented several recalculations in its 2018 submission following the recommendations of the ARR 2016, correcting found errors or because of changed methodology. Recalculations are reported in sections 4.11 and 9.1.2 of the NIR and no underestimations due to the recalculation have been detected. However, the ERT noted that the new methodologies reported in section 4.11 are not reflected in section 4.2.6 (ceramics) or section 4.3.4 (catalyst production), where calculation methods ought to be described. Thus, table 4.3.3 and the text in section 4.3.4 still states that for the years 1990–1995, production is estimated as the constant average of production in 1997–2001 (see ID#I.2 in table 3). During the review Denmark clarified the methodology used to calculate emissions from ceramics and catalyst production and indicated that the explanations of the methods would be amended in the next submission.<br>The ERT recommends that Denmark report the new methodology used to calculate emissions from ceramics and catalyst production in the relevant category sections of the NIR (sections 4.2.6 and 4.3.4, respectively, of the NIR 2018). | This has been corrected. | Chapter 4.2.6 Ceramics and Chapter 4.3.4 Catalyst production |
| I.12 | 2.F.1 Refrigeration and air conditioning – HFCs | While checking the trend of the reported emissions under category 2.E.5 Other (electronics industry) (see ID#I.3 in table 3), the ERT noted that the 2012 and 2013 trend in PFCs emissions is also affected by the use of PFC-14 in 2013 and 2014 in laboratory freezers for export. The use of PFC-14 is reported as not occurring in 2015 and 2016 in 2.E.5, since emissions from laboratory freezers in these years are reported under 2.F.1 Refrigeration and air conditioning (see sections 4.6.3 and 4.7.1 of the NIR).<br>The ERT recommends that Denmark ensure consistent reporting of the emissions from laboratory freezers in the CRF tables across the time series and include explanation on the methodology used and allocation of the emissions from the sub-category in the NIR. | It has unfortunately not been possible to improve the consistency on the matter of laboratory freezers for this submission. Laboratory freezers for export are therefore still reported in 2.E while those for use in Denmark are reported in 2.F. | |
| I.13 | 2.F.1 Refrigeration and air conditioning – HFCs | The ERT noticed that the value of the product life factor for HFC-134a from domestic refrigeration (1.25 per cent in 2016) is among the highest of all reporting Parties (ranging from 0.008 to 1.26 per cent in 2016). Similarly, the product life factors (1.26 per cent) for HFC-125 and HFC-143a are the highest of all reporting Parties in 2016. During the review Denmark explained that by mistake emissions from destruction have been reported together with | This has been corrected. | CRF |

| Table 4.11.3 Recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory. | | | | |
|---|---|---|---|---|
| Para. | CRF | ERT Comment | Denmark's response | Reference |
| | | emissions from stock. This resulted in the increase in the IEFs from 2010 onwards and the high IEF in 2016. The emissions will be reallocated in the 2019 submission. The ERT recommends that Denmark separate HFC emissions from destruction from those from stock for HFC-134a, HFC-125 and HFC-143a from domestic refrigeration. | | |
| I.14 | 2.F.1 Refrigeration and air conditioning – HFCs | The ERT noticed significant inter-annual changes in the HFC product life factors, e.g. for HFC-134a from transport refrigeration in 2001/2002 (119.0 per cent) and 2015/2016 (108.2 per cent) and significant inter-annual changes in HFC product life factors in domestic refrigeration, including for HFC-143a (1995/1996 (112.6 per cent), 1997/1998 (124.3 per cent)) and HFC-125 (1996/1997 (28.9 per cent), 1997/1998 (16.9 per cent), 1999/2000 (59.5 per cent), 2013/2014 (22.5 per cent) and 2014/2015 (-17.2 per cent)). The ERT also noted that no emissions of HFC-134a from stock were reported for 2000 despite amounts of fluid reported in operating systems. During the review Denmark explained that besides other reasons for the fluctuations, the emissions from stock are calculated based on the stock on 1 January, while the stock reported is for 31 December, which causes the fluctuations in the IEFs. Denmark indicated that the reporting approach will be corrected in the next submission. Furthermore, Denmark explained that HFC-134a is used both as a pure substance and as part of blend HFC-404A and that the use of the pure substance started in 2001 and therefore that year there are only emissions from filling and not from stock. The reporting will be corrected accordingly for the next submission. The ERT recommends that Denmark correct its reporting by using the same quantity of stocks for reporting AD and emissions and recheck the product life factors in transport refrigeration across the time series, including a relevant explanation in the case of remaining significant variations in the values. The ERT further recommends that Denmark include consistent information on quantities in operating systems and relevant emissions of HFC-134a for 2000. | This has been corrected. | CRF |

### 4.12.2 Planned improvements

There are currently no planned improvements for the greenhouse gas inventory for industrial processes and product use.

## 4.13 References

Ardagh, 2012: $CO_2$-overvågningsplan for Ardagh Glass Holmegaard A/S, CVR nr: 18445042. Driftsleders godkendte overvågningsplan gældende fra 10/12-2012 (In Danish).

Ardagh, 2014: Grønt regnskab for Ardagh Glass Holmegaard A/S 2013, CVR nr. 18445042 (In Danish). Including earlier versions 1997-2012.

Ardagh, 2019: $CO_2$-opgørelse og afrapportering 2018 (EU-ETS). Ardagh Glass Holmegaard A/S (In Danish). Including earlier versions 2006-2017. Confidential.

Asfaltindustrien, 2003. Asfalt 3/03, Asfalt vore veje. Direktion Ib Frandsen.

Danisco Sugar Assens, 2007: Grønt regnskab 2006/2007 Assens.

Danish Energy Agency, 2019: Danish Energy Agency (DEA), the Danish energy statistics for 2018, Available at: https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics (13/01-2020).

Directive, 1999: Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations, Brüssel, 1999.

ELTRA, 2004: Anvendelse og håndtering af $SF_6$-gas i højspændingsanlæg over 100kV (use and management of $SF_6$ in 100kV or more high-voltage plant). ELTRA Memo elt2004-47a of 18 March 2004.

EMEP/EEA, 2016: EMEP/EEA air pollutant emission inventory guidebook 2016, Technical guidance to prepare national emission inventories. Published by the EEA with the CLRTAP Task Force on Emission Inventories and Projections responsible for the technical content of the chapters. Technical report No 21/2016. Available at: https://www.eea.europa.eu/publications/emep-eea-guidebook-2016 (28/01-2020).

EMEP/EEA, 2019: EMEP/EEA air pollutant emission inventory guidebook 2019, Technical guidance to prepare national emission inventories. Published by the EEA with the CLRTAP Task Force on Emission Inventories and Projections responsible for the technical content of the chapters. Technical report No 13/2019. Available at: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (28/01-2020).

Energinet.dk, 2018: Miljørapport 2018 for dansk el og kraftvarme for statusåret 2017 (in Danish).

EU Commission, 2018: Regulations, Commission Implementing Regulation (EU) 2018/2066 of 19 December 2018, on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 601/2012 Available at:
https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R2066&from=EN (17/12-2019).

Fauser et al., 2009: Fauser, P., Saarinen, K., Harðardóttir, K., Kittilsen, M.O., Holmengen, N. & Skårman, T. 2009: Improvement of Nordic Emission Models for Solvent Use in Selected Sectors. TemaNord 2009:556. Nordic Council Of Ministers, Copenhagen.

Faxe Kalk, 2013a: $CO_2$-overvågningsplan for Faxe Kalk, CVR nr: 20882182. Driftsleders godkendte overvågningsplan gældende fra 01/01-2013 (In Danish).

Faxe Kalk, 2013b: Grønt regnskab 2013, Faxe Kalk A/S. Ovnanlægget Stubberup. Including earlier versions 1996-2012.

Faxe Kalk, 2019: $CO_2$-udledningsrapport for 2018 (EU-ETS). Faxe Kalk, Ovnanlægget Stubberup (In Danish). Including earlier versions 2007-2017. Confidential.

Haldor Topsøe, 2013: Miljøredegørelse for katalysatorfabrikken 2012. incl. 1996-2011. (In Danish).

Haldor Topsøe, 2019a: $CO_2$-udledningsrapport for 2018 (EU-ETS). Haldor Topsøe A/S (In Danish). Including earlier years 2011-2017. Confidential.

Haldor Topsøe, 2019b: PRTR for 2018 for Haldor Topsøe A/S. Inclu-ding earlier years 2009-2017.

Hals metal, 2019: Personal communication with Carsten Henriksen September 2019.

Hjelgaard & Nielsen., 2018: Hjelgaard, K.H. & Nielsen, O.-K. 2018. Danish emission inventory for industrial processes. Results of inventories up to 2016. Aarhus University, DCE – Danish Centre for Environment and Energy, 192 pp. Scientific Report No. 292. Available at: http://dce2.au.dk/pub/SR292.pdf (04/12-2019).

Illerup et al., 1999: Illerup, J.B., Geertinger A.M., Hoffmann, L. & Christiansen, K., Emissionsfaktorer for tungmetaller 1990-1996. Faglig rapport fra DMU, nr. 301. Miljø- og Energiministeriet, Danmarks Miljøundersøgelse 1999 (In Danish).

Imerys, 2019: $CO_2$-udledningsrapport for 2018 (EU-ETS) for Imerys Industrial Minerals Denmark A/S. Imerys Fur og Imerys Mors (In Danish). Including earlier versions 2006-2017 (Damolin). Confidential.

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/ (13/01-2020).

Kemira GrowHow, 2005: Miljø & arbejdsmiljø. Grønt regnskab 2004 (In Danish). Including earlier years 1996-2003.

Lassen et al., 2004: Carsten Lassen, Claus Lübeck Christensen og Susanne Skårup, Cowi A/S, Massestrømsanalyse for bly 2000 - revideret udgave, Miljøprojekt Nr. 917 2004. (Danish). Available at: https://www2.mst.dk/Udgiv/publikationer/2004/87-7614-231-0/pdf/87-7614-232-9.pdf (13/01-2020).

Leca, 2019: $CO_2$-udledningsrapport for 2018 (EU-ETS) for Saint-Gobain Weber A/S, Leca Danmark (In Danish). Including earlier versions 2006-2017. Confidential.

MIM, 1977: Bekendtgørelse om anvendelse af gifte og sundhedsfarlige stoffer til specielt angivne formål. BEK nr. 349 af 16/06/1977 (In Danish). Available at:
https://www.retsinformation.dk/Forms/R0710.aspx?id=48340
(21/01-2020).

MIM, 2002: Bekendtgørelse om regulering af visse industrielle drivhusgasser, Bek. Nr. 552, 02/07 2002. (In Danish) Available at:
https://www.retsinformation.dk/Forms/R0710.aspx?id=12578
(21/01-2020).

MIM, 2015: Bekendtgørelse om begrænsning i anvendelse af visse farlige kemiske stoffer og blandinger til specielt angivne formål. BEK nr. 1388 af 25/11/2015 (In Danish). Available at:: https://www.retsinformation.dk/Forms/R0710.aspx?id=175489 (21/01-2020).

Netherlands National Water Board, 2008, Emission estimates for diffuse sources, Netherlands Emission Inventory, Letting off fireworks, Version dated June 2008, Netherlands National Water Board – Water Unit in cooperation with Deltares and TNO. Available at:
http://www.emissieregistratie.nl/ERPUBLIEK/documenten/Water/Factsheets/English/Fireworks.pdf (28/01-2020).

Nielsen et al., 2012: Nielsen, O.-K., Plejdrup, M.S., Winther, M., Gyldenkærne, S., Thomsen, M., Fauser, P., Nielsen, M. Mikkelsen, M.H., Albrektsen, R., Hjelgaard, K., Hoffmann, L. & Bruun, H.G. 2012. Quality manual for the Danish greenhouse gas inventory. Version 2. Aarhus University, DCE – Danish Centre for Environment and Energy, 44 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 47. Available at:
http://www.dmu.dk/Pub/SR47.pdf (27/01-2020).

Nielsen et al., 2019: Nielsen, O-K., Plejdrup, M.S., Winther, M., Mikkelsen, M.H., Nielsen, M., Gyldenkærne, S., Fauser, P., Albrektsen, R., Hjelgaard, K.H., Bruun, H.G. & Thomsen, M. 2019. Annual Danish Informative Inventory Report to UNECE. Emission inventories from the base year of the protocols to year 2017. Aarhus University, DCE – Danish Centre for Environment and Energy, 549 pp. Scientific Report No. 313. Available at:
http://dce2.au.dk/pub/SR313.pdf (28/01-2020).

Nordic Sugar, 2019: $CO_2$-udledningsrapport for 2018 (EU-ETS). Nordic Sugar A/S Nakskov (In Danish). Including earlier versions 2006-2017 Confidential.

Nordic Sugar Nakskov, 2012: Miljøberetning 2010-2012 for Nordic Sugar Nakskov (In Danish). Including earlier versions 1996/97 - 2009/10.

Nordic Sugar Nykøbing, 2010: Grønt regnskab 2009/10 for Nordic Sugar Nykøbing (In Danish). Including earlier versions 1996/97 - 2008/09.

Poulsen, 2001: Poulsen, T.S., Indsamling og genanvendelse af $SF_6$ fra elsektoren. Miljøprojekt nr. 592 2001. Miljøstyrelsen (In Danish). Available at:
http://www2.mst.dk/Udgiv/publikationer/2001/87-7944-417-2/pdf/87-7944-418-0.pdf (21/01-2020).

Poulsen, 2019: Poulsen, T.S., Danish consumption and emission of F-gases. Miljøstyrelsen - The Danish Environmental Protection Agency, Environmental Project No. 2075, March 2019. Available at:
https://www2.mst.dk/Udgiv/publications/2019/03/978-87-7038-051-5.pdf (14/01-2020).

Poulsen, 2020: Poulsen, T.S., Danish consumption and emission of F-gases, Year 2018. Miljøstyrelsen - The Danish Environmental Protection Agency, Environmental Project 2019.

Report Seest, 2005: Rapport vedrørende fyrværkeriulykken i Seest den 3. november 2004, Udarbejdet af en uafhængig ekspertgruppe nedsat den 26. august 2005 af Økonomi- og Erhvervsministeren og Forsvarsministeren. Denmark (In Danish). Available at:
http://www.fmn.dk/nyheder/Documents/RAPPORT-vedroerende-fyrvaerkeriulykken-i-Seest.pdf (22/01-2020).

Rockwool, 2014a: Miljøredegørelse 2013 for fabrikkerne i Hedehusene, Vamdrup og Øster Doense (environmental reports). Including earlier versions 1996-2012. (In Danish).

Rockwool 2014b: $CO_2$-overvågningsplan for Rockwool A/S, Vamdrup og Doense CVR: 42391719. Driftsleders godkendte overvågningsplan gældende fra 25/3-2014 (In Danish)

Rockwool, 2019: $CO_2$-udledningsrapport for 2018 (EU-ETS). Rockwool A/S Doense og Vamdrup (In Danish). Including earlier versions 2006-2017. Confidential.

Saint-Gobain Isover, 2012: $CO_2$-overvågningsplan for Saint-Gobain Isover A/S, CVR nr: 11933238. Driftsleders godkendte overvågningsplan gældende fra 13/12-2012 (In Danish).

Saint-Gobain Isover, 2015: Grønt regnskab for 2014, Saint-Gobain Isover A/S (In Danish). Including earlier versions 1996-2013.

Saint-Gobain Isover, 2019: $CO_2$-udledningsrapport for 2018 (EU-ETS). Saint-Gobain Isover A/S (In Danish). Including earlier versions 2006-2017. Confidential.

Shires et al., 2004: Theresa M. Shires and Christopher J. Loughran. American Petroleum Institute (API), Com-pendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry, February 2004. Available at: http://www.scribd.com/doc/73896273/2004-COMPENDIUM-of-Greenhouse-Gas-Emissions-Estimates (13/01-2020).

Shires et al., 2009: Theresa M. Shires, Christopher J. Loughran, Stephanie Jones and Emily Hopkins. American Petroleum Institute (API), Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry, August 2009. Available at: http://www.api.org/~/media/files/ehs/climate-change/2009_ghg_compendium.ashx (13/01-2020).

SPIN on the Internet. Substances in Preparations in Nordic Countries.

Statistics Denmark, 2019: Statbank Denmark, in both Danish and English. Available at: www.statbank.dk (14/01-2020).

Stålvalseværket, 2002: Grønt regnskab og miljøredegørelse 2001. Det Danske Stålvalseværk A/S (In Danish). Including earlier years 1996-2000.

US EPA, 2004: Technology Transfer Network Clearinghouse for Inventories & Emissions Factors. AP 42, Fifth Edition, Volume I, Chapter 11: Mineral Products Industry Available at:
https://www3.epa.gov/ttnchie1/ap42/ch11/ (28/01-2020).

Aalborg Portland, 2005: Henrik Møller Thomsen, Personal communication 2005.

Aalborg Portland, 2008: Henrik Møller Thomsen, Personal communication 17 September 2008.

Aalborg Portland, 2013a: Torben Ahlmann-Laursen, Personal communication 19 November 2013.

Aalborg Portland, 2013b: $CO_2$-overvågningsplan for Aalborg Portland A/S, CVR nr: 14244441, signeret af Torben Ahlmann-Laursen den 15/03-2013 (In Danish).

Aalborg Portland, 2019a: $CO_2$-udledningsrapport for 2018 (EU-ETS). Aalborg Portland A/S. Including earlier versions 2006-2017. Confidential.

Aalborg Portland, 2019b: Miljøredegørelse 2018, Grønt regnskab og arbejdsmiljø (Environmental report). (In Danish).

# 5 Agriculture

The data presented in Chapter 5 relate to Denmark only, whereas information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 8.

The emission of greenhouse gases from agricultural activities includes:

- $CH_4$ emissions from enteric fermentation, manure management and field burning
- $N_2O$ emissions from manure management, agricultural soils and field burning
- $CO_2$ emissions from liming, urea use and use of other carbon-containing fertilisers

For emissions of air pollutants covered by the NEC Directive or the UNECE LRTAP Convention, see the Danish Informative Inventory Report (Nielsen et al., 2019).

Emissions from rice production and burning of savannahs do not occur in Denmark and consequently these categories have been reported as Not Occurring.

## 5.1 Overview of sector

In $CO_2$ equivalents, the agricultural sector contributes with 23 % of the Danish greenhouse gas emissions (GHG) in 2018 excl. LULUCF. Next to the energy sector, the agricultural sector is the largest source of GHG emission in Denmark. The majority of agricultural greenhouse gas emissions are covered by $N_2O$ and $CH_4$, which contributes in 2018 with 88 % and 78 % respectively of the total Danish emissions of $N_2O$ and $CH_4$.

From 1990 to 2018, the emissions decreased from 13.2 million tonnes $CO_2$ equivalent to 11.0 million tonnes $CO_2$ equivalent, which corresponds to a 16 % reduction (Table 5.1). $CH_4$ is the largest contributor to the overall agricultural greenhouse gas emission, accounting for 54 % in $CO_2$ equivalents in 2018. The decrease in the total agricultural emission is mainly caused by a decrease in $N_2O$ emission, while the $CH_4$ emission is nearly unaltered.

Table 5.1 Emission of GHG in the agricultural sector in Denmark 1990 – 2018.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $CH_4$, kt $CO_2$ eqv. | 5 895 | 6 111 | 6 006 | 6 005 | 5 970 | 5 925 | 5 943 | 5 896 | 5 919 | 5 919 | 5 990 |
| $N_2O$, kt $CO_2$ eqv. | 6 647 | 5 887 | 5 393 | 5 043 | 4 785 | 4 727 | 4 840 | 4 840 | 4 955 | 5 013 | 4 807 |
| $CO_2$, kt $CO_2$ eqv | 619 | 537 | 268 | 222 | 156 | 246 | 240 | 177 | 217 | 219 | 244 |
| Total, kt $CO_2$ eqv. | 13 161 | 12 536 | 11 667 | 11 270 | 10 911 | 10 898 | 11 024 | 10 913 | 11 090 | 11 150 | 11 041 |

The major part of the emission is related to livestock production, which in Denmark is dominated by the production of cattle and swine.

Figure 5.1a-b shows the distribution of $N_2O$ and $CH_4$ emissions across the main agricultural sources. The total $N_2O$ emission from 1990-2018 has decreased by 28 % and can largely be attributed to the decrease in $N_2O$ emissions from agricultural soils. This reduction is due to a proactive national environmental policy over the last thirty years to prevent loss of nitrogen from agricultural soil to the aquatic environment. The emission from agricultural soil is based on emission from a range of sources, where emission from inorganic fertiliser, animal manure applied to soil and organic soils are the most important emission sources. The main reason for the decrease is a strong decrease in use of inorganic fertiliser. In 2016 and 2017 is seen an increase in use of inorganic fertiliser which increases the emission of $N_2O$ from agricultural soils. In 2018, the emission decreases due to decrease in emission from inorganic fertiliser. The higher amount of used N in inorganic fertiliser in 2016 and 2017 is caused by a political agreement on Food and Agricultural package, adopted in December 2015 (MEFD, 2017). The purpose of the agreement was to establish better framework conditions for the agricultural production, to ensure opportunities for economic growth and increased exports and increased employment in interaction with nature and the environment. This agreement made it legally possible to use more nitrogen for some areas.

The $CH_4$ emissions from 1990 to 2018 shown in Figure 5.1b indicate a decrease in emission from enteric fermentation, which is mainly due to a decrease in the number of cattle. A contrasting development has taken place in emission from manure management. Structural changes in the sector have led to a move towards the use of slurry-based housing systems, which have a higher emission factor than systems with solid manure. The decrease and the increase almost balance each other out and the total $CH_4$ emission from 1990 to 2018 has increased less than 2 %.

$CO_2$ emissions from liming and inorganic N-fertiliser has decreased by 61 % from 1990 to 2018, mainly due to decrease in emission from liming. The decrease in use of lime is due to change in fertiliser practice where the use of inorganic N-fertiliser has decreased and use of N from manure has increased (Knudsen, 2004).

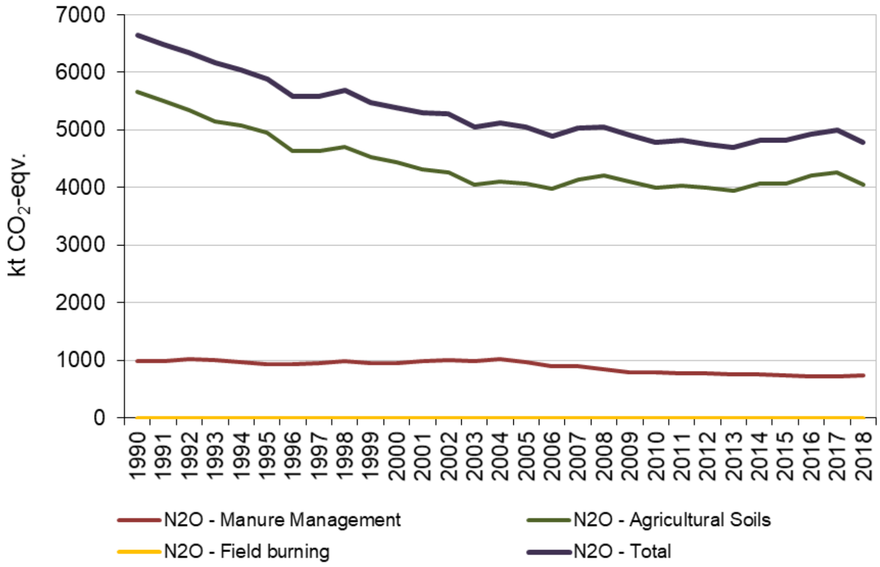

Figure 5.1a Danish agricultural $N_2O$ emissions 1990 – 2018.

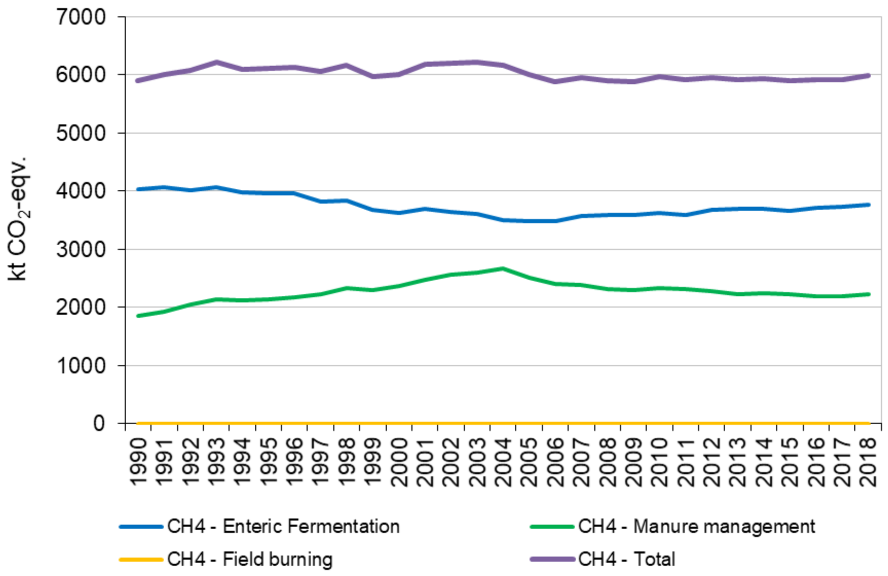

Figure 5.1b Danish agricultural $CH_4$ emissions 1990 – 2018.

### 5.1.1 Methodology overview, tier

Table 5.2 shows the methodology and emission factor used at subcategory level.

Table 5.2 Overview for methodology and emission factor used.

| CRF code | Category | Substance | Tier[1)] | EF[2)] |
|---|---|---|---|---|
| 3A | Enteric fermentation: | | | |
| 3A1a | Dairy cattle | $CH_4$ | Tier2 | CS |
| 3A1b | Non-dairy cattle | $CH_4$ | Tier2 | D |
| 3A2 | Sheep | $CH_4$ | Tier2 | D |
| 3A3 | Swine | $CH_4$ | Tier2 | D |
| 3A4 | Other livestock - deer | $CH_4$ | Tier2 | D |
| | Other livestock – goats | $CH_4$ | Tier2 | D |
| | Other livestock - horses | $CH_4$ | Tier2 | D |
| | Other livestock - poultry | $CH_4$ | Tier1 | OTH |
| | Other livestock – other[3] | $CH_4$ | Tier1 | OTH |
| 3B | Manure management: | | | |
| 3B1a | Dairy cattle | $CH_4$ | Tier2/CS | CS |
| 3B1b | Non-dairy cattle | $CH_4$ | Tier2/CS | CS |
| 3B2 | Sheep | $CH_4$ | Tier2/CS | D |
| 3B3 | Swine | $CH_4$ | Tier2/CS | CS |
| 3B4 | Other livestock - deer | $CH_4$ | Tier2/CS | D |
| | Other livestock – goats | $CH_4$ | Tier2/CS | D |
| | Other livestock - horses | $CH_4$ | Tier2/CS | D |
| | Other livestock - poultry | $CH_4$ | Tier2/CS | D |
| | Other livestock – other[3] | $CH_4$ | Tier2/CS | D |
| 3B | Manure management: | | | |
| 3B1a | Dairy cattle | $N_2O$ | Tier2 | D |
| 3B1b | Non-dairy cattle | $N_2O$ | Tier2 | D |
| 3B2 | Sheep | $N_2O$ | Tier2 | D |
| 3B3 | Swine | $N_2O$ | Tier2 | D |
| 3B4 | Other livestock - deer | $N_2O$ | Tier2 | D |
| | Other livestock – goats | $N_2O$ | Tier2 | D |
| | Other livestock - horses | $N_2O$ | Tier2 | D |
| | Other livestock - poultry | $N_2O$ | Tier2 | D |
| | Other livestock – other[3] | $N_2O$ | Tier2 | D |
| 3B5 | Indirect $N_2O$ emission | $N_2O$ | Tier2 | D |
| 3D | Agricultural soil: | | | |
| 3Da1 | Inorganic N fertilisers | $N_2O$ | Tier1/CS | D |
| 3Da2a | Animal manure applied to soils | $N_2O$ | Tier1/CS | D |
| 3Da2b | Sewage sludge applied to soils | $N_2O$ | Tier1/CS | D |
| 3Da2c | Other organic fertiliser applied to soils | $N_2O$ | Tier1/CS | D |
| 3Da3 | Urine and dung deposited by grazing animals | $N_2O$ | Tier1/CS | D |
| 3Da4 | Crop residue | $N_2O$ | Tier1/CS | D |
| 3Da5 | Mineralization | $N_2O$ | Tier2 | D |
| 3Da6 | Cultivation of organic soils | $N_2O$ | Tier1 | D |
| 3Db1 | Atmospheric deposition | $N_2O$ | Tier1/CS | D |
| 3Db2 | Nitrogen leaching and run-off | $N_2O$ | Tier1/CS | D |
| 3F | Field burning of agricultural residues | $CH_4$ | Tier1 | D |
| 3F | Field burning of agricultural residues | $N_2O$ | Tier1 | D |
| 3G | Liming | $CO_2$ | Tier1 | D |
| 3H | Urea application | $CO_2$ | Tier1 | D |
| 3I | Other carbon-containing fertilisers | $CO_2$ | Tier1 | D |

[1]Tier 1 and T2: IPCC (2006) default, CS: Country specific.

[2]D: IPCC (2006) default. CS: Country specific. OTH: Other.

[3]Ostrich, pheasants, fur bearing animals.

### 5.1.2 Key category identification

The key category analysis (KCA) divides the agricultural emissions into 19 subcategories. Table 5.3 lists the KCs covering Approach 1 and Approach 2. Approach 1 only gives key category identification based on the quantitative emission, while Approach 2 also includes the uncertainties (refer to Chapter 1.5). In 1990, 11 of the 19 agricultural sources were identified as key categories and 13 sources were key categories if uncertainties were taken into account (Approach 2). In 2018, five of the sources are listed as key categories according to level and trend for Approach 1 and 12 sources in Approach 2. One source is listed as key category according to trend in Approach 2. For the methodological choice, Denmark uses the key categories identified using both Approach 1 and Approach 2 for the latest year as well as key categories identified for the trend from 1990 to the latest year.

The two key categories with the highest emissions are $CH_4$ from enteric fermentation and $CH_4$ emissions from manure management. Regarding the enteric fermentation, the cattle production is the main contributor, while the swine production is the most important category for manure management.

Table 5.3 Key category identification Tie1 and Tier 2 from the agricultural sector 1990 and 2018.

| CRF table | Compounds | Emission source | Key category identification | |
|---|---|---|---|---|
| 2018 | | | Approach 1 | Approach 2 |
| 3.A | $CH_4$ | Enteric fermentation | Level/trend | Level/trend |
| 3.B | $CH_4$ | Manure management | Level/trend | Level/trend |
| 3.F | $CH_4$ | Field burning of agri. residues | - | - |
| 3.B | $N_2O$ | Manure management | Level | Level/trend |
| 3.B.5 | $N_2O$ | Atmospheric deposition | Level | Level |
| 3.Da.1 | $N_2O$ | Inorganic N fertilisers | Level/trend | Level/trend |
| 3.Da.2a | $N_2O$ | Animal manure applied to soils | Level/trend | Level/trend |
| 3.Da.2b | $N_2O$ | Sewage sludge applied to soils | - | - |
| 3.Da.2c | $N_2O$ | Other organic fertiliser applied to soils | - | - |
| 3.Da.3 | $N_2O$ | Urine and dung deposited by grazing animals | Level | Level/trend |
| 3.Da.4 | $N_2O$ | Crop residue | Level | Level/trend |
| 3.Da.5 | $N_2O$ | Mineralization | | Level/trend |
| 3.Da.6 | $N_2O$ | Cultivation of organic soils | Level | Level/trend |
| 3.Db.1 | $N_2O$ | Atmospheric deposition | Level | Level/trend |
| 3.Db.2 | $N_2O$ | Nitrogen leaching and run-off | Level | Level/trend |
| 3.F | $N_2O$ | Field burning of agri. residues | - | - |
| 3.G | $CO_2$ | Liming | Level/trend | Level/trend |
| 3.H | $CO_2$ | Urea application | - | - |
| 3.I | $CO_2$ | Other carbon-containing fertilisers | - | Trend |
| 1990 | | | | |
| 3.A | $CH_4$ | Enteric fermentation | Level | Level |
| 3.B | $CH_4$ | Manure management | Level | Level |
| 3.F | $CH_4$ | Field burning of agri. residues | - | - |
| 3.B | $N_2O$ | Manure management | Level | Level |
| 3.B.5 | $N_2O$ | Atmospheric deposition | - | Level |
| 3.Da.1 | $N_2O$ | Inorganic N fertilisers | Level | Level |
| 3.Da.2a | $N_2O$ | Animal manure applied to soils | Level | Level |
| 3.Da.2b | $N_2O$ | Sewage sludge applied to soils | - | - |
| 3.Da.2c | $N_2O$ | Other organic fertiliser applied to soils | - | - |
| 3.Da.3 | $N_2O$ | Urine and dung deposited by grazing animals | Level | Level |
| 3.Da.4 | $N_2O$ | Crop residue | Level | Level |
| 3.Da.5 | $N_2O$ | Mineralization | - | Level |
| 3.Da.6 | $N_2O$ | Cultivation of organic soils | Level | Level |
| 3.Db.1 | $N_2O$ | Atmospheric deposition | Level | Level |
| 3.Db.2 | $N_2O$ | Nitrogen leaching and run-off | Level | Level |
| 3.F | $N_2O$ | Field burning of agri. residues | - | - |
| 3.G | $CO_2$ | Liming | Level | Level |
| 3.H | $CO_2$ | Urea application | - | - |
| 3.I | $CO_2$ | Other carbon-containing fertilisers | - | - |

## 5.2 Data sources

The calculated emissions are based on methods described in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

Activity data and emission factors are collected and discussed in cooperation with specialists and researchers in various institutes with agricultural expertise, such as the DCA - Danish Centre for Food and Agriculture – Aarhus University, Statistics Denmark, SEGES, the Danish Agricultural Agency, the Danish Environmental Protection Agency and the Danish Energy Agency. In this way, both data and methods will be evaluated continually, according to the latest knowledge and information. DCE - Danish Centre for Environment and Energy, Aarhus University has established data agreements with the institutes and organisations to assure that the necessary data are available to prepare the emission inventory on time.

Table 5.4 List of institutes involved in the emission inventory for the agricultural sector.

| References | Link | Abbreviation | Data/information |
|---|---|---|---|
| Statistics Denmark – Agricultural Statistics | www.dst.dk | DSt | - livestock production<br>- milk yield<br>- slaughtering data<br>- export of live animal - poultry<br>- land use<br>- crop production<br>- crop yield |
| Danish Centre for Food and Agriculture, Aarhus University | www.dca.au.dk | DCA | - N-excretion<br>- feeding situation<br>- animal growth<br>- use of straw for bedding<br>- N-content in crops<br>- modelling of data regarding N-leaching/runoff<br>- $NH_3$ emissions factor |
| SEGES | www.seges.dk | SEGES | - housing type (until 2004)<br>- grazing situation<br>- manure application time and methods<br>- estimation of extent of field burning of agricultural residue<br>- acidification of slurry |
| Danish Environmental Protection Agency | www.mst.dk | EPA | - sewage sludge used as fertiliser (until 2004)<br>- industrial waste used as fertiliser |
| The Danish Agricultural Agency | www.lbst.dk | DAA | - inorganic N fertiliser (consumption and type)<br>- housing type (from 2005)<br>- sewage sludge used as fertiliser (from 2005 based on the register for fertilization)<br>- number of animals from the Central Husbandry Register |
| The Danish Energy Agency | www.ens.dk | DEA | - manure delivered to biogas plants |

The emissions from the agricultural sector are calculated in a comprehensive agricultural model complex called IDA (Integrated Database model for Agricultural emissions). The model complex is designed in a relational database system (MS Access). Input data are stored in tables in one database called IDA_Backend and the calculations are carried out as queries in another linked database called IDA. This model complex, as shown in Figure 5.2, is implemented in great detail and is used to cover emissions of air pollutants and greenhouse gases. Thus, there is a direct link between the $NH_3$ emission and the emission of $N_2O$.

**IDA - Integrated Database model for Agricultural emissions**

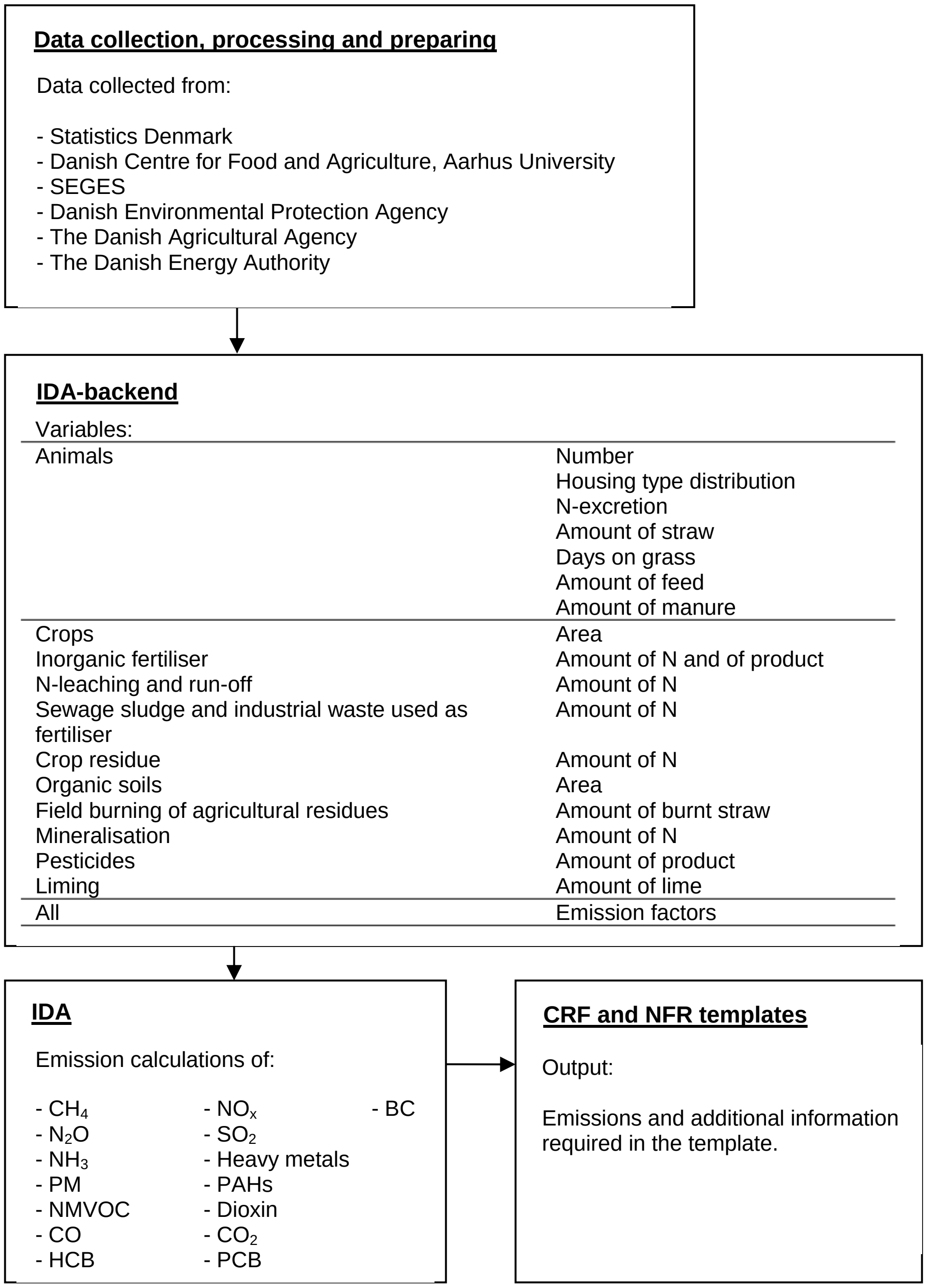


Figure 5.2 IDA - Integrated Database model for Agricultural emissions.

Most emissions relate to livestock production, which is based on information on the number of animals, the distribution of animals according to housing type and, finally, information on feed consumption and excretion.

IDA operates with 39 different livestock categories, according to livestock type, weight class and age. These categories are subdivided into housing type and manure type, which results in 269 different combinations of livestock subcategories and housing types (see Annex 3D Table 3D-1). For each of these combinations, information on e.g. feed intake, digestibility, excretion and grazing days is included. The emission is calculated from each of these subcategories and then aggregated in accordance with the IPCC livestock categories given in the CRF.

Table 5.5 Livestock categories and subcategories.

| CRF 3B | Aggregated livestock categories as given in IPCC | Includes | No. of subcategories in IDA, animal type/housing system |
|---|---|---|---|
| 3B 1a | Dairy Cattle[1] | Dairy Cattle | 35 |
| 3B 1b | Non-dairy Cattle[1] | Calves (<½ yr), heifers, bulls, suckling cattle | 129 |
| 3B 2 | Sheep | Sheep and lambs | 2 |
| 3B 3 | Swine | Sows, weaners, fattening pigs | 37 |
| 3B 4 | Deer | | 1 |
| | Goats | Including kids (meet, dairy and mohair) | 3 |
| | Horses | <300 kg, 300 - 500 kg, 500 - 700 kg, >700 kg | 4 |
| | Poultry | Hens, pullets, broilers, turkeys, geese, ducks | 44 |
| | Fur-bearing animals | Mink and foxes | 8 |
| | Ostriches | Mother ostriches, chickens | 4 |
| | Pheasants | Hens, chickens | 2 |

1) For all subcategories, large breed and jersey cattle are distinguished from each other.

It is important to point out that changes over the years, both to the national emission and the implied emission factor, are not only a result of changes in the numbers of animals, but also depend on changes in the allocation of subcategories, changes in feed consumption and changes in housing type.

### 5.2.1 Number of animals

Livestock production is primarily based on the agricultural census from Statistics Denmark (DSt). For many animal categories, the number given in the annual Agricultural Statistics can be used directly. However, for weaners, fattening pigs, bulls and poultry the number is based on slaughter data also collected from the Agricultural Statistics. This is because the production cycle for these animals is under one year and the normative figures are based on produced animals.

Only farms larger than five hectares are included in the annual census from Statistics Denmark. Especially horses, goats and sheep are placed on small farms, which mean that the number of animals given in the Agricultural Statistics is not representative (underestimates the actual animal population). Therefore, the number of sheep and goats is based on the Central Husbandry Register (CHR), which is the central register of farms and animals managed by the Ministry of Environment and Food of Denmark. From 2010, the annual census includes farms with more than 20 goats and sheep, but the CHR is considered as more reliable because the register include all animals regardless of farm size. The number of horses is based on data from SEGES (Clausen, 2018 and Kold, 2019).

The number of deer and ostriches is also based on CHR because these are not included in the Agricultural Statistics published by Statistics Denmark. The number of pheasants is based on expert judgement from Department of Bioscience, Aarhus University and the Danish pheasant breeding association (Stenkjær, 2010, pers. comm.).

The agricultural annual census in present form goes back to 1977 (Statistics Denmark, 2010). The survey has taken place every year as a questionnaire based survey, where the farmer has received a questionnaire in a letter with an obligation to complete it. The questionnaire has varied from year to year depending on EU requirements and national needs. From 1977 to 1983, the survey was based on total censuses where all farms where included, which also is the case for the years; 1985, 1987, 1989, 1999 and 2010. The remaining surveys is based on sample surveys; 1984, 1986, 1988, 1990-98, 2000-09 and 2011-18 and include around 20-35 % of all farms and around 50 % of the farms in 2003, 2005 and 2007.

As soon as the data from the questionnaires are processed, tested and quality assured, the data are published annually at Statistics Denmark's homepage; http://www.statistikbanken.dk and are available in both English and Danish.

Annex 3D Table 3D-2 provides number of animals allocated on all livestock subcategories.

### 5.2.2 Housing type

From 2005, all farmers have to report to the Danish Agricultural Agency (DAA) information concerning the housing type. Annex 3D Table 3D-1 shows the housing types for each livestock category for the years 1990 – 2018.

Before 2005, there exists no official statistics, which cover the distribution of animals according to housing type. Therefore, the distribution is based on an expert judgement from SEGES and DCA (Rasmussen, 2006, Lundgaard 2006).. Approximately 90-95 % of Danish farmers are members of SEGES, which regularly collects statistical data from the farmers on different issues, as well as making recommendations with regard to farm buildings. Hence, SEGES has a good understanding of which housing types that are currently in use and also the changes over time.

### 5.2.3 $NH_3$ reducing technology

$NH_3$ reducing technology in housings and storage has been taken in to account in the emission calculations. The technologies included are acidification in housings with cattle and swine, cooling of swine manure in housings, frequent removal of manure in fur animal housings, heat exchangers in housing of broilers and solid cover of manure tanks.

Reducing of $NH_3$ emission in housing and storage increase the amount of N in storage and for application, which increase the emission of $N_2O$ from agricultural soils.

No possible reduction in $CH_4$ emissions, because of $NH_3$ reducing technology, is taken in to account.

### 5.2.4 Feed consumption and manure excretion

The DCA provide Danish standards related to feed consumption, excreted volumes, nutrient content of nitrogen, phosphor and potassium, dry matter in manure and contribution of different manure type. These standards are all a part of the "Danish Normative System", which is used for fertiliser planning and control by the Danish farmers and authorities (Poulsen et al., 2001, Lund et al., 2019). The complexity and dynamics of the system has increased during the years to secure the development of accurate values. Furthermore, the normative system includes emission factors for $NH_3$, which is based on a combination of measurements and model calculations. Emission factors for $NH_3$ from the housing unit and storage are given in Annex 3D Table 3D-3 (a-d) and 3D-4.

The Danish normative standards are based on practical farming and thus reflect the actual Danish agricultural production conditions. DCA receive data from SEGES, which is the central office for all Danish agricultural advisory services. SEGES carries out a considerable amount of research itself, as well as collecting efficacy reports from the Danish farmers for dairy production, meat production, pig production, etc., to optimise productivity in Danish agriculture. Feeding plans are used to provide values to the Danish Normative System and for dairy cows; the values are based on approximately 800 feeding plans. In total the normative standards covers feed plans from 15-18 % of the Danish dairy production, 25-30 % of the pig production, 80-90 % of the poultry production and approximately 100 % of the fur production. A high fraction of the pig production is represented, which is caused by the intensive focus on the possibilities to optimize the feed intake to increase the feed efficiency. The values covering the cattle production can be considered as reliable, even though only 15-18 % of the productions are represented. These values include mainly feeding plans from the farmers with a production efficiency corresponding to a middle level. The farmers with a high productivity level are often not users of SEGES, which also is the case for farmers with a low productivity level.

Previously, the normative standards were updated and published every third or fourth year (Laursen, 1987; Laursen, 1994; Poulsen and Kristensen, 1997). From 2001, these standards are updated annually and available to download at the homepage of DCA:
http://anis.au.dk/forskning/sektioner/husdyrernaering-og-fysiologi/normtal/ (Jan. 2020).

One of the reports concerning the normative data is published in English in Poulsen and Kristensen (1998) and is available at the homepage of DCA, see list of references. The normative data are updated every year.

## 5.3 Enteric fermentation

### 5.3.1 Description

The major part of the agricultural $CH_4$ emission originates from digestive processes. In 2018, this source accounts for 35 % of the total GHG emission from agriculture. The emission is primarily related to ruminants and, in Denmark, particularly to cattle, which, in 2018, contributed with 87 % of the emission from enteric fermentation. The emission from swine production is the second largest source and covers 9 % of the emission from enteric fermentation, followed by horses (3 %) and sheep, goats, deer and poultry (1 %).

From 1990 to 2018, the emission from enteric fermentation has overall decreased by 7 %, which is primarily related to a decrease in the number of cattle, combined with increase in milk yield and gross energy (GE) for dairy cattle. The number of swine has increased from 9.5 million in 1990 to 12.8 million in 2018, but this increase is only of minor importance in relation to the total $CH_4$ emission from enteric fermentation. The emission where lowest in 2005 but have increased slightly until 2018, mainly due to a slightly increase in emission from cattle.

### 5.3.2 Methodological issues

The methodology for estimating emissions from enteric fermentation is based on IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). The methodology for poultry, ostrich and pheasants is based on Tier 1, while the remaining animal categories are based on a Tier 2/Country Specific (CS) approach. $CH_4$ emission from enteric fermentation from fur farming is considered to be non-applicable based on country-specific information (Hansen, 2010, pers. comm.). Feed consumption for all animal categories is based on the Danish normative figures. Default values for the methane conversion rate ($Y_m$) given by the IPCC are used for all livestock categories, except for dairy cattle, where a national $Y_m$ is used for all years.

**Tier 1**

Emission factors used for poultry, ostrich and pheasants are based on the emission factors given by Wang & Huang (2005). EF for broilers with a life cycle of 30-56 days is scaled in proportion to 42 days for broilers given by Wang & Huang (2005). Organic broilers with a life cycle of 81 days are scaled in proportion to the Taiwan country chicken with 91 days of life cycle and pullets with a life cycle of 112-119 days are scaled in proportion to the 140 days given for pullets by Wang & Huang (2005). EF for ducks, geese, turkeys, ostrich chickens and pheasant chickens is scaled by weight in proportion to a Danish broiler with 40 days of life cycle. For laying hens, the EF given by Wang & Huang (2005) is used and for ostrich hens and pheasant hens, the EF is scaled by weight in proportion to a laying hen. All EFs for $CH_4$ from enteric fermentation for poultry are shown in Annex 3D Table 3D-5.

**Tier 2**

The Tier 2/CS equation for EF of enteric fermentation is the sum of the feeding situation in winter and summer. The EF is based on actual feeding plans, which is provided from data for feed units (FU) in the feed for each livestock category. Except from dairy cattle, where the EF is based on kg dry matter (DM) in the feed. For dairy cattle, feeding with sugar beets is taken into account, because sugar beet feeding gives a higher methane production rate compared to grass and maize due to the high content of easily convertible sugar. However, it is only dairy cattle, which have sugar beets in the feed. The parts of the equation concerning sugar beet will be left out for the remaining animal categories.

$$EF = EF_{winter} + EF_{summer}$$

Dairy cattle:

$$EF_{winter,dairy\ cattle} = F \cdot \Big( (GE_{F\ winter}/55.65) \cdot Y_{m\ excl\ beet} \cdot (1 - grazing\ days/365 - days\ with\ beet/365) + (GE_{F\ winter}/55.65) \cdot Y_{m\ incl\ beet} \cdot days\ with\ beet/365 \Big)$$

$$EF_{summer,dairy\ cattle} = F \cdot \left(\frac{GE_{F\ summer}}{55.65}\right) \cdot Y_{m\ grazing} \cdot \frac{grazing\ days}{365}$$

Where:

$EF_{winter}$ = Emission factor for winter feed, kg $CH_4$ per head per year

$EF_{summer}$ = Emission factor for summer feed, kg $CH_4$ per head per year

F = feed, kg DM

$GE_{F,winter}$ = gross energy per kg DM, MJ per kg DM in winter

$GE_{F,\ summer}$ = gross energy per kg DM, MJ per kg DM in summer

$Y_m$ = methane conversion factor, per cent of gross energy in feed converted to methane
55.56 = energy content of $CH_4$, MJ per $CH_4$

Other animals:

$$EF_{winter} = FU \cdot \left(\left(\frac{GE_{FUwinter}}{55.65}\right) \cdot Y_m \cdot \left(1 - \frac{grazing\ days}{365}\right)\right)$$

$$EF_{summer} = FU \cdot \left(\frac{GE_{FU\ summer}}{55.65}\right) \cdot Y_{m\ grazing} \cdot \frac{grazing\ days}{365}$$

Where:
$EF_{winter}$ = Emission factor for winter feed, kg $CH_4$ per head per year
$EF_{summer}$ = Emission factor for summer feed, kg $CH_4$ per head per year
FU = feeding units
$GE_{FU,winter}$ = gross energy per feeding unit, MJ per FU in winter
$GE_{FU,\ summer}$ = gross energy per feeding unit, MJ per FU in summer
$Y_m$ = methane conversion factor, per cent of gross energy in feed converted to methane
55.56 = energy content of $CH_4$, MJ per $CH_4$

Thus, to calculate the total gross energy (GE) intake, the GE per kg DM or GE per feed unit – defined as $GF_F$ or $GE_{FU}$, respectively – needs to be estimated. A feed unit in Denmark is defined as the feed value in 1.00 kg barley with a dry matter content of 85 % (Statistics Denmark, yearbook 2010). For other cereals, e.g. wheat and rye one feed unit is 0.97 kg and 1.05 kg, respectively.

### Gross energy intake

$GE_F$ for dairy cattle are estimated by DCA (Aaes, 2016, pers. comm.). From 2014 feed intake for dairy cattle given in the normative figures are given in kg DM per year and the energy in the feed is given in MJ per kg DM. The energy intake is a standard winter feed regardless of whether the animal grazes or not. As recommended by previous expert review teams, the feed intake and energy in the feed for the years 1990-2013 is recalculated. Previous the calculation was based on FU for the years 1990-2013, which is now replaced by the calculation based on DM for all years. See Annex 3D Table 3D-10 for time series for GE for dairy cattle.

For all other livestock categories than dairy cattle, the estimation of GE is $GE_{FU}$. $GE_{FU}$ is based on the composition of feed intake and the energy content in proteins, fats and carbohydrates based on actual efficacy feeding controls or actual feeding plans at farm level, collected by SEGES or DCA. The data are given in Danish feed units or kg feedstuff and these values are converted to mega joule (MJ). The calculation is shown in the equation below:

$$GE_{FU} = \frac{MJ/day}{FU/day}$$

$$FU/day = \frac{kg\ dm}{day} \cdot \frac{FU}{kg\ dm}$$

$$MJ/day = \frac{kg\ dm}{day} \cdot \frac{MJ}{kg\ dm}$$

$$MJ/kg\ dm = \%_{Crude\ protein} \cdot E_{Crude\ protein} + \%_{Crude\ fat} \cdot E_{Crude\ fat} + \%_{Carbonhydrates} \cdot E_{Carbonhydrates}$$

$$\%_{Carbonhydrates} = 100 - (\%_{Crude\ protein} + \%_{Crude\ fat} + \%_{Raw\ ashes})$$

Where:

$GE_{FU}$ = gross energy per feed unit, MJ per FU
FU = feed unit
MJ = mega joule
DM = dry matter
$\%_{crude\ protein}$ = share of crude protein in the feed, %
$E_{crude\ protein}$ = energy factor for crude protein, 24.24 MJ per kg DM
$\%_{raw\ fat}$ = share of crude fat in the feed, %
$E_{raw\ fat}$ = energy factor for crude fat, 34.12 MJ per kg DM
$\%_{carbohydrates}$ = share of carbohydrates in the feed, %
$E_{carbohydrates}$ = energy factor for carbohydrates, 17.30 MJ per kg DM
$\%_{raw\ ashes}$ = share of raw ashes in the feed, %

For horses, heifers, suckling cattle, sheep and goats an average winter feed plan is provided based on information from DCA and SEGES on which the calculation of the GE content is based. Feeding conditions for deer is comparable with goats, why the GE for deer is based on feed plans for goats. In Annex 3D Table 3D-6 and 3D-7 are listed all parameters for winter feeding plans covering the amount of proteins, fats and carbohydrates in the feed, FU per kg, kg dry matter per day and MJ per day. Annex 3D Table 3D-8 and 3D-9 provides additional information about feed intake given in FU and grazing days for each livestock category.

Estimation of $GE_{FU,\ summer}$ covers the time where animals are grazing.

Table 5.6 GE per feeding unit, MJ per FU.

| | $GE_{FU,winter}$ | $GE_{FU,summer}$ |
|---|---|---|
| Calves and bulls | 18.3 | 18.8 |
| Heifers | 25.8 | 18.8 |
| Suckling cattle | 34.0 | 18.8 |
| Sows | 17.5 | 17.5 |
| Weaners | 16.5 | 16.5 |
| Fattening pigs | 17.3 | 17.3 |
| Horses, sheep, goats and deer | 30.0 | 18.8 |

In Annex 3D, Table 3D-11, the annual average feed intake given in GE as MJ per day is shown, from 1990 to 2018, for each livestock category. As seen in Annex 3D Table 3D-11, GE for heifers increases from 2005 to 2007. In 2007, new estimations and measurements received from DCA shows that the GE for heifers differs from the previous estimates. This development is not caused by a single year change in feed intake but due to changes in feed practice during some years. Therefore, interpolation of GE for heifers was chosen from year 2004 to 2007 to avoid a significant jump from 2006 to 2007. The GE for non-dairy cattle is an average of GE for calves, heifers, bulls and suckling cattle. However, heifers are the most important subcategory and thus affect the weighed GE average for non-dairy cattle, which also increases from 2004 to 2007.

The Tier2/CS for enteric fermentation differs from the IPCC Tier 2 in the calculation of GE. A comparison between these two methods is shown in Chapter 5.13.1.

#### Methane conversion rate ($Y_m$)

Investigations from DCA have shown a change in fodder practice from use of sugar beet to maize (whole cereal). Sugar beet feeding gives a higher methane production rate compared to grass and maize due to the high content of easily convertible sugar. Development in fodder practice reflects change in the average $Y_m$ for dairy cattle, from 6.38 in 1990 to 6.00 in 2002 and onwards.

The estimation of the national values of $Y_m$ is based on model "Karoline" developed by DCA based on average feeding plans for 20 % of all dairy cows in Denmark obtained from SEGES (Olesen et al.; 2005). DCA have estimated the $CH_4$ emission for a winter feeding plan for two years, 1991 ($Y_m$=6.7) and 2002 ($Y_m$=6.0). $Y_m$ for the years between 1991 and 2002 are estimated by interpolation. Sugar beets are only included in the winter feeding plan and the $Y_m$ is therefore also adjusted for days on winter and summer feeding plan. It is assumed that winter feeding plan covers 200 days.

New measurements (Hellwing et al. 2014) have shown an $Y_m$ value between 5.98 and 6.13. Based on this information the $Y_m$ value for dairy cattle are kept at 6.00 from 2002 onwards (Lund, pers. comm., 2014).

For non-dairy cattle and sheep $Y_m$ given in IPCC (2006) are used. For swine, horses and goats $Y_m$ are based on Crutzen et al. (1986).

Table 5.7 $CH_4$ conversion rate ($Y_m$) – national factor used for dairy cattle 1990 – 2018, %.

| Dairy cattle | 1990 | 1991 | 1995 | 2000 | 2002-2018 |
|---|---|---|---|---|---|
| $Y_{m\ \text{incl. sugar beet}}$ | 6.70 | 6.70 | 6.45 | 6.13 | 6,00 |
| $Y_{m\ \text{excl. sugar beet}}$ | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 |
| $Y_{m\ \text{grazing}}$ | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 |
| Average $Y_m$ | 6.38 | 6.38 | 6.24 | 6.07 | 6.00 |

Table 5.8 $CH_4$ conversion rate ($Y_m$) for non-dairy cattle, swine, sheep, goats and horses, %.

| | $Y_m$ |
|---|---|
| Bulls and bull calves | 3.00 |
| Heifers, heifer calves and suckling cattle | 6.50 |
| Swine | 0.60 |
| Sheep | 6.50 |
| Lamp | 4.50 |
| Goats | 5.00 |
| Horses | 2.50 |

### 5.3.3 Emission factor

IEFs vary across the years for dairy cattle, non-dairy cattle, swine, goats and poultry due to changes in feed intake, distribution of animals in subcategories and number of grazing days. For goats, new subcategories are introduced in 2005 and therefore the IEF differs from the other years. For sheep, horses, deer, ostrich and pheasants the IEF is constant. For IEFs for all categories for all years, see Annex 3D, Table 3D-12. The emission from fur farming is considered not applicable (Hansen, 2010, pers. comm.).

The IEF for dairy cattle has increased from 128 kg $CH_4$ per cow per year in 1990 to 161 kg $CH_4$ in 2018. The IEF depends on milk yield and feed intake – see Figure 5.3. From 1990 to 2000, the IEF is almost unchanged but increases significant from 2000 to 2018. The development in feed intake follows the same development as the IEF, while the milk yields in percentage increases even more and especially from year 2000. This is caused by an improvements of the feed utilization.

A significant increase of GE is seen from 2013 to 2014, which can be explained by a markedly increase of the average milk yield. In 2011 and 2012 is seen a decrease in the average milk yield, but from 2013 is seen a significant increase of milk yield to a level of approximately 10 200 litre per cow in 2018 (Lund et al., 2018). This development has to be set in context with the EU milk quota, which no longer existed from 2015. It was possible for the Danish dairy cattle farmers to increase the milk yield from 2010/2011, but the farmers choose to hold back the feeding because of the EU milk quota.

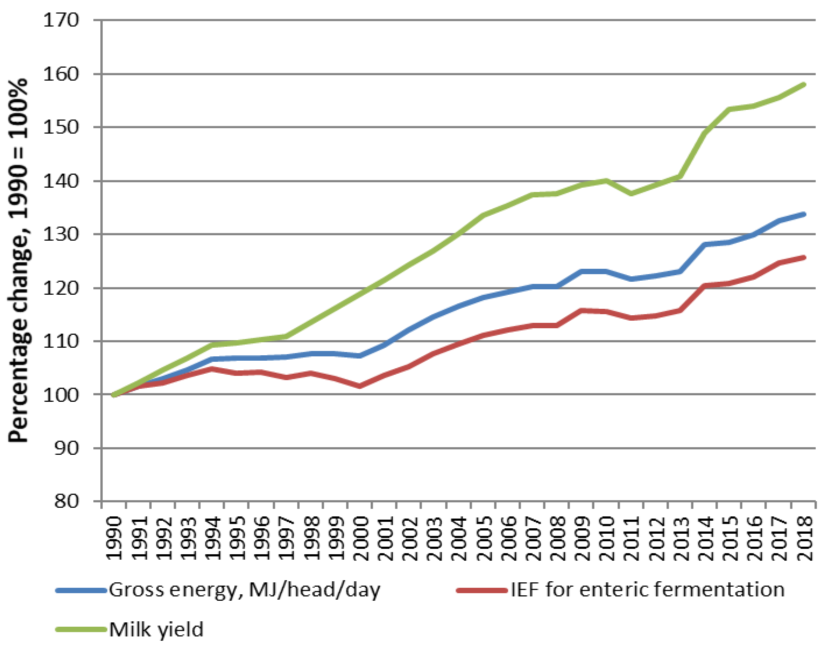


Figure 5.3 Comparison of feed intake, milk yield and IEF for dairy cattle (1990 = 100 %).

A comparison with the IPCC Tier 2 calculation in Chapter 5.13.1 shows that the IEFs using the country specific approach are higher. However, the national IEF reflects the Danish agricultural conditions and the higher level can be explained by high milk production and high feed intake.

The category “Non-Dairy Cattle” includes calves, heifers, bulls and suckling cattle and the IEF is a weighted average of these different subcategories. Changes in allocation of animals between subcategories are reflected in the IEF. The development 1990 - 2008 shows a slight increase due to a higher feed consumption for heifers. From 2008 – 2018 the IEF is stable.

The Danish IEF for non-dairy cattle is lower than the Tier 1 default value given in the 2006 IPCC Guidelines. This is due to a lower weight/lower feed intake (Table 5.9). In Chapter 5.13.1 the national IEF is compared with IPCC

Tier 2 calculation and the result shows a good correlation, which indicates the Danish estimate is correct.

Table 5.9 Subcategories for Non-Dairy Cattle 2018 – enteric fermentation.

| Non Dairy Cattle – subcategories | | Number of animals (DSt) | Energy intake, MJ per day | Methane conversion rate ($Y_m$), % | IEF, kg $CH_4$ per head per yr |
|---|---|---|---|---|---|
| Calves, bull (0-6 month) | 200 kg | 127 079 | 66.36 | 3 | 13.06 |
| Calves, heifer (0-6 month) | 150 kg | 163 949 | 51.07 | 6.5 | 43.55 |
| Bulls (6 month to slaughter) | large breed: 440 kg sl. weight | | 106.89 | 3 | 21.03 |
| | jersey: 330 kg sl. weight | 131 111 | | | |
| Heifers (6 month to calving) | 325 kg | 458 072 | 130.21 | 6.5 | 55.51 |
| Suckling cattle | Up to 800 kg | 84 812 | 159.49 | 6.5 | 68.00 |
| Average - Non-Dairy Cattle | | | 103.9 | | 40.47 |
| IPCC – default value | | | | 6.5 | 57 |

The annual variations for swine primarily reflect the changes in the distribution of animals in subcategories (sows, weaners and fattening pigs). The feed intake for sows and weaners has overall increased while the feed intake for fattening pigs has decreased as a result of improved fodder efficiency (Annex 3D Table 3D-8 and 3D-11).

Table 5.10 shows the IEFs for swine subcategories. The Danish IEF for swine is lower than the IPCC default value. The energy intake for fattening pigs is nearly the same as the default value, while the energy intake for weaners is significantly lower. The lower Danish IEF can be explained by the relatively high share of weaners.

Table 5.10 Subcategories for swine 2018 – enteric fermentation.

| Swine – subcategories | Number of animals (DSt) | Energy intake, MJ per day | Methane conversion rate ($Y_m$), % | IEF, kg $CH_4$ per head per year |
|---|---|---|---|---|
| Sows (incl. piglets until 6.6 kg) | 1 045 165 | 70.54 | 0.60 | 2.75 |
| Weaners (6.6 – 31 kg) | 6 390 667 | 10.74 | 0.60 | 0.42 |
| Fattening pigs (31 – 113 kg) | 5 345 416 | 38.84 | 0.60 | 1.53 |
| Average - Swine | | 22.0 | | 1.08 |
| IPCC – default value | | | | 1.5 |

It is important to point out that the IEF for goats includes emission from kids due to the Danish normative data. This explains why the Danish IEFs are nearly twice as high as the IPCC default values.

### 5.3.4 Activity data

Activity data are the number of animals from the agricultural statistics (Statistics Denmark), SEGES and CHR (see Chapter 5.2.1). For numbers see Annex 3D Table 3D-2.

Since 1990, the number of swine and poultry has increased, in contrast to the number of cattle, which has decreased. The number of cattle has decreased because the milk yield has increased while the total production of milk has been fixed by the EU milk quota. Buffalos, camels & llamas and mules & asses are not occurring in Denmark.

### 5.3.5 Time series consistency

The main part of the emission of $CH_4$ from enteric fermentation comes from cattle. The development in the milk production has been a high increase in milk per cow, which has increased the feed per cow and thereby increased the implied emission factor. Due to fixing of the total production of milk by the EU milk quota, the number of dairy cattle has decreased. The EU milk quota ended in 2015 and the total milk production has increased, but due to higher feed efficiency, the IEF and emission is almost unaltered. The emission of $CH_4$ from enteric fermentation from dairy cattle has decreased from 1990 to 2007 and increased from 2008 to 2018.

The emission from non-dairy cattle decreases from 1990 to 2007 and from 2008 to 2018, the emission is almost unaltered.

Emission from swine increases slightly due to increase in number of animals.

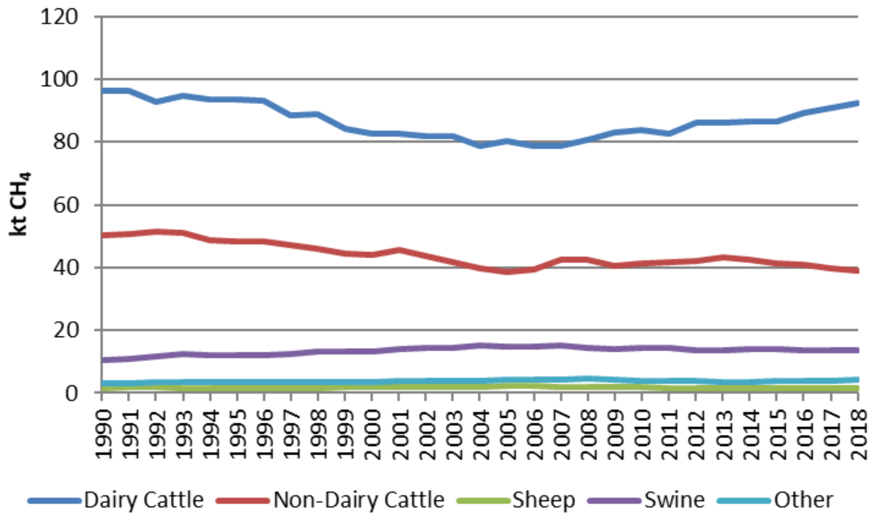


Figure 5.4 Emission of $CH_4$ from enteric fermentation, 1990-2018. For all numbers see Annex 3D Table 3D-13.

## 5.4 Manure management – methane

### 5.4.1 Description

This source contributes with 20 % of the total GHG from the agricultural sector in 2018. The major part of the emission originates from the production of swine (50 %) followed by cattle production (47 %). The remaining part is mainly from fur bearing animals (3 %).

### 5.4.2 Methodological issues

The IPCC Tier 2/CS methodology is used for the estimation of the $CH_4$ emission from manure management. The calculation is based on manure excretion instead of feed intake as described in IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). Default values for maximum methane producing capacity ($B_0$) given by the IPCC are used (see Table 5.11). For cattle and swine, a national MCF factor are used while for the other animal categories, MCF are based on IPCC (Annex 3D Table 3D-15 and Table 3D-16). The calculation of volatile solids (VS) is based on national data.

Table 5.11 Maximum methane producing capacity ($B_0$), $m^3$ $CH_4$ per kg VS.

| | $B_0$ |
|---|---|
| Dairy cattle | 0.24 |
| Non-dairy cattle | 0.18 |
| Swine | 0.45 |
| Sheep | 0.19 |
| Goats | 0.18 |
| Deer | 0.18 |
| Fur bearing animals | 0.25 |
| Horses | 0.3 |
| Hens | 0.39 |
| Broilers, turkeys, ducks and geese | 0.36 |
| Ostrich | 0.25 |

Table 5.12 $CH_4$ – Manure management – use of national parameters and IPCC default values.

| $CH_4$ – Manure management | Data source |
|---|---|
| Volatile solids, VS | Based on amount of manure (Annex 3D Table 3D-14) |
| Maximum methane producing capacity, $B_0$ | IPCC, 2006 |
| Methane conversion factor, MCF | |
| - Cattle and swine, liquid manure | Based on national measurements (Annex 3D Chapter 3D-1) |
| - Other | IPCC, 2006 |

The amount of manure is calculated for each combination of livestock subcategory and housing type and then aggregated to the IPCC livestock categories. In the calculation, grazing days and use of straw in the housing are taken into account. Equation for $CH_4$ calculation:

$$CH_{4,manure} = EF\ CH_{4,housing} \cdot n_{animals} + EF\ CH_{4,grazing} \cdot n_{animals}$$

Where:

$n_{animals}$ = number of animals

$$EF\ CH_{4,housing} = VS_{housing} \cdot MCF \cdot 0.67 \cdot B_0$$

$$EF\ CH_{4,grazing} = VS_{grazing} \cdot MCF \cdot 0.67 \cdot B_0$$

**Estimation of VS**

VS is calculated from data concerning amount of manure, dry matter content, share of VS in dry matter, amount of bedding and grazing days. Except for grazing days for dairy cattle and heifers, all these parameters are based on Danish Normative data. The determination of VS is country-specific, given that it is based on the amount of manure excreted.

$$VS_{housing} = \frac{m}{365} \cdot DM_M \cdot VS_{DM} \cdot (365 - g_1) + s \cdot DM_s \cdot \left(1 - \frac{\%\ ash}{100}\right) \cdot (365 - g_2)$$

$$VS_{grazing} = \frac{m}{365} \cdot DM_M \cdot VS_{DM} \cdot g_1$$

Where:

VS = volatile solids, kg per animal per year

m = amount of manure excreted, kg per animal per year

DM = dry matter of M manure or S straw, %

$VS_{DM}$ = volatile solids of dry matter, %

$g_1$ = feeding days on grass, days per year[1]
$g_2$ = actual days on grass, days per year
s = amount of straw, kg per animal per year
% ash = ash content in straw

The ash content in straw is set to 4.5 % (SEGES, 2005). VS of dry matter are 80 % for all livestock categories (Sommer et al., 2013). The number of days on grass are based on information from DCA and SEGES (Poulsen et al., 2001, Aaes, 2008, Clausen 2008) and is shown in Annex 3D Table 3D-9. The amount of manure excreted and straw used, depends on housing type and is given in the normative figures table (Lund et al., 2019).

The VS daily excretion in average for all main livestock categories and cattle subcategories is shown in Annex 3D Table 3D-14.

#### MCF - Methane conversion factor

Several studies have been carried out to support the calculation of a MCF for Danish slurry treated in anaerobic digestion systems (see Annex 3D Chapter 3D-1). This has led to a national MCF for liquid cattle and swine manure. For other animal categories and manure types, default values provided in the IPCC guidelines for MCF are used. For liquid systems for fur bearing animals, the MCF is a weighted value depended on the situation for covered and uncovered slurry tanks in Denmark. Also for swine on deep bedding housing system is used a weighted value due to the residence time of manure in the barn. In Annex 3D, Table 3D-15, is given an overview of all national manure management systems and the MCF related to each system.

#### Slurry

A national MCF for both untreated and biogas treated liquid manure from cattle and swine has been estimated, see Annex 3D Chapter 3D-1. MCF for liquid cattle and swine manure is higher compared to MCF given in IPCC 2006. See Annex 3D Table 3D-16 for time

series for the national MCF.

Due to legislation from 2003, all slurry tanks must be fully covered or have established a floating cover. However, it is difficult to achieve full floating cover all days of the year and some emission can take place during filling and mixing of manure in the tank. Therefore, it is assumed that floating/fixed covers are absent on 2 % in fur production, which results in a MCF of 10.1 in 2018 for fur slurry.

#### Deep bedding

The MCF for swine deep bedding depends on how long time the manure is stored in the barn and the emission is particularly higher for bedding store more than one month. The bedding situation is based on information from SEGES and is different for the three swine subcategories. The lowest MCF at 7.2 % is seen for weaners because 70% of the bedding material is removed during the first month. The situation is opposite for sows where only 20 % of the bedding is removed during the first month, which lead to a higher MCF at 14.7 %.

[1] Actual days on grass are the number of days that heifers are outside. Feeding days on grass is higher than actual days on grass due to a higher feed intake during grazing compared to the period in housing. Feeding days on grass is a conversion of this higher feed intake on grass. This is only relevant for heifers.

Table 5.13 MCF factor for swine, deep bedding.

| MCF, swine deep bedding | MCF, DK | DK condition, % of year | | MCF - IPCC, 2006 | |
|---|---|---|---|---|---|
| | | > 1 month | < 1 month | > 1 month | < 1 month |
| Deep bedding weaners | 7.2 % | 30 | 70 | 17 % | 3 % |
| Deep bedding fattening | 11.4 % | 60 | 40 | 17 % | 3 % |
| Deep bedding sows | 14.7 % | 80 | 20 | 17 % | 3 % |

### 5.4.3 Emission factor

The implied emission factor depends on the VS content in manure, the use of straw, the number of days on grass, MCF and the manure type. The changes of IEFs during the years thus reflect changes in the variables mentioned above. For some livestock categories, which include subcategories, the IEF can also be affected by changes in allocation of animals on the different subcategories. For IEFs for all animal categories for all years, see Annex 3D Table 3D-17.

The IEF for poultry, ostriches, pheasants and deer are almost unaltered from 1990 – 2018 because of very few changes in feed intake and grazing days. A more detailed division in subcategories for goats and horses is implemented from 2007 and 2003, respectively, and explains the small changes in IEFs.

IEF for dairy cattle has increased as a result of increase in feed intake and manure excretion, but also because of changes in housing types (Annex 3D Table 3D-1). Old-style tethering systems with solid manure have been replaced by loose-housing with slurry-based systems, which has a higher MCF. Same pattern is seen for non-dairy cattle, but here the increasing IEF is mainly caused by a higher proportion of bull-calves reared in housings with deep litter, where the MCF is high. The decrease in the IEF for non-dairy cattle from 2012 to 2013 is due to decrease in the use of straw for bulls.

IEF for swine increases from 1990 to 2004 but decreases from 2004 to 2018. This is mainly due to change in housing systems, which affect the calculation of the MCF because of differences in storage time and HRT (Hydraulic Retention Time) in the barns for the different housing types, see Annex 3D Chapter 3D-1.

### 5.4.4 Activity data

Activity data include both the number of animals and the allocation of animal on different housing types, which determines the manure type. The livestock production is based on the agricultural statistics (Statistics Denmark), SEGES and CHR (see Chapter 5.2.1) and the numbers are given in Annex 3D Table 3D-2. The allocation of housing types is based on registration from the Danish Agricultural Agency (see Chapter 5.2.2 and Annex 3D Table 3D-1).

### 5.4.5 Biogas treated slurry – activity data

Data regarding the amount of slurry delivered to biogas plants is available for the years 2001, 2015 - 2018. Data for year 2001 is based on a single investigation provided by the DEA – the Danish Energy Agency, while the data for year 2015 - 2018 is based on data registration covering the main part of all biogas plants, it is called the BIB – register (Biomass Input to Biogas production), managed by DEA. For the intervening years, 1990-1999 and 2002-2014, the data for amount of slurry delivered to the biogas production is based on an interpolation, by using the relation between the amount of slurry delivered and the total energy production produced at the biogas plants. The total energy production from biogas plants for all years is based on the Energy Statistics (DEA, 2019).

In 2018, manure based biogas plants account for 87 % of the total biogas production, which is produced by approximately 30 large-scale plants and 60 farm-level plants. The BIB register shows that manure accounts for 75 % of the total biomass input. The remaining biomass input is from sewage sludge, residues from the meat production and biomass from crops. The majority of manure sent to anaerobic digestion is slurry, 93 % (mainly from the cattle- and swine production). Deep litter to biogas treatment accounts for 6% of the total amount of manure.

In 1990, the energy production produced at the manure based biogas plants is by DEA estimated to 266 TJ, and the amount of slurry used in biogas plant was estimated to 220 kt. In 2018, the energy production is increased to 12 244 TJ (DEA, 2019), and the amount of slurry delivered to the manure based biogas plants is 5 739 kt slurry. In 2018, around 15 % of the total amount of slurry is delivered to the biogas plants.

The estimation of the national MCF for biogas treated slurry is described in Annex 3D Chapter 3D-1.

### 5.4.6 Time series consistency

The overall $CH_4$ emission from manure management is increased by 20 % from 1990 to 2018 and this is from both the cattle and swine production. The emission from swine has increase from 1990 to 2004 and hereafter decreased until 2018. The emission is mainly determined by the production of fattening pigs and the emission development follows the same trend as the number of produced fattening pigs. Also change in housing types influence the emission. The emission increases due to change to more slurry based housing systems but decreases again due to change to housing systems with a shorter storage time and HRT (Hydraulic Retention Time) for the manure in the barns.

The emission from dairy cattle is increased from 1990 to 2018, despite a decrease in number of dairy cattle, but is related to higher milk yield and thus higher feed intake and higher manure excretion.

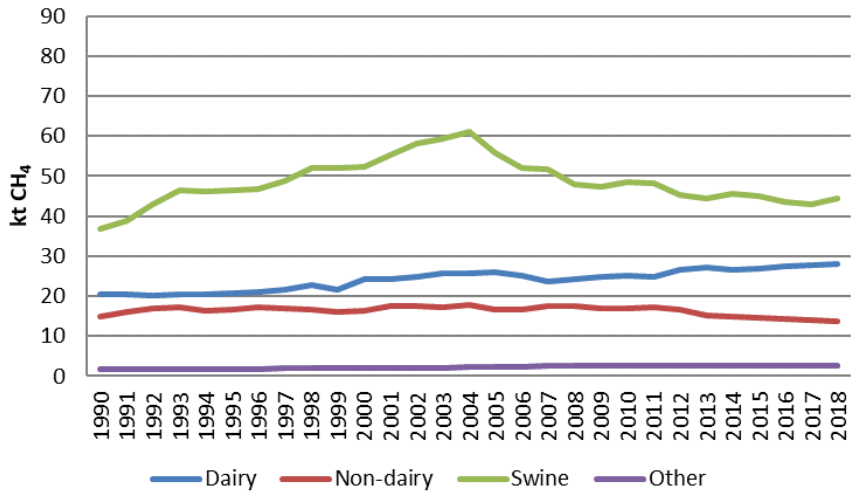


Figure 5.5 $CH_4$ emission from manure management, 1990 - 2018. For all numbers, see Annex 3D Table 3D-18.

## 5.5 $N_2O$ emission from manure management

### 5.5.1 Description

The $N_2O$ emission related to CRF category 3B covers a direct and an indirect emission source. The direct emission includes emission from handling of manure in housing and storage and the indirect emission includes the $N_2O$ emission estimated based on the emission of $NH_3$ and $NO_x$, which takes place in housing and storage.

The $N_2O$ emission from manure management represents 7 % of the total GHG from the agricultural sector in 2018 and the major part (82 %) originates from the direct emission. Cattle- and swine production account for the largest contribution.

The emission only includes the emission from housing and storage, while the emission from manure deposited on grass is included in CRF category 3D.3 Urine and dung deposited by grazing animals.

### 5.5.2 Methodological issues

The emission is based on IPCC 2006 Guidelines Tier 2 approach and depends on the N-content in manure. National data is used for N-excretion for all livestock categories.

### 5.5.3 Emission factor

For the direct emission, the IPCC default $N_2O$ emission factors are applied for all livestock categories. In following table is shown the Danish housing system compared to the housing system given in IPCC 2006 Guidelines Table 10.21 and the respective default emission factors.

Table 5.14 Manure management system (MMS) - emission factors.

| DK MMS | IPCC MMS | Emission factor, kg $N_2O$-N pr kg Nex |
|---|---|---|
| **Cattle** | | |
| Liquid/Slurry | Liquid/Slurry, with natural crust cover | 0.005 |
| Solid | Solid storage | 0.005 |
| Deep bedding | Cattle and Swine deep bedding, no mixing | 0.01 |
| Biogas treated slurry | Anaerobic digester | 0 |
| **Swine** | | |
| Liquid/Slurry | Liquid/Slurry, with natural crust cover | 0.005 |
| Solid | Solid storage | 0.005 |
| Deep bedding | Cattle and Swine deep bedding, Active mixing | 0.07 |
| Biogas treated slurry | Anaerobic digester | 0 |
| **Poultry** | | |
| Housing with or without litter | Poultry manure with or without litter | 0.001 |
| **Fur-bearing animals** | | |
| Slurry | Liquid/Slurry, with natural crust cover | 0.005 |
| Solid | Cattle and Swine deep bedding, no mixing | 0.01 |
| **Sheep and goats** | | |
| Deep bedding | Cattle and Swine deep bedding, no mixing | 0.01 |
| **Horses and ostrich** | | |
| Deep bedding | Cattle and Swine deep bedding, no mixing | 0.01 |

$N_2O$ emission factor for indirect emission is based on the IPCC default, i.e. 0.01 kg $N_2O$-N per kg $NH_3$-N and $NO_x$-N volatilized.

### 5.5.4 Activity data

Besides the number of animals, the activity data for direct emission also includes allocation to housing types and the N-excretion for each animal type.

The livestock production is based on the agricultural statistics (Statistics Den-mark), SEGES and CHR (see Chapter 5.2.1) and the numbers are given in Annex 3D Table 3D-2. The allocation to housing types is based on registration from the Danish Agricultural Agency (see Chapter 5.2.2 and Annex 3D Table 3D-1).

The total amount of nitrogen in manure for each animal category is based on the standards given in the "Danish Normative System", which builds on data from the farmers fertilisers plans – see Chapter 5.2.3 for further details. It is important to point out that the nitrogen excretion rates shown in Table 5.15 are values weighted for the subcategories and thus reflects the nitrogen excreted per AAP. The variations in N-excretion during the time series reflect changes in feed intake, feed efficiency and allocation of animals between subcategories. The nitrogen excretion increases for dairy and non-dairy cattle as a result of higher feed intake. It also has to be noted that the average nitrogen excretion for swine has decreased significantly from 1990 to 2010 due to an improvement of feed efficiency, from 2010 to 2018 it is almost unaltered. For poultry, the average nitrogen excretion varies over time due to distribution of animals in subcategories. The trend for the average nitrogen excretion for fur farming follow the trend for feed intake increases over time. The average nitrogen excretion for horses decreases from 1990 to 1995, but almost unaltered from 2995 to 2018.

Table 5.15 Nitrogen excretion, annual average 1990 – 2018, kg N per head per year (AAP).

| CRF Table 3.B(b) | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Livestock category | | | | | | | | | | | |
| Dairy cattle | 129.49 | 125.23 | 125.31 | 133.30 | 138.63 | 138.82 | 143.07 | 143.43 | 147.03 | 151.44 | 154.67 |
| Non-dairy | 35.57 | 35.93 | 35.70 | 40.66 | 42.90 | 43.08 | 41.61 | 43.09 | 42.49 | 42.41 | 42.33 |
| Sheep | 6.64 | 6.64 | 6.64 | 6.64 | 6.64 | 6.64 | 6.64 | 6.64 | 6.63 | 6.64 | 6.64 |
| Goats | 16.36 | 16.36 | 16.36 | 15.83 | 16.40 | 16.54 | 16.60 | 16.59 | 16.57 | 16.59 | 16.58 |
| Swine | 11.86 | 9.74 | 9.63 | 9.23 | 7.85 | 7.98 | 7.97 | 7.79 | 7.69 | 7.82 | 7.67 |
| Poultry | 0.63 | 0.62 | 0.55 | 0.73 | 0.60 | 0.50 | 0.52 | 0.55 | 0.56 | 0.46 | 0.49 |
| Horses | 44.15 | 39.56 | 39.56 | 39.56 | 39.56 | 39.56 | 39.56 | 39.56 | 39.56 | 39.56 | 39.56 |
| Fur farming | 4.90 | 4.65 | 4.62 | 5.38 | 5.82 | 5.35 | 5.11 | 5.31 | 5.38 | 5.48 | 5.11 |
| Deer | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 |
| Ostrich | NO | 15.61 | 15.60 | 15.60 | 15.60 | 15.60 | 15.60 | 15.60 | 15.51 | 15.60 | 15.60 |
| Pheasant | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| N-excretion, total, kt N per year | 292 | 274 | 269 | 277 | 261 | 256 | 257 | 256 | 258 | 261 | 264 |
| N-excretion, housing, kt N per year | 258 | 239 | 235 | 251 | 239 | 234 | 235 | 235 | 236 | 240 | 243 |

Activity data for the indirect emission covers the volatilisation of $NH_3$ and $NO_x$, which takes place in housing and during storage of the manure. These are based on national data, for detailed information see Annual Danish Informative Inventory Report (Nielsen et al., 2019). Emission of $NH_3$ from housing and storage has decreased from 1990 to 2018 mainly due to implementation of a number of action plans to reduce nitrogen losses from the agricultural production. $NO_X$ emission has also decreased over time, mainly due to changes from solid based systems to slurry-based systems for both the dairy cattle and the swine production.

Table 5.16 Volatilization of $NH_3$-N and $NO_x$-N in housing and during storage, 1990-2018.

| CRF Table 3.B(b) | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $NH_3$-N, housing and storage | 42 000 | 38 549 | 38 503 | 38 797 | 32 610 | 29 762 | 29 781 | 29 588 | 28 975 | 28 904 | 28 992 |
| $NO_x$-N, housing and storage | 146 | 132 | 112 | 95 | 72 | 65 | 63 | 61 | 62 | 62 | 64 |
| Sum, tons N | 42 145 | 38 681 | 38 615 | 38 891 | 32 682 | 29 826 | 29 844 | 29 650 | 29 038 | 28 966 | 29 056 |

### 5.5.5 Time series consistency

The $N_2O$ emission from manure management is estimated to 2.5 kt in 2018 of which only 0.5 kt is related to the indirect emission. The overall emission has decreased with 0.8 kt $N_2O$ from 1990 – 2018 corresponding to 25 %. This decrease is mainly caused by a decreased emission from swine, which is driven by improvements in feed efficiency. The average nitrogen excretion per swine has decreased significantly (see Table 5.15) from 1990 due to the farmers economic benefit of increased feed efficiency and due to environmental requirements.

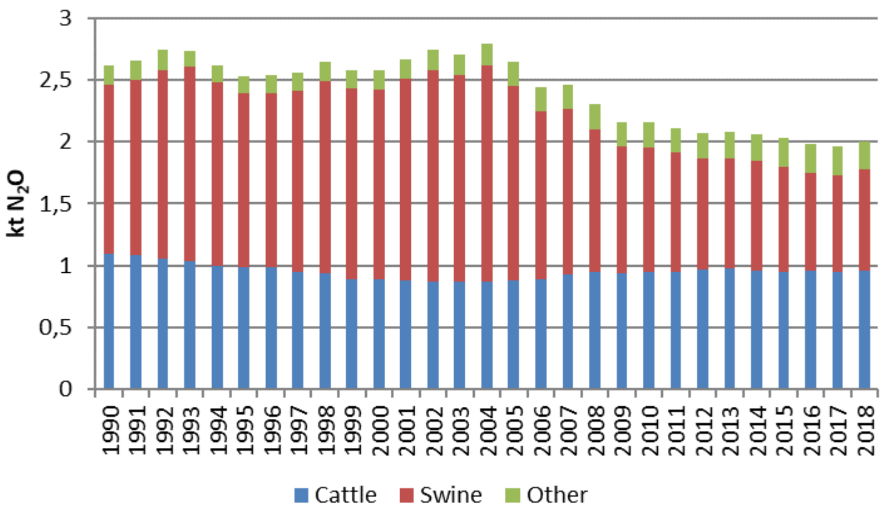


Figure 5.6 $N_2O$ direct emission from manure management, 1990 - 2018.

## 5.6 $N_2O$ emission from agricultural soils – direct emissions

### 5.6.1 Description

The emissions from agricultural soils – direct emissions, is emissions from inorganic N fertiliser, animal manure applied to soils, sewage sludge, industrial waste applied to soils, urine and dung deposited by grazing animals, crop residues, mineralization/immobilization and organic soils. Emission from agricultural soils – direct emissions contribute, in 2018 with 74 % of the $N_2O$ emission from the agricultural sector. The largest sources are manure and inorganic N fertiliser applied on agricultural soils. The emission has overall decreased 26 %.

### 5.6.2 Methodological issues

To calculate the $N_2O$ emission the IPCC Tier 1 methodology is used.

Emissions of $N_2O$ are closely related to the nitrogen balance and all data concerning the evaporation of $NH_3$ and data for manure condition is applied from the national $NH_3$ emission inventory. This is described in detail in Albrektsen et al. (2017) and Annual Danish Informative Inventory Report (Nielsen et al., 2019).

### 5.6.3 Activity data

Area of agricultural land is shown in Annex 3D Table 3D-19.

**Inorganic N fertiliser applied to soils**

The amount of nitrogen (N) applied to soil by use of inorganic N fertiliser is estimated from sales estimates managed by the Danish Agricultural Agency and from the Danish fertiliser N accounts controlled by The Danish Agricultural Agency. As a part of the QA/QC procedure the sale statistics and the actually consumption registered in the Danish fertiliser N accounts is compared. This indicate an increasing difference for the latest years and especially a significant difference for 2016. The difference is caused by the growing import of inorganic fertilisers. It is allowed for the farmer to import fertiliser, if the consumption is related to own fields, but not for onward sale. Because of the increasing import, the amount of N applied to soil by use of inorganic N fertiliser is based on Danish fertiliser N account from 2009 - 2016. For 2017, the sales estimates have been updated and sales information from more companies have been included (Danish Agricultural Agency, 2018).

Therefore, the amount of N applied to soil by use of inorganic N fertiliser in 2017 is based on the sales estimates managed by the Danish Agricultural Agency. For 2018, no sales estimates are available and therefore use of inorganic N fertiliser is based on the Danish fertiliser N accounts.

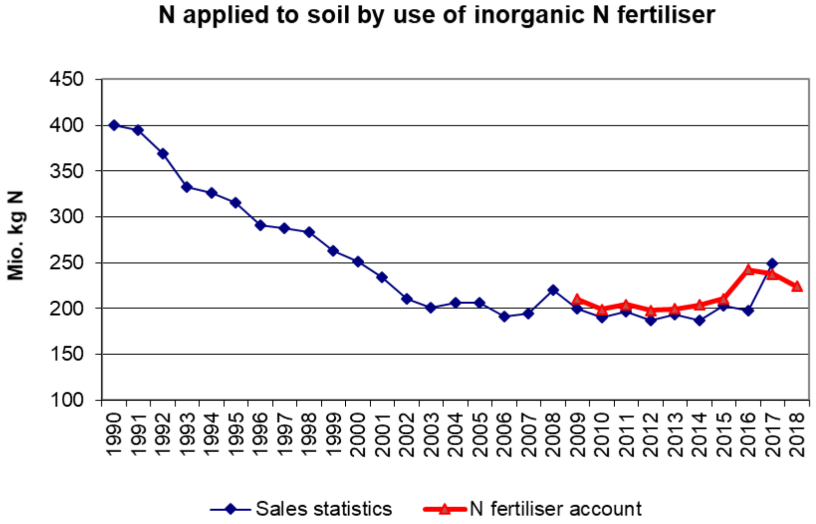


Figure 5.7 N applied from inorganic N fertiliser, sales statistic and N fertiliser account.

Table 5.17 shows the consumption of each fertiliser type for the inorganic fertiliser. Because no sales estimates are available for 2018, only the total amount of N from inorganic fertiliser is known. Therefore, the distribution of N from different types of fertiliser is based on the distribution from sales estimates from 2017.

The $NH_3$ emission factor for each fertiliser is given, based on the values from the EMEP/EEA Guidebook 2019. The $NH_3$ emission depends on fertiliser type and the major part of the Danish emission is related to the use of calcium ammonium nitrate and NPK fertiliser, where the emission factor is 0.008 and 0.05 kg $NH_3$-N per kg N, respectively. The Danish $Frac_{GASF}$ is low compared to the IPCC default value. This is due to the small consumption of urea (<1%), which has a high emission factor.

Table 5.17 Inorganic N fertiliser consumption 2018 and the $NH_3$ emission factors.

| | $NH_3$ Emission factor[1] kg $NH_3$-N per kg N | Consumption[2] 1000 t N |
|---|---|---|
| Fertiliser type | | |
| Calcium and boron calcium nitrate | 0.05 | 0.2 |
| Ammonium sulphate | 0.09 | 7.4 |
| Calcium ammonium nitrate and other nitrate types | 0.008 | 98.4 |
| Ammonium nitrate | 0.015 | 3.1 |
| Liquid ammonia | 0.019 | 5.4 |
| Urea | 0.155 | 0.9 |
| Other nitrogen fertiliser | 0.01 | 34.2 |
| Magnesium fertiliser | 0.05 | 0.0 |
| NPK-fertiliser | 0.05 | 63.4 |
| Diammonphosphate | 0.05 | 2.9 |
| Other NP fertiliser types | 0.05 | 7.1 |
| NK fertiliser | 0.015 | 1.5 |
| Total consumption of N in inorganic N fertiliser | | 224.2 |
| National emission of $NH_3$-N, kt | 5.77 | |
| Average $NH_3$-N emission ($Frac_{GASF}$) | 0.05 | |

[1]) EMEP/EEA (2019), cool climate, normal pH.

[2]) The Danish Agricultural Agency (2018).

The use of inorganic N fertiliser includes fertiliser used in parks, golf courses and private gardens. One percent of the inorganic N fertiliser can be related to these uses outside the agricultural area (Knudsen, 2011).

As a result of increasing requirements for improved use of nitrogen in livestock manure and reduce the nitrogen loss to the environment, the consumption of nitrogen in inorganic N fertiliser has decreased from 1990 to 2005 (Table 5.18). From 2005 to 2015, only small variation is seen in the consumption of N and emission of $N_2O$. In 2016 and 2017 the consumption and emission increases caused by a political agreement on Food and Agricultural package, adopted in December 2015 (MEFD, 2017). The purpose of the agreement was to establish better framework conditions for the agricultural production, to ensure opportunities for economic growth and increased exports and increased employment in interaction with nature and the environment. This agreement made it legally possible to use more nitrogen for some areas. For 2018 the consumption and emission decreases.

Table 5.18 Nitrogen applied as fertiliser to agricultural soils 1990 – 2018.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N content in inorganic N fertiliser, kt N | 400 | 316 | 251 | 206 | 199 | 200 | 204 | 211 | 243 | 249 | 224 |
| $N_2O$ emission, kt $N_2O$ | 6.29 | 4.96 | 3.95 | 3.24 | 3.13 | 3.14 | 3.20 | 3.31 | 3.81 | 3.91 | 3.52 |

### Animal manure applied to soils

The amount of nitrogen applied to soils is estimated as the N-excretion in housings which includes N from bedding. The total N-excretion in housings from 1990 to 2018 has decreased by 6 %.

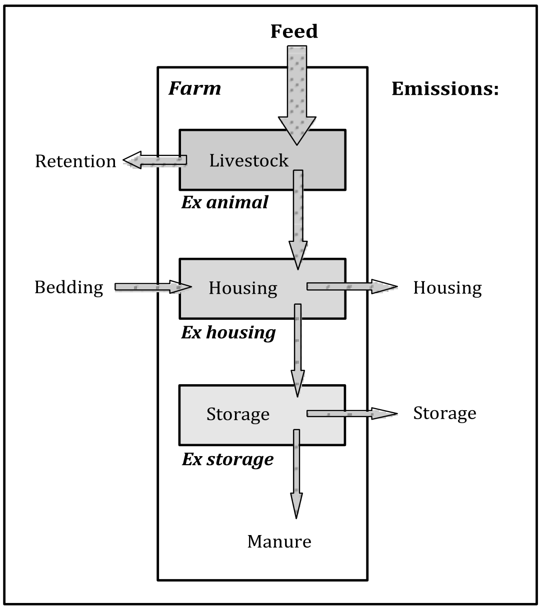


Figure 5.8 The flow dynamics of the Danish normative manure system, which quantifies nutrient content in livestock manure ex animal, ex housing and ex storage (Luostarinen and Kaasinen, 2016).

Table 5.19 Nitrogen applied as manure to agricultural soils 1990 – 2018.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N-excretion, housing, kt N | 258 | 239 | 235 | 251 | 239 | 234 | 235 | 235 | 236 | 240 | 243 |
| N in manure applied on soil, kt N* | 212 | 197 | 195 | 212 | 208 | 207 | 208 | 209 | 210 | 214 | 217 |
| $N_2O$ emission, kt $N_2O$ | 3.33 | 3.10 | 3.06 | 3.33 | 3.27 | 3.25 | 3.27 | 3.28 | 3.30 | 3.36 | 3.41 |

*Including N from bedding.

### Sewage sludge applied to soils

Information regarding the amount of sewage sludge applied on agricultural soil as fertiliser is based on information from the Danish Environmental Protection Agency, and covers the years 1990-2002, 2005, 2008-2009, 2013-2016. In the intervening years, the amount of sewage sludge applied is interpolated and 2017 and 2018 is based on an average of the years 2014-2016. The N-content is assumed to be 4.75 kg N per kg dry matter (DEA, 2009).

Table 5.20 Emission from sewage sludge applied on agricultural soils 1990 – 2018.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrogen in sewage sludge, t N | 3 115 | 4 635 | 3 625 | 2 710 | 3 622 | 3 800 | 4 133 | 4 038 | 3 990 | 4 053 | 4 053 |
| $N_2O$ emission, kt $N_2O$ | 0.05 | 0.07 | 0.06 | 0.04 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |

### Other organic fertilisers applied to soils

The category, “Other”, includes emission from sludge from industries, which is applied to agricultural soils as fertiliser. Information about industrial waste applied on agricultural soils and the content of nitrogen is obtained from a series of reports published by the Danish Environmental Protection Agency, where recent official figures covering year 2001 (Petersen & Kielland, 2003). From 2005 and forward the amount of N from sludge industries applied to soil, is based on the information registered in the Danish N fertiliser accounts controlled by the Danish Agricultural Agency. The N applied for years 2002- 2004 are interpolated.

Table 5.21 Emission from sludge from industries applied on agricultural soils 1990 – 2018.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrogen in industrial waste, t N | 1 529 | 4 445 | 5 147 | 2 359 | 3 401 | 4 596 | 4 342 | 4 455 | 4 914 | 5 099 | 4 788 |
| $N_2O$ emission, kt $N_2O$ | 0.02 | 0.07 | 0.08 | 0.04 | 0.05 | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 | 0.08 |

### Urine and dung deposited by grazing animals

The amount of nitrogen deposited on grass is based on estimations from the $NH_3$ inventory (Nielsen et al., 2019). Information on grazing days is based on expert judgement from DCA and SEGES (Poulsen et al., 2001, Aaes, 2008, Clausen 2008). N-excretion on grass has decreased due to a reduction in the number of dairy cattle and days on grass.

Table 5.22 Nitrogen excreted on grass 1990 – 2018.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N-excretion, grass, kt N | 34 | 35 | 34 | 26 | 22 | 22 | 22 | 21 | 21 | 21 | 21 |
| $N_2O$ emission, kt | 1.00 | 1.05 | 1.01 | 0.73 | 0.61 | 0.62 | 0.61 | 0.59 | 0.60 | 0.59 | 0.59 |

### $Frac_{GASM}$

The $Frac_{GASM}$ express the fraction of N applied from all organic N fertilisers and dung and urine deposited by grazing animals volatilised as $NH_3$ and $NO_x$ emission. Emission factors for $NH_3$ from the housing unit and storage are given in Annex 3D Table 3D-3 and 3D-4. The $Frac_{GASM}$ has decreased from 0.15 in 1990 to 0.09 in 2018 (Table 5.23). This is the result of an active strategy to improve the utilisation of the nitrogen in manure.

Table 5.23 $Frac_{GASM}$ 1990 – 2018.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N applied, kt N | 250 | 242 | 238 | 243 | 237 | 237 | 238 | 238 | 240 | 244 | 247 |
| $NH_3$-N and $NO_x$- N emission, kt N | 36 | 31 | 28 | 23 | 23 | 22 | 22 | 22 | 22 | 23 | 23 |
| $Frac_{GASM}$ | 0.15 | 0.13 | 0.12 | 0.10 | 0.10 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |

### Crop residues

The emission from crop residues is estimated based on the tier 1 methodology in the 2006 IPCC Guidelines. Default values for all parameters given in IPCC 2006 Table 11.2 are used except from dry matter fractions of the harvested product and the aboveground residue dry matter, both of which are based on national values. The default $N_2O$ emission factor at 0.01 kg $N_2O$-N per kg N in crop residues is used.

The dry matter fraction in crops is based on a feedstuff table produced by SEGES, which has information for content of dry matter, fatty acid, protein, starch, sugar and energy for each crop type (SEGES, 2005). The total amount of dry matter in harvest product used to estimate the "Above-ground residue dry matter $AG_{DM(T)}$" is based on data from Statistics Denmark (DSt, 2019). The $AG_{DM(T)}$ varies from year to year depending on the climate conditions – refer to Annex 3D Table 3D-20.

The amount of straw harvested and used for feeding, bedding and bio fuel in power plants is taken into account, because this quantity is removed from the fields. The amount of harvested straw is based on data from Statistics Denmark (DSt, 2019).

The total amount of nitrogen in crop residues is calculated and then the N-content in harvested straw is deducted. The N content in crop residues has increased from 122 million kg N in 1990 to 146 million kg N in 2017, which is a result of both increased total N content in crop residue and a lower amount of N from straw is removed from the fields. In 2018, N in crop residues is significantly decreased, this is due to very dry weather conditions, which resulted in very low yields of the crops.

Table 5.24 N-content in crop residue, 1990-2018.

| Million kg N | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total N in crop residue | 145.8 | 132.5 | 134.1 | 140.2 | 149.9 | 151.0 | 161.6 | 155.1 | 150.3 | 161.7 | 117.4 |
| N-content in harvested straw | 24.2 | 20.1 | 17.4 | 14.6 | 14.8 | 14.2 | 13.5 | 13.6 | 13.9 | 15.7 | 16.3 |
| CRF Table 3.D.4 N in crop residue | 121.6 | 112.4 | 116.7 | 125.6 | 135.1 | 136.8 | 148.1 | 141.5 | 136.4 | 146.0 | 101.0 |

The $N_2O$ emission is proportional to the N-amount in crop residues. Figure 5.9 shows the total N-content in crop residues allocated on the main crop types. Increase in N-content for maize and grass-clover mixtures in rotation is a result of increase of cultivated area. Some variations are seen from one year to another due to the annual climate conditions e.g. in 1992 and 2018 the spring and summer was extremely dry.

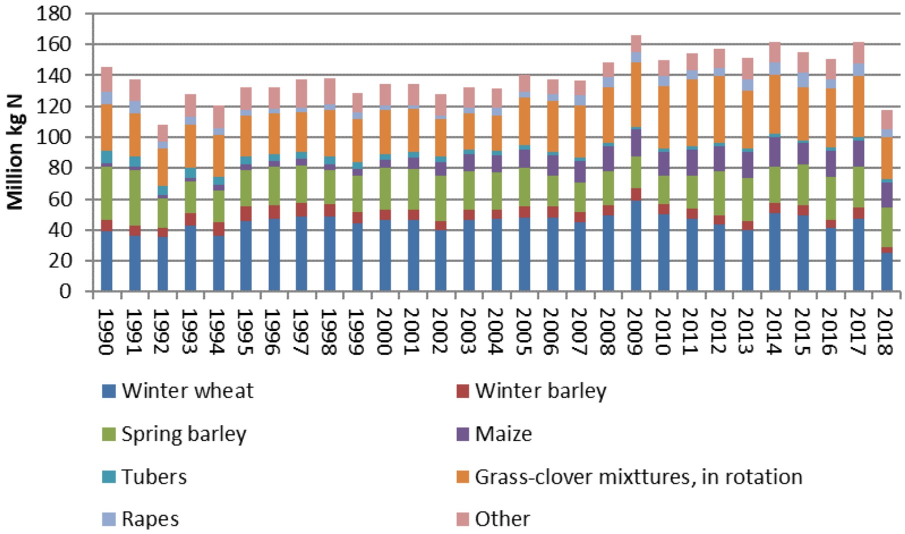

Figure 5.9 Total N in crop residue, 1990 – 2018.

**Mineralization/immobilization associated with loss/gain of soil organic matter**

The N mineralization from mineral soils associated with loss/gain of soil organic matter is estimated with a dynamical modelling tool - C-TOOL, which is used to estimate long-term changes in carbon from mineral soils. For a further description, see LULUCF, Section 6.3.1. Cropland and cropland management, mineral soils. C-TOOL is a 3-pooled dynamic model, where the approximate average half-live times for the three different pools, Fresh organic matter (FOM), Humified organic matter (HUM) and ROM (Resilient Organic Matter) are 0.6-0.7 years, 50 years and 600-800 years, respectively. The main part of biomass returned to soil each year is in the first and easiest degradable FOM pool. This pool consists of mainly fresh straw, fresh manure, root residues, fungi and small animals and fluctuates very much between years depending on the harvest yield and climatic conditions. The annual input to the FOM-pool is very close to the estimated annual amount of crop residues.

The estimated release of $N_2O$ follows eq. equation 11.8, page 11.16 in the 2006 IPCC Guidelines. The $N_2O$ formation is estimated from the annual changes in the HUM and ROM pool. Changes in the FOM pool is considered as being the same as crop residues incorporated in the soil and to avoid double-counting changes in the FOM is not included.

C-TOOL is subdivided into 44 combinations of regions and soil types. Within each subdivision are only losses included in the estimate. Only losses in soil carbon are included in the estimate. If a subdivision one year has an increase in the HUM and ROM pool the release of $N_2O$ by default are zero as only losses are included, cf. eq. 11.8. A C:N-ratio of 10, which is common in the fertilized Danish agricultural soils are used for all soil types. The recommended default value in the 2006 IPCC Guidelines is 15.

**Cultivation of organic soils**

$N_2O$ emissions from cultivation of organic soils are based on the area of organic soils of cropland, grassland and areas with no field identification, which are defined as grassland, shallow drained, nutrient-rich areas according to the 2013 Wetlands Supplement (IPCC, 2014). These areas are subdivided in areas with >12 % of soil organic carbon (SOC) and 6-12 % SOC. The Danish definition of organic soils are >10 % organic matter equivalent to app. 6 % SOC. It was defined in 1975 (Madsen et al., 1992). Agricultural soils in use under Danish conditions will normally have a carbon content of 1.5-3 % SOC (Taghizadeh-Toosi et al., 2014). This is the equilibrium state with a degradation condition and crop residue input. Drained land under agricultural use will therefore evidently approach a C content of 1.5-3 %. It is therefore assumed that the 6-12 % SOC soils will have losses of $CO_2$, $N_2O$ and $CH_4$. Almost all measurements in the literature is performed on soils having >12 % OC. The areas with >12 % of SOC are multiplied by the default emission factor from Table 2.5 of the 2013 Wetland Supplement, IPCC (2014), which for >12 % SOC is 13 kg per ha cropland, 8.2 kg per ha deep-drained, nutrient-rich grassland and 1.6 kg per ha shallow-drained, nutrient-rich grassland. It has not been able to find any solid documentation for areas with 6-12 % SOC, so it is chosen to use 50 % of the values for soils having >12 % SOC, i.e. 6.5, 4.1 and 0.8 kg per ha, respectively.

EF is constant for all years 1990-2018. The area of organic soils is shown in Table 5.25. The area of organic soils has decreased from 1990 to 2018, see more in Chapter 6.3.1.

Table 5.25 Area of organic soils in ha, 1990-2018.

| Year | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cropland, >12 % SOC | 67 025 | 63 131 | 59 237 | 55 343 | 51 449 | 48 047 | 47 707 | 49 026 | 47 527 | 45 970 | 44 999 |
| Grassland, >12 % SOC | 33 600 | 31 647 | 29 695 | 27 743 | 25 791 | 26 158 | 25 375 | 24 188 | 25 392 | 27 058 | 27 838 |
| SN grassland*, >12 % SOC | 0 | 0 | 0 | 0 | 0 | 2 626 | 2 829 | 1 440 | 2 881 | 4 424 | 5 395 |
| Cropland, 6-12 % SOC | 89 076 | 86 296 | 83 515 | 80 734 | 77 954 | 74 975 | 74 427 | 75 550 | 74 467 | 73 330 | 72 364 |
| Grassland, 6-12 % SOC | 25 072 | 24 289 | 23 507 | 22 724 | 21 941 | 22 312 | 21 898 | 21 073 | 21 872 | 22 975 | 23 493 |
| SN grassland*, 6-12 % SOC | 0 | 0 | 0 | 0 | 0 | 2 329 | 2 698 | 1 511 | 2 562 | 3 680 | 4 645 |

*SN grassland - shallow drained, nutrient-rich grassland.

### 5.6.4 Emission factors

In the calculation of $N_2O$ from agricultural soils, most of the $N_2O$ emission factors are based on the default values given by the IPCC (IPCC, 2006). EF for cultivation of organic soils are based on the 2013 Wetlands Supplement (IPCC, 2014). A $NH_3$ and $N_2O$ emission factor overview is presented in Table 5.26.

Table 5.26 Emission factors – $NH_3$ and $N_2O$ from agricultural soils – direct emissions.

| | $NH_3$ emission factor (national data) Kg $NH_3$-N per kg N | $N_2O$ emission factor (IPCC default value) kg $N_2O$ -N per kg N |
|---|---|---|
| Inorganic N fertilisers | 0.02 | 0.01[1] |
| Animal manure applied to soils | 0.19* | 0.01[1] |
| Sewage sludge applied to soils | 0.02 | 0.01[1] |
| Other organic fertilisers applied to soils | | 0.01[1] |
| Urine and dung deposited by grazing animals | 0.05-0.35[3] | 0.01-0.02[1] |
| Crop residues | | 0.01[1] |
| Mineralization/immobilization associated with loss/gain of soil organic matter | | 0.01[1] |
| Cultivation of organic soils | | 0.8-13**[2] |

*Varies from year to year, has decreased from 0.28 in 1990.

**Unit: kg $N_2O$-N per ha.

[1] IPCC (2006).

[2] IPCC (2014).

[3] EMEP/EEA Guidebook (2019).

### 5.6.5 Time series consistency

Figure 5.10 shows the distribution and the development from 1990 to 2018 according to different $N_2O$ sources. The yearly variations in emissions are mainly due to variations in the emission from inorganic N fertiliser and animal manure applied to soils. The main decrease is seen from 1990 to 2002 and is mainly due to the decrease in emission from inorganic N fertiliser, which is caused by increasing requirements for improved use of nitrogen in livestock manure and reduction of nitrogen loss to the environment. From 2003 to 2018 small yearly variations is seen, with increased emissions in 2008, 2016 and 2017 mainly due to increase in emission from inorganic N fertiliser. In 2018, the emission is decreased due to decrease in emission from inorganic N fertiliser and crop residues.

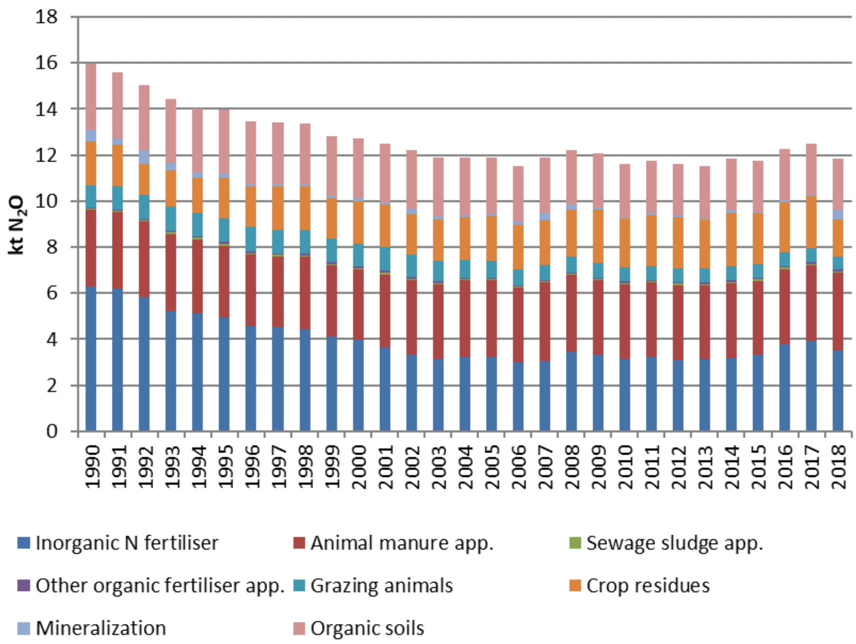


Figure 5.10 $N_2O$ emissions from agricultural soils – direct emissions 1990 - 2018.

## 5.7 $N_2O$ emission from agricultural soils – indirect emissions

### 5.7.1 Description

The emissions from agricultural soils – indirect emissions, are emissions from atmospheric deposition and from leaching and run-off. Agricultural soils – indirect emissions contribute, in 2018 with 11 % of the $N_2O$ emission from the agricultural sector. The largest source is nitrogen leaching and run-off. The emission has decreased by 42 % from 1990 to 2018.

### 5.7.2 Methodological issues

To estimate the emission of $N_2O$ from atmospheric deposition the Tier 1 methodology from the 2006 IPCC Guidelines is applied.

The calculation of the $N_2O$ emission from nitrogen leaching and runoff is based on IPCC model and a national model. Nitrogen, which is transported through the soil, can be transformed to $N_2O$. The IPCC recommends an $N_2O$ emission factor of 0.0075 used, of which 0.0025 is for leaching to groundwater, 0.0025 for transport to watercourses (in IPCC definition called rivers) and 0.0025 for transport out to sea (in IPCC definition called estuaries). The $N_2O$ emission from nitrogen leaching is a sum of the emission for all three parts calculated as:

$$N_2O_{leaching} = (N_{leach\ ground} \cdot EF_{ground} + N_{leach\ rivers} \cdot EF_{rivers} + N_{leach\ estuaries} \cdot EF_{estuaries}) \cdot \frac{44}{28}$$

In the Action Plans for the Aquatic Environment, nitrogen leaching to groundwater, rivers and estuaries has been estimated, see Table 5.28. The calculation of N to the groundwater is based on two different models– SKEP/Daisy and N-LES (Børgesen & Grant, 2003) carried out by DCA and DCE, Aarhus University (see overview of model in Annex 3D Figure 3D-1). SKEP/DAISY is a dynamical crop growth model taking into account the growth factors, whereas N-LES is an empirical leaching model based on more than 1500 leaching studies performed in Denmark during the last 15 years. The models produce rather similar results for nitrogen leaching on a national basis (Waagepetersen et al., 2008).

### 5.7.3 Activity data

#### Atmospheric deposition

Atmospheric deposition includes all agricultural $NH_3$ and $NO_x$ emission sources included in the Danish $NH_3$ emission inventory (Nielsen et al., 2019). Emission from atmospheric deposition from livestock manure, housing and storage, is reported in Sector 3B. Atmospheric deposition reported in Sector 3D includes the emission from livestock manure applied to soils and deposited during grazing, inorganic N fertiliser, growing crops, $NH_3$-treated straw used as feed, field burning of crop residues and sewage sludge plus sludge from industrial production applied to agricultural soils.

The emission from atmospheric deposition has decreased from 1990 – 2018 because of the reduction in the total $NH_3$ and $NO_X$ emission, from 76 743 tonnes of N in 1990 to 42 724 in 2018.

Table 5.27 $NH_3$ and $NO_x$ emission 2018.

| | t $NH_3$-N | t $NO_X$-N |
|---|---|---|
| Manure | 19 749 | 5 659 |
| Inorganic N fertilisers | 5 772 | 5 848 |
| Crops | 4 484 | |
| $NH_3$ treated straw | 130 | |
| Burning of agricultural residues | 100 | |
| Sewage sludge | 434 | 106 |
| Industrial sludge | 315 | 125 |
| Emission total | 30 984 | 11 740 |
| $N_2O$ emission, kt | | 0.67 |

#### Nitrogen leaching and Run-off

For N-leaching for ground water the SKEP/Daisy model has estimated the total N leached from 2003-2011 to be 149-174 thousand tonnes N, whereas N-LES model has estimated the total N leached to be 161-170 thousand tonnes in the same period. An average of the results from the two models is used in the emission inventory. From 2012 to 2017, data from N-LES is used. For 2018 no model estimations are available therefore are the N-leaching from ground water based on an average for 2015-2017.

Data concerning the N-leaching to rivers and estuaries are based on data from NOVANA (National Monitoring program of the Water Environment and Nature) received from the Department of Bioscience, Aarhus University (Windorf et al., 2011, Windorf, 2013, Thodsen, 2019). NOVANA is a monitoring program, which includes monitoring of the ecologic, physic and chemical condition of water areas and transport of water and a range of substances, including N, to lakes and the sea (Wiberg-Larsen et al., 2010). These studies include measurements from 223 monitoring stations in all parts of Denmark and they have been carried out since the early 1990's.

Table 5.28 N leaching to groundwater, rivers and estuaries in kt, 1990-2018.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Groundwater | 267 | 235 | 179 | 162 | 167 | 164 | 155 | 153 | 164 | 157 | 164 |
| Rivers | 102 | 104 | 95 | 67 | 68 | 65 | 80 | 94 | 80 | 76 | 74 |
| Estuaries | 100 | 91 | 81 | 56 | 55 | 54 | 62 | 77 | 62 | 64 | 54 |

Figure 5.11 shows leaching from groundwater estimated in relation to the nitrogen applied to agricultural soils as livestock manure, inorganic N fertiliser, sludge, crop residue and mineralization. The average proportion of nitrogen leaching from groundwater has decreased from around 35 % in the middle of the nineties to around 25 % in 2018. The decline is due to implementation of measures to avoid the nitrogen surplus in the agricultural production by improved nitrogen in manure, to use catch crops during winter and ban application of manure in winter. The reduction in nitrogen applied is particularly due to the fall in the use of inorganic N fertiliser. The main decrease in applied N to soil is seen from 1990 to 2002 due to the decrease in emission from inorganic N fertiliser. From 2003 to 2018, small yearly variations is seen with increase in 2008, 2016 and 2017 due to increase in N from inorganic N fertiliser. In 2018, a decreased is seen mainly due to decrease in N from inorganic N fertiliser and crop residues.

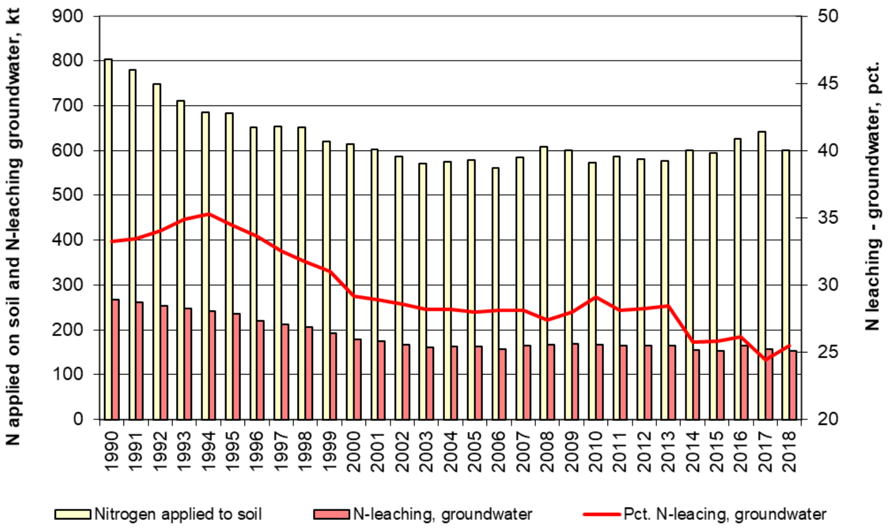


Figure 5.11 Nitrogen applied to agricultural soils and N-leaching, groundwater 1990-2018.

#### $Frac_{LEACH}$

The proportion of N input to soils lost through leaching and runoff ($Frac_{LEACH}$) used in the Danish emission inventory is in 2018 25 %, the default value of the IPCC is 30 %. $Frac_{LEACH}$ has decreased from 1990 and onwards. At the beginning of the 1990s, manure was often applied in autumn. Now, the main part of manure application takes place in the spring and early summer, where there is nearly no downward movement of soil water. The decrease in $Frac_{LEACH}$ over time is due to increasing environmental requirements and banning manure application after harvest.

### 5.7.4 Emission factors

In the calculation of indirect $N_2O$ emissions from agricultural soils, the emission factors for both sources are based on the default values given by the IPCC (IPCC, 2006). See Table 5.29.

Table 5.29 Emission factors – $N_2O$ from agricultural soils – indirect emissions.

| | $N_2O$ emission factor (IPCC default value) |
|---|---|
| | kg $N_2O$ -N per kg N |
| Atmospheric Deposition | 0.01 |
| Nitrogen Leaching and Run-off | 0.0075* |

*Groundwater = 0.0025, rivers = 0.0025 and estuaries = 0.0025.

### 5.7.5 Time series consistency

Figure 5.12 shows the emission of $N_2O$ from agricultural soils – indirect emissions. Both emissions from atmospheric deposition and leaching ad run-off have decreased from 1990 to 2018. The dips and jumps are mainly due to change in emission from leaching and run-off.

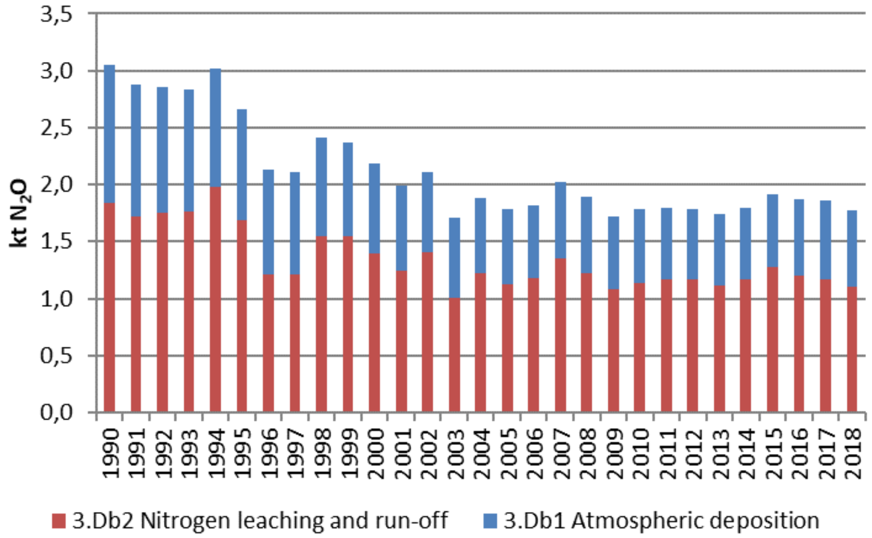


Figure 5.12 $N_2O$ emissions from agricultural soils – indirect emissions 1990 – 2018.

## 5.8 Field burning of agricultural residues

### 5.8.1 Description

Field burning of agricultural residues in Denmark, has been prohibited since 1990 and may only take place in connection with production of grass seeds on fields with repeated production and in cases of wet or broken bales of straw. Field burning produces emissions of a wide variety of different pollutants and only the greenhouse gases are covered in this report. For emission of air pollutants, see the Danish Informative Inventory Report (Nielsen et al., 2019).

### 5.8.2 Methodological issues

Equation for calculating emissions:

$$E = BB \cdot \frac{EF}{1\,000\,000} \cdot FO$$

$$BB = CP \cdot FB \cdot FR_{DM}$$

Where:
E = emission of compounds, kt
BB = total burned biomass, kt DM
CP = crop production, t
FB = fraction burned in fields
$FR_{DM}$ = dry matter fraction of residue
EF = emission factor, g per kg DM
FO = fraction oxidized

### 5.8.3 Activity data

The amount of burnt straw from the grass seed production is estimated as 15 % of the total amount produced. The amount of burnt bales of broken or wet bales of straw is estimated as 0.1 % of total amount of straw. Both estimates are based on an expert judgement by SEGES (Feidenhans'l, 2009, pers. comm.). The total amounts are based on data from Statistics Denmark.

### 5.8.4 Emission factor

Table 5.30 shows the emission factors used to estimate emissions of $CH_4$ and $N_2O$ (Andreae and Merlet, 2001).

Table 5.30 Factors for estimating emissions of $CH_4$ and $N_2O$, 2018.

| | | Crop production | Fraction burned in fields | Dry matter (dm) fraction of residue | Total Biomass burned | EF | Fraction oxidized | Emission |
|---|---|---|---|---|---|---|---|---|
| | | t | | | kt dm | g per kg dm | | kt |
| $CH_4$ | Mixed cereals | 4 045 400 | 0.001 | 0.85 | 3 439 | 2.7 | 0.90 | 0.008 |
| $CH_4$ | Straw from seeds of grass | 415 000 | 0.15 | 0.85 | 52 913 | 2.7 | 0.90 | 0.129 |
| $N_2O$ | Mixed cereals | 4 045 400 | 0.001 | 0.85 | 3 439 | 0.07 | 0.90 | 0.0002 |
| $N_2O$ | Straw from seeds of grass | 415 000 | 0.15 | 0.85 | 52 913 | 0.07 | 0.90 | 0.003 |
| Total $CO_2$ eqv | | | | | | | | 4.48 |

### 5.8.5 Time series consistency

The emission of $CH_4$, $N_2O$, $NO_x$, CO, $CO_2$, $SO_2$ and NMVOC from field burning contributes with less than 1 % of the national emission.

## 5.9 $CO_2$ from liming

### 5.9.1 Description

The emission of $CO_2$ from liming in Denmark occurs during liming with limestone. The emission of $CO_2$ from liming contributes with 98 % of the $CO_2$ emission from the agricultural sector.

### 5.9.2 Methodological issues

A Tier 1 method as given in the 2006 IPCC Guidelines is used.

### 5.9.3 Activity data

The amount of limestone used is based on the sales statistics. The amount used on the agricultural soils is collected by SEGES (Hansen, 2019). The amount of limestone used in private gardens is based on expert judgement (Andersen, 2004, pers. comm.).

### 5.9.4 Emission factors

The emission factor is 4.4 kt $CO_2$ per kt limestone and is the same for all years 1990 to 2018. It is based on the molecular weight for $CaCO_3$, $CO_2$ and C.

$$EF = M_{CaCO_3} \cdot M_C \cdot \frac{M_{CO_2}}{M_C}$$

Where:

EF Emission factor for $CO_2$ from liming

$M_i$ Molecular weight for *i* molecule

### 5.9.5 Time series consistency

The emission of $CO_2$ from liming has overall decreased by 58 % from 1990 to 2018. As shown in Figure 5.13, the main decrease is occurring from 1990 to 1997, and is due to a change in fertiliser practice with increase in use of manure as fertiliser and decrease in use of inorganic N fertiliser. When ammonium nitrogen is used as fertiliser and a loss of nitrogen from the soil is occurring, it causes an acidification of the soil and use of liming could be necessary to even out pH in the soil (Knudsen, 2,004).

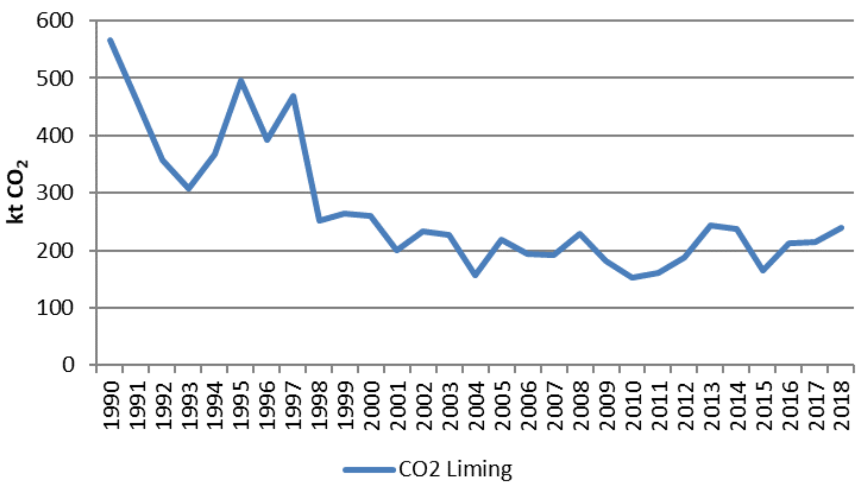


Figure 5.13 $CO_2$ emission from liming, 1990 to 2018.

## 5.10 $CO_2$ from urea

### 5.10.1 Description

Emission of $CO_2$ from use of urea contributes with less than 1 % of the $CO_2$ emission from the agricultural sector.

### 5.10.2 Methodological issues

A Tier 1 method as given in the 2006 IPCC Guidelines is used.

### 5.10.3 Activity data

The amount of urea used on agricultural soils is based on sales estimates from the Danish Agricultural Agency (Danish Agricultural Agency, 2018). For 2018, no sales statistic is available and the amount of urea is based on N from the Danish fertiliser accounts combined with the distribution of fertiliser types in 2017.

### 5.10.4 Emission factors

The default emission factor of 0.20 kg C per kg urea given in the 2006 IPCC Guidelines is used.

### 5.10.5 Time series consistency

Figure 5.14 shows the emission of $CO_2$ form use of urea. The emission has decreased with 91 % from 1990 to 2018, but the main decrease is occurring from 1990 to 2000. From 2003 to 2018, the emission is almost unaltered. The decrease is due to decrease in the use of urea.

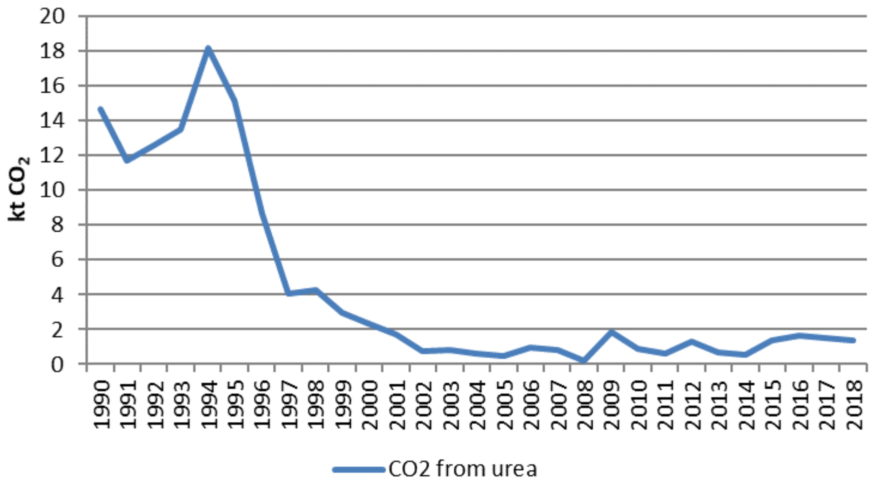


Figure 5.14 Emission of $CO_2$ from use of urea, 1990 to 2018.

## 5.11 $CO_2$ from other carbon-containing fertilisers

### 5.11.1 Description

Use of other carbon-containing fertilisers is in Denmark the use of calcium ammonium nitrate (CAN). The emission of $CO_2$ from CAN contributes with 2 % of the $CO_2$ emission from the agricultural sector.

### 5.11.2 Methodological issues

A Tier 1 method as given in the 2006 IPCC Guidelines is used.

### 5.11.3 Activity data

The amount of CAN used on agricultural soils is based on sales estimates from the Danish Agricultural Agency (Danish Agricultural Agency, 2018). For 2018, no sales statistic is available and the amount of CAN is based on N from the Danish fertiliser accounts combined with the distribution of fertiliser types in 2017.

### 5.11.4 Emission factors

The emission factor is 0.026 kg C per kg CAN and the same for all years 1990 to 2018. It is based on the molecular weight:

$$EF=\left(\frac{\text{kg CaCO}_3}{\text{kg CAN}}/100\right)\cdot M_{CaCO_3}\cdot M_C\cdot\frac{M_{CO_2}}{M_C}$$

$$\frac{\text{kg CaCO}_3}{\text{kg CAN}}=\left(100-M_{NH_4NO_3}\right)/M_{CaMg(CO_3)_2}\cdot M_{CaCO_3}\cdot 2$$

Where:

EF Emission factor for $CO_2$ from CAN
$M_i$ Molecular weight for *i* molecule

### 5.11.5 Time series consistency

Figure 5.15 shows the emission of $CO_2$ form use of CAN. The emission has decreased with 93 % from 1990 to 2018, but the main decrease is occurring from 1990 to 1999. From 2000 to 2018, the emission is almost unaltered but increases in 2015. The change is due to change in the use of CAN.

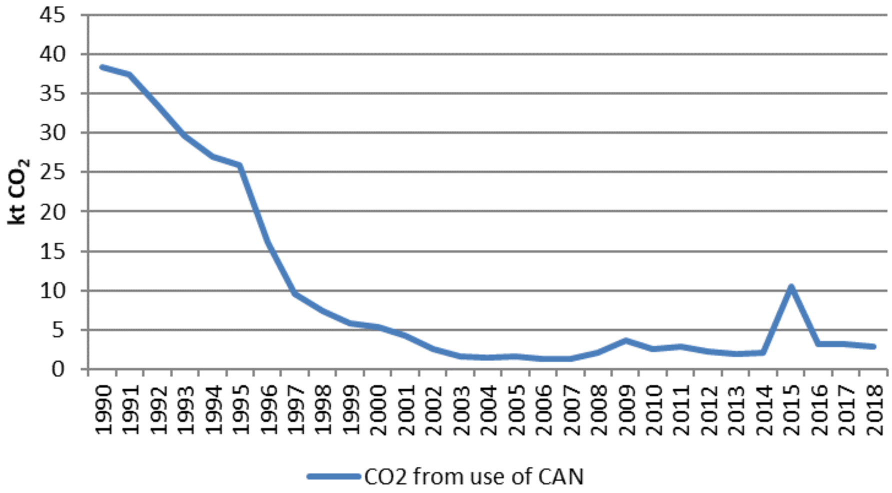


Figure 5.15 Emission of $CO_2$ from use of CAN, 1990 to 2018.

## 5.12 Uncertainties

Uncertainties are calculated using Approach 1.

### 5.12.1 Uncertainty values

Uncertainties regarding animal production, such as number of animals, feeding consumption, normative figures etc., are very small. The number of animals is estimated by Statistics Denmark and all cattle, sheep and goats have their own ID-number (ear tags) and, hence, uncertainty with regard to their numbers is almost non-existing. Statistics Denmark has estimated the uncertainty in the number of swine to be less than 1 %.

The Danish Normative System for animal excretions is based on data from SEGES, which is the central office for all Danish agricultural advisory services. SEGES engages in a great deal of research as well as the collection of efficacy reports from Danish farmers for dairy production, meat production, swine production, etc. to optimise productivity in Danish agriculture. In total, feeding plans from 15-18 % of Danish dairy production, 25-30 % of swine production, 80-90 % of poultry production and approximately 100 % of fur production are collected annually. These basic feeding plans are used to develop the standard values of the “Danish Normative System”.

The normative figures (Poulsen et al. 2001) are comprised of arithmetic means. Based on feeding plans, the standard deviation in N-excretion rates between farms can be estimated to ±20 % for all animal types (Poulsen, DCA). However, due to the large number of farms included in the norm figures the arithmetic mean can be assumed as a very good estimate with a low uncertainty.

Data for hectares under cultivation is estimated by Statistics Denmark and the uncertainties are based on their estimates. For the most common crops, the uncertainties are below 5 %.

For $CH_4$ emission from enteric fermentation, the uncertainty for activity data is the uncertainty for numbers of animals and the uncertainty for the emission factor is based on IPCC 2006. For the emission of $CH_4$ from manure management, the uncertainty for the activity data is the uncertainty for number of animals and the distribution of housing types. The uncertainty for the emission factor is based on uncertainty given in IPCC 2006.

For the $N_2O$ emission uncertainties, the activity data uncertainty is based on the uncertainties for $NH_3$ emission due to the high correlation between the $NH_3$ and $N_2O$ emission (Nielsen et al., 2019). Uncertainties related to the $N_2O$ emission factor are based on the IPCC 2006. See Table 5.31 for uncertainty values for the agricultural sector.

Table 5.31 Uncertainties values for activity data and emission factors for $CH_4$, $N_2O$ and $CO_2$.

| CRF category | Emission factor | Uncertainties value for activity data, % | Uncertainties value for emission factor, % |
|---|---|---|---|
| 3A Enteric Fermentation | $CH_4$ | 2 | 20 |
| 3B Manure Management | | | |
| | $CH_4$ | 5 | 20 |
| | $N_2O$ | 25 | 100 |
| 3B5 Atmospheric Deposition | $N_2O$ | 16 | 100 |
| 3D Agricultural Soils | | | |
| 3Da Direct soil emissions | | | |
| 3Da1 Inorganic N fertiliser | $N_2O$ | 3 | 100 |
| 3Da2a Animal manure applied to soils | $N_2O$ | 25 | 100 |
| 3Da2b Sewage sludge applied to soils | $N_2O$ | 15 | 100 |
| 3Da2c Other organic fertiliser applied to soils | $N_2O$ | 20 | 100 |
| 3Da3 Urine and dung deposited by grazing animals | $N_2O$ | 10 | 100 |
| 3Da4 Crop Residues | $N_2O$ | 25 | 100 |
| 3Da5 Mineralization | $N_2O$ | 50 | 100 |
| 3Da6 Cultivation of organic soils | | 20 | 100 |
| 3Db Indirect soil emissions | | | |
| 3Db1 Atmospheric deposition | $N_2O$ | 16 | 100 |
| 3Db2 Leaching | $N_2O$ | 20 | 100 |
| 3F Field Burning of Agricultural Residue | | | |
| | $CH_4$ | 25 | 50 |
| | $N_2O$ | 25 | 50 |
| 3G Liming | $CO_2$ | 5 | 100 |
| 3H Urea application | $CO_2$ | 3 | 100 |
| 3I Other carbon-containing fertilisers | $CO_2$ | 3 | 100 |

### 5.12.2 Result of the uncertainty calculation

Table 5.32 shows the result of Approach 1 uncertainty calculation for 2018. The overall uncertainty calculation for the agricultural sector based on Approach 1 is estimated to ±19 %.

The lowest uncertainties are seen for $CH_4$ emission from enteric fermentation and manure management and the highest for emission form mineralization and this pattern is reflected in both calculations.

Table 5.32 Uncertainty calculation, 2018.

| Uncertainty | | Emission, kt $CO_2$ eqv | Uncertainty, % Lower and upper (±) |
|---|---|---|---|
| 3 Agriculture total | $CH_4$, $N_2O$ and $CO_2$ | 11 042 | 19 |
| 3A Enteric Fermentation | $CH_4$ | 3 767 | 20 |
| 3B Manure Management | $CH_4$ and $N_2O$ | 2 952 | 26 |
| | $CH_4$ | 2 219 | 21 |
| | $N_2O$ | 597 | 103 |
| 3B5 Atmospheric deposition | $N_2O$ | 136 | 101 |
| 3D Agricultural Soils | $N_2O$ | 4 073 | 41 |
| 3Da Direct soil emissions | $N_2O$ | 3 543 | 48 |
| 3Da1 Inorganic N fertiliser | $N_2O$ | 1 050 | 100 |
| 3Da2a Animal manure applied to soils | $N_2O$ | 1 016 | 103 |
| 3Da2b Sewage sludge applied to soils | $N_2O$ | 19 | 101 |
| 3Da2c Other organic fertiliser applied to soils | $N_2O$ | 22 | 102 |
| 3Da3 Urine and dung deposited by grazing animals | $N_2O$ | 175 | 100 |
| 3Da4 Crop Residues | $N_2O$ | 473 | 103 |
| 3Da5 Mineralization | $N_2O$ | 135 | 112 |
| 3Da6 Cultivation of organic soils | $N_2O$ | 652 | 102 |
| 3Db Indirect soil emissions | $N_2O$ | 530 | 74 |
| 3Db1 Atmospheric deposition | $N_2O$ | 200 | 101 |
| 3Db2 Leaching | $N_2O$ | 329 | 102 |
| 3F Field Burning of Agricultural Residues | $CH_4$ & $N_2O$ | 4 | 45 |
| | $CH_4$ | 3 | 56 |
| | $N_2O$ | 1 | 56 |
| 3G Liming | $CO_2$ | 240 | 100 |
| 3H Urea application | $CO_2$ | 2 | 100 |
| 3I Other carbon-containing fertilisers | $CO_2$ | 3 | 100 |

## 5.13 Quality assurance and quality control (QA/QC)

### 5.13.1 Verification

#### Enteric fermentation

*Tier 2/Country Specific compared to IPCC Tier 2 method*

A comparison between the IPCC Tier 2 methodology and Denmark's Tier 2/Country Specific (CS) calculation method for enteric fermentation is made. In the IPCC Guidelines default values are given for dairy cattle and non-dairy cattle, therefore a comparison is made for these groups.

Calculations of IEFs are made by IPCC Tier 2, with both default and national values for $Y_m$, and Denmark's Tier 2/CS method. A comparison between IEFs (Table 5.33) shows that the Danish method gives a value for dairy cattle, which is 3 % higher than the IPCC Tier 2 method and for non-dairy cattle, the Danish method gives a value which is 2 % higher than the IPCC Tier 2.

Table 5.33 IEFs for enteric fermentation calculated by different methods, 2018.

| kg $CH_4$ per animal per year | Tier 2 (IPCC $Y_m$) | Tier 2 (DK $Y_m$) | Tier 2/CS |
|---|---|---|---|
| Dairy cattle | 155.7 | 143.8 | 160.6 |
| Non-dairy cattle | 39.6 | 39.6 | 40.5 |

The three different Tier 2 calculations for non-dairy cattle all show an IEF between 39.6-40.5 kg per head per year, which indicates that the Tier 2/CS used in the Danish inventory is reasonable. However, these values are lower compared to the Tier 1 default value at 57 kg per head per year given in the IPCC 2006, Table 10.11, which can be explained by a lower animal weight/lower feed intake.

The higher value for the IEF for dairy cattle is mainly due to a higher GE in the Danish method (Table 5.34). The Danish values for feed consumption are based on the Danish normative figures, the normative data are based on actual efficacy feeding controls or actual feeding plans at farm level, more info on GE calculations and $Y_m$ is included in Chapter 5.3.2.

Table 5.34 GE for dairy cattle calculated by different methods, 2018.

| MJ per animal per day | Tier 2 (IPCC $Y_m$) | Tier 2/CS |
|---|---|---|
| Dairy cattle | 365.3 | 408.1 |

**Manure management**

*Nitrogen excretion rates compared to the IPCC defaults*

For non-dairy cattle, goats, horses, poultry and mink nitrogen excretion rates given by 2006 IPCC Guidelines and the Danish nitrogen excretion rates are at the same level. For dairy cattle Denmark has a higher nitrogen excretion rate than given in 2006 IPCC Guidelines, this is probably due to a high feed consumption to give high milk production per cow at Danish dairy cattle. The nitrogen excretion rate for swine reported in the CRF is an average for the subcategories sows, weaners and fattening pigs, 7.7 in 2018. The Danish nitrogen excretion rate is lower than the default given in the 2006 IPCC Guidelines, this is due to the high feed efficiency in Danish swine and the high share of weaners. For sheep, the nitrogen excretion rate reported in CRF is an average for mother sheep and lambs and therefor lower than given in 2006 IPCC Guidelines. The Danish nitrogen excretion rate for mother sheep is 12.8 kg N per animal per year in 2018.

Table 5.35 Nitrogen excretion rates from the 2006 IPCC Guidelines and for Denmark, 2018.

| IPCC | kg N per 1000 kg animal per day | Weight kg (DK) | kg N per animal per year | Denmark | kg N per animal per year |
|---|---|---|---|---|---|
| Dairy cattle | 0.48 | 580 | 101.6 | Dairy cattle | 154.7 |
| Other cattle | 0.33 | 320 | 38.5 | Non-dairy cattle | 42.3 |
| Swine - market | 0.51 | 113 | 21.0 | Swine - fattening pigs and weaners | 6.2 |
| Swine - breeding | 0.42 | 140 | 21.5 | Swine - sows | 23.8 |
| Sheep | 0.85 | 48.5 | 15.0 | Sheep - mother | 6.6 |
| Goats | 1.28 | 38.5 | 18.0 | Goats | 16.6 |
| Horses | 0.26 | 438 | 41.6 | Horses | 39.6 |
| Hens | 0.96 | 2 | 0.7 | Hens | 1.0 |
| Pullets | 0.55 | 1.4 | 0.3 | Pullets | 0.1 |
| Broilers | 1.1 | 2 | 0.8 | Broilers | 0.7 |
| Turkeys | 0.74 | 14 | 3.8 | Turkeys | 2.6 |
| Ducks | 0.83 | 3.7 | 1.1 | Ducks | 1.0 |
| Mink | | | 4.59 | Mink | 5.1 |
| Fox | | | 12.09 | | |

*Nitrogen excretion compared to DCA numbers*

DCA, who estimates the normative figures for nitrogen excretions per animal, also estimate the total amount of nitrogen excreted for the years 2005-2016 (Blicher-Mathiesen et al., 2016).

A comparison of the total nitrogen excretion estimated by DCE for the emission inventory and that estimated by DCA is made, see Figure 5.16. It is seen that the trend for the total nitrogen excretion almost follow the same pattern for both estimations. The nitrogen excretion estimated by DCE are a bit higher than the nitrogen excretion estimated by DCA and this is probably due to the number of animals. The inventory includes animals on small farms, which are not included in numbers from DSt (horses, sheep and goats) and also some animal categories, which are not included in the normative system (deer, pheasants and ostriches). Another reason for the difference between the two estimations could be differences in definitions for grazing – e.g. days on grass vs. days in housings.

The comparison between the total N-excretion estimated by DCE and DCA, shows the same trend, and based on this, it is concluded that the total N-excretion estimated by DCE for all years 1982-2018 used in the national inventory, seems reliable.

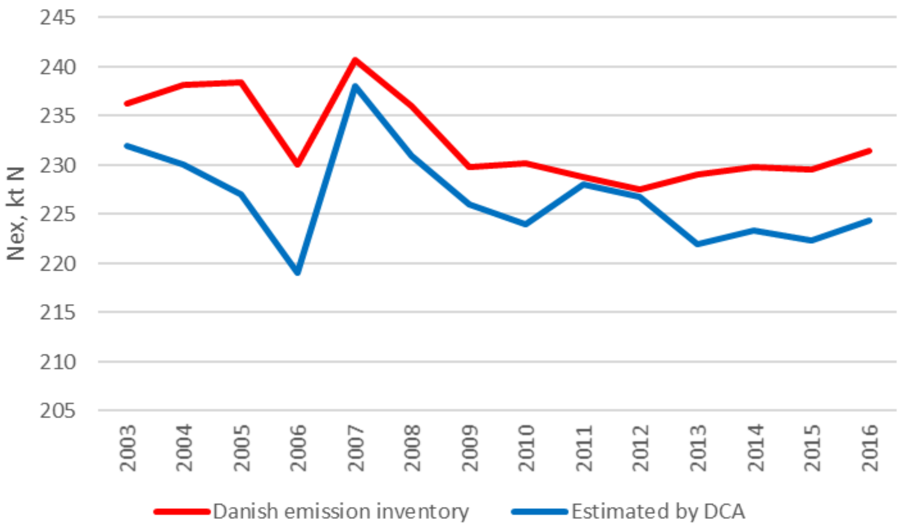


Figure 5.16 Comparison of nitrogen excretion estimated by DCE and DCA.

*MCF compared to IPCC default*

The comparison of MCF given in IPCC 2006 and the MCF used in the Danish inventory are shown in Annex 3D, Table 3D-15. For liquid untreated and biogas treated manure for cattle and swine, a national estimated MCF is used (see Annex 3D Chapter 3D-1). For other animal categories and manure types, the MCF is based on values from the 2006 IPCC Guidelines.

*Distribution of animals on housing types*

Table 5.36 shows the distribution of animals on different housing types given in IPCC 2006 and the Danish national distribution. The main part of Danish dairy cattle is housed in systems with liquid/slurry manure whereas the distribution given by IPCC, for a great part, is housed in systems with solid manure. For non-dairy cattle, the percentage of animal in systems with liquid/slurry and pasture, range and paddock are almost the same in IPCC and in Denmark. IPCC has a great part of non-dairy cattle on systems with solid manure, whereas this part of non-dairy cattle in the Denmark is in systems with deep litter that is the manure management system other. For swine, the main part of the animals in Denmark is housed in systems with liquid/slurry, whereas the main part in IPCC is in systems with pit > 1 month.

Table 5.36 Distribution of animals on housing types IPCC 2006 vs. national.

| | IPCC 2006 | | | DK 2018 | | |
|---|---|---|---|---|---|---|
| | Dairy cattle | Other cattle | Swine | Dairy cattle | Non-dairy cattle | Swine |
| Lagoon | 0 | 0 | 8.7 | 0 | 0 | 0 |
| Liquid/slurry | 35.7 | 25.2 | 0 | 71.1 | 31.6 | 85.8 |
| Solid storage | 36.8 | 39 | 13.7 | 0.9 | 0.4 | 0.1 |
| Drylot | 0 | 0 | 0 | 0 | 0 | 0 |
| Pasture, range and paddock | 20 | 32 | - | 4.9 | 28.6 | 0.1 |
| Daily spread | 7 | 1.8 | 2 | 0 | 0 | 0 |
| Digester | 0 | 0 | 0 | 16.3 | 0 | 12.1 |
| Burned for fuel | 0 | 0 | - | 0 | 0 | 0 |
| Other | 0.5 | 2 | 3 | 6.7 | 39.4 | 1.9 |
| Pit < 1 month | - | - | 2.8 | 0 | 0 | 0 |
| Pit > 1 month | - | - | 69.8 | 0 | 0 | 0 |

*Calculation of VS based on GE and DM*

Figure 5.17, 5.18 and 5.19 show a comparison of the calculation of VS based on gross energy (GE) and manure. In the Danish inventory, the calculation of VS is based on manure. For dairy cattle, the two calculations follow the same trend, but the VS based on manure are higher than the one based on GE. This is mainly due to the inclusion of bedding.

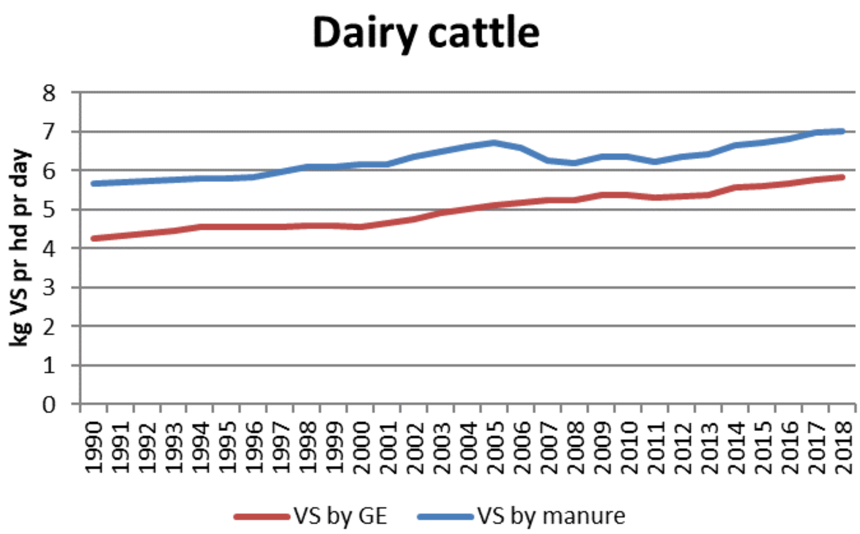


Figure 5.17 VS for dairy cattle based on GE and on manure.

For all non-dairy cattle, VS based on manure are higher than the one based on GE and this is mainly due to the inclusion of bedding. For bulls, VS based on manure, increase in 2001-2011 due to increase in the share of animals in housings with deep litter. From 2012 to 2013, the VS for bulls decrease due to reduction of bedding per animal per day given in the normative figures. VS based on manure for suckling cattle change due to increase in amount of manure per animal and decrease in dry matter (DM) in the manure for animals on some housing types. The decrease from 2006 to 2007 is due to division of suckling cattle in three wait classes with different amount of bedding per animal per day.

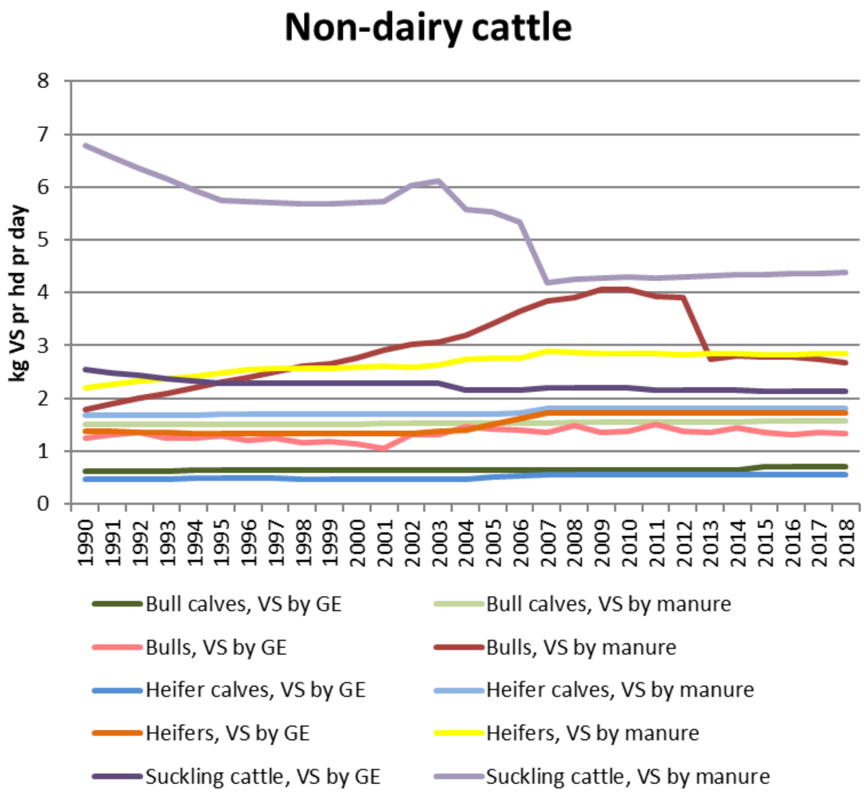

Figure 5.18 VS for non-dairy cattle based on GE and manure.

VS for weaners and fattening pigs based on both GE and manure follow the same trend, but the VS based on GE are a bit higher than VS based on manure. This is mainly due to high feed efficiency in Danish swine. The decrease in VS based on manure for sows in 2004-2007 is due to decrease in the share of animals in housings with bedding.

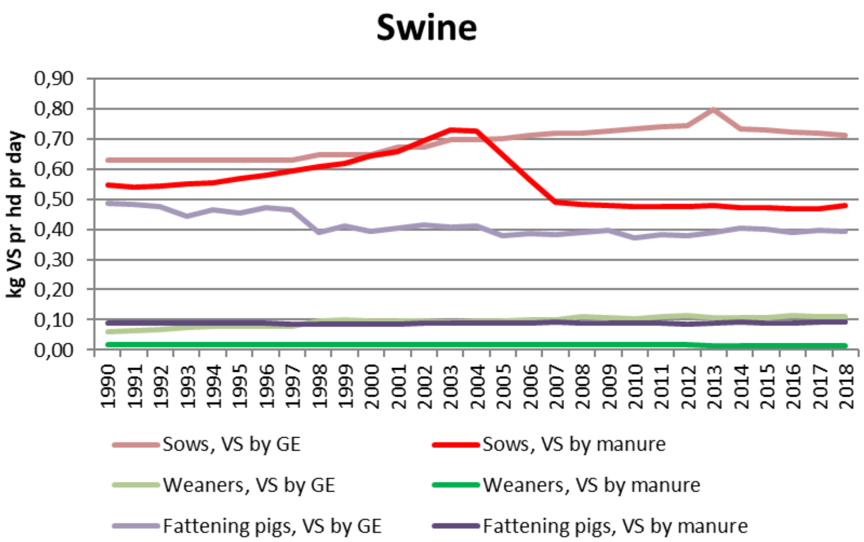

Figure 5.19 VS for swine based on GE and manure.

### 5.13.2 QA/QC plan

A first step of development and implementation of a general QA/QC plan for all sectors started in 2004 which is described in a publicised manual (Sørensen et al., 2005). The manual describes the concepts of quality work and how to handle quality management by using Critical Control Points and a list of Point of Measurements (Nielsen et al., 2013). For more detailed information of the structure in the general QA/QC plan, please refer to Chapter 1.6 for QA/QC.

A complete list Points of Measures (PM) are given in Table 1.2. PM related to the agricultural inventory is listed below in Chapter 5.13.3 and are primarily connected to data storage and data processing level 1. For PM not mentioned below please refer to Chapter 1.6.

The QA/QC work specific for the agricultural sector is still improved. The overall framework regarding a QA/QC plan for agriculture are constructed in form of six stages and each stage focus on quality assurance and quality check in different part of the inventory process. A more detailed set up for stage I, II and III are developed – refer to Annex 3D Table 3D-21.

The QA/QC procedure is divided in six stages as listed below:

Table 5.37 Stages of QA/QC procedure.

| | |
|---|---|
| **Stage I** | **Check of input data**<br>- check of data input in IDA are consistent with data from external data suppliers |
| **Stage II** | **Check of IDA data – overall**<br>- check of recalculations for total emissions compared with the latest submission<br>- check of total emissions for the total $CO_2$ eqv. and for each compound |
| **Stage III** | **Check of IDA data – specific**<br>- check of annual changes of activity data, emission factors, IEF and other important variables as GE, Nex, housing system distribution, grazing days |
| **Stage IV** | **Check by comparing calculation with estimates from other institutions**<br>- the total Nex for all livestock production estimated by DCA<br>- the Register for fertilization controlled by the Danish Agricultural Agency |
| **Stage V** | **Check of data registered in CRF**<br>- compare data in CRF with data from IDA |
| **Stage VI** | **Check of the inventory in general (external review)**<br>- check that data is used correctly<br>- check the methodology and the calculations |

#### Stage I: Check of input data

At stage I, it is checked that all input data in IDA are consistent with data from the external data suppliers. Data from the Statistics Denmark have to be checked for the livestock production, slaughter data for poultry and pigs, check of land use and crop yield. Data input from the DCA have to be checked for feed intake, N-excretion, manure production, dry matter content and grazing days. Data from the Danish Agricultural Agency: distribution of housing systems and the use of nitrogen in inorganic N fertiliser.

#### Stage II: Check of IDA data - overall

Stage II includes check of the overall calculations in IDA, where the first step is to compare the inventory with the last reported emission inventory - submission 2019. In the case where an error covers the whole time series, it can be difficult to identify this error by checking the changes in inter-annual values. Therefore, a check of recalculations is needed.

Next step in stage II is a check of total emissions of $CH_4$, $N_2O$, NMVOC and the other compounds, which are related to the field burning of agricultural residues. For each compound, a check of trends of time series 1990-2018 and inter-annual changes is provided. Significant jumps or dips from one year to another could indicate an error - otherwise it has to be explained.

#### Stage III: Check of IDA data - specific

At stage III, a check of specific variables in IDA is provided for both inter-annual changes and trends for the entire time series. Variables includes activity data, emission factors, IEFs and other important key variables such as feed intake, GE, Nex and housing system distribution.

#### Stage IV: Check by comparing calculation with estimates from other institutions

The purpose of stage IV is to verify the calculations in IDA, as far as external data estimations are available. For other purposes DCA for some years calculate the overall N excretion from the total livestock production in DK, this is compared with the estimated in the emission inventory, see Chapter 5.13.1.

Another possibility to check some of the IDA estimations is the information in the fertiliser accounts controlled by The Danish Agricultural Agency. Farmers with more than 10 animal units is registered and have to keep accounts of the N content in manure, received manure or other organic fertiliser. These comparisons will properly show some differences, which not necessarily indicate an error, but the most important cause of the difference has to be identified.

#### Stage V: Check of data registered in CRF

Stage V primarily focuses on the last reported year 2018 and the base year (1990), where all activity data, emissions and IEFs are checked. Furthermore, CRF sum emissions are checked with sum emissions in IDA. If an error is detected a more detailed check is done to find the reason for the error.

#### Stage VI: Check of the inventory in general

A detailed description of the methodology used to calculate the Danish agricultural emissions is published as a sectorial report for agriculture (Albrektsen et al., 2017). General checks of the inventory include considerations of which data input is used, how they are used in the calculations and whether more accurate data are available. The review of the sectorial report addresses these issues and is a most valuable part of the QA of the agricultural sector.

### Status for the QA/QC plan

The framework for working out a specific QA/QC plan for the agricultural sector is complete. Stage I-III is done as part of the process of inventory preparation, which has reduced the number of errors in the CRF and in this way meet the ERT recommendations. A more detailed list showing the checked variables of stage I – III is provided in Annex 3D Table 3D-21.

Concerning the stage IV we have provide some random checks but need to provide a more systematic check. We are aware of some external calculations, which can be compared with the estimations in IDA – e.g. some comparisons with the Register of Fertilisation administrated by the Danish Agricultural Agency can be provided.

Stage VI is implemented. Four reports describing the methodology in calculation of agricultural emissions in details are published (Mikkelsen et al., 2006, Mikkelsen et al., 2011, Mikkelsen et al., 2014 and Albrektsen et al., 2017). All reports have been reviewed by experts not involved with the preparation of the emission inventory. The 2017 report was reviewed by Peter Lund, Department of Animal Science, Aarhus University. The reviewers have reviewed all sections of the report.

### 5.13.3 QA/QC plan expressed in Critical Control Points and Point of Measurements

**Data storage level 1**

| | | | |
|---|---|---|---|
| Data Storage level 1 | 3. Completeness | DS.1.3.1 | Documentation showing that all possible national data sources are included by setting down the reasoning behind the selection of datasets. |

The following external data are in used in the agricultural sector, in more details see Table 5.3:

- Data from the annual agricultural census made by Statistics Denmark.
- DCA, Aarhus University.
  The Danish Agricultural Agency.
- SEGES
- The Danish Energy Agency.
- Danish Environmental Protection Agency.

The emission factors come from various sources:

- IPCC guidelines.
- DCA, Aarhus University: $NH_3$ emission, $CH_4$ emission from enteric fermentation and manure management.

*Statistics Denmark*

The agricultural census made by Statistics Denmark is the main supply of basic agricultural data. In Denmark, all cattle, sheep and goats have to be registered individually and hence the uncertainty in the data is negligible. For all other animal types, farms having more than 10 animal units are registered.

*DCA*

The DCA is responsible for the delivery of N-excretion data for all animal and housing types. Data on feeding consumption on commercial farms are collected annually by SEGES from on-farm efficacy controls. For dairy cattle, data is collected from 15-20 % of all farms, for pigs, 25-30 % and for poultry and mink, 90-100 % of all farms. The farm data are used to calculate average N-excretion from different animal and housing types. Due to the large amount of farm data involved in the dataset, N-excretion is seen as a very good estimate for average N-excretion at the Danish livestock production.

*Danish Agricultural Agency*

Total area with the various agricultural crops is provided to the Danish Agricultural Agency via the agricultural subsidy system. For every parcel of land (via a vector-based field map with a resolution of >0.01 ha), the area planted with different crops is reported. If the total crop area within a parcel is larger than the parcel area, a manual control of the information is performed by the Agency. The area with different crops, therefore, represents a very precise estimate.

All farmers are obligated to do N-fertiliser accounting on a farm and field level based on the Danish normative data provided by DCA. Data at farm level is reported annually to the Danish Agricultural Agency. The N figures also include the quantities of inorganic N fertilisers applied to agricultural soils. Suppliers of inorganic N fertilisers are required to report all N sales to commercial farmers to the Danish Agricultural Agency, which is registered and published in a sales statistic annually. Comparison between the sales statistics and the N fertiliser account, shows a higher consumption of N in inorganic fertilisers from 2005, which is caused be an import from the farmers them self. Therefore, the consumption of N in use of inorganic fertiliser registered in the n fertiliser account seems to be the most reliably reference.

The Danish Agricultural Agency, as the controlling authority, performs analysis of feed sold to farmers. On average, 1600 to 2000 samples are analysed every year. Uncertainty in the data is seen as negligible. The data are used when estimating average energy in feedstuffs for pigs, poultry, fur animals, etc.

From 2005, the Danish Agricultural Agency provides data for distribution of housing type based on registration from farmers to the Danish fertiliser N accounts.

*SEGES*

SEGES is the central office for all Danish agricultural advisory services. SEGES carries out a considerable amount of research itself, as well as collecting efficacy reports from the Danish farmers for dairy production, meat production, pig production, etc., to optimise productivity in Danish agriculture. From SEGES data on housing type until 2004, grazing situation and information on application of manure is received.

*The Danish Energy Agency*

The amount of slurry treated in biogas plants is received from the Danish Energy Agency.

*Danish Environmental Protection Agency*

Information on the sludge from wastewater treatment and the manufacturing industry and the amount applied on agricultural soil is obtained from the Danish Environmental Protection Agency.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 1. Accuracy | DS.1.1.1 | General level of uncertainty for every dataset including the reasoning for the specific values |

The most important emission source is related to the animal production. Uncertainty for the animal data is very low due to the very strict environmental laws in Denmark. Standard deviation regarding the numbers of cattle and pigs has been estimated to <0.7 %. For poultry the standard deviation is <2.1 %. For all years, 25-35 % of all holdings are included in the census. The standard deviation for N-excretion between farms is reported as 25 % for dairy cattle and pigs, but due to the large numbers involved in the estimation of the average N-excretion, the average is assumed a precise estimate for the Danish agricultural efficacy level.

Regarding uncertainties for the remaining emission sources, see Chapter 5.12.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 1. Accuracy | DS.1.1.2 | Quantification of the uncertainty level of every single data value including the reasoning for the specific values. |

Please, refer to Chapter 5.12 and Table 5.31.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 1. Comparability | DS.1.2.1 | Comparability of the data values with similar data from other countries, which are comparable with Denmark, and evaluation of discrepancy. |

The Danish N-excretion levels are generally lower than IPCC default values. This is due to the highly skilled, professional and trained farmers in Denmark, with access to a highly competent advisory system.

The feed consumption per animal is in line with similar data from Sweden, although they are not quite comparable because Denmark is using feeding units (FE) which cannot easily be converted to energy content. Earlier, one feeding unit was defined as one kg of barley. Today, the calculations are more complicated and depend on animal type.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 4. Consistency | DS.1.4.1 | The origin of external data has to be preserved whenever possible without explicit arguments (referring to other PMs). |

External data received are stored in the original format in the quality management database system.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 6. Robustness | DS.1.6.1 | Explicit agreements between the external institution holding the data and DCE about the conditions of delivery. |

DCE has established formal data agreements with all institutes and organisations, which deliver data, to assure that the necessary data is available to prepare the inventory on time.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 6. Robustness | DS.1.6.2 | At least two employees must have a detailed insight into the gathering of every external data set. |

Please refer to Chapter 1.6.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 7. Transparency | DS.1.7.1 | Summary of each dataset including the reasoning for selecting the specific dataset. |

Please refer to DS 1.1.1.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 7. Transparency | DS.1.7.2 | The archiving of data sets needs to be easy accessible for any person in the emission inventory. |

Please refer to Chapter 1.6.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 7. Transparency | DS.1.7.3 | References for citation for any external data set have to be available for any single value in any dataset. |

A great deal of documentation already exists in the literature list, and is also achieved in the quality management database system.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 7. Transparency | DS.1.7.4 | Listing of external contacts for every dataset. |

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**Data processing level 1**

| | | | |
|---|---|---|---|
| Data Processing level 1 | 1. Accuracy | DP.1.1.1 | Uncertainty assessment for every data source as input to Data Storage level 2 in relation to type of variability. (Distribution as: normal, log normal or other type of variability). |

The Approach 1 methodology is used to calculate the uncertainties for the agricultural sector. The uncertainties are based on a combination of IPCC guidelines and expert judgement (Olesen et al., 2001, Poulsen et al., 2001) and a normal distribution is assumed.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 1. Accuracy | DP.1.1.2 | Uncertainty assessment for every data source as input to Data Storage level 2 in relation to scale of variability (size of variation intervals). |

Please refer to DP 1.1.1.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 1. Accuracy | DP.1.1.3 | Evaluation of the methodological approach using international guidelines. |

Denmark has worked out a report with a more detailed description of the methodological inventory approach in Mikkelsen et al. (2006), Mikkelsen et al. (2011), Mikkelsen et al. (2014) and an updated version in Albrektsen et al. (2017). The first report has been reviewed by the Statistics Sweden, who is responsible for the Swedish agricultural inventory; the second was reviewed of qualified persons with comprehensive agricultural knowledge; Nicholas J. Hutchings from the DCA, Aarhus University and Johnny M. Andersen from the Faculty of Life Sciences, University of Copenhagen. The third was review by MST and the updated report has been reviewed by Peter Lund, from Department of Animal Science, Aarhus University. None of the reviewers is involved in the preparation of the annual inventory.

Furthermore, data sources and calculation methodology developments are continuously discussed in cooperation with specialists and researchers in different institutes and research sections. Consequently, both the data and methods are evaluated continually according to the latest knowledge and information.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 1. Accuracy | DP.1.1.4 | Verification of calculation results using guideline values |

The methodological approach is consistent with the IPCC 2006 Guidelines. See Chapter 5.13.1.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 2. Comparability | DP.1.2.1 | The inventory calculation has to follow the international guidelines suggested by UNFCCC and IPCC. |

The methodological approach is consistent with the IPCC 2006 Guidelines.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 3. Completeness | DP.1.3.1 | Assessment of the most important quantitative knowledge, which is lacking. |

Regarding the reduction potential for biogas treated slurry, more information and investigation would be preferred. There is on-going work to increase the accuracy of this emission source.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 3. Completeness | DP.1.3.2 | Assessment of the most important missing accessibility to critical data sources |

All known major sources are included in the inventory. In Denmark, only very few data are restricted. Accessibility is not a key issue; it is more lack of data.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 4. Consistency | DP.1.4.1 | In order to keep consistency at a high level, an explicit description of the activities needs to accompany any change in the calculation procedure |

The calculation procedure is consistent for all years.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 4. Consistency | DP.1.4.2 | Identification of parameters (e.g. activity data, constants) that are common to multiple source categories and confirmation that there is consistency in the values used for these parameters in the emission calculations |

Please refer to Chapter 1.6.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 5. Correctness | DP.1.5.1 | Show at least once, by independent calculation, the correctness of every data manipulation. |

During the development of the model, thorough checks have been made by all persons involved in preparation of the agricultural section.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 5. Correctness | DP.1.5.2 | Verification of calculation results using time series. |

Time series for activity data, emission factors and national emission are performed to check consistency in the methodology, to avoid errors, to identify and explain considerable year to year variations.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 5. Correctness | DP.1.5.3 | Verification of calculation results using other measures. |

A comparison between IPCC Tier 2 method for enteric fermentation and Denmark's Tier 2/CS is made, see Chapter 5.13.1.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 5. Correctness | DP.1.5.4 | Show one-to-one correctness between external data sources and the databases at Data Storage level 2 |

In the database key ids is used to identify the unique data. The data on DS level 1 is linked to the key id used in the database so a clear reference from DS level 1 to higher levels of both DP and DS is secured.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 6. Robustness | DP.1.6.1 | Any calculation must be anchored to two responsible persons that can replace each other in the technical issue of performing the calculations. |

Please refer to Chapter 1.6.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 7. Transparency | DP.1.7.1 | The calculation principle and equations used must be described. |

All calculation principles are described in the NIR and the documentation report (Albrektsen et al., 2017).

| | | | |
|---|---|---|---|
| Data Processing level 1 | 7. Transparency | DP.1.7.2 | The theoretical reasoning for all methods must be described. |

All theoretical reasoning is described in the NIR and the documentation report (Albrektsen et al., 2017).

| | | | |
|---|---|---|---|
| Data Processing level 1 | 7. Transparency | DP.1.7.3 | Explicit listing of assumptions behind methods. |

All theoretical reasoning is described in the NIR and the documentation report (Albrektsen et al., 2017).

| | | | |
|---|---|---|---|
| Data Processing level 1 | 7. Transparency | DP.1.7.4 | Clear reference to dataset at Data Storage level 1. |

In the database key ids is used to identify the unique data. The data on DS level 1 is linked to the key id used in the database so a clear reference from DS level 1 to higher levels of both DP and DS is secured.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 7. Transparency | DP.1.7.5 | A manual log to collect information about recalculations. |

Changes compared with the last emissions report are described in the NIR and the national emission changes is given in a table under the section, "Recalculation". The text describes whether the change is caused by changes in the dataset or changes in the methodology used. Furthermore, a log table is filled in when data are updated or adjusted continuously.

#### Data storage and processing level 2

For point of measurements not mentioned below, please refer to Chapter 1.6.

| | | | |
|---|---|---|---|
| Data Storage level 2 | 5. Correctness | DS.2.5.1 | Documentation of a correct connection between all data types at level 2 to data at level 1. |

A manual checklist is under development for correct connection between all data types at level 1 and 2.

| | | | |
|---|---|---|---|
| Data Processing level 2 | 5. Correctness | DS.2.5.2 | Check if a correct data import to level 2 has been made. |

A manual checklist is under development for correctness of data import to level 2.

## 5.14 Recalculations

Below an overview of improvements and recalculations implemented since the 2019 submission.

A range of changes in calculation of agricultural emissions 1990-2017 has taken place. The recalculation has contributed to an increase in the total agricultural emissions for the years 1990-2017 of 3-5 % and given in $CO_2$ equivalent (Table 5.38).

Table 5.38 Changes in GHG emission in the agricultural sector compared with the CRF reported last year.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Previous inventory** | | | | | | | | | | |
| 3.A Enteric Fermentation, kt $CH_4$ | 161.6 | 158.7 | 145.2 | 139.3 | 145.2 | 147.8 | 147.8 | 146.7 | 148.7 | 149.2 |
| 3.B Manure Management, kt $CH_4$ | 61.8 | 74.4 | 83.4 | 87.9 | 80.2 | 74.5 | 75.5 | 74.7 | 73.8 | 72.5 |
| 3.B Manure Management, kt $N_2O$ | 3.3 | 3.1 | 3.2 | 3.3 | 2.7 | 2.5 | 2.5 | 2.5 | 2.4 | 2.4 |
| 3.D Agricultural Soils, kt $N_2O$ | 18.4 | 16.2 | 14.5 | 13.2 | 12.8 | 12.7 | 13.2 | 13.2 | 13.6 | 14.0 |
| 3.F Field Burning of Agricultural Residues, kt $CH_4$ | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 3.F Field Burning of Agricultural Residues, kt $N_2O$ | 0.002 | 0.003 | 0.003 | 0.004 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| 3.G Liming, kt $CO_2$ | 565.5 | 496.0 | 260.6 | 219.7 | 152.8 | 243.9 | 237.7 | 165.6 | 211.8 | 214.4 |
| 3.H-I Urea and other C-containing fertilisers, kt $CO_2$ | 53.1 | 41.1 | 7.8 | 2.1 | 3.4 | 2.6 | 2.5 | 11.9 | 4.8 | 4.7 |
| Total in CO2-eqv., Mio. t | 12.67 | 12.13 | 11.26 | 10.81 | 10.40 | 10.35 | 10.52 | 10.40 | 10.57 | 10.64 |
| **Current inventory** | | | | | | | | | | |
| 3.A Enteric Fermentation | 161.6 | 158.7 | 145.2 | 139.3 | 145.2 | 147.8 | 147.8 | 146.7 | 148.7 | 149.2 |
| 3.B Manure Management, kt $CH_4$ | 74.1 | 85.6 | 94.9 | 100.7 | 93.5 | 89.1 | 89.8 | 89.0 | 88.0 | 87.4 |
| 3.B Manure Management, kt $N_2O$ | 3.3 | 3.1 | 3.2 | 3.3 | 2.7 | 2.5 | 2.5 | 2.5 | 2.4 | 2.4 |
| 3.D Agricultural Soils, kt $N_2O$ | 19.0 | 16.6 | 14.9 | 13.7 | 13.4 | 13.3 | 13.7 | 13.7 | 14.2 | 14.4 |
| 3.F Field Burning of Agricultural Residues, kt $CH_4$ | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 3.F Field Burning of Agricultural Residues, kt $N_2O$ | 0.002 | 0.003 | 0.003 | 0.004 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| 3.G Liming, kt $CO_2$ | 565.5 | 496.0 | 260.6 | 219.7 | 152.8 | 243.9 | 237.7 | 165.6 | 211.8 | 214.4 |
| 3.H-I Urea and other C-containing fertilisers, kt $CO_2$ | 53.1 | 41.1 | 7.8 | 2.1 | 3.4 | 2.6 | 2.5 | 11.9 | 4.8 | 4.7 |
| Total in $CO_{42}$-eqv., Mio. t | 13.16 | 12.54 | 11.67 | 11.27 | 10.91 | 10.90 | 11.02 | 10.91 | 11.09 | 11.15 |
| **Change** | | | | | | | | | | |
| 3.A Enteric Fermentation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.B Manure Management, kt $CH_4$ | 12.39 | 11.22 | 11.48 | 12.82 | 13.27 | 14.64 | 14.36 | 14.27 | 14.17 | 14.91 |
| 3.B Manure Management, kt $N_2O$ | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.01 | 0.01 | 0.01 | <-0.01 | 0.02 |
| 3.D Agricultural Soils, kt $N_2O$ | 0.61 | 0.42 | 0.42 | 0.45 | 0.58 | 0.60 | 0.47 | 0.52 | 0.54 | 0.44 |
| 3.F Field Burning of Agricultural Residues, kt $CH_4$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.F Field Burning of Agricultural Residues, kt $N_2O$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.G Liming, kt $CO_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.H-I Urea and other C-containing fertilisers, kt $CO_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total in CO2-eqv., Mio. t | 0.49 | 0.41 | 0.41 | 0.46 | 0.51 | 0.55 | 0.50 | 0.52 | 0.52 | 0.51 |
| **Change in pct.** | | | | | | | | | | |
| 3.A Enteric Fermentation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.B Manure Management, $CH_4$ | 20.07 | 15.07 | 13.76 | 14.59 | 16.54 | 19.66 | 19.04 | 19.10 | 19.19 | 20.57 |
| 3.B Manure Management, $N_2O$ | <0.01 | <0.01 | <0.01 | <0.01 | 0.15 | 0.25 | 0.29 | 0.37 | <-0.01 | 0.81 |
| 3.D Agricultural Soils, $N_2O$ | 3.34 | 2.61 | 2.87 | 3.44 | 4.55 | 4.75 | 3.52 | 3.96 | 3.98 | 3.13 |
| 3.F Field Burning of Agricultural Residues, $CH_4$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.F Field Burning of Agricultural Residues, $N_2O$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.G Liming, $CO_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.H-I Urea and other C-containing fertilisers, $CO_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total in pct. | 3.89 | 3.35 | 3.65 | 4.22 | 4.87 | 5.29 | 4.75 | 4.96 | 4.88 | 4.78 |

The most significant inventory changes are mentioned below:

### 5.14.1 Enteric fermentation

No recalculations

### 5.14.2 Manure management

Recalculations have been made for $CH_4$, $N_2O$ and NMVOC.

The model estimating the national MCF for cattle and swine has been updated. The model is based on a range of factors (see Annex Chapter 3D-1) and for cattle are the factor LnA changed due to error and the average temperature in cattle housings is changed due to updated values from new studies. For swine VS shares has been updated. This has increased MCF for both untreated and biogas treated slurry from cattle in the period 1990-2017. MCF for swine decreases some years and increases some years in the period 1990-2017.

Updated data for biogas and biomass for the years 2015-2017 changes the estimations for amount of biomass for the years 1990-2014, because these are based on the averaged relation between amounts of biomass and energy production in 2015-2017. These updated data gives changes in the allocation of number of animals in housings, were the manure is send to biogas plants.

Changes in MCF and biogas increases the emission of $CH_4$ from dairy and non-dairy cattle for all the years 1990-2017 with 68-98 % and 10-19 %, respectively. Emission of $CH_4$ from swine changes less than 1 % in the years 1990-2005 and decreases 1-2 % in the years 2006-2017.

Emission of $CH_4$ from fur animals is recalculated for 2017, due to rounding of factors.

No changes in emission of $CH_4$ is seen from remaining animal categories.

$N_2O$ from manure management increases for years 1990-2015 and 2017 and decreases in 2016, mainly due to changes for biogas treated slurry. Indirect emission of $N_2O$ from manure increases in 1990-2002 and decreases in 2003-2017, due to changes in the calculation of $NH_3$ emissions in housing and storage.

Calculations for NMVOC is updated to a Tier 2 methodology, which increases the emission for all years 1990-2017.

### 5.14.3 Agricultural soils

The overall $N_2O$ emission from agricultural soils increases for all the years 1990-2017, mainly due to increased area of organic soils. Changes for all subcategories a mentioned below.

3Da2a Animal manure applied to soil: Emission of $N_2O$ decreases in the years 1990-2014 and increases in the years 2015-2017 due to changes in the calculations for the amount of N applied to soil. New estimates for EF for NH3 emission from storage of slurry from cattle, swine and fur animals have been made, due to new estimates for cover of slurry tanks with solid cover. Furthermore are the calculations of N excretions changed, so it takes into account the difference between EF used for emission of NH3 from storage and the factor used to estimate the N excretions ab storage in the normative figures.

3Da4 Crop residues: A recalculation for 2017 have been made, due to updated activity data from DSt.

3Da5 Mineralization: $N_2O$ emissions from mineralization is changes for all the years 1990-2017. $N_2O$ emission from mineralization from organic soils are estimated with a dynamic soil model. An error in the area with catch crops from year 2000 has been corrected, and as a consequence of the reevaluation of the area with organic soils a smaller area with mineral soils is included in the calculation. Both has led to a change in the estimated $N_2O$ from mineralization of organic matter in mineral soils.

3Da6 Cultivation of organic soils: $N_2O$ emissions from organic soils is changes for all the years 1990-2017. The area with organic soils has been reevaluated with an updated map for the organic soils. This has slightly increased the area with organic soils having >12 % organic carbon (OC). The organic area with 6-12 % OC has been increased with approximately 70 000 hectares. In total the area with organic soils (> 6 % OC) in Cropland and Grassland has in 2018 been estimated to 178 734 ha. This has increased the estimated $N_2O$ emission from organic soils.

3Db1 Atmospheric deposition: The emission of $N_2O$ from atmospheric deposition increases for all the years 1990-2017, mainly due to changes in EF for $NH_3$ from grazing.

3Db2 Nitrogen leaching and run-off: Updated data for leaching for the years 2005-2017 have been implemented in the emission calculation and causes changes for all the years.

### 5.14.4 Field burning of agricultural residue

No recalculations

### 5.14.5 Liming

No recalculations

### 5.14.6 Urea and other C-containing fertilisers

No recalculations

## 5.15 Category-specific improvements

### 5.15.1 Response to the review process

The table below contains the recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory. The table details the status of implementation of the recommendations as well as references to where improvements have been implemented in this report.

Table 5.39 Response to the review process.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| **2018 submission (Review report: https://unfccc.int/sites/default/files/resource/dnk_0.pdf)** | | | | |
| A.1 | 3. General (agriculture) | Report, to the extent possible, the results of the comparison of total N excretion in the inventory with calculations of N excretion for all livestock production estimated by the Danish Centre for Food and Agriculture (stage IV of the QA/QC improvement plan).<br>Addressing. Table 9.6 of the NIR 2017 provided information on the ongoing comparisons and checks and indicated the need for more detailed data for different animal categories. The NIR 2018 provided no follow-up on this recommendation. During the review, Denmark explained that data for the total N excretion in animal manure for 2003 to 2007 have been received from the Danish Centre for Food and Agriculture and the comparisons for these years will be included in the next submission. The comparison shows the same trend as in | Included more text in NIR submission 2019 – Chapter 5.13.1 – section "Nex compared to DCA numbers".<br>A comparison of Nex estimated by DCE for the emission inventory and the Nex estimated by DCA is made and shown in Figure 5.16. The Nex estimated by DCE are a bit higher and could probably be explained by differences in the number of animals because DCE calculation include animals placed on small farms. Another explanation could be differences in definitions for grazing – e.g. days on grass vs. days in housings. | Chapter 5.13.1 |

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| | | the emission inventory, while the total N excretion (Nex storage) is approximately 10 per cent lower than estimated in the inventory. The next step according to Denmark would be to clarify the difference, which could possibly be explained by the amount of N deposited during grazing. The Party is working to extend the data comparison period up to 2016. | | |
| A.3 | 3. General (agriculture) | The ERT noticed that Denmark stated in the NIR (section 5.1.1) that in 2016, there are 6 key categories according to level and trend for approach 1 and 10 key categories for approach 2 and table 5.2 is referenced. However, in table 5.2, the ERT observed that for 2016, 11 sources are listed as key categories according to level and trend for approach 2. Information contained in the text is thus not consistent with the information in the referenced table. During the review, Denmark confirmed that there are 11 key categories in the sector as stated in the table 5.2. and that the information in the text is a typographical error.<br>The ERT recommends that Denmark ensure the consistency of the information in the NIR on the key categories between the explanatory text and the table on key categories (table 5.2 of the NIR). | The errors have been corrected. | Chapter 5.1.2. |
| A.4 | 3.D Direct and indirect $N_2O$ emissions from agricultural soils – $N_2O$ | The ERT noticed some inconsistencies between the NIR and CRF tables, as well within the NIR. The NIR indicates a reduction in atmospheric deposition from 75,862 in 1990 to 40,992 t N in 2016 (p.386), while in CRF table 3.D, the figure entered against atmospheric deposition is 40,997,394.31 kg N/year and table 5.24 of the NIR gives a total emission of 40,998 t N. In response to a question on the apparent inconsistency in the data in the NIR and between the NIR and CRF table 3.D, Denmark explained that the correct value is 40,997 t N as provided in the CRF table, and that the value in section 5.7.3 of the NIR (40,992) is a typographical error (it should have been 40,997) and the value in table 5.24 is due to rounding of the numbers in the table.<br>Furthermore, the ERT found that according to the NIR (p.383) "the N content in crop residues has increased from 122 million kg N in 1990 to 123 million kg N in 2016, which is mainly a result of a lower amount of N in harvested straw", while N in crop residues reported in table 5.21 is 129.8 million kg N for 2016, consistent with the value reported in CRF table 3.D (129,763 000 kg N/year). During the review, Denmark stated that the 123 million kg N in the text is a typographical error and the value should have been 130 million kg N as given in table 5.21.<br>The ERT recommends that Denmark correct the errors in the NIR and ensure the consistency of the provided information on the atmospheric deposition of nitrogen and N content in crop residues between the CRF tables and the NIR and within the NIR. | Denmark has corrected the errors due to number for N-atmospheric deposition and N content in crop residues, and will double check the estimate in next submission (2019) to ensure consistency between the CRF and the NIR. | Chapter 5.7.3 and 5.8.3 |
| A.5 | 3.D.a.6 Cultivation of organic soils (i.e. histosols) – $N_2O$ | The ERT noticed that Denmark is subdividing cultivated organic soils in areas with >12 per cent and areas with 6–12 per cent SOC and that Denmark is referring to the default EF from table 2.5 of the Wetlands Supplement for N2O emissions from these organic soils. In the NIR (p.384) Denmark stated that for areas with 6–12 per cent SOC the EFs for cropland, grassland and shallow-drained, nutrient-rich grass- | Denmark has provided further information in NIR explaining the halving of the $N_2O$ EFs for cultivated organic soils with 6–12 per cent SOC. | Chapter 5.6.3. |

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| | | land are halved to 6.5, 4.1 and 0.8 kg N2O-Nper ha per year, respectively. However, the ERT could not find a satisfactory rationale for halving the EFs in the NIR. During the review, Denmark provided arguments to support the halving of the EFs as indicating that the Danish definition of organic soils are >10 per cent organic matter equivalent to about 6 per cent SOC as defined in 1975. Agricultural soils in use under Danish conditions will normally have a carbon content of 1.5–3 per cent SOC. This is the equilibrium state with the degradation conditions and crop residue inputs. Drained land under agricultural use will therefore approach a SOC content of 1.5–3 per cent. Furthermore, Denmark highlighted that almost all measurements on N2O emissions from organic soils in the literature are performed on soils having >12 per cent SOC. Consequently, for cultivated organic soils having 6–12 per cent SOC, Denmark has chosen to use 50 per cent of the values in the Wetlands Supplement for N2O emissions. During the review, Denmark provided further supporting documentation (Taghizadeh-Toosi et al., 2014 and Madsen et al., 1992) for the low country-specific N2O EFs. The ERT recommends that Denmark provide further explanations to support the halving of the N2O EFs for cultivated organic soils with 6–12 per cent SOC and relevant references in the NIR | | |

## 5.16 Planned improvements

Caused by the requirements to continued focus on the possibilities to reduce the agricultural ammonia emission, a still increasing part of the farmers choose ammonia reducing technologies as for example air scrubbers, slurry acidification and slurry cooling, where the last two technologies mention also leads to a reduction in $CH_4$ emission. However, reduction of $CH_4$ are not yet included due to lack of verified reduction potential. Ammonia reduction from air scrubbers are not yet included either. However, a further work is ongoing to include effect of reduced $CH_4$ in the future emission inventories, as well as the ammonia reduction from air scrubbers.

## 5.17 References


Aaes, Ole, 2008: Personal communication. Knowledge Centre for Agriculture (now SEGES).

Aaes, Ole, 2016: Personal communication, data received. SEGES.

Albrektsen, R., Mikkelsen, M.H. & Gyldenkærne, S. 2017. Danish emission inventories for agriculture. Inventories 1985 – 2015. Aarhus University, DCE – Danish Centre for Environment and Energy, 190 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 250. Available at: http://dce2.au.dk/pub/SR250.pdf (Dec. 2018).

Andersen, L., 2004: Personal Communications. Lars Andersen, Kalklejer, Vildmosevej 13, 9293 Kongerslev, Tlf.: 98 33 13 77, d. 14. nov. 2004.

Andreae, M.O. and Merlet, P., 2001: Emission of trace gases and aerosols from biomass burning. Global Biogeochemical Cycles, vol. 15, no. 4, pages 955-966, Dec. 2001

Blicher-Mathiesen, G., Rasmussen, A., Rolighed, J., Andersen, H.E., Carstensen, M.V., Jensen, P.G., Wienke, J., Hansen, B. & Thorling, L. 2018. Landovervågningsoplande 2016. NOVANA. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 192 s. - Videnskabelig rapport fra DCE - Nationalt Center for Miljø og Energi nr. 273 (In Danish). Available at: http://dce2.au.dk/pub/SR273.pdf (Jan. 2019).

Børgesen, C.D. & Grant, R. 2003: Vandmiljøplan II – modelberegning af kvælstofudvaskning på landsplan, 1984 til 2002. Baggrundsnotat til Vandmiljøplan II - slutevaulering. December 2003, Danmarks Jordbrugsforskning og Danmarks Miljøundersøgelser. (In Danish).

Clausen, Eric F., 2008: Personal communication. Knowledge Centre for Agriculture (now SEGES).

Clausen, E., 2018: Number of horses in Denmark in 2017, received per mail 20.09.2018, from Eric Clausen, SEGES.

Crutzen, P.J., I. Aselmann and W. Seiler, 1986: Methane Production by Domestic Animals, Wild Ruminants, Other Herbivorous Fauna, and Humans. Tellus 38B:271-284.

Danish Agricultural Agency, 2018: Inorganic N fertiliser sold in Denmark 2016/2017. (in Danish). Available at: https://lbst.dk/fileadmin/user_upload/NaturErhverv/Statistik_over_salget_af_handelsgoedning_i_DK__planaaret_2016-17__.pdf (Jan. 2020).

Danish Energy Agency (DEA), 2009: Spildevandsslam fra kommunale og private renseanlæg i 2005. Orientering fra Miljøstyrelsen Nr. 3.

Danish Energy Agency (DEA), 2019: The Danish energy statistics, Available at: https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics (Jan. 2020).

DSt, 2019: Statistics Denmark - Agricultural Statistic from year 1990 to 2018. Available at: http://www.dst.dk/en.aspx (Jan. 2020).

EMEP/EEA air pollutant emission inventory guidebook, 2019. Available at: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (Jan. 2020).

Feidenhans'l, B., 2009: Amount of straw burnt. Barthold Feidenhans'l, SEGES, personal communication.

Hansen, M.N., 2019: Statistik for kalkforbruget i 2018. Available at: https://www.landbrugsinfo.dk/planteavl/goedskning/kalkning/sider/pl_18_2439_po_kalkstatistik.aspx (Jan. 2020)

Hansen, N.E. 2010: Department of Basic Animal and Veterinary Sciences/Animal Nutrition, Faculty of Life Science, University of Copenhagen. Pers. comm., mail 13.12.2010.

Hellwing, A.L.F., Weisbjerg, M.R. & Lund, P., 2014: Note: Calculation of Ym for dairy cows in Denmark. Department of Animal Science, Aarhus University, AU Foulum, P.O. Box 50, DK-8830 Tjele, Denmark.

IPCC 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (Jan. 2020).

IPCC, 2014: 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds). Published: IPCC, Switzerland. Available at: http://www.ipcc-nggip.iges.or.jp/public/wetlands/ (Jan. 2020).

Knudsen, L., 2004: Baggrund for kalkningsvejledning 2004. Planteavlsorientering – 07-521 Landbrugsinfo.dk, SEGES. (In Danish). Available at: https://www.landbrugsinfo.dk/Planteavl/Goedskning/Kalkning/Sider/Baggrund_for_kalkningsvejledning_2004.aspx

Knudsen, T., 2011: Amount of inorganic fertiliser used in pivate gardens. Personal communication. Troels Knudsen, Plantedirektoratet, now the Danish Agricultural Agency

Kold, J., 2019: Number of horses in Denmark in 2018. Meeting of the board of representatives for Dansk Rideforbund, 06.04.2019, Jørgen Kold, SEGES.

Laursen, B. 1987: Normtal for husdyrgødning. Report no. 82, Institute of Food and Resource Economics, University of Copenhagen (previously referred to as Statens Jordbrugsøkonomiske Institut). (In Danish).

Laursen, B. 1994: Normtal for husdyrgødning – revideret udgave af rapport nr. 28. Report no. 82, Institute of Food and Resource Economics, University of Copenhagen (previously referred to as Statens Jordbrugsøkonomiske Institut). (In Danish).

Luostarinen S. and Kaasinen, S. 2016: Manure nutrient content in the Baltic Sea countries. National resources and bioeconomy studies 40/2016. Natural Resources Institute Finland (Luke).

Lund, Peter, 2014: Personal communication. Department of Animal Science – Animal nutrition and physiology, Aarhus University.

Lund, P. 2019: Normative figures 2000-2018. DCA - Danish Centre for Food and Agriculture, Aarhus University. Available at: http://anis.au.dk/forskning/sektioner/husdyrernaering-og-fysiologi/normtal/ (Jan. 2020).

Lundgaard. N.H., 2006: Personal Communication: Department of Farm buildings and Machinery. Danish Agricultural Advisory Centre.

Madsen, H.B., Nørr, A.H. and Holst, K.A., 1992: Atlas over Danmark, Serie I, Bind 3, Den Danske Jordklassificering. Det Kongelige Danske Geografiske Selskab. (in Danish). Available at: https://rdgs.dk/publikationer/atlas-over-danmark-serie-1-bind-3-den-danske-jordklassificering.pdf (Jan. 2020).

MEFD, 2017: Ministry of Environment and Food in Denmark. Agreement on food and agriculture package in December 2015: Available at (in Danish): https://mfvm.dk/fileadmin/user_upload/FVM.dk/Dokumenter/Landbrug/Indsatser/Foedevare-_og_landbrugspakke/Aftale_om_foedevare-_og_landbrugspakken.pdf (Jan. 2020)

Mikkelsen, M.H., Albrektsen, R. & Gyldenkærne, S. 2011: Danish emission inventories for agriculture. Inventories 1985 - 2009. National Environmental Research Institute, Aarhus University. 136 pp. – NERI Technical Report No. 810. Available at: http://www2.dmu.dk/Pub/FR810.pdf (Jan. 2020).

Mikkelsen, M.H., Albrektsen, R. & Gyldenkærne, S. 2014. Danish emission inventories for agriculture. Inventories 1985 – 2011. Aarhus University, DCE – Danish Centre for Environment and Energy, 142 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 108. Available at: http://dce2.au.dk/pub/SR108.pdf (Jan. 2020).

Mikkelsen, M.H., Gyldenkærne, S., Poulsen, H.D. Olesen, J.E. & Sommer, S.G. 2006: Emission of ammonia, nitrous oxide and methane from Danish Agriculture 1985-2002. Methodology and Estimates. NERI Research Notes Nr. 231/2006. Available at http://www2.dmu.dk/Pub/AR231.pdf (Jan. 2020).

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Gyldenkærne, S., Thomsen, M., Fauser, P., Nielsen, M. Mikkelsen, M.H., Albrektsen, R., Hjelgaard, K., Hoffmann, L. & Bruun, H.G. 2013. Quality manual for the Danish greenhouse gas inventory. Version 2. Aarhus University, DCE – Danish Centre for Environment and Energy, 44 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 47. Available at: http://www.dmu.dk/Pub/SR47.pdf (Jan. 2020).

Nielsen, O-K., Plejdrup, M.S., Winther, M., Mikkelsen, M.H., Nielsen, M., Gyldenkærne, S., Fauser, P., Albrektsen, R., Hjelgaard, K.H., Bruun, H.G. & Thomsen, M. 2019. Annual Danish Informative Inventory Report to UNECE. Emission inventories from the base year of the protocols to year 2017. Aarhus University, DCE – Danish Centre for Environment and Energy, 549 pp. Scientific Report No. 313 http://dce2.au.dk/pub/SR313.pdf (Jan. 2020)

Olesen, J.E., Fenhann, J.F., Petersen, S.O., Andersen, J.M. & Jacobsen, B.H. 2001: Emission af drivhusgasser fra dansk landbrug. DJF rapport nr. 47, markbrug, Danmarks Jordbrugsforskning, 2001. (In Danish).

Olesen, J.E., Jørgensen, H., Danfær, A., Gyldenkærne, S., Mikkelsen, M.H., Asmon, W.A.H. & Petersen, S.O. 2005: Evaluering af mulige tiltag til reduktion af landbrugets metanemissioner. Arbejdsrapport fra Miljøstyrelsen Nr. 11 /2005. Chapter 1 (Allan Danfær): Methane emission from dairy cows. Available at:
http://www2.mst.dk/Udgiv/publikationer/2005/87-7614-699-5/pdf/87-7614-700-2.pdf (Jan. 2020).

Petersen, C. & Kielland, M. 2003: Statistik for jordbrugsmæssig anvendelse af affaldsprodukter fra husholdning og institutioner og virksomheder 2001. Miljøprojekt nr. 858 2003. The Danish Environmental Protection Agency.

Poulsen, H.D., Børsting, C.F., Rom, H.B. & Sommer, S.G. 2001: Kvælstof, fosfor og kalium i husdyrgødning – normtal 2000. DJF rapport nr. 36 – husdyrbrug, Danmarks Jordbrugsforskning. (In Danish).

Poulsen, H.D. DCA - Danish Centre for Food and Agriculture, Aarhus University, Pers. comm.

Poulsen, H.D. & Kristensen, V.F., 1997: Normtal for husdyrgødning – en revurdering af danske normtal for husdyrgødningens indhold af kvælstof, fosfor og kalium. Beretning nr. 736, Faculty of Agricultural Sciences, Aarhus University. (In Danish).

Poulsen, H.D. & Kristensen, V.F. 1998: Standards Values for Farm Manure – A revaluation of the Danish Standards Values concerning the Nitrogen, Phosphorus and Potassium Content of Manure. DJF Report No. 7 - Animal Husbandry. Danish Institute of Agricultural Sciences. Available at: http://web.agrsci.dk/djfpublikation/djfpdf/djfhd7.pdf (Jan. 2020).

Rasmussen, J.B., 2006: Personal Communication. Department of Farm buildings and Machinery. Danish Agricultural Advisory Centre.

SEGES, 2005: Møller, J., Thøgersen, R., Helleshøj, M.E., Weisbjerg, M.R., Søegaard, K. & Hvelplund, T. Fodermiddeltabel 2005. Rapport nr. 112. The Danish Agricultural Advisory Service, Department for Cattle. (In Danish).

Sommer, S.G., Christensen, M.L., Schmidt, T. and Jensen, L.S., 2013: Animal Manure Recycling: Treatment and Management. ISBN: 978-1-118-48853-9, 382 pages, September 2013.

Stenkjær, K., 2010: Number of pheasants. Personal communication.

Sørensen, P.B., Illerup, J.B., Nielsen, M., Lyck, E., Bruun, H.G., Winther, M., Mikkelsen, M.H., & Gyldenkærne, S. 2005: Quality manual for the greenhouse gas inventory Version 1. National Environmental Research Institute, Denmark. 25 pp. – Research Notes from NERI no. 224. – Available at: http://www2.dmu.dk/1_viden/2_Publikationer/3_arbrapporter/rapporter/AR224.pdf (Jan. 2020).

Taghizadeh- Toosi, A., Olesen, J. E., Kristensen, K., Elsgaard, L., Østergaard, H. S., Lægdsmand, M., Greve, M.H., Christensen, B.T., 2014: Changes in carbon stocks of Danish agricultural mineral soils between 1986 and 2009. European Journal of Soil Science. Vol. 65, Issue 5, page 730-740. Available at: https://onlinelibrary.wiley.com/doi/abs/10.1111/ejss.12169 (Jan. 2020).

Thodsen, H., 2019: Hans Thodsen, data received per mail, 30.10.2019

Wang, S.-Y. & Huang, D.-J. 2005: Assessment of Greenhouse Gas Emissions from Poultry Enteric Fermentation, Asian-Aust. J. Anim. Sci. Vol 18, No. 6: 873-878.

Wiberg-Larsen, P., Windolf, J., Baattrup-Pedersen, A.., Bøgestrand, J., Ovesen, N.B., Larsen, S.E., Thodsen, H., Sode, A., Kristensen, E., Kronvang, B. & Kjeldgaard, A. 2010: Vandløb 2009. NOVANA. Danmarks Miljøundersøgelser, Aarhus Universitet. 100 s. – Faglig rapport fra DMU nr. 804. (In Danish). Available at: http://www2.dmu.dk/Pub/FR804.pdf (Jan. 2020).

Windorf, J., 2013: Jørgen Windorf, data received per mail, 04.11.2013.

Windorf, J., Thodsen, H., Troldborg, L., Larsen, S.E., Bøgestrand, J., Ovesen, N.B. & Kronvang, B. 2011: A distributed modelling system for simulation of monthly runoff and nitrogen sources, loads and sinks for ungauged catchments in Denmark. Journal of Environmental Monitoring 2011, 13, 2645-2658. Available at:
http://pubs.rsc.org/en/Content/ArticleLanding/2011/EM/c1em10139k
(Jan. 2020).

Waagepetersen, J., Grant, R., Børgesen, C.D. & Iversen, T.M. 2008: Midtvejs-evaluering af Vandmiljøplan III. (In Danish). Available at:
http://pure.au.dk/portal/files/2841678/djfma142.pdf.pdf (Jan. 2020).

# 6 LULUCF

## 6.1 Overview of the sector

This chapter covers only the territory of Denmark without the Faroe Islands and Greenland. Greenland is submitting a separate NIR and the corresponding CRF tables for the Greenlandic territory to UNFCCC. This can be found as Chapter 16 in this NIR.

The current submission is based on the 2006 IPCC Guidelines combined with the emission factors from the 2013 Wetlands Supplement (IPCC, 2014) Chapter 2 and 3 for $CO_2$, $N_2O$ and $CH_4$ combined with national derived emission factors.

Denmark (Capital: Copenhagen) is situated around 56°N and 13°E and covers 43,098 km$^2$. No permanent ice is occurring and only very small insignificant areas with rocks. According to 2006 IPCC Guidelines, the climate is cold and wet. Denmark is an intensive agricultural country where most of the area is affected by agriculture. The average temperature in the standard 30-year period, 1961-1990, was 7.7°C with a minimum temperature in February of 0.3°C and a maximum in July of 17.0°C. Year 2018 was warm with an average mean temperature of 8.9°C, which is 1.2°C above the 1961-1990 average. The warmest year ever reported, since the Danish measurements began in 1884, was 2014 with an average temperature of 10.0°C.

All land is classified into Managed Forest, Cropland, Managed Grassland, Wetlands (managed and unmanaged), Settlements or Other Land (unmanaged).

### 6.1.1 Abbreviations

The following abbreviations are used in accordance with definitions in the IPCC guidelines:

A: Afforestation, areas with forest established after 1990 under article 3.3.
R: Reforestation, areas, which have temporarily been unstocked for less than 10 years - included under article 3.4.
D: Deforestation, areas where forests are permanently removed to allow for other land use, included under article 3.3.
FF: Forest remaining Forest, areas remaining forest after 1990.
FL: Forest Land meeting the definition of forests.
CL: Cropland.
GL: Grassland.
SE: Settlements.
OL: Other land, unclassified land.
FM: Forest Management, areas managed under article 3.4.
HWP: Harvested Wood Products
CM: Cropland Management, areas managed under article 3.4.
GM: Grazing land Management, areas managed under article 3.4.

Other abbreviations:

NFI: National Forest Inventory
LULC: Land Use, Land Cover
LPIS: Land Parcel Information System

PSU: Primary Sampling Unit (National Forest Inventory)
SSU: Secondary Sampling Unit (National Forest Inventory)
TSU: Tertiary Sampling Units (National Forest Inventory)
OC: Organic Carbon
SOC: Soil Organic Carbon
SINKS: Abbreviation for a research projects covering LULUCF
FOM: Fresh organic matter
HUM: Humified organic matter
ROM: Resilient Organic Matter
HWP: Harvested wood products

The LULUCF sector differs from the other sectors in that it contains both sources and sinks of carbon dioxide. Removals are given as negative figures and emissions are reported as positive figures according to the guidelines. For 2018, emissions from LULUCF were estimated to be a net source of 6594 Kt $CO_2$ equivalents or 14 % of the total reported Danish emission (excluding LULUCF).

### 6.1.2 Methodology overview

**Tier**

The type of emission factor and the applied tier level for each emission source are shown in Table 6.1 below. The tier level has been determined based on the 2006 IPCC Guidelines (IPCC, 2006).

The distinction between tier level 2 and 3 is due to differences in the emission factor used. The tier level definitions were interpreted as follows:

- Tier 1: The emission factor is an IPCC default tier 1 value.
- Tier 2: The emission factors are country specific and based on either a few emission measurements or IPCC tier 2 emission factors.
- Tier 3: Based on models, which include carbon stock changes methodologies.

Table 6.1 shows which of the source categories are key in 2018 in the respective key source analyses[1] (including LULUCF, tier 1/tier 2).

[1]Key category according to the KCA tier 1 or tier 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990/ level 2018/trend.

Table 6.1 Methodology and type of emission factor.

| | | Tier | EF [a] |
|---|---|---|---|
| 4.A.1 Forest | $CO_2$ | Tier 3, Tier 1 | CS, D |
| 4.A.2 Forest, Land converted to | $CO_2$ | Tier 3, Tier 1 | CS, D |
| 4(II) Drainage and Rewetting | $N_2O$, $CH_4$ | Tier 2 | D |
| 4.B Cropland, Living biomass | $CO_2$ | Tier 2 | CS |
| 4.B Cropland, Mineral soils | $CO_2$ | Tier 3 | CS, D |
| 4.B Cropland, Organic soils | $CO_2$ | Tier 2 | CS, D |
| 4(III) Direct nitrous oxide ($N_2O$) emissions from nitrogen (N) mineralization/immobilization | $N_2O$ | Tier 2 | CS, D |
| 4.C Grassland, Living biomass | $CO_2$ | Tier 2 | CS, D |
| 4.C Grassland, Mineral soils | $CO_2$ | Tier 2 | CS, D |
| 4.C Grassland, Organic soils | $CO_2$ | Tier 2 | CS, D |
| 4.D Wetlands, Living biomass | $CO_2$ | Tier 2 | CS, D |
| 4.D Wetlands, Soils | $CO_2$ | Tier 2 | CS, D |
| 4.E.2 Settlements, Living biomass | $CO_2$ | Tier 2 | CS, D |
| 4.G. Harvested Wood Product | $CO_2$ | Tier 2 | D |
| 4(V) Biomass Burning | $CH_4$ | Tier 2, Tier 1 | CS, D |
| 4(V) Biomass Burning | $N_2O$ | Tier 2, Tier 1 | CS, D |

[a] CS= Country Specific value. [a] D= Default value.

### 6.1.3 Key categories

Key Category Analysis (KCA) approach 1 and 2 for year 1990, 2017 and trend for Denmark has been carried out in accordance with the IPCC Guidelines (2006). Table 6.2 shows which of the LULUCF categories are identified as key categories. The table is based on the analysis including LULUCF. Detailed key category analysis is shown in NIR Chapter 1.5 and Annex 1.

The major key categories are the $CO_2$ emissions from forests remaining forest on both the level and the trend. For Cropland, both mineral and organic soils are major key sources.

Table 6.2 Key categories, LULUCF.

| | | Approach 1 | | | Approach 2 | | |
|---|---|---|---|---|---|---|---|
| | | 1990 | 2018 | 1990-2018 | 1990 | 2018 | 1990-2018 |
| 4.A.1 Forest land remaining forest land, Living biomass | $CO_2$ | Level | Level | Trend | | Level | Trend |
| 4.A.1 Forest land remaining forest land, Dead organic matter | $CO_2$ | | Level | Trend | | Level | Trend |
| 4.A.1 Forest land remaining forest land, Organic soils | $CO_2$ | | Level | | Level | Level | |
| 4.A.2 Land converted to forest land | $CO_2$ | | Level | Trend | | | |
| 4.B.1 Cropland remaining cropland, Mineral soils | $CO_2$ | Level | Level | Trend | Level | Level | Trend |
| 4.B.1 Cropland remaining cropland, Organic soils | $CO_2$ | Level | Level | Trend | Level | Level | Trend |
| 4.B.2 Forest land converted to cropland | $CO_2$ | | | | | | Trend |
| 4.C.1 Grassland remaining grassland, Organic soils | $CO_2$ | Level | Level | Trend | Level | Level | Trend |
| 4.C.2 Forest land converted to grassland | $CO_2$ | | | | | | Trend |
| 4.E.2 Other land uses converted to settlements | $CO_2$ | | Level | | | Level | Trend |
| 4.G Harvested wood products | $CO_2$ | | Level | Trend | | Level | Trend |
| 4(II) Cropland on organic soils | $CH_4$ | | Level | | Level | Level | |
| 4(II) Grassland on organic soils | $CH_4$ | | | | Level | Level | |
| 4(II) Land converted to wetlands | $CH_4$ | | | | | | Trend |

### 6.1.4 Overall emission estimates

Table 6.3 gives an overview of the emission from the LULUCF sector in Denmark. The total emission in 2018 have been estimated to 6594 kt $CO_2$ equivalents. The Danish forest have been estimated to be a net source of 402 kt $CO_2$ equivalents. Forests have been large sink in Denmark for the last decade but due to the age distribution of the forests - containing a majority of mature forests - a decrease of the carbon stock is observed, as the old forests are re-generated with young trees.

Cropland is ranging from being a net source from up to 5343 kt $CO_2$ equivalents in 1990 to be a net source of 4586 kt $CO_2$ equivalents in 2018. Cropland and grassland are general sources in Denmark due to large areas with drained organic soils. Fluctuations in the emission from cropland between years are related to the actual crop yield that year and the climatic conditions. Low crop yields combined with high temperatures reduce the total amount of carbon in agricultural soils, whereas a year with a high yield and low temperatures increase the carbon stock in soil. From 1990 and onwards, a general decrease in the emission from cropland is estimated due to the following reasons:

- A higher incorporation of straw (ban on field burning)
- Demands on growing of catch crops in the autumn, a change from low yielding spring barley to high yielding winter wheat
- An increased carbon stock in hedgerows
- A continuously smaller area with organic agricultural soils cultivated.

The area with restored wetlands has increased and the area with peat excavation has been reduced since 1990, leading to a lower emission from wetlands.

Table 6.3 Overall emission (kt $CO_2$ equivalents) from the LULUCF sector in Denmark, 1990 - 2018.

| Total GHG, kt CO2-eq. | 1990 | 2000 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| 4. Total LULUCF | 6456.6 | 5239.9 | 544.6 | 1917.1 | 1582.2 | 5158.2 | 6165.7 | 4485.5 | 6593.6 |
| A. Forest land | -542.5 | -562.5 | -3750.8 | -2440.1 | -3988.8 | 213.6 | 898.9 | -82.4 | 402.2 |
| 1. Forest land remaining forest land | -553.2 | -586.4 | -3552.5 | -2962.3 | -4154.0 | -318.3 | 702.4 | 116.6 | 512.1 |
| 2. Land converted to forest land | -19.8 | -18.4 | -250.0 | 469.5 | 112.5 | 478.9 | 143.2 | -252.3 | -163.4 |
| B. Cropland | 5343.2 | 4046.6 | 2794.7 | 2891.3 | 3987.2 | 3531.7 | 3737.0 | 3138.4 | 4586.0 |
| 1. Cropland remaining cropland | 5145.4 | 3867.1 | 2621.5 | 2738.0 | 3803.8 | 3257.1 | 3513.6 | 2978.6 | 4368.9 |
| 2. Land converted to cropland | 0.8 | 1.2 | 13.4 | -10.0 | 17.6 | 111.6 | 58.2 | -5.4 | 48.5 |
| C. Grassland | 1537.4 | 1370.2 | 1277.3 | 1281.5 | 1449.9 | 1313.9 | 1371.9 | 1341.4 | 1463.5 |
| 1. Grassland remaining grassland | 1435.2 | 1278.0 | 1144.3 | 1192.2 | 1170.4 | 1037.4 | 1216.3 | 1208.2 | 1305.6 |
| 2. Land converted to grassland | 2.3 | 2.4 | 53.3 | 8.4 | 200.9 | 201.3 | 76.9 | 49.8 | 72.1 |
| D. Wetlands | 102.0 | 92.1 | 125.2 | 93.3 | 102.3 | 96.9 | 97.8 | 87.3 | 110.0 |
| 1. Wetlands remaining wetlands | 99.5 | 67.9 | 52.4 | 40.3 | 48.2 | 40.7 | 42.2 | 30.5 | 52.6 |
| 2. Land converted to wetlands | -1.3 | -1.2 | 23.7 | -2.5 | -2.4 | -1.0 | -1.8 | -0.6 | 0.0 |
| E. Settlements | 18.8 | 48.8 | 120.2 | 165.4 | 125.3 | 148.5 | 231.6 | 174.6 | 194.0 |
| 1. Settlements remaining settlements | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2. Land converted to settlements | 18.8 | 48.8 | 120.2 | 165.4 | 125.3 | 148.5 | 231.6 | 174.6 | 194.0 |
| F. Other land | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| G. Harvested wood products | -2.4 | 244.7 | -22.0 | -74.2 | -93.6 | -146.4 | -171.5 | -173.9 | -162.1 |

### 6.1.5 Land presentation

Approximately 60 % of the total Danish land area is cultivated and 15 per cent forested. Together with a high number of cattle and pigs, there is a high (environmental) pressure on the landscape. To reduce the impact, an active policy has been adopted to protect the environment. The adopted policy aims at doubling the forested area in 1990 within a tree generation (80-100 years), restoration of former wetlands and establishment of protected national parks. In Denmark, almost all natural habitats and all forests are protected. Therefore only limited conversions from forest or wetlands into cropland or grassland are occurring.

No permanent snow cover exists in Denmark and only a very small insignificant area with rocks and cliffs. Other Land is thus restricted to beaches and sand dunes.

The official land area is 43 098 km$^2$. The Land Use Matrix has estimated the total area to 43 056 km$^2$. This area includes rivers and lakes. The small discrepancy is due to differences in the definition of the 7000 km long coastline. The Land Use Matrix uses the latest official vector maps from Danish Geodata Agency.

The emission data are reported in the CRF format under IPCC categories 4A (Forest land), 4B (Cropland), 4C (Grassland), 4D (Wetlands) and 4E (Settlements) and 4F (Other land).

Fertilisation of Forests and Other Land is negligible and all fertiliser consumption is therefore reported in the agricultural sector. Field burning of biomass is prohibited in Denmark. Wildfires in forest are reported. This is normally around 0-10 hectares per year, but due to the drought in 2018, the number of wildfires increased from approx. 500 to more than 2000, mainly in cropland and grassland and a few in forests. Controlled burning of heathland is taking place of approximately 300-700 hectares to maintain the heathland vegetation.

Savannas and rice cultivation do not occur in Denmark.

Estimation of carbon stock changes in the Danish forests is based on a combination of previous forest surveys and the present National Forest Inventory (NFI).

The cropland and grassland areas are based on agricultural EU subsidiary systems and are very detailed. A drawback is, however, that one field in one year can be classified as cropland and the next year as grassland, and then again converted back to cropland. This may create large conversion rates between cropland and grassland.

Table 6.4 shows the overall development in the land use classes from 1990 to 2018. Observe that the changes in Table 6.4 are from January 1st 1990 and onwards. This means, that the sum of the figures is slightly different from those reported in the CRF tables, because these are reported as the end of year 1990. Afforestation is mainly taking place on cropland and grassland, which has not previous been classified as forest. Areas, which are deforested, are mainly converted to wetlands, settlements or grassland. Only a very limited area is converted to cropland. Since 1990, 42 957 hectares have been changed into settlements and other infrastructure. No land is converted into other land.

Christmas trees on agricultural land are reported under forest land. This despite the fact that christmas trees often are clear cut and may later on have an intermediate agricultural crop before it is again replanted with christmas trees. The total area with christmas trees was approximately 26 264 ha in 2018. In addition, some forest areas are also used for christmas tree production, giving a total area of more than 33.000 ha of Nordmann christmas trees (Nord-Larsen et al. 2019).

In the Land Use Matrix, a linear approach for all land use changes has been adopted for the period 1990 to 2005 and from 2005 to 2011. From 2011 and onwards, annually updated data from the different data suppliers are used.

However, some of the data are not updated annually, and thus a time lag in the implementation of the land use changes may occur in some areas. Conversion to annual updates therefore creates more fluctuating area changes than in the previous years.

There are large area fluctuations between cropland and grassland in the annual field data in the IACS/LPIS [2]information (Integrated Administration and Control System/Land Parcel Information System) data. This cannot be seen as real changes in land use, but merely in the farmers definition of their fields actually use, the Land Use Matrix shows large changes. The effect of this has been taken into account and minimized as much as possible by including a rule that an agricultural field shall have been reported in the IACS/LPIS system as e.g. grassland, before it is moved from cropland to grassland and vice versa.

Table 6.4 Land Use Change from 1990 to 31. December 2018 based on GIS vector layers and Earth Observations[a].

| 1990\2018 | Forest | Cropland | Grassland | Wetlands | Lakes | Settlements | Other | Sum |
|---|---|---|---|---|---|---|---|---|
| | | | | Hectare | | | | |
| Forest | 531317 | 6561 | 4094 | 716 | 252 | 1599 | 0 | 544538 |
| Cropland | 99253 | 2776134 | 74645 | 6406 | 3382 | 38336 | 0 | 2998155 |
| Grassland | 6978 | 33548 | 96282 | 6645 | 630 | 2917 | 0 | 146999 |
| Wetlands | 1558 | 689 | 9 | 47453 | 42 | 106 | 0 | 49856 |
| Lakes | 0 | 0 | 0 | 0 | 52958 | 0 | 0 | 52958 |
| Settlements | 0 | 0 | 0 | 0 | 0 | 486614 | 0 | 486614 |
| Other | 0 | 0 | 0 | 0 | 0 | 0 | 26433 | 26433 |
| Sum | 639106 | 2816930 | 175029 | 61219 | 57264 | 529571 | 26433 | 4305552 |
| Percentage | 14.8% | 65.4% | 4.1% | 1.4% | 1.3% | 12.3% | 0.6% | 100.0% |

[a] Please observe that the matrix is from 1st January 1990. The figures are therefore not identical with figures given in the CRF tables, which are end of year 1990 data.

### 6.1.6 Methodology for land use presentation

The terrestrial area, which is defined as the inland land area above the highest tidal limit, forms the physical frame for the estimation of land-use changes. The coastal area from the inland tidal limit to the seaward extend of vascular plants is very limited in Denmark. In cases where these exist, they are often covered by coastal salt marches. These are included in the land-use category grassland. The object type "regions" from the national topographic database Kort10 (Danish Geodata Agency, 2011) was applied to represent the Danish terrestrial area. The object type covers 43 051 km$^2$, which corresponds to the total terrestrial area provided in the statistical yearbook for 2012 (Statistics Denmark, 2012). The object type was applied for 1990, 2005 and for 2011, assuming the total terrestrial area of Denmark has not changed during the assessed period.

From 2011 and onwards annual updates of the Land Use Matrix is used with the help from multiple available data sources. The annual updates create larger fluctuations in the annual changes compared to the period 1990-2005 and 2005-2011 because the observed changes over multiple years are averaged out.

[2] IACS/LPIS is an EU system where all agricultural fields are defined with its actual crop and its precise location. These data are fully available for the Danish inventory.

The Land Use Matrix is developed by giving the most certain data highest priority and the least certain information a lower priority. In Denmark is the most certain data the Danish building register (BBR, https://bbr.dk/forside), then with a higher uncertainty the cadastral maps, changes in roads, annually updated agricultural land parcel maps, new subsidized afforestation and hedges, restored wetlands etc. Today is both the BBR and the cadastral maps online instant updated and available for all. Many public data can be found here: https://arealinformation.miljoeportal.dk/html5/index.html?viewer=distribution

The category of settlements is defined as developed land including transportation infrastructure and human settlements. For this assessment, settlements were divided into build up land, related to urban land uses and into infrastructure, comprising roads and railways. The built up layer is based on 12 object types derived from Kort10 (Danish Geodata Agency, 2011), the Danish Area Information System (AIS, 2002) and from the cadastre map (Danish Geodata Agency, 2012) combined with the Danish building register (BBR) (Ministry of Housing, Urban and Rural Affairs, 2012). Object types representing built up land are not readily available historically. Therefore, the estimation of change in built up land is based on the national cadastre map (Danish Geodata Agency, 2011), combined with the Danish building register (Ministry of Housing, Urban and Rural Affairs, 2011). For each existing building, the register contains the building year and a link to the id-number of the cadastre on which the building is located. Based on this information, all cadastres containing buildings were assigned a building year, referring to the first year of establishment of a building. This map was overlaid with the built up layer for 2011, which then was divided into areas built up before 1990, areas built up between 1990 and 2005 and areas built up between 2005 and 2011. The method is illustrated in Figure 6.1.

Cropland is defined as land intensively utilized for agricultural purposes. Grassland, which is part of an annual agricultural rotation cycle, is included in the cropland category. Grassland is defined as agricultural permanent grassland, which is used for grazing and other areas where the vegetation is maintained in a state that implies no trees with a crown cover of at least 10 percent, in which case it would meet the definition for forest. Grassland includes among other extensively managed grassland, dry grassland and heathland. Information about cropland and grassland in 2011 was derived from the agricultural register for 2011 to 2018 (Ministry of Environment and Food of Denmark, 2020) in combination with the field parcel map for 2011 (Ministry of Food, Agriculture and Fisheries, 2011b). The field parcel map contains land use information for all field parcels, managed by land managers (e.g. farmers) who have applied for EU subsidies (Land Parcel Information System, LPIS). The field parcel map contains 277 land-use classes. These were aggregated into four classes: cropland, grassland, forest and wetland. Furthermore, grassland was also derived from the national registration of protected habitat types (Arealinformation, 2011a) and from management plans for state forests (Danish Nature Agency, 2011) from the management plans for defence holdings (Danish Defence, 2011) and from the registration of habitat types within Natura2000 designations (Arealinformation, 2011b). Hedges and biotopes not qualified to be Forest Land are included as a separate class in Cropland. Hence, no perennial wooden crops are reported under grassland.

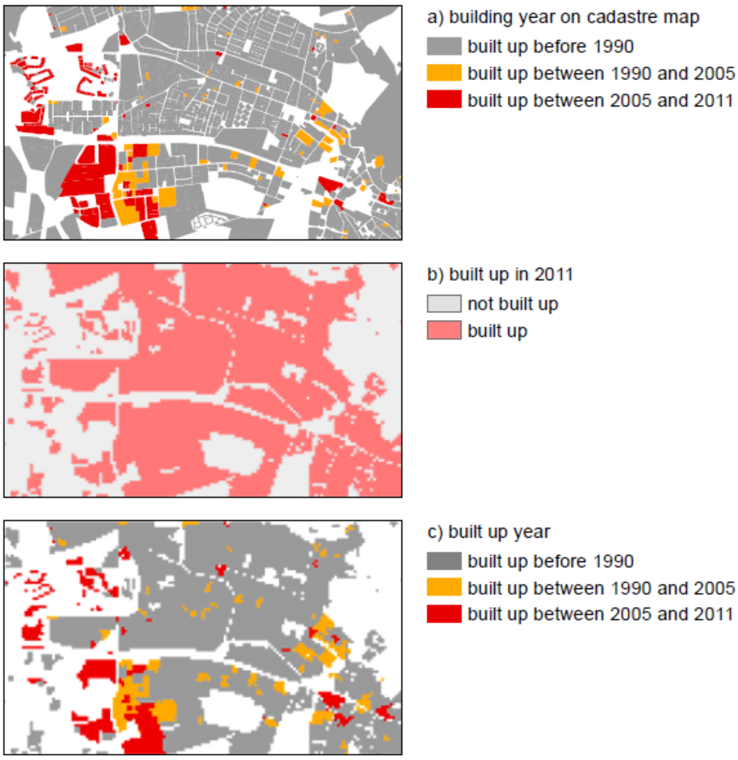


Figure 6.1 Illustration of change detection in settlement. Applying information from the Danish building register, cadastres were classified into cadastres built up before 1990, built up from 1990 to 2005 and built up between 2005 and 2011 (a). This map was overlaid with the built up layer for 2011, which was derived from Kort10 (b). Subsequently the built up layer was classified into areas built up before 1990, built up between 1990 and 2005 and built up between 2005 and 2011 (c).

Forest is defined as woody vegetation covering a minimum of 0.5 ha with a minimum width of 20 m. The vegetation must have a minimum tree crown cover of 10 % and a minimum height of 5 m or be able to obtain these values *in situ*. In addition, the forest area includes temporarily unstocked areas, smaller open areas in the forest needed for management purposes, such as fire breaks. Forests in national parks, reserves or areas under special protection are included. Conifers for production of christmas trees as well as forest for energy production, except willow plantations, are also reported under forest. Fruit plantations for commercial purposes, orchards, gardens etc., which might be able to reach the forest definition, are reported in the cropland layer.

Mapping of forest area in 1990 and 2005 was conducted in 2011 based on Landsat 5 Thematic Mapper scenes from 1989-90 and 2005-06 and SPOT XS. Images were purchased from Eurimage, USGS EROS Data Center, and Image2006. The imagery was resampled to 25 meters using a quadratic mapping function and 17 nearest neighbour resampling with a minimum of 20 ground control points per scene. For 2011, a national forest map was created based on Landsat data acquired during 2010 and 2011. For a full description, see Levin et al. (2014).

Wetlands are divided in two categories, i.e. fully covered wetlands, such as lakes and other permanent water bodies and in partly water covered wetlands. Fully water covered wetlands are represented by the object type “Lake” in the registration of protected habitat types (Arealinformation, 2011a) and other new information. Partly water covered wetlands are defined as land that is covered or saturated by water part of the year and areas with peat extraction. Partly water-covered wetlands include bogs, freshwater meadows, coastal meadows and marshlands as reported in Arealinformation, 2011a and other new information.

Other land comprises all land uses, which is not included in the other five land use categories. It is defined as beaches, sand dunes and rock and has none or very limited carbon stock, both as living or dead biomass or as carbon in the soil. Other land as represented in the applied input datasets from 2011 was decided to be representative for the whole period from 1990 to 2011. I.e. in the final estimation of Land Use/Land Cover (LULC) changes, the area covered by other land is stable.

In contrast to the estimation of land-use changes until 2011, for the period after 2011 fewer data sources are used. For cropland, grassland, afforestation and wetland restoration is annually used updated field parcel maps representing information from the agricultural register (Ministry of Environment and Food of Denmark, 2020) for cropland, grassland and wetland including conversion to and from. Further, the topographical database Kort10 (Danish Geodata Agency, 2012) has been used for settlements. For the remaining input datasets, the land use information for 2011 was also applied for 2012 and onwards.

#### Assessment of land-use changes

After conversion to raster format, the settlement layer and the field parcel layer for 2012 were embedded in the 2011 LULC map. In principle, the same hierarchy as for the 2011 map was applied. However, following exceptions were made:

1. For cells, where forest changes to settlement, the forest layer from Kort10 (Danish Geodata Agency, 2012) was applied to qualify the cell as forest. I.e. if the forest layer from Kort10 contains forest, the cell is kept in forest in 2012, otherwise the cell is attributed the change from forest to settlement.
2. Cells, which change from non-forest in 2011 to forest in 2012, are only registered as afforestation if the cell contains forest in at least two successive years. I.e. that afforestation is registered if the cell contains forest in 2013. Therefore, afforestation is registered with a delay of one year. Consequently, no afforestation is registered from 2011 to 2012. Afforestation from 2011 to 2012 is registered in the estimation of land use/land cover change from 2012 to 2013.
3. For cells, where LULC changed from grassland, cropland or wetland in 2011 to undefined LULC in the field parcel map for 2012, the cell is attributed the LULC from the 2011 map.
4. Cells which from one year to the next shows a change from CL to GL or vice versa is kept in the same LULC unless the cell has been in the same state for the last five year.
5. Cells with wetland (permanently covered) or with other land in 2011 are kept in the same class in 2012, also if 2012 data indicate a change. If the information for 2012 indicated a change in LULC, the type and extent of change was assessed. In cases where information for 2012 indicated no change as well as cases where the input layers for 2012 (settlement layer or field parcel map) did not contain any LULC information, LULC was reported unchanged.

A considerable proportion of changes, especially those including agricultural land uses, only contain few cells. These changes are most probably the result of imprecise mapping of input datasets (particularly for the field parcel maps), rather than actual changes. Therefore, regions, which change and have a size of ≤ 8 cells or 0.5 ha, were not accepted. This is in accordance with the elected Danish minimum forest definition (IRR, 2007) and the 2006 IPCC Guidelines (IPCC, 2006). These regions where identified and the land use category for 2011 was applied to the 2012 map and onwards.

In 2018, a validation of the resulting methodology was performed and reported in Johannsen et al. (2018). Results indicate that generally, the accuracy of land uses and land covers for the assessed years are reasonably high. For the reporting detailed analysis of the affected areas (Lidar based biomass maps – Nord-Larsen et al. 2017a) provides information on the estimated changes, reducing the impact of the uncertainty.

## 6.2 Forest land (4A)

Table 6.5 shows the total area reported under forest land under the Convention. The area with forest land has increased since 1990 due to an intensive afforestation programme. In the beginning of the 1990's, approximately 3000 ha were afforested every year. In recent years, approximately 1900 ha are afforested per year. The estimated emission from organic matter varies between years. Mineral soils are a small sink due to the afforestation. The $CO_2$ emission from organic soils is slightly reduced over time due to rewetting of the organic soils in the forests.

Table 6.5 Total area and annual emissions 1990 to 2018 from forest land.

| | 1990 | 2000 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Area, 1000 ha | 548.7 | 590.8 | 627.7 | 637.3 | 637.3 | 637.5 | 637.5 | 638.6 | 639.1 |
| Living and dead biomass, kt C | -185.9 | -185.4 | -481.4 | -843.4 | -840.4 | -617.1 | -29.9 | 216.6 | -760.4 |
| Litter, kt C | -17.9 | -17.8 | -544.9 | 159.3 | -218.8 | 613.7 | 174.4 | -372.2 | 762.5 |
| Dead wood, kt C | -4.8 | -4.8 | -43.8 | -23.0 | -69.7 | 11.6 | 50.0 | 81.9 | 55.7 |
| Mineral soils, kt C | -0.6 | -7.1 | -12.6 | -12.4 | -11.9 | -11.6 | -11.2 | -10.7 | -10.3 |
| Organic soils, kt C | 52.6 | 50.2 | 45.7 | 47.0 | 47.1 | 47.3 | 47.4 | 47.5 | 47.7 |
| Total, kt C | -156.6 | -165.0 | -1037.1 | -672.4 | -1093.7 | 43.8 | 230.6 | -37.0 | 95.1 |
| $CH_4$, kt $CH_4$ | 0.2 | 0.7 | 1.1 | 1.2 | 1.2 | 1.2 | 1.174 | 1.2 | 1.2 |
| $N_2O$, kt $N_2O$ | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Total, kt $CO_2$ eqv. | -542.5 | -562.5 | -3750.8 | -2413.0 | -3957.5 | 213.6 | 898.9 | -82.4 | 402.2 |

The forest definition adopted in the NFI is identical to the definition used by the Food and Agriculture Organization (FAO, 2010 Annex 2). It includes "wooded areas larger than 0.5 ha, that *in situ* are able to form a forest with a height of at least 5 m and crown cover of at least 10 %. The minimum width is 20 m." Temporarily non-wooded areas, firebreaks and other small open areas, that are an integrated part of the forest, are also included. The temporarily un-stocked areas make up 3 % and auxiliary areas 2 % of the total forest area. The temporarily un-stocked areas are caused by e.g. clear cutting and wind throw and are generally required to be reforested within a 10-year period according to the Forest Act. It is part of standard forest management in Danish Forestry to perform clear cuttings. The forest area constantly included these areas, ensuring consistency over time for the stock change method.

### 6.2.1 Forest inventory

### 6.2.2 Forest census 1881-2000

From 1881 to 2000, a National Forest Census was carried out roughly every 10 years based on questionnaires sent to forest owners (e.g. Larsen and Johannsen, 2002). Since the data were based on questionnaires and not field observations, the actual forest definition may have varied. The basic definition was that the tree-covered area should be minimum 0.5 ha to be a forest. There were no specific guidelines as to crown cover or the height of the trees. Open woodlands and open areas within the forest were generally not included. All estimates of growing stock, biomass or carbon pools were based on data from the National Forest Census estimated from the reported data on forest area and its distribution to main species, age class and site productivity classes using standard forestry yield tables. The two last censuses were carried out in 1990 and 2000.

### 6.2.3 National forest inventory 2002-

In 2002, a new sample-based on the National Forest Inventory (NFI) was initiated (Nord-Larsen and Johannsen, 2016). This type of forest inventory is very similar to inventories used in other countries such as Sweden or Norway. The NFI has replaced the National Forest Census.

The Danish NFI is a continuous sample-based inventory with partial replacement of sample plots based on a 2 x 2 km grid covering the Danish land surface. In each grid cell, a cluster of four circular plots (primary sampling unit, PSU) for measuring forest factors (e.g. wood volume) are placed in the corners of a 200 x 200 m square. Each circular plot (secondary sampling unit, SSU) has a radius of 15 meters. When plots are intersected by different land-use classes or different forest stands, the individual plot is divided into tertiary sampling units (TSU).

About one third of the plots is assigned as permanent and is re-measured in subsequent inventories every five years. Two thirds are temporary and are moved randomly within the particular 2x2 km grid cell in subsequent inventories. The sample of permanent and temporary field plots has been systematically divided into five non-overlapping, interpenetrating panels, which are each measured annually and constitute a systematic sample of the entire country. Hence, all the plots are measured in a five-year cycle.

A detailed description of the Danish NFI is presented in Nord-Larsen and Johannsen (2016).

In the most recent five-year rotation of the NFI (2014-2018), the number of clusters (PSU) and sample plots (SSU) containing forest were 4 332 and 9 500, respectively; see Table 6.6. In the reporting, estimation of carbon pools in the period with the forest census (1990 – 2000) have been harmonized with the results of the NFI, both in terms of the area estimation (as described above in the paragraph on land use mapping) and in terms of the carbon pools. The estimates of all forest carbon pools are based on direct NFI measurements from 2002 and onwards, with no usage of yield tables. As there are no field sampled data prior to 2002, there are no systematic way of harmonizing based on data with the previous census data. The area and species distribution have been compared and reported in previous publications, e.g. Nord-Larsen et al. 2019.

Table 6.6 Number of measured clusters and sample plots in the five-year rotation 2014-2018.

| Year | Clusters | | Sample plots | |
|---|---|---|---|---|
| | Total | Forest | Total | Measured |
| 2014 | 2 187 | 844 | 8 590 | 1 830 |
| 2015 | 2 204 | 876 | 8 590 | 1 899 |
| 2016 | 2 184 | 857 | 8 572 | 1 858 |
| 2017 | 2 212 | 853 | 8 652 | 1 899 |
| 2018 | 2 191 | 902 | 8 586 | 2 014 |
| Total | 10 978 | 4 332 | 42 990 | 9 500 |

Note: Measured plots are plots that are selected for inventory based on aerial photographs.

### 6.2.4 Forest area mapping

Due to differences in methodologies, major inconsistencies in forest areas and other forest variables are observed between the different forest inventories (i.e. the 1990 and 2000 Forest Census and the National Forest Inventory from 2002). With the objective to obtain time consistent and precise estimates of forest areas to report to UNFCC and the Kyoto protocol, two projects have aimed at mapping the forest area in Denmark based on satellite images. Forest area and forest area change have been estimated for the years 1990, 2005 and 2011.

A land use/land cover map was produced for the base year 1990 and for the year 2005 based on EO data (23 August 1990) and other data collected from 1992-2005 and for 2005 using NFI *in situ* data. Forest maps were developed using satellite imagery - mainly Landsat 5 (Thematic Mapper) and 7 (ETM+) data - to classify and estimate the area of forest cover types in Denmark. Portions of seven scenes covering the whole country were classified into forest and non-forest classes. The approach involved the integration of sampling, image processing and estimation. A detailed QA/QC process was conducted in 2011/2012. Maps for 2011 were produced in 2012. In order to map the forest cover, multi-spectral and multi-temporal landsat data of June 2010 and April 2011 with a spatial pixel resolution of 30 m were used. Except for the island of Bornholm, none of the scenes were cloud-free. So, to obtain a national forest cover map without gaps, the forest cover map of some minor areas is solely based on one image.

The product is specified by a Minimum Mapping Unit of 0.5 ha, a geometric accuracy of < 15 m RMS and a thematic accuracy of 90 % +/- 5 % for the land use class Forest.

### 6.2.5 Estimation of forest carbon pools

In the following, procedures for estimating forest carbon pools are described in general. For a more detailed description of the calculations and the specific formulas used, readers are referred to Nord-Larsen and Johannsen (2016).

#### Estimation of forest area

Based on analysis of aerial photos, each NFI sample plot (SSU) is allocated to one of three forest status categories, reflecting the likelihood of forest or other wooded land in the plot: (0) Unlikely to be covered by forest or other wooded land, (1) Likely to be covered by forest, and (2) Likely to be covered by other wooded land. All NFI sample plots within clusters (PSU) with one or more SSU belonging to (1) or (2) are inventoried in the field.

Overall forest cover fraction is calculated as the sum of the forest covered plot area divided by the total sample plot area. In this calculation, the forest area in plots belonging to (0) is assumed to be 0 (zero). In the early years of the NFI, not all sample plots were inventoried due to insufficient resources. Furthermore, every year some plots are inaccessible due to infrastructure, water, or dangerous conditions on the site (e.g. leaning trees after wind throw). The estimated forest area in un-inventoried plots belonging to 1 or 2 was assumed to equal the average forest area in inventoried plots belonging to 1 or 2.

The overall forest area is calculated as the overall average forest cover fraction in the sample plots with status categories (0), (1) and (2) times the total land area.

The fraction of forest area with a specific characteristic, such as forest established before or after 1990, is estimated as the forested plot area with the particular characteristic divided by the total forested plot area. The total forest area with a particular characteristic is subsequently found as the fraction of forest area with the particular characteristic times the total forest area.

#### Estimation of volume, biomass and carbon pools

Growing stock is calculated using species-specific individual tree volume functions developed for the most common Danish forest tree species (e.g. Madsen, 1987; Madsen, 1987; Madsen and Heusèrr, 1993). The functions use individual tree diameter and height as well as quadratic mean diameter of the forest stand as independent variables. For trees lacking volume functions, volumes are calculated using functions for trees with a similar phenology.

Biomass (dry mass) and carbon stocks are calculated using species specific individual tree biomass models developed for the most common forest tree species in Denmark with tree diameter and height as input (Nord-Larsen et al., 2017). For species where no biomass function is available, above ground biomass is calculated as the stem volume times the basic density (e.g. Moltesen, 1985; Skovsgaard et al., 2011; Skovsgaard and Nord-Larsen, 2012). Finally, total biomass (below and above ground) is estimated using expansion factors. For calculation of forest biomass and carbon pools, national individual tree volume and biomass functions are available for beech, oak, ash, silver fir, Norway spruce, grand fir, Douglas fir, Sitka spruce and Japanese larch. This means that species-specific models are applied for 57 % of the area and 73 % of the total standing volume. Only for the remaining species, the generic models for beech (Skovsgaard and Nord-Larsen, 2012) and Norway spruce (Skovsgaard et al., 2011) are applied. It has not been tested systematically, but they are expected not to be biased in terms of biomass or carbon estimates.

The full documentation of the estimation and calculations of biomass and carbon pools are given in Nord-Larsen et al. 2018. See Nord-Larsen et al. (2019) for further info on areas and volume for the specific species. Biomass is converted to carbon using a concentration of 0.47 g C $g^{-1}$.

Total growing stock, biomass and carbon stocks are estimated by obtaining an estimate of average stocks per hectare on inventoried NFI plots times the overall forest area. The total growing stock, biomass or carbon stocks with a given characteristic are estimated as the sum of the stocks with the particular characteristic divided by the inventoried plot area, times the total forest area.

#### Dead wood volume, biomass and carbon content

The volumes of standing dead trees and lying dead trees with their base inside the sample plots are calculated using individual tree volume functions, similarly to the calculations for live trees. The volume of lying dead tree parts (e.g. broken off branches, but excluding lying dead trees with their base outside the sample plot), within the sample plot is calculated as the length of the dead wood times the horizontal cross sectional area at the middle of the dead wood piece. Biomass of the dead wood is calculated as the volume multiplied with species specific basic densities (Moltesen 1985) and a reduction factor of the density according to the structural decay of the wood (decay class). Biomass is converted to carbon using a concentration of 0.47 g C $g^{-1}$.

Similar to live biomass, total dead wood biomass and carbon stocks are estimated by obtaining an estimate of average stocks per hectare on inventoried NFI plots times the overall forest area.

#### Forest floor

Forest floor depth measurements are performed on all NFI plots in the annual census by the method described in the NFI protocol (Knudsen et al., 2017). Carbon stocks are subsequently calculated by multiplying the forest floor depth with standard species-specific forest floor basic densities.

#### Forest mineral soil and organic soil

According to decision 16/CMP: "A Party may choose not to account for a given pool in a commitment period if transparent and verifiable information is provided that the pool is not a source". The forest soil inventory aims to document that forest soils are not a source for emissions of $CO_2$, i.e. that there is no detectable depletion in soil carbon. This may be called the "no source principle." According to the 2006 IPCC Guidelines (IPCC, 2006), the necessary documentation may come from various sources such as:

- Representative and verifiable sampling and analysis to show that the pool has not decreased
- Reasoning based on sound knowledge of likely system responses
- Surveys of peer-reviewed literature for the activity, ecosystem type, region and pool in question
- Combined methods.

Based on literature and reasoning based on sound knowledge there is little evidence to support that the soil C pool in forest remaining forest would currently be changing to an extent that would be detectable by sampling with decadal frequency.

The NFI monitoring is supplemented by an additional forest soil inventory in order to document that forest soils are not an overlooked source for $CO_2$ emissions and to be able to distinguish mineral soils from organic soils (by a topsoil carbon concentration of 12 % organic carbon (OC) in the 0-25 cm soil layer below the O-horizon) for calculations of soil carbon stocks and area of mineral soils and organic soils, respectively. Based on this criteria, organic forest soils are estimated to represent 5 % of the forest area. This fraction is consistent with the map classification of organic soils using the Digital Geological Map of Denmark (1:25.000 and 1:200.000). For organic soils, the default carbon source emission factor of 2.6 t C $ha^{-1}$ $yr^{-1}$ was used (Wetland supplement, IPCC 2014, Table 2.1). The forest soil inventory does not provide data on emissions for forest soils with 6-12 % OC as for Cropland (CL) and Grassland (GL) and hence only emissions from organic forest soils > 12 % OC are reported.

Since the reporting in 2009 for years 1990-2007, quantitative information has gradually become available; a project "SINKS" initiated in 2007 has delivered data on soil C change based on repeated sampling of soil C pools in forests remaining forests for 1990 and 2009-2010, with more data on soil C pools being made available during 2019-2020.

The sampling is taking place in two grids, the so-called "Kvadratnet" (Agricultural network, 7 x 7 km) and the NFI grid (2 x 2 km). The data from "Kvadratnet" included archived soil samples from around 1990 and new samples from 2007-2010. These 108 re-measured sites (sampled in six depth sections: forest floor, 0-10, 10-25, 25-50, 50-75 and 75-100 cm, with some variation for historical reasons) suggested that mineral forest soil C pools are not sources for $CO_2$ and thus supported that more accurate estimates of litter and soil C pool removals/emissions do not need to be included in the reporting (Callesen et al., 2015). The methodology of the 2007-2010 survey is described in Callesen et al. (2015).

Considering the forest structure in Denmark with many small forests (about 70 % of the forest estates are of less than five hectares) the "Kvadratnet" is a very coarse grid. Even if the grid was fully sampled, it is therefore unlikely that the 108 plots represent the Danish area of forests remaining forest of approximately 500 000 ha. Based on power analyses, it was thus evaluated in 2007 that further sampling is necessary for future monitoring and a randomly selected subset of the permanent plots of NFI was included for this purpose. In 2007-2010, in total 277 plots were sampled in six depth sections: forest floor, 0-10, 10-25, 25-50, 50-75 and 75-100 cm. The samples were processed as described in Callesen et al. (2015). A re-measurement of these plots is taking place in 2019-2020, and it will soon be possible to provide further documentation if forest soils is a sink or a source of carbon.

#### Soil carbon stock changes in forest remaining forest

Mineral soil C stocks in forest remaining forest are estimated at an average of 155 t C $ha^{-1}$ to 1 m depth for soils with < 12 % C in the 0-25 cm layer. For organic soils, it is estimated at 500 t C $ha^{-1}$. No overall changes in Soil Organic Carbon (SOC) stock to 1 m depth were detectable in mineral soils in a depth of 0-100 cm between 1990 and 2007-2009 (Callesen et al. 2015).

#### Christmas trees

Christmas trees are recorded as forest, as the areas fulfil the forest definition applied. The christmas tree plantations occur on both traditional Forest Land (FL) and on areas formerly used for Cropland (CR). The christmas trees are managed intensively compared to forest in many cases. Carbon stock in above-ground living biomass based on the NFI data for christmas tree is estimated to 0.01 kt C $ha^{-1}$ and 0.002 kt C $ha^{-1}$ in the below-ground biomass. No dead wood or litter layer of significance is present in these areas and the carbon stocks area set to 0 (zero).

### 6.2.6 Carbon pools in forest remaining forest

The carbon pool in live and dead biomass estimated for the most recent rotation of the NFI (2014-2018) is 42 million tonnes C (Figure 6.2). The live above ground biomass carbon makes up 81 % of the total carbon in biomass, while dead wood makes up only 1 % of the total. Carbon in biomass in forests established after 1990 makes up 4 % of the total. The amount of carbon in biomass in forests established before 1990 has been slowly increasing since 2006. Based on preliminary results of an evaluation of the subsequent measurement cycles 2002-2006 and 2007-2011, the increase is partly caused by an increased average biomass per hectare. However, part of the increase is also due to an increase of the forest area, due to improved detection of forest caused by improvements of aerial photos used for this.

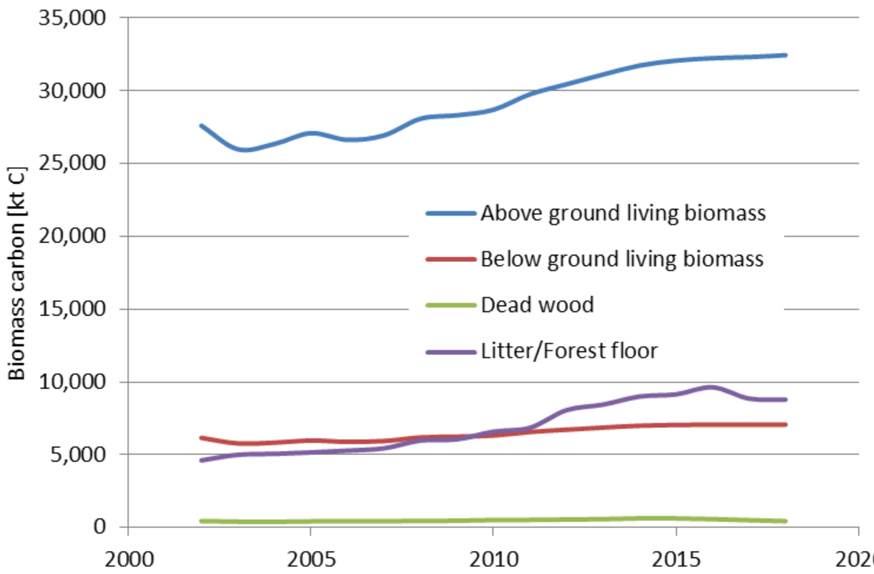


Figure 6.2 Forest carbon in forests established before 1990 estimated from NFI data from 2002-2018. Note that estimates for 2002-2005 are based on only 1-4 years of measurements. Only from 2006 are the estimates based on a full five-year rotation of the NFI.

### 6.2.7 Uncertainties and time series consistency

Danish national forest resource assessment has developed over the years from the earliest forest census more than a century ago to the current national inventory. More recently, the development has been quite rapid, thus influencing the estimation of forest carbon pools in relation to LULUCF.

In the 1990 forest census, the number of questionnaires sent to respondents was 22 300. In the subsequent inventory, the number of respondents increased to 32 300. Not unexpectedly, this led to a substantial increase in estimated forest area, which is not possible to separate from the actual increase in forest area that occurred during that period of time. Also, it is not possible to single out the effect of the increased number of questionnaires on estimates of species distribution, carbon pools etc.

In 2002, the sample based forest inventory substituted the previous forest census, for the first time enabling annual forest statistics. The NFI includes areas and forest owners that have not previously been included in the forest census. Firstly, because not every forest owner was included in the previous surveys and secondly because not all forest areas according to the FAO definitions would be perceived as forest by the respondents. Consequently, the change from questionnaire based forest census to sample based forest inventory has led to an increase in forest area estimates that is not possible to separate from the actual increase in forest area that occurred during that period of time.

Specifically, in relation to the reporting of carbon pools in forest, the change from questionnaire based forest census to sample based forest inventory has changed the calculation of forest volume, biomass and carbon. In the forest census, forest carbon is estimated from the reported forest area within different species, age and site classes and a number of forest growth models. In the forest inventory, forest volume (and subsequently carbon) is measured on the plots. The observed forest area and carbon is subsequently expanded to regions or the entire country using statistical models. This has led to a substantial increase in forest volume, biomass and carbon estimates, mainly due to methodological improvements.

In the estimation of carbon emissions from existing forests, the information collected in relation to different forest census and inventories is combined with the satellite based land use/land cover map for the base year 1990 and for the year 2005. Hereby, consistent estimates of emissions from existing forests are obtained utilising as much information from the data sources as possible and thus providing the best possible time series. For the period from 2006 and onwards, there is full consistency of the data.

In a statistical sense, the Danish NFI has a cluster design with unequal cluster size. The estimation of carbon stocks is therefore associated with a statistical uncertainty. Design based estimators are available for such designs, but the Danish NFI design is further characterised by the partitioning of sample plots and unequal representation of different tree sizes within the circular sample plots. Considering the nature of the design, derivation of an analytical estimator may be a dubious undertaking.

An alternative to the derivation of analytical estimators is the use of resampling methods in which random samples are repeatedly generated from the original data and estimates are obtained for the specific variable. One such resampling method is bootstrap sampling in which a random sample is repeatedly drawn with replacement from the original sample with. Estimates from each bootstrap sample are collected and used for calculation of population mean and corresponding confidence intervals.

In an analysis of the Danish NFI data collected from 2011-2015 (Johannsen et al. 2017), the living above ground, below ground and total carbon stocks were 33 064, 7170, and 40 234 M tonnes C, respectively. For 1000 bootstraps, the standard error corresponded to 1.1 % of the mean for the forest area and 1.6 % for total above and below ground carbon stock.

When estimating the change in stocks rather than the stocks themselves (i.e. when using the stock change approach in carbon reporting), the statistical uncertainty is expected to increase, as the uncertainty depends on both the uncertainty of the estimate for the first and second period and their covariance. In this case, where the annual change is small and the pools are large, the relative uncertainty is expected to be very large.

When the bootstrap analysis was conducted to obtain one-year change estimates, the standard error obtained from 1000 bootstraps was large compared to the average change. For the change in total live carbon stocks, the standard error corresponded to 162 % of the mean. The confidence intervals calculated from the 1000 bootstrap samples included zero, which means that the change in carbon stocks between subsequent time points one year apart were not statistically significant. One obvious reason for this result is that only about 20 % of the data used for the estimates at the two time points are different due to the overlap of five-year data cycles. Another reason is the large relative uncertainty caused by analysing relatively small differences between large pools.

The uncertainty of the estimates for subsets of the full forest area is related to the sampling intensity. With more subdivisions, the uncertainty increases as the sampling size is reduced. An initial bootstrap analysis of this has been performed (Table 6.7).

Considerations have been done as to whether a development of models for gains and losses would provide estimates of change with less uncertainty. However, such models will be highly dependent on the data available for the estimation and even though the changes from year to year may seem more stable, the uncertainty may be even higher, as it will not be directly related to observed data.

Table 6.7 Tier 1 estimates of the uncertainty for the forest.

| | | 1990 | 2018 | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Emission/ sink, kt $CO_2$ eqv. | Emission/ sink, kt $CO_2$ eqv. | Activity data, % | Emission factor, % | Combined uncertainty | Total, uncertainty, % | Uncertainty, 95 %, kt $CO_2$ eqv. |
| **4.A Forests** | | -542.5 | 402.2 | | | | 4.1 | 16.3 |
| 4.A.1 Forest land remaining forest land, Living biomass | $CO_2$ | -738.3 | -2607.2 | 5 | 2 | 5.4 | 5.4 | 140.4 |
| 4.A.1 Forest land remaining forest land, Dead organic matter | $CO_2$ | -5.8 | 2977.9 | 5 | 3 | 6.0 | 6.0 | 178.2 |
| 4.A.1 Forest land remaining forest land, Organic soils | $CO_2$ | 189.8 | 141.4 | 10 | 50 | 51.0 | 51.0 | 72.1 |
| 4.A.2 Land converted to forest land | $CO_2$ | -19.8 | -163.4 | 10 | 9 | 13.3 | 13.3 | 21.7 |
| 4(II) A. Forest land, organic soils | $CH_4$ | 4.0 | 29.4 | 10 | 90 | 90.6 | 90.6 | 26.6 |
| 4(V) Biomass Burning | $CH_4$ | 0.7 | 0.0 | 10 | 30 | 31.6 | 0.0 | 0.0 |
| 4(V) Biomass burning | $N_2O$ | 0.4 | 0.0 | 10 | 30 | 31.6 | 0.0 | 0.0 |

### 6.2.8 QA/QC and verification

Continuous focus on the measurements of carbon pools in forest will contribute to QA/QC and verification in the following submissions. As we gain more data through resampling of permanent plots in the NFI, this will further support the verification of the data reported.

On-going development of the NFI in terms of sampling procedures and estimation methods is essential for the continued QA/QC process of the NFI.

New models for biomass calculations have previously been implemented based on a substantial dataset collected in long-term common garden experiments with tree species. Further, improvements to the existing biomass models were made by adding a novel set of biomass data, including six new broadleaved species (Nord-Larsen et al. 2017). Further, projects aimed at improving consistency of forest carbon pool estimation across Europe (Diabolo), is expected to yield a new set of biomass equations from a very large dataset collected across Europe.

Integration with multi-phase and multi scale inventory, e.g. through other in-situ data like LiDAR scanning or satellite imagery, will contribute to the continued QA/QC process of the NFI and the carbon stock estimates for forests, when funding for this part of the verification becomes available.

### 6.2.9 Recalculation

Time for all land use transition has been revised to 30 years for all sectors; this affects all sectors but only related to changes in soil carbon stocks.

### 6.2.10 Planned improvements

Below is a list of planned improvements.

- A constant focus on the QA/QC of the Land Use Matrix with focus on afforestation, permanent clearing of forest vs temporary unstocked areas.
- SINKS2, which is a continuation of SINKS project, is ongoing for further documentation of carbon pools in soil and forest floor. It will take some years before the data is collected, analysed and ready for application in the reporting.
- SINKS2 will deliver: 1) improved data for bulk densities of forest floor for modelling of forest floor C stocks based on forest floor depth measurements from the NFI, 2) estimates of SOC changes over time based on ca. 400 plots in DK compared to 125 plots at present, 3) new estimates of cropland to forest conversion effects on SOC based on repeated sampling and modelling, 4) bulk density measurements in mineral soil for development of pedo-transfer functions for better estimation of bulk densities stocks based on measured soil C concentrations.
- The work with the National Forest Accounting Plan (Johannsen et al., 2019) have led to a number of analyses related to estimates of changes in forest carbon pools based on the stock change methodology. The analyses also include estimates of uncertainties. During the year of 2020, it will be evaluated a more robust methodology to identification of the change in the forest carbon pools.

### 6.2.11 Land converted to forest

See section 6.2.1 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation.

**Forest definition**
The definition of land converted to forest corresponds to the definition used for forest remaining forest (see section 6.2) and the LULUCF categories used elsewhere.

The composition of the afforestation by species has been analysed by a project resulting in a report in 2014 (Schou et al. 2015). The age distribution of the afforestation, based on age estimates in the NFI field sampling, has some uncertainty. In the age distribution, a large part of the young stands is tree species suited for christmas tree production or establishment of coniferous plantations. Generally, the afforestation is 10-30 years old. The species composition of the afforestation reflects whether it has been performed with subsidies. The subsidies have promoted afforestation with broadleaved trees, as these are native species to Denmark. The scheme for afforestation has been focused on domestic species for the benefit of stability, biodiversity and recreation more than for carbon storage.

**Methodological issues for land converted to forest**
**Living biomass**
As with forest remaining forest, Denmark applies the stock change method, hereby including both growth and harvesting in the overall estimation.

When converting land to forestland, the standing living above- and below ground biomass is assumed to be removed from the land. For land converted, e.g. from cropland, a standard default loss value of 9 577 kg DM (dry matter) per hectare in above ground biomass and 2 298 kg DM per hectare in below ground biomass is used. This value is equivalent to the average harvest of living biomass for all cereals grown in Denmark from 2000 to 2010, including straw, stubble and glumes based on data from Statistics Denmark combined with expansion factors. The expansion factors are those used in modelling of turnover of organic matter in agricultural soil with the dynamic model, C-TOOL, see section 6.3.7. For conversion from DM to carbon, a default concentration of 0.50 g C $g^{-1}$. is used. The default values for the amount of living biomass removed is shown in Table 6.8.

Table 6.8 Default values for the amount of DM (dry matter, kg per hectare) used for estimating carbon stock changes where land use conversions take place. The default C stocks in mineral soil (<6%C in 0-25 cm) are used for estimation of C stock changes following land-use change.

| | | Dry matter, kg DM pr hectare | | |
|---|---|---|---|---|
| | | Above ground biomass | Below ground biomass | Default C stock in mineral soil, tonne C/ha |
| Forest land | | | | 142[c] (excl. ff) |
| Christmas trees | | 21 277 | 4 255 | 142 |
| Cropland | | 9 577 | 2 298 | 120.8 |
| Grassland | Improved Grassland | 2 400 | 6 720 | 142[a] |
| | Unmanaged Grassland | 2 200 | 6 160 | 142 |
| Wetlands | Peat extraction | 0 | 0 | NE |
| | Other Wetland | 3 600 | 10 080 | NE |
| Settlements | | 2 200 | 2 200 | 96.6[b] |
| Other land | | 0 | 0 | NA |

[a] Same as for forest land.
[b]80 % of the carbon stock in Cropland (IPCC chapter 8.3.3.2).
**[c]** Average of all forest mineral soils (<6 % SOC, 262 plots in NFI and "Kvadratnettet").

**Forest floor**

The included soil carbon pool changes concern carbon sequestration due to development of forest floors, i.e. the organic layer on top of the mineral soil as well as C sequestration in the mineral soil.

Forest floor C stocks after afforestation are estimated based on depth measurements performed as an integrated part of the NFI. Depth measurements are converted to C stocks based on bulk densities and concentrations similar to the method described for forests remaining forest, as described in Nord-Larsen and Johannsen (2016).

**Mineral soil**

Several previous national field studies mentioned above (Vesterdal et al. 2002a, 2002b, 2007) did not suggest statistically significant decadal changes in mineral soil carbon following afforestation. In the Forest Soil Inventory (SINKS project), soil carbon content to 100 cm in forest land remaining forest land was compared with soil carbon in the same depth for mineral soils (<6%C in 0-25 cm) reported from a parallel project for cropland soils (Table 6.8). These data indicate that mineral soils are small sinks for $CO_2$ following afforestation of former cropland.

**Carbon pools in land converted to forest**

The amount of carbon in biomass in forests established after 1990 has been increasing rapidly during the time of NFI measurements (Figure 6.3). The very low estimates of forest carbon at the beginning of the NFI measurements may in part be due to a large number of plots not measured in the field as a result of start-up problems, which may have biased the results. In addition, in the early measurements, aerial photographs were of a poorer quality and recent afforestation may have been difficult to detect.

The sequestration of $CO_2$ in forests established since 1990 has gradually increased and the annual $CO_2$ sequestration will increase much more over the next decades when cohorts of afforestation areas enter the stage of maximum current increment. Forest floor C increases abruptly in 2011/2012, which is due to changes in methodology regarding the soil sampling in that year.

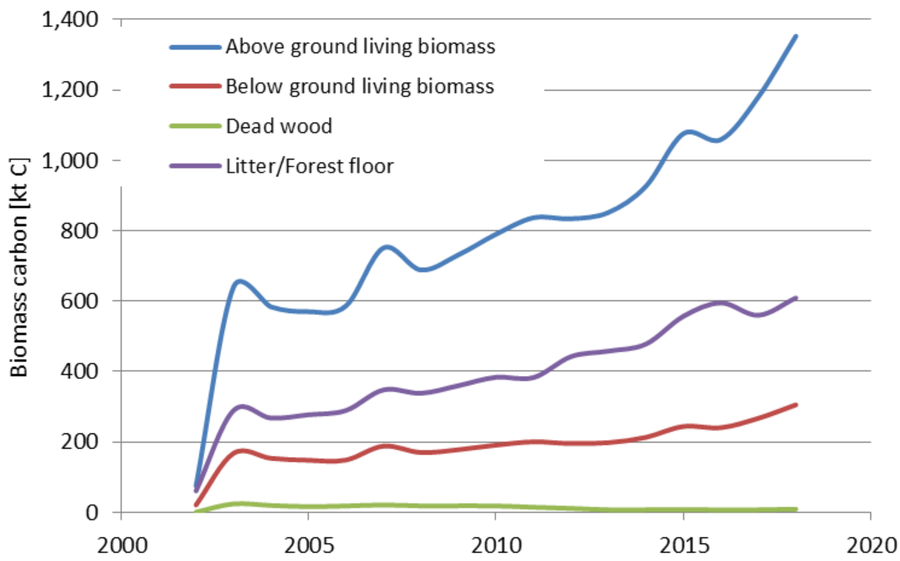


Figure 6.3 Forest carbon in forests established after 1990 estimated from NFI data from 2002-2018. Note that estimates for 2002-2005 are based on only 1-4 years of measurements. Only from 2006, the estimates are based on a full five-year rotation of the NFI.

**Emissions from wet and drained Forest soils**

The 2013 Wetlands Supplement (IPCC, 2014), Figure 1.2, p 1.6) has introduced new soil categories including 'mineral wet soils' and 'mineral drained soils' (inland or coastal) as soil categories in addition to the formerly used 'dry mineral soils' (IPCC, 2006). These categories are small and knowledge is uncertain with respect to activity data and emission factors. A range has been indicated in the reporting, but we are aware of the need for better assessment of SOC levels and effects of rewetting on non-$CO_2$ greenhouse gases. The peat definition of the soil map used for activity data (category FT – ferskvandstørv' is 'peat formed by accumulation of dead organic plant material in lakes, near streams or in moorlands' – a limit of at least 12 % C applies to this definition.

The temporal change in shares of drained and rewetted soils has been assessed based on current trends in forest management (Table 6.9). A change in these soil categories was made in 2008 based on expert assessment of observed trends in the past 20 years of active maintenance of pre-existing ditches in forests.

Table 6.9 Outline of assumptions on drainage changes over time for mineral and organic soils in forest.

| Share, % | Mineral soil | | Organic soil | |
|---|---|---|---|---|
| | Drained (ditched) | Undrained (not ditched) | Drained (ditched) | Undrained (not ditched) |
| 1990 - 2008 | 65% - > 55% (0.5% points per year) | 35%->45% (0.5 % points per year) | 75% | 25% |
| After 2008 | 55% | 45% | 50% | 50% |

The area of rewetted mineral and organic soil following the previously reported area shares of ditched/unditched is:

Rewetted mineral soil: 65 % - 55 % = 10 % of total forest area on mineral soils.

Rewetted organic soil: 75 %-50 % = 25 % of total forest area on organic soils.

**Reporting of nitrous oxide emissions**

The only soil category for which nitrous oxide emissions apply is 'organic soils, drained', and default emission values have been used. Measurements of nitrous oxide emissions from conditions applying for organic drained soils in Denmark are scarce or lacking. Danish measurements that apply to a hydromorphic, loamy soil were 0.4 – 0.6 kg $N_2O$-N $ha^{-1}$ $yr^{-1}$ (Christiansen et al., 2012b), which is similar to the low end of the uncertainty range given in the 2013 Wetlands Supplement value, Table 2.5 (IPCC 2014).

Organic soils, drained: 2.8 (range 0.57 – 6.1) kg $N_2O$-N $ha^{-1}$ $yr^{-1}$ (Table 2.5 in IPCC 2014, p. 2.33). Remaining soil categories do not apply, since they are either too dry or too wet to produce nitrous oxide.

**Reporting of methane emissions**

The following emission factors for methane were identified (Table 6.10); we note that units vary between chapters in 2013 Wetlands Supplement (IPCC 2014). A default area of 2.5 % ditches was assumed. Table numbers refer to the 2013 Wetland Supplement (IPCC 2014).

Table 6.10 Identified emission factors for methane and nitrous oxide in 2013 Wetlands Supplement (IPCC 2014) used in methane emission calculations.

| | | | |
|---|---|---|---|
| $CH_4$ EF for organic drained soils | Table 2.3 | kg $CH_4$/ha/yr | 2.5 |
| $CH_4$ EF for ditches on organic drained soils | Table 2.4 | kg $CH_4$/ha/yr | 217.0 |
| $CH_4$ EF for organic rewetted poor soils | Table 3.3 | kg $CH_4$-C/ha/yr | 92.0 |
| $CH_4$ EF for organic rewetted rich soils | Table 3.3 | kg $CH_4$-C/ha/yr | 216.0 |
| $CH_4$ EF rewetted Inland Mineral Wetland Soils | Table 5.4 | kg $CH_4$/ha/yr | 235.0 |
| $N_2O$ EF for organic drained soils | Table 2.5 | kg $N_2O$-N/ha/yr | 2.8 |
| $N_2O$ EF for ditches on organic drained soils | | NO | |
| $N_2O$ EF for organic rewetted poor soils | | p.3.19 'negligible' | |
| $N_2O$ EF for organic rewetted rich soils | | p.3.19 'negligible' | |
| $N_2O$ EF rewetted Inland Mineral Wetland Soils | No info in WS chap 5 IWMS | Assumed negligible | |

In a Danish study of three forests in eastern Denmark on hydromorphic soils, the reported methane emissions were -0.08 - 3.2 kg $CH_4$ $ha^{-1}$ $yr^{-1}$ (Christiansen et al. 2012a; Christiansen et al. 2012b). The default value for drained organic soils seems to be reasonable until national estimates are better founded by representative measurements. Since no water level measurements in ditches and rewetted soils are available, it is not possible to judge whether the 2013 Wetland Supplement (IPCC 2014) default values for methane emissions apply to Danish conditions.

**QA/QC and verification**

A continuous focus on the measurements of carbon pools in land converted to forest will contribute to QA/QC and verification in the following submissions. See also Chapter 6.2.1

### Recalculation

Time for all land use transition has been revised to 30 years for all sectors; this affects all sectors but only related to changes in soil carbon stocks.

### Implemented and planned improvements

The basic information utilised to provide the data for the emission estimates for units of land subjected to afforestation/reforestation is based on NFI observations of stock change, specifically related to the afforested areas. This will include all changes in carbon pools - also if affected by harvest - including thinning of young stands. Based on the NFI, it will for the next reporting be possible to provide some indications of the frequency of harvesting/thinning occurring on the afforested areas. Given the fact that the afforested area is still a relatively small part of the full forest area, there will be more uncertainty on the estimate related to afforested areas compared to the area of forest remaining forest. New data sources based on e.g. ALS/LiDAR data will potentially improve the estimates and the mapping process, bur requires more development to be implemented on an annual reporting basis.

Documentation for carbon pools in soil and litter is expected to be further improved following the next resampling of forest soils.

In the updated land use matrix that now includes mapping of three years (1990, 2005 and 2011), changes have been noted related to land use and land use changes. This includes increased afforestation in areas without support from public funds as well as establishment of minor forests areas, to improve hunting options and to produce biomass. Some forest areas have been established through natural succession, a method now approved by the Forest Act (from 2005). In the previous reporting, mainly afforestation based on subsidies were expected and included in the reporting. The area of christmas trees is now handled as a specific part of the forestland use and the dynamics therein are handled directly in the estimation of the carbon pools.

See also the chapter on “Methodology for land use representation” for a more detailed description of methods and validation.

The estimations of forest floor will be reviewed in 2020 to ensure consistent estimates over time.

The work with the National Forest Accounting Plan (Johannsen et al. 2019) have led to a number of analyses related to change estimates based on the stock change methodology, uncertainties. During the year of 2020, it will be evaluated if there are even more robust methods to estimate the change of the carbon pools in land converted to forest. This could lead to recalculations for the next submission.

## 6.3 Cropland (4B)

Cropland in the reporting consists of:

- Agricultural cropland, defined as agricultural crops, approx. 2.4 million ha.
- Perennial wooden crops, defined as horticultural wooden crops and willow plantations, approx. 11 000 ha.
- Hedges and small biotopes in the landscape, which do not meet the definition of forest, approx. 103 000 ha.

- Other cropland. "Other cropland" is defined as the difference between the three defined crop types and the area in the land use matrix. Consequently, Other cropland is without any major carbon stocks and typically minor roads (not included in settlements), roadsides, banks between fields without hedges etc., approx. 280 000 ha.

According to this, cropland accounts for approximately 2.8 million ha in 2018, a decline from approximately 3.0 million ha in 1990.

The total Danish cropped agricultural area of approximately 2.65 million hectare consists of approximately 580 000 individual fields, which again is located at 190 000 land parcels. This gives an average field size of less than four ha. The actual crop grown in each land parcel (LPIS) is known from 1998 and onwards. According to Statistics Denmark 220 000 ha is reported as permanent grassland. The area reported to Statistics Denmark are in the land use matrix reported under either cropland or grassland.

Table 6.11 shows the areas and the emissions from cropland from 1990 and onwards.

Table 6.11 Total area and annual emissions 1990 to 2018 from Cropland.

| Cropland | 1990 | 2000 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Area, 1000 ha | 2993.2 | 2944.0 | 2884.2 | 2861.9 | 2844.3 | 2831.5 | 2823.8 | 2817.3 | 2816.9 |
| Living and dead biomass, kt C | -5.2 | 3.1 | -4.1 | -7.9 | 85.2 | 97.9 | 61.6 | 26.9 | 22.4 |
| Mineral soils, kt C | 125.7 | -109.6 | -317.2 | -245.5 | -34.7 | -186.2 | -78.0 | -188.88 | 220.4 |
| Organic soils, kt C | 1292.4 | 1170.0 | 1047.5 | 1004.8 | 999.2 | 1013.6 | 997.3 | 980.4 | 968.9 |
| Total, kt C | 1412.9 | 1063.5 | 726.2 | 751.5 | 1049.6 | 925.4 | 980.8 | 818.3 | 1211.7 |
| $CH_4$, kt $CH_4$ | 6.50 | 5.88 | 5.27 | 5.42 | 5.53 | 5.42 | 5.51 | 5.51 | 5.64 |
| $N_2O$, kt $N_2O$ | 0.000 | 0.000 | 0.001 | 0.001 | 0.001 | 0.011 | 0.011 | 0.001 | 0.007 |
| Total, kt $CO_2$ eqv. | 5343.2 | 4046.6 | 2794.7 | 2891.3 | 3987.2 | 3531.7 | 3737.0 | 3138.4 | 4586.0 |

### 6.3.1 Cropland remaining Cropland (4B1)

Since 1990, the agricultural area recorded by Statistics Denmark has decreased from 2.78 million hectare to 2.63 million hectare in 2018 (Table 6.12). The overall cereal yield has increased with 33 % during the same period (average 1990-1994 compared to average 2013-2018).

Table 6.12 shows the development in the agricultural area from 1990 to 2018 (Statistics Denmark). A general trend is a continuous decrease of the agricultural area by 6000 - 7000 ha per year. From 1993 to 2008, there was a mandatory European Union regulation for set-a-side, due to overproduction of agricultural products. In these years, more than 200 000 ha were often left as set-a-side. In 2009, this regulation was lifted and the area ceased to a very low level. In the latter years the reported area has increased and for 2018 set-a-side area was reported 76 377 ha. Part of the increase of the reported area is due to a change of the definition by Statistics Denmark, but also a change in the farmers reporting. The Danish farmers receive single payment per ha, regardless of what is grown on the land and thus not bounded to the specific crops. In the carbon stock calculation for mineral agricultural soils, Denmark is using a dynamic model (C-TOOL, see section 6.3.7). In this model, the set-a-side area is treated as a specific crop similar to grassland. However, the input of organic material to the soil is lower for the set-a-side area compared to grass in rotation.

Table 6.12 Cropland area in Denmark 1990-2016 according to Statistics Denmark and the Land Use Matrix, hectares.

| | 1990 | 2000 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|
| Annual crops (CL) 1 | 2236535 | 1938633 | 2049304 | 2064949 | 2064503 | 2056398 | 2049720 |
| Grass in rotation (CL) | 306325 | 330834 | 327319 | 258202 | 271906 | 274124 | 265518 |
| Permanent grass (CL and GL) | 217235 | 166261 | 199859 | 254770 | 225620 | 234680 | 212657 |
| Horticulture – vegetables (CL) | 16428 | 10803 | 10812 | 11119 | 12081 | 13057 | 12970 |
| Perennial fruit trees – perennial wooden crops (CL) | 10267 | 9892 | 8181 | 7391 | 6859 | 6264 | 6338 |
| Set-a-side (CL) | 0 | 191295 | 9874 | 4501 | 6079 | 5461 | 76377 |
| Other land and uncropped areas (CL) | 3861 | 1146 | 41435 | 33058 | 38868 | 42007 | 9578 |
| Total agricultural land area reported by Statistics Denmark | 2788276 | 2646982 | 2646400 | 2632947 | 2625093 | 2631289 | 2632453 |
| Willow and other crops for energy purposes (CL) | 588 | 695 | 4049 | 5478 | 5161 | 5062 | 5039 |
| Hedgerows (CL) | 98643 | 100194 | 97290 | 97881 | 98022 | 98139 | 98372 |

[1]CL refers to that the area is reported under Cropland. GL refers to Grassland.

Despite the decreasing agricultural area, the total crop yield has increased since 1990, as measured in dry matter (million kg dry matter per year (Figure 6.4). Year 2018 was very dry and the consequences was a 25 % lower crop yield than the average.

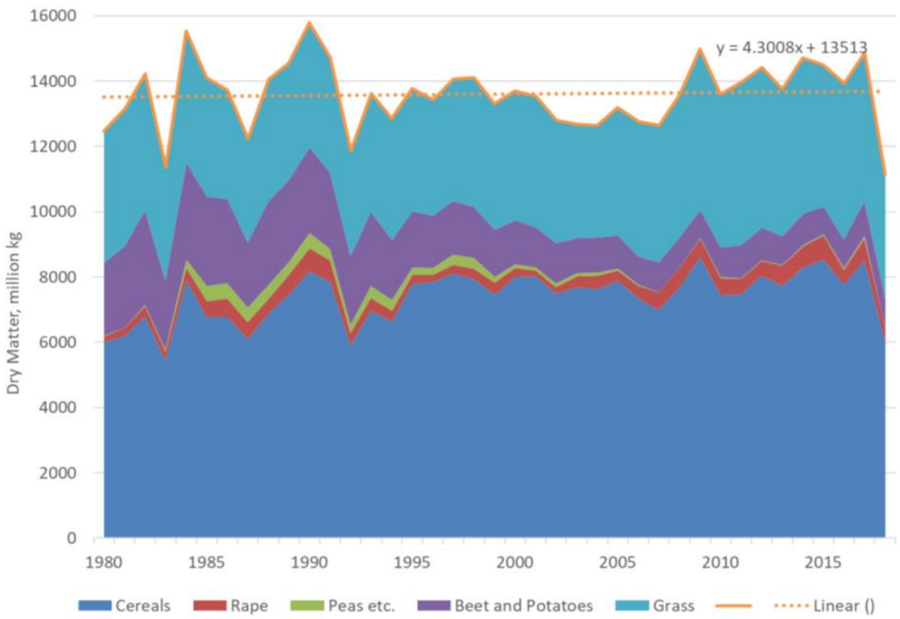


Figure 6.4 Total crop yield given as kernel, root fruits and grass as measured in dry matter (Million kg dry matter per year, Source: Statistics Denmark).

The main reason for the loss of land for agricultural purposes is urbanisation and afforestation. The major part of the agricultural area is grown with annual crops: cereals, grass in rotation, oilseed, sugar beets, potatoes and temporarily set-a-side. Permanent grass outside rotation with none or very little fertiliser application rates (>25 kg N per ha per year) is reported under Grassland. All fertilisation with nitrogen is reported under Agriculture (Chapter 5).

### 6.3.2 Cropland area

The Cropland area is defined as the agricultural area as given by Statistics Denmark, Perennial wooden crops (fruit trees, orchards and willow), hedgerows (perennial trees/bushes not meeting the forest definition) in the agricultural landscape and “Other agricultural land”. The latter is defined as the difference in the area between the total Cropland area as defined by the land use matrix minus agricultural crops in rotation as given by statistics Denmark, minus the area with fruit trees and the area with hedgerows. “Other agricultural land” is thus comparable small areas and probably without agricultural and wooden crops, which cannot be allocated to other land use categories. In the inventory, carbon in living biomass for “Other agricultural land” is given the same value as for annual crops so that inter-annual changes in the cropland area from Statistics Denmark are eliminated.

The area with perennial wooden crops are defined by Statistics Denmark and for some categories it is split further down with data from the EU crop subsidiary system, which gives information on which crops are grown where on species level.

The main data for land use of cropland (4.B) is the agricultural area given by Statistics Denmark. Both annual agricultural and wooden perennial crops are allocated into grids (climatic, soil type and municipality) with the help of the EU Land Parcel Information System (LPIS). LPIS contains information of the exact position of the field. The survey data from Statistics Denmark differs a little from the LPIS system (<±2 % for the major crops). Area and yield data from each region are used for the calculations as reported by Statistics Denmark.

The area with hedgerows and small biotopes is based on analysis of LiDAR measurements for year 2006 and 2014/2015 (see section 6.3.6) combined with planting and removal statistics of hedges from the Ministry of Environment and Food of Denmark. Most establishment of hedges is subsidised in Denmark and therefore monitored.

### 6.3.3 Cropland definition

The land area under "CL" consists of Cropland with annual crops, cropland with wooden perennial crops, areas with hedgerows and “Other agricultural area”. The latter consists of small, undefined areas lying inside the area, which is allocated as cropland in the cropland area.

For purposes of the calculations for annual crops a division as follows is used: Winter and spring wheat, rye, triticale, winter and spring barley, oat, winter and spring rape, grass for grass seed production, grassland in rotation, potatoes, sugar beets, peas, maize for silage, cereals for silage, vegetables and miscanthus.

For purposes of perennial wooden crops a division as follows is used: apple, pears, cherries, plumes, rosehips, elderberries, hazel and walnuts, grapes, other fruit trees, black current, other fruit bushes, hedgerows and willows.

### 6.3.4 Cropland - Methodological issues

The following data sources are used for determination of cropland area, for determination of any land-use changes, for allocation of natural and administrative parameters, for development of emission factors for soils and biomass and for calculation of carbon stocks in soils and biomass at various times.

- Agricultural area data from Statistics Denmark, 1980 to 2018
- Area and harvest surveys from Statistics Denmark, 1980 to 2018

- Area with willow from the agricultural subsidiary system
- EUs Land Parcel Information System, 1998 to 2018 (grown crops on field and soil level)
- Digital soil map, 1:25.000
- LiDAR analysis in 2006 and 2014/2015 combined with hedgerow planting data 1977 to 2018 (very little planting has taken place in the later years).

Emissions from living biomass

For annual agricultural crops on cropland remaining cropland (4B1), it is assumed that no changes in above-ground, below-ground, dead biomass and litter are occurring, cf. IPPC 2006 (5.2.1.1). The variations in the actual agricultural area collected by Statistics Denmark may be up to 100 000 hectares per year. When estimating the carbon stock in living biomass such changes may create large variations between years, which may be artefacts. As the amount of living biomass is defined according to the time where the peak of living biomass is occurring, the variation in the area from Statistics Denmark creates large fluctuations in the carbon stock in living biomass compared to other sources. To counteract this problem, the sub-division "Other agricultural land" has been created with a default carbon stock of living biomass as in the designated agricultural area. The default carbon stock in living biomass is equivalent to an average spring barley crop with aboveground biomass of 9577 kg DM (dry matter) per hectare and a below ground DM of 2298 kg per hectare. Default dry matter values for the different crop categories used in the inventory was given in Table 6.8. This default value is based on the average cereal yield in Denmark from 2000-2010 combined with the expansions factors used in C-TOOL.

### 6.3.5 Fruit trees and other perennial wooden plants

Fruit trees, other perennial commercial wooden plants and durable horticultural plantations are included under cropland (CFR Table 4.B). These are only of minor importance in Denmark and cover approximately 9477 ha in 2018 of which >5000 ha is willow (Table 6.13) out of a total agricultural area of 2.8 million ha. The total area for different main classes and the used carbon stock in above-ground and below-ground biomass are given in Table 6.13. Due to the limited area and small changes between years, the $CO_2$ removal/emission is calculated without a growth model for the different tree categories. Instead, the average stock figures are used in Table 6.13 multiplied with changes in the area to estimate the annual emissions/removals. Perennial horticultural crops account for approximately 0.07 % of the standing carbon stock.

The carbon fraction of dry matter (DM) is assumed 0.5 for all species.

Table 6.13 Tonnes living biomass per hectare and area, ha, with perennial wooden trees and bushes, 1990-2018.

| | Living biomass, Mg DM per ha | 1990 | 2000 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|
| Black currant | 5.20 | 1269 | 1492 | 1935 | 1121 | 755 | 588 | 541 |
| Other berries | 5.20 | 663 | 611 | 533 | 690 | 804 | 617 | 733 |
| Rosehip | 13.99 | 0 | 0 | 197 | 133 | 115 | 138 | 142 |
| Cherries | 25.45 | 1787 | 2804 | 1743 | 1059 | 1047 | 870 | 639 |
| Plumes | 25.45 | 0 | 0 | 68 | 67 | 63 | 66 | 68 |
| Hazelnut and walnuts | 25.45 | 0 | 0 | 14 | 27 | 34 | 30 | 35 |
| Aples | 33.76 | 2726 | 1678 | 1684 | 1501 | 1490 | 1471 | 1677 |
| Pears | 13.99 | 351 | 441 | 357 | 317 | 317 | 333 | 305 |
| Elderberry | 25.45 | 0 | 0 | 9 | 12 | 12 | 12 | 53 |
| Grapes | 5.20 | 0 | 0 | 45 | 79 | 77 | 79 | 91 |
| Other fruit trees | 13.99 | 0 | 0 | 60 | 90 | 106 | 52 | 50 |
| Rowan-berries | 33.76 | 0 | 0 | 16 | 26 | 31 | 31 | 31 |
| Willow | 17.43 | 588 | 695 | 4049 | 5478 | 5161 | 5062 | 5039 |
| Miscanthus | 17.43 | 1 | 6 | 156 | 69 | 61 | 62 | 74 |
| Total | | 7385 | 7727 | 10865 | 10668 | 10072 | 9412 | 9477 |

### 6.3.6 Hedgerows

Since the beginning of the early 1930s, governmental subsidiaries have been given to increase the area with hedgerows to reduce soil erosion. In the 1950-60's, 6-9 million single rowed conifers, mainly white spruce *(Picea glauca)* was planted annually. From around 1965, the annual rate decreased sharply to almost zero in lack of financial subsidies but also because the planting turned into hedges made of broad leave trees/plants, however, only to around 2-3 million trees. This can be converted to annually financial support given to 400-800 km of hedgerow per year. In the latter years, financial support has only been given to approx. 100 ha. From 2014, this subsidiary was ceased, however, re-established from 2016. There are no figures on the total removed the same period as these to a large extend are not protected.

A new model for biomass estimation in hedges and small biotopes not included in the forest definition has been included in the 2020 submission. The model is based LiDAR measurements in 2006 and 2014/2015 (Levin et *al*. 2020). The LiDAR measurements has a resolution of 1.6 * 1.6 $m^2$ in 2006 and 0.4 * 0.4 $m^2$ in 2014/2015. The LiDAR measurements revealed an increase in the area with hedges and small biotopes of 96 660 ha in 2006 increasing to 103 105 ha in 2014/2015 (Levin et *al*. 2020). In combination with project with the LiDAR analysis biomass of approximately 10 000 m (10.3 ha) was measured. The removed biomass were chipped, brought to biomass burned power plants weighed and burned. Analysis of the data showed that regardless of the height there was a stable biomass volume per $m^3$ of hedge/biotope of 2.54 (± 0.56) kg DM $m^{-3}$ hedge. The analysis showed a tendency that more windy regions in Denmark have slightly lower hedges but as no significant differences in the volume per $m^3$ could be found these areas are reported with lower carbon stocks. To convert to carbon was used the IPCC default value of 0.47 and a Root/Shoot ratio of 0.192 (IPCC, 2006). The average height were estimated to 4.96 m and an average aboveground C stock of 59.2 ton C/ha. The volume density is higher than seen in the Danish NFI plots with similar heights. The most plausible explanation is that in the forest, the trees are competing for light and forced to grow vertically, whereas in the hedges more branches are produced. The measured DM $m^{-3}$ hedge is similar to what have been found in other studies in Germany (Lingner et al. 2018) and UK (Axe et al. 2017)

Table 6.14 shows the actual planting and removal rates for hedgerows. As the planting of white spruce from the 1930's and onwards is getting old, high replacement rates were seen in the 1980's and the 1990's. Many of the white spruce hedges are now replaced by broadleaves hedges and the replacement rate has gone down as well as the immediate need for hedges to lower sand drift from cropland. In 1990, 75 % of the replaced conifers hedgerows were replaced with 3- to 6-rowed broad-leaved hedges. Over the years, a decrease in the number of subsidized hedgerows has taken place. The Danish Agricultural Agency is responsible for all administration, registration and mapping of all subsidised hedgerow planting in Denmark.

Table 6.14 Hedges planted and removed under the governmental subsidiary system 1990 to 2010.

| | 1990 | 2000 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Planted, ha | 464.0 | 626.1 | 141.7 | 114.8 | 153.9 | 145.0 | 125.3 | 121.3 | 64.4 |
| Removed, ha | 522.0 | 219.1 | 13.0 | 10.7 | 14.6 | 4.3 | 8.6 | 6.9 | 1.3 |
| Net change, ha | -58.0 | 407.1 | 128.7 | 104.1 | 139.2 | 140.7 | 116.7 | 114.4 | 63.1 |
| Net change, kt C/yr | 7.6 | 30.1 | 51.6 | 46.3 | 43.9 | 43.1 | 25.9 | 24.8 | 23.8 |

### 6.3.7 Emission from soils

Based on a GIS analysis of the data in the LPIS and a newly produced soil map of the organic soil (Greve et al. 2014), the agricultural area is distributed between mineral soils and organic soils and subdivided into cropland and permanent grassland.

#### Mineral soils – 4B1

For carbon changes in mineral agricultural crops, a 3-pooled dynamic soil model is used (Taghizadeh-Toosi et al. 2014b) to calculate the soil carbon dynamics in relation to the Danish commitments to UNFCCC. Mineral soils are defined as soils having < 6 % OC in the topsoil (0-30 cm). The outcome from C-TOOL is reported under cropland, although it also includes grassland. Mineral soils in grassland is therefore reported as 'Included Elsewhere' (IE). No change in the carbon stock in soils under perennial wooden plants, hedgerows and "Other agricultural cropland" is expected and therefore reported as 'Not Occurring' (NO). These areas are also only a minor part of the cropland area. For agricultural crops, C-TOOL is run on a regional level with different soil types with initialization in 1980.

#### C-TOOL

C-TOOL (Taghizadeh-Toosi et al., 2014b) is a 3-pooled dynamic model, where the approximate average half-live times for the three different pools, Fresh organic matter (FOM), Humified organic matter (HUM) and ROM (Resilient Organic Matter) are 0.6-0.7 years ($k_{FOM}$ = 1.44 yr-1), 50 years ($k_{HUM}$ = 0.0336 ± 0.002 yr-1), and 600-800 years ($k_{ROM}$ = 4.63 x 10-4 yr-1),, respectively. When setting up the model, $k_{FOM}$ and $k_{ROM}$ is taken from short-term and long-term field experiments and based on these static parameters is $k_{HUM}$ estimated with the long-term field experiments to 0.0336 ± 0.002 $yr^{-1}$. (Taghizadeh-Toosi, A., 2015)

The main part of biomass returned to soil each year is in the first and easiest degradable FOM pool. This pool consists of mainly fresh straw, fresh manure, root residues, fungi and small animals and fluctuates very much between years depending on the harvest yield and climatic conditions. The FOM pool accounts for approximately 1-2 % of the total carbon stock in the upper 0 - 100 cm. The ROM pool is the most resilient part of the soil organic carbon. In most "old" soils, which has been cultured for hundreds of years it approximate around 50 % of the organic soil carbon (0-100 cm). The remaining amount of organic carbon is allocated to the HUM pool.

However, there is a difference to coarse sandy soils, which is old heathland in Jutland. In 1200-1800 of these, sandy soils were heavily overgrazed and turned into marginal heathland giving a low but very stable carbon content. Since the 1870's, this land has been cultivated, more farmed cattle were introduced and from the 1950's fertilized with mineral fertilizer. For these areas, our results show that the amount of HUM is much lower here, 29.0 t HUM $ha^{-1}$, compared to the other soil types, which have an average of 49.4 t HUM $ha^{-1}$ (Table 6.15).

Table 6.15 Estimated amount of HUM and ROM in Jutland and on the Danish Islands.

| | Total, t C/ha (0-100 cm) | |
|---|---|---|
| Location | HUM | ROM |
| Coarse Sand, Jutland | 29.0 | 93.4 |
| Loamy Sand, Jutland | 42.2 | 80.4 |
| Sandy Loam, Jutland | 57.8 | 75.7 |
| Loamy Sand, Islands | 44.1 | 63.1 |
| Sandy Loam, Islands | 53.4 | 67.2 |
| Average Loamy Sand and Sandy Loam | 49.4 | 71.6 |

It is obvious that the ROM pool has a minor influence on the annual C stock changes because it reacts slowly. The FOM has a very large influence because in Denmark the process of turning organic matter (OM) from crop residues into soil organic matter (SOM) starts after harvest from August to October. If there is a large input of crop residues (CR) and low temperatures during autumn, the outcome from the modelling by 31 December of the reporting year, is that only a small amount of the applied CR has been degraded out of the approximate 3.5-5 tonnes C per ha, which is incorporated every year. The result is a rather high total content of SOM at the end of the year and the changes between two successive years are large, if the previous year showed the opposite pattern with a low crop yield and a high temperature in the autumn. Such changes can be seen as "artefacts" as it is a matter of definition of the organic matter, whether it is partly degraded as crop residues or SOM. Therefore, we have agreed with a previous ERT (ARR 2011) to exclude FOM from the reporting in soils and only include the HUM and ROM pools. As a result, the HUM pool is more or less solely responsible for the changes in the SOC stock between years.

In the case of the sandy heathland in Jutland, the low amount of HUM means that these soils will store higher amounts of C in the future than the other soil types, until it reach the equilibrium state between incorporation and degradation. The history of heathlands C stock can be explained as small annual inputs for hundreds of year has given a higher distribution ROM compared to soils that are more fertile and a low share of HUM. Furthermore, we find large amounts of inert C (partly degraded OM) comparable compared to the other soil types, which we assume is due to burning of the heathland for hundreds of years (biochar). In the case with the old heathland, the annual input of CR has increased tremendously due to cultivation and fertilization. In factual terms, the average Danish cereal yield has doubled from 1900 to 1965 - but on sandy soils, it has quadrupled from a very low level (Statistics Denmark, annual year book). The consequence of this is that these sandy soils haven not reached their equilibrium state yet and are still increasing the SOC. This in contradiction to the old fertile clay soils, which are more in their equilibrium state, although still increasing their C stock due to increased annual CR input.

A simple diagram of C-TOOL is shown in Figure 6.5. C-TOOL is parameterised and validated against long-term field experiments (100-150 years) conducted in Denmark, the United Kingdom (Rothamsted) and Sweden and is "State-of-the-art". All dynamic models are allocating the total soil carbon stock into sub-compartments each having different degradation times. This distribution cannot be measured but have to be estimated from long-term experiments. As the models are parameterised on mineral soils the model cannot be used on soils having higher carbon contents such as organic soils as there is a limited number of data for validation and that the large amount of easily degradable OC in the organic soils affect the distribution in the different sub-ppols. Therefor is C-TOOL only used on soils having < 6 % OC. For soils having >= 6 % OC is used fixed emission factors per ha. In the inventory has soils having 6-12 % OC been given an emission factor of 50 % of organic soils > 12 % OC.

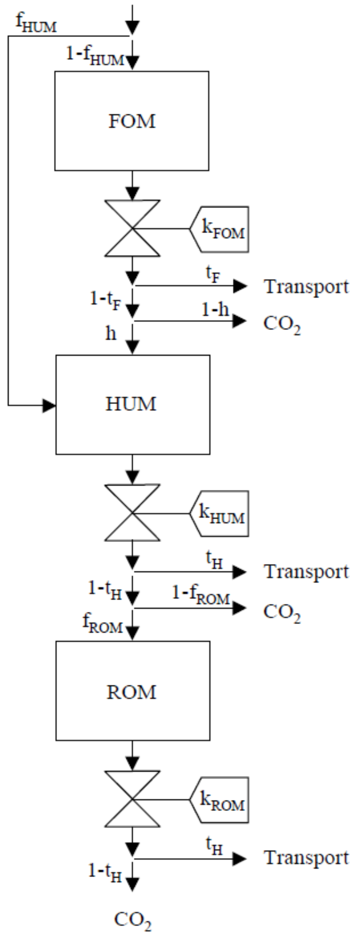


Figure 6.5 A simple diagram of C-TOOL.

### Input data to C-TOOL and output

A major revision of the soil parameters was made in 2016. The new version (Version 2.3) was implemented in the 2017 submission for all years. Version 2.3 includes ALL agricultural mineral soils in cropland and grassland. In the modelling, Denmark is subdivided into eight counties. Each county are further subdivided into two or three soil types. On the islands, where the soils typical are loamy sand or loam, two different soil types are used. Jutland, which has a large area with sandy wash-out plains, are split into three different soil types. As C-TOOL treats all agricultural crops on mineral soils including within grassland the emission from grassland is reported as IE as these carbon stock changes are included under cropland. This is also to facilitate the trivial annual conversions from cropland to grassland and vice versa as mentioned in the Land use matrix (Table 6.4). Set-a-side is treated as a separate crop type in C-TOOL with a low input of organic matter similar to unfertilized permanent grass.

As carbon input to each region for each year is taken the actual crop area and crop yields from Statistics Denmark (www.dst.dk Table AFG, AFG07, HST7 and HST77). The dry matter content depends on the actual crop. For cereals, it is 15 % (DST, 2020). The amount of agricultural residues returned to soil is the amount estimated by Statistics Denmark (www.dst.dk Table HALM and HALM1). The dry matter content depends on the actual crop. For cereal straw, it is 16 % (DST, 2020).

The amount of animal manure produced (Volatile Substance) and applied to soil is estimated with the same methodology as in the Agricultural sector for estimating $CH_4$ and $N_2O$ emission where annually updated feeding and excreting data are provided for the regulation of the animal production in Denmark. Here detailed data on the number of animal, housing and manure type are available on farm level. As the animals are distributed unevenly over the country, data on animal units of different animal types on each farm from the Danish mandatory nitrogen accounting system is used as proxy for the distribution of the animal manure on regions and soil types. From 2000, each farm has been geocoded on regions and soil type and multiplied with the animal units on the farm. For the years 1980 to 1999, the same distribution is used as in year 2000.

Since 1997, there has been a requirement for growing N catch crops in Denmark in order to reduce N-leaching. Besides reducing the N leaching, the catch crops increase the carbon stock in the soil. Between 120 000 and 332 000 hectares of the agricultural area are cultivated with catch crops and this area will increase further in the coming years. The requirement for catch crops has altered the way of farming in two ways. Cattle farmers typically sowing grass seed in their normal cereal fields. This grass sword must not be ploughed into the soil before winter/next spring. For farmers growing grass seed, which is common in Denmark, the old grass seed fields are not ploughed in to the soil before next spring, in contradiction to the current situation where it would be ploughed early autumn and act as a carbon sink. Eriksen et *al*. (2014) have estimated that the mandatory catch crops expects to increase the amount of C returned to soil by 0.27 tonnes carbon per hectare per year. The area with catch crops in each region is estimated from each farms' obligatory N accounting (LBST, 2020). As for the distribution of animal manure, the area with catch crops have been geocoded since 1997 and the organic matter input has been allocated to the different soil types.

More detailed figures on the distribution as an example of the crop yield and areas are given in Annex 3E, Table 3.E10-12.

C-TOOL is initiated with data from 1980. Actual regional monthly average temperatures are used as temperature driver. The main drivers in the degradation of soil biomass are temperature and humidity. The Danish climate is quite humid with winter temperatures around zero degrees Celsius and hence the importance of soil humidity on the model outcome is low in comparison to temperature, which has a high effect on the emission. As mentioned, when biomass is returned to the soil the major part of it is quite easily degradable. Warm winters with unfrozen soils in connection with high inputs of biomass will therefore, as a result, give high emissions from the soil compared to more cold years, which will give low emissions. The variation in the input to C-TOOL results inter-annual variation in the carbon input to the soil for all years. Combined with inter-annual differences in the temperature, this creates inter-annual differences in the net carbon stock change in mineral soils, where low yields combined with high temperatures, reduce the total amount of carbon in agricultural soils. The opposite situation, whit the combination of high yield and low temperatures, leads to an increase of the carbon stock in soils.

Figure 6.6 shows the total SOC included in the model and Figure 6.7 shows the annual changes. The blue line represent all three pools (FOM, HUM and ROM) and the red line represent only HUM and ROM. It is obvious, that the total carbon stock fluctuates more than the two more steady pools, HUM and ROM. 2017 was a good year for growing cereals giving high yields compared to 2016. For 2018, the yields were very low due to a severe draught in the growing season. Consequently, an increase in the overall SOC stock compared to 2016 is seen and a large decrease from 2017 to 2018 (Figure 6.6).

**Two examples**

Both year 2006 and 2007 were bad cropping years with a cereal crop yields of 7-9 % below the average of 2001-2010. The average Danish temperature was, however, 1.9 °C higher than the reference for 1961-1990 in 2007. Therefore, both due to the low C input and a high degradation rate, the agricultural soils were estimated to have a high loss of carbon in these years, cf. Figure 6.6 and 6.7.

In recent years (1999 - 2018), Denmark has experienced very warm winters, except from 2010, which was very cold and below the average from 1961 to 1990. Year 2010 had an average of 7.0 °C against the normal of 7.7 °C. The means that the degradation goes down. The average cereal yield was 3.5 % lower than the average of 2001-2010. The result was an increased carbon stock in the soil.

In 18 out of the last 20 years, the annual average temperature has been above the average temperature from 1961 to 1990. Year 2018 had an average temperature of 9.5 °C or 1.8 °C above the average from 1961 to 1990.

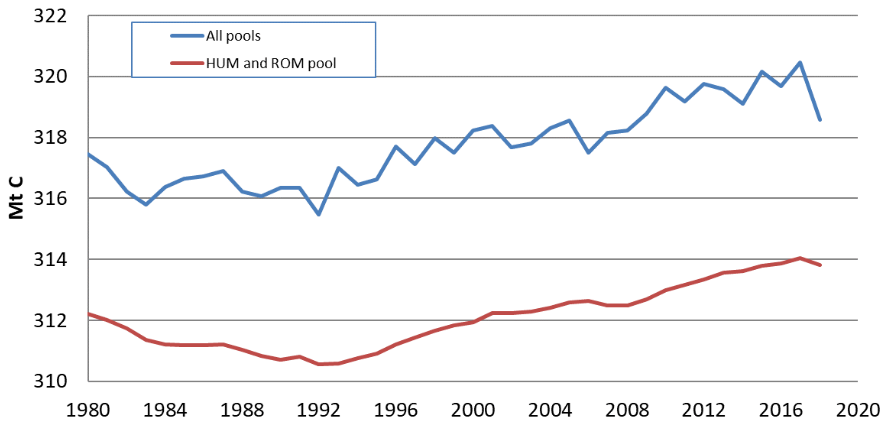


Figure 6.6 The development in the C-stock in agricultural soils, 1980-2018, Mt C (million tonnes C).

As a whole, the modelled emissions are found to be the most reliable emission estimates reflecting the Danish conditions. As described in the agricultural sector, the Danish farmers have faced increased demands for lower environmental impact since the mid-1980s. The general effect on the carbon stock in soil is that during the 1980s shows a decrease in the carbon stock, while during the 1990s, the carbon stock seemed to stabilise due to the higher input of organic matter. Due to the increased global warming, a steady carbon stock was modelled between 2000 and 2010, while the total SOC increase after 2010. Since 1990, C-TOOL has estimated an increase of 0.98 % of the total SOC in the mineral agricultural soils (average 1988-1992 to average 2013-2018). No precise uncertainty calculation has been made. However, it is assumed that the uncertainty of the annual loss/gain is around 25 %. Denmark has very good data on harvest yields and cultivated area data, which indicate a low uncertainty.

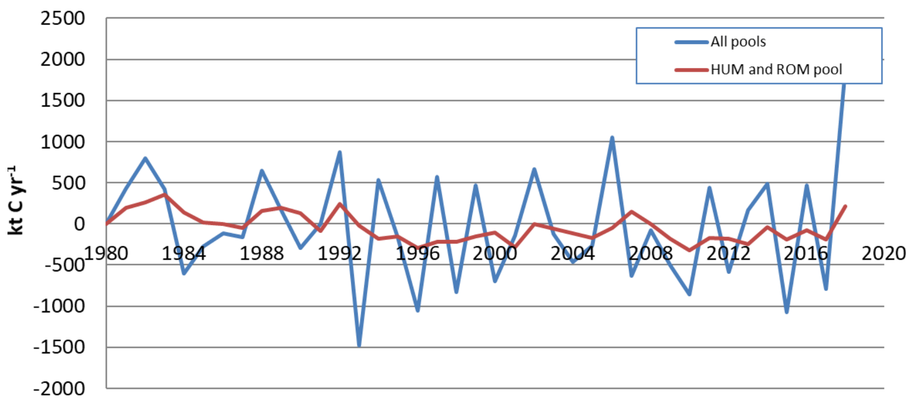


Figure 6.7 Estimated annual emissions from mineral soils 1981 to 2018 (kilo tonnes $CO_2$ $yr^{-1}$).

### Verification of C-TOOL

C-TOOL is partly parameterised with data from the Danish Agricultural soil sampling grid. The grid was established in 1987 in a 7 x 7 $km^2$ grid. In 1987, > 600 agricultural plots were sampled and analysed for carbon. Half of the grid were resampled in 1998 and a full resampling of 464 plots was made in 2008/2009. Figure 6.8 shows the development of the carbon stock in 0-100 cm depth in the paired plots, which indicate an increase for the soil C stock at the sandy soils (Coarse Sand, Fine Sand and Loamy Sand). This is mainly due to increase of the crop yields, which increase the amount of organic matter returned to soil. Furthermore, the Danish cattle herd is located on the sandy soils and typically have large areas with grass in rotation. This favours the soil

C stock. Contrary to this, a loss in the C stock on the loamy soils (Sandy Loam and Loam) is observed. On the loamy soils, annual crops are the most common cultivars and usually have a limited number of cattle and pigs. The measurements uncertainty is high, so overall it is concluded that the modelled results are in line what is found in plot sampling.

As C-TOOL is partly parameterised with the development in the soil sampling grid, the model output will mimic the measured development in the soil carbon stock in mineral soils. The variation in measured carbon stock in paired soil samples in the soil sampling grid is high. The conclusion is that the modelled outcome from C-TOOL represents a proper value for the development of the carbon stock in the Danish agricultural soils. A new sampling in grid is planned in 2018/2019. This will further verify the development.

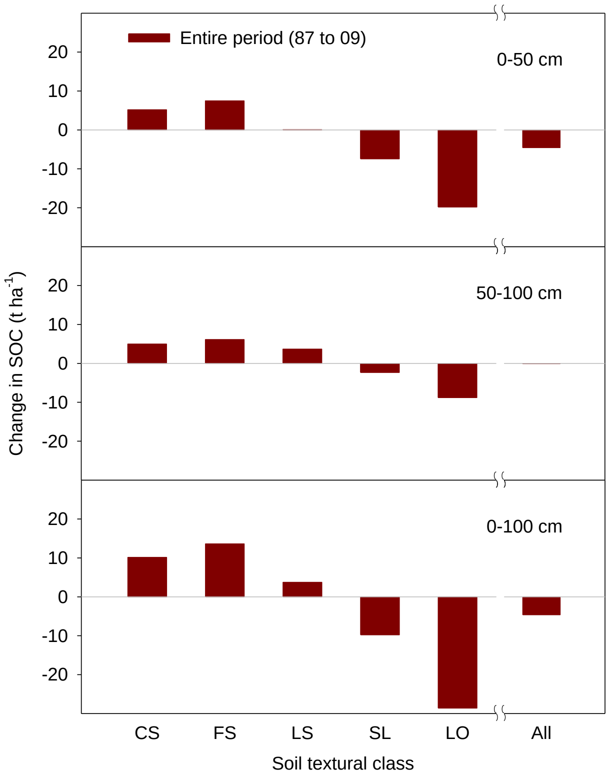


Figure 6.8 The change in carbon stock in soil (0 - 100 cm) in >460 paired agricultural plots from 1987 to 2009 (Taghizadeh-Toosi et al. 2014 a).

**Organic soils - 4B1**

The basic Danish soil classification system from 1975 (Arealklassifikationen, 1975) has a definition for organic soils as having >=10 % organic matter (OM) in the topsoil, equivalent to 6 % OC. In 2010, a new soil map of the organic soils was made for the inventory based on the definition in the IPCC guidelines (Greve et al. 2014), i.e. 20 % OM (Figure 6.9). The soil map is a statistical map based on >10 000 soil samples down to the mineral soil in 30 cm intervals combined with a very detailed digital elevation map (DEM) for each 1.6 x 1.6 $m^2$ covering the entire Denmark, water table maps and other old maps with organic soils. The definition of an organic soil in the map is 20 % organic matter with a depth of minimum 30 cm (Greve et al. 2014). The total area with organic soils in the area covered by the soil map has been estimated to 298 000 ha. In 2010, 177 135 ha of the organic area was included in the farmers Land Parcel Information System.

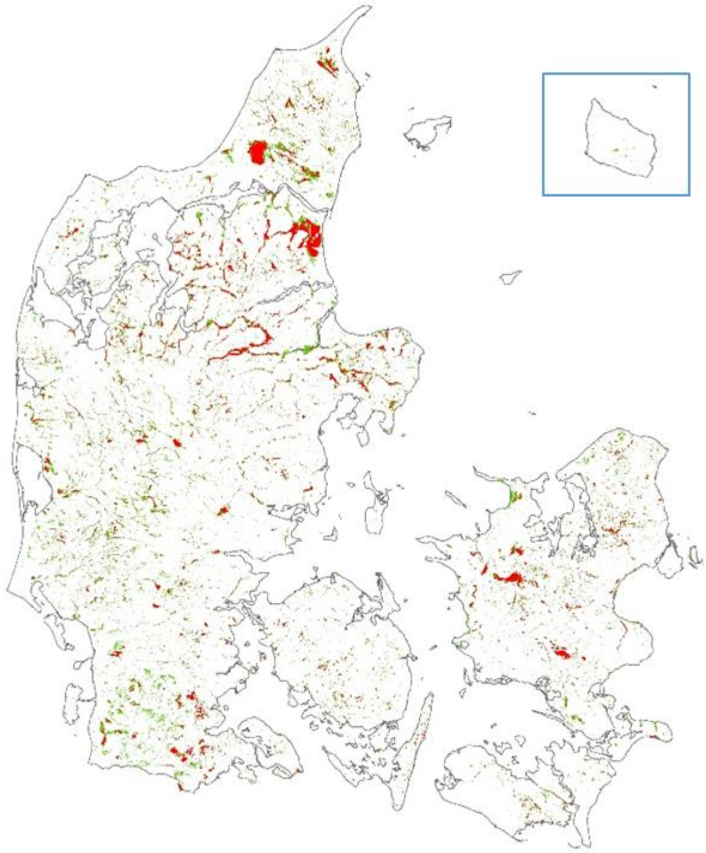

Figure 6.9 The organic soil map for Denmark for year 2010, > 6 % OC (Greve et al. 2014). Green colour indicate 6-12 % OC and red colour indicate >12 % OC soils.

To estimate the actual land use of organic soils a digital map field map has been placed on top of the organic soil map. The digital field map include all agricultural fields in Denmark (>619 000 fields). This map from the EU subsidiary system is precisely mapped with an uncertainty down to < ± 0.5 meter. The actual grown crop is known for each field. In total, more than 270 different crop types or combination of crop and crop management are recorded. In 2018, 117 362 hectares with annual crops and 51 335 with perennial grass were located to be grown on the organic soil area in the defined CL with >= 6 % OC. Every year we can see that some areas are falling out of the field map. Areas where the farmers are not applying for subsidies. Some of these are found in the map for Wetlands (4.D), but not all of them. In 2018, 10 040 hectares could not be recognized. Further drainage of the organic soils in Denmark has not been allowed for many years. The most likely situation is that these areas have become wet and not suitable for cropping purposes. These areas has been assigned an emission of 3.6 tonnes C per ha as for shallow-drained nutrient-rich grassland from the 2013 Wetland Supplement (IPCC 2014).

The previous Danish soil classification carried out in 1975, estimated that there were 243 000 hectares of organic soils in agricultural land (>= 6 % C). Of these were 176 124 ha in the Cropland and the remaining 66 875 ha were with grass. In 2010 we only could find 177 135 ha. The major reason for the drastic reduction is that Denmark is quite flat with shallow organic layers, which combined with intensive agricultural utilisation with high drainage rates has oxidized a major part of the organic matter.

### Emission factors for organic soils

An intensive research programme has been carried out to monitor the $CO_2$ emission from three organic soils in Denmark with annual crops in rotation and permanent fertilized grassland (Elsgaard et al. 2012). The overall result is shown in Table 6.16 compared with the IPCC default values. For areas not reported in the land field system, default Tier 1 emission factors from the 2013 Wetland Supplement (IPCC 2014) are used. Maljanen et al. (2010) recently reviewed the GHG balance of managed organic peatlands in the Nordic countries. For areas with agricultural grasslands, the available studies suggested a net $CO_2$ emission of 4.9 ± 3.2 t C $m^{-2}$ $yr^{-1}$ (mean +/- standard deviation, n = 4). The available studies (n = 4) represented three Finnish and one Norwegian site (Lohila et al. 2004; Maljanen et al. 2001, 2004; Grønlund et al. 2008). The up-scaled annual emission from the Danish declining carbon stock is in line with these figures when taking into account the differences in temperatures. Considering that the IPCC estimate also covers the boreal zone, the measured Danish values seems to be in line with the IPCC guidelines. Emissions from organic soils on permanent grassland are reported under Grassland (CRF Table 4.C.1). The emission factors are given in Table 6.16.

The dominating use of the organic soils is fertilised annual crops and grass in rotation. As C-TOOL has shown not to be able to simulate the emissions from soils having >6 % OC, fixed emission factors have been used for this area. No data has been found in the literature as it does not qualify as organic in the scientific world and hence little attention has been paid to these soils. Normally, mineral soils in equilibrium will have an organic matter of 1-1.5 % OC. Soils having higher contents are most likely developed under humid conditions with low degradation rates. Drained and managed soils having >= 6-12 % OC can therefore not be seen as being in their equilibrium state and will evidently lose carbon. It has therefore been decided to allocate an emission of 50 % of what was measured for soils > 12 % OC in an attempt to account for these losses. These emissions are included in 4B and 4C.

Table 6.16 Emission factors from organic soils, tonnes C per ha per year.

| | Cropland Annual crops and grass in rotation | Grassland Permanent grass | | Abandoned land | |
|---|---|---|---|---|---|
| | | C, tonne $yr^{-1}$ | $CH_4$, kg $yr^{-1}$ | C, tonne $yr^{-1}$ | $CH_4$, kg $yr^{-1}$ |
| Soils > 12 % OC | 11.5 (SE = ±2.0) | 8.4 (SE = ±1.0) | 16 | 3.5 | 39 |
| Soils 6-12 % OC | 5.75 | 4.2 | 8 | 1.75 | 19,5 |
| IPCC 2014, Boreal and Temperate | 7.9 (CI = 6.5-9.4) | 3.8-6.1 (CI = 5.0-7.3) | 16 | Grassland shallow drained 3.6 (CI = 1.8-5.4) | 39 |

As emission factor for $N_2O$ from the 2013 Wetland Supplement, the default value of 13 kg $N_2O$-N per ha per year is used for the area with > 12 % OC. This emission is reported in the agricultural sector, 3Da6 (cultivation of organic soils). No $CH_4$ emission is reported from drained CL except for $CH_4$ from ditches, with default values from the 2013 Wetland Supplement (IPCC, 2014); although for the shallow-drained abandoned organic soils a $CH_4$ emission factor of 39 kg $CH_4$ $ha^{-1}$ $yr^{-1}$ for soils with >12 % OC and 19.5 $CH_4$ $ha^{-1}$ $yr^{-1}$ for soils with 6-12 % OC are reported.

To estimate the emission from the organic soils, a linear decrease in the area with organic soils between 1975 and 2010 has been assumed. All $CO_2$ emissions from organic soils converted from other land use categories to cropland are reported under 4.B.1 and not under the respective land use conversion classes 4.B.2.1 to 4.B.2.5. The related

The total $CO_2$ emissions from the organic soils in cropland are given in Table 6.17.

Table 6.17 Emissions from cropland organic soils 1990 to 2018.

| | 1990 | 2000 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Cropland, 6-12 % OC, ha | 89632 | 84071 | 78510 | 77394 | 77305 | 77125 | 77061 | 77029 | 77009 |
| Cropland, >= 12 % OC, ha | 67025 | 59237 | 51449 | 50673 | 50536 | 50466 | 50408 | 50394 | 50394 |
| Cropland, total, ha | 156657 | 143308 | 129959 | 128067 | 127840 | 127591 | 127469 | 127422 | 127403 |
| Emission, from drained land, kt C | 1283.0 | 1161.4 | 1039.9 | 997.3 | 991.6 | 1006.1 | 989.7 | 972.8 | 961.4 |
| Emission from leached C, kt C | 34.6 | 31.3 | 28.0 | 27.7 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 |
| $CH_4$, kt $CH_4$ | 6.5 | 5.9 | 5.3 | 5.4 | 5.4 | 5.3 | 5.3 | 5.4 | 5.5 |
| Emission, total, kt $CO_2$ | 4993.5 | 4520.5 | 4047.4 | 3892.1 | 3871.0 | 3922.0 | 3863.6 | 3803.7 | 3763.0 |

### 6.3.8 Uncertainties and time series consistency

A Tier 1 uncertainty analysis has been made for part of the LULUCF sector cf. Table 6.18. The uncertainty in the activity data for the agricultural sector is very low. The highest uncertainty is associated with the emission factors. Especially the emission/sink from mineral soils and organic soils has a high influence on the overall uncertainty.

The LULUCF sector contributes to a large extend to the total estimated uncertainty. In recognition of the difficulties in analyses of uncertainty, the estimated uptake of $CO_2$ in the forestry sector must be treated with caution.

Table 6.18 Tier 1 uncertainty analysis for Cropland for 2018.

| | | 1990 | 2018 | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Emission/ sink, kt $CO_2$ eqv. | Emission/ sink, kt $CO_2$ eqv. | Activity data, % | Emission factor, % | Combined uncertainty | Total, uncertainty, % | Uncertainty, 95 %, kt $CO_2$ eqv. |
| **4.B Cropland** | | 5343.2 | 4586.0 | | | | 41.7 | 1911.9 |
| 4.B.1 Cropland remaining cropland, Living biomass | $CO_2$ | -19.7 | 48.3 | 3 | 15 | 15.2 | 15.2 | 7.3 |
| 4.B.1 Cropland remaining cropland, Mineral soils | $CO_2$ | 460.9 | 795.6 | 3 | 75 | 75.0 | 75.0 | 597.1 |
| 4.B.1 Cropland remaining cropland, Organic soils | $CO_2$ | 4704.2 | 3525.0 | 3 | 50 | 50.1 | 50.1 | 1766.3 |
| 4.B.2 Forest land converted to cropland | $CO_2$ | 2.3 | 74.5 | 10 | 50 | 51.0 | 51.0 | 38.0 |
| 4.B.2 Other land uses converted to cropland | $CO_2$ | -1.6 | -28.0 | 10 | 50 | 51.0 | 51.0 | 14.3 |
| 4(II) Cropland on organic soils | $CO_2$ | 34.6 | 27.6 | 3 | 40 | 40.1 | 40.1 | 11.1 |
| 4(III) Mineralization/immobilization, Cropland | $N_2O$ | 0.1 | 2.0 | 10 | 50 | 51.0 | 51.0 | 1.0 |
| 4(II) Cropland on organic soils | $CH_4$ | 162 | 141.0 | 10 | 90 | 90.6 | 1797.3 | 0.2 |

The time series are complete.

### 6.3.9 QA/QC and verification

A general QA/QC plan is developed for Cropland. The following Points of Measures (PM) are taken into account.

- Collection and error check on in-data.
- Control of sums.
- Comparison with other data.

The area estimates for Cropland and Grassland since 2010 are very precise due to unrestricted access to detailed data from EUs Integrated Administration and Control System (IACS) on agricultural crops on field level and the use of the vector based Land Parcel Information System (LPIS). This access includes both Statistics Denmark and DCE. The total uncertainty in the major crop data is estimated by Statistics Denmark to be <2 %. Together with detailed soil maps, this gives a unique possibility to estimate the agricultural crops on different soil types and hence track changes in land use. However, IACS and LPIS are only available from 1998 and onwards, and estimates for 1990 are therefore more uncertain. The QA of crop data is made by Statistics Denmark.

Data on newly planted and removed hedgerows are based on subsidised hedgerows and QA is carried out by the Danish Agricultural Agency, who is responsible for the administration of the subsidy scheme. The uncertainty in the number of plants used for the hedgerows is not estimated but is assumed very low because of the subsidy system.

There is an unknown uncertainty in the number of un-registered removals of hedgerows. A linear approach has therefore been made for "missing" hedges over the years. Establishment of wetlands is based on vector maps received from every county in Denmark. The uncertainty is not estimated but assumed very low due to the subsidised system.

As shown in Figure 6.7 and 6.8, the increase in carbon stock as estimated by C-TOOL seems close to the results from 464 paired soil samples.

A range of experts from the Faculty of Agricultural Sciences, Aarhus University, are repeatedly involved in discussions and report writings on topics related to the inventory.

### 6.3.10 Recalculations, including changes made in response to the review process

A major has been made for area estimate of the organic soils. Due to a misinterpretation of the first developed organic soil map in 2014 the area especially 6-12 % OC organic soils was underestimated. In the previous submission was reported a total of 112 505 ha was reported in 2017. The new figure for 2017 is 169 440 ha. This misinterpretation affects more or less all emissions as it affect the area with mineral soils, $N_2O$ emissions and $CH_4$ emissions.

Furthermore, a consistent 30 yrs default transition time has been implemented for all sectors and for the whole time series.

This has increased the overall emission from cropland in 2017 from 2335 kt $CO_2$ eqv to 3138 kt $CO_2$ eqv or an increase of 34 %.

All changes have been implemented for all years.

### 6.3.11 Planned improvements

During the review in 2018, the ERT recommended Denmark to provide more specific references/documentation substantiating the justification for insignificant change and the disproportionate effort of estimating soil emissions from pre-1990 conversions. As a first step has a default transition time of 30 years been applied for all sectors. A full land use matrix from 1954 and onwards is developed. This will be implemented in the next submission after further validation.

The emission factors for organic soils will be investigated further in the coming years.

### 6.3.12 Land converted to cropland (4B2)

Agriculture covers more than 63 % of the total area giving a large impact on the environment. As a consequence, there are many initiatives to transfer agricultural land into natural habitats and forest, and the continuous development of infrastructure demands more land. Land converted to cropland is therefore not an issue. The largest challenge is that the farmers in one year may report that a certain field is cropland and the next year is permanent grassland where it could stay for several years before it again is ploughed and turned into annual cropland for one year. Despite or rather because of the detailed information, which is available, is it impossible to have a conservative land use transition between these two land use categories. To avoid large conversion ratios between cropland and grassland, a rule has been set up, where cropland and grassland (in the farmers reporting system) has been in the same category for five years before land use conversion in the LUM takes place. In the previous set-up, where annual land use change was included, there could be up to 40 000 ha changes annual. With the new set up, the annual change is between 2000-6000 ha. However, as the carbon stock changes in mineral soils are estimated with C-TOOL combined for cropland and grassland, the effect of this has no impact on the overall emission estimate from agricultural soils.

#### Approaches used for representing land

The area converted from other land use to Cropland is based on remote sensing of the Danish area in 1990, 2005, 2011, 2012-2018 combined with data in LPIS on which crops are grown in each field.

#### Methodological issues

#### Change in carbon stock in living biomass

For land converted to cropland, a standard default gain value of 9577 kg DM (dry matter) per hectare in above ground biomass and 2298 kg DM per hectare in below ground biomass is used. This value is equivalent to the average harvest of living biomass for all cereals grown in Denmark from 2000 to 2010, including straw, stubble and glumes. For conversion from DM to carbon, a default fraction of 0.5 kg C per kg DM is used (Table 6.8).

For conversion from cropland to other land use categories, the same value is used but recorded as a loss of carbon in the respective category (4A2, 4C2, 4D2 and 4E2).

The loss in living biomass for conversion from another land use category into CL is estimated as the default value for DM in that particular land use category. I.e. for deforested areas, the average carbon stock per hectare for all deforested areas is used.

#### Change in carbon stock in dead organic matter

When forest is converted to cropland, it is assumed that all dead organic matter will have an instant oxidation. The actual amount depends on which type of forest is converted. Due to current harvest practises (chipping), no significant amount of dead organic matter is left on site. Based on the NFI measurements of O-horizon thickness, default bulk density values and a C:N ratio of 22 (Vejre et al. 2003) an average emission factor of 5.1 kg $N_2O$-N per ha is used.

Conversion from other categories is assumed as not occurring, as no dead organic matter is reported for these categories.

#### Change in carbon stock in soils

The actual amount depends on which type of land it is converted from (see Table 6.8). To reach the new equilibrium state, a default transition period of 30 years is used. The default IPCC-value of 20 years seems according to Danish investigations, not to be applicable for Danish conditions.

$N_2O$ emissions for forest land converted to cropland is based on the Tier 2 methodology with the default C stock of 142 t C/ha as given in Table 6.8 and using a C:N value of 22 (Callesen et al. 2007) and an emission factor of 0.01 kg $N_2O$-N kg $N^{-1}$ released.

#### Uncertainties and time series consistency

The time series are complete.

See uncertainties and time series consistency in Section 6.3.1.

#### QA/QC and verification

See QA/QC and verification in Section 6.3.1.

#### Recalculation

See recalculation in Section 6.3.1.

#### Planned improvements

See planned improvements in Section 6.3.1.

## 6.4 Grassland (4C)

Grassland is defined as the remaining land category after subtracting the areas of settlements, forest, cropland, wetlands and other land from the total land area. As cropland includes all perennial wooden areas such as hedges, shelterbelts, fruit plantations and other wooden areas that do not qualify as forest, no perennial wooden crops is reported in grassland. Thus, grassland consist of heath- scrubland and marginal agricultural grazed land.

The total area reported under grassland has increased, cf. Table 6.18. The $CO_2$ emission from mineral soils is reported under cropland except where land use changes has taken place. The increase in the emission from living and dead biomass is mainly due to the land use conversion to and from cropland and should as such not be seen as loss of living biomass. The emission from organic soils has decreased due to a smaller area with grassland on organic soils.

Table 6.18 Total area and annual emissions 1990 to 2018 from Grassland.

| Grassland | 1990 | 2000 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Area, 1000 ha | 146.4 | 140.5 | 141.9 | 142.6 | 159.1 | 170.1 | 173.4 | 176.6 | 175.0 |
| Living and dead biomass, kt C | 4.5 | 1.3 | 18.4 | 14.7 | 69.4 | 46.3 | 48.2 | 20.0 | 43.8 |
| Mineral soils, kt C | 0.0 | -0.2 | -0.6 | -0.7 | -0.7 | -0.7 | -0.8 | -0.8 | -0.7 |
| Organic soils, kt C | 391.4 | 351.7 | 311.9 | 316.6 | 308.2 | 294.6 | 308.2 | 327.0 | 335.9 |
| Total, kt C | 395.9 | 352.7 | 329.7 | 330.6 | 376.8 | 340.1 | 355.6 | 346.3 | 378.9 |
| $CH_4$, kt $CH_4$ | 3.4 | 3.1 | 2.7 | 2.8 | 2.7 | 2.6 | 2.7 | 2.9 | 2.9 |
| $N_2O$, kt $N_2O$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total, kt $CO_2$ eqv. | 1537.4 | 1370.2 | 1277.3 | 1281.5 | 1449.9 | 1313.9 | 1371.9 | 1341.4 | 1463.5 |

### 6.4.1 Grassland remaining grassland (4C1)

Denmark is an intensive agricultural country with many small holders and small fields where cropland and grassland is mixed together making it difficult to distinguish between dedicated cropland and dedicated grassland. According to the Danish Land Parcel Information System (LPIS), there are approx. 191 000 fields of total 341 000 ha with permanent grassland in 2018 giving an average size of two ha. Some of them cannot be regarded as permanent grassland and are therefore included in cropland.

### 6.4.2 Grassland area

The total area with grassland has been estimated in the Land Use Matrix. In 1990, the total area was 146 407 hectares and in 2018 the area had increased to 175 029. This is quite a small area, but here it should be taken into account the uncertainty to accurately report the area with grassland and cropland. According to Statistics Denmark, there are 235 000 ha of permanent GL, cf. Table 6.12. This means that part of what is reported by Statistics Denmark here, are reported under CL. As C-stock changes in the mineral soils are modelled as a whole with C-TOOL the allocation between cropland and grassland has no effect on the emission estimates.

### 6.4.3 Grassland definition

Grassland is split into grazing grassland and other grassland. Grazing grassland is the area with permanent grassland as recorded by Statistics Denmark. Other grassland is the difference between the grassland area in the land use matrix and the area reported by Statistics Denmark.

### 6.4.4 Methodological issues for grassland

The area for grazing grassland is the area reported by statistics Denmark and the rest of the grassland is the residual part of the grassland area. The area with organic soils in grassland is estimated from the new organic soil map with an overlay of the fields were the farmers are reporting agricultural crops. Permanent grass fields receiving $<25$ kg N per ha per year is reported under grassland. If the farmers are reporting permanent grassland but are using $>25$ kg N per ha per year, it is assumed that this field is grass in rotation because of the fertilization level.

### 6.4.5 Change in carbon stock in living biomass

No changes in living biomass are assumed for grassland remaining grassland, except for a minor conversion between "Grazing land" and "Other grassland". However, the sector grassland remaining grassland is showing a loss in carbon stock due to a high inter-annual land use conversion. This has some effect on the inventory, but limited as a whole, as the estimated loss can be found under the land use category, to which grassland is converted.

### 6.4.6 Change in carbon stock in dead organic matter

No changes in dead organic matter are estimated, as this is not occurring for this category.

### 6.4.7 Change in carbon stock in soils

No changes in the carbon stock in GL mineral soils is reported for grassland, which can be seen as purely uncultivated grassland. For grassland, which is part of the agricultural area, the emission is included under cropland and therefore reported as 'Included Elsewhere' (IE) under grassland. For organic soils, a nationally developed emission factor of 8 400 kg C per ha per year is used for soils with at least 12 % OC (Elsgaard et al. 2012). For organic soils having 6-12 % OC is used an emission of 4200 kg C per ha per year. As the reported area with organic soils has decreased over time, the overall emission from grassland has gone down too, including $CH_4$. Since 2010, there has been a marginalisation of cropland to grassland increasing the reported area with grass, increasing the emission of $CO_2$ and $CH_4$ from grassland over the latest years, Table 6.20.

Table 6.20 $CO_2$ emissions from drained Grassland organic soils 1990 to 2018.

| | 1990 | 2000 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Grassland, 6-12 % OC, ha | 25072 | 23507 | 21941 | 22312 | 21898 | 21073 | 21872 | 22975 | 23493 |
| Grassland, >= 12 % OC, ha | 33600 | 29695 | 25791 | 26158 | 25375 | 24188 | 25392 | 27058 | 27838 |
| Grassland, total, ha | 58671 | 53202 | 47733 | 48471 | 47273 | 45260 | 47264 | 50033 | 51331 |
| Emission, drained land, kt C | 387.5 | 348.2 | 308.8 | 313.4 | 305.1 | 291.7 | 305.2 | 323.8 | 332.5 |
| Emission from leached C, kt C | 14.3 | 12.8 | 11.4 | 11.6 | 11.3 | 10.8 | 11.3 | 11.9 | 12.3 |
| $CH_4$, kt $CH_4$ | 3.4 | 3.1 | 2.7 | 2.8 | 2.7 | 2.6 | 2.7 | 2.9 | 2.9 |
| Emission, total, kt CO2 | 1559.1 | 1400.7 | 1242.3 | 1261.0 | 1227.5 | 1173.4 | 1227.6 | 1302.6 | 1337.7 |

In agriculture, CRF Table 3D, $N_2O$ emissions from both Cropland and Grassland are reported.

### 6.4.8 Uncertainties and time series consistency

Uncertainty estimates are given in Table 6.21.

Table 6.21 Tier 1 uncertainty analysis for Grassland for 2018.

| | | 1990 | 2018 | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Emission/ sink, kt $CO_2$ eqv. | Emission/ sink, kt $CO_2$ eqv. | Activity data, % | Emission factor, % | Combined uncertainty | Total, uncertainty, % | Uncertainty, 95 %, kt $CO_2$ eqv. |
| **4.C Grassland** | | 1537.4 | 1463.5 | | | | 42.0 | 613.9 |
| 4.C.1 Grassland remaining grass-land, Living biomass | $CO_2$ | 14.3 | 99.2 | 3 | 7 | 7.4 | 7.4 | 7.4 |
| 4.C.1 Grassland remaining grass-land, Organic soils | $CO_2$ | 1420.9 | 1206.4 | 3 | 50 | 50.1 | 50.1 | 604.5 |
| 4.C.2 Forest land converted to grassland | | 1.4 | 47.3 | 10 | 50 | 51.0 | 51.0 | 24.1 |
| 4.C.2 Other land uses converted to grassland | $CO_2$ | 0.9 | 24.0 | 10 | 50 | 51.0 | 51.0 | 12.2 |
| 4(II) Grassland on organic soils | $CO_2$ | 14.3 | 12.3 | 3 | 40 | 40.1 | 40.1 | 4.9 |
| 4(II) Grassland on organic soils | $CH_4$ | 85.6 | 73.5 | 10 | 90 | 90.6 | 90.6 | 66.5 |
| 4(V) Biomass Burning | $CH_4$ | 0.002 | 0.024 | 10 | 30 | 31.6 | 31.6 | 0.008 |
| 4(V) Biomass burning | $N_2O$ | 0.002 | 0.026 | 10 | 30 | 31.6 | 31.6 | 0.008 |
| 4(III) Mineralization/immobilization, Grassland | $N_2O$ | 0.005 | 0.771 | 10 | 90 | 90.6 | 90.6 | 0.699 |

The time series are complete.

### 6.4.9 QA/QC and verification

See QA/QC and verification in Section 6.3.

### 6.4.10 Recalculations

A major recalculation has been made for $CO_2$ and $CH_4$ due to the error in the area with organic soils and a correction of the area with mineral soils. This has increased the overall emission from grassland in 2017 from 761 kt $CO_2$ eqv to 1341 kt $CO_2$ eqv in 2017 or an increase of 75 %.

A 30 years transistion time has been implemented for all sectors and for the whole timeseries.

### 6.4.11 Planned improvements

In the coming years we will look further on the emission factors from organic soils used in grassland.

### 6.4.12 Land converted to grassland (4C2)

As agriculture covers more than 63 % of the land area, and in order to reduce the environmental impact, there is a strategy for turning cropland into grassland or forest; and where deforestation takes place, it is often turned into grassland, settlements or wetland.

#### Approaches used for representing land

The area converted from other land uses to grassland is based on use of Land Parcel Information data, Natura 2000 vector layers, other vector maps and remote sensing of the Danish area in 1990, 2005, 2011 combined with field maps from 2011-2018. Areas used for gravel digging are normally converted to grassland because the normal procedure is removal of the topsoil, and then gravel digging. After having finished the gravel digging the topsoil is reversed to the land and the area turned into marginal grassland/recreational area. To avoid too many land conversions, gravel digging areas are converted directly from cropland to grassland instead of cropland to settlement to grassland. As an example with an open gravel pit and a restored area, please see: Hedeland resort.

### Methodological issues

***Change in carbon stock in living biomass***

For land converted to "grazing land", a standard default gain value of 2 400 kg DM (dry matter) per hectare in above-ground biomass (IPCC 2006, Table 6.4) and 6 720 kg DM per hectare in below-ground biomass (IPCC 2006, Table 6.1) is used. For "Other grassland" not purely free of wooden trees/bushes, it is assumed that there is a living biomass of 2 200 kg DM per ha in above ground biomass and 6 160 kg DM per ha in below ground biomass (R:S-factor of 2.8, 2006 IPCC Guideline). For conversion from DM to C, a default fraction of 0.5 kg C per kg DM is used (Table 6.8).

For conversion from grassland to other land use categories, the same values are used, but recorded as a loss of carbon in the respective category (4A2, 4B2, 4D2 and 4E2).

### Change in carbon stock in dead organic matter

When forest is converted to grassland, it is assumed that all dead organic matter will be cleared and instant oxidation will take place.

Emissions associated with dead organic matter from conversion from other categories is assumed as NO.

### Change in carbon stock in soils

The actual amount depends on which type of land it is converted from (see Table 6.8). To reach the new equilibrium state, a linear approach is used (IPCC 2006). The IPCC default transition period is 20 years. According to Danish investigations, the default IPCC-value of 20 years seems to be not applicable for Danish conditions and 30 years has been used.

### Uncertainties and time series consistency

See uncertainties and time series consistency in Section 6.4.1.

## 6.5 Wetlands (4D)

In Denmark, wetlands include the following subcategories:

- unmanaged fully water covered wetlands (lakes and rivers)
- unmanaged partly water covered wetlands (fens and bogs)
- managed drained land for peat extraction
- managed partly water covered wetlands (re-established wetlands on primarily former cropland and grassland)
- managed fully water covered (new lakes)

### 6.1.1 Wetlands remaining wetlands (4D1)

In the beginning of 1990, the total area with wetland was estimated to be 103 267 hectares. By the end of 2018, this area has increased to 118 483. Of this, 53 091 ha were lakes and rivers in 1990 - increasing to 57 264 ha by the end of 2018 inside the > 7000 km long coastline, Table 6.22.

Table 6.22 Total area and annual emissions 1990 to 2018 from Wetlands.

| Wetlands | 1990 | 2000 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Lakes, 1000 ha | 53.1 | 54.4 | 56.0 | 57.2 | 57.2 | 57.2 | 57.2 | 57.2 | 57.2 |
| Partly water covered, 1000 ha | 48.6 | 51.8 | 56.9 | 59.6 | 60.2 | 60.3 | 60.4 | 60.5 | 60.5 |
| Peat extraction area, 1000 ha | 1.6 | 1.6 | 1.6 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Wetlands, total, 1000 ha | 103.3 | 107.8 | 114.6 | 117.7 | 118.2 | 118.4 | 118.4 | 118.5 | 118.5 |
| Managed Wetlands, Living and dead biomass, kt C | -0.3 | -0.3 | 6.5 | -0.7 | -0.7 | -0.3 | -0.5 | -0.2 | 0.0 |
| Soil organic matter, Peat extraction, kt C | 27.1 | 18.5 | 14.3 | 11.0 | 13.2 | 11.1 | 11.5 | 8.3 | 14.3 |
| Total, kt C | 26.8 | 18.2 | 20.7 | 10.3 | 12.5 | 10.8 | 11.0 | 8.1 | 14.3 |
| $CH_4$, kt $CH_4$ | 0.140 | 1.009 | 1.956 | 2.217 | 2.256 | 2.282 | 2.292 | 2.292 | 2.292 |
| $N_2O$, kt $N_2O$ | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Total, kt $CO_2$ eqv. | 102.0 | 92.1 | 125.2 | 93.3 | 102.3 | 96.9 | 97.8 | 87.3 | 110.0 |

The land use matrix provides updated figures on the area with partly water covered and fully water covered wetland areas. Partly water covered areas are moors and other areas with raised water table. Fully water covered areas are lakes and rivers.

### 6.5.1 Wetland area

In the beginning of 1990, the total area with partly covered wetlands remaining wetlands was estimated to be 49 856 hectares. By the end of 2018, the area with partly water covered wetlands remaining wetlands had increased to 61 219 hectares. The total area with peat extraction is about 300 hectares open surface (Larsen, 2014). Based on aerial photos, it is assumed that 800 hectares are affected by drainage in 2018.

### 6.5.2 Approaches used for representing land areas

The area for wetlands remaining wetlands is primarily based on data from the Danish Geodata Agency and Natura 2000 maps (moors and other natural habitats). The area with peat excavation is a vector map layer made by DCE based on aerial photos of the three excavation sites. The actual three locations are Fuglsø mose on Djursland, Lille Vildmose and Store Vildmose – both in Northern Jutland. All locations are nutrient poor raised bogs.

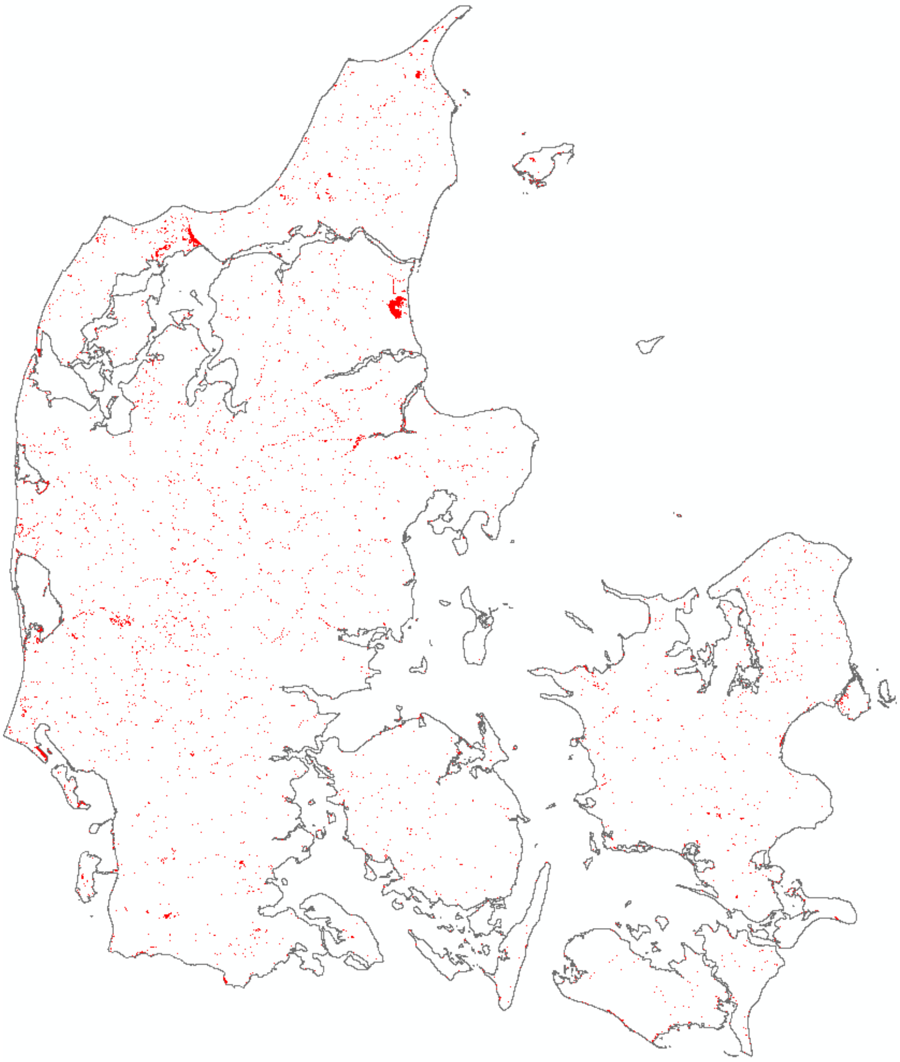

Figure 6.10 Areas with established wetlands and increased water tables in 2018.

### 6.5.3 Methodological issues for peat extraction areas

Approximately 300 hectares are utilized for peat extraction. It is assumed that 800 hectares are drained and affected by the excavation. The amount of excavated peat is decreasing. In 2017, 107 000 $m^3$ were excavated; a reduction of 30 % since 2016, but due to the very dry summer in 2018 an increased harvest was reported to 213 000 $m^3$.

### 6.5.4 Change in carbon stock in living biomass

No changes in living biomass are occurring.

### 6.5.5 Change in carbon stock in dead organic matter

Dead organic matter is not occurring.

### 6.5.6 Change in carbon stock in soils

The surface emission from the open peat extraction area is calculated according to Tier 1 from the 2013 Wetlands Supplement (IPCC 2014).

The amount of excavated peat ($m^3$ per year) is for each individual extraction site reported to and published by Statistics Denmark (www.dst.dk, Table RST). The total amount of peat excavated has been reduced from 399 000 $m^3$

in 1990 to 213 000 m[3] in 2013. This is a 50 % reduction. For conversion to carbon, a density factor of 200 kg per m[3] is used (Larsen, 2014) who is responsible for the majority of the extraction sites. Furthermore, a DM content of 0.5, an ash content of 0.02 and a carbon content of 0.58 kg C per kg OM are applied.

For other areas in wetlands remaining wetlands, no changes are reported.

### 6.5.7 $CH_4$ and $N_2O$ emissions

The $CH_4$ and $N_2O$ emissions from peat land extraction areas are based on the 2013 Wetland Supplement (IPCC 2014).

### 6.5.8 Recalculation

No recalculation has been made.

**Category-specific planned improvements**

No improvements are planned.

### 6.5.9 Methodological issues for flooded land

No emissions are estimated from flooded land.

### 6.5.10 Methodological issues for partly water covered wetlands

No changes in the carbon stocks and emissions are reported from unmanaged partly water covered wetlands. Only emissions from wetlands established from 1990 and onwards are reported, see Chapter 6.5.2.

### 6.5.11 Uncertainties and time series consistency

Table 6.23 shows the emission estimates and estimated uncertainties for Wetlands.

Table 6.23 Tier 1 uncertainty analysis for WE remaining WEs and re-established WE for 2018.

| | | 1990 | 2018 | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Emission/ sink, Gg $CO_2$ eqv. | Emission/ sink, Gg $CO_2$ eqv. | Activity data, % | Emission factor, % | Combined uncertainty | Total, uncertainty, % | Uncertainty, 95 %, Gg $CO_2$ eqv. |
| **4.D Wetlands** | | 102.0 | 110.0 | | | | 59.0 | 64.9 |
| 4.D.1.1 Peat extraction remaining peat extraction | $CO_2$ | 99.5 | 52.6 | 10 | 75 | 75.7 | 75.7 | 39.8 |
| 4.D.1.2 Flooded land remaining flooded land | $CO_2$ | NO | 0.0 | 10 | 75 | 75.7 | 0.0 | 0.0 |
| 4.D.2. Land converted to wetlands | $CO_2$ | -1.3 | 0.0 | 10 | 75 | 75.7 | 0.0 | 0.0 |
| 4(II) Land converted to wetlands | $CH_4$ | 2.2 | 56.6 | 10 | 90 | 90.6 | 90.6 | 51.3 |
| 4(II) Peatland | $CH_4$ | 1.3 | 0.7 | 10 | 90 | 90.6 | 90.6 | 0.6 |
| 4(II) Peat extraction remaining peat extraction | $N_2O$ | 0.2 | 0.1 | 10 | 90 | 90.6 | 90.6 | 0.1 |

The time series are complete.

### 6.5.12 QA/QC and verification

The peat excavation area has been verified with aerial photos and the amount of excavated peat is made by Statistics Denmark.

### 6.5.13 Land converted to wetland (4D2)

In order to restore nature and reduce the environmental impact, Denmark has actively re-established wetlands (Figure 6.10). The size of each restoration project range from less than 1 ha and up to 2500 ha. The benefit of the restoration programme is more nature but also a reduction in leaching of nitrogen into lakes, rivers and coastal water. The establishment of wetlands takes place either as large areas turned into lakes or low laying fens.

Since 1990, 15 227 ha have been established. These are primarily established on cropland and grassland. Of this, 4306 hectares are converted into new lakes. A major part is restored as a part of the Danish Action Plan for the Aquatic Environment part two (VMP II, running from 1997 to 2006) where land was bought for this purpose; an additional 927 hectares of forest has been converted to wetlands. This has primarily taken place in the state owned forests. The establishment often takes place in connection to existing wetlands.

Water reservoirs for human purposes have not been established for the past 100 years, and hence are not occurring.

#### Methodological issues

Geographical vector layers are available for almost all established wetlands.

#### Change in carbon stock in living biomass

For land converted to partly covered wetland, a standard default gain value of 3600 kg DM (dry matter) per hectare in above-ground biomass and 1200 kg DM per hectare in below-ground biomass is used. For conversion from DM to carbon, a default fraction of 0.5 kg C per kg DM is used (IPCC 2014).

For conversion from wetland to other land use categories, the same values - recorded as a loss of carbon in the respective category (4A2, 4B2, 4C2 and 4E2) - are used.

#### Change in carbon stock in dead organic matter

When forest is converted to wetland, it is assumed that all dead organic matter will be cleared with instant oxidation.

Dead organic matter associated with conversion from other land use categories is assumed as not applicable.

#### Change in carbon stock in soils

No carbon sequestration or carbon loss is assumed for land converted to partly covered wetlands or fully water covered wetlands (lakes).

#### $CH_4$ and $N_2O$ emissions

According to the 2013 Wetlands Supplement, the $N_2O$ emission is negligible from restored wetlands (Chapter 3). Therefore, no $N_2O$ emission has been estimated for land converted to wetlands.

According to the 2013 Wetlands Supplement, the $CH_4$ emission is 216 kg $CH_4$-C per ha for temperate areas, equivalent to 288 kg $CH_4$ per ha from restored rich wetlands (Chapter 3, Table 3.3). This has been included in the inventory. The area with organic soils reported under wetlands is the converted area multiplied with 16.5 % for the years 2010 to 2015. This is based on our detailed maps from 2010-2015 with a GIS overlay of the organic soil map from 2010. This showed that only 16.5 % of the area was located on soils having >= 12 % OC. In 2016, the share of soils having >= 12 % OC on the established wetlands dropped to 9.0% and in 2017 8.3%. No data on new wetlands could be verified as established in 2018.

The $CH_4$ from established wetlands is estimated as the sum of organic land (>= 12 % OC) converted from other land uses to wetlands since 1990 multiplied with the default emission factor of 288 kg $CH_4$ $ha^{-1}$. The slightly deviation in the reported IEF in CRF table 4(II) is due to rounding errors.

#### Uncertainties and time series consistency

The time series are complete. For uncertainty, see 6.5.1

#### QA/QC and verification

No verification has been made yet.

#### Recalculation

No recalculations has been made.

#### Planned improvements

An evaluation of actual water level on wetlands before and after conversion from cropland and grassland to wetland will be conducted in 2020 to 2022.

## 6.6 Settlements (4E)

The annual changes in carbon stock in settlements remaining settlements is assumed to be negligible, and because no estimates have been made, most changes are reported as NA in the CRF Table 4.E. For reporting purposes for land use conversions, a default biomass in low buildings and graveyards is established.

The total settlements area has been estimated to 486 614 hectares by the end of 1989 increasing to 529 571 hectares by the end of 2018 or to 12.3 % of the total Danish area (Table 6.24). The reported emission is hence the emission from land use changes to SE.

Table 6.24 Total area and annual emissions 1990 to 2018 from Settlement.

| Settlements | 1990 | 2000 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Settlement remaining Settlement, 1000 ha | 486.6 | 486.6 | 487.5 | 490.0 | 490.9 | 491.8 | 492.6 | 493.5 | 494.3 |
| New Settlements since 1990, 1000 ha | 0.9 | 9.4 | 23.2 | 29.7 | 29.2 | 29.8 | 33.4 | 34.6 | 35.2 |
| Settlement, total, 1000 ha | 487.5 | 496.0 | 510.7 | 519.7 | 520.1 | 521.6 | 526.0 | 528.1 | 529.6 |
| Living and dead biomass, kt C | 4.3 | 4.4 | 10.1 | 13.7 | 2.4 | 7.3 | 25.4 | 7.9 | 11.4 |
| Soil, kt C | 0.7 | 8.1 | 20.6 | 28.5 | 28.8 | 30.1 | 34.3 | 36.0 | 37.6 |
| Total, kt C | 5.1 | 12.5 | 30.6 | 42.1 | 31.2 | 37.4 | 59.6 | 43.9 | 49.0 |
| $N_2O$, kt $N_2O$ | 0.001 | 0.010 | 0.026 | 0.037 | 0.037 | 0.039 | 0.044 | 0.046 | 0.048 |
| Total, kt $CO_2$ eqv. | 18.8 | 48.8 | 120.2 | 165.4 | 125.3 | 148.5 | 231.6 | 174.6 | 194.0 |

### 6.1.2 Settlements remaining settlements (4E1)

#### Settlement area

No changes in the area with settlements remaining settlements are taking place. The area is estimated from the cadastral maps and the date where the land parcel was included in the cadastral map, e.g. a change from agriculture to a permanent residence or a road.

#### Settlement definition

Settlements are defined as all areas with infrastructure, e.g. roads, graveyards, sport facilities etc.

### 6.6.1 Methodological issues

### 6.6.2 Change in carbon stock in living biomass

No changes in carbon stocks are reported for settlements remaining settlements.

### 6.6.3 Change in carbon stock in dead organic matter

No changes in carbon stocks are reported for settlements remaining settlements.

### 6.6.4 Change in carbon stock in soils

No changes in carbon stock in soils are assumed.

### 6.6.5 Uncertainties and time series consistency

Uncertainty estimates and emissions for land converted to settlements are shown in Table 6.25.

Table 6.25 Tier 1 uncertainty analysis for Settlements for 2018.

| | | 1990 | 2018 | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Emission/ sink, Gg $CO_2$ eqv. | Emission/ sink, Gg $CO_2$ eqv. | Activity data, % | Emission factor, % | Combined uncertainty | Total, uncertainty, % | Uncertainty, 95 %, Gg $CO_2$ eqv. |
| **4.E Settlements** | | 18.8 | 204.3 | | | | 56.4 | 115.2 |
| 4.E.2 Forest land converted to settlements | $CO_2$ | 4.8 | 45.8 | 10 | 75 | 75.7 | 75.7 | 34.7 |
| 4.E.2 Other land uses converted to settlements | $CO_2$ | 13.8 | 144.2 | 10 | 75 | 75.7 | 75.7 | 109.1 |
| 4(III) Mineralization/immobilization, Land converted to Settlements | $N_2O$ | 0.3 | 14.3 | 10.0 | 90.0 | 90.6 | 90.6 | 12.9 |

The time series are complete.

### 6.6.6 QA/QC and verification

Changes in SE area are based on legal registers and thus very reliable.

### 6.6.7 Recalculations

A recalculation for land converted to settlement has been made, because the land use transition time has been changed to 30 years for all land use changes. This has increased the emission estimates for both $CO_2$ and $N_2O$ as the equilibrium state is reached within a shorter time than in the previous submission.

### 6.6.8 Planned improvements

No improvements are planned.

### 6.6.9 Land converted to settlement (4E2)

Land conversions to settlements is mostly taking place around the big cities and primarily on cropland and grassland.

**Settlement area**

The area converted to settlements is based on cadastral maps and other digital maps. For simplicity, and for the years 1990 to 2011, only three occasions are used (1990, 2005 and 2011) with a linear increase in the area in the years between. Annual recorded changes in cadastral maps are used to estimate the annual changes from 2011 and onwards. Regarding the increase from 2012 to 2013, all new houses and roads are included in the cadastral map from 31.12.2012 to 31.12.2013. In 2018, it is estimated that 1494 hectares has been converted, mainly from cropland. There is a variation in the area conversion between years. There are two major factors. The first is the building activity and the second is the updating frequency of the cadastral maps made by The Ministry of Climate, Energy and Utilities.

#### Methodological issues

#### Change in carbon stock in living biomass

For land converted to settlement, a standard default gain value of 2200 kg DM (dry matter) per hectare in above ground biomass and 2200 kg DM per hectare in below ground biomass is used. For conversion from DM to carbon, a default fraction of 0.5 kg carbon per kg DM is used (IPCC 2014).

For conversion from settlements to other land use categories, the same value is used, but recorded as a loss of carbon in the respective category (4A2, 4B2, 4C2 and 4D2).

#### Change in carbon stock in dead organic matter

When forest is converted to settlements, it is assumed that all dead organic matter will be cleared. Conversion from other categories is assumed as not applicable.

The dead organic matter and the litter layer is assumed to oxidise instantly. The N content in the organic matter is converted to an $N_2O$ emission with a default EF of 0.01 (IPCC 2014)

#### Change in carbon stock in soils

A default value of 96.7 tonnes carbon per ha is assumed for Settlements (Table 6.7) or 80 % of the carbon stock in mineral agricultural soils. For all areas converted from other land use to settlements, it is assumed that equilibrium state will be reached after 30 years from the carbon stock in the previous land use category. The 30 years period is chosen because of the relatively cold climate in Denmark with an average annual temperature of 8°C. The degradation rates of soil organic carbon according to C-TOOL shows that 99 % of the SOM has half-lives with > 40 years and that the IPCC 2006 GL assumes that 20 % of the SOC can be lost (IPCC 2006, Chapter 8.3.3.2).

#### Uncertainties and time series consistency

See uncertainties and time series consistency in Section 6.6.1

The time series are complete.

#### QA/QC and verification

Changes in SE area are based on legal registers and thus very reliable.

#### Category-specific recalculations

A recalculation for land converted to settlement has been made due that the land use transition time has been changed to 30 years for all land use changes. This has increased the emission estimates for both $CO_2$ and $N_2O$ as the equilibrium state is reached within a shorter time than in the previous submission planned improvements.

## 6.7 Other Land (4F)

No permanent snow cover exists in Denmark and only a very small insignificant area with rocks and cliffs. Other land is restricted to beaches and sand dunes and estimated to 26 433 hectares.

No land use changes from 4A, 4B, 4C, 4D and 4E is reported.

## 6.8 Direct $N_2O$ emissions from N fertilization of Forest Land and Other Land use

Only a very small amount of nitrogen fertilisers is used in the Danish forests and only to Christmas trees. All emissions are reported under Agriculture CRF Table 3. Ds1 since there is only one common national statistics for N fertilization in agriculture and forestry.

## 6.9 Emissions and removals from drainage and rewetting and other management of organic and mineral soils

$CO_2$ emissions are reported in Table 4A-F. $N_2O$ emissions from CL and GL are reported under agriculture, CRF Table 3D. The $N_2O$ emissions reported here is primarily from forest soils. $CH_4$ emissions from organic soils converted to other land uses are reported here. So far, no $CH_4$, emission from organic forest land remaining forest land has been estimated.

A large proportion of the Danish forest area may be considered as drained in the sense that the natural hydrology has been modified by establishment of ditches. Large forest areas have been drained in order to enable establishment of Norway spruce in depressions, fens and pond areas. As an example, a major state forest, Gribskov in Northern Zealand, by 1850 had an estimated wetland area 400 % larger than that of 1988 (Gribskov). During recent years, there has been an effort to restore wetland habitats in the state forests and several drained areas have been restored by filling up ditches; and in many areas of the state forests ditches are no longer maintained and will be gradually more and more ineffective over time. This is a direct consequence of the strategic plan for the state forests to convert to more Close to Nature Forest Management with a specific aim to restore natural hydrology in as many places as possible.

### 6.9.1 Methodological issues

Very few data exist for $N_2O$ emissions in Danish forests. A Tier 1 emission factor of 2.8 kg $N_2O$-N per ha drained forest soil from the 2013 Wetland Supplement is included (IPCC 2014 - Table 2.5).

Rewetted forest soils were assumed to have an $N_2O$ emission corresponding to the natural level and emissions were therefore by default set to zero.

$CH_4$ emission from organic forest soils is based on the emission factors in Table 6.10, a default area of ditches of 2.5 %, and the areas described in Section 6.9.2. No methane emissions were calculated for Inland mineral wet soils, as it has not been able to assess the area of such soils.

### 6.9.2 Areas of drained forest soils

Based on expert judgment, the area of drained forest soils were 65 % of mineral forest soils and 75 % of organic forest soils in 1990. It is further estimated that the amount of drained forest soils have decreased in the period until 2008 resulting in an area of drained forest soils with 55 % of mineral forest soils and 50 % of organic forest soils (see Table 6.9, Section 6.2.15 this report). Organic soils constituted 5 % of the forest area based on information on presence of peat from the NFI. The area of rewetted organic forest soils are remains under the forest land category, since the actual changes in water level are unknown. However, we assume that the $CO_2$ emissions have ceased and replaced by $CH_4$ emissions.

### 6.9.3 Emissions of $N_2O$ from drained forest soils

The total $N_2O$ emission from forest soils has been estimated to 0.094 kt $N_2O$ in 1990 and 0.080 kt $N_2O$ in 2018.

### 6.9.4 Emissions of $CH_4$ from rewetted cropland and grassland soils

The default $CH_4$ emission factor of 39 kg $CH_4$ $ha^{-1}$ $yr^{-1}$ for rewetted organic cropland and grassland soils from the 2013 Wetland Supplement has been applied for organic soils having >12 % OC. For soils having 6-12 % OC, 50 % of the value is used, i.e. 19.5 kg $CH_4$ $ha^{-1}$ $yr^{-1}$. The area is the LPIS area included in the 2010 LPIS where the farmers not has applied for subsidies in following years. It is assumed that these areas have become so wet that they are not used for farming anymore. In 2018, the area >6 % OC has been estimated to 10 040 ha.

### 6.9.5 Emissions of $CH_4$ from drained grassland soils

The default $CH_4$ emission factor of 16 kg $CH_4$ $ha^{-1}$ $yr^{-1}$ for drained organic grassland soils from the 2013 Wetland Supplement has been applied. The area is the drained grassland area with at least >12 % OC. For organic soils with 6-12 % OC is used an EF of 8 kg $CH_4$ $ha^{-1}$ $yr^{-1}$.

## 6.10 Direct nitrous oxide ($N_2O$) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter

The main land-use conversion involving deforestation is the conversion from forest to cropland and grassland and a minor deforestation to SE.

### 6.10.1 Methodological issues

According to IPCC (2006, Chapter 11.2.1.2, p. 11.11), a default fraction of 1 % is assumed emitted as $N_2O$-N during mineralization of the total N content following conversion.

For all deforestated areas, it is assumed, that the forest floor disappears regardless of the land use conversion is into CL, GL, WE or SE. The average nitrogen content of forest floors based on the repeated soil inventory (13 t C/ha) with a default C:N value of 22 was used to estimate the N mineralized. A proportion of 1 % of the N stock mineralized equalling 5.13 kg $N_2O$-N/ha is assumed to be emitted as $N_2O$-N (IPCC (2006, Chapter 11.2.1.2, p. 11.11)).

$N_2O$ emissions due to long-term changes in the carbon stock in mineral cropland soils are reported under Agriculture, CRF Table 3D.1.5. This is estimated by C-TOOL based on 20 subdivisions (counties and soil types). For each subdivision, the C:N ratio in the individual soil type is used, ranging from 10.53 to 15.89.

For estimation of the $N_2O$ emission from CL and GL to SE, the average carbon stock in the respective land use classes, combined with a C:N value of 12 for CL and 15 for GL, is used. A proportion of 1 % of the N stock mineralized is assumed to be emitted as $N_2O$-N.

For land use conversion from GL and WE to CL, the default methodology from the 2006 GL is used (IPCC 2006). The used average carbon stocks are given in Table 6.8. The default methodology assumes that an $N_2O$ emission only occur if there is a decrease in the carbon stock. The methodology will only estimate a $N_2O$ emission if the land subject to conversion has a higher carbon stock than the land use, which it is converted to. As the carbon stock in Danish GL soil has been estimated to have lower value than cropland soils, the default methodology will only estimate a low $N_2O$ emission for occasions where CL is converted to GL.

### 6.10.2 Emissions of $N_2O$ from deforestation and land-use conversion

In 2018, the total emission of $N_2O$ from all sources has been estimated to 0.138 kt $N_2O$. The far major part of this is an expected release of N in the soil organic matter when soil organic matter is degraded in the process where land is converted to a land use class having a lower default soil carbon stock like conversion to settlements.

## 6.11 Biomass burning

Burning of forest is prohibited as well as burning of wooden debris from hedgerows are very seldom. In 2014, there were forest fires on two hectares, and 724 hectares with controlled burning of heathland and five hectares with Mountain Pine (*Pinus mugo*). In 2015 and 2016, no forest fires were reported. Due to the humid climate, wildfires in the forest are very seldom and normally affect 0-10 hectares per year.

Data on wild and controlled fires has been collected by the Danish Nature Agency from the forest departments for the period 1990 to 2018. The emission factors are taken from the IPCC 2006 guidelines. As the burned forest is located on poor sandy soils, the default standing wood volume is assumed to be 150 Cubic meter per hectare, which is slightly lower than the average standing carbon stock in the Danish forests. The fraction burned for forest is taken from the guidelines whereas for heat land, a factor of 0.33 is used (based on expert judgment made by the Danish Nature Agency who is responsible for the controlled burning, Table 6.26).

Table 6.26 Burned areas 1990 –2018, ha per year.

| | 1990 | 2000 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Forest area burned, ha | 150.0 | 0 | 0 | 2.0 | 2.0 | 0 | 0 | 0 | 0 |
| Heathland area burned, ha | 47.0 | 121.6 | 359.0 | 729.0 | 705.0 | 714.0 | 796.0 | 192.6 | 569.5 |
| Total burned area, ha | 197.0 | 121.6 | 359.0 | 731.0 | 707.0 | 714.0 | 796.0 | 192.6 | 569.5 |
| Emission, $CH_4$, kt | 0.0261 | 0.0002 | 0.0006 | 0.0017 | 0.0017 | 0.0012 | 0.0013 | 0.0005 | 0.0010 |
| Emission, $N_2O$, kt | 0.0014 | 0.0000 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0000 | 0.0001 |
| Total, kt $CO_2$ eqv. | 1.0855 | 0.0106 | 0.0313 | 0.0847 | 0.0826 | 0.0622 | 0.0694 | 0.0235 | 0.0496 |

Uncertainty estimates are given in Table 6.27.

Table 6.27 Tier 1 uncertainty analysis for Biomass burning for 2018.

| | 1990 | 2018 | | | | | |
|---|---|---|---|---|---|---|---|
| | Emission/ sink, kt $CO_2$ eqv. | Emission/ sink, kt $CO_2$ eqv. | Activity data, % | Emission factor, % | Combined uncertainty | Total, un-certainty, % | Uncertainty, 95 %, kt $CO_2$ eqv. |
| 4(V) Biomass Burning | 1.1 | 0.0 | | | | 22.4 | 0.0 |
| 4(V) Biomass Burning $CH_4$ | 0.7 | 0.0 | 10 | 30 | 31.6 | 31.6 | 0.008 |
| 4(V) Biomass burning $N_2O$ | 0.4 | 0.0 | 10 | 30 | 31.6 | 31.6 | 0.008 |

## 6.12 Harvested Wood Products (HWP)

Carbon emissions from harvested wood products (HWP) have been reported since 2013. Denmark has chosen to report under Approach B, the production approach, which refers to equations 12.1, 12.3 and 12.A.6 of volume 4 of the 2006 IPCC Guidelines and the 2013 Supplementary GPG.

Carbon in the HWP pool is accounted for based on the semi-finished wood product categories: sawn wood, wood-based panels and paper, and paper products with default half-lives of 35, 25 and two years, respectively, stipulated by the 2013 Supplementary GPG. HWP originating from imported wood is excluded. HWP originating from deforestation activities (estimated directly as biomass in deforested areas able to produce HWP products – biomass from deforested areas with a canopy height above 10 m) is excluded from the calculations, as they are accounted as instantaneous oxidation.

For calculating carbon stocks in HWP, Denmark has applied the default first order decay (FOD) model stipulated by the IPCC, with the default half-lives (IPCC Tier 2 methodology). Activity data has been collected from international databases as well as from surveying the Danish wood industry. Carbon conversion factors have been derived from national forest inventory data (IPCC Tier 3 methodology).

The primary source for data on the HWP pool in Denmark is an annual questionnaire that now provides the basis for all Danish reporting to e.g. EUROSTAT and FAO, and serves as input to Statistics Denmark. Previously, there was no collection of data on the actual amounts and hence the previous reports were mainly based on data with less accuracy.

A comparison was performed for the year included in the questionnaire 2011-2013 and subsequently an extensive validation of activity data was carried out leading to corrections of historic data, especially regarding the production and export of sawnwood. The details and graphs can be found in Schou et al. (2015), where also an extensive validation of activity data, including comparison with the FAO data, was performed. The corrected data are available in the report.

According to a questionnaire on the production of the Danish wood industry, the production of sawnwood in 2018 was about 270 000 $m^3$, while the production of wood-based panels was about 428 000 $m^3$. The questionnaire covered an estimated >90 % of the revenue generated in the sawnwood sector and 100 % of the sector revenue for wood-based panels (there were only two relevant companies). A cross validation of the roundwood consumption showed an average deviation of 8 % for 2011-2013 between the questionnaire and the figures reported by Statistics Denmark based on harvest and trade statistics. As of 2018, the HWP pool originating from domestic harvest and domestic consumption consisted of about 5 million tonnes carbon (66 % from sawnwood and 34 % from wood-based panels – the paper pool was insignificant). This is equivalent to 13 % of the carbon stock in live forest biomass. The total inflow of carbon to the HWP pool in 2018 is reported to about 164 000 tonnes carbon – 64 000 tonnes from sawnwood and 100 000 tonnes from wood-based panels. The outflow from the pool is reported to about 138 000 tonnes carbon in 2018 – 38 000 tonnes from sawnwood and 100 000 tonnes carbon from wood-based panels. Thus, there has been a net carbon sequestration in HWP of about 49 000 tonnes carbon in 2018. See Table 6.28.

The estimate of the size of the total HWP stock is quite uncertain, as the empirical basis for the First Order Model (FOD) and the attached half-lives is weak. Conducting direct inventories of the carbon stock may be a method to reduce uncertainty. In the Danish case, estimates based on the FOD model for the total HWP pool, including imported wood and converted to finished wood products actually came quite close, when measured per capita, to estimates from Finland originating from a direct inventory. Regarding estimates for pool changes, uncertainty on half-life may be of less importance, as longer retention time in the pool may be traded off against higher emissions levels from the historic pool. This depends on the characteristics of the pool, i.e. the size of the pool vs. the recent inflow. Uncertainty on activity data relates to both uncertainty on measurements, e.g. caused by reporting errors, and statistical uncertainty, caused by variation in the sampled population.

Judging from the coverage and the validation results, surveying the production of semi-finished wood products in Denmark by questionnaire has been successful. It will be repeated in the following years as part of the future reporting of HWP.

Table 6.28 HWP in use from domestic harvest and exported HWP (CRF table 4.Gs1).

| HWP produced and consumed domestically (ΔC HWPdom IU DH) + exported | HWP in use from domestic harvest | | | | Net emissions/ removals from HWP in use |
|---|---|---|---|---|---|
| | Gains | Losses | Half-life | Annual Change in stock (ΔC HWP IU DH) | |
| | (t C) | | (yr) | (kt C) | (kt $CO_2$) |
| Total | 137802.1 | -137802.1 | | 48.8 | -178.9 |
| 1. Solid wood | 137802.1 | -137802.1 | | 48.8 | -179.0 |
| Sawnwood | 37988.2 | -37988.2 | 35 | -2.2 | 8.2 |
| Wood panels | 99813.9 | -99813.9 | 25 | 51.1 | -187.2 |
| 2. Paper and paperboard | NO | NO | 2 | 0.0 | 0.1 |

Uncertainty estimates are given in Table 6.29.

Table 6.29 Uncertainty in HWP in use from domestic harvest.

| | | 1990 | 2018 | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Emission/ sink, kt $CO_2$ eqv. | Emission/ sink, kt $CO_2$ eqv. | Activity data, % | Emission factor, % | Combined uncertainty | Total, uncertainty, % | Uncertainty, 95 %, kt $CO_2$ eqv. |
| 4.G Harvested wood products | | -2.4 | -162.1 | | | | 79.1 | 128.2 |
| 4.G Harvested wood products | $CO_2$ | -2.4 | -162.1 | 25 | 75 | 79.1 | 79.1 | 128.2 |

## 6.13 QA/QC plan

A first step of development and implementation of a general QA/QC plan for all sectors started in 2004 which is described in a publicised manual (Sørensen et al., 2005). The manual describes the concepts of quality work and how to handle quality management by using Critical Control Points and a list of Point of Measurements (Nielsen et al., 2013). For more detailed information of the structure in the general QA/QC plan, please refer to Chapter 1.6 for QA/QC.

A complete list Points of Measures (PM) are given in Table 1.2. PM related to the agricultural inventory is listed below in Chapter 5.13.3 and are primarily connected to data storage and data processing level 1. For PM not mentioned below please refer to Chapter 1.6.

The QA/QC work specific for the LULUCF sector is still improved. The overall framework regarding a QA/QC plan for LULUCF are constructed in form of six stages and each stage focus on quality assurance and quality check in different part of the inventory process.

### 6.13.1 QA/QC plan expressed in Critical Control Points and Point of Measurements

**Data storage level 1**

| | | | |
|---|---|---|---|
| Data Storage level 1 | 3. Completeness | DS.1.3.1 | Documentation showing that all possible national data sources are included by setting down the reasoning behind the selection of datasets. |

The following external data are in used in the LULUCF sector.

- Data from multiple public GIS-layers to develop the annual Land Use Matrix (Building register, cadastral maps, lakes, railroads, afforestation, subsidized hedges and small biotopes, wetland restoration maps etc.
- Data from the Danish National forest inventory carried out by Department of Geosciences and Natural Resource Management, Copenhagen University
- Data from the annual agricultural census made by Statistics Denmark
- Land parcel information from the The Danish Agricultural Agency including location of all agricultural fields
- Soil type maps – mineral and organic
- Input of organic matter to agricultural soils from manure is estimated in the agricultural sector.

Carbon stock changes are generally measured or modelled. The used emission factors comes primarily from IPCC Wetland supplement (IPCC 2014) and country specific measurements.

*Statistics Denmark*

The agricultural census made by Statistics Denmark is the main supply of basic agricultural data for crops. This include crop area and harvest yields and amount of excavated peat.

*Danish Agricultural Agency*

The Danish Agricultural Agency is responsible for handing all EU subsidiaries to the Danish farmers. All data needed for the inventory purpose is given freely to be used in the inventory. This include detailed field maps, all subsidized activities in the landscape including afforestation, areas with catch crops on farm level, location of all animals in Denmark, etc. These data are very precise.

The Danish Agricultural Agency, as the controlling authority, performs analysis of crop areas and their location. On average, 1600 to 2000 samples are analysed every year. Uncertainty in the data is seen as negligible.

*National Forest Inventory*

The Department of Geosciences and Natural Management (IGN), University of Copenhagen, who is responsible for the forest part of the inventory, carries out the NFI. IGN has been given unrestricted legal access to all NFI plots to monitor their current state of the forests.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 1. Accuracy | DS.1.1.1 | General level of uncertainty for every dataset including the reasoning for the specific values |

The most important emission source is related to the carbon stock in the forest, carbon stock changes in mineral agricultural soils and loss of carbon from the cultivated organic agricultural soils.

The uncertainty on the absolute C stock in the forest has been estimated to approximately 2 %. This in a very large C stock. However, because of the large stock the difference in the C stock between two consecutive measuring years can be very large, yielding a change in the emission around 80-100%. It is very difficult to reduce this uncertainty.

The same is also valid for the dynamic modelling of C stock in the mineral agricultural soils. The very large C stock of 100-120 ton C/ha may cause that small annual changes in input between years gives large changes in the estimated emissions between years. The input of agricultural debris to the model is estimate by Statistics Denmark. These data are well documented.

As the reported area with organic soils are almost constant combined with a fixed EF for the organic soils only little variation is seen between years. The largest uncertainty in relation to organic soils are the related to the country specific EF.

Regarding uncertainties for the remaining emission sources, see Chapter 6.

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| Data Storage level 1 | 1. Accuracy | DS.1.1.2 | Quantification of the uncertainty level of every single data value including the reasoning for the specific values. |

Please, refer to Chapter 6.

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| Data Storage level 1 | 1. Comparability | DS.1.2.1 | Comparability of the data values with similar data from other countries, which are comparable with Denmark, and evaluation of discrepancy. |

The estimated emission from the forest depends on growth rate (species, weather conditions) and harvest rate. It is assumed that the NFI with > 10000 sampling plots can cover this variability. The outcome cannot directly be compared to other countries. The general view is that the Danish forests is a sink like many other European forests.

Only a few countries are modelling the carbon stock changes in mineral agricultural soils. The Danish model estimates the agricultural soils to be in steady state or a slightly increase in the carbon stock. This because of an increasing biomass input to the soils due increased yield levels and more catch crops.

The area with organic soils differs between countries and is difficult to compare. Denmark has a large share of cultivated organic soils > 12 % OC. The Danish reporting include organic soils having 6-12% OC. These soils will also have large emissions, as the organic matter in these drained soils at a certain point in the future will approach the equilibrium state for cultivated organic soils of 1-1.5 % OC. As no other countries report emissions from 6-12 % OC soils a direct comparability is difficult. The Danish CS EF for soils >12 % OC is slightly higher than the IPCC default (IPCC 2014) but similar to the German CS EF used in the German 2020 submission to UNFCCC.

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| Data Storage level 1 | 4. Consistency | DS.1.4.1 | The origin of external data has to be preserved whenever possible without explicit arguments (referring to other PMs). |

External data received are stored in the original format in the quality management database system.

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| Data Storage level 1 | 6. Robustness | DS.1.6.1 | Explicit agreements between the external institution holding the data and DCE about the conditions of delivery. |

DCE has established formal data agreements with all institutes and organisations, which deliver data, to assure that the necessary data is available to prepare the inventory on time.

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| Data Storage level 1 | 6. Robustness | DS.1.6.2 | At least two employees must have a detailed insight into the gathering of every external data set. |

Please refer to Chapter 1.7.

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| Data Storage level 1 | 7. Transparency | DS.1.7.1 | Summary of each dataset including the reasoning for selecting the specific dataset. |

Please refer to DS 1.1.1.

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| Data Storage level 1 | 7. Transparency | DS.1.7.2 | The archiving of data sets needs to be easy accessible for any person in the emission inventory. |

Please refer to Chapter 1.7.

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| Data Storage level 1 | 7. Transparency | DS.1.7.3 | References for citation for any external data set have to be available for any single value in any dataset. |

A great deal of documentation already exists in the literature list, and is also achieved in the quality management database system.

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| Data Storage level 1 | 7. Transparency | DS.1.7.4 | Listing of external contacts for every dataset. |

Statistics Denmark:

Mrs. Mona Larsen (mla@dst.dk)

Mr. Karsten K. Larsen (kkl@dst.dk)

DCA (Aarhus University):

Mr. Mogens H. Greve (greve@agro.au.dk)

Danish Agricultural Agency:

Mrs. Signe Kynding Borgen Signe Kynding Borgen (SIKYBO@lbst.dk)

Mr. Sebastian Iuel Berg (SEBBER@lbst.dk)

**Data processing level 1**

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|---|---|---|---|
| Data Processing level 1 | 1. Accuracy | DP.1.1.1 | Uncertainty assessment for every data source as input to Data Storage level 2 in relation to type of variability. (Distribution as: normal, log normal or other type of variability). |

The Approach 1 methodology is used to calculate the uncertainties for the agricultural sector. The uncertainties are based on a combination of IPCC guidelines and expert judgement and measured uncertainty in the National Forest Inventory) and a normal distribution is assumed.

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| Data Processing level 1 | 1. Accuracy | DP.1.1.2 | Uncertainty assessment for every data source as input to Data Storage level 2 in relation to scale of variability (size of variation intervals). |

Please refer to DP 1.1.1.

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| Data Processing level 1 | 1. Accuracy | DP.1.1.3 | Evaluation of the methodological approach using international guidelines. |

Data sources and calculation methodology developments are continuously discussed in cooperation with specialists and researchers in different institutes and research sections. Consequently, both the data and methods are evaluated continually according to the latest knowledge and information.

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| Data Processing level 1 | 1. Accuracy | DP.1.1.4 | Verification of calculation results using guideline values |

The methodological approach is consistent with the IPCC 2006 Guidelines and the 2013 Wetland Supplement (IPCC 2014). See Chapter 6.

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| Data Processing level 1 | 2. Comparability | DP.1.2.1 | The inventory calculation has to follow the international guidelines suggested by UNFCCC and IPCC. |

The methodological approach is consistent with the IPCC 2006 Guidelines and the 2013 Wetland Supplement (IPCC 2014).

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| Data Processing level 1 | 3. Completeness | DP.1.3.1 | Assessment of the most important quantitative knowledge, which is lacking. |

The most important lacking information is the emission from the organic soils. Over time the organic soils becomes more wet due to lack of drainage. Hence the used EF should be reduced over time. There is no information on emissions from soils having 6-12 % OC. As times go, the organic matter disappears and the drained soils will reach a low equilibrium state. This should lead to reclassification of the area with organic soils from e.g. 6-12 % OC in the previous years and 0-6 % in the future. No information is available on this issue. There is on-going work to increase the accuracy of this emission source.

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| Data Processing level 1 | 3. Completeness | DP.1.3.2 | Assessment of the most important missing accessibility to critical data sources |

All known major sources are included in the inventory. In Denmark, only very few data are restricted. Accessibility is not a key issue; it is more lack of data.

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| Data Processing level 1 | 4. Consistency | DP.1.4.1 | In order to keep consistency at a high level, an explicit description of the activities needs to accompany any change in the calculation procedure |

The calculation procedure is consistent for all years.

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| Data Processing level 1 | 4. Consistency | DP.1.4.2 | Identification of parameters (e.g. activity data, constants) that are common to multiple source categories and confirmation that there is consistency in the values used for these parameters in the emission calculations |

Please refer to Chapter 1.7.

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| Data Processing level 1 | 5. Correctness | DP.1.5.1 | Show at least once, by independent calculation, the correctness of every data manipulation. |

During the development of the model, all persons involved in preparation of the agricultural section have made thorough checks.

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| Data Processing level 1 | 5. Correctness | DP.1.5.2 | Verification of calculation results using time series. |

Time series for activity data, emission factors and national emission are performed to check consistency in the methodology, to avoid errors, to identify and explain considerable year to year variations.

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| Data Processing level 1 | 5. Correctness | DP.1.5.3 | Verification of calculation results using other measures. |

None

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| Data Processing level 1 | 5. Correctness | DP.1.5.4 | Show one-to-one correctness between external data sources and the databases at Data Storage level 2 |

In the database key ids is used to identify the unique data. The data on DS level 1 is linked to the key id used in the database so a clear reference from DS level 1 to higher levels of both DP and DS is secured.

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| Data Processing level 1 | 6. Robustness | DP.1.6.1 | Any calculation must be anchored to two responsible persons that can replace each other in the technical issue of performing the calculations. |

Please refer to Chapter 1.7.

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| Data Processing level 1 | 7. Transparency | DP.1.7.1 | The calculation principle and equations used must be described. |

All calculation principles are described in the NIR.

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| Data Processing level 1 | 7. Transparency | DP.1.7.2 | The theoretical reasoning for all methods must be described. |

All theoretical reasoning is described in the NIR.

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| Data Processing level 1 | 7. Transparency | DP.1.7.3 | Explicit listing of assumptions behind methods. |

All theoretical reasoning is described in the NIR.

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| Data Processing level 1 | 7. Transparency | DP.1.7.4 | Clear reference to dataset at Data Storage level 1. |

Links between the different dataset are constructed.

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| Data Processing level 1 | 7. Transparency | DP.1.7.5 | A manual log to collect information about recalculations. |

Changes compared with the last emissions report are described in the NIR and the national emission changes is given in a table under the section, "Recalculation". The text describes whether the change is caused by changes in the dataset or changes in the methodology used. Furthermore, a log table is filled in when data are updated or adjusted continuously.

#### Data storage and processing level 2

For point of measurements not mentioned below, please refer to Chapter 1.7.

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| Data Storage level 2 | 5. Correctness | DS.2.5.1 | Documentation of a correct connection between all data types at level 2 to data at level 1. |

A manual checklist is under development for correct connection between all data types at level 1 and 2.

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| Data Processing level 2 | 5. Correctness | DS.2.5.2 | Check if a correct data import to level 2 has been made. |

A manual checklist is under development for correctness of data import to level 2.

## 6.14 Category-specific improvements

### 6.14.1 Response to the review process

The table below contains the recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory. The table details the status of implementation of the recommendations as well as references to where improvements have been implemented in this report.

Table 9.6 Main recommendations from the latest UNFCCC review.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| **2018 submission (Review report:)** | | | | |
| L.1 | 4. General (LULUCF) | Research the impact of the land-use conversions prior to 1990 on the estimated emissions and removals from soils from 1990 onwards and revise the reporting allocation and estimates, or, if Denmark considers that a disproportionate amount of effort would be required to estimate these impacts in terms of the likely level of emissions and removals (i.e. if they would be insignificant in terms of the overall level and trend in national emissions), provide justifications in the NIR for this.<br>Addressing. The NIR 2018 (section 6.1.4) includes a justification stating that the switching between cropland and grassland will have a limited effect on the overall emission estimates, as a gain one year in one category will be counteracted by a loss in the other category. However, the ERT considers that Denmark should provide more specific references/documentation substantiating the justification for insignificant change and the disproportionate effort of estimating soil emissions from pre-1990 conversions. | This will be included in the 2021 submission where a 30-year transition time will be implemented. A land use matrix has been developed and the first step has been taken for estimating C stock in forest. | Included in the NIR under planned improvements, Chapter 6.2. See also Annex 3E where the issue is discussed. |
| L.2 | 4. General (LULUCF) | Ensure consistent reporting of the area of organic soils between the NIR and CRF table 4 and improve QC procedures for consistent reporting of the areas of organic soils.<br>Not Resolved. Figures presented in table 6.16 (section 6.3.1.7) of the NIR 2018 indicate 85.64 kha organic soils for cropland, whereas those in CRF table 4.B indicate 112.76 kha. | There were an error in the area in Table 4.B which has been corrected. The error was only associated to the area estimate, not the emission. | See Chapter 6 and CRF. |
| L.7 | 4.A.1 Forest land remaining forest land | Provide additional information on the area and volume of clear cutting and the area subject to destructive disturbance, subject to the availability of data.<br>Addressing. In the NIR 2018 (table 9.6) Denmark has indicated that specific data on clear cutting area and volumes are not available because that requires forest mapping, which is not scheduled. However, the NFI-based data provide full documentation of the carbon dynamics. The Party further indicated in section 6.2 of the NIR that "the temporarily unstocked areas can be caused by e.g. clear cutting and wind throw and is generally required to be reforested within a 10-year period according to the Forest Act. It is part of standard forest management in Danish Forestry to perform clear cuttings".<br>However, the ERT noted that the Party does not specify what 'destructive disturbance' means and how it is considered in the stock change method, so that it is possible to assess whether the forest area between two reference years is consistently considered in line with the 2006 IPCC Guidelines. | The reply have been incorporated in the new NIR reporting.<br>The forest area constantly include areas that are temporarily unstocked, as this is included in the forest definition. This ensures consistency over time for the stock change method. | See Chapter 6.2. |

Table 9.6 Main recommendations from the latest UNFCCC review.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| KL.1 | Afforestation and reforestation – $CO_2$ | Implement the country-specific carbon sequestration rates for broadleaves and conifers for forest floor development in CRF table 4(KP-1)A.1.<br>Addressing. According to the explanation included in table 9.6 of the NIR, changes in the litter pool for afforestation and reforestation activities are measured/modelled in the permanent NFI plots and used in CRF table 4(KP-1)A.1. However, the values of 0.09 and 0.31 t C/ha/year for litter layer for broadleaves and conifers referred to as used in the estimates and the resulting IEF of 0.15 t C/ha for 2014 cannot be tracked back in the relevant chapter in the NIR and broadleaves and conifers are not separately reported in CRF table 4(KP-1)A.1. | The NIR was not updated to reflect the current methodology of directly measuring amount of forest floor and transferring this to carbon. This is not separated into forest types.<br>The NIR has been updated. | See Chapter 6.1. |
| KL.3 | Deforestation – $CO_2$ | Perform a QA assessment of the approach used to determine the 100-year transition period for deforested lands that were converted to settlements, using independent model verification based on country-specific data relevant to deforestation.<br>Addressing. An assessment of the rationale for a 100-year transition period is referred to in table 9.6 of the NIR and annex 3E, which mostly refers to the conversion from cropland to settlements but - as explained by the Party in the NIR – can be assimilated to all conversions, including deforestation affecting a relatively small area (940 ha from 1990 to 2017). However, no independent model verification based on country-specific data dedicated to deforestation was performed. The Party also indicated that this choice of transition period will be investigated further for the next submission. | There is some scientific evidence that increasing the carbon stock under Afforestation takes around 100 years to reach a new equilibrium state. When D is taking place it very likely takes shorter time and depends on the stability of the organic matter. Estimating C stock in SE is a challenge as you nowhere can find undisturbed soil cores. The Guidelines assume a default C stock in SE of 80% of the original C stock before conversion. The loss can therefore be attributed to the stability of the initial C stock. Such data can more or less only be found in agricultural long-term field trials like those in Rothamsted, Sweden and in Denmark. These data are normally using exponential functions to describe the changes with half-lives of the OM. To describe the loss we have to deal with curvilinear decay. For inventory purposes (and in the Guidelines) is used strict linear functions and 20 yr. Our problem is to find proper values of the fractions of different C pools in forest land in the literature and the different pools stability. That's why we are talking about using the half-lives used in agriculture in the forest sector too. We have some work to do, and hopefully it can be completed for the submission in 2020. | See Chapter 6.1.10 and 6.1.17. |
| | 4. General (LULUCF) | The ERT noted significant recalculations in the 2018 submission compared with the 2017 submission for the sector of up to 90.9 per cent. However, the references included in the NIR did not provide sufficient information on the reasoning or the numerical impact of the recalculations over the time series in the category specific sections of the report or in the section on recalculations (section 9.1.4), which indicates only minor changes in the estimates for cropland and grassland. The ERT noted that recalculations for total aggregate $CO_2$ equivalent emissions from grassland are within the range of 0.2–0.3 | | |

Table 9.6 Main recommendations from the latest UNFCCC review.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| | | per cent for the entire time series. The recalculations total aggregate $CO_2$ equivalent emissions for cropland, however, result in a reduction in emissions at the beginning of the period (up to -23.0 per cent in 2001) and an increase in the later years (e.g. by 4.4 per cent for 2014). The NIR contains no numerical information on the recalculations and no explanations on the impact of the recalculation on the trend.<br>The ERT recommends that the Party ensure that any recalculations in the sector are reported with a relevant explanation and justification in line with paragraph 44 of the UNFCCC Annex I inventory reporting guidelines. In addition, the ERT encourages the Party to include a discussion on the impact of the recalculation on the trend in emissions and removals at the category and sectoral level. | | |
| L.13 | 4.A Forest land – $CO_2$ | The ERT noted large inter-annual variations in removals/emissions figures throughout the forest land time series. In the NIR (section 6.2.1.6) the Party explained that when estimating the change in stocks rather than the stocks themselves (i.e. when using the stock change method using a one-year reporting interval), the uncertainty depends on both the uncertainty of the estimate for the first and second period and their covariance. Moreover, where the annual change is small and the pools are large, the relative uncertainty is expected to be very large. This means that the changes in carbon stocks between subsequent time points one year apart are not statistically significant. When changes are less than the standard error, an alternative option would be to change the period of change observed/reported to over one year. During the review, Denmark also pointed out that an analysis was performed with five-year change intervals, and the relative errors became much smaller and changes in carbon stocks were statistically significant. Therefore, the explanation for the variations in the reported values is the fact that they are based on direct measurements, reported with a shorter time interval than justified in the measurement accuracy. The Danish National Forest Inventory Report (2016) indicates that the NFI is a continuous, sample-based inventory, with partial replacement of sample plots based on a 2 x 2-km grid covering the Danish land surface and all the permanent and temporary field plots are measured in a five-year cycle. The ERT notes that the 2016 IPCC Guidelines indicate that "under tier 3, process-based estimation will have access to detailed forest inventory or monitoring system with data on growing stock and past and projected net annual increment and functions relating to growing | Denmark will definitely consider applying a long reporting interval of 5 years, to allow for consistency with NFI cycle intervals.<br>The stock change approach is maintained as method in the reporting, as this is directly related to observations in the field.<br>Considerations have been done as to whether a development of models for gains and losses would provide estimates of change with less uncertainty. However, such models will be highly dependent on the data available for the estimation and even though the changes from year to year may seem more stable, the uncertainty may be even higher, as it will not be directly related to observed data. | See Chapter 6.1.12. |

Table 9.6 Main recommendations from the latest UNFCCC review.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
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| | | stock or net annual increment directly to biomass and biomass growth" (section 4.2.1.2), but do not specify a time interval for the stock change method.<br>The ERT considers that the method used by Denmark to estimate emissions/removals from forest land is in line with the 2006 IPCC Guidelines. A possible underestimation of emissions or overestimation of removals from forest land that may affect the accounting under the Kyoto Protocol would therefore be linked with the uncertainties that are inherent in the method per se, rather than its implementation in the specific case. The ERT recommends that the Party make a simulated comparative analysis between the stock change method (at one-year and five-year reporting intervals) and the gain-loss method, including the associated uncertainty analysis, and report the results of this comparison in its next NIR. Based on the results of this analysis, the ERT encourages the Party to consider adopting a longer reporting interval for the stock change method in forest land (e.g. five years, i.e. the complete NFI cycle). | | |
| L.14 | 4.A Forest land – $CO_2$ | The ERT noted that according to the NIR (pp.416 and 422) the estimation of carbon stock changes in forest land is based on a combination of previous forest surveys (National Forest Census, 1990 and 2000) and the NFI from 2002 onwards. Owing to differences in methodologies, major inconsistencies in forest areas and other forest variables are observed between the two data sets. To ensure their consistency, the approach taken involved the integration of sampling, image processing and estimation. During the review, the Party confirmed that the estimates of all forest carbon pools are based on direct NFI measurements from 2002 and onwards (with no usage of yield tables), and since there are no data prior to 2002, there is no systematic way of harmonizing NFI data with the previous census data. The area and species distribution have been compared and reported in previous publications such as Nord-Larsen et al. (2008).<br>The ERT recommends that Denmark include in the NIR summary information regarding the harmonization of the two different types of forest data (NFI and National Forest Census), relevant for the stock change method in use. | In the reporting estimation of carbon pools in the period with the forest census (1990 – 2000) have been harmonized with the results of the NFI, both in terms of the area estimation (as described above in the paragraph on land use map-ping) and in terms of the carbon pools. The estimates of all forest carbon pools are based on direct NFI measurements from 2002 and onwards, with no usage of yield tables. As there are no field sampled data prior to 2002, there are no systematic way of harmonizing based on data with the previous census data. The area and species distribution have been compared and reported in previous publications, e.g. Nord-Larsen et al 2018.<br>A detailed description of the Danish NFI is presented in Nord-Larsen and Johannsen (2016). | Chapter 6.1.8. |
| L.15 | 4.A Forest land – $CO_2$ | The ERT noted in section 6.2.1.4 of the NIR (p.423) that for coniferous species an expansion factor model developed for Norway spruce (Skovsgaard et al., 2011) is applied whereas for deciduous species an expansion factor model developed for beech (Skovsgaard and Nord-Larsen, 2012) is used. During the review, the Party provided further information on the | For calculation of forest biomass and carbon pools, local individual tree volume and biomass functions are available for, beech, oak, ash, silver fir, Nor-way spruce, grand fir, Douglas fir, Sitka spruce and Japanese larch. This means that species-specific models are applied for 57 pct. of the area and 73 pct. of the total standing volume. Only for the remaining species | Chapter 6.1.10. |

Table 9.6 Main recommendations from the latest UNFCCC review.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| | | tree species composition of the Danish forest area and biomass expansion factor values used in the models. The Party also made a reference to the documentation of the estimation of biomass and carbon pools a (Nord-Larsen and Johannsen, 2016) and for areas and volume by species (Nord-Larsen et al., 2017). According to the provided materials, for the calculation of forest biomass and carbon pools, local individual tree volume and biomass functions are available for beech, oak, ash (broadleaves) and silver fir, Norway spruce, grand fir, Douglas fir, Sitka spruce and Japanese larch (conifers), representing 57 per cent of the area and 73 per cent of the total standing volume. For the remaining species, generic models for beech and Norway spruce have been applied. Although not tested systematically, these methodological assumptions are not expected by the Party to be biased in terms of biomass or carbon estimates.<br>The ERT accepts the explanations provided by the Party regarding the measures in place to avoid over- or underestimation in living biomass and recommends that Denmark include the information on methodology used to develop a biomass expansion factor for conifers and broadleaves species in forest land in the NIR. | are applied the generic models for beech (Skovsgaard and Nord-Larsen, 2012) and Norway spruce (Skovsgaard et al. 2011). It has not been tested systematically, but they are expected not to be biased in terms of biomass or carbon estimates.<br>The full documentation of the estimation and calculations of biomass and carbon pools are given in Nord-Larsen and Johannsen 2016). See Nord-Larsen et al 2017 for further info on areas and volume for the specific species. | |
| L.16 | 4.A Forest land – $CO_2$ | The ERT noted that according to section 6.2.1.4 of the NIR (p.423) the total growing stock, biomass or carbon stocks with a given characteristic are estimated as the sum of the stocks with the particular characteristic divided by the inventoried plot area, times the total forest area. However, the NIR does not provide information on the details of the characteristics of the forest stands considered. During the review, the Party provided documentation on the NFI calculations (Nord-Larsen and Johannsen, 2016), containing information regarding the NFI design.<br>The ERT recommends that Denmark include in the NIR synthesized information on the main parameters defining the characteristics used in the calculation of biomass and growing stocks. | To avoid replicates of information, the NIR include some information and detailed information is given in the National Forest Statistics published annually. (www.ign.ku.dk/) | See Chapter 6.1.10. |
| L.17 | 4.A.1 Forest land remaining forest land – $CH_4$ | The ERT noted that the Wetlands Supplement (p.2.25) provides a default EF of 2.0 kg $CH_4$/ha from drainage of nutrient-rich organic soils in boreal forests, while CRF table 4(II) of Denmark reports an IEF of 64.24 kg $CH_4$/ha. During the review, Denmark explained that the reported $CH_4$ emissions arise from multiple sources, whereby several tier 1 default EFs were used (depending on the site (e.g. rich vs. poor nutrient soils) and management type (e.g. drained vs rewetted)) with higher values compared with the default EF for drained organic soil. | The emission factors for methane were identified from the Wetland Supplement. We note that units vary between chapters in 2013 Wetlands Supplement (IPCC 2014). A default area of 2.5% ditches was assumed. Table numbers refer to the 2013 Wetland Supplement (IPCC 2014). The values used are given in the updated NIR.<br>In a Danish study of three forests in eastern Denmark on hydromorphic soils the reported methane emissions were -0.08 - 3.2 kg $CH_4$ ha-1 yr-1 (Christiansen et al., | See Chapter 6.1.19. |

Table 9.6 Main recommendations from the latest UNFCCC review.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| | | The ERT recommends that the Party include in the NIR information on the methodologies and factors used for the estimation of CH4 emissions from the drainage of different types of forest organic soils reported under drained organic soil/forest land in CRF table 4(II). | 2012a; Christiansen et al., 2012b). The default value for drained organic soils seems to be reasonable until national estimates are better founded by representative measurements. Since no water level measurements in ditches and rewetted soils are available, it is not possible to judge whether the 2013 Wetland Supplement (IPCC, 2014) default values for methane emissions apply to Danish conditions. | |
| L.18 | 4.A.2 Land converted to forest land – $CO_2$ | The ERT noted in section 6.2 of the NIR (p.420) that "the area with forest land has increased since 1990 due to an intensive afforestation programme. In the beginning of the 1990's, approximately 3,000 ha were afforested every year. In recent years approximately 1,900 ha are afforested per year." However, table 6.5 of the NIR shows relatively constant AD from 2013 onwards, at circa 637 kha. During the review, the Party explained that the average of 1,900 ha is based on the full period of 1990–2016, and the trend is declining. The Party also mentioned that updates for the estimation of land areas converted to forests are now done by use of the LPIS.<br>The ERT recommends that the Party improve the transparency of the NIR by explaining how land converted to forest land changed over the entire time series. | In 2018 a validation of the resulting methodology was performed and reported in Johannsen et al. (2018). Results indicate that generally, accuracies of land uses and land covers for the assessed years are reasonably high. However, detailed analyses show that assessed changes within afforestation and particularly deforestation are significantly overestimated. | See Chapter 6.1.6. |
| L.19 | 4.B Cropland – $CO_2$ | The ERT noted in section 6.3.1.5 of the NIR (p. 436) 2018 that some areas of Christmas tree plantations are included in cropland. At the same time, section 6.2.2.7 NIR (p. 433) indicates planned improvements regarding estimates from Christmas tree plantations included in forest land. Following up on the recommendation of ID#L.18 in the ARR 2016 (see ID#L.11 in table 3), the ERT asked the Party to specify: the areas of Christmas tree plantations included under forest land (4A) and cropland (4B) categories in the 2018 submission, respectively; and the approach/method used to avoid gaps/overlaps between the two. The Party responded that all Christmas trees are included under forest reporting and subject to the NFI. The ERT noted further that the NIR (p.436) states that the "analysis of the rotations showed that up to 80 per cent of Christmas trees was followed by an annual crop or grass. The major part of this crop growing could therefore not be seen as afforestation followed by deforestation", and asked for clarification. The Party acknowledged the existence of redundant text on Christmas trees on cropland from the previous NIR and recognized the need for correction in the next submission.<br>The ERT recommends that the Party correct the description of the representation of Christmas tree plantations and provide up-to-date information on their estimation and allocation in the NIR. | All references to Christmas trees as part of CL has been removed. | See Chapter 6.2. |

Table 9.6 Main recommendations from the latest UNFCCC review.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| L.20 | 4.B Cropland – $CO_2$ | The ERT noted that the NIR (p.438) states that C-TOOL, a 3-pooled dynamic model used for the estimate of soil carbon turnover, uses the approximate average half-lifetimes of 0.6–0.7 years, 50 years and 600–800 years, respectively, for the three different pools, FOM, HUM and ROM. However, the ERT noted that the values used are not referenced or justified in the NIR. During the review, Denmark provided specific references for these values and the technical documentation for C-TOOL, including a more detailed description of the methodology employed for the calculations.<br>The ERT recommends that the Party include in the NIR summary information on the half-lifetimes used in the estimation of the tree soil pools (FOM, HUM and ROM) by the C-TOOL model. | More information is given in section 6.2 Cropland. Furthermore, the technical report has been uploaded with link from the inventory homepage: http://envs.au.dk/videnudveksling/luft/emissioner/supporting-documentation/greenhouse-gases-nir/lulucf/ | See Chapter 6.2. |
| L.21 | 4.B Cropland – $CO_2$ | The ERT noted that as reported in the NIR (p. 441) the FOM pool reported under composed crop residues has a very fast turnover rate and low share (circa 1 per cent) in the agricultural soil. The reported changes in the cropland soil pool assume an instant turnover of the FOM pool, hence the model in place only consists of the other two pools, HUM and ROM. The ERT noted, however, that while HUM and ROM pools are relatively constant in the time series 1980–2016, the change in all pools (FOM, HUM and ROM) has relatively large inter-annual fluctuations according to figures 6.6 and 6.7 of the NIR (p. 442). During the review, Denmark explained the trends, stating that crop residues normally have an input of 3–4 t C/ha/year, but vary between years owing to actual harvest yields. In the model set-up, this is added to the soil in August/September after harvest. On the contrary, the carbon stock "deadline" for inventory purposes is 31 December, hence the fluctuations between years. If the reporting were by, for example, 31 July the FOM amount would have been levelled out as the undegraded FOM in the reporting year will degrade the following summer and level out the trend in the FOM pool.<br>The ERT recommends the Party to include in the NIR summary information explaining the inter-annual variation between the FOM, HUM and ROM soil pools. | More information has been included in the NIR. | See Chapter 6.2. |
| L.22 | 4.B Cropland – $CO_2$ | According to the NIR (p. 448) "for land converted to cropland a standard default gain value of 9,577 kg DM (dry matter)/ha in above ground biomass and 2,298 kg DM/ha in below ground biomass are used. This value is equivalent to the average harvest of living biomass for all cereals grown in Denmark from 2000 to 2010, including straw, stubble and glumes". The ERT noted that the choice of values is not supported by a specific reference from the NIR and asked for clarification. | More information has been included in the NIR. | See Chapter 6.2. |

Table 9.6 Main recommendations from the latest UNFCCC review.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
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| | | The Party responded that the default values of 9,577 kg DM/ha and 2,298 kg DM/ha are based on average cereal grain yield over 10 years combined with default factors for estimating straw, stubble and husks, which is higher than the IPCC default of 4.7/ 5 t C/ha. The Party also confirmed that the values have been used for all land-use changes for all years as a loss (where cropland has been converted to other land uses) and as a gain (when other land uses are converted to cropland).<br>The ERT recommends that Denmark include in the NIR specific information and references on the selection of the values on gains in living biomass used for land converted to cropland and cropland converted to other land. | | |
| L.23 | 4.C.2 Land converted to grassland – $CO_2$ | The NIR (p. 451) states that as there has been a fairly high conversion of cultivated organic soils to permanent grass, emissions from organic soils on grassland have increased over recent years. The ERT noted, however, that the total emissions in table 6.19 of the NIR showed a decreasing trend in emissions, as follows: 769.1 kt $CO_2$ eqv. in 2014; 743.1 kt $CO_2$ eqv. in 2015; and 673.5 kt $CO_2$ eqv. in 2016. The trend of decreasing emissions/increasing removals from land undergoing a change from more intensive (i.e. cultivated organic soils) to less intensive (i.e. permanent grassland) use is indeed closer to ERT expectations. During the review, the Party explained that the text in the NIR is left over from a previous submission and indicated the changed approach in handling conversion from cropland to grassland.<br>The ERT recommends that Denmark correct the text in the NIR on emissions from organic soils on grassland related to the trend in conversion of cultivated organic soils to permanent grassland. | The NIR has been corrected. | See Chapter 6.3. |
| L.24 | 4.D.2 Land converted to wetlands – $CH_4$ | According to the NIR (p. 456) since 1990, 17,001 ha of converted wetlands have been established, primarily on cropland and grassland. In accordance with the Wetlands Supplement the $CH_4$ emissions (216 kg $CH_4$-C per ha for temperate areas, equivalent to 288 kg $CH_4$ per ha from restored rich wetlands (chapter 3, table 3.3)), the resulting $CH_4$ emissions have been included in the inventory. The ERT noted that CRF table 4(II) includes only values for rewetted organic soils in cropland, while for forest land and grassland, notation key "IE" is used, which is not further explained in CRF table 9 or in the NIR. During the review, the Party explained that the value of 288 kg $CH_4$/ha is used only for known rewetted soils, which are reported in table 4(II) under category D.3 (other wetlands). The Party also pointed out difficulties in verifying changes in agricultural practice leading to rewetting of drained organic soils, | More information is given in the NIR. The emission is estimated as the summed area of organic soils since 1990 converted to WE multiplied with the default EF from the 2013 Wetland Supp of 288 kg $CH_4$/ha/yr. The small difference in the CRF table 4(II) for the IEF is due to roundings of small numbers. | See Chapter 6.4. |

Table 9.6 Main recommendations from the latest UNFCCC review.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| | | which depends on the availability of data in LPIS on active re-wetting of these areas. Based on the information in LPIS it can be observed when some farmers are no longer applying for subsidies for some land, hence the assumption that the land no longer qualifies as "farmed land". For the organic soils, Denmark continues to report the land in cropland, but assumes that it can no longer be used for agricultural purposes as it is too wet (deepening ditches in Denmark is not permitted). The ERT recommends that Denmark include in the NIR information on methodological assumptions made to estimate and allocate $CH_4$ emissions from land converted to wetlands and to provide an explanation of the use of notation key "IE" in CRF table 4(II). | | |
| KL.6 | Afforestation and reforestation $CO_2$ | The ERT noted in section 10.2 of the NIR (p.543) that the Party indicated that there might be a slight time delay in the actual recording of the afforestation/afforestation and reforestation but that Denmark plans more frequent land-use mapping and improved methods for mapping in the coming years. The ERT considered that this delayed reporting may have an impact on afforestation/afforestation and reforestation estimates and asked Denmark whether and how the provisions of the Kyoto Protocol Supplement (chapter 2, sections 2.5.1 and 2.5.2) are applied in order to demonstrate that the geographical location of the boundaries of the areas that encompass lands subject to AR activities are identifiable (in addition to information already included in sections 10.2 and 10.3 in the NIR). The Party referred to the support schemes for afforestation, which require that the plants are in the soil and can be documented within a short time frame. This is recorded in the LPIS system and used as input to the continuous update of the land-use matrix and mapping of geographical boundaries of Denmark. Furthermore, the forests are inventoried and mapped at intervals, to supplement and validate the registered information. The ERT recommends that Denmark include information to support the geographical location of boundaries of AR activities in the NIR, for both plantations and natural expansion of forests. | In 2018, a validation of the resulting methodology was performed and reported in Johannsen et al (2018). Results indicate that generally, accuracies of land uses and land covers for the assessed years are reasonably high. However, detailed analyses show that assessed changes within afforestation and particularly deforestation are significantly overestimated. There are still limited resources for very frequent updates of mapping of all land uses based on field data, whereas LPIS and other registry data are updated on some intervals. | See Chapter 6.1.6. |
| KL.7 | Deforestation – $CO_2$ | Section 10.2.1 of the NIR (p.543) states that deforestation is identified where areas at the beginning of the commitment period were covered by forest and where subsequent information (through remote sensing or NFI) is recorded to have another land use. The identification of the areas is in most cases supported by reports on, for example, nature restoration or establishment of settlements. From the statement, the | In 2018, a validation of the resulting methodology was performed and reported in Johannsen et al. (2018). Results indicate that generally, accuracies of land uses and land covers for the assessed years are reasonably high. However, detailed analyses show that assessed changes within afforestation and particularly deforestation are significantly overestimated. Work on | See Chapter 6.1.6. |

Table 9.6 Main recommendations from the latest UNFCCC review.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| | | ERT was not able to assess how the provisions of the Kyoto Protocol Supplement (chapter 2, section 2.6.1) are applied in order to demonstrate that the geographical location of the boundaries of the areas that encompass lands subject to deforestation activities are identifiable. During the review, the Party explained that through the cadastral data of Denmark, all settlements (roads, houses, etc.) are clearly geographically located. For nature restoration, the information on the changes is documented through the LPIS system used for managing support instruments for nature restoration. Furthermore, for all restoration projects on publicly owned land, the planning data and maps with high accuracy are available as input for documentation of these changes.<br>The ERT recommends that Denmark amend the information to support the geographical location of boundaries of deforestation activities in the NIR, including information on how deforestation (i.e. land-use change) is distinguished from regeneration clear-cuts in forest land (i.e. temporary change in land cover), and how different end uses of deforested land (e.g. settlements versus 'nature restoration') are distinguished from one another. | differentiating different uses of deforested land is still ongoing. | |
| KL.8 | Cropland management – $CO_2$ | The ERT noted that the description of land cover types included under cropland (p.538 of the NIR) did not include hedgerows. The ERT also recalled that under planned improvements for the cropland estimates under the LULUCF sector (p.447) "verification and investigation of the hedgerows will take place in 2018." However, according to table 6.14 of the NIR, there are consistent records of hedgerows established up until 2013 on cropland and section 10.6.3 of the NIR (p.548) indicates that above- and below-ground living biomass for perennial fruit plantations, hedgerows and willow plantations for bioenergy purposes on agricultural land are reported under cropland management. During the review, Denmark confirmed that hedgerows are considered under cropland management, covering around 60,000 ha. In 2007, Denmark made stereoscopic analysis of 144 2*2 km2 aerial photos for 1990 and 2005 to estimate the area, width, height and changes between the two periods to estimate the carbon stock. The method was able to detect changes, which were combined with information from the LPIS system on subsidies for new hedges. For a couple of years there have been no subsidies for hedges and therefore there were no new data on new and removed hedges for those years. Hence, there were no changes in the area but there was still a build-up in previously planted hedges. The Party informed the ERT of its plan | More information is included in the 2020 submission. In the 2020 submission, a complete new LiDAR based hedge model has been implemented. The new model covers the whole country with a very high resolution (0.4 * 0.4 $m^2$). The result, seen from above, has increased the area from app. 60 000 ha in the previous submission to 103 000 ha in the 2020 submission (year 2015). The estimated carbon stock has increased but the changes in C stock between years are neglible compared to the previous model set-up. The model has been implemented for all years with back trajections. For 2016 and onwards is used a new developed growth model for the hedges. New LiDAR measurements are planned to occur regularly for one fifth of the country every year from 2019 and onwards. When we have a complete new LiDAR sample the C stock in the hedges will be revised according to the latest measurement. | See Chapter 6.2 and Annex 3E. |

Table 9.6 Main recommendations from the latest UNFCCC review.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| | | to update the estimates on hedgerows in its next submission based on new information and LiDAR data analysis. The ERT welcomes planned improvements and recommends that Denmark provide updated estimates on hedgerows across the entire time series and include transparent documentation on the methodologies used to estimate annual changes to AD in the NIR. | | |
| KL.9 | Grazing land management – $CO_2$ | The ERT noted that section 10.7.2 of the NIR (p.549) states that since all the grazed grassland is more or less unimproved without fertilizer or limited fertilization, no changes in management practice has been applied. This is considered in accordance with the 2006 IPCC Guidelines, chapter 6, and the Kyoto Protocol Supplement, chapter 2.10. Nevertheless, the ERT noted that CRF table NIR-1 and table 4(KP-I)B.3 suggest that soil estimates for grazing land are reported, which appears to be inconsistent with the no-change assumption referred to above. During the review the Party explained that its modelling tool, C-TOOL, is used on all agricultural mineral soils (<6 per cent organic carbon) with area data and crop yields from Statistics Denmark and LPIS data. This area also includes permanent grassland for agricultural purposes. As Denmark uses only "managed land" in the reporting, marginal land such as heathland was included in managed grassland, but not in the modelling, as this is not included in the agricultural statistics. So, de facto, grassland can be considered as being two different areas, one agricultural part and one non-agricultural. C-TOOL is running on the agricultural part covering both land in rotation and permanent grassland. Therefore, carbon stock changes in grassland are reported under cropland in the Convention reporting and in KP.B.2, while notation key "IE" is used for grassland (4C). However, when land reported under the Kyoto Protocol is changed to grazing land management, this has to be reported and "R" (reported) is used in NIR-1. There is a slight increase in carbon stocks in mineral soils due to conversion of land from other land-use classes to grassland. When running C-TOOL, Denmark uses for the permanent agricultural grassland a carbon input factor, which matches the degradation in the soil. The net outcome is around zero for permanent agricultural grassland. The ERT recommends that Denmark include the information on grazing land management estimates obtained through C-TOOL in its next NIR, including the methodological changes compared with grassland estimates under the Convention. | More information is given in the NIR. The difference between the Convention and the KP reporting is that all modelled changes in C stock in mineral soils is included under CL and CM. C stock changes due to land use conversions are reported separately under CL/CM and GL/GM. Only C stock changes in mineral soils due to Land use changes taken place from 01.01.2008 (start of CP1) is included in the CM and GM reporting. | See Chapter 6.2. Link to the technical report for C-TOOL is included. In NIR-I is IE replaced by R. |
| KL.10 | Harvested wood products – $CO_2$ | The ERT noted that in CRF table 4(KP-I)C removals in the HWP pool resulting from deforestation activities are accounted for (0.46 kg $CO_2$eq in 2016). The ERT also noted that | For deforestation direct estimation of the removed biomass above and below ground are based on biomass maps based on Lidar data, utilising that the land use | See Chapter 6.1.6 and 6.1.17. |

Table 9.6 Main recommendations from the latest UNFCCC review.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| | | section 10.10 of the NIR (p.551) states that "HWP accounting in the current commitment period is solely based on changes in the HWP pool in this period. Hereby the emissions in the first commitment period have no influence on the current reporting". The ERT considered that this is not in line with the Kyoto Protocol Supplement, table 1, where it is stipulated that HWP resulting from deforestation shall be accounted on the basis of instantaneous oxidation, and emissions occurring in the second commitment period from HWP removed from forests prior to the start of the second commitment period shall also be accounted for. Asked to explain the different approaches on deforestation and the relation between the first and second commitment periods, compared with the guidelines in the Kyoto Protocol Supplement, the Party explained that potential HWP from deforestation is accounted as instantaneous oxidation and that the HWP accounting is based on emissions from the full HWP pool, as well as the new inflow to the HWP pool. They represent the basis of the changes in the HWP pool in the second commitment period, hence the estimates are in line with the Kyoto Protocol Supplement. The Party also committed to improving the explanations of the estimates in the next NIR.<br>The ERT recommends that Denmark improve the transparency of the NIR by clarifying that deforestation is accounted as instantaneous oxidation and explain in detail what the revised HWP accounting is based on, as well as the specific means used to discount deforestation from the HWP inflow. | mapping provide georeferenced location of the deforestation. The height of the deforested areas and the related biomass pools are also derived from the Lidar based maps. This gives information on the deforested areas where harvest will include use wood (areas with height > 12 m), which in the HWP reporting have to be accounted based on instantaneous oxidation (see further details in the updated NIR) | |

## 6.15 References

AIS, 2002: Nielsen, K., Stjernholm, M., Olsen, B.Ø., Müller-Wohlfeil D.-I., Madsen I.-L., Kjeldgaard, A., Groom, G., Hansen, H.S., Rolev, A.M., Hermansen, B., Skov-Petersen, H., Johannsen, V.K., Hvidberg, M., Jensen, J.E., Bacher, V. & Larsen, H., 2000: AIS, 2002: The Area Information System - AIS. Ministry of Environment and Energy, Denmark.

Arealinformation, 2011a: The national registration of protected habitat types. Copenhagen: Arealinformation. Available at: http://arealinformation.miljoeportal.dk/distribution/

Arealinformation, 2011b: Registration of habitat types within Natura2000 designations (DEVANO). Copenhagen: Arealinformation. Available at: http://arealinformation.miljoeportal.dk/distribution/ (accessed April 2014).

Axe, M.S., Grange, I.D. & Conway, J.S., 2017: Carbon storage in hedge biomass—A case study of actively managed hedges in England, Agriculture, Ecosystems and Environment 250 (2017) 81–88.

Danish Defence, 2011: Management plans for defence holdings. Copenhagen: Danish Defence.

Danish Geodata Agency, 2011: National topographic database (Kort10) 2011. Copenhagen: Danish Geodata Agency. Danish Geodata Agency, 2012a: National cadastre map 2012. Copenhagen: Danish Geodata Agency.

Danish Geodata Agency, 2012: National topographic database (Kort10) 2012. Copenhagen: Danish Geodata Agency. Danish Nature Agency, 2011: Management plans for state forests. Copenhagen: Danish Nature Agency.

Callesen, I., Liski, J., Raulund-Rasmussen, K., Olsson, M., Tau-Strand, L. & Westman, C.J. 2007: Nitrogen pools and C:N ratios in Nordic well-drained forest soils related to climate and soil texture. Boreal environment research 12, 681-692.

Callesen, I., Stupak, I., Georgiadis, P., Johannsen, V.K., Østergaard, H.S. & Vesterdal, L. 2015: Soil carbon stock change in the forests of Denmark between 1990 and 2008. Geoderma Regional 5, 169-180.

Christiansen, J.R., Gundersen, P., Frederiksen, P. & Vesterdal, L. 2012a: Influence of hydromorphic soil conditions on greenhouse gas emissions and soil carbon stocks in a Danish temperate forest. Forest Ecology and Management 284, 185-195.

Christiansen, J.R., Vesterdal, L. & Gundersen, P. 2012b: Nitrous oxide and methane exchange in two small temperate forest catchments-effects of hydrological gradients and implications for global warming potentials of forest soils. Biogeochemistry 107, 437-454.

DST, 2020: Statistics Denmark. Available at: https://www.dst.dk/da/Statistik/dokumentation/statistikdokumentation/hoesten-af-korn--raps-og-baelgsaed/statistisk-behandling)

Elsgaard L, Görres, C.M., Hoffman, C.C., Blicher-Mathiesen, G., Schelde K. & Petersen S.O. 2012: Net ecosystem exchange of $CO_2$ and carbon balance for eight temperate organic soils under agricultural management. Agriculture Ecosystems and Environment 162:52-67.

Eriksen, J., Nordemann Jensen, P. & Jacobsen, B.H. (eds) 2014: Virkemidler til realisering af 2. generations vandplaner og målrettet arealregulering. DCA report No. 52, 330 pp. Aarhus University.

FAO, 2010: Global Forest Resources 2010. Food and Agriculture Organization of the United Nations, Rome.

Greve, M.H., Christensen, O.F., Greve, M.B. & Kheir, R.B. 2014: Change in Peat Coverage in Danish Cultivated Soils During the Past 35 Years, Soil Science, May 2014 - Volume 179 - Issue 5 - p 250–257.

Grønlund, A., Hauge, A., Hovde, A. & Rasse, D.P. 2008: Carbon loss estimates from cultivated peat soils in Norway: a comparison of three methods, Nutr. Cy. Agroecos., 81, 157–167.

IRR, 2007: Report of the review of the initial report of Denmark. Available at: https://unfccc.int/files/kyoto_protocol/compliance/plenary/application/pdf/cc-ert-irr-2007-13_report_of_review_of_ir_of_denmark.pdf

IPCC 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. & Tanabe K. (eds). Published: IGES, Japan.

IPCC, 2014: Wetland supplement. Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. & Troxler, T.G. (eds). Published: IPCC, Switzerland.

Johannsen, V.K., Nord-Larsen, T., Vesterdal, L., Suadicani, K. & Callesen, I. 2017: Identifying potential uncertainties associated with forecasting and monitoring carbon sequestration in forests and harvested wood products. København: Department of Geosciences and Natural Resource Management, University of Copenhagen, 2017. 82 p. (IGN Report).

Johannsen, V.K., Levin, G., Caspersen, O.H., Nord-Larsen, T. & Sørensen, I.H. 2018: Validation of land use/land cover changes for Denmark. Department of Geosciences and Natural Resource Management, University of Copenhagen, Frederiksberg. 23 p. ill. Available at: https://static-curis.ku.dk/portal/files/209289237/Validation_of_land_use_land_cover_changes_for_Denmark_report_2018.pdf

Knudsen, M.A., Nord-Larsen, T., Riis-Nielsen, T., Cordius-Hansen, J.G., Nielsen, A.O. & Kudahl, T. 2017: Skovstatistisk feltinstruks 2016. Frederiksberg: Institut for Geovidenskab og Naturforvaltning, Københavns Universitet, 2017. 198 p. (IGN Rapport).

Larsen, L., 2014: Pindstrup Mosebrug, (personal comm.). https://www.pindstrup.dk/home.

Larsen, P.H. & Johannsen, V.K. (eds.) 2002: Skove og plantager 2000. Danmarks Statistik, Skov and Landskab og Skov- og Naturstyrelsen. 171 p. ISBN: 87-501-1287-2.

LBST, 2020: www.lbst.dk. Confidential data on farm level received from the Danish Agricultural Agency.

Levin, G., Blemmer, M., Gyldenkærne, S., Johannsen, V.K., Caspersen, O.H., Petersen, H.S., Nyed, P.K., Becker, T., Bruun, H.G., Fuglsang, M., Münier, B., Bastrup-Birk, A. & NordLarsen, T. 2014: Estimating land use/land cover changes in Denmark from 1990 – 2012. Technical documentation for the assessment of land use/land cover changes for estimation of carbon dioxide fixation in soil. Aarhus University, DCE – Danish Centre for Environment and Energy, 34 pp. Technical Report from DCE – Danish Centre for Environment and Energy No. 38 Available at:
http://www.dce.au.dk/pub/TR38.pdf

Levin, G., Angelidis, I. & Gyldenkærne, S. 2020: Assessment of change in biomass from 2006 to 2014/2015 of non-forest woody vegetation in Denmark, Technical Report from DCE – Danish Centre for Environment and Energy, Aarhus University, No. xxx, 20xx. *(In press).*

Lingner, S., Thiessen, E., Müller, K. & Hartung, E. 2018: Dry Biomass Estimation of Hedge Banks: Allometric Equation vs. Structure from Motion via Unmanned Aerial Vehicle, JOURNAL OF FOREST SCIENCE, 64, 2018 (4): 149–156.

Lohila, A., Aurela, M., Tuovinen, J.-P. & Laurila, T. 2004: Annual $CO_2$ exchange of a peat field growing spring barley or perennial forage, J. Geophys. Res., 109, D18116, doi:10.1029/2004JD004715

Madsen, S.F. 1987: Vedmassefunktioner for nogle vigtige danske skovtræarter. Det Forstlige Forsøgsvæsen 40, 47-242.

Madsen, S.F. & Heusèrr, M. 1993: Volume and stem taper functions for Norway spruce. Forest and Landscape Research 1, 51–78.

Maljanen, M., Martikainen, P.J., Walden, J. & Silvola, J. 2001: $CO_2$ exchange in an organic field growing barley or grass in eastern Finland, Global Change Biol., 7, 679–692.

Maljanen, M., Komulainen, V.-M., Hytönen, J., Martikainen, P.J. & Laine, J. 2004: Carbon dioxide, nitrous oxide and methane dynamics in boreal organic agricultural soils with different soil management, Soil Biol. Biochem., 36, 1801–1808.

Maljanen, M., Sigurdsson, B.D., Guđmundsson, J., Óskarsson, H., Huttunen, J.T. & Martikainen, P.J. 2010: Greenhouse gas balances of managed peatlands in the Nordic countries – present knowledge and gaps. Biogeosciences 7, 2711-2738.

Ministry of Environment and Food of Denmark, 2020: Supplier of field block maps, field maps, subsidized afforestation data, wetland restoration areas, supported new hedges and biotopes, etc.

Ministry of Housing, Urban and Rural Affairs, 2012: Danish building register (BBR). Copenhagen: Ministry of Housing, Urban and Rural Affairs.

Moltesen, P. 1985: Skovtræernes ved og anvendelse. Skovteknisk Institut, Frederiksberg. 132 p.

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Gyldenkærne, S., Thomsen, M., Fauser, P., Nielsen, M. Mikkelsen, M.H., Albrektsen, R., Hjelgaard, K., Hoffmann, L. & Bruun, H.G. 2013. Quality manual for the Danish greenhouse gas inventory. Version 2. Aarhus University, DCE – Danish Centre for Environment and Energy, 44 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 47. Available at: http://www.dmu.dk/Pub/SR47.pdf (Jan. 2020).

Nord-Larsen, T. & Johannsen V.K., 2016: Danish National Forest Inventory. Design and calculations. NFI working paper 2016. Available at: http://ign.ku.dk/samarbejde-raadgivning/myndighedsbetjening/skovovervaagning

Nord-Larsen, T., Johannsen, V.K., Riis-Nielsen, T., Thomsen, I.M. & Jørgensen, B.B. 2019: Skovstatistik 2018: Forest statistics 2018. Frederiksberg: Institut for Geovidenskab og Naturforvaltning, Københavns Universitet.

Nord-Larsen, T., Meilby, H. and Skovsgaard, J.P. 2017: Simultaneous estimation of biomass models for 13 tree species: effects of compatible additivity requirements.

Schou, E., Suadicani, K. & Johannsen, V.K. 2015: Carbon Sequestration in Harvested Wood Products (HWP): Data for 2013-Reporting to the UNFCCC, Final Draft. Institut for Geovidenskab og Naturforvaltning, Københavns Universitet. IGN Rapport. Available at: http://static-curis.ku.dk/portal/files/153826852/5_Carbon_sequestration_in_HWP.pdf

Skovsgaard, J.P., Bald, C. & Nord-Larsen, T. 2011: Functions for biomass and basic density of stem, crown and root system of Norway spruce (*Picea abies* (L.) Karst.) in Denmark, Scandinavian Journal of Forest Research, vol. 26 (Suppl 11), pp. 3-20.

Skovsgaard, J.P. & Nord-Larsen, T. 2012: Biomass, basic density and biomass expansion factor functions for European beech (Fagus sylvatica L.) in Denmark. European Journal of Forest Research 131(4):1035-1053. DOI: 10.1007/s10342-011-0575-4

Taghizadeh-Toosi, A., 2015, C-TOOL A simple tool for simulation of soil carbon turnover Technical report October 2015. Available at: https://agro.au.dk/fileadmin/DJF/Agro/Medarbejderportal_AGRO/Sektioner/KLIMA/C-TOOL_Documentation.pdf

Taghizadeh-Toosi, A., Olesen, J.E., Kristensen, K., Elsgaard, L., Østergaard, H.S., Lægdsmand, M., Greve, M.H. & Christensen, B.T. 2014a: Changes in carbon stocks of Danish agricultural mineral soils between 1986 and 2009. European Journal of Soil Science, vol. 65, no. 5, pp. 730-740. DOI: 10.1111/ejss.12169

Taghizadeh-Toosi, A., Christensen, B.T., Hutchings, N.J., Vejlin, J., Kätterer, T., Glendinin, M. & Olesen, J.E. 2014b: C-TOOL: A simple model for simulating whole-profile carbon storage in temperate agricultural soils, Ecological Modelling 292, 11–25.

Vejre, H., Callesen, I., Vesterdal, L. & Raulund-Rasmussen, K. 2003: Carbon and Nitrogen in Danish forest soils – Contents and distribution determined by soil order. Soil Science Society of America Journal 67: 335-343.

Vesterdal, L., Ritter, E. & Gundersen, P. 2002a: Change in soil organic carbon following afforestation of former arable land. Forest Ecology and Management 169: 141-151.

Vesterdal, L., Jørgensen, F.V., Callesen, I. & Raulund-Rasmussen, K. 2002b: Skovjordes kulstoflager - sammenligning med agerjorde og indflydelse af intensiveret biomasseudnyttelse. In: Christensen, B.T. (ed.), Biomasse til energiformål - konsekvenser for jordens kulstofbalance i land- og skovbrug. DJF rapport Markbrug nr. 72.

Vesterdal L., Rosenqvist, L., van der Salm, C., Hansen, K., Groenenberg B.-J. & Johansson, M.-B. 2007: Carbon sequestration in soil and biomass following afforestation: experiences from oak and Norway spruce chronosequences in Denmark, Sweden and the Netherlands. In: Heil G., B. Muys and K. Hansen. Environmental Effects of Afforestation in Northwestern Europe - From Field Observations to Decision Support. Springer, Plant and Vegetation 1: 19-52.

# 7 Waste

## 7.1 Overview of the sector

The waste sector consists of the *CRF source categories: 5.A. Solid Waste Disposal*, *5.B. Biological treatment of solid waste*, *5.C. Incineration and open burning of waste*, *5.D. Wastewater treatment and discharge* and *5.E. Other*. The data presented in Chapter 7 relate to Denmark only, whereas information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 8.

For the CRF category 5.A Solid Waste Disposal, the $CH_4$ emissions reported in this chapter are a result of calculations in continuation of previously used and reported methodology. Minor changes (less than 1%) in the time trend and the year emissions in the period 2010-2017 for this year´s submission are due updated activity data obtained from the Danish EPA as documented in Chapter 7.2 and 7.9.

The *CRF category 5.B. Biological treatment of solid waste*, is comprised by sub-category *5.B.1 Composting* and sub-category *5.B.2 Anaerobic digestion at biogas facilities.* Sub-category *5.B.1* includes $CH_4$ and $N_2O$ emissions from composting of garden and park waste (GPW), organic waste from households (and other sources), sludge and home composting of garden and vegetable food waste. Change in the time trend for this year´s submission are due to changes in activity data on amount of organic waste composted obtained from the Danish EPA for the years 2010-2017 resulting in changes in the emissions in the range of 2.6-8.5%. Similarly, updated data on the biogas to energy production obtained from the Danish Energy Agency has caused minor changes in the emission from biogas production in the years 2010-2017 in the range of 0.001-0.23 %, as documented in Chapter 7.3 and 7.9.

The CRF source category *5.C. Incineration and open burning of waste*, the main emissions are included in the energy sector since all incineration of municipal, industrial, medical and hazardous waste in Denmark is done with energy recovery. No recalculations have occurred in this submission, except for a minor correction in the decimals of activity data for the year 2012 has occurred.

For the CRF source category *5.D. Wastewater treatment and discharge*, the emissions reported in this chapter are a result of calculations in continuation of previously used and reported methodology. Minor changes in the years 2014, 2016 and 2017 are due to minor corrections in the activity data (all below 0.5%) as explained and documented in Chapter 7.5 and 7.9.

The CRF source category *5.E. Other* covers $CO_2$, $CH_4$ and $N_2O$ emissions from the sources: accidental building fires and accidental vehicle fires. No recalculations have occurred in this submission.

Emissions from sludge spreading on fields, are included in agriculture, see Chapter 5.

In Table 7.1.1, an overview of all emissions from the waste sector is presented. The emissions are taken from the CRF tables and are presented as rounded figures. The full time series is presented in Annex 3F, Table 3F-1.1.

Table 7.1.1 Emissions for the waste sector, kt $CO_2$ equivalents.

| | | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5.A. Solid waste disposal | $CH_4$ | 1 536 | 1 331 | 1 073 | 909 | 772 | 703 | 687 | 651 | 617 | 588 | 560 |
| 5.B. Biological treatment of solid waste | $CH_4$ | 40 | 62 | 111 | 135 | 163 | 165 | 184 | 209 | 264 | 316 | 359 |
| 5.B. Biological treatment of solid waste | $N_2O$ | 12 | 21 | 153 | 59 | 86 | 78 | 74 | 65 | 80 | 83 | 83 |
| 5.C. Incineration and open burning of waste | $CH_4$ | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| 5.C. Incineration and open burning of waste | $N_2O$ | 0.19 | 0.21 | 0.21 | 0.23 | 0.28 | 0.26 | 0.26 | 0.26 | 0.27 | 0.27 | 0.28 |
| 5.D. Waste water treatment and discharge | $CH_4$ | 41 | 43 | 46 | 47 | 48 | 49 | 50 | 49 | 50 | 50 | 51 |
| 5.D. Waste water treatment and discharge | $N_2O$ | 109 | 115 | 80 | 73 | 63 | 64 | 66 | 69 | 65 | 67 | 65 |
| 5.E. Other | $CO_2$ | 20 | 23 | 21 | 20 | 17 | 16 | 14 | 15 | 17 | 16 | 18 |
| 5.E. Other | $CH_4$ | 2.4 | 2.7 | 2.4 | 2.4 | 1.9 | 1.8 | 1.7 | 1.7 | 1.9 | 1.7 | 2.1 |
| 5. Waste | total | 1 762 | 1 598 | 1 487 | 1 246 | 1 151 | 1 078 | 1 077 | 1 059 | 1 095 | 1 121 | 1 139 |

*5.A. Solid Waste Disposal* is the dominant source in the waste sector with contributions in the time series varying from 87 % (1990) to 49 % (2018) of the total emission given in $CO_2$ equivalents. The emissions are decreasing throughout the time series, due to a reduction in the amounts of waste deposited at landfills. Comparing 2018 with 1990, the emissions from Solid Waste Disposal Sites have decreased with 63.5 %.

*5.B. Biological treatment of solid waste.* This source contributes with $CH_4$ emissions from composting and manure-based biogas production and $N_2O$ emissions from composting. $CH_4$ contributes the most to the sectorial total, varying between contributions of 2.3 % (1990) and 31.5 % (2018). $N_2O$ contributes with between 0.7 % (1990) and 7.3 % (2018) of the sectorial total. The emissions increase steadily over the time series for both components. Comparing 2018 with 1990, the sum of $CH_4$ and $N_2O$ emissions (in units $CO_2$ equivalent) from composting and manure-based biogas plants in total have increased with a factor 7.4.

The contribution from 5.B.1 and 5.B.2 to the total emission from the waste sector provided in units $CO_2$ equivalent ranges from 2.7 % and 0.5 % in 1990 to 16.7 and 22.1 % in 2018; in sum, sector 5.B contributes the sectorial total with 3 % in 1990 and 38.8 % in 2018.

The increase in the GHG emission trend from category *5.B* is most significant for sub-sector 5.B.2, manure-based biogas production, the level of methane emissions in 2018 being a factor 44 higher than in the methane emission level in 1990. The methane emission from biogas production increases from 5.6 kt in 1990 to 252 kt $CO_2$ equivalents in 2018, while the GHG emission from composting increased from 47 kt in 1990 to 190 kt $CO_2$ equivalents in 2018.

*5.C. Incineration and open burning of waste.* This source contributes with $CH_4$ and $N_2O$ emissions from human and animal cremations. The contribution to the sectorial total ranges between 0.01 % and 0.03 %throughout the time series. The trend for the total emissions 1990 - 2018 from this source have increased with 43.7 %.

*5.D. Waste water treatment and discharge.* This source contributes with $CH_4$ and $N_2O$ emissions. The contribution to $CO_2$ equivalent emissions from the sum of $CH_4$ and $N_2O$ is 13.2 % in 1990 and 10.2 % in 2018.
$CH_4$ contributes with 3.6 % and 4.5 % to the sectorial total in 1990 and 2018, the $CH_4$ emissions increasing steadily over the time series from 41 kt $CO_2$ equivalents in 1990 to 51 kt $CO_2$ equivalents in 2018. $N_2O$ contributes with 9.6 % and 5.7 % to the sectorial total in 1990 and 2018 with a decreasing trend

from 109 kt $CO_2$ equivalents in 1990 to 65 kt $CO_2$ equivalents in 2018. The $N_2O$ emission in 2018 compared to 1990 shows a decrease of 40.1 %, while for $CH_4$ a steadily increase from 1990 to 2018 of 23.4 % is observed.

The trend for the total $CO_2$ equivalent emissions from sector 5.D Wastewater treatment and discharge has decreased from 150.3 kt $CO_2$ equivalents in 1990 to 116.1 kt $CO_2$ equivalents in 2018. Compared to 1990, the 2018 emissions have decreased with 22.7 %.

*5.D. Other*. This source contributes with $CO_2$ and $CH_4$ emissions from accidental fires. The contribution to the total emissions from the waste sector varies between 1.3 % and 2%.

As a result for the entire waste sector, the sectorial total emission in units of $CO_2$ equivalents (provided in Table 7.1.1) is decreasing throughout the time series; the emission in 2018 has decreased with 35.3 % compared to 1990.

The Waste Sectors contribution to the national total excluding LULUCF has decreased slightly from 2.5 % in 1990 to 2.4% in 2018.

Table 7.1.2 Reported emissions, calculated methods and type of emissions factors for the subcategory waste handling in the Danish inventory, (CS=country specific, D=default, OTH=other).

| CRF Source | Emissions reported | Method | Emission factor |
|---|---|---|---|
| 5.A Solid Waste Disposal | $CH_4$ | Tier 2,CS | CS,D |
| 5.B Biological treatment of solid waste | | | |
| 5.B.1 Composting | $CH_4$ | Tier 1, CS | CS, OTH |
| 5.B.1 Composting | $N_2O$ | Tier 1, CS | CS, OTH |
| 5.B.2 Anaerobic digestion at biogas facilities | $CH_4$ | Tier 1 | CS |
| 5.C Incineration and open burning of waste | | | |
| 5.C.1 Incineration of corpses | $CH_4$ | Tier 1 | D/CS |
| 5.C.1 Incineration of corpses | $N_2O$ | Tier 1 | D/CS |
| 5.C.2 Incineration of carcasses | $CH_4$ | Tier 1 | D/CS |
| 5.C.2 Incineration of carcasses | $N_2O$ | Tier 1 | D/CS |
| 5.D Wastewater treatment and discharge | | | |
| 5.D.1 Domestic wastewater | $N_2O$ | CS | CS |
| 5.D.1 Domestic wastewater | $CH_4$ | CS | CS |
| 5.D.2 Industrial wastewater | $N_2O$ | CS | CS |
| 5.E Other | | | |
| 5.E.1 Accidental fires | $CO_2$ | Tier 1, CS | CS, OTH |
| 5.E.1 Accidental fires | $CH_4$ | Tier 1, CS | CS, OTH |

### 7.1.1 Key category identification

In the key category analysis (KCA) the waste emissions are divided into twelve categories. In the Approach 1 KCA, two of the twelve categories is identified as a key category. At Approach 2 KCA, four of the twelve source categories are identified as key categories in 2018 (Table 7.1.3). The Approach 1 key category analysis is based on ranking of absolute quantitative emissions/removals, while the Approach 2 KCA takes into account the uncertainties in the calculated emissions (cf. Chapter 1.5).

Of the twelve categories, *5.A Solid Waste Disposal*, *5.B.1 Composting* and *5.B.2 Anaerobic digestion at biogas facilities* are identified as key sources for level.

According to the level assessment for both Approach 1 and 2, *5.A. Solid Waste Disposal* is a key category for level in both 1990 and 2018.

Category *5.B.1 Composting* is a $CH_4$ and $N_2O$ key category for level in 2018 according to the level assessment for Approach 2 KCA only. Category *5.B.2 Anaerobic digestion at biogas facilities* is identified as $CH_4$ key category for level in 2018 according to the level assessment for Approach 1 KCA only.

Both category *5.A. Solid Waste Disposal* and *5.B.2 Anaerobic digestion at biogas facilities* are $CH_4$ key categories for trend calculated in $CO_2$ equivalents, from 1990 to 2018 according to both Approach 1 and 2. Category *5.B.1 Composting* is identified as a key category for $CH_4$ and $N_2O$ for trend according to the Approach 2 only.

Identified key source categories within the waste sector are presented in Table 7.1.3. For further information on the KCA level and trend assessments please refer to Chapter 1.5 and Annex 1.

Table 7.1.3 Key category identification Approach 1 and Approach 2 from the waste sector 1990 and 2018.

| | | Approach 1 | | | Approach 2 | | |
|---|---|---|---|---|---|---|---|
| | | 1990 | 2018 | 1990-2018 | 1990 | 2018 | 1990-2018 |
| 5.A Solid waste disposal | $CH_4$ | Level | Level | Trend | Level | Level | Trend |
| 5.B.Biological treatment of solid waste | | | | | | | |
| 5.B.1. Composting | $CH_4$ | - | - | - | - | Level | Trend |
| 5.B.1. Composting | $N_2O$ | - | - | - | - | Level | Trend |
| 5.B.2. Anaerobic digestion at biogas facilities | $CH_4$ | - | Level | Trend | - | - | Trend |
| 5.C. Incineration and open burning of waste | | | | | | | |
| 5.C.1 Incineration of corpses | $CH_4$ | - | - | - | - | - | - |
| 5.C.1 Incineration of corpses | $N_2O$ | - | - | - | - | - | - |
| 5.C.2 Incineration of carcasses | $CH_4$ | - | - | - | - | - | - |
| 5.C.2 Incineration of carcasses | $N_2O$ | - | - | - | - | - | - |
| 5.D Wastewater treatment and discharge | | | | | | | |
| 5.D Anaerobic wastewater treatment | $CH_4$ | - | - | - | - | - | - |
| 5.D Aerobic wastewater treatment and discharge* | $N_2O$ | - | - | - | - | - | - |
| 5.E. Other | | | | | | | |
| 5.E Accidental fires** | $CO_2$ | - | - | - | - | - | - |
| 5.E Accidental fires** | $CH_4$ | - | - | - | - | - | - |

*Direct and indirect emissions.

** Vehicles and Buildings.

## 7.2 Solid waste disposal

For many years, only managed waste disposal sites have existed in Denmark. Unmanaged and illegal disposal of waste is considered to play a negligible role in the context of this category. The amount of deposited waste has decreased markedly throughout the time series and is reported under the CRF source category *5.A.1 Managed waste disposal sites*.

In 2010, the Danish EPA implemented to the new Waste Data System to collect waste statistics. The design of the Waste Data System is considerably different from the ISAG Waste Information System it succeeds. The new waste reporting system (2010-2018) provides statistics of waste amounts according to the waste producer and the amount of waste according to treatment type, e.g. landfill. Both statistics refers to the receiver, i.e. receivers of produced waste (waste collection companies, and receivers of waste for treatment, e.g. landfill operators. Statistics on treatment types are assumed to be final treatment; i.e. meaning that none of the waste is temporary landfilled (Nissen, 2017a). The Danish EPA are conducting quality assurance of the reported data in the new data reporting system continuously supported by in house plant level recalculations of activity data at plant level. This have led to recalculations resulting in minor changes in the period 2010-2017 below 1% (see Chapter 7.9 and Annex 3F, Table 3F-7.1).

The general development for solid waste at disposal sites is influenced by government instruments such as the "Action plan for Waste and Recycling 1993-1997" and "Waste 21 1998-2004" (The Danish Government, 1999). The latter plan had, inter alia, the goal to recycle 64 %, incinerate 24 % and deposit 12 % of all waste. The goal for deposited waste was met in 2000. Further, in 1996 a municipal obligation to assign combustible waste to incineration was introduced. In 2003, the Danish Government set up targets for the year 2008 for waste handling in a “Waste Strategy 2005-2008” report (The Danish Government, 2003). According to this strategy, the target for 2008 is a maximum of 9 % of the total waste to be deposited at landfills. In the waste statistics report for the year 2004, data shows that this target was met, since 7.7 % of total waste was deposited in 2004 (DEPA, 2006a). Waste Strategy 2009-12, part I (The Danish Government, 2009) was the sixth waste management plan or strategy adopted by the successive governments dating back to 1986. Waste Strategy 2009-12 set up targets for 2012 according to which a maximum of 6 % of the total waste produced is to be deposited (The Danish Government, 2009). In 2009, it appears that this target has already been met as only 6 % of all produced waste was deposited at landfills. Data on final disposal of waste in Denmark is presented in Annex 3F, Table 3F-2.1, showing that the per cent amount of waste deposited at landfills equals a constant level of 4 % of the total waste produced in the country since 2013.

Waste Strategy 2009-2012, Part II included goals of continued decrease in the amount of waste being deposited in Denmark and an increase in reuse, recycling and recovery (The Danish Government, 2010). This report includes an evaluation of the capacity of Danish solid waste disposal sites divided into waste classes: inert, mineral, mixed and hazardous waste. The same waste classes are defined in the new Statutory Order for Landfill (Statutory Order no. 719, 24/06/2011), which refers to the Statutory Order for Waste (Statutory Order no. 1309, 18/12/2012) regarding characterisation of the waste according to the European waste code system; the EWC-code list included in Annex 2 of the statutory Order no. 1319. The New Danish Waste Reporting System (www.ads.mst.dk) is based on the EWC-code system, which forms the basis for the estimation of yearly deposited 18 waste types as further described in this chapter and in Annex 3F.

### 7.2.1 Source category description

From 1994 to 2005, the number of registered solid waste disposal sites (SWDSs) landfill sites in Denmark has decreased from 176 to 134 (DEPA, 2006b, 2013). There were 56 active disposal sites (SWDS) in 2015 (Nissen, 2017a, b). In 2018, 49 active disposal sites reporting to the new waste data system. Methane collections from 29 of these SWDS are reported to be used at energy-producing installations in the Energy statistics in 2019 (DEA, 2019, 2020). Furthermore, biocover has been implemented at 13 SWDS, while 10 more SWDS are planned to have biocover implemented in 2020 (Bang-Andreasen, 2020; Kjeldsen & Scheutz, 2016; Mønster et al., 2015; Pedersen et al, 2012).

A quantitative overview of the source category are provided in Table 7.2.1 presenting the amounts of landfilled waste, the annual gross emissions of $CH_4$, the recovered $CH_4$ in terms of collected biogas at the landfill sites used for energy production, the amount of $CH_4$ oxidised in the top layers and the resulting net $CH_4$ emissions. The $CH_4$ emission from the Danish landfills has decreased 63.5 % from 1990 to 2018.

A full time series (1990-2018) of these data are shown in Annex 3F, Table 3F-2.2. The amount of waste and the resulting $CH_4$ emission can also be found in the CRF tables available at UNFCCC webpage (http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/10116.php).

Table 7.2.1 Annual amounts of deposited waste, generated methane, recovered methane collected for biogas production, oxidised methane in the top layer and resulting net emission for the Danish SWDS.

| Year | Landfilled waste | Gross methane emission | Recovered methane | Methane oxidised in the top layers | Net methane emission | |
|---|---|---|---|---|---|---|
| | kt | kt $CH_4$ | kt $CH_4$ | kt $CH_4$ | kt $CH_4$ | kt $CO_2$ eqv. |
| 1990 | 3 190 | 68.8 | 0.5 | 6.8 | 61.5 | 1 536 |
| 1995 | 1 969 | 66.8 | 7.6 | 5.9 | 53.2 | 1 331 |
| 2000 | 1 489 | 58.9 | 11.3 | 4.8 | 42.9 | 1 073 |
| 2005 | 983 | 50.4 | 9.9 | 4.0 | 36.4 | 909 |
| 2010 | 2 487 | 40.0 | 5.7 | 3.4 | 30.9 | 772 |
| 2011 | 2 576 | 38.3 | 3.9 | 3.4 | 31.0 | 774 |
| 2012 | 2 477 | 36.7 | 3.7 | 3.3 | 29.7 | 742 |
| 2013 | 1 390 | 35.2 | 4.0 | 3.1 | 28.1 | 703 |
| 2014 | 1 330 | 33.7 | 3.2 | 3.1 | 27.5 | 687 |
| 2015 | 987 | 32.3 | 3.4 | 2.9 | 26.0 | 651 |
| 2016 | 1 025 | 31.0 | 3.6 | 2.7 | 24.7 | 617 |
| 2017 | 706 | 29.7 | 3.6 | 2.6 | 23.5 | 588 |
| 2018 | 700 | 28.5 | 3.6 | 2.5 | 22.4 | 560 |

The yearly methane emission is a function of the type and amount of degradable organic waste deposited (Table 7.2.2 and 7.2.3). The net methane emission results from the gross emission minus the amount of recovered methane collected for bioenergy production minus the amount of methane oxidised in the top layers of the landfills (Eq. 7.2.7). The decreasing trend in the net $CH_4$ emission is explained by an exponential decrease over time according to first order degradation kinetics (cf. eq. 7.2.4) and a significant decrease in the amount of degradable organic waste deposited at landfills in Denmark (cf. Table 7.2.3 and 7.2.6 and Annex 3F, Table 3F-2.2 and Table 3F-2.3).

**Methodological issues**

The estimation of $CH_4$ emission from Danish SWDSs is based on a First Order Decay (FOD) model, with good quality country-specific activity data on current and historical waste disposal at SWDS, equivalent to the IPCC Tier 2 methodology (IPCC, 2006). The model calculations are performed using national statistics on landfill waste categories reported in the national waste statistics. Activity data are based on allocation of the old ISAG, and the new waste reporting system according to the European waste codes, into 18 waste types characterised by individual content of degradable organic matter and half-life´s as provided in Table 7.2.2.

The degradation of a deposited waste type of quantity N is modelled according to first order kinetics. The mathematical formulation of this type of exponential decay is

$$\frac{dN}{dt} = -k \cdot N \qquad \text{Eq. 7.2.1}$$

where $k$ is the decay constant. Equation 7.2.1 can be solved for the simple case of a momentarily single deposition at time t ($W_t$) yielding:

$$N(t) = W_t \cdot e^{-k\,t} \qquad \text{Eq. 7.2.2}$$

where $k$ relates to the half-life time for the content of degradable organic carbon (DOC) in the bulk waste, as:

$$t_{1/2} = \frac{ln2}{k} \Rightarrow k = \frac{ln2}{t_{1/2}} \qquad \text{Eq. 7.2.3}$$

The content of degradable organic carbon ($DOC_i$), half-life times ($t_{½}$) and the corresponding methane generation constants ($k$) are provided in Table 7.2.2.

Table 7.2.2 Half-life times ($t_{½}$), degradation rates constants (k) and content of degradable organic matter ($DOC_i$) according to 18 waste type, of which 11 are characterised as inert*.

| Waste type[1] | $DOC_i$, [%, ww][2] | $t_{½}$, [yr, ww][3] | $k$, [$yr^{-1}$, ww] |
|---|---|---|---|
| Food | 15 | 4 | 0.17 |
| Paper and cardboard | 40 | 12 | 0.06 |
| Wood | 43 | 23 | 0.03 |
| Plastic* | 0 | | |
| Textile. fur and leather | 24 | 12 | 0.06 |
| Biodegradable garden waste | 20 | 7 | 0.10 |
| Chemicals. inert* | 0 | | |
| Electric & Hazardous* | 0 | | |
| Glass* | 0 | | |
| Metal* | 0 | | |
| Scrap vehicles* | 0 | | |
| Demolition | 4 | 23[4] | 0.03 |
| Soil & Stone* | 0 | | |
| Particulate matter and dust* | 0 | | |
| Sludge. inert* | 0 | | |
| Sludge. Degradable | 15[5] | 12 | 0.06 |
| Ash & Slag* | 0 | | |
| Other not combustible waste* | 0 | | |

[1]Waste types marked "*"are characterised as being inert, meaning that these fraction do not decompose, i.e. $DOC_f = 0$.
[2]Default IPCC, 2006, Vol. 5, Chapter 2, Table 2.4.
[3]Default IPCC, 2006, Vol. 5. Chapter 3, Table 3.4. Sludge deposited of at landfills is normally the endproduct from anaerobic digestion with a lower degradation rate than that of undigested sludge and the default value for slowly degrading waste (paper, textiles) is considered more suitable for Danish digestate.
[4]For demolition waste, the degradable fraction is assumed to be wood and the half-life for wood is therefore used.
[5]Default IPCC, 2006, Vol. 2, Chapter 2, Table 2.5 and 2.6.

The amount of generated methane decreases exponentially over time according to first order degradation kinetics of the content of degradable organic carbon in the deposited waste.

At a given year (t) the amount of degradable organic carbon (D$DOCm$(t)) which decomposes is a result of accumulated contributions from all former years deposit of waste ($W(x)$), where $x$ is year since depositing. The residue of organic matter, i.e. decomposable DOC, left from waste deposited at landfill sites *x* years ago, is calculated using the exponential decomposition rule (Eq. 7.2.4).

$$DDOCm(t) = W_i \cdot DOC_i \cdot DOC_f \cdot MCF + DDOCm(t-1) \cdot e^{-k} \qquad \text{Eq. 7.2.4}$$

where the methane conversion factor, *MCF,* is set to the default value of 1 for managed SWDS corresponding to the situation in Denmark (page 3.14, IPCC 2006). $DOC_i$ is the mass fraction of degradable organic carbon in the deposited waste types (Table 7.2.2), and $DOC_f$ represents the fraction of the degradable organic carbon that will decompose at the SDWS. For Denmark the default $DOC_f$ value is set to 0.5 (IPCC 2006, page 3.13).

Eq. 7.2.4 assumes that the deposition of degradable organic carbon takes place momentarily once a year and just after the time *t,* where *t* is defined as whole years (integer: *t*=1,2...), so Eq. 7.2.4 consists of two overall contributions that may be expressed as

*DDOCm(t) = New deposit* + *Remaining part of former years deposit*

The total amount of degraded organic matter during year *t* ($DDOCm\ decomp_T$) is assumed to be equal to the degradation during year t of the organic matter that was deposited at the beginning of the year (*DDOCm*(*t*-1)):

$$DDOCm\ decomp_T = DDOCm(t-1) \cdot (1 - e^{-k}) \qquad \text{Eq. 7.2.5}$$

Based on Equation 7.2.4 and 7.2.5 it is possible to calculate the degraded amount of organic matter in a step wise manner based on last year result. The degraded amount of organic matter is assumed to generate the $CH_4$ as described by

$$CH_4\ generated_T = DDOCm\ decomp_T \cdot F \cdot 16/12 \qquad \text{Eq. 7.2.6}$$

where *F,* which is the fraction of methane in the gas from landfills, is set equal to 0.5 (IPCC, 2006) and 16/12 is the conversion factor from units of C to $CH_4$.

For deriving the net emissions, the amount of recovered or collected methane as well as the amount of oxidised methane in the SWDS top layers needs to be subtracted from the generated methane:

$$CH_4\ Emissions = \left( \sum_x CH_4\ generated_{x,T} - R_T \right) \cdot (1 - OX_T) \qquad \text{Eq. 7.2.7}$$

where $CH_4$ *Emissions* is the methane emitted in year *T*, in units of Kt, *T* is the inventory year, *x* is the waste category or type. $R_T$ is the amount of recovered $CH_4$ at the Danish disposal sites, which are used for energy production. The Danish Energy Agency registers the biogas amounts recovered at disposal sites in energy units (TJ) (DEA, 2016). The amount of gas in energy unit is converted to volume of gas using the net calorific value of 15.19 MJ per $Nm^3$ (DGC, 2009; Vattenfall, 2010; Verdo, 2011). As for the FOD model, the content of $CH_4$ in the gas recovered is estimated to 41 % and the density of $CH_4$ is 0.678 kg per $m^3$.

$OX_T$ is the assumed oxidation of $CH_4$ in the top layer. The amount oxidised is uncertain and varies according to SWDS characteristics and management practices. For the Danish model an oxidation factor (OX) of 0.1 used; i.e. the default value for industrialised countries with well-managed disposal sites (IPCC, 2006).

The amount of $CH_4$ recovered, *R(t),* is calculated as:

$$R_T = \frac{B \cdot 0.41 \cdot 0.678\text{kg/m}^3}{15.19\text{MJ/m}^3} \qquad \text{Eq. 7.2.8}$$

where B is the collected amount of biogas as reported by the DEA in units of MJ. The $CH_4$ recovered is reported in Table 7.2.1 and 7.2.9 in units of kt.

### Model results and activity data

The amounts of waste deposited are registered and published in the national ISAG and new waste system (www.ads.mst.dk) databases and have been allocated into 18 waste types as presented in Table 7.2.3 and in Annex 3F, Table 3F-2.3.

Table 7.2.3 Waste amounts according to eighteen waste types of which eleven* represents inert waste fractions, kt.

| Waste types | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Food | 112 | 52 | 26 | 5 | 1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Paper and cardboard | 180 | 84 | 43 | 8 | 3 | 3 | 2 | 1 | 2 |
| Wood | 201 | 261 | 255 | 3 | 7 | 6 | 5 | 2 | 3 |
| Plastic* | 27 | 14 | 9 | 5 | 7 | 5 | 3 | 2 | 3 |
| Textile, fur and leather | 5 | 3 | 2 | 1 | 3 | 3 | 2 | 1 | 2 |
| Biodegradable garden waste | 136 | 65 | 35 | 7 | 7 | 5 | 1 | 0.01 | 0.02 |
| Chemicals, inert* | 8 | 5 | 4 | 1 | 1 | 2 | 0.3 | 1 | 1 |
| Electric & Hazardous* | 1 | 0.3 | 1 | 84 | 3 | 0.04 | 0.1 | 1 | 1 |
| Glass* | 37 | 19 | 11 | 5 | 5 | 4 | 3 | 2 | 3 |
| Metal* | 184 | 128 | 107 | 78 | 179 | 93 | 64 | 78 | 85 |
| Scrap vehicles | 105 | 64 | 49 | 49 | 21 | 0.005 | 0 | 0 | 0 |
| Demolition, inert* | 283 | 175 | 132 | 87 | 136 | 177 | 168 | 185 | 176 |
| Soil & Stone* | 466 | 309 | 271 | 174 | 1 978 | 613 | 694 | 365 | 363 |
| Particulate matter and dust* | 32 | 0.0 | 0.3 | 0.1 | 3 | 2 | 5 | 4 | 4 |
| Sludge, inert* | 91 | 44 | 25 | 11 | 3 | 6 | 5 | 6 | 4 |
| Sludge, degradable | 211 | 136 | 107 | 38 | 25 | 8 | 20 | 11 | 11 |
| Ash & Slag* | 466 | 145 | 9 | 34 | 48 | 29 | 23 | 23 | 17 |
| Other not combustible waste* | 646 | 465 | 403 | 396 | 56 | 31 | 30 | 23 | 25 |
| Total degradable | 1 128 | 776 | 601 | 147 | 182 | 203 | 198 | 202 | 194 |
| Total inert | 2 062 | 1 193 | 888 | 836 | 2 305 | 784 | 827 | 504 | 506 |
| Total | 3 190 | 1 969 | 1 489 | 983 | 2 487 | 987 | 1 025 | 706 | 700 |

Data on the amounts of solid waste deposited at managed solid waste disposal sites, in the old database ISAG database (1990-2009) and the new waste data system (2010-2018), are reported by the Danish Environmental Protection Agency (DEPA). The ISAG data system provides landfill data for the years 1994-2009 (DEPA, 1996a, 1998a, 1999a, 2001a, 2001b, 2002a, 2004a, 2004b, 2005a, 2006a, 2006b, 2008, 2010a, 2011a,) and the new waste data system provides data for 2011-2018 (DEPA, 2013, 2014, 2015, 2016, 2017, 2018, 2019). Data have been provided by the Danish EPA (Table 7.8.1).

For the years 2010-2018 allocations has been performed according to the reported European waste codes (Statutory Order no. 1309, 18/12/2012) in the new waste data system (cf. Annex 3F, Table 3F-2.4 and 3F-2.5).

For the old ISAG database, 1994-2009 (DEPA, 1996a, 1998a, 1999a, 2001a, 2001b, 2002a, 2004a, 2004b, 2005a, 2006a, 2006b, 2008, 2010a, 2011a, 2014, 2015), have been analysed in depth and specific waste fractions have been allocated according to the 18 defined waste types as provided in Table 7.2.3 (and Annex 3F, Table 3F-2.3).

Waste characterization data for the year 1985 and information on the total amount of waste deposited at SWDSs in 1970 reported by the Danish EPA in 1993 (DEPA, 1993) was used in the back calculation of the time series from 1994-1985.

Data for 1971-1984 have been determined by assuming a linear development between 1970 and 1985, while data for the period 1940-1969 are kept constant at the 1970 level.

Waste amounts for the whole time series, i.e. 1940- 2018, categorised, allocated and divided into 18 waste types as described above, are provided in Annex 3F, Table 3F-2.3 and Table 3F-2.4. Corresponding annual fractional distributions of the total amount of deposited waste according to type, respecting mass conservation, is presented in units of mass fractions in Table 7.2.4 (for the whole time series the reader is referred to Annex 3F, Table 3F-2.5).

Table 7.2.4 Fractional distribution of reported waste, according to the old ISAG and the new waste data system (EWC), allocated according to the 18 waste types.

| Waste types | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Food | 3.5 | 2.6 | 1.8 | 0.5 | 0.1 | 0.04 | 0.01 | 0.01 | 0.005 | 0.02 | 0.01 |
| Paper and cardboard | 5.7 | 4.3 | 2.9 | 0.8 | 0.1 | 0.2 | 0.3 | 0.3 | 0.2 | 0.2 | 0.3 |
| Wood | 6.3 | 13.3 | 17.1 | 0.3 | 0.3 | 0.4 | 0.4 | 0.6 | 0.5 | 0.3 | 0.4 |
| Plastic* | 0.8 | 0.7 | 0.6 | 0.5 | 0.3 | 0.3 | 0.4 | 0.5 | 0.3 | 0.3 | 0.4 |
| Textile. fur and leather | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.2 | 0.3 | 0.3 | 0.2 | 0.2 | 0.3 |
| Biodegradable garden waste | 4.3 | 3.3 | 2.4 | 0.7 | 0.3 | 0.4 | 0.2 | 0.5 | 0.1 | 0.002 | 0.003 |
| Chemicals. inert* | 0.2 | 0.2 | 0.2 | 0.1 | 0.04 | 0.00 | 0.02 | 0.2 | 0.03 | 0.1 | 0.1 |
| Electric & Hazardous* | 0.02 | 0.02 | 0.05 | 8.5 | 0.1 | 0.1 | 0.002 | 0.004 | 0.01 | 0.2 | 0.2 |
| Glass* | 1.2 | 0.9 | 0.7 | 0.5 | 0.2 | 0.3 | 0.3 | 0.4 | 0.3 | 0.3 | 0.4 |
| Metal* | 5.8 | 6.5 | 7.2 | 7.9 | 7.2 | 8.9 | 12.1 | 9.4 | 6.2 | 11.0 | 12.2 |
| Scrap vehicles* | 3.3 | 3.3 | 3.3 | 5.0 | 0.9 | 0.001 | 0 | 0.001 | 0 | 0 | 0 |
| Demolition | 8.9 | 8.9 | 8.9 | 8.9 | 5.5 | 13.2 | 14.2 | 18.0 | 16.4 | 26.3 | 25.2 |
| Soil & Stone* | 14.6 | 15.7 | 18.2 | 17.7 | 79.5 | 68.0 | 63.9 | 62.1 | 67.7 | 51.7 | 51.8 |
| Particulate matter and dust* | 1.0 | 0.0004 | 0.02 | 0.01 | 0.1 | 0.6 | 0.5 | 0.3 | 0.4 | 0.6 | 0.6 |
| Sludge. inert* | 2.8 | 2.3 | 1.7 | 1.1 | 0.1 | 0.6 | 0.6 | 0.6 | 0.5 | 0.8 | 0.6 |
| Sludge. degradable | 6.6 | 6.9 | 7.2 | 3.8 | 1.0 | 1.1 | 0.9 | 0.8 | 1.9 | 1.6 | 1.6 |
| Ash & Slag* | 14.6 | 7.4 | 0.6 | 3.4 | 1.9 | 2.4 | 3.0 | 2.9 | 2.2 | 3.3 | 2.5 |
| Other waste. inert*/** | 20.3 | 23.6 | 27.1 | 40.3 | 2.3 | 3.3 | 3.0 | 3.2 | 2.9 | 3.2 | 3.5 |

While Table 7.2.4 presents the fractional distribution of 18 identified waste types of known $DOC_i$ values, corresponding methane generation potentials are presented in Table 7.2.5.

Table 7.2.5 Methane generation potential for each of the 18 waste types, kt $CH_4$ per kt waste.

| Waste types | $L_{o,i}/W_i$ |
|---|---|
| Food | 0.05 |
| Paper and cardboard | 0.133 |
| Wood | 0.143 |
| Plastic* | 0 |
| Textile. fur and leather | 0.08 |
| Biodegradable garden waste | 0.067 |
| Chemicals, inert* | 0 |
| Electric & Hazardous* | 0 |
| Glass* | 0 |
| Metal* | 0 |
| Scrap vehicles* | 0 |
| Demolition | 0.013 |
| Soil & Stone* | 0 |
| Particulate matter and dust* | 0 |
| Sludge, inert* | 0 |
| Sludge, Degradable | 0.05 |
| Ash & Slag* | 0 |
| Other waste, inert* | 0 |

The content of degradable organic matter, $DOC_i$ values, in each waste type is shown separately in Table 7.2.2 and has been kept constant for the whole time series. The methane generation potential per unit waste type *i* is obtained from equation 7.2.9:

$$\frac{L_{o,i}}{W_i} = DOC_f \cdot MCF \cdot F \cdot 16/12 \cdot DOC_i$$
$$\Rightarrow \frac{L_{o,i}}{W_i} = 0.27 \cdot DOC_i \qquad \text{Eq. 7.2.9}$$

where the yearly decomposable fraction of the organic carbon content, $DOC_f$. are set equal to 0.5, the methane conversion factor, *MCF* are set equal to 1 and the volume fraction of $CH_4$ in generated landfill gas, F, are 0.5 (IPCC, 2006). The methane generation potentials according to waste types are reported in Table 7.2.5.

The annual amounts of the waste types (Table 7.2.3) and their emission generation potentials per mass unit (Eq. 7.2.9 and Table 7.2.5) are used to calculate the deposited $CH_4$ generation potential and the actual generated $CH_4$ emission from the annually amount of deposited waste (Eq. 7.2.6).

Figure 7.2.1 shows the time trend in annual amounts of deposited methane generation potential for each of the deposited waste type per year.

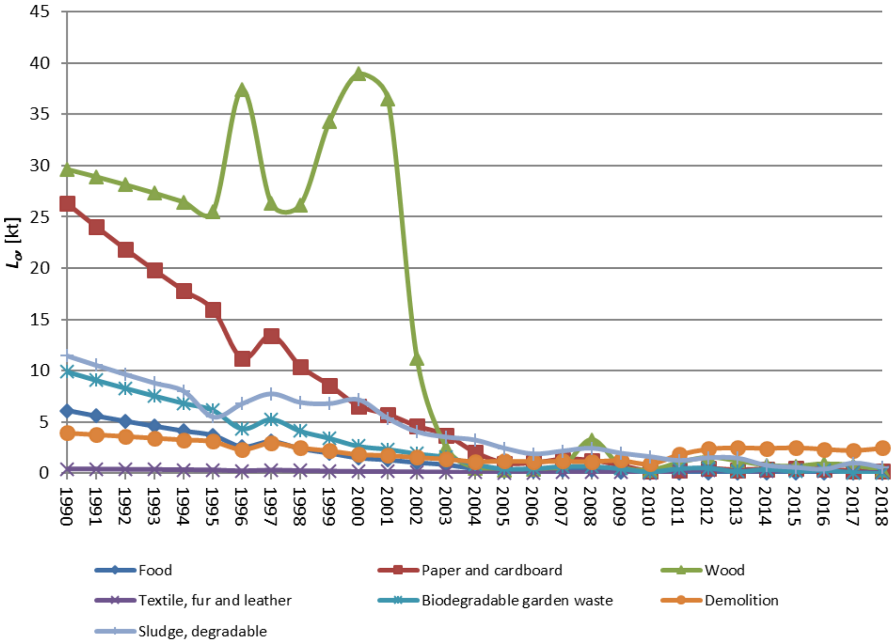



Figure 7.2.1 Annual amounts of deposited methane generation potential per waste type.

Figure 7.2.1 shows that the amounts of yearly deposited methane generation potential has decreased significantly in the period from 1990 to 2005. However, only a fraction of the deposited methane generation potential is release per year; i.e. a function of the degradation rate constants of the individual waste types, the content of degradable organic carbon and according to first order degradation kinetics for each waste type (Eq. 7.2.1 to 7.2.6 and Table 7.2.2). The seemingly significant fluctuations in the yearly amounts of deposited methane generation potentials become insignificant when looking at the annual implied emission factors, calculated from the net methane emission per waste type divided by the accumulated amount of decomposable organic matter per waste type (Table 7.2.6), as illustrated in Figure 7.2.2.

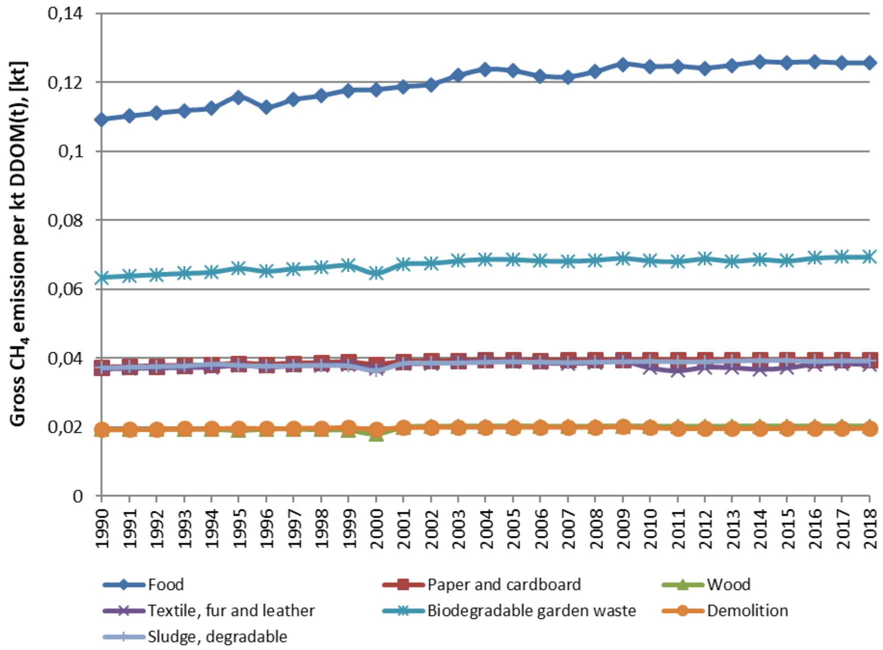



Figure 7.2.2 Annual gross implied emission factors for each waste type.

Figure 7.2.2 shows the time trend in the gross implied methane emission factor calculated as the gross methane emission divided by the accumulated (or remaining) amount of degradable organic carbon within each waste type (the sum across waste types are provided in Table 7.2.6). As may be observed from comparing Figure 7.2.2 with Figure 7.2.1, food waste has the highest gross methane emission factor and one of the lowest yearly methane generation potentials. The highest methane emission factor (Figure 7.2.2) for food waste throughout the time series may be explained by the lowest half-life (high $CH_4$ release rate) and content of degradable organic carbon for food waste compared to other waste types. Still, the yearly amounts of deposited food waste is low and so is the yearly methane generation potential (Eq. 7.2.9).

The net $CH_4$ emission (Eq. 7.2.7) is obtained upon subtraction of the recovered $CH_4$, utilized for energy production at some of the sites, and the amount of oxidized methane in the SWDS top layers from the gross methane emission. The annual total amounts of deposited waste, accumulated degradable organic waste, degraded organic matter and the calculated $CH_4$ emissions are presented in Table 7.2.6.

Table 7.2.6 Waste deposited, total organic degradable matter, amounts of annual degraded organic matter and resulting $CH_4$ emissions for 1990-2018.

| Year | Total Deposited Waste | Accumulated amount of decomposable D*DOCm* Eq. 7.2.4 | Annual amount of degraded D*DOCm* Eq. 7.2.5 | Annual deposited $CH_4$ potential | Annual Gross $CH_4$ emission Eq. 7.2.6 | Recovered methane | Annual net emission before oxidation | Annual net emission after oxidation Eq. 7.2.7 | Implied emission factors | |
|---|---|---|---|---|---|---|---|---|---|---|
| | [kt] | | | [kt $CH_4$] | | | | | kt $CH_4$/kt waste | kt $CH_4$/kt D*DOCm* |
| 1990 | 3190 | 2063 | 92.9 | 87.7 | 69 | 1 | 68 | 61.5 | 0.019 | 0.030 |
| 1995 | 1969 | 2063 | 91.9 | 60.2 | 67 | 8 | 59 | 53.2 | 0.027 | 0.026 |
| 2000 | 1489 | 2009 | 86.4 | 58.9 | 59 | 11 | 48 | 42.9 | 0.029 | 0.021 |
| 2005 | 983 | 1681 | 72.7 | 5.7 | 50 | 10 | 40 | 36.4 | 0.037 | 0.022 |
| 2010 | 2487 | 1395 | 58.7 | 3.3 | 40 | 6 | 34 | 30.9 | 0.012 | 0.022 |
| 2013 | 1390 | 1257 | 52.0 | 6.0 | 35 | 4 | 31 | 28.1 | 0.020 | 0.022 |
| 2014 | 1330 | 1213 | 49.9 | 5.1 | 34 | 3 | 31 | 27.5 | 0.021 | 0.023 |
| 2015 | 987 | 1172 | 47.9 | 4.8 | 32 | 3 | 29 | 26.0 | 0.026 | 0.022 |
| 2016 | 1025 | 1132 | 46.0 | 4.7 | 31 | 4 | 27 | 24.7 | 0.024 | 0.022 |
| 2017 | 706 | 1093 | 44.2 | 4.4 | 30 | 4 | 26 | 23.5 | 0.033 | 0.022 |
| 2018 | 700 | 1056 | 42.4 | 3.6 | 29 | 4 | 25 | 22.4 | 0.032 | 0.021 |

The total waste amount in the second column of Table 7.2.6 is the sum of the amounts of the 18 different waste types (Table 7.2.3). The total waste amount is reported as the activity data for the Annual Municipal Solid Waste (MSW) at SWDSs in the CRF Table 5.A.

The implied emission factors (IEFs) in the second last column in Table 7.2.6 reflects an aggregated emission factor calculated as the net methane emission divided by the total amount of waste deposited in the current year and corresponds to the reported IEFs in the CRF Table 5.A. However, the IEF values in the last column in Table 7.2.6 represents more appropriate IEF values, i.e. calculated as the net methane emission divided by the total amount of decomposable degradable organic matter, D*DOCm*. The D*DOCm* are provided in in Table 7.2.6.

The trend in the total amount of decomposable DOC accumulated at the Danish landfills and amount annual degraded organic matter, provided in the third and fourth column in Table 7.2.6, shows that the percent degraded decreases slightly from 4.5 % in 1990 to 4.0 % in 2018.

Figure 7.2.3 visualises the trend in the annual deposited methane potential, the annual gross emission, the annual amount of recovered methane and the net methane emission with and without methane oxidation.

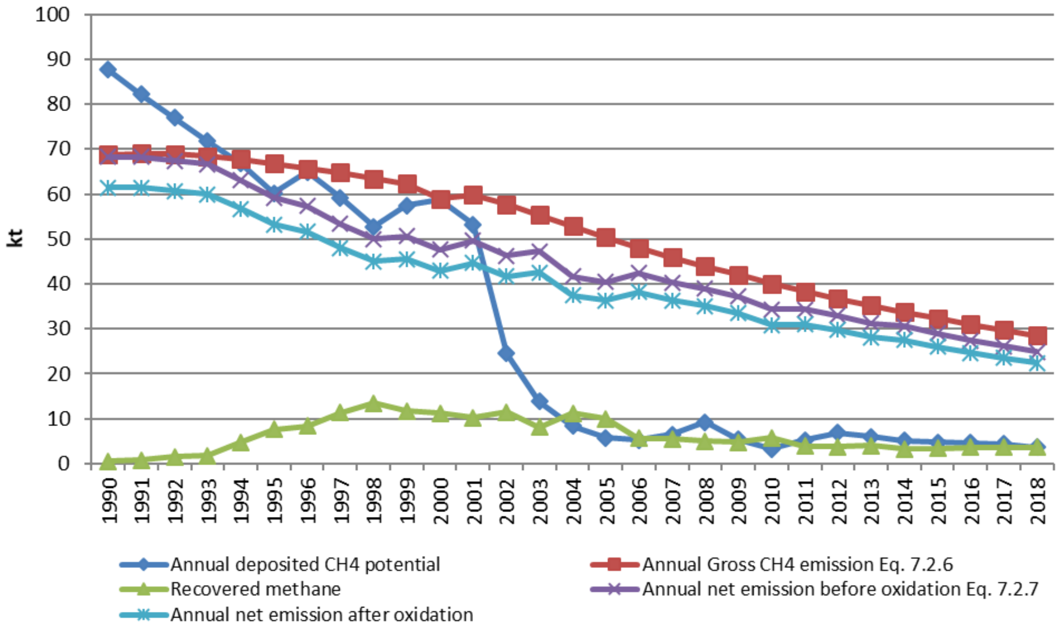



Figure 7.2.3 Time trend in the annual deposited methane potential, gross methane emission, recovered methane, annual net methane emission before and after oxidation.

In total, a reduction in the net methane emission from 1990 to 2018 of 63.5 % is observed. This reduction in the methane emission is accompanied by a decrease in the accumulated amount of decomposable degradable organic matter (D*DOCm*) of 48.8 % and in the annual amount of deposited methane potential which is reduced by 95.9 % 2018 compared to 1990. The fluctuation in the net methane emission is explained by the fluctuations in the annual amount of deposited methane potential and the amount of recovered methane.

## 7.3 Biological treatment of solid waste

This sector provides an overview of the Danish greenhouse gas emission from the CRF source category *5.B Biological treatment of solid waste,* which consists of the presently of the *sub-category 5.B.1 Composting,* while documentation for the methane emissions from anaerobic sludge digestion is presented in Chapter 7.3.2 and 7.5 respectively.

### 7.3.1 Composting

This section covers the sub-category of biological treatment of solid wastes called composting. Greenhouse gasses that are emitted from this process are $CH_4$. $N_2O$ and $CO_2$ as presented in Table 7.3.1. $CO_2$ emissions from compost production are biogenic. The full time series for emissions related to composting are shown in Annex 3F, Table 3F-3.1.

Table 7.3.1 National emissions from composting, t.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $CH_4$ | 1 387 | 1 859 | 3 241 | 3 420 | 3 831 | 3 731 | 3 689 | 3 978 | 4 008 | 4 335 | 4 272 |
| $N_2O$ | 41 | 70 | 513 | 198 | 289 | 263 | 247 | 218 | 268 | 277 | 280 |

The whole time series is visualised in figure 7.3.1 showing a steady increase in the $CH_4$ emissions correlated to the pattern in the AD excluding sludge explained by the minor size of the $CH_4$ EF value for sludge compared to the remaining three biowaste types treated at the Danish composting plants (see Table 7.3.4). The $N_2O$ emissions, however, are explained by the significant increase in the amount of sludge being composted in the period 1999 to 2003 as shown in Figure 7.3.2 (and Annex 3F, Table 3F-3.2) and a high $N_2O$ EF value for sludge compared to the remaining biowaste types (Table 7.3.4).

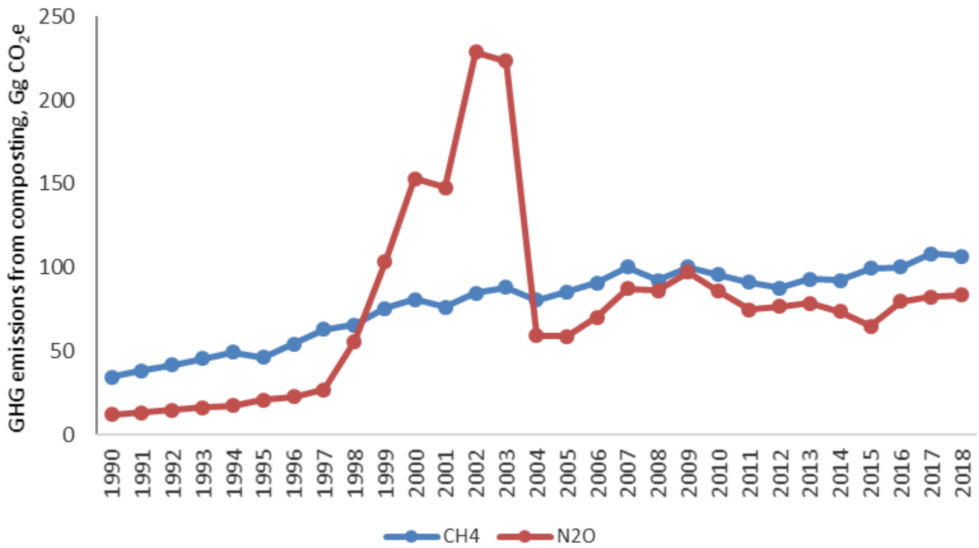



Figure 7.3.1 Time trend for $N_2O$ and $CH_4$ emissions from composting plants.

**Methodological issues**

Emissions from composting have been calculated using both IPCC default emission factors and other emission factors considered country-specific, corresponding to a hybrid tier 1/tier 2 methodology.

In Denmark, composting of solid biological waste includes composting of:

- garden and park waste (GPW)
- organic waste from households and other sources
- sludge
- home composting of garden and vegetable food waste

In 2017, 150 composting facilities treated only garden and park waste (type 2 facilities), nine facilities treated organic waste mixed with GPW or other organic waste (type 1 facilities) and 10 facilities treated GPW mixed with sludge and/or “other organic waste” (type 3 facilities). 92 % of these facilities consisted entirely of windrow composting, which is a simple technology composting method with access to only natural air. It is assumed that all facilities can be considered using windrow composting (Petersen & Hansen, 2003).

Composting is performed with simple technology in Denmark; this implies that temperature, moisture and aeration are not consistently controlled or regulated. Temperature is measured but not controlled, moisture is regulated by watering the windrows in respect to weather conditions and aeration is assisted by turning the windrows (Petersen & Hansen, 2003).

During composting, a large fraction of the degradable organic carbon (DOC) in the waste material is converted into $CO_2$. Even though the windrows are occasionally turned to support aeration, anaerobic sections are inevitable and will cause emissions of $CH_4$. In the same manner, aerobic biological digestion of N leads to emission of $N_2O$ (IPCC, 2006).

#### Activity data

All Danish waste treatment plants are obligated to statutory registration and reporting of all waste entering and leaving the plants. All waste streams are weighed, categorised with a waste type and a type of treatment and registered to the ISAG waste information system, which contain data for 1995-2009 (ISAG). Activity data for 2010-2018 have been received from the Danish EPA. The approach of last year's submission was based on the assumption of the distribution of the total amount composted across waste types to be equal to 2009 (Nissen, 2017a). For 2010-2017, data from the new waste reporting system (www.ads.mst.dk) have been corrected by subtracting the amount of biowaste going to biogasification (sub-category 5.B.2). Such subtraction are based on plant level data on biowaste going to composting and biogasification respectively (DEPA, Ellen Nissen, personal communication). AD for each biowaste type, for the whole time series, are provided in Annex 3F, Table 3F-3.2.

Figure 7.3.2 illustrates the composted amount of waste divided in the four categories mentioned earlier.

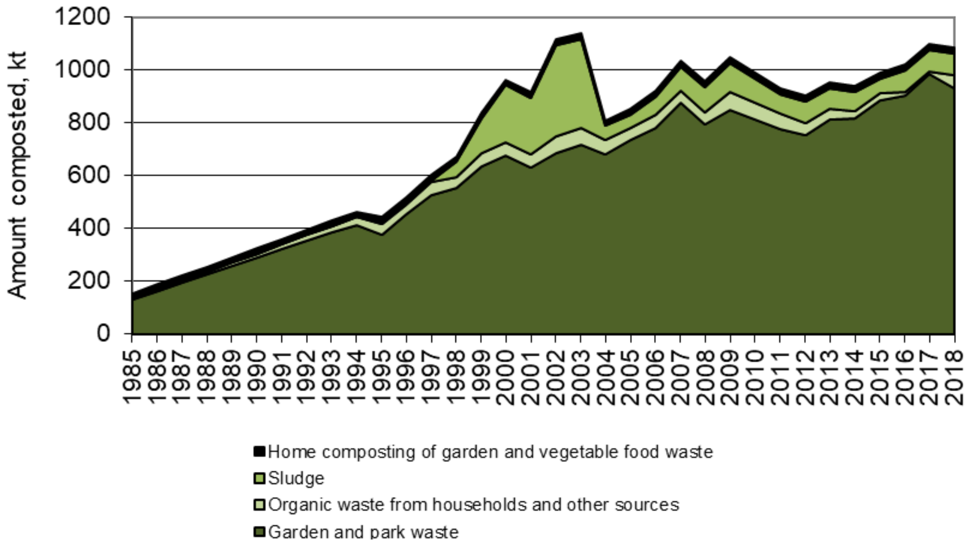



Figure 7.3.2 Trends in the national amount of composted waste.

Activity data for the years 1995-2009 are collected from the ISAG database for the categories: "sludge", "organic waste from households and other sources" and "garden and park waste". For 2010 to 2018 European Waste Codes (EWC) were applied to quantify biowaste according to types of biowaste composted.

The Danish legislation on sludge (DEPA, 2006c) was implemented in the summer of 2003. This stated that composted sludge must only be used as a fertilizer on areas not intended for growing foods of any kind for at least 2-

3 years. This restriction caused the amount of composted sludge to drop drastically from 2003 to 2004.

The trend in composting of sludge does not demonstrate a convincing trend that can be used for estimation of activity data for previous years. Since this activity is insignificant for 1995-1997 (1-2 %) it is assumed to be "not occurring" for 1990-1994.

The amount of organic waste from households composted in the years 1990-1994 is estimated by multiplying the number of facilities treating this type of waste with the average amount composted per facility in the years 1995-2001 (2.6-3.8 kt per facility per year). The following Table 7.3.2 shows the number of composting sites divided in the three types, where type 1 is mainly receiving source separated organic waste, type receive only garden and park waste, while type 3 receive garden park waste in combination with other organic waste types (Petersen, 2001 and Petersen & Hansen, 2003).

Table 7.3.2 Number of composting facilities in the years 1990-2001.

| Facility type | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2010-2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type 1 | 5 | 6 | 7 | 8 | 9 | 13 | 14 | 13 | 14 | 13 | 11 | 9 | |
| Type 2 | 38 | 54 | 70 | 86 | 102 | 113 | 108 | 99 | 102 | 111 | 115 | 123 | |
| Type 3 | 1 | 2 | 2 | 3 | 4 | 9 | 9 | 11 | 10 | 10 | 7 | 10 | |
| Total | 44 | 62 | 79 | 97 | 115 | 136 | 133 | 126 | 130 | 139 | 138 | 149 | 110* |

Type 1 waste treatment sites normally includes biogas-producing facilities, but these have been excluded in Table 7.3.1.

*The number of composting plants in the dataset received by the Danish EPA for the period 2010-2017.

The ISAG activity data for composting of garden and park waste (GPW) include wood chipping. Compost data for GPW provided by Petersen (2001) and Petersen & Hansen (2003) show that for 1997-2001, wood chipping accounts for about 3 % of the total chosen ISAG activity data for GPW. Activity data for GPW for the years 1985-1994 are estimated by extrapolating the trend.

The last waste category involved in composting is home composting of garden waste and vegetable waste. The activity data for this category are known from Petersen & Kielland (2003) to be 21.4 kt in 2001. It is assumed that the following estimates made by Petersen & Kielland (2003) are valid for all years 1990-2018.

- 28 % of all residential buildings with private gardens (including summer cottages) are actively contributing to home composting.
- 14 % of all multi-dwelling houses are actively contributing to home composting.
- On average, 50 kg waste per year will be composted at every contributing residential building.
- On average, 10 kg waste per year will be composted at every contributing multi-dwelling house.

Multi-dwelling houses include apartment buildings. It is very un-common for people in these types of buildings to compost their bio waste and the average amount of composted waste is therefore lower in spite of the higher number of residents. The total number of occupied residential buildings, summer cottages and multi-dwelling houses are found at the Statistics Denmark's website. The calculated activity data for composting are shown in Table 7.3.3 and in Annex 3F, Table 3F-3.2.

Table 7.3.3 Activity data composting, kt.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Composting of garden and park waste | 288 | 376 | 677 | 737 | 811 | 810 | 818 | 884 | 901 | 983 | 929 |
| Composting of organic waste from households and other sources | 16 | 40 | 47 | 45 | 65 | 42 | 24 | 29 | 16 | 12 | 53 |
| Composting of sludge | NO* | 7 | 218 | 50 | 90 | 80 | 73 | 53 | 80 | 80 | 80 |
| Home composting of garden and vegetable food waste | 20 | 21 | 21 | 22 | 23 | 23 | 23 | 23 | 23 | 23 | 23 |
| Total | 324 | 444 | 963 | 854 | 989 | 955 | 938 | 989 | 1 020 | 1 097 | 1 084 |

*Data included in the National Waste Statistics (DEPA, 2017) for composting of sludge have resulted in a reduction in the AD of 22, 41 and 57 % for the 2013, 2014 and 2015, respectively. This change in AD influences the emission from sub-category 5.B.1 as the $N_2O$ EF value for composting is significant (cf. Table 7.3.4, Annex 3F, Table 3F-7.2).

**Emission factors**

The emissions from composting strongly depend on both the composition of the treated waste and on process conditions such as aeration, mechanical agitation, moisture control and temperature pattern (Amlinger et al., 2008).

The emission factors stated in Table 7.3.4 are considered the best available for the calculation of Danish emissions from composting.

Table 7.3.4 Emission factors for composting.

| | Garden and park waste (GPW) | Organic waste from households and other sources | Sludge | Home composting of garden and vegetable food waste |
|---|---|---|---|---|
| Unit | kg per Mg | kg per Mg | kg per Mg | kg per Mg |
| $CH_4$ | 4.20 | 4.00 | 0.41 | 5.63 |
| $N_2O$ | 0.12 | 0.24 | 1.92 | 0.11 |
| Source | Boldrin et al., 2009 | IPPC, 2006 EEA, 2009 | MST, 2013 | Boldrin et al., 2009 |

Emission factors for composting of GPW and for home composting of garden and vegetable food waste are derived from Boldrin et al. (2009). No other sources were found that describe the emission from home composting.

Boldrin et al. (2009) and MST (2013) do not directly provide any emission factors, the following assumptions were made to derive the factors shown in Table 7.3.3:

- 0.5 % N per dry matter waste water sludge
- 25 % moisture in wastewater sludge.
- 2 % N per dry matter garden waste (incl. home composting)
- 25-50 % DOC per dry matter garden waste (incl. home composting)
- 50 % moisture in garden waste (incl. home composting)

The $CO_2$ produced and emitted during composting is short-cycled C and is therefore regarded as $CO_2$ neutral (Boldrin et al., 2009).

### 7.3.2 Anaerobic digestion at biogas plants

Biogas production in this sector covers emissions from the handling of biological waste including garden and park waste, household waste, sludge and manure.

Methane emission from biogas plants using landfill gas as feedstock is implicitly included in the CRF source category *5.A.1. Managed Waste Disposal Sites*, as the collected biogas is monitored in terms of energy production subtracted from the yearly methane release from SWDS in Denmark.

Emissions from storage of manure are included in the agricultural sector (cf. Chapter 5).

Emissions from anaerobic digestion at wastewater treatment plants are included in the inventory for the CRF source category *5.B. Wastewater treatment and discharge*. Fugitive emissions of $CH_4$ from anaerobic digestion of sludge have been set equal to 1.3 % of the biogas production (Thomsen, 2016) as reported in the Danish Energy Statistics, and are included in Chapter 7.5. In the below section a presentation of status for available plant level data on the loss of methane via flaring and venting from WWTP using anaerobic sludge digestion as sludge management strategy is provided.

#### Flaring and venting from biogas production at WWTPs

Flaring and venting may occur in different degrees at WWTPs, which have implemented anaerobic treatment of sludge for biogas generation. Venting may occur intentionally or unintentionally if there are technical problems at the plant. Flaring is intentional combustion of biogas and occurs for regulation of the gas pressure.

Table 7.3.5 presents available information on the amount of flared and vented biogas in absolute numbers as well as in per cent of the recovered biogas at three of the biggest wastewater treatment plants in Denmark as further detailed in Thomsen (2016).

Table 7.3.5 Biogas production data for the WWTPs Lynetten, Avedøre and Damhusåen.

| WWTP | | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|
| **Lynetten**[1] | | | | | | | |
| Biogas produced | Nm$^3$/year | | 6 330 381 | 5 942 571 | 5 792 838 | 6 695 142 | 7 154 932 |
| Flaring | Nm$^3$/year | | 284 615 | 659 576 | 494 972 | 946 468 | 903 613 |
| | % | | 4.50 % | 11.10 % | 8.54 % | 14.14 % | 12.63 % |
| Venting | Nm$^3$/year | | NR | NR | NR | NR | NR |
| | % | | NR | NR | NR | NR | NR |
| Biogas consumed at plant | Nm$^3$/year | | 6 045 766 | 5 282 995 | 5 297 866 | 5 748 674 | 6 251 319 |
| Biogas reported to DEA[3] | Nm$^3$/year | 4 417 670 | 4 953 913 | 4 650 708 | 4 533 525 | 3 969 338 | 6 251 318 |
| | % | | 82 % | 88 % | 86 % | 69 % | 100 % |
| **Avedøre**[3] | | | | | | | |
| Biogas produced | Nm$^3$/year | 3 300 000 | 3 400 000 | 3 100 000 | 3 300 000 | 3 100 000 | 3 300 000 |
| Flaring | Nm$^3$/year | 140 000 | 140 000 | 54 000 | 170 000 | 36 000 | 10 000 |
| | % | 4.24 % | 4.12 % | 1.74 % | 5.15 % | 1.16 % | 0.30 % |
| Venting | Nm$^3$/year | 0 | 2661 | 9179 | 54400 | 130063 | 50246 |
| | % | 0 % | 0.08 % | 0.30 % | 1.65 % | 4.20 % | 1.52 % |
| Biogas consumed at plant | Nm$^3$/year | 3 200 000 | 3 300 000 | 3 000 000 | 3 200 000 | 2 900 000 | 3 300 000 |
| Biogas reported to DEA[3] | Nm$^3$/year | 2 874 932 | 3 161 242 | 2 813 589 | 2 769 597 | 2 581 438 | 2 966 742 |
| | % | 90 % | 96 % | 94 % | 87 % | 89 % | 90 % |
| **Damhusåen**[2] | | | | | | | |
| Biogas produced | Nm3/year | | 2 690 037 | 1 665 416 | 2 123 357 | 1 997 333 | 1 918 325 |
| Flaring | Nm3/year | | 57 750 | 57 750 | 307 335 | 94 150 | 236 950 |
| | % | | 2.15 % | 3.47 % | 14.47 % | 4.71 % | 12.35 % |
| Venting | Nm3/year | | NR | NR | NR | NR | NR |
| | % | | NR | NR | NR | NR | NR |
| Biogas consumed at plant | Nm3/year | | 2 632 287 | 1 607 666 | 1 816 022 | 1 903 183 | 1 681 375 |
| Biogas reported to DEA[3] | Nm3/year | | NR | NR | NR | NR | NR |
| | % | | NR | NR | NR | NR | NR |

[1]Lynettefællesskabet (2009, 2010, 2011, 2012, 2013, 2014); [2]Spildevandscenter Avedøre (2012, 2013, 2014); [3]DEA (2014); [4]NR:Not Reported.

As may be observed from Table 7.3.5, the amount of flaring is varying from year to year for the same plant as well as between WWTPs. The average flaring is 10 % at Lynetten (data for five years), 2.8 % at Avedøre (data for six years) and 7.4 % at Damhusåen (data for five years). Venting is only reported for Avedøre and constitute in average 1.3 % of the produced amount of biogas. Work is ongoing to extend the documentation for flaring and venting at biogas producing WWTPs (cf. Chapter 7.5).

The methodology used for estimating the $CH_4$ and $N_2O$ emissions from wastewater handling are described in Chapter 7.5.

#### Fugitive emissions from anaerobic digestion of organic waste

Emissions of $CH_4$ from biogas plants occur from stacks and ventilation during several stages of the process, e.g. ventilation in the receiving hall of the plant, from the emergency flare and from upgrading units.

Emissions that are more significant occur from leakages in the production equipment and pipelines. These leakages are by nature very variable from plant to plant and as such difficult to quantify at a national level.

The 2006 IPCC Guidelines consider emissions from biogas plants (anaerobic digestion) as part of the waste sector. According to the 2006 IPCC Guidelines, emissions of $CH_4$ from such facilities due to unintentional leakages during process disturbances or other unexpected events will generally be between 0 and 10 % of the amount of $CH_4$ generated. In the absence of further information, use 5 percent as a default value for the $CH_4$ emissions (IPCC, 2006).

A Danish project measured leakages from nine biogas plants in Denmark. The results are reported in DEA (2015). Five of the plants were small farm-based plants while the other four were larger plants. The results were that the $CH_4$ leakage varied from nil to 10 % of the production. The largest leakage rates were detected for the larger plants. The weighted average for the nine plants was 4.2 % and the adopted emission factor, EF, set equal to 0.42 (Eq. 7.3.1).

The activity data and resulting emissions are estimated according to equation 7.3.1 and shown in Table 7.3.6 below.

$$CH_{4,mbb} = (E : NCV) \cdot EF_{mbb} \quad \text{Eq. 7.3.1}$$

where $CH_{4,mbb}$ is the methane emission from manure-based biogas, E is energy production included in the annual energy statistics, divided by the net calorific value (*NCV*) of $CH_4$ of 50 GJ per tonnes (Morvay and Gvozdenac, 2009) and multiplied by the EF value of 0.42.

Table 7.3.6 Activity data and emissions from anaerobic digestion of organic waste.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Biogas production, TJ | 266 | 746 | 1 442 | 2 375 | 3 184 | 3 434 | 4 359 | 5 199 | 7 795 | 9 882 | 12 244 |
| $CH_4$ production, tonnes | 5 328 | 14 917 | 28 834 | 47 504 | 63 682 | 68 679 | 87 176 | 103 970 | 155 902 | 197 639 | 240 078 |
| $CH_4$ emission, tonnes | 224 | 627 | 1 211 | 1 995 | 2 675 | 2 885 | 3 661 | 4 367 | 6 548 | 8 301 | 10 083 |

## 7.4 Incineration and open burning

The CRF source category *5.C. Incineration and open burning* includes cremation of human bodies and animal carcasses.

Incineration of municipal, industrial, clinical and hazardous waste takes place with energy recovery and therefore the emissions are included in the relevant subsectors under CRF sector 1A. For documentation, please refer to Chapter 3.2. Flaring off-shore and in refineries are included under CRF sector 1B2c, for documentation please refer to Chapter 3.5. No flaring in chemical industry occurs in Denmark.

Table 7.4.1 gives an overview of the Danish greenhouse gas emission from the CRF source category *5.C Incineration and open burning* comprised by emission from human and animal cremations. $CO_2$ emissions from animal and human cremations are considered biogenic.

Table 7.4.1 Methane and Nitrous oxide emissions from human and animal cremations, tonnes.

| Year | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **$CH_4$ emission from** | | | | | | | | | | | |
| Human cremation | 0.48 | 0.52 | 0.49 | 0.48 | 0.49 | 0.50 | 0.49 | 0.51 | 0.51 | 0.52 | 0.54 |
| Animal cremation | 0.03 | 0.04 | 0.08 | 0.14 | 0.26 | 0.21 | 0.21 | 0.20 | 0.21 | 0.21 | 0.21 |
| Total | 0.51 | 0.55 | 0.57 | 0.62 | 0.76 | 0.71 | 0.70 | 0.71 | 0.73 | 0.73 | 0.76 |
| **$N_2O$ emission from** | | | | | | | | | | | |
| Human cremation | 0.60 | 0.64 | 0.61 | 0.60 | 0.62 | 0.62 | 0.61 | 0.64 | 0.64 | 0.65 | 0.68 |
| Animal cremation | 0.03 | 0.05 | 0.10 | 0.17 | 0.33 | 0.26 | 0.26 | 0.25 | 0.27 | 0.26 | 0.26 |
| Total | 0.64 | 0.69 | 0.71 | 0.77 | 0.95 | 0.88 | 0.87 | 0.89 | 0.91 | 0.91 | 0.95 |
| Total human cremation $CO_2$ eqv. | 192 | 205 | 195 | 191 | 197 | 198 | 194 | 202 | 205 | 207 | 217 |
| Total animal cremation $CO_2$ eqv. | 11 | 14 | 32 | 55 | 104 | 82 | 83 | 80 | 85 | 84 | 84 |

While emissions from human cremations have been steady over the last two decades, emissions from animal cremations have increased. In 1990, animal cremations represented 5.3 % of the total emission of $CO_2$ equivalents from cremations. In 2018, this number has increased to 28 %. Emissions for the whole time series are provided in Annex 3F, Table 3F-4.1.

### 7.4.1 Human cremation

The incineration of human corpses is a common practice that is performed on an increasing part of the deceased. All Danish crematoria use optimised and controlled cremation facilities with temperatures reaching 800-850 °C, secondary combustion chambers, controlled combustion airflow and regulations for coffin materials.

#### Methodological issues

During the 1990s, all Danish crematoria were rebuilt to meet new standards. This included installation of secondary combustion chambers and in most cases replacement of old primary combustion chambers (Schleicher et al., 2001). All Danish crematoria are therefore performing controlled incinerations with a good burnout of the gases and a low emission of pollutants.

Following the development of new technology, the emission limit values for crematoria were lowered again in January 2011. These new standards were originally expected from January 2009 but were postponed two years for existing crematoria. Table 7.4.2 shows a comparison of the emission limit values from February 1993 and the new standard limits.

Table 7.4.2 Emission limit values, mg per $Nm^3$ at 11 % $O_2$ (Schleicher & Gram, 2008).

| Component | Report 2/1993 | Standard terms (1/2011) |
|---|---|---|
| | Emission limit value mg per normal $m^3$ at 11 % $O_2$ | |
| CO | 500 | 500 |
| Other demands: | | |
| Stack height | 3 m above rooftop | 3 m above rooftop |
| Temperature in stack | Minimum 150 °C | Minimum 110 °C |
| Flue gas flow in stack | 8 – 20 m/s | No demands |
| Temperature in after burner | 850 °C | 800 °C |
| Residence time in after burner | 2 seconds | 2 seconds |

To meet the new standards, some crematoria have been rebuilt to larger capacity while others are closed (MILIKI, 2006). In 2018, there were 19 operating crematoria in Denmark, some with multiple furnaces. In 2010, there were 31 operating crematoria (DKL, 2019).

Crematoria that are not closed are equipped with flue gas cleaning (bag filters with activated carbon) and use of air pollution control devices. The use of air pollution control devices will however not affect the greenhouse gas emissions.

Around half of the Danish crematoria are currently connected to the district heating system and in addition, a few crematoria produce heat for use in their own buildings. The bag filter cleaning system requires that the flue gas is cooled down to 125-150 °C, and the cheapest way to do so is to use the surplus heat in the district heating system (DKL, 2009). The heat contribution from crematoria is negligible compared to the total district heat production and is not part of the Danish energy statistics. Therefore, it is not included in the Energy sector.

### Activity data

Table 7.4.3 shows the time series of total number of nationally deceased persons (Statistics Denmark, 2019), number of cremations and the fraction of cremated corpses in relation to the total number of deceased (DKL, 2019). Annex 3F, Table 3F-4.2 presents data for the entire time series 1990-2018.

Table 7.4.3 Data human cremations, DKL (2018), Statistics Denmark (2018).

| Year | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nationally deceased | 60 926 | 63 127 | 57 998 | 54 962 | 54 368 | 52 471 | 51 340 | 52 555 | 52 824 | 53 261 | 55 232 |
| Cremations | 40 991 | 43 847 | 41 651 | 40 758 | 42 050 | 42 349 | 41 532 | 43 238 | 43 792 | 44 209 | 46 340 |
| Cremation fraction, % | 67.3 | 69.5 | 71.8 | 74.2 | 77.3 | 80.7 | 80.9 | 82.3 | 82.9 | 83.0 | 83.9 |

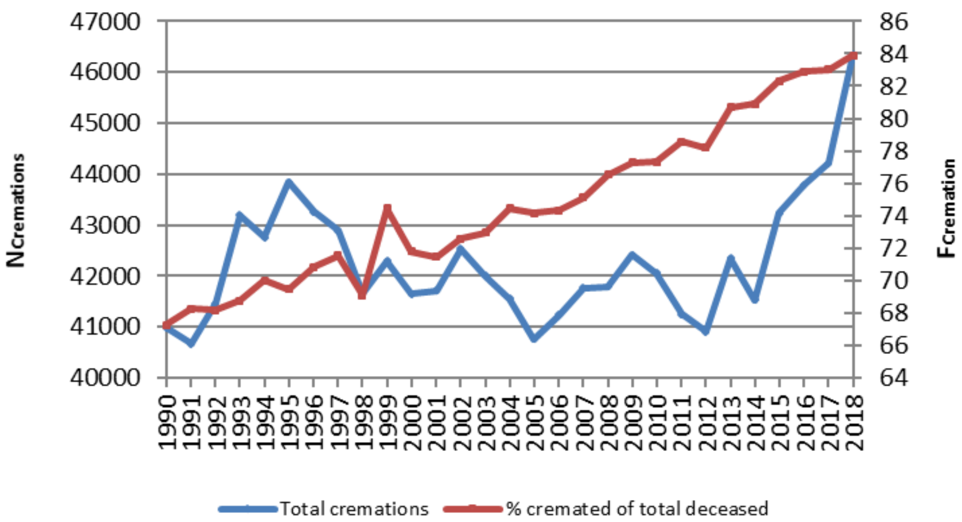



Figure 7.4.1 Visualisation of the development in cremations (DKL, 2018) where the number of cremation, $N_{cremations,}$ is shown at the left Y-axis. The cremation percentage, $F_{cremations}$, shows the percentage of cremated deceased of the total number of deceased for the years 1990-2018.

Even though the total number of annual cremations is fluctuating, the cremation percentage has been steadily increasing since 1990. The average body weight is assumed to be 65 kg (EEA, 2016).

Figure 7.4.2 presents the trend of the number of deceased persons together with the activity data for human cremation. The figure shows a direct connection between the number of deceased and the activity of human cremation as the two trends are quite similar. Figure 7.4.2 also shows the effect of the increasing fraction of cremations per deceased, as the number of cremations is not decreasing along with the number of deceased.

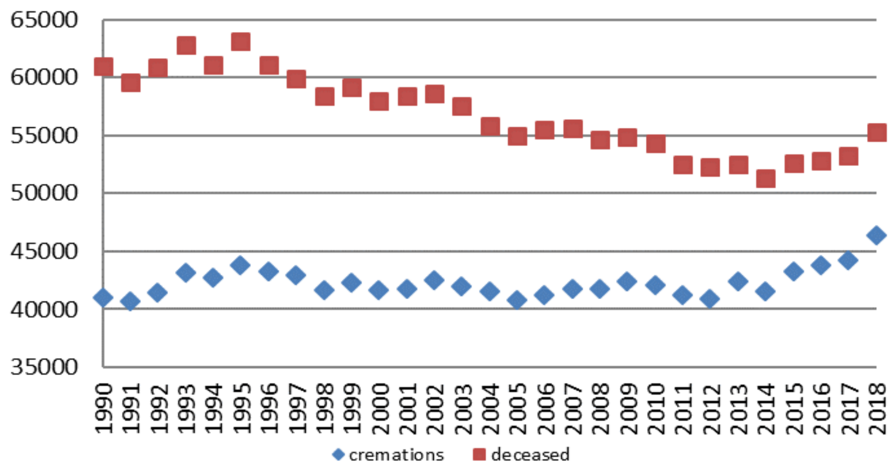



Figure 7.4.2 Trends of the activity data for cremation of human corpses and the national number of deceased persons.

#### Emission factors

For human cremation, emissions are calculated by multiplying the total number of human cremations by the emission factors. Since there are no continuous measurements available of the annual emission from Danish crematoria, the estimation of emissions is based on emission factors from literature.

A literature search has provided the emission factors shown in Table 7.4.4. It has not been possible to find any additional data to validate the emission factors.

Table 7.4.4 Emission factors for human cremation with references.

| Pollutant name | Unit | Emission factor | Reference |
|---|---|---|---|
| $CH_4$ | g/body | 11.8 | Aasestad, 2008 |
| $N_2O$ | g/body | 14.7 | Aasestad, 2008 |

### 7.4.2 Animal cremation

The incineration of animal carcasses in animal crematoria follows much the same procedure as human cremation. Animal crematoria use similar two chambered furnaces and controlled incineration. However, animal carcasses are incinerated in special designed plastic (PE) bags rather than coffins. Emissions from animal cremation are similar to those from human cremation.

Animal cremations are performed in two ways, individually where the owner often pays for receiving the ashes in an urn or collectively which is most often the case with animal carcasses that are left at the veterinarian.

#### Methodological issues

Open burning of animal carcasses is illegal in Denmark and is not occurring, and small-scale incinerators are not known to be used at Danish farms. Livestock that is diseased or in other ways unfit for consumption is disposed of through rendering plants. Incineration of livestock carcasses is illegal and these carcasses are therefore commonly used in the production of fat and soap at Daka Bio-industries.

The only animal carcasses that are approved for cremation in Denmark are deceased pets and animals used for experimental purposes, where the incineration must take place at a specialised animal crematorium. There are four animal crematoria in Denmark but one of these is situated at a waste incineration company in northern Jutland called AVV. The specially designed cremation furnaces are at this location connected to the flue gas cleaning equipment of the municipal waste incineration plant with energy recovery and the emission from the cremations are therefore included in the annual inventory from AVV and consequently included under the energy sector in this report. Therefore, only three animal crematoria are included in this section.

Animal by-products are regulated under the EU commission regulation no. 142/2011. This states that animal crematoria must be approved by the authority and comply either with the EU directive (2000/76/EC) on waste incineration or with Regulation (EC) No. 1069/2009 (EC, 2009).

The incineration of animal carcasses is, as the incineration of human corpses, performed in special incineration chambers. All Danish animal crematoria have primary combustion chambers with temperatures around 850 ºC and secondary combustion chambers with temperatures around 1100 ºC. The support fuel used at the Danish facilities is natural gas.

#### Activity data

Activity data for animal cremation are gathered directly from the animal crematoria. There is no national statistics available on the activity from these facilities. The precision of activity data therefore depends on the information provided by the crematoria.

Table 7.4.5 lists the four Danish animal crematoria, their foundation year and provides each crematorium with an id letter.

Table 7.4.5 Animal crematoria in Denmark.

| Id | Name of crematorium | Founded in |
|---|---|---|
| A | Dansk Dyrekremering ApS | May 2006 |
| B | Ada's Kæledyrskrematorium ApS | Unknown, Has existed for more than 30 years |
| C | Kæledyrskrematoriet | 2006 |
| D | Kæledyrskrematoriet v. Modtage-station Vendsyssel I/S | - |

Crematoria D is situated at the AVV municipal waste incineration site and the emissions from this site are, as previously mentioned, included in the annual emission reporting from AVV and consequently included in the energy sector in this report as waste incineration with energy recovery. Therefore, only crematoria A-C are considered in this chapter.

Table 7.4.6 lists the activity data for animal crematoria A-C. The entire dataset for 1990-2018 is available in Annex 3F, Table 3F-4.3.

Table 7.4.6 Activity data. Source: direct contact with all Danish crematoria.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total. tonnes | 150 | 200 | 443 | 762 | 1,449 | 1,146 | 1,161 | 1,119 | 1,187 | 1,162 | 1,169 |

Crematorium B delivered exact annual activity data for the years 1998-2011 and 2015-2018. They were not certain about the founding year but believe to have existed since the early 1980es. Activity data for 1990-1997, 2012, 2013 and 2014 has therefore been estimated by expert judgement by DCE. It is not possible to extrapolate data back to 1990 because the activity, due to the steep trend line, in this case would become negative.

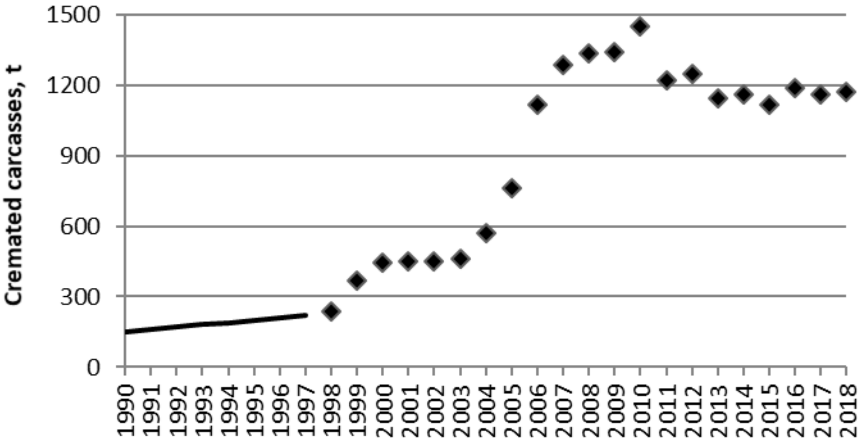



Figure 7.4.3 The amount of animal carcasses cremated (t). Data from 1998-2018 are delivered by the crematoria and is considered to be exact; these data are marked as points. Data from 1990-1997 are estimated and are shown as the thick line in the figure.

#### Emission factors

Concerning the incineration of animal carcasses in animal crematoria there is not much literature to be found.

Emission factors for $CH_4$ and $N_2O$ are collected from the literature search on human cremation and it is assumed that humans and animals are similar in composition for this purpose. Emission factors from human cremation are recalculated to match the activity data for animal cremation. Table 7.4.7 lists the emission factors and their respective references.

Table 7.4.7 Emission factors for animal cremation.

| Pollutant name | Unit | Emission factor | Reference |
|---|---|---|---|
| $CH_4$ | g/t | 182 | Aasestad, 2008 |
| $N_2O$ | g/t | 226 | Aasestad, 2008 |

## 7.5 Wastewater treatment and discharge

The Danish wastewater treatment system is characterised by few big and advanced wastewater treatment plants (WWTPs) and many smaller WWTPs. From 1993 to 2014, the amount of wastewater treated at the most advanced technological WWTPs in Denmark has increased from 53 % to above 90 %. Improvements of the decentralised wastewater treatment systems as well as the sewer system are on-going in Denmark (DEPA, 2010b). For the part of the population, which is not connected to the collective sewer system, i.e. scattered houses, septic sludge are collected once per year or as appropriate by judgement of the local authorities (DEPA, 1999b). Municipal collection and transportation of sludge from septic tanks for treatment at the centralised WWTPs occurs at a frequency set by the local authorities and in general, septic tanks are emptied one time each year.

A presentation of methodological approach, emission factors, activity data and recalculations are presented in the following sub-chapters.

### 7.5.1 Source category description

This source category includes an estimation of the emission of $CH_4$ and $N_2O$ from wastewater handling; i.e. wastewater collection and treatment. $CH_4$ is produced during anaerobic conditions and treatment processes, while $N_2O$ may be emitted as a by-product from nitrification and denitrification processes under anaerobic as well as aerobic conditions (e.g. Adouani et al., 2010; Kampschreur et al., 2009).

Wastewater streams from households and industries are increasing mixed in the sewer system prior to further treatment at centralised WWTPs. The contribution from the industry to the influent wastewater at the centralised WWTPs has increased from zero in 1987 to around 40 % from 2006 (Table 7.5.3) with the highest influent contribution occurring at the biggest and most advanced technological WWTPs in Denmark (DNA, 2010; Thomsen, 2016).

Documentation for the fraction of the population not connected to the sewer system is still missing, and therefore the fraction of the population not connected to the collective sewer system is kept at 10 % (DEPA, 2015; Thomsen, 2016).

Regarding diffuse emissions from the sewer system, very little data are available (e.g. Lyngby-Taarbæk Kommune, 2014). It is known that centralized wastewater treatment plants are associated with increased residence times, which increases the risk of the occurrence of bottom sediments and thus biological decomposition of organic matter in the sewage system. However. The sewer system is hydraulically designed to prevent the accumulation of bottom sediments and under such conditions, temporary anaerobic processes will be dominated by fermentation and sulphate reduction, which means that the possibility of methane formation may be ignored (DANVA, 2008; DANVA, 2011; Hvitved-Jacobsen, 2001).

The indirect $N_2O$ emissions from separate industries are included, as effluent N-data are available from the National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environments (NOVANA) (DEPA, 1994, 1996b, 1997, 1998b, 1999b, 2000, 2001c, 2002b, 2003b, 2004c, 2005b, 2005c and DNA, 2007, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020). In this year´s NIR, the direct $N_2O$ from separate industries have been included for the first time based on data on the treatment efficiency of industrial wastewater treatment plants. The methodological approach are described in Thomsen (2016) and in chapter 7.5.2.

#### Methane emission

Fugitive methane emissions from the municipal and private WWTPs have been divided into contributions from 1) the sewer system, primary settling tank and biological N and P removal processes, 2) from anaerobic treatment processes in closed systems with biogas recovery for energy production and 3) septic tanks. The individual contribution to the net methane emission is given in Table 7.5.1, data for the whole time series is provided in Annex 3F, Table 3F-5.1.

Table 7.5.1 Produced, recovered and emitted $CH_4$ from wastewater treatment, kt.

| Year | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Biogas production, TJ | 458 | 598 | 857 | 913 | 840 | 938 | 1029 | 901 | 1057 | 975 | 1 002 |
| $CH_{4,AD,gross}$ | 12.69 | 18.43 | 21.20 | 20.87 | 21.28 | 22.33 | 24.58 | 21.61 | 24.83 | 24.10 | 24.83 |
| $CH_{4,recovery}$ | 12.57 | 18.27 | 20.97 | 20.63 | 21.06 | 22.08 | 24.30 | 21.37 | 24.55 | 23.85 | 24.56 |
| $CH_{4,AD,net}$ | 0.12 | 0.16 | 0.23 | 0.24 | 0.22 | 0.25 | 0.27 | 0.24 | 0.28 | 0.26 | 0.26 |
| $CH_{4,sewer+MB}$ | 0.22 | 0.25 | 0.27 | 0.27 | 0.28 | 0.29 | 0.29 | 0.29 | 0.28 | 0.30 | 0.30 |
| $CH_{4,st}$ | 1.30 | 1.32 | 1.35 | 1.37 | 1.40 | 1.42 | 1.43 | 1.44 | 1.45 | 1.46 | 1.47 |
| $CH_{4,total}$ | 1.64 | 1.73 | 1.85 | 1.89 | 1.91 | 1.96 | 1.99 | 1.96 | 2.01 | 2.01 | 2.03 |

Regarding the time trend, the net $CH_4$ emission from anaerobic treatment has increased 119 % from 1990 to 2018, while a less significant increase is observed in the $CH_4$ emission from the sewer system, mechanical and biological treatment is observed (35%). Lastly, the $CH_4$ emission from scattered houses not connected to the collective sewer system has increased with 13 % reflecting the increase in the number of people not connected to the collective sewer system. In total $CH_4$ emissions quantified as a sum of $CH_4$ emissions from anaerobic treatment processes, i.e. $CH_{4,AD,net}$, the sewer system, mechanical and biological treatment, i.e. $CH_{4,sewer+MB}$ and scattered houses, i.e. $CH_{4,st}$, has increased by 23 % from 1990 to 2018.

**Nitrous oxide emission**

$N_2O$ formation and releases, both during the treatment processes at the WWTPs and from discharged effluent wastewater, are included.

The emission of $N_2O$ from wastewater handling is calculated as the sum of contributions from wastewater treatment processes at the WWTPs (direct emissions) and from sewage effluents (indirect emissions). The emission from effluent wastewater, i.e. indirect emissions, includes separate industrial discharges, rainwater-conditioned effluents as well as effluents from scattered houses and from aquaculture.

Table 7.5.2 shows the total $N_2O$ emission originating from treatment processes at the Danish WWTPs (direct emissions) and effluents to the Danish surface waters (indirect emissions). The full time series 1990-2018 is shown in Annex 3F, Table 3F-5.2.

Table 7.5.2 N2O emissions from wastewater, Mg.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_2O_{\text{. indirect}}$ | 133 | 119 | 79 | 55 | 55 | 52 | 55 | 57 | 52 | 53 | 45 |
| $N_2O_{\text{. direct, seperates industries}}$ | 161 | 83 | 32 | 23 | 17 | 21 | 17 | 23 | 23 | 23 | 23 |
| $N_2O_{\text{. direct}}$ | 73 | 111 | 134 | 161 | 136 | 147 | 150 | 152 | 146 | 153 | 151 |
| $N_2O_{\text{. total}}$ | 366 | 385 | 269 | 245 | 212 | 216 | 223 | 230 | 219 | 223 | 219 |

Regarding the time trend, the indirect $N_2O$ emission has decreased 66 % $N_2O$ from 1990 to 2018, while the direct $N_2O$ emission has decreased 25 %, resulting total $N_2O$ emission has decreased 40 % from 1990 to 2018.

### 7.5.2 Methodology and data

The methodology developed for this submission for estimating emission of methane and nitrous oxide from wastewater handling follows the IPCC Guidelines (IPPC, 2006).

Monitoring data on the influent and effluent resources, i.e. N. P, biological oxygen demand (BOD) and chemical oxygen demand (COD) for the wastewater are available for all WWTPs in Denmark reported by the Danish Nature Agency, the National Focal Point for point sources. The Danish Nature Agency collects all point source data the National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environments, NOVANA. Since the late eighties annually reports documenting results from the monitoring of point sources; wastewater treatment plants, industry, rainwater conditioned effluent (storm water), scattered houses, freshwater aquaculture and mariculture. The results of point source monitoring are reported in reported yearly (DEPA, 1994, 1996b, 1997, 1998b, 1999b, 2000, 2001c, 2002b, 2003b, 2004c, 2005b, 2005c and DNA, 2007, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020).

Data on energy production from Danish wastewater treatment plant with anaerobic sludge digestion is reported in the energy statistics; data received from the Danish Energy Agency (Table 7.5.1 and Annex 3F, Table 3F-5.1). These data do not include any information on venting or flaring, which are however included in the reported gross energy production data (Tafdrup, 2014).

Data on flaring and venting have been obtained from Environmental reports (or green accounts) publish by the individual WWTPs, in some cases on a yearly basis. Data on biogas lost via venting is scarce but based on a review of plant level environmental account data reported voluntary by the WWTPs an EF value of 1.3 % of the gross energy production were applied (Table 7.5.3; Thomsen, 2016).

Country-specific data on the emission factor for direct $N_2O$ emissions are based on monitoring data as presented in Thomsen et al., 2015 and Thomsen, 2016.

This section is divided into methodological issues related to the $CH_4$ and $N_2O$ emission calculations, respectively.

**Methane emissions from private and municipal WWTPs**

The methane emissions from WWTP are divided into a contribution from the sewer system, primary settling tank and biological N and P removal processes. $CH_{4.\ sewer+MB}$, and from anaerobic treatment processes in closed systems with biogas extraction for energy production, $CH_{4.AD}$.

$$CH_{4,WWTP} = CH_{4,sewer+MB} + CH_{4,AD} \qquad \text{Eq. 7.5.1}$$

The fugitive emissions from the sewer system, primary settling tank and biological N and P removal processes, $CH_{sewer+MB}$, are estimated as:

$$CH_{4,sewer+MB} = EF_{sewer+MB} \cdot TOW_{inlet}$$
$$\Downarrow \qquad \text{Eq. 7.5.2}$$
$$CH_{4,sewer+MB} = B_o \cdot MCF_{sewer+MB} \cdot TOW_{inlet}$$

where

$\boldsymbol{TOW_{inlet}}$ equals the influent organic degradable matter measured as the chemical oxygen demand (COD) in the influent wastewater flow.

***Bo*** is the default maximum $CH_4$ producing capacity, i.e. 0.25 kg $CH_4$ per kg COD (IPCC, 2006).

$\boldsymbol{MCF_{sewer+MB}}$ is the fraction of DOC that is anaerobically converted in sewers and WWTPs. $\boldsymbol{MCF_{sewer+MB}}$ equals 0.003 based on an expert judgement (Vollertsen, 2012) of a conservative estimate of the fugitive methane emission from the primary settling tanks and biological treatment processes is well below 0.1 % of influent COD, while the fugitive emission from the sewer system is judged to be negligible or zero (DANVA, 2008; DANVA, 2011).

The emission factor, $EF_{sewer+MB,}$ for these three processes and systems equals 0.0008 kg $CH_4$ per kg COD.

<u>The methane emission from anaerobic digestion is calculated as:</u>

The gross methane emission potential from anaerobic processes, $CH_{4.AD.gross}$, is calculated as:

$$CH_{4,AD,gross} = f_{AD} \cdot MCF_{AD} \cdot B_o \cdot TOW_{inlet} \qquad \text{Eq. 7.5.3}$$

where

$f_{AD}$ is the fraction of the COD in the influent wastewater that are conserved in the ingestate set equal to 0.6 (Jensen et al., 2015; Thomsen et al., 2015).

$MCF_{AD}$, the methane correction factor, adjust the default maximum $CH_4$ producing capacity or theoretical methane yield to the expected conversion under real operating conditions and is set equal to 0.8 (IPCC, 2006).

$TOW_{inlet}$ equals the influent organic degradable matter measured as the sum of chemical oxygen demand (COD) in the influent wastewater at WWTPs using anaerobic sludge digestion in a digester tank for the production of biogas.

$B_o$ is the default maximum $CH_4$ producing capacity, i.e. 0.25 kg $CH_4$ per kg COD (IPCC, 2006). By dividing $B_o$ with the density of methane, i.e. 0.72 kg $CH_4/m^3$ t STP (Standard Temperature and Pressure), the theoretical methane yield of 0.35 $Nm^3$ $CH_4$ per kg COD is obtained, a value which, as expected, is strongly under matched in real operating conditions (DEA, 2015).

The net methane emission from anaerobic digestion in biogas tanks are at present estimated according to equation 7.5.4:

$$CH_{4,AD,net} = EF_{AD} \cdot CH_{4,AD,recovered} \qquad \text{Eq. 7.5.4}$$

where the emission factor, $EF_{AD}$, has been set equal to 1.3 % of the methane content in the gross energy production at national level reported by the Danish Energy Agency, i.e. 0.013 (Thomsen, 2016).

At the present stage of verification of activity data, equation 7.5.4 has been applied for estimating the net methane emission from anaerobic digestion of sludge, i.e. the net methane emission from anaerobic digestion equals the methane emissions due to venting (Thomsen, 2016).

### Methane emissions from septic tanks

For the part of the population not connected to the collective sewer system, simple decentralised wastewater handling is assumed and modelled as septic tanks. Only little knowledge is available about the frequency of collection and few measurements of the methane emissions from septic tanks and the pumping and management of septage, including its transportation to a wastewater treatment facility exist (Nielsen et al., 2018). The methane emission is calculated as:

$$CH_{4,st} = B_o \cdot MCF_{ST} \cdot f_{nc} \cdot P \cdot DOC_{st} \qquad \text{Eq. 7.5.5}$$

$$CH_{4,st} = EF_{st} \cdot f_{nc} \cdot P \cdot DOC_{st}$$

where

*Bo*, the default maximum $CH_4$ producing capacity of 0.25 kg $CH_4$ per kg COD (IPCC, 2006).

$MCF_{st}$ is the methane conversion factor. It depends on the extent to which COD settles in the septic tanks. The default MCF value of 0.5 (IPCC, 2006) is assuming that degradation for the settled DOC occurs at 100 % anaerobic conditions.

Using the default maximum methane producing capacity, *Bo*, and a methane conversion factor, $MCF_{st}$, of 0.5 (IPCC guidelines, 2006, Table 6.3) results in an emission factor, $EF_{st}$, equal to 0.125.

However, new measurement have shown that the EF value is overestimated (Nielsen et al, 2018; Vollertsen, 2018).

$f_{nc}$ is the fraction of the population that is not connected to the sewer system, i.e. scattered houses, which is set equal to 10 %.

*P* is the population number.

From the submission in 2019 an onwards, a country-specific $MCF_{st}$ has been calculated based on the measured methane emission of 0.695 g $CH_4$/PE/d (Nielsen et al., 2018), as shown in equation 7.5.6. Based on these measurements, a country-specific EF value has been derived as shown below:

$$EF_{st} = \frac{0.695\ \text{g CH}_4/\text{PE/d}}{DOC_{st}} * 10 = 0.047\ \frac{\text{kg CH}_4}{\text{kg DOC}} \qquad \text{Eq. 7.5.6}$$

where $DOC_{st}$ is set equal to 148.8 g COD/PE/d. The country-specific $EF_{st}$ value is derived by applying an uncertainty factor of 10 to account for the fact that the general state of installed septic tanks are of older date and may not be functioning optimal (Vollertsen, 2018). As such, the $MCF_{ST}$, hence the *EF* value, is reduced by a factor 2.6 (from 0.125 to 0.047).

### Annual activity data and emission factors used for calculation the net methane emission

Monitoring data on the influent BOD and COD are available for mixed industrial and household wastewater, which are used for calculating the total organic waste (TOW) in the influent wastewater. From 1990 to 1997, no BOD or COD data for Danish WWTPs exists. For the years 1998-2014, data on COD and BOD are available.

Table 7.5.3 shows the increase in the contribution from industries to the influent wastewater, the development in the population number of Denmark, compared to the  In the second approach, an average of BOD/COD ratios throughout the time series equal to 2.7 was applied to in place of the default value of Danish monitoring data for BOD and COD. The Danish COD/BOD ratio is on average 2.7 throughout the time series. Based on plant level data on TOW and energy production, the fraction of TOW in units of Kt COD at anaerobic WWTPs has been derived. Details on the activity data reported in Thomsen, 2016. The time series for activity data on TOW are presented in Table 7.5.3. The full time series is presented in Annex 3F, Table 3F-5.3.

Table 7.5.3 Total degradable organic waste in the influent wastewater (TOW), kt.

| Year | Industrial inlet [%] | Population-Estimate (1000) | TOW (kt COD/year) | TOW (kt BOD/year) | COD/BOD ratio |
|---|---|---|---|---|---|
| 1990 | 2.5 | 5 135 | 295 | 97 | 3.1 |
| 1995 | 22.2 | 5 216 | 327 | 116 | 2.8 |
| 2000 | 38 | 5 330 | 365 | 149 | 2.5 |
| 2005 | 40.5 | 5 411 | 364 | 141 | 2.6 |
| 2010 | 40.5 | 5 535 | 372 | 145 | 2.6 |
| 2013 | 40.5 | 5 603 | 383 | 136 | 2.8 |
| 2014 | 40.5 | 5 627 | 384 | 138 | 2.8 |
| 2015 | 40.5 | 5 660 | 385 | 168 | 2.3 |
| 2016 | 40.5 | 5 707 | 378 | 169 | 2.2 |
| 2017 | 40.5 | 5 749 | 397 | 170 | 2.3 |
| 2018 | 40.5 | 5 781 | 398 | 171 | 2.3 |

The TOW data, measured in units of Gg COD/year, were used to estimate the fugitive methane emissions from the sewer system, primary settling tank and biological N and P removal processes according to equation 7.5.2.

For the anaerobic digestion of sludge, the Danish energy statistics were used to quantify the amount of methane lost by venting; i.e. $EF_{AD}$ value of 0.013 (Equation 7.5.4). A detailed verification of the activity data used for justifying the national $EF_{AD}$ value is provided in Table 7.3.5 and in Thomsen, 2016.

For scattered houses, the default IPPC BOD/COD conversion factor of 2.4 was considered most representative, as the average Danish BOD/COD ratio of 2.6 reflects the presence of industrial COD in the influent wastewater at Danish WWTPs (Table 7.5.3).

### Overall methane emission time trends

The trends in the $CH_4$ emission from the Danish WWTPs. as summarised in Table 7.5.1, are presented graphically in Figure 7.5.1.

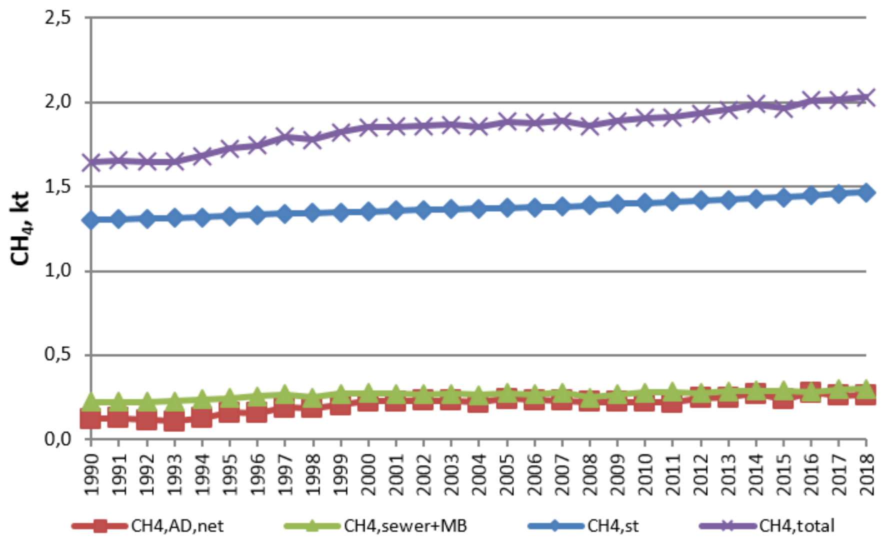



Figure 7.5.1 Time trends for net methane emission, methane emission from sewer systems, mechanical and biological treatment, from septic tanks and from anaerobic treatment processes.

The methane emission due to venting, i.e. $CH_{4.AD.net}$, has increased by 119 % from 1990 to 2018. The methane emission from the sewer system, mechanical and biological treatment, i.e. $CH_{4.sewer+MB}$, has increase by 35 % from 1990 to 2018. The methane emission from scattered houses, i.e. $CH_{4.st}$, has increased by 13 %.

The total methane emissions, i.e. $CH_{4.total}$, has increased from 1.64 kt in 1990 to 2.03 kt methane in 2018 corresponding to an increase in net methane emissions from wastewater handling of 23 %.

### $N_2O$ emissions from WWTPs

$N_2O$ may be generated by nitrification (aerobic processes) and denitrification (anaerobic processes) during biological treatment. Starting material in the influent may be urea, ammonia and proteins, which are converted to nitrate by nitrification. Denitrification is an anaerobic biological conversion of nitrate into dinitrogen. $N_2O$ is an intermediate of both processes. A Danish investigation indicates that $N_2O$ is formed during aeration steps in the sludge treatment processes as well as during anaerobic treatments, the former contributing most to the $N_2O$ emissions during sludge treatment (Gejlsbjerg et al., 1999; Thomsen et al., 2015). A review by Kampschreur et al. (2009) documents that around 90 % of the emitted $N_2O$ originates from activated sludge processes. Based on this review an average of two highest EF values, i.e. 0.6 % $N_2O$ (Wicht et al., 1995) and 0.035 % (Czepiel et al., 1995), both reported in units of per cent N load in the influent wastewater was used to derive a national EF for the direct emission of nitrous oxide. The EF value has been verified in Thomsen et al., 2015)

The direct $N_2O$ emission from wastewater treatment processes is calculated according to Equation 7.5.6:

$$E_{N_2O} = EF_{N_2O,direct} \cdot m_{N,\inf luent} \cdot \frac{M_{N_2O}}{2 \cdot M_N} \qquad \text{Eq. 7.5.6}$$

where

$EF_{N2O.direct}$ is set equal to a fraction of 0.0032 of the N load in the influent wastewater.

$m_{N.influent}$ is the annually reported N load in the Danish Water Quality Parameter Database provided in Table 7.5.4.

$M_{N2O}/M_{N2}$ is the mass ratio i.e. 44/28 to convert the fraction of N emitted as nitrous oxide from total N.

The country-specific EF value of 0.0032 kg $N_2O$-N/kg N may be expressed as $EF_{N2O.direct}$ = 4.99 g $N_2O$ per kg N load in the influent wastewater by reducing eq. 7.5.6 to:

$$E_{N_2O} = EF_{N_2O,direct} \cdot m_{N,\inf luent}$$ Eq. 7.5.7

The methodology adopted for estimating the direct $N_2O$ emission only relies on the influent N load as activity data.

The indirect $N_2O$ emission from WWTPs is calculated according to Equation 7.5.8:

$$E_{N_2O,WWTP,effluent} = D_{N,WWTP} \cdot EF_{N_2O,WWTP,effluent} \cdot \frac{M_{N_2O}}{2 \cdot M_N}$$ Eq. 7.5.8

where

$D_{N.WWTP}$ is the effluent discharged sewage nitrogen load consisting of contributions from municipal wastewater treatment plants, the separate industry, effluent from aquaculture, rainwater conditioned effluents and scattered houses not connected to the sewage system (cf. Table 7.5.4).

$EF_{N2O.WWTP.effluent}$ is the IPCC default emission factor of 0.005 kg $N_2O$-N per kg sewage-N produced (IPPC, 2006).

$M_{N2O}/M_{N2}$ is the mass ratio i.e. 44/28 to convert the fraction of discharged N emitted as nitrous oxide from total N.

#### Annual activity data and emission factors for calculating the nitrous oxide emission

Data on the N content in the influent and effluent wastewater flows are provided in Table 7.5.4. The effluent data provided in the table constitute a sum of the N content in effluent wastewater from municipal wastewater treatment plants, the separate industry, effluent from aquaculture, rainwater conditioned effluents and scattered houses. For the entire time series, 1990-2018 cf. Annex 3F, Table 3F-5.4.

Table 7.5.4 Nitrogen content in the influent and effluent wastewater, tonnes.

| Year | Influent, Municipal WWTPs[1] | Influent, Industrial WWTPs[1] | Effluent wastewater from WWTP[1] | Effluent wastewater, Total[2] |
|---|---|---|---|---|
| 1990 | 14 679 | 32 175 | 16 884 | 16 884 |
| 1995 | 22 340 | 30 888 | 11 409 | 15 152 |
| 2000 | 26 952 | 11 213 | 5 550 | 10 005 |
| 2005 | 32 288 | 5 688 | 3 831 | 7 038 |
| 2010 | 27 357 | 4 225 | 4 363 | 6 960 |
| 2013 | 29 557 | 3 393 | 3 739 | 6 557 |
| 2014 | 30 033 | 3 565 | 3 763 | 6 997 |
| 2015 | 30 509 | 4 141 | 4 036 | 7 288 |
| 2016 | 29 166 | 4 250 | 3 740 | 6 612 |
| 2017 | 30 636 | 3 450 | 3 758 | 6 798 |
| 2018 | 30 288 | 4 636 | 3 498 | 5 745 |

[1]Data on the influent wastewater N load from municipal WWTPs are available from the Danish Water Quality Parameter Database held by the Danish Nature Agency.
[2]Effluent wastewater, total includes discharges from the separate industry; rainwater conditioned effluent, scattered houses, aquaculture farming and effluents from WWTPs (DEPA, 1994, 1996b, 1997, 1998b, 1999b, 2000, 2001c, 2002b, 2003b, 2004c, 2005b, 2005c and DNA, 2007, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020)

The reduction of N in the effluent wastewater from Danish WWTPs compared to in influent wastewater has increased from a reduction efficiency of 30 % in 1990 to a reduction efficiency of 88 % in 2016 (DNA, 2018). The significant reduction in the effluent wastewater content of nitrogen has been a driver for the increasing direct $N_2O$ emission from WWTPs. However, emerging wastewater treatment technologies may cause an increased N capture in the sludge (Kristensen & Jørgensen, 2008; Thomsen et al., 2015).

The influent N load at industrial WWTPs not collected to the collective sewer systems were estimated from reported N in the effluents from separate industries and knowledge of an N reduction efficiency of 92 % for industrial WWTPs (Thomsen, 2016).

### Overall nitrous oxide emission trends

The trends in the direct $N_2O$ emission from WWTPs, the indirect emission from wastewater effluent and the total nitrous oxide emissions, as summarised in Table 7.5.5, are presented graphically in Figure 7.5.2.

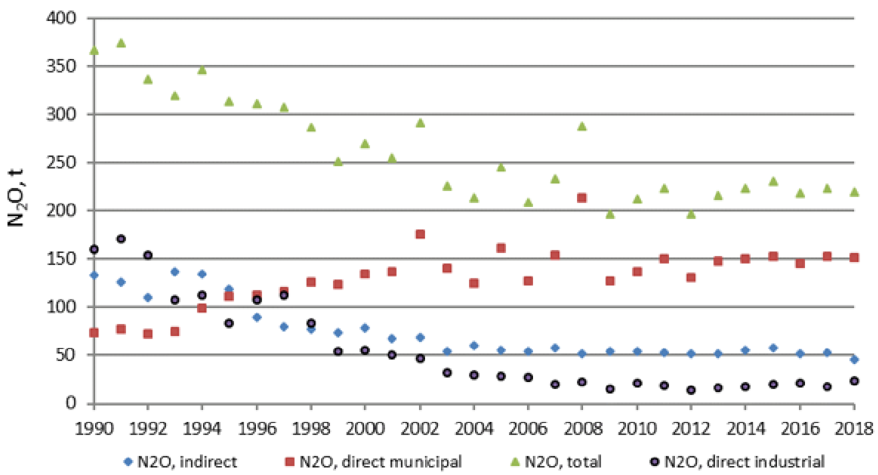



Figure 7.5.2 Time trends for the direct and indirect emission of $N_2O$ (from wastewater effluents) and total $N_2O$ emission.

The annual fluctuations may be caused by several factors, e.g. climatic condition such as variations in precipitation and as a result varying contributions to the influent N and varying characteristics of especially the industrial contributions to the influent. Furthermore, infiltration of groundwater, as well as exfiltration of overload rainwater and wastewater ((DEPA, 1994, 1996b, 1997, 1998b, 1999b, 2000, 2001c, 2002b, 2003b, 2004c, 2005b, 2005c and DNA, 2007, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, Vollertsen et al., 2002), may contribute to the "noise" or fluctuation in the trend of the calculated $N_2O$ emission.

The direct emission shows an increasing trend from 234 tonnes in 1900 to 174 tonnes in 2018. Comparing 2018 with the base year 1990, a decrease of 25.5 % is observed. This trend reflects the sum of direct $N_2O$ emissions from municipal and industrial WWTPs. The direct $N_2O$ emissions from municipal WWPTs are increasing from 73 tonnes in 1990 to 151 tonnes $N_2O$ in 2018 while the direct $N_2O$ emissions from industrial WWPTs are in decreasing from 161 tonnes in 1990 to 23 tonnes in 2018. The opposite trends is partly explained by an increase in the number of industrial WWTPs connected to the collective sewer system as reflected by the increased per cent contribution form industries to the influent wastewater at municipal WWTPs (Table 7.5.3 and Annex 3F, Table 3F-5.4).

The decrease in the emission from effluent wastewater is due to the technical upgrade and centralisation of the Danish WWTPs following the adoption of the Action Plan on the Aquatic Environment in 1987. The indirect emission from wastewater effluent has decreased from 133 tonnes $N_2O$ in 1990 to 45 tonnes $N_2O$ in 2018 corresponding to a reduction of 66 %.

The indirect emission is the major contributor to the emission of nitrous oxide in the period 1990-1995. From 1996 and forward, the direct $N_2O$ emission is the major contributor to the total $N_2O$ emission. Overall, a net reduction of 40 % is observed for the total $N_2O$ emission from wastewater handling in 2018 compared to 1990.

## 7.6 Other 5.E.1 Accidental fires

The *CRF category 5.E, Other* is comprised by the subcategory accidental fires grouped into accidental building and vehicle fires as presented in sub-chapter 7.6.1 and 7.6.2. Greenhouse gasses that are emitted from these processes are $CH_4$, $N_2O$ and $CO_2$ as presented in Table 7.6.1. The full time series for emissions related to composting are shown in Annex 3F-6, Table 3F-6.1.

Table 7.6.1 Overall emission of greenhouse gasses from accidental fires,1990-2018.

| | | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ emission from | | | | | | | | | | | | |
| Accidental building fires | kt | 67.5 | 77.5 | 68.0 | 65.6 | 47.7 | 48.2 | 44.7 | 48.9 | 55.9 | 46.0 | 57.3 |
| - of which non-biogenic | kt | 14.4 | 16.5 | 14.5 | 14.0 | 10.5 | 10.3 | 9.4 | 10.0 | 11.4 | 9.5 | 11.8 |
| Accidental vehicle fires | kt | 5.9 | 6.1 | 6.2 | 6.3 | 6.9 | 5.8 | 5.0 | 5.1 | 5.7 | 6.2 | 6.2 |
| Total. non-biogenic | kt | 20.3 | 22.6 | 20.7 | 20.2 | 17.4 | 16.1 | 14.4 | 15.1 | 17.1 | 15.7 | 18.0 |
| $CH_4$ emission from | | | | | | | | | | | | |
| Accidental building fires | t | 84.3 | 96.8 | 85.0 | 81.9 | 62.4 | 60.6 | 55.9 | 58.8 | 66.0 | 55.7 | 69.3 |
| Accidental vehicle fires | t | 12.4 | 12.7 | 13.0 | 13.0 | 14.4 | 12.0 | 10.4 | 10.6 | 11.8 | 12.9 | 13.0 |
| Total | t | 96.6 | 109.5 | 97.9 | 94.9 | 76.9 | 72.7 | 66.3 | 69.4 | 77.8 | 68.6 | 82.3 |
| 5.E. Other | | | | | | | | | | | | |
| $CO_2$-eqvivalents | kt | 22.7 | 25.3 | 23.2 | 22.6 | 19.4 | 17.9 | 16.0 | 16.8 | 19.1 | 17.4 | 20.1 |

### 7.6.1 Accidental building fires

Emissions that escape from building fires are $CO_2$ and $CH_4$.

#### Methodological issues

Emissions from building fires are calculated by multiplying the number of building fires with selected emission factors. Six types of buildings are distinguished with different emission factors: detached house, undetached houses, apartment buildings, industrial buildings, additional buildings and containers.

#### Activity data

In January 2005, it became mandatory for the local authorities to register every rescue assignment in the online data registration- and reporting system called ODIN (www.odin.dk). ODIN is developed and run by the Danish Emergency Management Agency (DEMA, 2007).

Activity data for accidental building fires are given by ODIN (DEMA, 2019). Fires are classified in four categories: full, large, medium and small. The emission factors comply for full-scale fires and the activity data are therefore recalculated as a full-scale equivalent where it is assumed that a full, large, medium and a small scale fire leads to 100 %, 75 %, 30 % and 5 % of a full-scale fire, respectively.

In practice, a full-scale fire is defined as a fire where more than three fire hoses were needed for extinguishing the fire. A full-scale fire is considered as a complete burnout. A large fire is in this context defined as a fire that involves the use of two or three fire hoses for fire extinguishing and is assumed to typically involve the majority of a house, an apartment, or at least part of an industrial complex. A medium size fire is in this context defined as a fire involving the use of only one fire hose for firefighting and will typically involve a part of a single room in an apartment or house. A small size fire is in this context, defined as a fire that was extinguished before the arrival of the fire service, extinguished by small tools or a chimney fire.

The total number of registered fires is known for the years 1990-2018. For the years 2008-2016, the total number of registered building fires is known with a very high degree of detail.

Table 7.6.2 shows the occurrence of all types of fires (registered for 1990-2018) and the occurrence of building fires (2008-2016) registered at DEMA. In 2008-2016, the average per cent of building fires, in relation to all fires, was 51 %. The total numbers of building fires 1990-2007 and 2017-2018 are calculated using this percentage. The full time series is presented in Annex 3F-6, Table 3F-6.2.

Table 7.6.2 Occurrence of all fires and building fires.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| All fires | 17 025 | 19 543 | 17 174 | 16 551 | 16 785 | 15 353 | 14 093 | 12 728 | 12 710 | 12 186 | 15 169 |
| Building fires | 8 733 | 10 024 | 8 809 | 8 490 | 8 047 | 7 833 | 7 527 | 7 476 | 7 694 | 6 997 | 8 709 |

The building fires that occurred in the years 2008-2016 are sub-categorised into six building types, detached houses, undetached houses, apartment buildings, industrial buildings, additional buildings and container fires.

Table 7.6.3 presents the calculated averages of the registered activity data for building fires for the years 2008-2016, divided in both damage size and building type. These data describe the average share of building fires from 2008-2016 of a certain type and size, in relation to all building fires in the same four years period.

Table 7.6.3 Average registered occurrence of building fires for 2008-2016 (DEMA, 2017).

| | Size | Detached | Undetached | Apartment | Industry | Additional | Container | All building fires |
|---|---|---|---|---|---|---|---|---|
| | full | 3.70 | 0.73 | 0.38 | 1.35 | 0.66 | 0.05 | 6.87 |
| | large | 6.56 | 2.10 | 1.82 | 2.70 | 4.50 | 2.17 | 19.85 |
| Average % | medium | 8.37 | 4.66 | 9.14 | 4.14 | 5.19 | 18.91 | 50.41 |
| | small | 9.85 | 1.93 | 5.65 | 1.94 | 1.11 | 2.39 | 22.87 |
| | all | 28.48 | 9.42 | 16.99 | 10.13 | 11.46 | 23.52 | 100.00 |

It is assumed that the average percentages provided by the years 2008-2016 shown in Table 7.6.3 are compliable for the years 1990-2007 and 2017-2018. Hereby, similar activity data for building fires can be estimated back to 1990 and for 2017-2018.

By applying the damage rates of 100 %, 75 %, 30 % and 5 % corresponding to the damage sizes of full, large, medium and small, a full-scale equivalent can be determined. Table 7.6.4 shows the calculated full-scale equivalents (FSE). The whole time series is shown in Annex 3F, Table 3F-6.3.

Table 7.6.4 Accidental building fires full-scale equivalent activity data.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Container fires | 652 | 749 | 658 | 634 | 513 | 445 | 352 | 331 | 475 | 357 | 444 |
| Detached house fires | 1 015 | 1 165 | 1 023 | 986 | 813 | 735 | 685 | 706 | 799 | 675 | 840 |
| Undetached house fires | 332 | 381 | 335 | 323 | 271 | 244 | 209 | 167 | 119 | 153 | 190 |
| Apartment building fires | 417 | 479 | 421 | 405 | 308 | 310 | 281 | 276 | 331 | 274 | 341 |
| Industry building fire | 412 | 473 | 415 | 400 | 238 | 284 | 269 | 340 | 415 | 315 | 393 |
| Additional building fires | 493 | 566 | 497 | 479 | 424 | 389 | 349 | 306 | 255 | 281 | 349 |

#### Emission factors

For building fires, emissions are calculated by multiplying the number of full-scale equivalent fires with the emission factors. The emission factors are produced from different measurements and assumptions from literature and expert judgements. When possible, emission factors are chosen that represent conditions that are comparable to Denmark. By comparable is meant countries that have similar building traditions, with respect to the materials used in building structure and interior.

In the process of selecting the best available emission factors for the calculation of the emissions from Danish accidental building fires, a range of different sources has been studied. Unfortunately, it is difficult to perform an interrelated comparison of the different sources because they all establish emission factors on different assumptions and many of these assumptions are not fully accounted for.

Table 7.6.5 lists the emission factors that were chosen as the best reliable and their respective references.

Table 7.6.5 Average emission factors for building fires, per FSE fire. Used for all years.

| Compound | Unit /fire | Detached house | Undetached house | Apartment building | Industrial building | Additional building | Container | Reference |
|---|---|---|---|---|---|---|---|---|
| $CO_2$ - total | t | 31.3 | 25.7 | 14.9 | 78.1 | 3.9 | 1.8 | Blomqvist et al., 2002 |
| $CO_2$ - biogenic | t | 25.5 | 21.0 | 12.1 | 67.6 | 3.2 | 0.2 | Blomqvist et al., 2002 |
| $CO_2$ - non-biogenic | t | 5.8 | 4.8 | 2.8 | 10.5 | 0.7 | 1.7 | Blomqvist et al., 2002 |
| $CH_4$ | kg | 41.5 | 34.1 | 19.7 | 52.0 | 2.1 | 0.3* | NAEI, 2009 |

*Container fires have a different source of $CH_4$ emission factor than the other five categories. Blomqvist et al. 2002.

Emission factors for detached, undetached and apartment fires depend on the average floor space in 1990 to 2014 (cf. Table 7.6.6). The average emission factors is used for all years. Industrial, additional and container fires on the other hand are assumed to have a constant size/volume throughout the time series. Emission factors for detached, undetached and apartment fires for 1990-2014 are shown in Annex 3F, Table 3F-6.4a-c.

Emission factors from Aasestad (2008) are already specified for four of the six building types, detached houses, undetached houses, apartment buildings and industrial buildings (Aasestad. 2008) and all other sources considered were altered to match the six building types. This alternation was performed simply by adjusting the average floor space for each of the building types respectively, whereas factors like loss rate and mass of combustible contents per area are not altered.

The average floor space in Danish buildings is stated in Table 7.6.6. The data are collected from Statistics Denmark and takes into account possible multiple building floors but not attics and basements. For the whole time series see Annex 3F, Table 3F-6.5. The average floor space in industrial buildings, schools etc. is estimated to 500 square meters for all years and the average floor space for additional buildings, sheds etc. is estimated to 20 square meters for all years.

Table 7.6.6 The average floor space in Danish buildings (square metre).

| | 1990 | 1995 | 2000 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|
| Detached houses | 156 | 155 | 156 | 163 | 164 | 165 | 165 | 165 |
| Undetached houses | 129 | 129 | 131 | 134 | 132 | 134 | 133 | 133 |
| Apartment buildings | 75 | 75 | 75 | 77 | 78 | 78 | 78 | 78 |

Some emission factors are delivered in mass emission per mass burned. In order to connect these emission factors to the activity data, the total combustible building masses are estimated using the data from Table 7.6.7.

Table 7.6.7 Building mass per building type.

| | Unit | Detached house | Undetached house | Apartment building | Industry building | Additional building | Container |
|---|---|---|---|---|---|---|---|
| Average floor area* | $m^2$ | 165 | 134 | 78 | 500 | 20 | - |
| Building mass per floor area | kg per $m^2$ | 40 | 40 | 35 | 30 | 30 | - |
| Total building mass | t per fire | 6.6 | 5.4 | 2.7 | 15.0 | 0.6 | 1 |

* 2012 numbers.

Emission factors for container fires cannot be calculated based on an average floor space but on an average mass. The average mass of a container is set to 1 Mg and covers all types of containers, from small residential garbage containers to large shipping containers and waste/goods in storage piles.

No data was available for $N_2O$.

For more information on the emission factors, please refer to Hjelgaard (2013).

### 7.6.2 Accidental vehicle fires

Emissions that escape from vehicle fires are $CO_2$ and $CH_4$.

#### Methodological issues

Emissions from vehicle fires are calculated by multiplying the mass of vehicle fires with selected emission factors. Emission factors are not available for different vehicle types, whereas it is assumed that all the different vehicle types leads to similar emissions. The activity data are calculated as an annual combusted mass by multiplying the number of different full scale vehicle fires with the Danish registered average weight of the given vehicle type.

#### Activity data

As with accidental building fires, data for accidental vehicle fires are available for some years through the Danish Emergency Management Agency (DEMA, 2017). DEMA provides very detailed data for 2008-2016 for passenger cars and heavy duty vehicles. For buses, light duty vehicles (vans and motor homes), motorcycles/mopeds, other transport, caravans, trains, boats, airplanes, bicycles, tractors, combine harvesters and machines detailed data are available for 2008-2012. The remaining years 1990-2007 and 2013-2018 are estimated by using surrogate data.

Table 7.6.8 shows the occurrence of fires in general and vehicle fires registered at DEMA. Between 2008 and 2012, the average per cent of vehicle fires, in relation to all fires, was 25 %. The total numbers of vehicle fires in 1990-2007 and 2013-2018 are calculated using this percentage. The full time series is presented in Annex 3F, Table 3F-6.6a-c.

Table 7.6.8 Occurrence of all fires* and vehicle fires**.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| All fires | 17 025 | 19 543 | 17 174 | 16 551 | 16 785 | 15 353 | 14 093 | 12 728 | 12 710 | 12 186 | 15 169 |
| Vehicle fires | 4 274 | 4 906 | 4 312 | 4 155 | 3 454 | 3 854 | 3 538 | 3 195 | 3 191 | 3 059 | 3 808 |

*(DEMA, 2019).
**(DEMA, 2017).

There are fourteen different vehicle categories. The activity data are categorised in passenger cars (lighter than 3500 kg), buses, light duty vehicles (vans and motor homes), heavy duty vehicles (trucks and tankers), motorcycles/mopeds, other transport, caravans, trains, boats, airplanes, bicycles, tractors, combine harvesters and machines.

In the same manner as accidental building fires, the 2008-2016 data from DEMA can be divided in four categories according to damage size. It is assumed that a full-scale fire is a complete burnout of the given vehicle, and that a large, medium and small-scale fire corresponds to 75 %, 30 % and 5 % of a full-scale fire respectively. The total number of full-scale equivalent (FSE) fires can be calculated for each of the fourteen vehicle categories for 2008-2016.

The total number of registered vehicles is known from Jensen et al. (2013) and Statistics Denmark (2019). By assuming that the share of vehicle fires in relation to the total number of registered vehicles, of every category respectively, can be counted as constant, the number of vehicle fires is estimated for the years 1990-2007 and 2017-2018.

Table 7.6.9 states the total number of national registered vehicles and the number of full-scale equivalent vehicle fires. The whole time series 1990-2018 is shown in Annex 3F, Table 3F-6.6a-c.

Table 7.6.9 Number of nationally registered vehicles and full-scale equivalent vehicle fires.

| | Passenger Cars | | Buses | | Light Duty Vehicles | | Heavy Duty Vehicles | |
|---|---|---|---|---|---|---|---|---|
| | Registered | FSE fires | Registered | FSE fires | Registered | FSE fires | Registered | FSE fires |
| 1990 | 1 590 345 | 437 | 8 109 | 10 | 247 563 | 21 | 45 678 | 55 |
| 1995 | 1 675 432 | 460 | 14 371 | 18 | 286 049 | 24 | 48 085 | 58 |
| 2000 | 1 853 403 | 509 | 15 051 | 19 | 335 670 | 28 | 50 227 | 61 |
| 2005 | 1 964 057 | 540 | 15 132 | 19 | 421 019 | 35 | 49 311 | 59 |
| 2010 | 2 147 178 | 726 | 14 781 | 23 | 447 722 | 38 | 45 632 | 60 |
| 2013 | 2 278 963 | 573 | 12 831 | 16 | 401 828 | 33 | 42 000 | 49 |
| 2014 | 2 330 805 | 470 | 12 693 | 16 | 397 603 | 33 | 41 419 | 34 |
| 2015 | 2 392 282 | 454 | 12 438 | 16 | 395 397 | 33 | 41 369 | 38 |
| 2016 | 2 467 102 | 546 | 12 368 | 16 | 396 731 | 33 | 41 897 | 48 |
| 2017 | 2 531 874 | 696 | 12 181 | 15 | 395 264 | 33 | 42 333 | 51 |
| 2018 | 2 596 322 | 713 | 11 817 | 15 | 389 161 | 32 | 42 606 | 51 |

*Continued*

| | Motorcycles/Mopeds | | Caravans | | Train | | Ship | |
|---|---|---|---|---|---|---|---|---|
| | Registered | FSE fires | Registered | FSE fires | Registered | FSE fires | Registered | FSE fires |
| 1990 | 163 133 | 54 | 86 257 | 22 | 7 156 | 8 | 2 324 | 25 |
| 1995 | 165 272 | 55 | 95 831 | 25 | 6 854 | 7 | 1 911 | 20 |
| 2000 | 233 337 | 78 | 106 935 | 28 | 4 907 | 5 | 1 759 | 19 |
| 2005 | 273 946 | 91 | 121 350 | 32 | 3 195 | 3 | 1 792 | 19 |
| 2010 | 304 744 | 83 | 142 354 | 37 | 2 740 | 2 | 1 773 | 16 |
| 2013 | 284 874 | 95 | 142 667 | 37 | 3 066 | 3 | 1 781 | 19 |
| 2014 | 281 037 | 94 | 141 418 | 37 | 3 085 | 3 | 1 722 | 18 |
| 2015 | 278 390 | 93 | 139 654 | 36 | 3 642 | 4 | 1 742 | 19 |
| 2016 | 276 849 | 92 | 137 404 | 36 | 3 738 | 4 | 1 735 | 18 |
| 2017 | 275 103 | 92 | 134 768 | 35 | 3 282 | 3 | 1 738 | 18 |
| 2018 | 267 416 | 89 | 131 257 | 34 | 3 063 | 3 | 1 712 | 18 |

*Continued*

| | Airplane | | Tractor | | Combined Harvester | | Bicycle | Other transport | Machine |
|---|---|---|---|---|---|---|---|---|---|
| | Registered | FSE fires | Registered | FSE fires | Registered | FSE fires | FSE fires | FSE fires | FSE fires |
| 1990 | 1 055 | 1 | 131 880 | 93 | 33 594 | 57 | | | |
| 1995 | 1 058 | 1 | 130 028 | 92 | 27 986 | 47 | | | |
| 2000 | 1 070 | 1 | 111 736 | 79 | 23 272 | 39 | | | |
| 2005 | 1 073 | 1 | 104 551 | 74 | 20 965 | 36 | | | |
| 2010 | 1 155 | 1 | 89 141 | 77 | 15 986 | 32 | 4 | 58 | 94 |
| 2013 | 1 067 | 1 | 79 045 | 56 | 12 998 | 22 | | | |
| 2014 | 1 067 | 1 | 77 362 | 55 | 12 500 | 21 | | | |
| 2015 | 1 064 | 1 | 75 680 | 54 | 12 002 | 20 | | | |
| 2016 | 1 041 | 1 | 73 997 | 52 | 11 504 | 20 | | | |
| 2017 | 1 021 | 1 | 72 314 | 51 | 11 006 | 19 | | | |
| 2018 | 1 014 | 1 | 70 632 | 50 | 10 508 | 18 | | | |

The average weights of a passenger car, bus, light commercial vehicle, truck and motorcycle/moped are known for every year back to 1993 (Statistics Denmark. 2019). The corresponding weights from 1990 to 1992 and the average weight of the units from the remaining categories are estimated by an expert judgment (see Table 7.6.10 and Annex 3F, Table 3F-6.7).

Table 7.6.10 Average weight of different vehicle categories, kg.

| Year | Cars | Buses | Vans | Trucks | Motorcycles/ Mopeds |
|---|---|---|---|---|---|
| 1990 | 850 | 10 000 | 2 000 | 15 000 | 87 |
| 1995 | 923 | 8 938 | 2 338 | 14 855 | 97 |
| 2000 | 999 | 9 062 | 2 479 | 15 041 | 103 |
| 2005 | 1 068 | 9 171 | 2 524 | 14 598 | 116 |
| 2010 | 1 134 | 9 160 | 2 517 | 13 902 | 133 |
| 2013 | 1 162 | 9 571 | 2 510 | 16 245 | 139 |
| 2014 | 1 160 | 9 654 | 2 504 | 16 269 | 142 |
| 2015 | 1 158 | 9 698 | 2 502 | 16 303 | 144 |
| 2016 | 1 159 | 9 722 | 2 502 | 16 357 | 147 |
| 2017 | 1 161 | 9 885 | 2 506 | 16 412 | 149 |
| 2018 | 1 164 | 9 814 | 2 522 | 16 504 | 153 |

It is assumed that the average weight of a boat equals that of a bus. That tractors and vans weigh the same and that trains, airplanes and combine harvesters have the same average weight as trucks.

Bicycles, machines and other transport can only be calculated for the years 2007-2012 due to the lack of surrogate data (number of nationally registered vehicles). The average weight of a bicycle, caravan, machine and other transport is estimated as 12 kg, 90 % of a car, 50 % of a car and 40 % of a car respectively.

By multiplying the number of full-scale fires with the average weight of the vehicles respectively, the total amount of combusted vehicle mass can be calculated. The result is shown in Table 7.6.11 and in Annex 3F, Table 3F-6.8.

Table 7.6.11 Burnt mass of different vehicle categories, tonnes.

| Vehicle category | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Passenger cars | 371 | 425 | 509 | 577 | 830 | 623 | 545 | 526 | 633 | 808 | 830 |
| Buses | 102 | 161 | 171 | 174 | 207 | 154 | 154 | 152 | 151 | 151 | 146 |
| Light duty vehicles | 41 | 55 | 69 | 88 | 96 | 84 | 82 | 82 | 82 | 82 | 81 |
| Heavy duty vehicles | 825 | 860 | 910 | 867 | 828 | 797 | 557 | 621 | 780 | 837 | 847 |
| Motorcycle. moped | 5 | 5 | 8 | 11 | 11 | 13 | 13 | 13 | 14 | 14 | 14 |
| Other transport | 0 | 0 | 0 | 0 | 33 | 0 | 0 | 0 | 0 | 0 | 0 |
| Caravan | 29 | 35 | 42 | 51 | 63 | 65 | 64 | 63 | 62 | 61 | 60 |
| Train | 113 | 107 | 78 | 49 | 28 | 53 | 53 | 63 | 64 | 57 | 53 |
| Ship | 247 | 182 | 170 | 175 | 147 | 181 | 177 | 180 | 179 | 183 | 179 |
| Airplane | 9 | 9 | 9 | 9 | 8 | 10 | 10 | 10 | 10 | 10 | 10 |
| Bicycle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tractor | 187 | 215 | 196 | 187 | 194 | 140 | 137 | 134 | 131 | 128 | 126 |
| Combine harvester | 541 | 487 | 434 | 418 | 398 | 286 | 278 | 270 | 262 | 253 | 244 |
| Machine | 0 | 0 | 0 | 0 | 43 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 2 471 | 2 542 | 2 596 | 2 605 | 2 885 | 2 406 | 2 071 | 2 114 | 2 369 | 2 584 | 2 590 |

**Emission factors**

In the process of selecting the most reliable emission factors for the calculation of the emissions from Danish vehicle fires, a range of different sources have been studied. Unfortunately, it is difficult to make an interrelated comparison of the different sources because they all establish emission factors on different assumptions and many of these assumptions are not fully accounted for. Table 7.6.12 lists the accepted emission factors and their respective references.

Table 7.6.12 Emission factors for vehicle fires, per tonnes.

| | Unit | Emission factor | Source |
|---|---|---|---|
| $CO_2$ | t | 2.4 | Lönnermark et al., 2006 |
| $CH_4$ | kg | 5 | NAEI. 2009 |
| $N_2O$ | - | NAV | **-** |

NAV = not available

### 7.6.3 Other

Other combustion sources included under Waste Other are the open burning of yard waste and bonfires.

Due to the cold and wet climatic conditions in Denmark, wild fires very seldom occur. Controlled field burnings and the occasional wild fires are categorised under the Chapters 6 Agriculture and 7 Land Use, Land Use Change and Forestry (LULUCF), respectively.

In Denmark, the open burning of private yard waste is under different restrictions according to the respective municipality. These restrictions involve what can be burned but also the quantity, how, when and where, or in some cases, a complete ban is imposed. The burning of yard waste is not allowed within urban areas (DEPA, 2011b). There is no registration of private waste burning and the activity data on this subject are very difficult to estimate. Citizens are generally encouraged to compost their yard waste or to dispose of it through one of the many waste disposal/recycling sites.

The occurrences of bonfires at Midsummer Eve, and in general, are likewise not registered, therefore it has not been possible to obtain activity data and consequently, bonfires are not included in this inventory.

## 7.7 Uncertainties and time series consistency

The uncertainty models follow the methodology in the IPCC Guidelines (IPCC, 2006). Tier 1 is based on the simplified uncertainty analysis.

### 7.7.1 Input data

**Solid Waste Disposal**

The waste amounts for solid waste disposal are registered in a national database held by the Danish EPA and assessed to be of high quality resulting in the adoption of an uncertainty for reported waste amounts of 10 %.

Input parameter uncertainties for SWDS considered in the Tier 1 uncertainty analysis are based on the IPCC (IPCC 2006, Table 3.5) default values and provided in Table 7.7.1.

Table 7.7.1 Tier 1 input parameter uncertainty, %.

| Parameter | Parameter ID | Uncertainty % |
|---|---|---|
| The Waste amount sent to SWDS | $W$ | 10 |
| Degradable Organic Carbon | $DOC_i$ | 20 |
| Fraction of DOC dissimilated | $DOC_f$ | 20 |
| Methane Correction Factor | $MCF$ | 10 |
| Fraction of $CH_4$ in landfill gas | | **5** |
| Methane Generation Rate Constant | $k$ | 100 |

The waste amounts for solid waste disposal on land are registered in a national database held by the Danish EPA and assessed to be of high quality resulting in the adoption of an uncertainty for reported waste amounts of 10 % (IPCC, 2006, Table 3.4).

Based on the uncertain range provided in Table 3.4, a simple standard deviation assuming normal probability distribution of the half-live times was calculated. The standard deviation of $t_{½}$ was transformed into k-values using eq. 7.2.3, resulting in an uncertainty range for the methane generation constants, k, of -71 % to +166 %. For the Tier 1 uncertainty calculation the uncertainty of k were kept at 100 %. For the remaining parameters, default uncertainties are used. The uncertainty on the implied emission factor, $U_{ief}$, is based on uncertainty estimates in Table 7.7.1 and is approximated with IPCC (2006) Equation 3.1 equals

$U_{ief}$ % = SQRT($20^2+20^2+10^2+5^2+100^2$) = 104.5 %

These uncertainties give the combined Tier 1 uncertainty on the emission from SWDS of: SQRT($10^2+104.5^2$) = 105 %.

In addition, the average and standard deviation of the half-life times and DOC values and remaining input parameters in Table 7.7.2 (except for the deposited amounts of waste) were derived from the 2006 IPCC guidelines (Chapter 3, Table 3.4; Chapter 2, Table 2.4) assuming a normal distribution. A Monte Carlo calculation based on random selected values for each of the input parameters within defined 95 % confidence interval uncertainty ranges were run 1000 times returning resulting IEF and net $CH_4$ emission values for 1990 and 2017 (Nielsen et al, 2019). The resulting uncertainty of the IEF is 24 % in 1990 and 26 % in 2017 indicating that the tier 1 uncertainty of IEF is rather conservative.

### Biological treatment of Solid waste - Composting

Table 7.7.2 lists the 95 % confidence interval uncertainties for activity data and emission factors used in this inventory and at the present level of available information. The uncertainties are assumed valid for all years 1990-2018.

Table 7.7.2 Estimated uncertainty rates for activity data and emission factors, %.

| 95 % confidence interval uncertainties | $CO_2$ | $CH_4$ | $N_2O$ |
|---|---|---|---|
| 5.B.1 Composting | | | |
| Activity data | - | 20 | 20 |
| Emission factor | - | 100 | 100 |
| 5.B.2 Biogas production | | | |
| Activity data | | 5 | |
| Emission factor | | 20 | |

The uncertainty on the amount of biowaste being composted has been reduced from 40 to 20 % due to improved statistics on plant level data (DEPA, 2018, unpublished).

### Waste Incineration

The uncertainty of the number of human cremations is miniscule, however for the purpose of uncertainty calculation it has been set to 1 %. Table 7.7.3 lists the 95 % confidence interval uncertainties for activity data and emission factors used in this inventory and at the present level of available information.

Table 7.7.3 Estimated uncertainty rates for activity data and emission factors, %.

| 95 % confidence interval uncertainties | $CO_2$ | $CH_4$ | $N_2O$ |
|---|---|---|---|
| Human cremation | | | |
| Activity data | - | 1 | 1 |
| Emission factor | - | 150 | 150 |
| Animal cremation | | | |
| Activity data | - | 40 | 40 |
| Emission factor | - | 150 | 150 |

### Wastewater Handling

The uncertainty levels used in the Tier 1 models are shown in Table 7.7.4.

Table 7.7.4 Estimated uncertainty rates for activity data and emission factors, %.

| 95 % confidence interval uncertainties | $CH_4$, | $N_2O$ |
|---|---|---|
| 5.D.1 Domestic wastewater | | |
| Activity | 24 | 30 |
| Emission factor | 32 | 50 |
| 5.D.2 Industrial wastewater | | |
| Activity | IE* | 30 |
| Emission factor | IE* | 50 |

*Industrial effluent wastewater is send to the collective sewer system for treatment at municipal wastewater treatment plants, where anaerobic treatment at biogas plants take place.

Default IPCC values are assumed to be given at 95 % confidence level. Uncertainties have been derived from IPCC default values and uncertainties in country-specific parameters, respectively.

### Other

The uncertainty of the total number of accidental fires is very small, but the division into building and transportation types and also the calculation of full scale equivalents will lead to some uncertainty, partly caused by the category "other". The uncertainty for both building and vehicle activity data is therefore set to 10 % for all years. The uncertainty is however lowest for the most recent years (2008-2018) (Authors expert judgement).

Table 7.7.5 lists the 95 % confidence interval uncertainties for activity data and emission factors used in this inventory and at the present level of available information. The uncertainties are assumed valid for all years 1990-2018.

Table 7.7.5 Estimated uncertainty rates for activity data and emission factors, %.

| 95 % confidence interval uncertainties | $CO_2$ | $CH_4$ | $N_2O$ |
|---|---|---|---|
| Accidental building fires | | | |
| Activity data | 10 | 10 | - |
| Emission factor | 300 | 500 | - |
| Accidental vehicle fires | | | |
| Activity data | 10 | 10 | - |
| Emission factor | 500 | 700 | - |

### 7.7.2 Tier 1 uncertainty results

The Tier 1 uncertainty estimates for the waste sector are calculated from 95 % confidence interval uncertainties, results are shown in Table 7.7.6.

The overall uncertainty interval for greenhouse gases (GHG) is estimated to be ±54 % and the trend in GHG emission, calculated as the per cent change in GHG emissions in 2018 compared to 1990, is 27 %.

Table 7.7.6 National Tier 1 uncertainty estimates for the waste sector.

| Pollutant | National emission, 2018, kt $CO_2$ eqv. | Total emission uncertainty, % | Trend* 1990-2018, % | Trend uncertainty, % |
|---|---|---|---|---|
| GHG** | 1 139 | ±54 | -35 | ±27 |
| $CO_2$ | 18 | ±300 | -11 | ±13 |
| $CH_4$ | 972 | ±62 | -40 | ±25 |
| $N_2O$ | 149 | ±62 | 23 | ±67 |

*Per cent change in emission in 2018 with respect to the base year 1990.
**GHG emissions are calculated in units of $CO_2$ equivalents.

### 7.7.3 Time series consistency and completeness

**Solid Waste Disposal**

Registration of the amount of waste has been carried out since the beginning of the 1990s in order to measure the effects of action plans. Therefore, the activity data are considered to be consistent through the time series to make the activity data input to the FOD model reliable.

The consistency of the emissions and the implied emission factors is a result of the same methodology and the same model used for the whole time series. The parameters in the FOD model are the same for the whole time series. The use of a model of this type is recommended in IPCC (2006) and IPCC (2000).

As regards completeness, waste amounts for the whole time series, i.e. 1940-2018, have been allocated according to 18 waste types as described in Chapter 7.2.1. Corresponding annual fractional distributions of the total amount of deposited waste according to type, respecting mass conservation, is presented in units of mass fractions in Table 7.2.4 (for the whole time series the reader is referred to Annex 3F, Table 3F-2.5). The composition of these waste types is, according to Danish data used to estimate DOC values for the waste types (refer IPCC 2006, Chapter 2 on Waste data). Plant level data and modelling is in progress as part of the national biocover action plan (Executive Order No. 752 of 21/06/2016).

**Biological treatment of solid waste**

For compost production, activity data are not consistent as data are only available for 1995-2009. Data for 1990-1994 and 2010-2018 along with data for home composting are estimated through linear regression and with surrogate data respectively. Emission factors and calculation method are consistent throughout the time series. For 2010-2018, improved quality of the composting data has been achieved through detailed data on the waste type garden and park waste, sludge and organic waste (Nissen, 2017a).

Emissions from compost production are believed to be complete; calculations include composting at all nationally registered sites and best available estimated data for home composting.

#### Waste Incineration

Activity data for human cremation is considered to be consistent, as these data have been collected by DKL throughout the time series. Activity data for animal cremation on the other hand is not fully consistent. Data for 1998-2018 are gathered directly from the crematoria and data for 1990-1997 are estimated by the author's expert judgement, no surrogate data or data regression is possible.

Emission factors and calculation method are consistent throughout the time series for both human and animal cremation.

Cremation of both corpses and carcasses is considered to be complete. Open burning of carcasses is illegal and therefore not occurring in Denmark, and small-scale incinerators are not known to be used at Danish farms.

#### Wastewater Handling

Consistency and completeness have been improved by integrating plant level data from the Danish Energy Statistics with plant level COD data from the Danish monitoring program and plant level environmental reports (Thomsen, 2016).

Data regarding industrial on-site wastewater treatment processes have been achieved and included in this year´s NIR. Activity data for the whole time series 1990-2018 are provided in Annex 3F, 3F-5.4.

#### Waste Other

For accidental fires, DEMA provides detailed data for 2008-2016 and the total number of nationally registered fires for 1990-2018 (DEMA, 2019). Activity data for accidental fires are there for believed to be consistent. Both emission factors and calculation method are also consistent throughout the time series.

Emissions from accidental fires are believed to be complete. Field burning of agricultural residue is included in Chapter 5 Agriculture.

## 7.8 QA/QC and verification

In general terms, for this part of the inventory, the Data Storage (DS) Level 1, 2 and 4 and the Data Processing (DP) Level 1 can be described as follows.

### 7.8.1 Data Storage Level 1

The external data level refers to the placement of the original input data used for estimating annual activity and emission factors in the waste sector. Data references in terms of reports and databases used for deriving input for the emission calculations. Reports and a list of links to external data sources are stored in a common data storage system including all sectors of the annual NIR.

Table 7.8.1 Overview of annually stored external data sources at DS level1.

| http. file or folder name | Description | AD or EF | Reference | Contact | Data agreement/ Comment |
|---|---|---|---|---|---|
| DCE data-exchange folder: O:\ST_ENVS-Luft-Emi\Inventory\2018\6_Waste\Level_1b_Processing | Inventory data storage system | AD and EF | DCE | | |
| Report series published by the Danish Nature Agency (DNA) and available from the Danish Nature Agency (DNA) www.nst.dk and the Danish Environmental Protection Agency www.mst.dk | | | Report series: "*Point sources*" (2006-2017) | MST Østjylland Lisbeth Nielsen (linie@mst.dk)<br><br>Marianne Thomsen (mth@envs.au.dk) | Public available reports |
| Danish Water Quality parameter Database | Annually reported wastewater characteristics at plant level which includes all years 1990-2015 | AD | www.miljoeportal.dk | MST Østjylland Lisbeth Nielsen (linie@mst.dk) Marianne Thomsen (mth@envs.au.dk) | Authorised access |
| DCE data-exchange folder: O:\ST_ENVS-Luft-Emi\Inventory\2018\6_Waste\Level_1a_Storage | Raw data extracts from the Danish Waste Reporting System | AD | The Danish Environmental Protection Agency. Database on all registered Danish waste. Available at: www.ads.mst.dk | Ellen Lindholt Nissen Unit of Circular Economy and Waste (elnli@mst.dk | The amounts are registered due to statutory requirements |
| DCE data-exchange folder: O:\ST_ENVS-Luft-Emi\Energy\2018 | Basic data DS1 Dataset for energy-producing SWDS and WWTPs. $CH_4$ recovery data | | The Danish Energy Agency (DEA) | | Prepared due to the obligation of DEA |
| DCE data-exchange folder: O:\ST_ENVS-Luft-Emi\Inventory\2018\6_Waste\Level_1b_Processing\5A Solid Waste Disposal | Excel file with the FOD model: swds_fod_model_1940-2017.xls" | AD, EF, Model | IPCC 2000, 2006 | Marianne Thomsen (mth@envs.au.dk) | - |
| http://www.dkl.dk | Number for cremations | AD | Association of Danish Crematories | Hanne Ring hr@dkl.dk | Public access |
| http://www.statistikbanken.dk | Statistics for population. buildings and vehicles | AD | Statistics Denmark | | Public access |
| DCE data-exchange folder: O:\ST_ENVS-Luft-Emi\Inventory\2018\6_Waste\Level_1a_Storage | Cremated animal carcasses | AD | Dansk Dyrekremering ApS | Knud Ribergaard info@danskdyrekremering.dk | Personal contact |
| DCE data-exchange folder: O:\ST_ENVS-Luft-Emi\Inventory\2018\6_Waste\Level_1a_Storage | Cremated animal carcasses | AD | Ada's Kæledyrskrematorium ApS | Anders Oxholm anders@adakrem.dk | Personal contact |
| DCE data-exchange folder: O:\ST_ENVS-Luft-Emi\Inventory\2018\6_Waste\Level_1a_Storage | Cremated animal carcasses | AD | Kæledyrskrematoriet | Annette Laursen dyrepension@skyline-mail.dk | Personal contact |
| https://statistikbank.brs.dk | Categorized fires | AD | The Danish Emergency Management Agency | Steen Hjere Nonnemann shn@beredskabsstyrelsen.dk | Public access |
| DCE data-exchange folder: O:\ST_ENVS-Luft-Emi\Inventory\2018\6_Waste\Level_1a_Storage | Waste categories for composting | AD | Danish Environmental Protection Agency (DEPA). Waste Statistics | | Public access |

### 7.8.2 Data Processing Level 1

This level comprises a stage where the external data extracted from the waste data system (DEPA, 2014) are processed internally.

For CRF category 5.A, data are prepared for the DCE First Order of Decay model by allocation of the reported waste amounts according to the European Waste Codes (EWC) as presented in Chapter 7.2 and in Annex 3F, Table 3F-2.3 – F-2.5. The model runs in excel and the output are stored inside the excel file.

For the CRF category 5.B, composting data are delivered by the Danish Environmental Protection Agency for the period 2010-2018 at plant level. Total amount of composted biowaste is extracted from the waste reporting system (www.ads.mst.dk).

For the CRF category 5.C, activity data are used directly and for category 5.E., the activity data and emission factors are recalculated to match each other by using national average data like the average floor space in houses etc. Calculations are carried out and the output stored in a not editable format each year. The DP at level 1 has been improved to fit into a more uniform and easily accessible data reporting format.

For CRF category 5.D, data are prepared for the input to the country-specific models. The plant level data for WWTPs using anaerobic sludge digestion, i.e. biogas production, have been integrated with plant level energy recovery data from the Energy Statistics and a mass balance for the $CH_4$ potential in the influent TOW, the ingestate, the digestate, the amount of recovered and lost $CH_4$ by flaring and venting. Status for the improvements are presented Chapter 7.5 and in Thomsen, 2016. Calculations are carried out and the output stored in a not editable format each year. The DP at level 1 has been improved to fit into a more uniform and easily accessible data reporting format. Regarding the derivation of activity data and emission factors used in the model calculations, improvements are documented in Chapter 7.5.

### 7.8.3 Data Storage Level 2

Data Storage Level 2 is the placement of selected output data from the calculation of emissions as inventory data on SNAP levels in the Access (CollectER) database.

### 7.8.4 Data Storage Level 4

Data Storage Level 4 is the placement of the calculated output data from the calculation of emissions as data on SNAP levels in the CRFs.

### 7.8.5 Points of measurement

The present stage of QA/QC for the Danish emission inventories for the waste sector is described below for DS level 1, 2 and 4 and DP level 1 Points of Measurement (PMs). This is to be seen in connection with the general QA/QC description in Section 1.6 and, especially, 1.6.10 on specific description of PMs common to all sectors, general to QA/QC.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 1. Accuracy | DS.1.1.1 | General level of uncertainty for every dataset including the reasoning for the specific values |

The sources of data described in the methodology sections and in DS.1.2.1 and DS.1.3.1 are used in this inventory. Thus, it is the accuracy of these data that define the uncertainty of the inventory calculations.

With regard to the general level of uncertainty for SWDS, the amounts in waste fractions/categories are reasonably certain (per cent uncertainty set equal to 10 %. cf. Table 7.7.1. Due to the statutory environment for these data, while the distribution of waste fractions according to waste type and their content of *DOC* are more uncertain (per cent uncertainty set equal to 20 %. cf. Table 7.7.1). It is generally accepted that FOD models for $CH_4$ emission estimates offer the best and the most certain way of estimation. The half-life in the FOD models is an important parameter with some uncertainty (cf. Table 7.7.1).

For the *CRF category 5.B Biological Treatment of Solid Waste, 5.C Incineration and open burning* and *5.E Other* the level of uncertainty is generally low for activity data but higher for emission factors, cf. Table 7.7.2. Table 7.7.3 and Table 7.7.5. Expert judgments are used whenever default uncertainties are not available.

The input parameter uncertainties *for CRF category 5.D Wastewater Treatment and Discharge* have been derived from standard deviations between activity data extracted from national databases and reported national statistics as shown in Table 7.7.4. Uncertainty of activity data are based on simple standard deviations accompanying the annual reported monitoring data.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 2.Comparability | DS.1.2.1 | Comparability of the emission factors/calculation parameters with data from international guidelines and evaluation of major discrepancies. |

Comparison of Danish data values from external data sources with corresponding data from other countries has been carried out in order to evaluate discrepancies.

Comparison of Danish data values with data sources from other countries has been carried out as presented in the national verification report by Fauser et al., 2007, 2011 and 2013.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 3.Completeness | DS.1.3.1 | Ensuring that the best possible national data for all sources are included, by setting down the reasoning behind the selection of datasets. |

**SWDS**

- Danish Environmental Protection Agency (DEPA). ISAG database and the new waste data system (DEPA, 1996a, 1998a, 1999a, 2001a, 2001b, 2002a, 2004a, 2004b, 2005a, 2006a, 2006b, 2008, 2010a, 2011a, 2014, 2015, 2016, 2017, 2018, 2019): amounts of the various waste fractions deposited (refer to Chapter 7.2).
- A Danish investigation and verification of the overall mass balance upon allocating waste fractions within the old ISAG and the new waste data system (DEPA, 2013, 2014, 2015, 2016, 2017, 2018, 2019) into 18 well-defined waste types as described in Chapter 7.2.
- Danish Energy Agency (DEA): Official Danish energy statistics: $CH_4$ recovery data.

The selection of sources is obvious. The ISAG database is based on statutory registrations and reporting from all Danish waste treatment plants for all waste entering or leaving the plants. Information concerning waste in the previous year must be reported to the DEPA no later than January 31 each year. Registration is made by mass according to EAK codes, which are automatically reallocated into 18 waste types of which 11 are characterised as inert. The individual waste type characteristics have been documented in Chapter 7.2 and Table 7.2.2 as well as in Annex 3F, Table F3-2.3 and F3-2.5.

For recovery data, the DEA registers the energy produced from plants where installations recover $CH_4$ in the national energy statistics. For the parameters of the FOD model, references are made to IPCC (2000 and 2006).

#### Composting

- ISAG Waste Statistics (DEPA, 1996a, 1998a, 1999a, 2001a, 2001b, 2002a, 2004a, 2004b, 2005a, 2006a, 2006b, 2008, 2010a, 2011a, 2014, 2015, 2016, 2017, 2018)
- The New Danish Waste Reporting System (www.ads.mst.dk) (DEPA, 2013, 2014, 2015, 2016, 2017, 2018, 2019)

All Danish waste treatment plants are obligated to statutory registration and reporting of all waste entering and leaving the plants. All waste streams are weighed, categorised with a waste type and a type of treatment and registered to the ISAG waste information system, which contain data for 1995-2009 (ISAG). For 2010-2017 data from the new waste reporting system are delivered by the Danish EPA according to the three compost types (Exclusive home composting).

#### Waste Incineration

- Tables from Association of Danish Crematories available online
- Direct contact with the Danish animal crematories
- Emission factors from literature

Data from the Association of Danish Crematories is based on annual reporting from all Danish crematories. Specific reported data are available for the complete time series.

#### WWTP

- Integrated TOW-Energy recovery database
- The Danish Water Quality Parameter Database (www.miljoeportal.dk)

Data plant level on energy recovery has been integrated with plant level data on influent TOW, which have made it possible to quantify the amount of TOW in the influent at plants using anaerobic digestion as sludge management strategy as reported in Table 7.5.3.
Knowledge of the amount of sludge treated at WWTPs with anaerobic sludge digestion has been used as input parameter for calculation of the gross methane emission from anaerobic treatment. It constitutes a major improvement of the activity data for CRF category 5.D, while the energy statistics have been used to quantify the amount of methane lost via venting and flaring.

#### Other

- Waste Statistics (DEPA, 2017)
- Danish Emergency Management Agency (DEMA) database (DEMA 1998-2019)
- Emission factors from literature

The waste statistics are based on data from the ISAG database, which is the only Danish registration of waste amounts. Also, the DEMA database is the only provider of data on accidental fires, data for newer years (2008-2016) are extremely detailed.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 4.Consistency | DS.1.4.1 | The original external data has to be archived with proper reference. |

Data are predominantly extracted from the internet and databases (The Danish Waste Reporting System. the Water Quality Parameter database, Statistics Denmark, DEMA database, human cremation). The origin of external activity data has been preserved as much as possible by saving them as original copies in their original form. Files are saved for each year of reporting; in this way changes to previously received data and calculations are reflected and explanations are given. Specific information from reports, industries and experts are saved as e-mails and pdf files.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 6.Robustness | DS.1.6.1 | Explicit agreements between the external institution holding the data and DCE about the conditions of delivery. |

As stated in DS.1.4.1 most data are obtained from the internet. It is a statutory requirement that amounts of waste are reported annually to DEPA, no later than January 31 for the previous year. No explicit agreements have been made with external institutions.

| | | | |
|---|---|---|---|
| Data Storage level 1 | 7.Transparency | DS.1.7.1 | Listing of all archived datasets and external contacts. |

Contact persons related to the delivery of specific data are provided in Table 8.7.1.

For a listing of all archived external data sets the reader is referred to DS 1.3.1.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 1. Accuracy | DP.1.1.1 | Uncertainty assessment for every data source not part of DS.1.1.1 as input to Data Storage level 2 in relation to type and scale of variability. |

No data are used in addition to those included in DS.1.1.1. Uncertainties are reported in Section 7.7.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 2.Comparability | DP.1.2.1 | The methodologies have to follow the international guidelines suggested by UNFCCC and IPCC. |

The methodological approach is based on the detailed methodology as outlined in the Emission Inventory Guidebook. The calculation used for SWDS is a Tier 2 methodology from IPCC (2000 and 2006). For WWTP the calculations follow the IPCC (2000 and 2006). Exemptions have been documented whenever occurring. The inventory calculations for Waste Incineration and Waste Other are a simple multiplication of activity data and emission factors (See also DS.1.3.1).

| | | | |
|---|---|---|---|
| Data Processing level 1 | 3.Completeness | DP.1.3.1 | Identification of data gaps with regard to data sources that could improve quantitative knowledge. |

Emission factors for cremation and accidental fires are gathered from literature studies. There is no Danish literature or measurements available on greenhouse gas emissions from these categories.

Activity data for accidental fires for the years 1990-2006 are not sub categorised into vehicles, buildings or sizes.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 4.Consistency | DP.1.4.1 | Documentation and reasoning of methodological changes during the time series and the qualitative assessment of the impact on time series consistency. |

There is no change in calculation procedure during the time series and the activity data are, as far as possible, kept consistent for the calculation of the time series. Any changes in calculation procedures are noted for each year's inventory in the individual chapters for each CRF category.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 5.Correctness | DP.1.5.1 | Verification of calculation results using time series |

The time series of activities and emissions from the model output in the SNAP source categories and in the CRF format have been prepared. The time series are examined and significant changes are checked and explained. Comparison is made with the previous year's estimate and any major changes are verified.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 5.Correctness | DP.1.5.2 | Verification of calculation results using other measures |

The correct interpretation in the model/calculation of the methodology and the parameterisation has been checked as far as possible.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 7.Transparency | DP.1.7.1 | The calculation principle. The equations used and the assumptions made, must be described. |

The calculation principle and equations are described in Chapter 7.2 to 7.6 for each CRF category in the waste sector.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 7.Transparency | DP.1.7.2 | Clear reference to dataset at Data Storage level 1 |

Refer to the table at the start of this Section and DS.1.1.1 (Table 8.7.1).

The calculation principle and equations are described in Chapter 7.2 to 7.6 for each CRF category in the waste sector.

| | | | |
|---|---|---|---|
| Data Processing level 1 | 7.Transparency | DP.1.7.3 | A manual log to collect information about re-calculations. |

Recalculation and changes in the emission inventories are described in the NIR whenever occurring. The logging of the changes takes place in the annual model file.

| | | | |
|---|---|---|---|
| Data Storage level 2 | 5.Correctness | DS.2.5.1 | Check if a correct data import to level 2 has been made |

The transfer of emission data from level 1, storage and processing, to data storage level 2 is manually checked. This check is performed, comparing model output and report files made by the CollectER database system.

| | | | |
|---|---|---|---|
| Data Storage level 4 | 4. Consistency | DS.4.4.3 | The IEFs from the CRF are checked regarding both level and trend. The level is compared to relevant emission factors to ensure correctness. Large dips/jumps in the time series are explained. |

See DP.1.5.1 and DP.1.5.2.

## 7.9 Source specific recalculations

Table 7.9.1 presents the recalculations to the waste sector for this year's inventory. Tables with the full time series 1990-2018 are shown in Annex 3F, Table 3F-7.1 to 3F-7.6.

The joint effect of these recalculations is a decrease in the GHG emissions between 0.7 and 1.3 % in the period 2010-2018.

Table 7.9.1 Changes in emissions from the waste sector compared with last year´s submission.

| | Unit | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **5.A. Solid Waste Disposal** | | | | | | | | | | | |
| $CH_4$. previous inventory | kt | 61.5 | 53.2 | 42.9 | 36.4 | 30.9 | 28.1 | 27.6 | 26.1 | 24.8 | 23.7 |
| $CH_4$. recalculated | kt | 61.5 | 53.2 | 42.9 | 36.4 | 30.9 | 28.1 | 27.5 | 26.0 | 24.7 | 23.5 |
| Change. $CO_2$ equivalents | kt | 0 | 0 | 0 | 0 | 0 | -1.0 | -1.4 | -2.0 | -2.7 | -4.5 |
| Change | % | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.8 |
| **5.B. Biological treatment of Solid Waste** | | | | | | | | | | | |
| *5.B1 Composting* | | | | | | | | | | | |
| $CH_4$, previous inventory | t | 1387 | 1859 | 3241 | 3420 | 4010 | 3977 | 3829 | 4180 | 4264 | 4416 |
| $CH_4$, recalculated | t | 1387 | 1859 | 3241 | 3420 | 3831 | 3731 | 3689 | 3978 | 4008 | 4335 |
| $N_2O$, previous inventory | t | 41 | 70 | 513 | 198 | 299 | 278 | 256 | 230 | 283 | 287 |
| $N_2O$, recalculated | t | 41 | 70 | 513 | 198 | 289 | 263 | 247 | 218 | 268 | 277 |
| Change, $CO_2$ equivalents | Kt | 0 | 0 | 0 | 0 | -8 | -11 | -6 | -9 | -11 | -5 |
| Change | % | 0 | 0 | 0 | 0 | -4 | -6 | -3 | -5 | -6 | -3 |
| *5.B2 Biogas* | | | | | | | | | | | |
| $CH_4$, previous inventory | t | 224 | 627 | 1211 | 1995 | 2675 | 2885 | 3661 | 4367 | 6548 | 8282 |
| $CH_4$, recalculated | t | 224 | 627 | 1211 | 1995 | 2675 | 2885 | 3661 | 4367 | 6548 | 8301 |
| Change, $CO_2$ equivalents | Kt | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Change | % | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 |
| **5.C. Incineration and open burning of waste** | | | | | | | | | | | |
| $CH_4$, previous inventory | t | 0.51 | 0.55 | 0.57 | 0.62 | 0.76 | 0.71 | 0.70 | 0.71 | 0.73 | 0.73 |
| $CH_4$, recalculated | t | 0.51 | 0.55 | 0.57 | 0.62 | 0.76 | 0.71 | 0.70 | 0.71 | 0.73 | 0.73 |
| $N_2O$, previous inventory | t | 0.64 | 0.69 | 0.71 | 0.77 | 0.95 | 0.88 | 0.87 | 0.89 | 0.91 | 0.91 |
| $N_2O$, recalculated | t | 0.64 | 0.69 | 0.71 | 0.77 | 0.95 | 0.88 | 0.87 | 0.89 | 0.91 | 0.91 |
| Change, $CO_2$ equivalents | kt | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Change | % | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **5.D. Wastewater treatment and discharge** | | | | | | | | | | | |
| $CH_4$, previous inventory | kt | 1.64 | 1.73 | 1.85 | 1.89 | 1.91 | 1.96 | 1.99 | 1.96 | 2.01 | 2.05 |
| $CH_4$, recalculated | kt | 1.64 | 1.73 | 1.85 | 1.89 | 1.91 | 1.96 | 1.99 | 1.96 | 2.01 | 2.01 |
| $N_2O$, previous inventory | kt | 0.37 | 0.38 | 0.27 | 0.24 | 0.21 | 0.22 | 0.22 | 0.23 | 0.22 | 0.22 |
| $N_2O$, recalculated | kt | 0.37 | 0.38 | 0.27 | 0.24 | 0.21 | 0.22 | 0.22 | 0.23 | 0.22 | 0.22 |
| Change, $CO_2$ equivalents | kt | 0 | 0 | 0 | 0 | 0 | 0 | -0.001 | 0 | 0.1 | -0.6 |
| Change | % | 0 | 0 | 0 | 0 | 0 | 0 | -0.0009 | 0 | 0.09 | -0.5 |
| **5.E. Other** | | | | | | | | | | | |
| $CO_2$, previous inventory | kt | 20.31 | 22.61 | 20.73 | 20.22 | 17.44 | 16.05 | 14.37 | 15.06 | 17.12 | 15.70 |
| $CO_2$, recalculated | kt | 20.31 | 22.61 | 20.73 | 20.22 | 17.44 | 16.05 | 14.37 | 15.06 | 17.12 | 15.70 |
| $CH_4$, previous inventory | kt | 0.10 | 0.11 | 0.10 | 0.09 | 0.08 | 0.07 | 0.07 | 0.07 | 0.08 | 0.07 |
| $CH_4$, recalculated | kt | 0.10 | 0.11 | 0.10 | 0.09 | 0.08 | 0.07 | 0.07 | 0.07 | 0.08 | 0.07 |
| Change, $CO_2$ equivalents | kt | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Change | % | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### 7.9.1 Solid waste disposal on land

Recalculations have been made for the years 2010-2017 due to updated activity data in the Danish waste reporting system. This has led to minor changes in the methane emissions from solid waste disposal sites in the range of $0.31*10^{-8}$ % to 0.77 % in this period. Recalculations for the whole time series is provided in Annex 3F, Table 3F-7.1.

### 7.9.2 Biological treatment of solid waste

For Composting, improved data on the amount of biowaste types going to biogas plant and composting within the new waste reporting system have caused major change in the activity data for the years 2010-2017. Correction in the amount of waste being composted, have resulted in increased amounts (2.6-8.5 %) in 2010-2017. Recalculations for the whole time series is provided in Annex 3F, Table 3F-7.2.

Activity data for biogas production in 2017 have been updated and the total $CH_4$ emission from sub-sector 5.B have changed the range of -0.23 % in 2017.

### 7.9.3 Waste incineration and open burning

For sub-sector 5.C Incineration and open burning of waste, constituting human and animal cremations, corrections in the decimal places of the EF values have resulted in minor recalculation in 2012 of -0.0002 % (cf. Annex 3F, table 3F-7-3).

### 7.9.4 Wastewater treatment and discharge

For *5.D Wastewater treatment and discharge*, recalculations occur 2014, 2016 and 2017 resulting in minor changes between 0.0009 and 0.53% as shown in Annex 3F, Table 3F-5.3.

### 7.9.5 Other

For *5E Other*, no recalculations have occurred.

## 7.10 Source specific improvements

### 7.10.1 Response to the review process

The table below contains the recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory. The table details the status of implementation of the recommendations as well as references to where improvements have been implemented in this report.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| **2018 submission (Review report: https://unfccc.int/sites/default/files/resource/dnk_0.pdf)** | | | | |
| W.4 | 5.A Solid waste disposal on land – $CH_4$ | Use the notation key "NA" to report $CO_2$ emissions for solid waste disposal on land.<br>Addressing. The notation keys were already changed for Denmark in the 2016 submission. During the review, Denmark explained that the notation key was corrected in the CRF tables for Greenland, but was not reflected correctly in the aggregation of the DNK CRF tables. The reason will be further investigated and corrected for the 2019 submission. | The notation key has been corrected for all submissions. | CRF |
| W.7 | 5.A.1 Managed waste disposal sites – $CH_4$ | Change the approach for the uncertainty analysis by applying the updated default uncertainty values from the 2006 IPCC Guidelines.<br>Addressing. According to Section 7.7.1 of the NIR default uncertainty values from the 2006 IPCC Guidelines are used in the uncertainty analysis with one exception. The uncertainties for the rate constants (k) are taken from the IPCC good practice guidance. During the review, Denmark responded that it considered the new uncertainty values for the rate constants too low. Denmark also informed the ERT of its plans to re-evaluate the uncertainties of the k values for the 2019 submission. The re-evaluation would include assessing the ranges provided in the 2006 IPCC Guidelines, but also whether it will be feasible to implement either a sensitivity analysis or Monte Carlo simulation in the uncertainty estimation. | The default uncertainty range for the t½ values provided in Table 3.4 (2006 IPCC guidelines, Chapt.3) translates into an uncertainty range for the methane generation constants, k, of -71 % to +166 %. The uncertainty of 100 % applied in former National Inventory Reporting was kept in this year's NIR.<br><br>As recommended by the ERT, a Monte Carlo simulation was performed using the default average values and uncertainty range for the t½ values for each waste type as input, together with default and uncertainties DOC and remaining FOD model, resulting in an uncertainty on the IEF of 24 % and 26 % in 1990 and 2017.<br><br>The above has been explained below in Table 7.7.1 in Chapter 7.7.1, the subsection entitled " Solid Waste Disposal" | NIR |
| W.15 | 5. General (waste) – $CO_2$, $CH_4$ and $N_2O$ | The ERT noted that total emissions from the waste sector in Table 7.1.1 in the NIR and those in CRF table 10s1 differ. The emissions for 2016, for example, are 1,271.28 kt $CO_2$ eqv. in the CRF table versus 1,212 kt $CO_2$ eqv. according to the summary table in the NIR mainly owing to a difference in the value for $CH_4$ emissions from biological treatment of solid waste. During the review, Denmark explained that the correct values are reported in the CRF table.<br>The ERT recommends that Denmark provide correct data for the aggregate emissions in $CO_2$ equivalent from the waste sector in the corresponding NIR table. | Correct data for the aggregate emissions are provided in Table 7.1.1 | |
| W.16 | 5.A Solid waste disposal on land – $CH_4$ | The ERT noted that DOCf in CRF table 5.A is given as 4.08 per cent when according to the NIR (p.477) the default value of 0.5 is used. Denmark confirmed that the error was in the CRF table and that it does not affect the emission estimation.<br>The ERT recommends that Denmark correct the erroneous entry of DOCf in CRF table 5.A. | The value provided in the CFR tables are the weighted average DOCi values. The values will be corrected to the constant DOCf value of 0.5. | CRF |
| W.17 | 5.A Solid waste disposal on land – $CH_4$ | According to Table 7.2.2 of the NIR, Denmark uses half-life values for sludge from Table 3.4 in the 2006 IPCC Guidelines corresponding to a dry climate, while for other waste types values for a wet climate are used. Denmark's climate is categorized as wet. In response to the clarification on the choice made, Denmark explained that a country-specific half-life for sludge is used based on expert judgement. It takes into account that the sludge landfilled is normally the end product from anaerobic digestion with a lower degradation rate than that of undigested sludge. Hence the IPCC default for slowly degrading waste (paper, textiles) corresponding to a wet climate in Table 3.4 in the 2006 IPCC Guidelines was considered to be more suitable for sludge from anaerobic digestion.<br>The ERT considers the explanation provided by the Party during the review plausible and recommends that Denmark include information and references justifying the country-specific half-life for sludge in the NIR. | An explanation have been added to Table 7.2.2 in the NIR. | Chapter 7,2 |

### 7.10.2 Planned improvements

For the category 5.A. Solid Waste Disposal, the FOD model has been applied at plant level for the whole life time of the individual SWDS. The purpose is to calibrate the plant level modelled emissions by comparing to monitoring data and validated the model as more monitoring data becomes available (Nissen, 2017b). The reason for efforts put into plant level emission modelling is the Government financed implementation of biocovers on Danish landfills as instrument for reducing methane emissions from category 5.A (Executive Order No. 752 of 21/06/2016). The plant level emission model is expected to be documented in a sector report in 2021, while emission reductions from implementation of biocover in 2019 and 2020 will be reported for the first time in the NIR submitted in 2022 (Bang-Andreasen, 2020).

Improvements of plant level activity data for composting as well as wastewater treatment technologies influencing the $N_2O$ and CH4 emissions are ad hoc effort for improvement emission inventory for these sub-sectors.

Development in aquaculture and marine fish farming activities in Denmark will influence indirect $N_2O$ emissions, why improvements are expected. However, these improvements are long-term aspects implemented ad hoc as the necessary documentation becomes available.

There are no other planned improvements for the waste sector.

## 7.11 References


Aasestad, K., 2008. The Norwegian Emission Inventory 2008**.** Documentation of methodologies for estimating emissions of greenhouse gases and long-range transboundary air pollutants. Available at:
http://www.ssb.no/english/subjects/01/04/10/rapp_emissions_en/rapp_200848_en/rapp_200848_en.pdf (03/02-2020).

Adouani, N., Lendormi, T., Limousy, L., Sire, O., 2010: Effect of the carbon source on N2O emissions during biological denitrification. Resources, Conservation and Recycling 54(5), 299-302. doi:10.1016/j.resconrec.2009.07.011. Available at:
https://www.researchgate.net/publication/222256958_Effect_of_the_carbon_source_on_N2O_emissions_during_biological_denitrification_Resources_Conservation_and_Recycling_545_299-302 (03/02-2020).

Danish Nature Agency (DNA), 2007: Point sources 2006. In Danish: Punktkilder 2006. Det nationale program for overvågning af vandmiljøet, Fagdatacenterrapport. Available at:
http://www2.blst.dk/udgiv/Publikationer/2007/978-87-92256-36-2/pdf/978-87-92256-37-9.pdf (03/02-2020).

Danish Nature Agency (DNA), 2009: Point sources 2007. In Danish: Punktkilder 2007. Det nationale program for overvågning af vandmiljøet, Fagdatacenterrapport. Available at:
http://naturstyrelsen.dk/media/nst/70162/Punktkilderapport_.pdf (03/02-2020).

Danish Nature Agency (DNA), 2010: Point sources 2008. In Danish: Punktkilder 2008. Det nationale program for overvågning af vandmiljøet, Fagdatacenterrapport. Available at:

http://naturstyrelsen.dk/media/nst/70006/PunktkildeRapport200815022010.pdf (03/02-2020).

Danish Nature Agency (DNA), 2010: Point sources 2009. In Danish: Punktkilder 2009. Det nationale program for overvågning af vandmiljøet, Fagdatacenterrapport. Available at:
http://naturstyrelsen.dk/publikationer/2011/jan/punktkilder-2009/
(03/02-2020).

Danish Nature Agency (DNA), 2011: Point sources 2010. In Danish: Punktkilder 2010. Det nationale program for overvågning af vandmiljøet, Fagdatacenterrapport. Available at:
http://naturstyrelsen.dk/media/nst/66770/Punktkilder%202010.pdf
(03/02-2020).

Danish Nature Agency (DNA), 2012: Point sources 2011. In Danish: Punktkilder 2011. Det nationale program for overvågning af vandmiljøet, Fagdatacenterrapport. Available at:
http://naturstyrelsen.dk/media/nst/66851/Punktkilderapport%202011.pdf (03/02-2020).

Danish Nature Agency (DNA), 2013: Point sources 2012. In Danish: Punktkilder 2012. Det nationale program for overvågning af vandmiljøet, Fagdatacenterrapport. Available at:
http://naturstyrelsen.dk/publikationer/2013/dec/punktkilder-2012/
(03/02-2020).

Danish Nature Agency (DNA), 2015: Point sources 2013. In Danish: Punktkilder 2013. Det nationale program for overvågning af vandmiljøet, Fagdatacenterrapport. Available at:
http://naturstyrelsen.dk/publikationer/2015/feb/punktkilder-2013/
(03/02-2020).

Danish Nature Agency (DNA), 2015: Point sources 2014. In Danish: Punktkilder 2014. Det nationale program for overvågning af vandmiljøet, Fagdatacenterrapport. Available at:
http://naturstyrelsen.dk/media/175045/punktkilderapport-2014.pdf
(03/02-2020).

Danish Nature Agency (DNA), 2017: Point sources 2015. In Danish: Punktkilder 2015. Det nationale program for overvågning af vandmiljøet, Fagdatacenterrapport. Available at: http://mst.dk/media/114910/punktkilder-2015.pdf (03/02-2020).

Amlinger, F., Peyr, S. & Cuhls, C., 2008: Greenhouse gas emissions from composting and mechanical biological treatment. Florian Amlinger. Stefan Peyr and Carsten Cuhls. Waste Management & Research 2008, 26, 47. Sage publications. International Solid Waste Association. Available at:
http://wmr.sagepub.com/cgi/reprint/26/1/47.pdf (03/02-2020).

Blomqvist, P., Persson, B. & Simonson, M., 2002: Utsläpp från bränder till miljön. Utsläpp av dioxin. PAH och VOC till luften. Räddnindsverket. Karlstad. FoU rapport. SP Brandteknik. Borås. Available at:
http://rib.msb.se/Filer/pdf%5C18193.pdf (03/02-2020) (Swedish).

Boldrin, A., Andersen, J.K. & Christensen, T.H., 2009: Environmental assessment of garden waste management in Århus Kommune (Miljøvurdering af haveaffald i Århus kommune). Technical University of Denmark - Miljø. 3R. Available at:
https://www.sciencedirect.com/science/article/pii/S0956053X11000201?via%3Dihub (03/02-2020).

Czepiel, P., Crill, P. & Harriss, R. 1995: Nitrous oxide emissions from municipal wastewater treatment. Environmental Science and Technology. 29. 2352-2356. Available at:
https://pubs.acs.org/doi/abs/10.1021/es00009a030 (03/02-2020).

Danish Emergency Management Agency (DEMA), 1998: Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 1998. Available at:
http://brs.dk/viden/statistik/statistiskepublikationer/rapporter/Documents/Redningsberedskabets_Statistiske_Beretning_1998.pdf (03/02-2020) (Danish).

Danish Emergency Management Agency (DEMA), 1999: Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 1999. Available at:
http://brs.dk/viden/statistik/statistiskepublikationer/rapporter/Documents/Redningsberedskabets_Statistiske_Beretning_1999.pdf (29/01-2019) (Danish).

Danish Emergency Management Agency (DEMA), 2000: Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 2000. Available at:
http://brs.dk/viden/statistik/statistiskepublikationer/rapporter/Documents/Redningsberedskabets_Statistiske_Beretning_2000.pdf (29/01-2019) (Danish).

Danish Emergency Management Agency (DEMA), 2001: Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 2001. Available at:
http://brs.dk/viden/statistik/statistiskepublikationer/rapporter/Documents/Redningsberedskabets_Statistiske_Beretning_2001.pdf (29/01-2019) (Danish).

Danish Emergency Management Agency (DEMA), 2002: Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 2002. Available at:
http://brs.dk/viden/statistik/statistiskepublikationer/rapporter/Documents/Redningsberedskabets_Statistiske_Beretning_2002.pdf (29/01-2019) (Danish).

Danish Emergency Management Agency (DEMA), 2003: Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 2003. Available at:
http://brs.dk/viden/statistik/statistiskepublikationer/rapporter/Documents/Redningsberedskabets_Statistiske_Beretning_2003.pdf (29/01-2019) (Danish).

Danish Emergency Management Agency (DEMA), 2004: Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 2004. Available at:
https://brs.dk/viden/publikationer/Documents/RBS_Statistisk_Beretning_2004.pdf (29/01-2019) (Danish).

Danish Emergency Management Agency (DEMA), 2005: Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 2005. Available at:

https://brs.dk/viden/publikationer/Documents/RBS_Statistisk_Beretning_2005.pdf (29/01-2019) (Danish).

Danish Emergency Management Agency (DEMA), 2006: Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 2006. Available at: https://brs.dk/viden/publikationer/Documents/RBS_Statistisk_Beretning_2006.pdf (29/01-2019) (Danish).

Danish Emergency Management Agency (DEMA), 2007: Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 2007. Available at: http://brs.dk/viden/publikationer/Documents/RBS_Statistisk_Beretning_2007.pdf (03/02-2020) (Danish).

Danish Emergency Management Agency (DEMA), 2008: Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 2008. Available at: http://www.ft.dk/samling/20081/almdel/fou/bilag/212/715319.pdf (03/02-2020) (Danish).

Danish Emergency Management Agency (DEMA), 2009: Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 2009. Available at: https://brs.dk/viden/publikationer/Documents/RBS_Statistisk_Beretning_2009.pdf (03/02-2020) (Danish).

Danish Emergency Management Agency (DEMA), 2011: Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 2011. Available at: https://brs.dk/viden/publikationer/Documents/Redningsberedskabets_%20Statistik_2011.pdf (03/02-2020) (Danish).

Danish Emergency Management Agency (DEMA), 2012: Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 2012. Available at: http://brs.dk/viden/statistik/Documents/Redningsberedskabets%20Statistik%202012.pdf (03/02-2020) (Danish).

Danish Emergency Management Agency (DEMA), 2013: Beredskabsstyrelsens statistic 2013. Available at: http://brs.dk/viden/statistik/Documents/Redningsberedskabets%20Statistik%202013.pdf (03/02-2020) (Danish).

Danish Emergency Management Agency (DEMA), 2014: Beredskabsstyrelsen. Statistic 2014. Available at: http://brs.dk/viden/statistik/Documents/Redningsberedskabets%20Statistik%202014.pdf (03/02-2020) (Danish).

Danish Emergency Management Agency (DEMA), 2015: Beredskabsstyrelsen. Statistic 2015. Available at: http://brs.dk/viden/publikationer/Documents/Redningsberedskabets%20Statistik%202015.pdf (03/02-2020) (Danish).

Danish Emergency Management Agency (DEMA), 2016: Beredskabsstyrelsen. Statistic 2015. Available at: http://brs.dk/viden/publikationer/Documents/Redningsberedskabets%20Statistik%202016.pdf (03/02-2020) (Danish).

Danish Emergency Management Agency (DEMA), 2017: Data received per mail from Magnus Høegh Jensen, Danish Emergency Management Agency, 25 Oct. 2017.

Danish Emergency Management Agency (DEMA), 2019: Available at: https://statistikbank.brs.dk/sb#page=1c572bbd-e3fe-40cf-bc71-4244c3b750e8 (04/02-2020)

Danish Energy Agency (DEA), 2015: Drivhusgasemissioner fra biogasanlæg (English title: GHG emissions from biogasplants). Available at: https://ens.dk/sites/ens.dk/files/Bioenergi/cowi_-_drivhusgasemissioner_fra_biogasanlaeg_v3_4.pdf (03/02-2020).

Danish Energy Agency (DEA), 2019: The Danish energy statistics. Available at: https://ens.dk/service/statistik-data-noegletal-og-kort/maanedlig-og-aarlig-energistatistik (03/02-2020).

Danish Energy Agency (DEA), 2020: The Danish energy statistics. Energiproducenttællingen 1990-2018, unpublished.

Danish Environmental Protection Agency (DEPA), 1993: Affaldsstrømmene i Danmark. Arbejdsrapport fra Miljøstyrelsen Nr. 15 1993. Available at: https://www2.mst.dk/Udgiv/publikationer/1993/87-7909-716-2/pdf/87-7909-716-2.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 1994: Point Sources 1993. In Danish: Punktkilder 1993. Orientering fra Miljøstyrelsen. nr. 8. Available at: http://www2.mst.dk/Udgiv/publikationer/1994/87-7810-279-0/pdf/87-7810-279-0.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 1996a: Affaldsstatistik 1995 (Waste Statistics 1995. Orientering fra Miljøstyrelsen nr. 14 1997) Available at: http://www2.mst.dk/Udgiv/publikationer/1996/87-7810-704-0/pdf/87-7810-704-0.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 1996b: Point Sources 1995. In Danish: Punktkilder 1995. Orientering fra Miljøstyrelsen. nr. 16. Available at: http://mst.dk/service/publikationer/publikationsarkiv/1997/jan/punktkilder-1995/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 1997: Point Sources 1996. In Danish: Punktkilder 1996. Orientering fra Miljøstyrelsen. nr. 16. Available at: http://mst.dk/service/publikationer/publikationsarkiv/1998/feb/punktkilder-1996/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 1998a: Waste Statistics 1996. Available at: http://mst.dk/service/publikationer/publikationsarkiv/1997/nov/affaldsstatistik-1996/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 1998b: Point Sources 1997. In Danish: Punktkilder 1997. Orientering fra Miljøstyrelsen. nr. 9. Available at:
http://mst.dk/service/publikationer/publikationsarkiv/1998/dec/punktkilder-1997/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 1999a: Waste Statistics 1997. Available at:
http://mst.dk/service/publikationer/publikationsarkiv/1999/jun/affaldsstatistik-1997/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 1999b: Point Sources 1998. In Danish: Punktkilder 1998. Orientering fra Miljøstyrelsen. nr. 6. Available at:
http://mst.dk/service/publikationer/publikationsarkiv/2000/jan/punktkilder-1998/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2000: Point Sources 1999. In Danish: Punktkilder 1999. Orientering fra Miljøstyrelsen. nr. 16. Available at:
http://www2.mst.dk/Udgiv/publikationer/2000/87-7944-298-6/pdf/87-7944-299-4.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2001a: Waste Statistics 1998. Available at:
http://mst.dk/service/publikationer/publikationsarkiv/2000/jan/affaldsstatistik-1998/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2001b: Waste Statistics 1999. Available at:
http://mst.dk/service/publikationer/publikationsarkiv/2000/dec/affaldsstatistik-1999/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2001c: Point Sources 2000. In Danish: Punktkilder 2000. Orientering fra Miljøstyrelsen. nr. 13. Available at:
http://mst.dk/service/publikationer/publikationsarkiv/2001/dec/punktkilder-2000/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2002a: Waste Statistics 2000. Available at:
http://mst.dk/service/publikationer/publikationsarkiv/2001/dec/affaldsstatistik-2000/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2002b: Point Sources 2001. In Danish: Punktkilder 2001. Orientering fra Miljøstyrelsen. nr. 7. Available at:
http://www2.mst.dk/Udgiv/publikationer/2002/87-7972-384-5/pdf/87-7972-385-3.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2003b: Point Sources 2002. In Danish: Punktkilder 2002. Orientering fra Miljøstyrelsen. nr. 10. Available at:
http://www2.mst.dk/Udgiv/publikationer/2003/87-7614-074-1/pdf/87-7614-076-8.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2004a: Waste Statistics 2001. Available at: http://mst.dk/service/publikationer/publikationsarkiv/2003/mar/affaldsstatistik-2001/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2004b: Waste Statistics 2002. Available at: http://mst.dk/service/publikationer/publikationsarkiv/2003/jul/affaldsstatistik-2002/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2004c: Point Sources 2003. In Danish: Punktkilder 2003. Orientering fra Miljøstyrelsen. nr. 16. Available at: http://www2.mst.dk/Udgiv/publikationer/2004/87-7614-482-8/pdf/87-7614-483-6.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2005a: Waste Statistics 2003. Available at: http://mst.dk/service/publikationer/publikationsarkiv/2004/nov/affaldsstatistik-2003/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2005b: Point Sources 2004. In Danish: Punktkilder 2004. Orientering fra Miljøstyrelsen. nr. 9. Available at: http://www2.mst.dk/Udgiv/publikationer/2005/87-7614-865-3/pdf/87-7614-866-1.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2005c: Point Sources 2003. Revision. In Danish: Punktkilder 2003 – revideret udgave. Orientering fra Miljøstyrelsen. nr. 1. Availble at: http://www2.mst.dk/Udgiv/publikationer/2005/87-7614-512-3/pdf/87-7614-513-1.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2006a: Waste Statistics 2004. Available at: http://mst.dk/service/publikationer/publikationsarkiv/2005/okt/affaldsstatistik-2004/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2006b: Affaldsstatistik 2005 (Waste Statistics 2005). Orientering fra Miljøstyrelsen nr. 6. Available at: http://mst.dk/service/publikationer/publikationsarkiv/2006/okt/affaldsstatistik-2005/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2006c: Legislation on sludge. Bekendtgørelse om anvendelse af affald til jordbrugsformål (Slambekendtgørelsen). BEK nr. 1650 af 13/12/2006. Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=13056 (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2008: Affaldsstatistik 2006. (Waste Statistics 2006) Orientering fra Miljøstyrelsen nr. 2 2008. Available at: http://www2.mst.dk/udgiv/publikationer/2008/978-87-7052-753-8/pdf/978-87-7052-754-5.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2010a: Affaldsstatistik 2007 og 2008. (Waste Statistics 2007 and 2008). Available at: http://mst.dk/media/mst/70152/Affaldsstatistik%202007%20og%202008.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2010b: Anvendelse af affald til jordbrugsformål. Vejledning fra Miljøstyrelsen Nr. 1 2010. Available at: http://mst.dk/service/publikationer/publikationsarkiv/2010/aug/anvendelse-af-affald-til-jordbrugsformaal/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2011a: Affaldsstatistik 2009 og fremskrivning af affaldsmængder 2011-2050. (Waste Statistics 2009). Available at: http://www2.mst.dk/udgiv/publikationer/2011/10/978-87-92779-44-1/978-87-92779-44-1.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2011b: Legislation on waste (Affaldsbekendtgørelsen). BEK nr. 1415 af 12/12/2011 Gældende. Chapter 7. §46 and §47. Available at: https://www.retsinformation.dk/forms/r0710.aspx?id=139654#Kap7 (03/02-2020) (In Danish).

Danish Environmental Protection Agency (DEPA), 2013: Affaldsstatistik 2011, (Waste Statistics 2011). Available at: https://mst.dk/media/mst/Attachments/Affaldsstatistik2012.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2014: Affaldsstatistik 2012, (Waste Statistics 2012). Available at: http://mst.dk/media/93643/affaldsstatistikken-2012.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2015: Affaldsstatistik 2013, (Waste Statistics 2013). Available at: https://mst.dk/media/93478/affaldsstatistik-2013.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2016: Affaldsstatistik 2014, (Waste Statistics 2014). Available at: https://www2.mst.dk/Udgiv/publikationer/2016/09/978-87-93529-05-2.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2017: Affaldsstatistik 2015, (Waste Statistics 2015). Available at: https://www2.mst.dk/Udgiv/publikationer/2017/05/978-87-93614-01-7.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2018 Affaldsstatistik 2016, (Waste Statistics 2016). Available at: https://www2.mst.dk/Udgiv/publikationer/2018/06/978-87-93710-39-9.pdf (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2019 Affaldsstatistik 2017, (Waste Statistics 2017). Available at: https://mst.dk/service/publikationer/publikationsarkiv/2019/sep/affaldsstatistik-2017/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2018: Point sources 2016. In Danish: Punktkilder 2016. Det nationale program for overvågning af vandmiljøet, Fagdatacenterrapport. Available at: https://mst.dk/service/publikationer/publikationsarkiv/2018/apr/punktkilder-2016// (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2019: Point sources 2017. In Danish: Punktkilder 2016. Det nationale program for overvågning af vandmiljøet, Fagdatacenterrapport. Available at: https://www2.mst.dk/Udgiv/publikationer/2019/02/978-87-7038-042-3.pdf/ (03/02-2020).

Danish Environmental Protection Agency (DEPA), 2020: Point sources 2018. In Danish: Punktkilder 2016. Det nationale program for overvågning af vandmiljøet, Fagdatacenterrapport. Available at: https://mst.dk/service/publikationer/publikationsarkiv/2019/dec/punktkilder-2018/ (03/02-2020).

Danish Gas Technology Center (DGC), 2009: DGC målerapport 731-28-5 November 2009. Gasmotoranlæg. Jenbacher J 316. deponigas. Steen D. Andersen. Available at: http://www.energinet.dk/SiteCollectionDocuments/Danske%20dokumenter/Klimaogmiljo/Emissionsprojektet%20-%20Anl%C3%A6g%2005%20-%20Motor%20(biogas%20deponigas).pdf (03/02-2020).

Danske Krematoriers Landsforening (DKL), 2009: Røggasrensning, Miljøbehandling og varmeudnyttelse, Status juni 2009. Miljø- og Planlægningsudvalget, MPU alm. del - Svar på Spørgsmål 591. Available at: https://www.ft.dk/samling/20081/almdel/mpu/spm/591/svar/641398/714098.pdf (03/02-2020).

Danske Krematoriers Landsforening (DKL), 2019: Association of Danish crematories. statistisk materiale. Available at: http://www.dkl.dk/ (03/02-2020).

DANVA, 2008. Eksplosiv atmosfære i kloakker (English title: Explosive atmosphere in sewers). Report no. 77. ISBN: 87-90455-79-7. Available at: https://www.danva.dk/media/2695/eksplosiv_atmosfaere_i_kloakker_samlet_rapport.pdf (07/02-2020).

DANVA, 2011. Køkkenkværne: energi-, miljø- og driftsmæssige konsekvenser ved brug i boliger. Report no. 85. Available at: http://www.insinkerator.dk/Files/Billeder/InsinkErator/K%C3%B8kkenkv%C3%A6rne_Rapport_85_DANVA_COWI_august%202011.pdf (07/02-2020).

EC, 2009: REGULATION (EC) No 1069/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 October 2009. Available at: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:300:0001:0033:EN:PDF (07/02-2020).

European Environment Agency (EEA), 2009: The EMEP/EEA air pollutant emission inventory guidebook. Technical report No 9/2009. Available at:

http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009 (07/02-2020).

European Environment Agency (EEA), 2016: The EMEP/EEA air pollutant emission inventory guidebook. Technical report No 21/2016. Available at: https://www.eea.europa.eu/publications/emep-eea-guidebook-2016 (07/02-2020).

Executive Order No. 752 of 21/06/2016. Executive Order on grants to establish biocover at landfills and landfills. Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=180307 (07/02-2020).

Fauser, P., Thomsen, M., Nielsen, O., Winther, M., Gyldenkærne, S., Hoffmann, L., Lyck, E. & Illerup, J.B., 2007: Verification of the Danish emission inventory data by national and international data comparisons. Danmarks Miljøundersøgelser. Aarhus University. 53 pp - NERI Technical Report No. 627. Available at:
http://www2.dmu.dk/Pub/FR627_Final.pdf (07/02-2020).

Fauser, P., Sørensen, P.B., Nielsen, M., Winther, M., Plejdrup, M.S., Hoffmann, L., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Lyck, E., Thomsen, M., Hjelgaard, K. & Nielsen, O-K., 2011: Monte Carlo (Tier 2) Uncertainty Analysis of Danish Greenhouse Gas Emission Inventory. Greenhouse Gas Measurement & Management. 1(3/4). 145-161.Available at:
doi.org/10.1080/20430779.2011.621949 (07/02-2020).

Fauser, P., Nielsen, M., Winther, M., Plejdrup, M. S., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Hoffmann, L., Thomsen, M., Hjelgaard, K. & Nielsen, O-K., 2013: Verification of the Danish GHG Key Categories and Annex II Indicators. Greenhouse Gas Measurement & Management 3(3-4). 107-127. Available at: doi.org/10.1080/20430779.2013.870022 (07/02-2020).

Gejlsbjerg, B., Frette, L. & Westermann, P. 1999: $N_2O$ release from active sludge, water and soil. In Danish: Lattergasfrigivelse fra aktiv-slam, Vand & Jord, 1, pp. 33-37. Available at: http://www.vand-og-jord.dk/tidligere.htm (07/02-2020).

Hjelgaard, K., 2013: Danish Emission Inventory for Waste Incineration and Other Waste. Inventories until year 2011. Aarhus University. DCE – Danish Centre for Environment and Energy. 96 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 70. Available at:
http://dce.au.dk/udgivelser/vr/nr-51-100/abstracts/no-70-danish-emission-inventory-for-waste-incineration-and-other-waste/ (28/01-2019).

Hvitved-Jacobsen, T., 2001: Sewer Processes – Microbial and Chemical Process Engineering of Sewer Networks. CRC Press. Available at:
https://www.crcpress.com/Sewer-Processes-Microbial-and-Chemical-Process-Engineering-of-Sewer-Networks/Hvitved-Jacobsen-Vollertsen-Nielsen/p/book/9781439881774 (06/03-2020).

Intergovernmental Panel on Climate Change (IPCC), 2000: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Available at:
http://www.ipcc-nggip.iges.or.jp/public/gp/english/index.html (06/03-2020).

Intergovernmental Panel on Climate Change (IPCC), 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (06/03-2020).

ISAG: The Danish Environmental Protection Agency. Database on all registered Danish waste. Available at: http://mst.dk/affald-jord/affald/affaldsdatasystemet/find-affaldsdata/isag-udtraek/ (06/03-2020).

Jensen, T.C. & Kveiborg, O. 2013: Dokumentation af konvertering af trafiktal til emissionsopgørelser. Arbejdsnotat. DTU Transport. 2013.

Jensen, MD, Tychsen, P, Thomsen, M, Martinsen, L & Hasler, B 2015, Bæredygtig udnyttelse af fosfor fra spildevand. Miljøprojekt 1661, ISBN nr. 978-87-93283-94-7. Available at: https://www2.mst.dk/Udgiv/publikationer/2015/03/978-87-93283-94-7.pdf (06/03-2020).

Kampschreur, M.J., Temmink, H., Kleerebezem, R., Jetten, M.S.M. & van Loosdrecht, M.C.M., 2009: Nitrous oxide emission during wastewater treatment.Water Research 43. 4093-4103. DOI: 10.1016/j.watres.2009.03.001. Available at: https://www.sciencedirect.com/science/article/pii/S0043135409001420?via%3Dihub (06/03-2020).

Kjeldsen, P., Scheutz, C., 2016. Etablering og monitering af biocoversystemer på affaldsdeponeringsanlæg Vidensopsamling (English title: Establishment and monitoring of biocover systems on landfill - knowledge collection). DEPA Environmental project 1817. ISBN nr. 978-87-93435-14-8. Available at: https://www2.mst.dk/Udgiv/publikationer/2016/03/978-87-93435-14-8.pdf (07/02-2020).

Kristensen, G.H. & Jørgensen, P.E., 2008: Renseteknik – oversigt over ny miljøteknologi indenfor spildevandshåndtering (English title: Wastewater treatment Technologies - Overview of new environmental technology in waste water management). ASEP report. Available at: http://www2.blst.dk/udgiv/Publikationer/2008/978-87-92256-39-3/pdf/978-87-92256-40-9.pdf (07/02-2020).

Lyngby-Taarbæk Kommune, 2014: Midlertidig tilslutningstilladelse til udledning af byggegrubevand fra bygge- og anlægsarbejdet på Kanalvej 7 (English title:Temporary connection permit for the discharge of water in relation to the construction work on Kanalvej 7). Available at: http://www.ltk.dk/sites/default/files/uploads/public/user_uploads/CMP/Hoeringer/tilslutningstilladelse.pdf (07/02-2020).

Lönnermark, A. & Blomqvist, P., 2006: Emissions from an automobile fire. Chemosphere 62 (2006) 1043–1056. Available at: http://www.sciencedirect.com/science/article/pii/S0045653505006351 (07/02-2020).

MILIKI, 2006: Ministeriet for Ligestilling og Kirke (Ministry for Gender Equality and Ecclesiastical Affairs). Rapport fra arbejdsgruppe vedrørende krematorievirksomhed i Denmark. December 2006. Available at: http://www.km.dk/fileadmin/share/publikationer/Krematorier/Rapport_om_krematorier.pdf (07/02-2020).

MST, 2013: Livscyklusvurdering og samfundsøkonomisk analyse for anvendelse af spildevandsslam. Miljøministeriet. Miljøstyrelsen (MST). Miljøprojekt nr. 1459. 2013. ISBN nr. 978-87-92903-81-5. Available at: https://www2.mst.dk/Udgiv/publikationer/2013/01/978-87-92903-81-5.pdf (07/02-2020).

Morvay, Z.K. & Gvozdenac, D.D., 2009: Applied Industrial Energy and Environmental Management. John Wiley & Sons, Ltd.Online ISBN: 9780470714379. DOI: 10.1002/9780470714379. Available at: https://onlinelibrary.wiley.com/doi/book/10.1002/9780470714379 (07/02-2020).

Mønster, J., Samuelsson, J., Kjeldsen, P. & Scheutz, C., 2015: Quantification of methane emissions from 15 Danish landfills using the mobile tracer dispersion method. Waste Management 35, 177–186 doi.org/10.1016/j.wasman.2014.09.006. Available at: https://www.sciencedirect.com/science/article/pii/S0956053X14004280 (07/02-2020).

National Atmospheric Emission Inventory of UK (NAEI), 2009: Available at: http://www.naei.org.uk/emissions/selection.php (07/02-2020).

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Nielsen, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Thomsen, M., Hjelgaard, K., Fauser, P., Bruun, H.G., Johannsen, V.K., Nord-Larsen, T., Vesterdal, L., Callesen, I., Caspersen, O.H., Scott-Bentsen, N., Rasmussen, E., Petersen, S.B., Olsen, T. M. & Hansen, M.G., 2019. Denmark's National Inventory Report 2019. Emission Inventories 1990-2017 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Aarhus University, DCE – Danish Centre for Environment and Energy, 886 pp. Scientific Report No. 318 http://dce2.au.dk/pub/SR318.pdf (03/02-2020).

Nielsen, A.H., Vollertsen, J., Højmark J., Simon, M., Rudelle, E.A., 2018. Hybridfilter for fjernelse af lugt- og drivhusgasser fra septiktanke og iltfri spildevandsnet. Publisher: Danish EPA. ISBN: 978-87-93710-18-4. Available at: https://www2.mst.dk/Udgiv/publikationer/2018/05/978-87-93710-18-4.pdf (03/02-2020).

Nissen, E.L., 2017a: Expert judgement, Composting in Denmark, DEPA, personal communication.

Nissen, E.L., 2017b. Expert judgement, Number of active landfills in Denmark, DEPA, personal communication.

Pedersen, R.B., Scheutz, C. & Kjeldsen, P., 2012; Reduktion af metanemissionen fra Klintholm losseplads ved etablering af Biocover. Environmental Project report no. 1401, Ministry of Environment. Available at: http://www2.mst.dk/Udgiv/publikationer/2012/03/978-87-92779-77-9.pdf (03/02-2020).

Petersen, C., 2001: Statistik for behandling af organisk affald fra husholdninger – Revideret udgave (Statistics for treatment of organic waste from households – revised version). Miljøprojekt Nr. 654 2001. Miljøstyrelsen. Miljøministeriet. Available at: http://www2.mst.dk/Udgiv/publikationer/2001/87-7944-932-8/pdf/87-7944-933-6.pdf (03/02-2020).

Petersen, C. & Hansen, V.L., 2003: Statistik for behandling af organisk affald fra husholdninger 2001 (Statistics for treatment of organic waste from households). Miljøprojekt Nr. 856 2003. Miljøstyrelsen. Miljøministeriet. Available at:
http://www2.mst.dk/Udgiv/publikationer/2003/87-7972-962-2/pdf/87-7972-963-0.pdf (03/02-2020).

Petersen, C. & Kielland, M., 2003: Statistik for hjemmekompostering (Statistics on home composting). Econet A/S. Miljøprojekt Nr. 855 2003. Miljøstyrelsen. Miljøministeriet. Available at:
http://www2.mst.dk/udgiv/publikationer/2003/87-7972-960-6/pdf/87-7972-961-4.pdf (03/02-2020).

Schleicher, O. & Gram, L.K., 2008: Miljøprojekt Nr. 1191. Analyse af omkostningerne for rensning for kviksølv på krematorier i Danmark. Miljøministeriet. Miljøstyrelsen. Available at:
https://www2.mst.dk/udgiv/publikationer/2008/978-87-7052-594-7/html/default.htm (03/02-2020).

Schleicher, O., Jensen, A.A. & Blinksbjerg, P., 2001: Miljøprojekt Nr. 649. Måling af dioxinemissionen fra udvalgte sekundære kilder. Miljøministeriet. Miljøstyrelsen. Available at:
http://www2.mst.dk/Udgiv/publikationer/2001/87-7944-868-2/pdf/87-7944-869-0.pdf (03/02-2020).

Statistics Denmark, 2019: StatBank Denmark. Available at:
http://www.statistikbanken.dk/statbank5a/default.asp?w=1024
(03/02-2020).

Statutory order for Landfilling. No. 719.24/06/2011 (Deponeringsbekendtgørelsen). Available at:
https://www.retsinformation.dk/forms/R0710.aspx?id=137791
(07/02-2020).

Statutory order for Waste. no 1309 af 18/12/2012 (Affaldsbekendtgørelsen). Available at:
https://www.retsinformation.dk/Forms/R0710.aspx?id=144826
(07/02-2020).

Tafdrup, S., 2014. Expert Judgement of the gross energy production. Søren Tafdrup, Consultant, Danish Energy Agency. Personal communication.

The Danish Government, 1999: Waste 21. Waste Management plan 1998-2004. Available at:
http://www2.mst.dk/Udgiv/publications/1999/87-7909-571-2/pdf/87-7909-570-4.pdf (07/02-2020).

The Danish Government, 2003: Affaldsstrategi 2005-2008. (In Danish: Waste Strategy 2005-2008. Available at:
http://www2.mst.dk/Udgiv/publikationer/2003/87-7972-971-1/pdf/87-7972-973-8.pdf (07/02-2020).

The Danish Government, 2009: Affaldsstrategi 2009-2012 1. delstrategi. (In Danish: Waste Strategy 2009-2012. Available at:

http://mst.dk/media/mst/69997/Endelig%201%20%20del%20af%20Affaldsstrategi%202009-12.pdf (07/02-2020).

The Danish Government, 2010: (Waste Strategy 2009-2012. Part II) Available at: http://eng.mst.dk/media/164923/denmark-without-waste-ii_waste-prevention.pdf (07/02-2020).

The Danish Government, 2013: Denmark without waste. Recycle more – incinerate less. Available at: http://mfvm.dk/fileadmin/user_upload/MFVM/Miljoe/Ressourcestrategi_UK_web.pdf (07/02-2020).

Thomsen, M., With Ottosen, T. & Nyrup Drejer, L., 2015: Analyse af potentialer for ressourceudnyttelse i vand- og spildevandsforsyningen. Naturstyrelsen, Miljøministeriet, 2015. 85 s. Available at: http://ecoinnovation.dk/media/130961/analyse-af-potentialer-for-ressourceudnyttelse-i-vand-og-spildevandsforsyningen.pdf (07/02-2020).

Thomsen, M., 2016. Wastewater treatment and discharge. Aarhus University, DCE – Danish Centre for Environment and Energy, 79 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 193. Available at: http://dce2.au.dk/pub/SR193.pdf (28/01-2018).

Vattenfall, 2010: Fynsværket $CO_2$-udledningsrapport 2010.

Verdo, 2011: Verdo (Randers) $CO_2$-kvote indberetning 2011.

Vollertsen, J., Vorkamp, K., Hvitved-Jacobsen, T. & Jensen, N.A., 2002: Udsivning af spildevand fra afløbssystemer. Miljøprojekt Nr. 685. Available at: https://www2.mst.dk/udgiv/publikationer/2002/87-7972-084-6/html/helepubl.htm (07/02-2020).

Vollertsen, J., 2012: Expert judgement of the $MCF_{sewer+MB}$. Jes Vollertsen, PhD, Professor of Environmental Engineering. Personal communication

Vollertsen, J., 2018: Expert judgement of the $MCF_{st}$ *and* $EF_{st}$. Jes Vollertsen, PhD, Professor of Environmental Engineering. Personal communication.

Wicht, H. & Beier, M., 1995: $N_2O$ emission aus nitrifizierenden und denitrificierenden Kläranlagen. Korrespondenz Abwasser 42, 404–406. Available at: https://www.tib.eu/de/suchen/id/olc%3A1745053824/N20-Emissionen-aus-nitrifizierenden-und-denitrifizierenden/ (07/02-2020).

# 8 Other

In CRF Sector 6, there are no activities and emissions for the inventories of Denmark.

# 9 Recalculations and improvements

Explanations for the recalculations of the Danish inventory are included in the sectoral chapters of the NIR.

The overall impact of recalculations is shown in Table 9.1. A more detailed overview is provided in Tables 9.2 – 9.5.

Information on recalculations for the aggregated submission of Denmark and Greenland are included in Chapter 17.

## 9.1 Explanations and justifications for recalculations

Explanations and justifications for the recalculations performed in this submission, since submission of data to the UNFCCC due April 15, 2019 for Denmark, are given in the individual sector chapters.

## 9.2 Implications for emission levels

For the national total $CO_2$ equivalent emissions without Land-Use, Land-Use Change and Forestry, the general impact of the improvements and recalculations performed is small and the changes for the whole time-series are between 0.11 % (2002) and 0.31 % (2013). The implications of the recalculations on the level and on the trend, 1990-2017, of the national total are very small, see Table 9.1.

For the national total $CO_2$ equivalent emissions with Land-Use, Land-Use Change and Forestry, the general impact of the recalculations is larger due to recalculations in the LULUCF sector, see Table 9.1 and explanations in Chapter 6.

Table 9.1 Recalculation performed in the 2020 submission for 1990-2017. Differences in pct. of $CO_2$ equivalents between this submission and the April 2019 submission for Denmark, excluding Greenland and the Faroe Islands.

| Year | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total $CO_2$ eqv. Emissions with Land-Use Change and Forestry | 2.70 | 2.10 | 2.61 | 2.56 | 2.05 | 2.19 | 1.98 | 2.03 | 2.11 | 2.12 | 2.78 |
| Total $CO_2$ eqv. Emissions without Land-Use Change and Forestry | 0.70 | 0.61 | 0.65 | 0.57 | 0.52 | 0.52 | 0.47 | 0.50 | 0.53 | 0.50 | 0.58 |
| | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
| Total $CO_2$ eqv. Emissions with Land-Use Change and Forestry | 2.30 | 2.32 | 2.37 | 2.53 | 2.78 | 2.24 | 2.56 | 3.10 | 2.85 | 3.32 | 3.85 |
| Total $CO_2$ eqv. Emissions without Land-Use Change and Forestry | 0.62 | 0.54 | 0.55 | 0.63 | 0.69 | 0.56 | 0.59 | 0.70 | 0.77 | 0.76 | 0.83 |
| | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | | | | | |
| Total $CO_2$ eqv. Emissions with Land-Use Change and Forestry | 3.69 | 3.75 | 3.97 | 3.91 | 3.97 | 3.88 | | | | | |
| Total $CO_2$ eqv. Emissions without Land-Use Change and Forestry | 0.95 | 0.99 | 0.97 | 1.02 | 1.00 | 0.94 | | | | | |

## 9.3 Implications for emission trends, including time series consistency

It is a high general priority in the considerations leading to recalculations back to 1990 to have and preserve the consistency of the activity data and emissions time-series. As a consequence activity data, emission factors and methodologies are carefully chosen to represent the emissions for the time-series correctly. Often considerations regarding the consistency of the time-series have led to recalculations for single years when activity data and/or emission factors have been changed or corrected. Furthermore, when new sources are considered, activity data and emissions are as far as possible introduced to the inventories for the whole time-series based on preferably the same methodology.

The implication of the recalculations is further shown in Tables 9.2-9.5.

Table 9.2 Recalculation for $CO_2$ performed in the 2020 submission for 1990-2017. Differences in kt $CO_2$ equivalents between this and the April 2019 submission for Denmark. Excluding Greenland and Faroe Islands.

| $CO_2$ kt | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total National Emissions and Removals | 1451 | 1218 | 1522 | 1555 | 1226 | 1293 | 1353 | 1229 | 1203 | 1197 | 1557 | 1213 | 1296 | 1417 |
| 1. Energy | -5 | -5 | -3 | -4 | -4 | -3 | -2 | -2 | -2 | -1 | -2 | -2 | -1 | -2 |
| 1.A. Fuel Combustion Activities | -5 | -5 | -3 | -4 | -4 | -3 | -2 | -2 | -2 | -1 | -2 | -2 | -1 | -2 |
| 1.A.1. Energy Industries | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| 1.A.2. Manufacturing Industries and Construction | -4 | -4 | -2 | -3 | -3 | -3 | -2 | -2 | -4 | -1 | -1 | -1 | -1 | -1 |
| 1.A.3. Transport | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -2 | 0 | 0 | 0 | 0 |
| 1.A.4. Other Sectors | -1 | -1 | -1 | -1 | -1 | 0 | 0 | 0 | 1 | 2 | 0 | -1 | 0 | -1 |
| 1.A.5. Other | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 1.B. Fugitive Emissions from Fuels | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2. Industrial Processes and product use | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -2 | 0 |
| 2.A. Mineral industry | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.B. Chemical industry | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2.C. Metal industry | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2.D. Non-energy products from fuels and solvent use | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -2 | 0 |
| 2.G. Other product manufacture and use | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3. Agriculture | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3. G. Liming | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3.H. Urea application | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3.I. Other carbon-containing fertilizers | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4. Land Use, Land-Use Change and Forestry (net) | 1455 | 1224 | 1525 | 1559 | 1230 | 1296 | 1355 | 1232 | 1205 | 1199 | 1559 | 1216 | 1298 | 1419 |
| 4.A. Forest Land | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4.B. Cropland | 929 | 825 | 829 | 825 | 825 | 817 | 823 | 828 | 828 | 830 | 835 | 839 | 819 | 819 |
| 4.C. Grassland | 527 | 523 | 519 | 515 | 511 | 507 | 503 | 499 | 495 | 491 | 487 | 483 | 479 | 475 |
| 4.D. Wetlands | -2 | -2 | -2 | -2 | -2 | -2 | -2 | -2 | -2 | -2 | -2 | -2 | -2 | -2 |
| 4.E. Settlements | 2 | 4 | 6 | 8 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 24 | 26 |
| 4.F. Other Land | | | | | | | | | | | | | | |
| 4.G. Harvested wood products | - | -125 | 174 | 214 | -113 | -37 | 19 | -108 | -132 | -139 | 219 | -127 | -22 | 100 |
| 5. Waste | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 5.E. Other | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

| | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total National Emissions and Removals | 1356 | 1400 | 1249 | 1320 | 1390 | 1241 | 1448 | 1519 | 1304 | 1412 | 1399 | 1399 | 1525 | 1329 |
| 1. Energy | -2 | -2 | -1 | -2 | -9 | -17 | -16 | -14 | -13 | -6 | -9 | -24 | -31 | -73 |
| 1.A. Fuel Combustion Activities | -2 | -2 | -1 | -2 | -9 | -17 | -16 | -14 | -13 | -6 | -9 | -24 | -31 | -73 |
| 1.A.1. Energy Industries | 0 | -18 | - | 0 | 6 | -12 | 0 | -2 | 8 | 0 | - | - | 0 | -11 |
| 1.A.2. Manufacturing Industries and Construction | -1 | -1 | 0 | -1 | -6 | 0 | 1 | 3 | 0 | 0 | -6 | -18 | -22 | -38 |
| 1.A.3. Transport | 0 | 0 | 0 | 0 | -7 | -16 | -17 | -16 | -13 | -5 | -2 | -5 | -18 | -34 |
| 1.A.4. Other Sectors | -1 | 17 | 0 | -1 | -1 | 12 | -1 | 0 | -8 | -1 | -1 | -1 | 9 | 11 |
| 1.A.5. Other | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 1.B. Fugitive Emissions from Fuels | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2. Industrial Processes and product use | -1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 2.A. Mineral industry | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 2.B. Chemical industry | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2.C. Metal industry | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2.D. Non-energy products from fuels and solvent use | -1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | -1 |
| 2.G. Other product manufacture and use | - | - | - | - | - | - | - | - | - | - | - | - | 0 | 0 |
| 3. Agriculture | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3. G. Liming | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3.H. Urea application | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3.I. Other carbon-containing fertilizers | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4. Land Use, Land-Use Change and Forestry (net) | 1359 | 1403 | 1249 | 1322 | 1398 | 1258 | 1464 | 1533 | 1316 | 1417 | 1407 | 1422 | 1556 | 1401 |
| 4.A. Forest Land | - | - | - | - | - | - | 0 | -1 | -1 | -1 | 0 | -2 | -1 | 1 |
| 4.B. Cropland | 811 | 814 | 703 | 783 | 798 | 784 | 917 | 970 | 877 | 908 | 864 | 906 | 925 | 773 |
| 4.C. Grassland | 471 | 467 | 463 | 459 | 455 | 451 | 446 | 439 | 411 | 425 | 417 | 416 | 542 | 546 |
| 4.D. Wetlands | -2 | -1 | -1 | -1 | -1 | -1 | -1 | -2 | -3 | 0 | 0 | - | - | - |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Continued* | | | | | | | | | | | | | | |
| 4.E. Settlements | 28 | 32 | 36 | 40 | 45 | 49 | 53 | 57 | 68 | 73 | 74 | 77 | 88 | 92 |
| 4.F. Other Land | | | | | | | | | | | | | | |
| 4.G. Harvested wood products | 51 | 90 | 48 | 41 | 102 | -25 | 50 | 71 | -36 | 13 | 53 | 25 | 2 | -12 |
| 5. Waste | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 5.E. Other | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

Table 9.3 Recalculation for $CH_4$ performed in the 2020 submission for 1990-2017. Differences in kt $CO_2$ equivalents between this and the April 2019 submission for Denmark. Excluding Greenland and Faroe Islands.

| $CH_4$, kt $CO_2$ equivalents | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total National Emissions and Removals | 370 | 366 | 359 | 356 | 348 | 348 | 346 | 339 | 340 | 328 | 364 | 369 | 382 | 401 |
| 1. Energy | -3 | -3 | -3 | -3 | -3 | -3 | -3 | -3 | -2 | -2 | -2 | -2 | -3 | -3 |
| 1.A. Fuel Combustion Activities | -3 | -3 | -3 | -3 | -3 | -3 | -3 | -3 | -2 | -2 | -2 | -2 | -3 | -3 |
| 1.A.1. Energy Industries | - | - | - | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.A.2. Manufacturing Industries and Construction | 0 | 0 | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.A.3. Transport | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.A.4. Other Sectors | -3 | -3 | -3 | -3 | -3 | -3 | -2 | -2 | -2 | -2 | -2 | -2 | -3 | -3 |
| 1.A.5. Other | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.B. Fugitive Emissions from Fuels | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2. Industrial Processes and product use | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3. Agriculture | 310 | 305 | 296 | 292 | 282 | 280 | 276 | 268 | 266 | 253 | 287 | 291 | 303 | 321 |
| 3.A. Enteric Fermentation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0 | 0 |
| 3.B. Manure Management | 310 | 305 | 296 | 292 | 282 | 280 | 276 | 268 | 266 | 253 | 287 | 291 | 303 | 321 |
| 3.F. Field Burning of Agricultural Residues | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4. Land Use, Land-Use Change and Forestry (net) | 63 | 65 | 66 | 68 | 69 | 71 | 72 | 74 | 75 | 77 | 78 | 80 | 82 | 83 |
| 4.A. Forest Land | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4.B. Cropland | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| 4.C. Grassland | 31 | 31 | 31 | 31 | 30 | 30 | 30 | 30 | 30 | 29 | 29 | 29 | 29 | 28 |
| 4.D. Wetlands | 2 | 4 | 5 | 7 | 9 | 11 | 12 | 14 | 16 | 18 | 19 | 21 | 23 | 25 |
| 5. Waste | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.A. Solid waste disposal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.B. Biological treatment of solid waste | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 5.C. Incineration and open burning of waste | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 5.D. Waste water treatment and discharge | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.E. Other | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
| Total National Emissions and Removals | 401 | 399 | 391 | 386 | 403 | 417 | 416 | 417 | 442 | 453 | 452 | 440 | 437 | 465 |
| 1. Energy | -6 | -7 | -8 | -7 | -5 | -4 | -4 | -4 | -5 | -5 | -5 | -6 | -6 | -6 |
| 1.A. Fuel Combustion Activities | -6 | -7 | -8 | -7 | -5 | -4 | -4 | -4 | -5 | -5 | -5 | -6 | -6 | -6 |
| 1.A.1. Energy Industries | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.A.2. Manufacturing Industries and Construction | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.A.3. Transport | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.A.4. Other Sectors | -6 | -7 | -8 | -7 | -5 | -4 | -4 | -4 | -5 | -5 | -5 | -6 | -6 | -6 |
| 1.A.5. Other | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.B. Fugitive Emissions from Fuels | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2. Industrial Processes and product use | - | - | - | - | - | - | - | - | - | - | - | - | 0 | 0 |
| 3. Agriculture | 322 | 321 | 312 | 304 | 317 | 329 | 332 | 336 | 358 | 366 | 359 | 357 | 354 | 373 |
| 3.A. Enteric Fermentation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.B. Manure Management | 322 | 321 | 312 | 304 | 317 | 329 | 332 | 336 | 358 | 366 | 359 | 357 | 354 | 373 |
| 3.F. Field Burning of Agricultural Residues | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4. Land Use, Land-Use Change and Forestry (net) | 85 | 86 | 87 | 89 | 90 | 92 | 93 | 94 | 95 | 99 | 103 | 96 | 98 | 104 |
| 4.A. Forest Land | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4.B. Cropland | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 29 | 31 | 33 | 37 | 30 | 25 | 30 |
| 4.C. Grassland | 28 | 28 | 28 | 27 | 27 | 27 | 27 | 26 | 25 | 25 | 25 | 25 | 32 | 33 |
| 4.D. Wetlands | 26 | 28 | 30 | 31 | 33 | 34 | 36 | 39 | 39 | 41 | 41 | 41 | 41 | 41 |

| Continued | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5. Waste | 0 | 0 | 0 | 0 | 0 | 0 | -4 | -9 | -6 | -7 | -5 | -7 | -9 | -7 |
| 5.A. Solid waste disposal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -2 | -3 | -5 |
| 5.B. Biological treatment of solid waste | - | - | - | - | - | - | -4 | -9 | -5 | -6 | -3 | -5 | -6 | -2 |
| 5.C. Incineration and open burning of waste | - | - | - | - | - | - | - | - | 0 | - | - | - | - | - |
| 5.D. Waste water treatment and discharge | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 |
| 5.E. Other | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

Table 9.4 Recalculation for $N_2O$ performed in the 2020 submission for 1990-2017. Differences in kt $CO_2$ equivalents between this and the April 2019 submission for Denmark. Excluding Greenland and Faroe Islands.

| $N_2O$, kt $CO_2$ equivalents | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total National Emissions and Removals | 183 | 189 | 189 | 150 | 144 | 126 | 153 | 145 | 150 | 127 | 125 | 149 | 89 | 99 |
| 1. Energy | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 0 |
| 1.A. Fuel Combustion Activities | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 0 |
| 1.A.1. Energy Industries | - | - | - | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.A.2. Manufacturing Industries and Construction | 0 | - | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.A.3. Transport | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 0 |
| 1.A.4. Other Sectors | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.A.5. Other | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.B. Fugitive Emissions from Fuels | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2. Industrial Processes and product use | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. Agriculture | 183 | 190 | 189 | 150 | 144 | 126 | 152 | 145 | 149 | 126 | 124 | 147 | 88 | 97 |
| 3.B. Manure Management | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| 3.D. Agricultural soils | 183 | 190 | 189 | 150 | 144 | 126 | 152 | 144 | 149 | 124 | 124 | 146 | 88 | 97 |
| 3.F. Field Burning of Agricultural Residues | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4. Land Use, Land-Use Change and Forestry (net) | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 3 |
| 4.A. Forest Land | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4.B. Cropland | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4.C. Grassland | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4.D. Wetlands | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4.E. Settlements | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 3 |
| 5. Waste | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 5.B. Biological treatment of solid waste | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 5.C. Incineration and open burning of waste | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 5.D. Waste water treatment and discharge | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0 |

| | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total National Emissions and Removals | 122 | 139 | 106 | 108 | 148 | 168 | 176 | 171 | 174 | 189 | 148 | 170 | 183 | 157 |
| 1. Energy | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 1 | 3 | 4 | 2 | 7 | 17 | 15 |
| 1.A. Fuel Combustion Activities | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 1 | 3 | 4 | 2 | 7 | 17 | 15 |
| 1.A.1. Energy Industries | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.A.2. Manufacturing Industries and Construction | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 2 | 3 | 4 | 1 | 6 | 17 | 15 |
| 1.A.3. Transport | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | -1 |
| 1.A.4. Other Sectors | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 1.A.5. Other | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.B. Fugitive Emissions from Fuels | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2. Industrial Processes and product use | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. Agriculture | 120 | 135 | 103 | 103 | 144 | 163 | 175 | 171 | 169 | 182 | 141 | 159 | 162 | 136 |
| 3.B. Manure Management | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 0 | 6 |
| 3.D. Agricultural soils | 120 | 135 | 102 | 102 | 144 | 162 | 173 | 169 | 168 | 180 | 139 | 156 | 162 | 130 |
| 3.F. Field Burning of Agricultural Residues | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4. Land Use, Land-Use Change and Forestry (net) | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 8 | 8 | 8 | 9 | 10 |
| 4.A. Forest Land | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4.B. Cropland | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4.C. Grassland | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| 4.D. Wetlands | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

| *Continued* | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.E. Settlements | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 8 | 8 | 8 | 9 | 10 |
| 5. Waste | 0 | 0 | 0 | 0 | 0 | 0 | -3 | -6 | -4 | -4 | -3 | -4 | -4 | -3 |
| 5.B. Biological treatment of solid waste | - | - | - | - | - | - | -3 | -6 | -4 | -4 | -3 | -4 | -5 | -3 |
| 5.C. Incineration and open burning of waste | - | - | - | - | - | - | - | - | 0 | - | - | - | - | - |
| 5.D. Waste water treatment and discharge | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 9.5 Recalculation for f-gases performed in the 2020 submission for 1990-2017. Differences in kt $CO_2$ equivalents between this and the April 2019 submission for Denmark. Excluding Greenland and Faroe Islands.

| f-gases kt $CO_2$ eqv | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HFCs | | | - | - | - | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 4 |
| PFCs | | | | | - | - | - | - | - | - | - | - | - | - |
| $SF_6$ | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
| HFCs | 6 | 6 | 6 | 6 | 6 | 8 | 1 | 2 | 1 | 8 | 7 | 3 | 15 | 14 |
| PFCs | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| $SF_6$ | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

## 9.4 Recalculations, including those in response to the review process, and planned improvements to the inventory (e.g. institutional arrangements. inventory preparations)

The review on the submissions in 2007 and 2008 was finalised and the report was published 15 April, 2009. For the 2009 submission the review report was finalised and published 15 April 2010. The review report of the in-country review of the 2010 submission was published 3 March 2011. The draft review report for the review of the 2011 submission was available 9 February 2012. The final review report was published 30 April 2012. The draft review report of the 2012 submission was made available 30 April 2013 and the final review report was dated 2 August 2013. The draft review report of the 2013 submission was made available April 28 2014 and the final review report was dated 23 June 2014. The draft of the review report from the centralised review carried out in September 2014 was received on December 9 2014. The final report was published on February 4 2015. No review took place in 2015. The review of the 2016 submission took place as an in-country review in September 2016. The final report was published on 9 August 2017. No review took place in 2017.

The review of the 2018 submission took place in October 2018. A draft report was provided to Denmark on 14 December 2018. While the final report was published on 5 February 2019.

The status of the implementation of review recommendations from the latest review is for the general recommendations included in Table 9.6. For the sector specific recommendations, please refer to the individual sector chapters.

Table 9.6 General recommendations from the latest UNFCCC review.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| G.2 | Recalculations | The ERT noted that recalculations were made to indirect $CO_2$ and $N_2O$ emissions in the 2018 submission compared with the 2017 submission. The recalculations for the indirect $CO_2$ emissions were mainly due to changes in estimations of CO emissions in stationary and mobile combustion. The recalculations were not transparently explained in the energy sector of the NIR or in NIR section 11 on indirect $CO_2$ and $N_2O$ emissions. Section 11.5 of the NIR on category-specific recalculations indicates only that a large number of recalculations were carried out and makes a reference to the 2016 Annual Danish Informative Inventory Report to UNECE (Nielsen et al., 2018) for further information on recalculations. Based on the reference, the ERT could not find specific information on the recalculations of the CO emissions from mobile combustion. During the review, Denmark explained that the large reduction in CO emissions was due to reallocation of gasoline from a subcategory with a high CO EF to one with a significantly lower CO EF (residential machineries to road vehicles). During the review, Denmark further explained that quantitative information on the recalculations of indirect $CO_2$ and $N_2O$ emissions will be included in section 11 of the next NIR and the detailed information on the recalculations of precursors and hence indirect $CO_2$ and $N_2O$ will continue to be included in the Danish Informative Inventory Report and referenced in the NIR.<br>The ERT recommends that Denmark ensure that any recalculations of indirect $CO_2$ emissions included in the national totals are reported in the NIR with relevant explanations and references. The ERT further encourages the Party to include in the NIR a discussion on the impact of the recalculation on the trend of emissions and removals at the category and sectoral level. | Quantitative information on the recalculations of indirect $CO_2$ and $N_2O$ emissions have been included in Chapter 11. We note that the reporting of precursors as well as indirect $CO_2$ and $N_2O$ is not mandatory and as such we do not believe that the requirement to report on recalculations extend to pollutants where no reporting requirement exist. The explanation for the recalculations of precursors and hence indirect $CO_2$ and $N_2O$ will continue to be included in the Danish Informative Inventory Report and referenced in the National Inventory Report. | See Chapter 11. |
| G.3 | Annual submission | Section 1.8 and Annex 5 of the NIR focus on the completeness of the inventory, indicating that all categories identified in the 2006 IPCC Guidelines are included. The ERT agrees with this statement regarding the DNM submission. However, it noted several categories reported as "NE" in the DNK CRF tables for Greenland and the Faroe Islands. For Greenland, emissions reported as "NE" include emissions from different HFC species under refrigeration and air conditioning (2.F.1), SF6 emissions under electrical equipment (2.G.1) and $CO_2$, $CH_4$ and $N_2O$ emissions and removals under forest land – drainage and rewetting (4. II); for the Faroe Islands emissions reported as "NE" include $CO_2$, $CH_4$ and $N_2O$ emissions from various subcategories under fuel combustion (1.A), $CO_2$ emissions from lubricant use (2.D.1) and paraffin wax use (2.D.2), different HFC species under refrigeration and air conditioning (2.F.1), $SF_6$ under electrical equipment (2.G.1), indirect $N_2O$ emissions from manure management (3.B.5), $CH_4$ emissions from agricultural soils (3.D), $CH_4$ emissions from solid waste disposal (5.A) and $CH_4$ and $N_2O$ emissions from wastewater treatment and discharge (5.D). In line with the UNFCCC Annex I inventory reporting guidelines, an Annex I Party shall indicate in both the NIR and the CRF completeness table why such emissions have not been estimated. The ERT could not find any such information in the NIR or CRF table 9, "Completeness – information on notation keys". During the review, Denmark explained that the categories were reported as "NE" owing to a lack of available AD and that the sources were considered to be minor. The Party estimated, for example, that emissions from | In several cases, the activity reported as NE does in fact not occur and should have been reported as such. We have checked NKs used for Greenland and the Faroe Islands and added NK explanations for the remaining NE and IE notation keys. | CRF |

Table 9.6 General recommendations from the latest UNFCCC review.

| Para. | CRF | ERT Comment | Denmark's response | Reference |
|---|---|---|---|---|
| | | paraffin wax use (2.D.2) amounted to less than 1 kt $CO_2$ eq. Denmark also explained that because of technical problems with the CRF Reporter, no explanations had been entered in CRF table 9, and that explanations in the NIR and CRF table would be added in the 2019 submission. The ERT recommends that Denmark estimate and report the following categories for Greenland: HFC emissions from refrigeration and air conditioning (category 2.F.1), SF6 emissions from electrical equipment (2.G.1) and $CO_2$, $CH_4$ and $N_2O$ emissions and removals under forest land – drainage and rewetting (4. II). The ERT further recommends that Denmark estimate the following categories for the Faroe Islands: $CO_2$, $CH_4$ and $N_2O$ emissions from missing subcategories under fuel combustion (1.A), CO2 emissions from lubricant use (2.D.1) and paraffin wax use (2.D.2), HFC emissions from refrigeration and air conditioning (2.F.1), $SF_6$ emissions from electrical equipment (2.G.1), indirect $N_2O$ emissions from manure management (3.B.5), $CH_4$ emissions from agricultural soils (3.D), $CH_4$ emissions from solid waste disposal (5.A), and CH4 and $N_2O$ emissions from wastewater treatment and discharge (5.D)). If it is not possible to estimate emissions, in line with the UNFCCC Annex I inventory reporting guidelines, the ERT recommends that the Party indicate in both the NIR and the CRF completeness table why the notation key "NE" has been used. Where a category is determined to be insignificant, the ERT encourages Denmark to provide a qualitative and quantitative justification in the NIR for the exclusion in terms of the likely level of emissions. Furthermore, the ERT recommends that Denmark ensure that the total national aggregate of estimated emissions for all gases and categories considered insignificant remain below 0.1 per cent of the national total GHG emissions. | | |
| G.5 | QA/QC and verification | The ERT noted that the latest version of the Danish QA/QC plan was published in 2013 in its "Quality manual for the Danish greenhouse gas inventory" (Nielsen et al., 2013) and is thus referring to the UNFCCC Annex I reporting guidelines reporting guidelines as per decisions 18/CP.8 and 14/CP.11. In the manual (p.42) it is stated that the manual was to have been updated in 2015/2016. During the review, Denmark explained that the reason for not updating the manual before the 2018 submission was that the Party wanted to gain experiences from reporting and review under the revised UNFCCC Annex I inventory reporting guidelines (decision 24/CP.19) and review guidelines. Denmark also explained that, tentatively, an updated manual is expected to be published in 2019 following the individual review of its 2018 submission.<br>The ERT recommends that Denmark update its quality manual from 2013 and to ensure its consistency with the revised UNFCCC Annex I inventory reporting guidelines. | An updated version is expected to be published in the first half of 2020. | |

## 9.5 Explanations, justifications and implications of recalculations for KP-LULUCF inventory

### 9.5.1 Recalculations

Almost all sectors in the KP-LULUCF have been recalculated.

For more information on KP-LULUCF recalculations please refer to Chapter 10.

### 9.5.2 Review recommendations

The recommendations for KP-LULUCF are included in Chapter 10.

# 10 KP-LULUCF

## 10.1 General information

For this chapter, the following abbreviations are used in accordance with definitions in the IPCC guidelines:

| | |
|---|---|
| A: | Afforestation |
| R: | Reforestation |
| D: | Deforestation |
| FF: | Forest remaining Forest, areas remaining forest after 1990 |
| FL: | Forest Land meeting the Danish definition of forests |
| CL: | Cropland |
| GL: | Grassland |
| WE: | Wetlands |
| SE: | Settlements |
| OL: | Other land, unclassified land |
| FM: | Forest Management, areas managed under article 3.4 |
| HWP: | Harvested Wood Product |
| CM: | Cropland Management, areas managed under article 3.4 |
| GM: | Grazing land Management, areas managed under article 3.4 |
| RV: | Revegetation |
| WDR: | Wetland Drainage and Rewetting |
| CP: | Commitment Period |

Other abbreviations:

| | |
|---|---|
| EO: | Earth Observation |
| NFI: | National Forst Inventory |
| LPIS: | Land Parcel Information System |
| FMRL: | Forest Management Referech Level |
| HWP: | Harvested Wood Products |
| SINKS2: | SINKs 2 is a Danish funding project for the 2nd commitment period |

### 10.1.1 Definition of forest and any other criteria

For the estimation of anthropogenic emissions by sources and removals by sinks associated with afforestation (A), reforestation (R) and deforestation (D) since 1990 under Article 3.3 and forest management (FM) under Article 3.4 of the Kyoto Protocol, the following forest definition will be applied:

- Minimum values for tree crown cover: 10 % tree crown cover for forests
- Minimum values for land area: 0.5 ha
- Minimum width of 20 m
- Minimum value for tree height: trees must be able to reach a minimum height of 5 m in the site.

In addition, the forest area includes temporarily unstocked areas, smaller open areas in the forest needed for management purposes and fire breaks. Forests in national parks, reserves, or areas under special protection are included. Windbreaks and groves covering more than 0.5 ha and with a minimum width of 20 m are also considered forest. Farmlands, fruit plantations for commercial purposes, orchards, gardens (houses and summer houses) are

NOT included in the forest area. Willow plantations on agricultural soils for bioenergy purposes are included in Cropland (CL).

### 10.1.2 Elected activities under Article 3.4 of the Kyoto Protocol

Regarding the possibility of including the first commitment period emissions and removals associated with land use, land-use change and forestry activities under Article 3.4 of the Kyoto Protocol, it has been decided to include emissions and removals from forest management (FM), cropland management (CM) and grazing land management (GM). Revegetation and Wetland Drainage and Rewetting (WDR) is not elected by Denmark in the second Commitment Period (CP).

Natural disturbances are very seldom in Denmark and has not been elected.

Reporting is required by parties that apply the provision in decision 2/CMP.7, annex, and paragraphs 37-39 on Carbon Equivalent Forests. Denmark has decided not to use this in its accounting.

The Danish territory covers mainland Denmark and Greenland, but not the Faroe Islands.

The tables in this chapter covers only the Danish territory and not data from Greenland and thus only data, which shall be included in the submission to the European Union (EU) and for the 2$^{nd}$ commitment period of the Kyoto Protocol.

For Greenland separate CRF and KP tables are produced, see Chapter 15. The Greenlandic tables are named: **GRL.**

The Greenlandic impact on the overall estimates is very low: <0,01 % and thus the figures given below can be regarded as very proximate values for both Denmark and Greenland.

The Danish and the Greenlandic CRF and KP tables are merged into one set of CRF and KP tables and named: **DKE**.

The Faroe Islands has not signed the Kyoto-Protocol and has therefore not submitted KP tables or been included in the Danish and the Greenlandic submission.

The national system has identified land areas associated with the activities under Article 3.4 of the Kyoto Protocol in accordance with definitions, modalities, rules and guidelines relating to land use, land-use change and forestry activities under the protocol by satellite monitoring, use of Land Parcel Information System (LPIS) from the EU subsidiary system as well as the Greenlandic subsidiary system, detailed crop information data on field level, soil mapping and sample plots from the national forest inventory (NFI).

Inventories of emissions and removals under Article 3.3 and Article 3.4 are prepared for 2013 and onwards, and reported annually together with the other greenhouse gas inventory information.

### 10.1.3 Description of how the definitions of each activity under Article 3.3 and each elected activity under Article 3.4 have been implemented and applied consistently over time

The definition of afforestation, reforestation and deforestation is in accordance with the Supplementary GPG (IPCC 2014).

Afforestation (A) or reforestation (R) is identified when areas have wooded tree cover and fulfils the forest definition given above. The time of the A is given by the time of action - i.e. planting of trees. For R, the time is given by the first spontaneous regeneration of tress, typically either by absence of management or by management inducing natural regeneration. All types of establishment of forest (A or R) are considered human induced, as all land area of Denmark is under management or as minimum specifically left for spontaneous revegetation. Regulations and support for A and R include natural revegetation as a specific method, often supplementing already existing forest areas. (Danish Forest and Nature Agency, Support forafforestation http://mst.dk/natur-vand/natur/tilskud-til-skov-og-naturprojekter/ )
Deforestation is identified where areas in 1990 were covered by forest and where subsequent information (through remote sensing, NFI or LPIS) is recorded to have another land use. Deforestation occurs for a number of reasons, e.g. nature restoration, which in the period 1990 - 2018 have been the predominant reason. Other reasons may be urban or infrastructure development.

Temporarily unstocked areas - as integral part of forest management or as result of windthrow - which is expected to continue in forest management - is not considered as deforestation. Destinction between temporarily unstocked areas and deforestation is based on either specific information or more than 10 years of no tree cover.

As for the forest management (Article 3.4) - the forest areas fulfilling the definition given above are included under this activity. All forest areas are considered managed due to the intense utilisation of the land area of Denmark. The Forest Act in Denmark gives the frame for most of the forest area ('Fredskov' constitutes approx. 70%) - thereby ensuring continued forest cover - or by deforestation at least afforestation of a similar area or in most cases the double area. As described in Chapter 6, the changes in forest floor and mineral soils pools are not significant in the period observed (1990-2018) and thus not considered being a source of emissions.

For Cropland and Grassland, the area accounted for under Art. 3.4 has been estimated with the Earth Observation (EO) mapping combined with agricultural data from Statistics Denmark, Statistics Greenland and the EU agricultural subsidiary system. Only activities, which began after January 1st 1990 are included in the inventory. Only areas reported as CL and GL are included in the accounted area.

### 10.1.4 Description of precedence conditions and/or hierarchy among article 3.4 activities and how they have been consistently applied in determining how land was classified

All Forest activities have precedence, after this Cropland activities and then Grassland activities.

Afforestation has precedence. All land converted to forest are included as afforested area. Deforestated areas are reported under D. The following categories in the Convention reporting are included under afforestation:

- 4A21 CL to A
- 4A22 GL to A
- 4A23 WE to A
- 4A24 SE to A
- 4A25 OL to A

Deforestation is estimated as:

- 4B21 to CL
- 4C21 to GL
- 4D21 to WE
- 4E21 to SE
- 4F21 to OL

Forest Management activities are only related to:

- 4A1 Forest remaining Forest

Cropland Management activities are related to:

- 4B1 CL remaining CL
- 4B22 GL to CL
- 4B23 WE to CL
- 4B24 SE to CL
- 4B25 OL to CL
- 4D22 CL to WE
- 4E22 CL to SE
- 4F22 CL to OL (not occurring)

Grazing land Management activities are related to:

- 4C1 GL remaining GL
- 4C22 CL to GL
- 4C23 WE to GL
- 4C24 SE to GL
- 4C25 OL to GL
- 4D23 GL to WE
- 4E23 GL to SE
- 4F23 GL to OL (not occurring)

No elected land has left land, which it is accounted for. Land conversion between elected activities (FM, CM and GM) has been allowed. FF, CL and GM, which has been converted to WE and SE are still included in the accounted area. No land elected under 3.4 activities has been converted to Other Land. No Other Land, represented as WE, has been converted to land included in Art. 3.3 and 3.4 activities. As a consequence, there has been a small increase in Other land, which is accounted for under Art. 3.3 and Art. 3.4 (Table 10.1) with 445 hectares from 2013 to 2018 which is mainly caused by a conversion of WE til CM.

Table 10.1 The area development in the different Kyoto Protokol classes, which are included in the accounting (only mainland Denmark) 1990 to 2018 (ha).

| | 1990 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|
| Afforestation | 4328 | 88976 | 99621 | 100127 | 102955 | 104741 | 105879 | 107789 |
| Deforestation | 121 | 5785 | 6904 | 7366 | 9950 | 11797 | 11819 | 13221 |
| Forest management | 544417 | 538753 | 537633 | 537172 | 534588 | 532741 | 532719 | 531317 |
| Crop management | - | 2910509 | 2898383 | 2881438 | 2868589 | 2863470 | 2858883 | 2858494 |
| Grazing land management | - | 147212 | 148961 | 165425 | 175654 | 179198 | 182648 | 181127 |
| Other land | - | 614317 | 614050 | 614024 | 613817 | 613606 | 613605 | 613605 |
| Total area, hectares | 4305552 | 4305552 | 4305552 | 4305552 | 4305552 | 4305552 | 4305552 | 4305552 |

The Land Use matrix developed for the purpose of reporting Art. 3.3 and 3.4 activities for 2018 are shown in Table 10.2.

Table 10.2 Land Use matrix for Art. 3.3 and 3.4 activities from 2017 to 2018, in 1000 hectares.

| | ARTICLE 3.3 ACTIVITIES | | ARTICLE 3.4 ACTIVITIES | | | Other | Total area at the end of the previous inventory year |
|---|---|---|---|---|---|---|---|
| | Afforestation and reforestation | Deforestation | Forest management | Cropland management | Grazing land management | Other | |
| Article 3.3 activities | | | (kha) | | | | (kha) |
| Afforestation and reforestation | 105879 | NO | | | | | 105879 |
| Deforestation | | 11819 | | | | | 11819 |
| Article 3.4 activities | | | | | | | |
| Forest management | | 1402 | 531317 | | | | 532719 |
| Cropland management | 1705 | | NO | 2853455 | 3722 | | 2858883 |
| Grazing land management | 0205 | | NO | 5038 | 177405 | | 182648 |
| Other | NO | NO | NO | NO | NO | 613605 | 613605 |
| Total area at the end of the current inventory year | 107789 | 13221 | 531317 | 2858494 | 181127 | 613605 | 4305552 |

Table 10.3 shows the estimated accounting parameters for the period 2013-2018. Afforestation is assumed to add 1859 kt $CO_2$ eqv. to the Danish reduction commitment in the 2nd commitment periode for the period 2013-2018. Deforestation has been estimated to give a net debit of 762 kt $CO_2$ eqv. Forest Management gave large net credits in 2013 and 2014 but turned to net debits in 2015 - 2018. For the years 2013 to 2018, a net credit of 4028 kt $CO_2$ eqv. has been estimated. See Chapter 6 for further details on uncertainty and reporting periods as well as planned improvements.

Cropland Management has been estimated to give a net credit of 10180 kt $CO_2$ eqv. whereas Grazing land Management has been estimated to yield a kredit of 1222 kt $CO_2$ eqv.

Table 10.3 Estimated accounting quantities for the period 2013-2018, kt $CO_2$ eqv.

| | 1990 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Total | Accounting parameters | Accounting quantity |
|---|---|---|---|---|---|---|---|---|---|---|
| A. Article 3.3 activities | | | | | | | | | | |
| A.1. Afforestation/reforestation | | 9 | -342 | -621 | 28 | -601 | -332 | -1859 | | -1859 |
| A.2. Deforestation | | 37 | 122 | 256 | 155 | 26 | 166 | 762 | | 762 |
| B. Article 3.4 activities | | | | | | | | | | |
| B.1. Forest management | | | | | | | | -4028 | | -5986 |
| Net emissions/removals | | -2544 | -3741 | 677 | 703 | 323 | 554 | -4028 | | |
| Forest management reference level (FMRL) | | | | | | | | | 409 | |
| Technical corrections to FMRL | | | | | | | | | -83 | |
| Forest management cap | | | | | | | | | 19822 | -5986 |
| B.2. Cropland management | 5448 | 3029 | 4093 | 3589 | 3849 | 3281 | 4667 | 22508 | | -10180 |
| B.3. Grazing land management | 1574 | 1316 | 1417 | 1246 | 1391 | 1382 | 1471 | 8222 | | -1222 |

The above given information in the hierarchy between the Convention and the KP-LULUCF activities ensures that emission from activities under article 3.4 are not double counted under both article 3.3 and 3.4 activities.

## 10.2 Land-related information

### 10.2.1 Spatial assessment unit used for determining the areas of the units of land under Article 3.3

Afforestation and reforestation are identified as areas in 1990, which are not covered by forest and where subsequent information (through remote sensing or NFI) is recorded to have forest cover fulfilling the forest definition. Even though the definition for A and R refers to the time of establishment, there may be a slight time delay in the actual recording of the A/AR. This will be improved through more frequent land use mapping and improved methods for mapping in the coming years.

Deforestation is identified as areas covered by forest at the beginning of the commitment period and where subsequent information (through remote sensing or NFI) is recorded to have another land use. The identification of the areas is in most cases supported by reports on e.g. nature restoration or establishment of settlements.

### 10.2.2 Methodology used to develop the land transition matrix

A land use/land cover map was produced for the Kyoto reference year 1990, 2005 and 2011 based on EO data for the forest land use. For mostly all other land uses the main data comes from detailed vector maps. These include data such as different vector layers from cadastral maps, road maps, wetland areas, agricultural land use data, vector layers of established wetlands, gravel maps etc. as well as aerial photos. The primary data used for the forest land use mapping is Landsat imagery, mainly Landsat 5 (TM) and 7 (ETM+) data, to classify and estimate the area and in combination with NFI data and other sources of data, including LiDAR data. The product is specified by a Minimum Mapping Unit (MMU) of 0.5 ha, a geometric accuracy of < 15 m RMS and a thematic accuracy of 90% +/- 5%.

The land use was allocated to the six major Kyoto classes: Forest, Cropland, Grassland, Wetland, Settlements, and Other. Highest priority was given to maps having the highest reliability in the production of the land use matrix. To avoid transition artefacts due to minor updates in the precision of the vector maps, a Minimum Mapping Unit (MMU) for land use change has been set to 0.5 ha, which is the same as the elected Danish minimum MMU for forests in the Initial Report under the Kyoto protocol: Initial Report

In Table 10.1 shows the overall development of the area of the six Kyoto Protokol classes, from 1990 to 2018. The preliminary result shows an increase in the afforested area of 107 789 hectares, but also that deforestation has taken place on approximately 13 221 ha. Afforestation is mainly taking place on CL and GL. Areas, which are deforestated, are mainly converted to CL and GL areas with agricultural crops in rotation or permanent grass. Only to a small extend is forest converted to SE.

Since 1990, almost 42 957 hectares have changed into SE. No FF, CL and GL has been converted into OL by definition.

Based upon the combination vector layer of know information a full land use map and satellite images land use map 1990, 2005, 2011 and 2012-2018 was produced. A validation of the map and the change estimates are reported in Johannsen et al. 2018.

### 10.2.3 Maps and/or database to identify the geographical locations, and the system of identification codes for the geographical locations

The entire Danish territory (Denmark and Greenland) except the Faroe Islands is included in the Kyoto-reporting. The text in this chapter includes only the territory of Denmark without Greenland. Denmark is reported as one unit and no sub-geographical locations are used.

Greenland is submitting a full separate NIR and CRF to be included in the submission to UNFCCC (Chapter 16).

## 10.3 Afforestation, Reforestation & Deforestation (ARD)

### 10.3.1 Methods for carbon stock change and GHG emission and removal estimates

For afforestation, the carbon stock change estimates in the period 1990 - 2018 were based both on the area of afforestation, the information on species composition from the Forest Census 2000 and from the NFI since 2002. Afforestation include normal afforestation as well as the large production of christmas trees on agricultural.

The estimation of afforestation biomass carbon stocks for the period 1990-2000, species composition is based on the information from the 2000 Forest Census. Subsequently, the NFI, provides information on the afforestation area and the carbon pools - up til 2018. The estimates for the carbon pools for the afforestation area is consistent for all years.

Carbon stock change caused by deforestation was estimated based on the deforested area, and the mean values of carbon stock per hectare of the total forest area in the period 1990-2005 obtained from the procedure described above. Based on analysis by aerial photographs and LiDAR data of the deforested area for years 2005-2011, is estimated that 50 % of this deforestation has taken place in very young forests or forests with low biomass (e.g. christmas tree plantations or small open forests on the edge of agricultural land). The biomass carbon removed from these areas is estimated to be in average 15 t C $ha^{-1}$, whereas the remaining deforested areas were assumed to have average carbon pools similar to those of the remaining forest area. From 2015, the estimates of carbon removals are based on combined information from a national mapping of biomass, based on canopy height estimated with Lidar data (Schumacher et al., 2013, Nord-Larsen et al., 2017) and the land use map, giving geographical specific information on the deforested areas. With this combination of data, details on the deforestation and the related decreases in carbon pools can be extracted.

In case of deforestation, the living and dead biomass were assumed removed and oxidized instantly. This includes also the litter layer in the forest. Furthermore, the $N_2O$ emission from nitrogen mineralization in the litter layer is multiplied with a C:N ratio of 25 and an emission factor of 0.01. A large part of the deforestation is conversion of forest to restore wetlands by clearcutting the forest and closing the drainage systems.

Further details are available in Johannsen et al. (2011).

### 10.3.2 Description of the methodologies and the underlying assumptions used

The climate in Denmark is cold and wet, which limits the growth of the forests. Therefore afforestation in Denmark requires long rotations (> 50 years), to give a reasonable amount of wood and wood products at the time of the final harvesting. It should be mentioned that the afforested areas are in many cases protected against deforestation by law, and therefore, afforested areas under article 3.3. will seldom be deforested during the commitment period.

The National Forest Inventory (NFI) observations of stock change, specifically related to the afforestated areas, are used as basic information to estimate the emission for units of land subjected to afforestation/reforestation.

### 10.3.3 Justification when omitting any carbon pool or GHG emissions/ removals from ARD (Afforestation, Reforestation and Deforestation)

When deforestation occurs, it is assumed that all dead organic matter will be cleared. The actual amount depends on which type of forest is converted.

### 10.3.4 Information on whether or not indirect and natural GHG emissions and removals have been factored out

No factoring out has been performed in the emission and removal estimates.

### 10.3.5 Changes in data and methods since the previous submission (recalculations)

A recalculation has been made for HWP for the whole timeseries because a displacement in the timeseries. In the previous submission was used a 100 yr time in the transition. This has been changed to 30 yrs for all land use conversions. This increase affects all forest sectors. More detailes is given in Chapter 6.2.2.

### 10.3.6 Uncertainty estimates

Not estimated under KP. Please look in Chapter 6 for the overall LULUCF sector.

### 10.3.7 Information on other methodological issues

See Chapter 6.

### 10.3.8 The year of the onset of an activity, if after 2008

Not applicable.

## 10.4 Forest Management (FM)

### 10.4.1 Methods for carbon stock change and GHG emission and removal estimates

See Chapter 6 in LULUCF on "Forest remaining forest (4.A.1)".

There are very limited "natural forests" in Denmark and these are designated as protected. No conversion of natural forests to planted forests are occurring and hence no emissions arising.

Methodological consistency between the reference level and reporting for forest management is ensured.

Christmas trees within the forest area are included in FM, although the area outside the forest border is reported separately.

### 10.4.2 Methodologies and the underlying assumptions

See Chapter 6 in LULUCF on "Forest remaining forest (4.A.1)".

### 10.4.3 Omission of pools from FM

No pools omitted.

### 10.4.4 Factoring out

No factoring out has been made.

### 10.4.5 Recalculations

Only recalculations due to update with minor adjustments of the land use mapping.

Transition time for Land Use Converstion have been changed to 30 years for all land use Conversions.

### 10.4.6 Uncertainty estimates

Not estimated under KP. Please look in Chapter 6 for the entire LULUCF sector.

### 10.4.7 Information on other methodological issues

See Chapter 6 in LULUCF on "Forest remaining forest (6.2)".

### 10.4.8 The year of the onset of an activity, if after 2008

Not applicable.

## 10.5 Forest Management Reference level (FMRL)

The value inscribed in the appendix to annex of decision 2/CMP.7 is reported to 409 kt $CO_2$ eqv./yr for the second commitment period. For year 2015, a technical correction has been calculated to -83 kt consisting of a correction of the HWP contribution and a technical correction to the Forest Management level to ensure reporting consistency.

**Emissions from harvested wood products originating from forests prior to the start of the second commitment period – cf. paragraph 1(j) in Annex I to Decision 2/CMP.8**

The technical correction is documented in the following report (Schou et al. 2015).

For the second commitment period, a corrected FMRL is estimated specifying the expected average annual net emissions from the HWP pool. Due to the data corrections, it was decided to correct the original FMRL reported in 2011 (Johansen et al. 2011). This correction also entailed a change in the reference period used to project the inflow to the HWP pool – from 2005-2009 to 2008-2012. In order to provide a more accurate reference level using the most recently collected data, the reference period has not been changed. The FMRL would have significantly underestimated the inflow for 2013 and thus caused a significant gap between the reported net emissions and the projected net emissions by the FMRL. This means that the HWP pool would actually have been projected to decrease as opposed to the expected increase in the pool, during the second commitment period.

The corrected FMRL has projected the inflow in 2013 to approximately 132000 tonnes carbon (61000 tonnes from sawnwood and 71000 tonnes from wood-based panels), and the outflow to approxemately 110000 tonnes carbon in 2013 (65000 tonnes from sawnwood and 45000 tonnes from wood-based panels). The projected net sequestration is estimated to 22000 tonnes carbon. Thus, the corrected FMRL projects an average annual net emission of -65 kt $CO_2$ equivalents per year covering the entire second commitment. I.e. the HWP pool is projected to increase over the period.

**Emissions from forest management**

Regarding the FMRL for forest management, the revision is based on technical improvements of calculations, ensuring consistency with the reporting techniques. This relates to the previously mentioned biomass expansion functions, and the updated revision includes pools for soil - mineral and organic and all the emission pools ($CO_2$, $CH_4$ and $N_2O$). The overall technical corrections are included in the table given below.

**Overall technical correction**

The overall result shows that the forest in the FMRL will continue to be a source of emissions, while HWP with the new data from SINKS2 project will be a sink in the overall FMRL.

With this, Denmark has a technical correction to the FMRL as shown in Table 10.4.

Table 10.4 Values inscribed in the appendix to the annex of decision 2/CMP.7 for FMRL for instant oxidation and first order decay and the performed technical correction.

| | Assuming instantaneous oxidation of HWP kt $CO_2$ eqv./year | FMRL applying first order decay function for HWP kt $CO_2$ eqv./year |
|---|---|---|
| Decision 2/CMP.7 | 334 | 409 |
| Technical correction | +58 | -83 |
| Sum | 392 | 326 |

## 10.6 Cropland Management (CM)

### 10.6.1 Methods for carbon stock change and GHG emission and removal estimates

CL is subdivided in four classes: agricultural CL, wooded perennial fruit plantations, hedgerows and "other agricultural CL".

### 10.6.2 Methodologies and the underlying assumptions used

The area with agricultural CL is given as the agricultural area in Statistics Denmark for cereals, fodder crops, grass for seed, sugar beets, potatoes and other root crops.

Land converted from other Land use categories to CL is included under CL. Land converted to forest is reported under forest (A and R). Land, which according to the land use matrix is converted to WE and SE are still included in CM. Land conversion to OL is not allowed.

The same methodology, as used in the Convention reporting, is used in the KP reporting.

### 10.6.3 Omission of pool from CM

Aboveground and belowground living biomass, litter and dead organic are only reported for perennial woody crops, in accordance with IPCC Supplementary GPG 2014. No litter and dead organic matter are reported under CM, as this is seen as not occurring, or as very insignificant because it only related to a small area with fruit plantations and hedges. Therefore, only above- and belowground living biomasses for perennial fruit plantations, hedgerows and willow plantations for bioenergy purposes on agricultural land, are reported under CM. CL converted to other land uses, such as WE and SE, is assumed not to store litter and other dead organic matter. Christmas trees are reported under Forest management.

### 10.6.4 Factoring out

The latter years increase in the temperature, results in a higher turn-over rate of organic matter in soils, which haven lead to an increased emission from soils compared to pre 1990. A dynamical temperature dependent model (Tier 3) is used for the agricultural soils, which is expected to give the best estimate of the actual emission reflecting the Danish soil and climate conditions. Had Denmark used the default IPCC Tier 1 or 2 there, it would likely have been a *negative* factoring out, because the emission factor in these methods are based on long-term scientific data, and thus not having the recent increase in temperatures included. Therefore by using the actual temperature in the Tier 3, no factoring out has been made.

### 10.6.5 Recalculations

Recalculations have been made due to the error estimate of organic soils. See Chapter 6.4. As the increase in the with organic soils reduce the area with mineral soils the emission from mineral soils has been affected. The changes in the area has also affected the emission of $N_2O$ and $CH_4$.

A new model for hedgerows and small biotopes has been introduced. It has increased the area covered with 60 % and increased the standing carbon stock. The model change has, however, only affected the estimated annual changes in biomass very slightly.

Transition time for Land Use Converstion have been changed to 30 years for all land use conversions.

### 10.6.6 Uncertainty estimates

Not estimated separately under KP. Please refer to Chapter 6 for the entire LULUCF sector.

### 10.6.7 Information on other methodological issues

None.

### 10.6.8 The year of the onset of an activity, if after 2008

Not applicable.

## 10.7 Grazing land management (GM)

### 10.7.1 Methods for carbon stock change and GHG emission and removal estimates

Grazing land is defined as land used for permanent grazing as well as dry land not meeting the definitions for FL, CL, WE or SE. GL is subdivided into two types: Land strictly used for grazing and other grassland. Land used for grazing has no wooden vegetation, whereas other grassland may have some wooden vegetation, that does not meet the forest definition. The area with strict grazing land is the remaining area between the grazing area and the grassland area in the land use matrix. All hedges are reported under CM.

### 10.7.2 Description of the methodologies and the underlying assumptions used

As all the grazed grassland is more or less unimproved without fertiliser or limited fertilisation, no changes in management practice has been applied. This is in accordance with IPCC 2006 Chapter 6 and IPCC Supplementary GPG Chapter 2.10.

For land converted to GL and not purely free of wooden trees/bushes, it is assumed that there is a living biomass of 2,200 kg DM per ha in above ground biomass and 6,160 kg DM per ha in below ground biomass (IPCC 2006). No changes in soil carbon stock in mineral soils are assumed for Grazing land, which is under heathland and other non-agricultural influence. Carbon stock changes in mineral soils for Grazing land, which are under agricultural influence, are included in the dynamic modelling with C-TOOL and hence reported under Cropland Management. For organic soils, an emission as reported in Chapter 6 is assumed.

### 10.7.3 Factoring out

No factoring out has been made.

### 10.7.4 Recalculations

See section 10.6.5 as this also affect GM.

### 10.7.5 Uncertainty estimates

Not estimated under KP. Please look in chapter 6 for the whole LULUCF sector.

### 10.7.6 Information on other methodological issues

None.

### 10.7.7 The year of the onset of an activity, if after 2008

Not applicable.

## 10.8 Article 3.3

### 10.8.1 Information that demonstrates that activities under Article 3.3 began on or after 1 January 1990 and before 31 December 2012 and are direct human-induced

The land use mapping in 1990, 2005, 2011 and 2012-2018 is the documentation for activities under Article 3.3 - after 1.1.1990. As all land area is under management, all changes are evaluated as direct human induced. This also includes A and R, which are based on approved methods of establishing new forest - both planting and natural revegetation. In some cases the absence of removal of tree growth is an easy and cheap method for establishing new forest. Hence this method has also been supported through public support for establishment of new forest areas.

### 10.8.2 Information on how harvesting or forest disturbance that is followed by the re-establishment of forest is distinguished from deforestation

Deforestation is detected by information from the Danish Building registry, cadastral maps and the annual update of the Land Parcel Information System on agricultural activities. Furthermore, deforestation of larger areas is confirmed by e.g. projects on nature restoration. Temporarily unstocked areas are typically located within larger forest areas and will in most cases be reforestated within a period of 10 years as according to the Forest Act of Denmark, which applies to all Legal Forest Reserves (Fredsskov) and equals approximately 70 % of the total forest area. Clearcuts outside forests, e.g. small plantations of conifers on former cropland, is considered as deforestation and will most often be recorded through the LPIS system. Deforestation within the forest area boundaries (e.g. caused be change in hydrology or restoration of open areas by means of grazing), will be documented with a new forest cover/forest land use mapping, when resources become available.

Most forest areas - including new forest areas - are subject to intermediate thinnings - harvesting of small trees. This is done with the purpose of reducing stem number and often to produce firewood or wood chips. Clearcuts of new forest areas occur in most cases first at maturity of the stand – after 50-

100 years. A subset of the new forest area are managed as coppice like management, e.g. for production of christmas trees.

### 10.8.3 Information on the size and geographical location of forest areas that have lost forest cover but which are not yet classified as deforested

This is a small area in Denmark and mainly unstocked areas within the forest area. These areas will most likely be replanted within 10 years and therefore kept as Forest Land. A geographic location of these areas would require more frequent updates of mapping of tree cover/forest land use based on e.g. remote sensing data.

### 10.8.4 Uncertainty on article 3.3 activities

Not estimated under KP. Please refer to chapter 6 for the whole LULUCF sector.

## 10.9 Article 3.4

### 10.9.1 Information that demonstrates that activities under Article 3.4 have occurred since 1 January 1990 and are human induced

#### Forest Management

In FM, all forest area is under management and changes in carbon stock are hence seen as human induced. The baseline for 1990 is estimated as documented in Johannsen et al. 2011.

#### Cropland Management

Since 1990, major changes have taken place in Danish agriculture. Due to environmental demands for "green crops during winter", the previous major crop, spring barley, has been replaced by primarily winter wheat. Furthermore, a ban on field burning was implemented in January 1990 (Executive order NO. 142 of 08/03/1989). This has reduced the burning of field residues, which were widely occurring until then. Furthermore, as part of actions to reduce the nitrogen leaching, Executive order NO. 624 of 15/07/1997, the farmers is met with requirements of a certain percentage of the area have to be grown with an extra crop after harvest of annual crops. Currently about eight per cent of the agricultural area is growing an extra crop. From 2003, agricultural areas have been taken out of rotation due to demanded borders along watersheds to protect the watersheds. Specific subsidies, based on EU single payment schemes, to the farmers targeted towards organic soils are currently taking place. The size and location of these areas taken from the LPIS is used in qualifying the effect on emission for CL and GL converted to WE. These areas are included in CM and GM.

#### Grassland Management

No specific activities have taken place in Grassland to increase or decrease the carbon stock. GM was elected so that all human induced activities affecting the carbon stock in the landscape are included in the Danish commitments under the Kyoto Protocol. Furthermore, it is very difficult to distinguish between activities in CM and GM in the heterogenic patchy Danish landscape.

### 10.9.2 Information relating to Cropland Management. Grazing Land Management and Revegetation, if elected, for the base year

No further information is available.

### 10.9.3 Information relating to Forest Management

No further information is available.

### 10.9.4 Uncertainty on article 3.4 activities

Not estimated under KP. Please refer to Chapter 6 for the entire LULUCF sector.

## 10.10 Harvested Wood Products

HWP accounting in the current commitment period is solely based on changes in the HWP pool in this period. Therefore the emissions in the first commitment period have no influence on the current reporting. Furthermore, Denmark has also reported on article 3.4 in the first commitment period.

No further information is available. Please refer to Chapter 6 for further description of HWP.

## 10.11 Other information

### 10.11.1 Key category analysis for Article 3.3 activities and any elected activities under Article 3.4

According to the 2013 Revised Supplementary GPG (Chapter 2.3.6) for LULUCF, a category that is identified as key in the UNFCCC inventory should also be considered key under the Kyoto Protocol.

In 2013, the following LULUCF categories were identified as key categories in the UNFCCC reporting:

- Forest land remaining forest land.
- Cropland remaining cropland – living biomass
- Cropland remaining cropland – organic soils
- Cropland remaining cropland – mineral soils
- Grassland remaining grassland – living biomass

According to Table 5.4.4 in the IPCC GPG for LULUCF, this means that the following Kyoto Protocol activities are initially considered key.

Table 10.5 Relationship between activities in the UNFCCC LULUCF and the KP-LULUCF.

| LULUCF activity | KP-LULUCF activities |
|---|---|
| Forest land remaining forest land | FM, GM, CM |
| Land converted to forest land | A and R |
| Cropland remaining cropland | CM |
| Grassland remaining grassland | GM |

For Denmark, the relevant KP-LULUCF activity corresponding to forest land remaining forest land identified as being a key category in the UNFCCC reporting is FM. Land converted to forest afforestation/reforestation is a key category. For cropland remaining cropland, the relevant KP-LULUCF activity is CM. For grassland remaining grassland, the relevant KP-LULUCF activity is GM.

Therefore A, R, FM, CM and GM are considered key categories in the Danish KP-LULUCF inventory.

For the full list of identified key categories please refer to Annex 1.

## 10.12 Information relating to Article 6

There are no Article 6 projects (Joint Implementation) on the Danish territory.

## 10.13 References


Johannsen, V.K., Nord-Larsen T. & Suadicani, K., 2011: Submission of information on forest management reference levels by Denmark. Forest & Landscape Working Papers No. 58-2011, 34 pp. Forest & Landscape Denmark, Frederiksberg. Available at:: https://unfccc.int/files/home/application/pdf/awgkp_denmark_2011.pdf

Johannsen, V.K., Levin, G., Caspersen, O.H., Nord-Larsen, T., & Sørensen, I.H. 2018: Validation of land use/land cover changes for Denmark. Department of Geosciences and Natural Resource Management, University of Copenhagen, Frederiksberg. 23 p. ill. Available at: https://static-curis.ku.dk/portal/files/209289237/Validation_of_land_use_land_cover_changes_for_Denmark_report_2018.pdf

Nord-Larsen, T., Riis-Nielsen, T., & Ottosen, M. B. 2017. Forest resource map of Denmark: Mapping of Danish forest resource using ALS from 2014-2015. Department of Geosciences and Natural Resource Management, University of Copenhagen. IGN Report. Available at https://static-curis.ku.dk/portal/files/177147904/LiDAR2014_report.pdf and online version https://ign.ku.dk/samarbejde-med-ign/forskningsbaseret-raadgivning/skovovervaagning/kort-over-skovressourcer/

Schou, E., Johannsen, V.K., Nord-Larsen, T., & Jørgensen, B.B. 2014: *Konkrete opgørelser og erfaringer fra 20 års skovrejsning - med fokus på lokalitet, træart og vækst*. Institut for Geovidenskab og Naturforvaltning, Københavns Universitet. IGN Rapport.

Schou, E., Suadicani, K., & Johannsen, V.K. 2015: Carbon Sequestration in Harvested Wood Products (HWP): Data for 2013-Reporting to the UNFCCC, Final Draft. Institut for Geovidenskab og Naturforvaltning, Københavns Universitet. IGN Rapport.

# 11 Indirect $CO_2$ and $N_2O$ emissions

## 11.1 Description of sources of indirect emissions in GHG inventory

The estimation of indirect $CO_2$ and $N_2O$ emissions is based on the official Danish inventories for the precursor gases (CO, NMVOC, $NH_3$ and $NO_x$) reported under the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP) and the $CH_4$ emissions reported to the UNFCCC.

For an in-depth description of the Danish inventories for the precursor gases, please see the Danish Informative Inventory Report submitted to the UNECE (Nielsen et al., 2020).

## 11.2 Methodological issues

The activity data used to estimate the emissions of the precursors and hence the indirect emissions are the same as it used to estimate direct greenhouse gas emissions. Therefore, the information provided in Chapters 3-7 on the activity data is valid also for the reporting of the indirect emissions.

The emission factors used to estimate the emissions of the precursors are for $CH_4$ documented in this report; see Chapter 3-7. For emissions of CO, NMVOC, $NO_x$ and $NH_3$, the emission factors are based on a very large selection of data sources. All emission factors are documented in the annual documentation report (Informative Inventory Report – IIR) produced by Denmark and reported as part of the reporting commitments under the Convention on Long-Range Transboundary Air Pollution under the United Nations Economic Commission for Europe; see Nielsen et al. (2020).

The structure of the IIR is very similar to the structure of the NIR, so it is easy for interested parties to get the information on the methodologies and emission factors used to estimate emissions of CO, NMVOC, $NO_x$ and $NH_3$ in Denmark.

Indirect emissions are generally calculated using the methodology described in the 2006 IPCC Guidelines (IPCC, 2006). However, for some sources a more detailed calculation is performed.

The indirect $CO_2$ emission from $CH_4$ is calculated as the emission of $CH_4$ multiplied by 44/16, the indirect $CO_2$ emission from CO is calculated as the emission of CO multiplied by 44/28 and the indirect $CO_2$ emission from NMVOC is calculated as the emission of NMVOC multiplied with the carbon content multiplied by 44/12. The default carbon fraction as per the 2006 IPCC Guidelines is 0.6. This fraction is used for all other sources than solvent use, where the inventory is based on a chemical specific approach and hence the exact carbon fraction is known. For more information on the estimation of $CO_2$ emissions from solvent use, road paving with asphalt and asphalt roofing, please see Chapter 4.5.

In order for consistency with the reporting done by Denmark under the first commitment period of the Kyoto Protocol, the indirect $CO_2$ emissions from solvent use, road paving with asphalt and asphalt roofing are reported in category 2D3 of the CRF tables in accordance with the reporting guidelines (UNFCCC, 2013) that allows for the use of these categories in a drop-down list within this category.

For other sources of indirect $CO_2$, the emissions are reported in CRF Table6. In the calculation of indirect $CO_2$, only fossil carbon has been considered, hence indirect $CO_2$ is not calculated for precursors originating from biomass combustion, nor from other biogenic sources, e.g. agriculture and waste disposal on land. In addition, indirect $CO_2$ has not been calculated for fuels in the combustion sector where an oxidation factor of 1 is already assumed, i.e. for the IPCC default $CO_2$ emission factors. Denmark only uses the IPCC default emission factors for fuels with a very low consumption; see Chapter 3 for more information.

The precursor emissions used in the calculation of indirect $CO_2$ therefore differs from the emissions reported in the CRF. Table 11.1 below shows the precursor emissions on which the calculation of indirect $CO_2$ is based.

Table 11.1 Emissions of precursors used in the calculation of indirect $CO_2$ for 2018, kt.

| | $CH_4$ | CO | NMVOC |
|---|---|---|---|
| Energy | 7.67 | 136.65 | 20.24 |
| Industrial processes and product use | 0.01 | 0.26 | 0.12 |

The resulting indirect emissions are shown in Table 11.2 below.

Table 11.2 Indirect $CO_2$ emissions for 1990 and 2018, kt $CO_2$e.

| | 1990 | 2018 |
|---|---|---|
| Indirect $CO_2$ from solvent use | 93.73 | 60.71 |
| Indirect $CO_2$ from road paving with asphalt | 0.58 | 0.94 |
| Indirect $CO_2$ from asphalt roofing | 0.02 | 0.02 |
| Indirect $CO_2$ from other sources | 1133.23 | 281.05 |
| Total GHG emission excluding all indirect $CO_2$ | 69241.45 | 47520.84 |
| Total GHG emission consistent with CP1 | 69335.78 | 47582.51 |

For indirect $N_2O$ the emissions resulting from ammonia emissions in agriculture and LULUCF are covered in the sectoral tables for agriculture and LULUCF. The indirect $N_2O$ emissions resulting from $NO_x$ emissions in these sectors are included in CRF Table6. The indirect $N_2O$ emissions are calculated using the below equation.

$$N_2O = (NO_X - N + NH_3 - N) * EF * 44/28$$

The default emission factor of 0.1 kg $N_2O$-N per kg $NH_3$-N or $NO_x$-N emitted is used for all sources.

## 11.3 Uncertainties and time-series consistency

Uncertainties for the precursors are estimated using a simple error propagation method similar to the IPCC Approach 1.

Please see Nielsen et al. (2019) for further information on the uncertainties and time-series consistency for the Danish inventories of indirect greenhouse gases.

## 11.4 Category-specific QA/QC and verification

Please see Nielsen et al. (2019) for further information on the QA/QC for the Danish inventories of indirect greenhouse gases.

## 11.5 Category-specific recalculations

A large number of recalculations are carried out annually to take into account new data, updated knowledge, new sources and correction of errors. The recalculations for 1990 and 2017 are shown in Table 11.3 and 11.4 below. Only short explanations are provided in this report as the number of recalculations are vast and it is beyond the scope of this report to include them here.

Please see Nielsen et al. (2020) for further information on the recalculations for the Danish inventories of indirect greenhouse gases.

Table 11.3 Recalculations of indirect emissions and precursors for 1990, kt.

| | Source emissions | | | | | Indirect emissions | |
|---|---|---|---|---|---|---|---|
| | $CH_4$ | CO | NMVOC | $NO_x$ | $NH_3$ | $CO_2$ | $N_2O$ |
| Total | -2.39 | -13.61 | -30.19 | 0.71 | 0.00 | -3.91 | 0.00 |
| Energy | 0.12 | -13.61 | 0.37 | 0.75 | 0.00 | -3.91 | 0.00 |
| Industrial processes and product use | - | 0.00 | -0.04 | - | - | - | - |
| Agriculture | 0.01 | - | -30.51 | -0.04 | | | 0.00 |
| LULUCF | -2.52 | - | - | - | | | - |
| Waste | 0.00 | - | 0.00 | - | - | | 0.00 |

The recalculations in 1990 are generally small. For $CH_4$, the largest recalculation is in the LULUCF sector (updating the area of drained organic soils. This does not affect the indirect $CO_2$ emission, as they are biogenic.

The recalculations of CO is dominated by the energy sector. This is mainly changes for small combustion in households (i.e. residential wood burning) and national aviation. Emission changes are due to the updated emission factors.

The NMVOC emissions have increased significantly due to a recalculation in the agricultural sector. In the 2020 submission, Denmark has implemented the tier 2 methodology from the EMEP/EEA Guidebook (EEA, 2016).

For $NO_x$, the main changes are related to road transport, where a more detailed split of vehicle classes has been implemented.

The changes for $NH_3$ are minor and are not further discussed here.

The indirect $CO_2$ emissions have increased as a consequence of the increasing emissions of CO and NMVOC.

Table 11.4 Recalculations of indirect emissions and precursors for 2017, kt.

| | Source emissions | | | | Indirect emissions | | |
|---|---|---|---|---|---|---|---|
| | $CH_4$ | CO | NMVOC | $NO_x$ | $NH_3$ | $CO_2$ | $N_2O$ |
| Total | -3.96 | -3.66 | -15.75 | 0.94 | -0.05 | -12.03 | 0.00 |
| Energy | 0.22 | -3.65 | 0.16 | 1.19 | -0.04 | -12.05 | 0.00 |
| Industrial processes and product use | 0.00 | 0.01 | -0.08 | 0.00 | 0.00 | 0.02 | 0.00 |
| Agriculture | -0.29 | - | -15.90 | -0.27 | | | 0.00 |
| LULUCF | -4.17 | 0.00 | 0.00 | 0.02 | | | 0.00 |
| Waste | 0.28 | -0.02 | 0.08 | - | -0.01 | | -0.01 |

The main recalculations for $CH_4$, CO and NMVOC in 2017 are caused by the same improvements as mentioned for 1990, i.e. for $CH_4$ updated area of drained organic soils in the LULUCF sector, for CO changes for residential wood combustion and for NMVOC change to a higher methodological tier. For $NO_x$, the recalculation is due to a correction of fuel consumption for navigation that had previously been assumed domestic but is in fact international.

Please see Nielsen et al. (2020) for further information on the recalculations for the Danish inventories of indirect greenhouse gases.

## 11.6 Category-specific planned improvements

Please see Nielsen et al. (2020) for further information on the planned improvements for the Danish inventories of indirect greenhouse gases.

## 11.7 References

EEA, 2016: EMEP/EEA air pollutant emission inventory guidebook 2016. Technical guidance to prepare national emission inventories. EEA Report 21/2016. Available at: http://www.eea.europa.eu/publications/emep-eea-guidebook-2016 (27-01-2020).

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. & Tanabe K. (eds). Published: IGES, Japan. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (27-01-2020).

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Mikkelsen, M.H., Nielsen, M., Gyldenkærne, S., Fauser, P., Albrektsen, R., Hjelgaard, K., Bruun, H.G. & Thomsen, M., 2020: Annual Danish Informative Inventory Report to UNECE. Emission inventories from the base year of the protocols to year 2018. Aarhus University, DCE – Danish Centre for Environment and Energy. (In press).

UNFCCC, 2013: Decision 24/CP.19 – Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention.

# 12 Information on accounting of Kyoto units

Referring to Decision 3/CMP.11 on 'Implications of the implementation of decisions 2/CMP.7 to 4/CMP.7 and 1/CMP.8 on the previous decisions on methodological issues related to the Kyoto Protocol, including those relating to Articles 5, 7 and 8 of the Kyoto Protocol, part I: implications related to accounting and reporting and other related issues' for the preparation of the information required under Articles 7 of the Kyoto Protocol (UNFCCC, 2015), this chapter and chapters 13, 14 and 15 include information and references to the annual supplementary information under the Kyoto Protocol. Decision 3/CMP.11 states that decisions 13/CMP.1, 15/CMP.1, 18/CMP.1 and 19/CMP.1 shall apply mutatis mutandis, except where otherwise specified in decisions 1/CMP.8 and 2/CMP.8 and in decision 3/CMP.11.

## 12.1 Information on transferred or acquired units

In accordance with paragraph 10 of the annex to Decision 15/CMP.1 information on emission reduction units (ERUs), certified emission reductions (CERs), temporary certified emission reductions (tCERs), long-term certified emission reductions (lCERs), assigned amount units (AAUs) and removal units (RMUs) will be reported for the first calendar year in which these units will be transferred or acquired.

## 12.2 Summary of information reported in the SEF tables

The Standard Electronic Format (SEF) report for 2017 CP2 has been submitted to the UNFCCC Secretariat electronically and the contents of the reports can also be found in annex 6.

## 12.3 Discrepancies and notifications

Annex I parties are inter alia required to submit four reports according to paragraphs 12 to 16 of the annex to decision 15/CMP.1. These reports are:

- Paragraph 12 – List of discrepancies identified by the ITL. List not included as no discrepant transactions occurred in 2019.
- Paragraph 13/14 – List of notifications from the CDM Executive Board regarding lCERs. No CDM notifications occurred in 2019.
- Paragraph 15 – List of non-replacement identified by the ITL. No non-replacements occurred in 2019.
- Paragraph 16 – List of invalid Kyoto units. No invalid units exist as of 31 December 2019.

No actions were taken or changes made to address discrepancies for the period under review.

## 12.4 Publicly accessible information

Information from the SEF available to the public will be included in the Danish SEF report 2018. The report will be available on the Danish Business Authority's website in addition to other public reports (pursuant to paragraphs 44 to 48 of the annex to Decision 13/CMP.l) as well as in the ETS registry:

In English: https://danishbusinessauthority.dk/public-information

In Danish:
https://erhvervsstyrelsen.dk/offentlig-information-og-persondata

Link to reports available from the ETS registry:
https://unionregistry.ec.europa.eu/euregistry/DK/public/reports/publicReports.xhtml

The reports are updated every month.

The reports include information on each account as required in paragraph 45 of the annex to Decision 13/CMP.1. Please note that publishing the contact information (paragraph 45 (d) and (e)) requires the consent of the account holder according to EU legislation. Thus, this information is not publicly available. The Danish Business Authority complies with the requirements stipulated in the European Commission's Union Registry Regulation, No. 389/2013, concerning the publication of confidential information.

Other information that is required to be publicly available can be found on the EUTL website: https://ec.europa.eu/clima/ets/

Information on article 6 projects is not available as Denmark to this date has not approved any Joint Implementation projects in Denmark.

## 12.5 Calculation of the commitment period reserve

The calculation of the Commitment Period Reserve (CPR) is based on the assigned amount of 269,377,890 tonnes of $CO_2$ equivalents (UNFCCC, 2017). Subsequently, the CPR calculated as 90 % of the assigned amount is 242,440,102 tonnes $CO_2$ equivalent, during the commitment period and has not changed since the Report of the review of the initial report of Denmark published on 9 August 2017 (UNFCCC, 2017). The commitment period reserve has not changed since the previous submission, as 100 % times the most recent inventory times eight would amount to a higher value.

## 12.6 KP-LULUCF accounting

Accounting of KP-LULUCF under the second commitment period of the Kyoto Protocol will not begin until the entering into force of the Doha-amendment to the Kyoto Protocol. Table 12.1 below contains data as submitted under the Kyoto Protocol for the purposes of the Doha Amendment.

Table 12.1 Information on accounting for activities under articles 3.3 and 3.4 of the Kyoto Protocol.

| Greenhouse gas source and sink activities | Base year | Net emissions/-removals | | | | | | | | | Accounting Parameters | Accounting Quantity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total | | |
| | (kt $CO_2$ equivalent) | | | | | | | | | | | |
| A. Article 3.3 activities | | | | | | | | | | | | |
| A.1. Afforestation and Reforestation | | 8.56 | -341.86 | -620.66 | 27.58 | -600.50 | -332.29 | | | -1859.17 | | -1859.17 |
| A.2. Deforestation | | 36.50 | 122.41 | 256.38 | 154.53 | 26.39 | 165.55 | | | 761.75 | | 761.75 |
| B. Article 3.4 activities | | | | | | | | | | | | |
| B.1. Forest Management | | | | | | | | | | -4027.60 | | -5985.90 |
| Net emissions/removals | | -2543.65 | -3741.03 | 677.04 | 703.31 | 322.53 | 554.20 | | | -4027.60 | | |
| Forest management reference level (FMRL) | | | | | | | | | | | 409.00 | |
| Technical corrections to FMRL | | | | | | | | | | | -82.62 | |
| Forest management cap | | | | | | | | | | | 19822.07 | -5985.90 |
| B.2. Cropland Management | 5448.09 | 3028.97 | 4093.35 | 3588.46 | 3848.83 | 3281.26 | 4667.32 | | | 22508.18 | | -10180.34 |
| B.3. Grazing Land Management | 1573.90 | 1315.61 | 1417.16 | 1246.10 | 1390.53 | 1381.45 | 1470.80 | | | 8221.66 | | -1221.76 |

## 12.7 References


EC, 2004: COMMISSION REGULATION (EC) No 2216/2004 of 21 December 2004 for a standardised and secured system of registries pursuant to Directive 2003/87/EC of the European Parliament and of the Council and Decision No 280/2004/EC of the European Parliament and of the Council. Available at:
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:386:0001:0077:EN:PDF

UNFCCC, 2015: Report of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol on its eleventh session, held in Paris from 30 November to 13 December 2015. Available at:
http://unfccc.int/resource/docs/2015/cmp11/eng/08a01.pdf#page=5

UNFCCC, 2017: Report on the review of the report to facilitate the calculation of the assigned amount for the second commitment period of the Kyoto Protocol of Denmark. Available at: http://unfccc.int/resource/docs/2017/irr/dnk.pdf

# 13 Information on changes in the national system

Since the 2019 submission, no changes have been made to the national system.

# 14 Information on changes in the National Registry

The ETS operates in the EU Member States plus Iceland, Liechtenstein and Norway. It covers certain GHG emissions from installations such as power stations, combustion plants, oil refineries and iron and steel works, as well as factories making cement, glass, lime, bricks, ceramics, pulp, paper and board. Emissions from aircraft operators performing aviation activities in the EU and EFTA states are also included in the ETS.

The following changes to the National Registry of Denmark have occurred in 2019:

| Reporting Item | Description |
|---|---|
| 15/CMP.1 annex II.E paragraph 32.(a)<br>Change of name or contact | The Danish Business Authority<br>The Danish Kyoto Registry<br>Dahlerups Pakhus<br>Langelinie Allé 17<br>DK-2100 København Ø<br>Telephone 1: +45 3529 1000<br>Telephone 2: +45 7220 0038<br>E-mail: co2register@erst.dk<br><br>https://erhvervsstyrelsen.dk/co2-kvoteregistret<br>https://danishbusinessauthority.dk/eu-ets-registry-and-danish-kyoto-registry<br><br>The Registry Staff has changed to:<br><br>Registry Manager Ms. Susanne Petersen<br>Phone: +45 3529 1884<br>E-mail: susbod@erst.dk<br><br>Ms. Eydis Ingimundardottir<br>Phone: +45 3529 1817<br>E-mail: eyding@erst.dk<br><br>Ms. Betina Elmelund<br>Phone: +45 3529 1182<br>E-mail: betelm@erst.dk<br><br>Ms. Kathrine Lindholm<br>Phone: +45 3529 1392<br>E-mail: katlin@erst.dk<br><br>Ms. Eydis Ingimundardottir<br>Phone: +45 3529 1817<br>E-mail: eyding@erst.dk<br><br>Ms. Benét Hermind<br>Phone: +45 3529 1546<br>E-mail: benhim@erst.dk |
| 15/CMP.1 annex II.E paragraph 32.(b)<br>Change regarding cooperation arrange-ment | No change of cooperation arrangement occurred during the reported period. |

| | |
|---|---|
| 15/CMP.1 annex II.E paragraph 32.(c) Change to database or the capacity of national registry | There have been no new EUCR releases after version 8.2.2 (the production version at the time of the last Chapter 14 submission).<br>No change was therefore required to the database and application backup plan or to the disaster recovery plan. The database model is provided in Annex A.<br>No change to the capacity of the national registry occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(d) Change regarding conformance to technical standards | No changes have been introduced since version 8.2.2 of the national registry (Annex B). No changes were made in Annex B, and it is included for the completeness of the report.<br>It is to be noted that each release of the registry is subject to both regression testing and tests related to new functionality. These tests also include thorough testing against the DES and are carried out prior to the relevant major release of the version to Production (see Annex B).<br>No other change in the registry's conformance to the technical standards occurred for the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(e) Change to discrepancies procedures | No change of discrepancies procedures occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(f) Change regarding security | No changes regarding security occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(g) Change to list of publicly available information | In English:<br>https://danishbusinessauthority.dk/public-information<br>https://danishbusinessauthority.dk/danish-emission-trading-registry<br>In Danish:<br>https://erhvervsstyrelsen.dk/co2-kvoteregistret<br>http://www.erhvervsstyrelsen.dk/kyoto-registeret<br><br>The content of the publicly available information is updated monthly, and confidential information is clearly marked as confidential. The information is available in English and Danish.<br><br>No change to the type of publicly available information occurred during the report period.<br><br>As previously, information concerning transactions, holdings and total volumes via the EUTL is considered confidential. This information is not publicly available before year x+3 (“x” denotes the year of the transaction).<br><br>Furthermore the following information is considered confidential:<br>• Account identifier<br>• Representative’s identifier, name, and contact information<br>• Holdings of all accounts<br>• All transactions made<br>• The unique unit identification code of the allowances<br>• The unique numeric value of the unit serial number of the Kyoto units held or affected by a transaction except for the retirement transaction<br><br>No public information is available concerning article-6 projects as Denmark has not approved any joint implementation projects in the country. |
| 15/CMP.1 annex II.E paragraph 32.(h) Change of Internet address | The internet address of the Danish registry has not changed during the reported period. The URL is https://unionregistry.ec.europa.eu/euregistry/DK/index.xhtml |
| 15/CMP.1 annex II.E paragraph 32.(i) Change regarding data integrity measures | No change of data integrity measures occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(j) Change regarding test results | No change during the reported period. |
| The previous Annual Review recommendations | The 2018 assessment report included no recommendations for Denmark. |

The mentioned Annex A and Annex B contains confidential information and is therefore not part of the NIR.

# 15 Information on the minimization of adverse impacts in accordance with Article 3, paragraph 14

No changes have occurred since the information reported in NIR 2011.

# 16 Methodology applied for the greenhouse gas inventory for Greenland

## 16.1 Introduction

This chapter is Greenland's National Inventory Report (NIR) 2020 for submission to the United Nations Framework Convention on Climate change and the Kyoto Protocol.

The following sections contain detailed information on Greenland's inventories for all the years from 1990 to 2018. The structure of the report follows the UNFCCC guidelines on reporting and review.

The issues addressed in this report are trends in greenhouse gas emission, a description of each IPCC category, uncertainty estimates, recalculations, planned improvements and procedures for quality assurance and control.

The annual emission inventories for the years 1990-2018 are reported in the Common Reporting Format (CRF) as requested in the reporting guidelines. The CRF-spreadsheets contain data on emissions, activity data and implied emission factors for each year. Emission trends are given for each greenhouse gas and for the total greenhouse gas emission in $CO_2$ equivalents.

According to the instrument of ratification, the Danish government has ratified the UNFCCC on behalf of Denmark, Greenland and the Faroe Islands. The Danish government has ratified the Kyoto Protocol on behalf of Denmark and Greenland. In the first commitment period under the Kyoto Protocol, Greenland had a reduction commitment. However, for the second commitment period a territorial exemption has been made in the ratification of the Doha Amendment. Hence, in the second commitment period Greenland does not have a commitment.

The information in this chapter relates to Greenland only. Chapter 17 contains information on the aggregated submission of Denmark and Greenland under the Kyoto Protocol.

This report does not contain the full set of CRF Tables. However, the full set of CRF tables is available at the EIONET, Central Data Repository, kept by the European Environment Agency:
http://cdr.eionet.europa.eu/dk/Air_Emission_Inventories/Submission_UNFCCC

The greenhouse gas inventory submitted in 2020 is completed by Ministry of Industry, Energy, Research and Labour with technical support from the Danish National Center of Environment and Energy (DCE). This report on methodology is written by the Ministry of Industry, Energy, Research and Labour with documental support by DCE.

### 16.1.1 Greenhouse gases

The greenhouse gases to be reported under the Climate Convention are:

- Carbon dioxide $CO_2$

- Methane $CH_4$
- Nitrous Oxide $N_2O$
- Hydrofluorocarbons HFCs
- Perfluorocarbons PFCs
- Sulphur hexafluoride $SF_6$
- Nitrogen triflouride $NF_3$

According to the IPCC and their Fourth Assessment Report, which UNFCCC has decided to use as reference for reporting inventory years throughout the commitment period 2013-2020, the global warming potentials for a 100-year time horizon are:

- Carbon dioxide ($CO_2$) 1
- Methane ($CH_4$) 25
- Nitrous Oxide ($N_2O$) 298

Based on weight and a 100-year period, methane is thus a 25 times more powerful greenhouse gas than $CO_2$, and nitrous oxide is 298 times more powerful. Some of the other greenhouse gases (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) have considerably higher global warming potential values.

The indirect greenhouse gases reported are nitrogen oxides ($NO_x$), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and sulphur dioxide ($SO_2$).

### 16.1.2 A description of the institutional arrangement for inventory preparation

All calculations and reporting in this 2020 submission has been conducted by Ministry of Industry, Energy, Research and Labour. This includes reporting the Greenlandic national emission inventory to DCE in the Common Reporting Format in accordance with the UNFCCC guidelines.

DCE is responsible for reporting the national inventory for the Kingdom of Denmark to the UNFCCC and for reporting the national inventory under the Kyoto Protocol for both Denmark and Greenland.

The inventory for LULUCF and KP-LULUCF is carried out by DCE and the documentation of the inventory (Sections 16.6 and 16.10) is completed by the Danish LULUCF experts.

The work concerning the annual greenhouse gas emission inventory is carried out in cooperation with Greenlandic ministries, research institutes, organisations and companies.

#### Ministry of Industry, Energy, Research and Labour

The Ministry of Industry, Energy, Research and Labour conducts an annual energy statistics in a format suitable for the emission inventory work and fuel-use data for the large combustion plants. Since 2009 annual surveys on emissions of F-gases has been conducted.

#### Agricultural Advisory Service (Ministry of Fisheries, Hunting and Agriculture)

Background data on cropland and grassland, and statistics on livestock (sheep and reindeer).

**Former Ministry of Nature and Environment**

Data on waste and emissions of F-gases. Annual Survey carried out by the former Ministry of Domestic Affairs, Nature and Environment until 2008 and by Statistics Greenland from 2009 to 2016. The Ministry of Industry, Energy, Research and Labour has conducted the survey for the data since 2017.

**Ministry of Fisheries, Hunting and Argriculture.**

Background data on forestry.

**Greenland Airport Authority (Ministry of Housing and Infrastructure)**

Statistics on domestic and foreign flights to and from Greenland.

### 16.1.3 Brief description of the process of inventory preparation - data collection, data processing, data storage

The background data (activity data and emission factors) for estimation of the Greenlandic emission inventories is collected and stored at the Ministry of Industry, Energy Research and Labour. The methodologies and data sources used for the different sectors are described briefly in Section 16.1.4 and more in depth in Sections 16.3 to 16.7 and Section 16.10.

For each submission, databases and additional tools and submodels are frozen together with the resulting CRF-reporting format. The material and backups are placed at the Ministry of Industry, Energy, Research and Labour.

### 16.1.4 Brief general description of methodologies and data sources used

The Greenlandic air emission inventory is based on the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000), the Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC, 2003) and the CORINAIR methodology.

CORINAIR (COoRdination of INformation on AIR emissions) is a European air emission inventory program for national sector-wise emission estimations, harmonised with the IPCC guidelines. To ensure estimates are as timely, consistent, transparent, accurate and comparable as possible, the inventory program has developed calculation methodologies for most subsectors and software for storage and further data processing (EMEP/CORINAIR, 2007).

A thorough description of the CORINAIR inventory programme used for Greenlandic emission estimations is given in Illerup et al. (2000). The CORINAIR calculation principle is to calculate the emissions as activities multiplied by emission factors. Activities are numbers referring to a specific process generating emissions, while an emission factor is the mass of emission per unit activity. Information on activities to carry out the CORINAIR inventory is largely based on official statistics. The most consistent emission factors have been used either as national values or as default factors proposed by international guidelines.

A list of all subsectors at the most detailed level is given in Illerup et al. (2000) together with a translation between CORINAIR and IPCC codes for sector classifications.

The greenhouse gas inventory for Greenland includes the following sectors:

- Energy
- Industrial Processes and Product Use
- Agriculture
- Land Use, Land-use Change and Forestry
- Waste
- KP LULUCF

The applied methodologies follow the IPCC Guidelines and IPCC Good Practice Guidance. In some cases the methodology is identical to the methodology applied in the Danish inventory, however, the availability of data – especially site specific data – do not allow the same methodology to be used for all the sectors. The brief methodological description is included below for the different sectors. Descriptions that are more thorough are included in Sections 16.3-16.7 and 16.10.

**Energy**

***Fuel Combustion***

The Greenlandic emission inventory for fuel combustion has been performed according to the IPCC tier 1 methodology. The inventory is based on activity data from the Greenlandic energy statistics and on emission factors for different fuels, plants and sectors.

Total fuel combustion is based on data from Polaroil, Statoil and Malik Supply A/S. Polaroil imports fuel and distributes fuel in all parts of Greenland. Statoil imports and distributes fuel in Kangerlussuaq. Malik Supply A/S, a Danish company, re-distributes fuel bought from Polaroil to Greenlandic trawlers, ships etc. By using detailed data from Polaroil, Statoil and Malik Supply A/S it is possible to determine total import, total export, total international bunkers and total domestic fuel combustion.

Total domestic fuel combustion is divided into sectors and private households by using data from a survey on energy consumption, company specific sales data from Polaroil and local fuel distributors, relevant tax accountings and by estimation.

Fuel combustion in private households is estimated using detailed information from a number of local fuel distributors. Fuel deliveries are registered by buildings. In Greenland, each building has a unique number registered in the Greenlandic Area Register (NIN). By combining the NIN-register and the Greenlandic Business Register (GER) with statistics on housing and population, each building is labelled *private household* or located to a sector describing the main activity in the building. This new building-sector register, completed annually, is used extensively to determine the buyer of fuel delivered by Polaroil or local fuel distributors.

Fuel combustion in road traffic is based on a model designed by Statistics Greenland. The model contains data on the vehicle stock obtained from the Greenland Police Department's register on engine data. The vehicles are divided into broad categories of type i.e. personal car, lorry, taxi, truck, ambulance, motorbike etc. Each category is assigned with ratios on fuel type and mileage. Input data on mileage is derived from an annual survey among businesses and private road traffic since 2008. Each vehicle is divided in business categories or labelled *private vehicle* according to the owner. For each group the emissions are estimated by combining vehicle and annual mileage numbers with standard emission factors according to the type of fuel. However, the model does not take cold start or hot engines into account.

For air traffic annual emissions are based on activity data from Air Greenland A/S and sales data from the Greenland Airport Authority. For navigation, ferries and freight, annual emissions are based on activity data from Royal Arctic Line A/S (freight), Royal Arctic Tankers A/S (freight), and Arctic Umiaq Line A/S (passengers).

For further information please refer to Section 16.3.

#### Memo Items

##### *International Aviation Bunkers*

Previously, emissions from international aviation bunkers have been considered to be of neglible importance in terms of Greenland. For that matter the annual amount of jet fuel loaded into foreign aircrafts has been included as part of the IPCC category 1A3a Domestic Aviation. However, some misunderstanding has taken place and this assumption seems to be incorrect! New data has emerged regarding the distinction between domestic and international flights, and it seems possible that combustion of jet fuel in international bound aircrafts taking off from Greenland can be determined and reported as international aviation bunkers as from the coming 2021 submission. However, in this 2020 submission jet fuel loaded into foreign aircrafts is still included as part of the IPCC category 1A3a Domestic Aviation.

##### *International Navigation Bunkers*

Emissions from international marine bunkers are included from 2004 and onwards. Before 2004, international marine bunkers are considered to be of negligible importance.

##### *Fugitive emissions*

Greenland has no coal mines, no off-shore activities, no oil refineries, no natural gas transmission or distribution. For that reason, there have been no fugitive emissions from such activities in 1990-2009. However, in 2010 a Scottish company initiated a search for oil along the westcoast of Greenland. Three wells were drilled and tested in 2010. Five wells in 2011. There has been no oil exploration since 2011.

In the 2014 National Inventory Report calculation of fugitive emission was based on the annual number of drilled and tested wells and IPCC Guideline emission factors. Since the 2015 National Inventory report fugitive emission is to be based on the amount of drilled oil and gas and IPCC Guideline emission factors.

However, the Scottish company has not been able to provide the Government of Greenland with any information on the amount of oil and gas picked up during drillings in 2010 and 2011. To our knowledge, the Scottish company only discovered a few minor kicks with some minor inflow of water or gas during drillings.

With no data available, activity data in 2010 and 2011 has been marked with the notation key Not Applicable (NA). Since no amounts could be estimated, all fugitive emissions are assumed to be zero, and also marked with the notation key Not Applicable (NA). This decision has been made in agreement with the DCE.

Aside from energy production, some fugitive emission occurs in the distribution of fuel e.g. when refuelling from ships to on-shore tanks, onshore loading of fuel to ships and offshore loading of ships. The emission would only be in the form of NMVOC. The fugitive emission from loading/unloading of ships is currently not estimated.

#### Industrial Processes and Product Use

##### *Mineral Industry*

$CO_2$ emissions occur from limestone and dolomite use. Import statistics of limestone are used as activity data for estimating the emissions.

##### *Chemical Industry*

Greenland has no chemical industry.

##### *Metal Industry*

Greenland has no metal industry.

##### *Non-energy Products from Fuels and Solvent Use*

$CO_2$ emissions occur from paraffin wax use, road paving with asphalt and asphalt roofing. Import statistics of paraffin wax and asphalt are used as activity data for estimating the emissions.

The emission estimates for solvent use are also prepared by using import statistics of pure chemicals that fits the criteria for being considered a NMVOC compound. Additionally, import statistics are used for products containing NMVOC's. The NMVOC emission is then calculated in to a $CO_2$ emission by using a standard value for carbon content in the NMVOC's. For further information, see Section 16.4.

##### *Electronics Industry*

Greenland has no electronics industry.

##### *Product Uses ...*

Greenland has no production of halocarbons or $SF_6$. Data on consumption of F-gases (HFCs and $SF_6$) are obtained from an annual survey on consumption of halocarbons and $SF_6$ conducted by the Ministry of Industry, Energy, Research and Labour. Information on emission of industrial gases is available from 1995 onwards. Greenland has no consumption of PFCs.

##### *Product Uses as Substitutes for ODS*

Consumption of halocarbons for refrigeration

##### *Other Product Manufacture and Use*

Consumption of $SF_6$ in electrical equipment.

##### *Other Production*

There are several manufacturers of fish products and one tannery. Emissions of NMVOC are estimated, but there are no emissions of greenhouse gases occurring.

For further information on the methodology for calculating emissions from industrial processes, please refer to Section 16.4.

### Agriculture

***Livestock, Enteric Fermentation and Manure Management***

Agriculture is sparse in Greenland due to climatic conditions. However, sheep and reindeer are considered to contribute to emission of greenhouse gases. Enteric fermentation and manure management is assumed to contribute to emission of $CH_4$, and nitrogen excretion is assumed to contribute to emission of $N_2O$.

Activity data for livestock is on a one-year average basis from the agriculture statistics published by Statistics Greenland. Data concerning the land use and crop yield is obtained from the Agricultural Advisory Service.

Data concerning the feed consumption and nitrogen excretion from sheep is based on information from the Agricultural Advisory Service supplemented by data on imported feed. Data concerning the feed consumption and nitrogen excretion from reindeer is based on information from the Agricultural Advisory Service and information from an article on reindeer management in Greenland.

Emission of $N_2O$ is closely related to the nitrogen balance. Thus, quite a lot of the activity data is related to the calculation of ammonia emission. National standards are used to estimate the amount of ammonia emission. When estimating the $N_2O$ emission the IPCC standard value is used for all emission sources. The emission of $CO_2$ from Agricultural Soils is included in the LULUCF sector.

For a more thorough description of the methodology for the agricultural sector, please refer to Section 16.5.

### Land Use, Land-Use Change and Forestry

Greenland is the world's largest non-continental island on the northern American continent between the Arctic Ocean and the North Atlantic Ocean, northeast of Canada. The northernmost point of Greenland, Cape Morris Jesup, is only 740 km from then North Pole. The southernmost point is Cape Farewell, which lies at about the same latitude as Oslo in Norway. Greenland is covering approx. 2,166,086 km$^2$. It has been estimated that 81 % is covered permanently with ice leaving only 410,449 km$^2$ ice free. The climate is Arctic to sub arctic with cool winters and cold summers. The capitol Nuuk is having an average temperature of 1.4°C.

Due to its cold climate the LULUCF sector is of minor importance in relation to the emission of green house gases. Only a very minor area is covered by forest of which the major part has been planted within the last 40 years. Cropland was introduced in year 2000 and grassland management within the last 30 years. The cold climate slows down the biological processes making all growth rates very low.

In total the emission from the LULUC sector in 2018 has been estimated to a net source of 1.19 kt $CO_2$ equivalent or 0.2 % of the total Greenlandic emission.

#### *Forest land*

Greenland has a few forests, which may qualify to the FAO criteria of forest definitions. The major forest areas are:

A natural forest in the Qinngua valley of 45 ha consisting mainly of *Betula Pubescens ssp. Czerepanovii*, which in the period 1990 to 2018 has had an average height of six meters and approx. 100 trees per ha. It is thus assumed that it has had the same biomass for the whole period.

An additional 187 ha other planted forest. The largest of this is an arboretum (a research area) where different species and origins of trees are investigated which are adaptable to the harsh climate.

***Cropland***

In 1990, no annual crops were grown in Greenland. In 2018, 10.5 ha of cropland were used for annual crops. The primary production is potatoes. Potato fields are mainly managed by hand and primarily fens with a high content of organic matter, which is used for this purpose. It is thus assumed that the IPCC standard emission factor for boreal/cold areas of five tonnes C pr ha can be used although it is probably an overestimation due to the cold climate and the current management practice.

***Grassland***

In total is 242,000 hectare reported as grassland. The grassland is located in mountainous areas used for grazing of sheep. Due to the global warming, there are some smaller areas, which have become improved fertilised grassland. The total area with improved grassland has increased from 490 ha in 1990 to 1,136ha in 2018.

***Wetlands***

Reported area with wetlands consists only of water-reservoirs. Due to lack of methodology for methane emissions under arctic conditions, no emission estimates has been made, which is in accordance with the IPCC Good Practice Guidance guidelines.

***Settlements***

The few settlements are mainly built on cliffs with very sparse vegetation. Hence, it is assumed that no changes in C stock occur.

***Other land***

No emission estimates has been made since no data is available which is in accordance with IPCC Good Practice Guidance guidelines.

***Harvested wood products***

Due to an only marginal area with slowgrowing forests is it assumed that no national changes in the carbon stock in Harvested Wood Products (HWP) are taking place.

For a more thorough description of the methodology applied for LULUCF and KP-LULUCF please refer to Section 16.6 and 16.10.

**Waste**

***Solid Waste Disposal***

The solid waste disposal in Greenland can be divided in the following processes:

- Managed waste disposal sites, anaerobic.
- Unmanaged waste disposal sites.

#### *Biological Treatment of Solid waste*

Greenland has no biological treatment of solid waste.

#### *Incineration and Open Burning of Waste*

Waste incineration with or without energy recovery and open burning of waste is both divided in the following processes:

- Waste incineration/Open burning, biogenic.
- Waste incineration/Open burning, non-biogenic.

Waste incineration with energy recovery is according to IPCC Guidelines included under the energy sector.

Information on amount of waste produced per year, amount of waste treated in the different processes, distribution between household and commercial waste, composition of the household waste and commercial waste, respectively, are provided by the Ministry of Environment and Nature.

#### *Wastewater Treatment and Discharge*

$N_2O$ emission from human sewage is estimated. The calculation of the $N_2O$ emission uses population data from Statistics Greenland website and an estimate for average protein consumption combined with default values from the IPCC Guidelines. No emissions of $CH_4$ are assumed to occur.

For more information, please refer to Section 16.7.

#### KP-LULUCF

Regarding the possibility of including in the second commitment period emissions and removals associated with land use, land-use change and forestry activities under Article 3.4 of the Kyoto Protocol, Greenland as part of the Kingdom of Denmark has included emissions and removals from forest management (FM), cropland management (CM) and grazing land management (GM).

The national system has identified land areas associated with the activities under Article 3.4 of the Kyoto Protocol in accordance with definitions, modalities, rules and guidelines relating to land use, land-use change and forestry activities under the protocol. All land converted from other activities into Cropland and Grassland is accounted for. No land has been allowed to leave elected areas under Article 3.4, see Section 16.10 for further details.

### 16.1.5 Brief description of key categories

A key category analysis (KCA) for year 1990 and 2018 has been carried out in accordance with the IPCC Good Practice Guidance.

The categorisation used results in a total of 36 categories. In the level KCA for the inventory for 1990, five key categories were identified. In the KCA for 2018, seven categories were identified as key categories due to the level whereas eight categories were key categories due to the trend.

Of the seven key sources due to level for the reporting year 2018 five are in the energy sector, of which $CO_2$ from liquid fuels excluding transport in the analysis contributes most with 72.6 % of the national total (this contribution and the percentage contributions in the following are results from the level

KCA based on the absolute values of the emissions; this contribution as percentages may differ somewhat from the percentage used in the sectoral chapters). Of the remaining level key categories in the energy sector three are $CO_2$ from the transport sector and one is $CO_2$ from combustion of other fuels excluding transportation. Domestic aviation, domestic navigation and road transportation comprise respectively 8.2 %, 5.6 % and 5.9 % of the national total. The last two key categories are HFCs from the consumption of HFCs and $CH_4$ from enteric fermentation.

The trend assessment shows that $N_2O$ from wastewater treatment and discharge and $CO_2$ from incineration and open burning of waste are key categories to the trend. Further five sources from the energy sector are also key categories to the trend as well as HFCs from the consumption of HFCs.

The categorisation used, results, etc. are included in Section 16.11 (Annex 1).

### 16.1.6 Information on QA/QC plan including verification

A number of measures are in place to ensure the quality of the Greenlandic greenhouse gas inventory.

The general QC activities include:

- Check that data are correctly moved between data processing steps, e.g. it is ensured that the data are imported correctly from the emission spreadsheets/databases to the CRF Reporter.
- The time-series are analysed. Any large fluctuations are investigated and explained/corrected.
- The recalculations are analysed and the consistency of the emission estimates are verified.
- The completeness of the inventory is checked utilising the completeness checker incorporated in the CRF Reporter as well as expert knowledge from the inventory compilers.
- All references are checked and it is ensured that the citations are correct.

These types of QC checks are recommended as tier 1 QC checks in the IPCC Good Practice Guidance (IPCC, 2000).

The Greenlandic emission inventory is reviewed by Danish emission experts, who provide input to the Greenlandic inventory compilers on necessary improvements etc. This is done as a QA procedure. When the emission estimates are transferred to DCE, the quality control system of the Danish emission inventory is applied to the Greenlandic data.

All information related to the Greenlandic emission estimates are documented and archived securely annually. This is done in order to ensure that any part of the inventory can be reproduced at a later stage if necessary.

In addition, source specific QA/QC activities are conducted; please see the associated paragraphs in the sectoral chapters.

### 16.1.7 General uncertainty evaluation

The uncertainty estimates are based on the Tier 1 methodology in the IPCC 2006 Guidelines (IPCC, 2006). Uncertainty estimates for the following sectors are included in the current year: fuel combustion, industrial processes and product use, solid waste, wastewater treatment and waste incineration, agriculture and LULUCF.

The uncertainties for the activity rates and emission factors are shown in Table 16.1.4. The estimated uncertainties for total GHG and for $CO_2$, $CH_4$, $N_2O$ and F-gases are shown in Table 16.1.3. The base year for F-gases is 1995 and for all other sources, the base year is 1990. The total Greenlandic GHG emission is estimated with an uncertainty of ± 4.3 %. The trend in the GHG emission (since 1990) has been estimated to be -10.9 % ± 3.6 %-age points. The GHG uncertainty estimates do not take into account the uncertainty of the GWP factors.

With regard to uncertainty the largest sources in the Greenlandic GHG Inventory are $CO_2$ and $N_2O$ from liquid fuels in fuel combustion, $N_2O$ emission from waste water treatment, $CH_4$ emission from enteric fermentation, $CH_4$ emission from solid waste disposal and HFC from consumption of HFC. However, the result is skewed by the fact that more than 90 % of the Greenlandic Greenhouse gas emission is from fuel combustion of liquid fuels.

Table 16.1.3 Uncertainties 1990-2018.

| | Uncertainty [%] | Trend [%] | Uncertainty in trend [%-age points] |
|---|---|---|---|
| GHG | ± 4.3 | -10.9 | ± 3.6 |
| $CO_2$ | ± 3.5 | -12.1 | ± 3.7 |
| $CH_4$ | ± 56.0 | -11.9 | ± 8.8 |
| $N_2O$ | ± 133 | -19 | ± 28.4 |
| F-gases | ± 51 | +14.391 | ± 6.055 |

Table 16.1.4 Uncertainty rates for each emission source.

| IPCC Source category | Gas | Base year emission | Year t emission | Activity data uncertainty | Emission factor uncertainty |
|---|---|---|---|---|---|
| | | Gg $CO_2$ eqv | Gg $CO_2$ eqv | % | % |
| 1A Liquid fuels | $CO_2$ | 620 | 531 | 3 | 2 |
| 1A Municipal waste | $CO_2$ | 2 | 8 | 3 | 25 |
| 1A Liquid fuels | $CH_4$ | 1 | 1 | 3 | 100 |
| 1A Municipal waste | $CH_4$ | 0 | 0 | 3 | 100 |
| 1A Biomass | $CH_4$ | 0 | 0 | 3 | 100 |
| 1A Liquid fuels | $N_2O$ | 2 | 2 | 3 | 500 |
| 1A Municipal waste | $N_2O$ | 0 | 0 | 3 | 500 |
| 1A Biomass | $N_2O$ | 0 | 0 | 3 | 200 |
| 1B2 Oil exploration | $CO_2$ | 0 | 0 | 3 | 1000 |
| 1B2 Oil exploration | $CH_4$ | 0 | 0 | 3 | 1000 |
| 1B2 Oil exploration | $N_2O$ | 0 | 0 | 3 | 1000 |
| 2A4 Limestone and dolomite use | $CO_2$ | 0 | 0 | 5 | 5 |
| 2D2 Paraffin wax use | $CO_2$ | 0 | 0 | 5 | 25 |
| 2D3 Solvent use | $CO_2$ | 0 | 0 | 5 | 25 |
| 2D3 Road paving with asphalt | $CO_2$ | 0 | 0 | 5 | 25 |
| 2D3 Asphalt roofing | $CO_2$ | 0 | 0 | 5 | 25 |
| 2F Consumption of HFC | HFC | 0 | 8 | 10 | 50 |
| 2G Consumption of $SF_6$ | $SF_6$ | 0 | 0 | 10 | 50 |
| 3A Enteric Fermentation | $CH_4$ | 8 | 6 | 10 | 100 |
| 3B Manure Management | $CH_4$ | 0 | 0 | 10 | 100 |
| 3B Manure Management | $N_2O$ | 1 | 1 | 10 | 100 |
| 3D Agricultural soils | $N_2O$ | 1 | 1 | 20 | 50 |
| 3G Liming | $CO_2$ | 0 | 0 | 5 | 50 |
| 4A Forest | $CO_2$ | 0 | 0 | 5 | 50 |
| 4A Forest | $CH_4$ | 0 | 0 | 5 | 50 |
| 4A Forest | $N_2O$ | 0 | 0 | 5 | 50 |
| 4B Cropland | $CO_2$ | 0 | 0 | 5 | 50 |
| 4C Grassland | $CO_2$ | 0 | 1 | 5 | 50 |
| 4C Grassland | $CH_4$ | 0 | 0 | 5 | 50 |
| 5A Solid Waste Disposal | $CH_4$ | 4 | 5 | 10 | 100 |
| 5C Incineration and open burning of waste | $CO_2$ | 3 | 3 | 10 | 25 |
| 5C Incineration and open burning of waste | $CH_4$ | 3 | 2 | 10 | 50 |
| 5C Incineration and open burning of waste | $N_2O$ | 1 | 1 | 10 | 100 |
| 5D Wastewater treatment and discharge | $N_2O$ | 7 | 5 | 30 | 100 |

### 16.1.8 General assessment of completeness

The present Greenlandic greenhouse gas emission inventory includes all major sources identified by the Revised IPCC Guidelines.

### 16.1.9 References

Ministry of Environment and Nature: Data on waste and ozone depleting substances and greenhouse gases HFCs, PFCs and $SF_6$ (1995-2008)

Agricultural Advisory Service: Statistics on livestock (sheep and reindeer) and background data on land use (cropland and grassland).

Ministry of Fisheries and Hunting and the Greenlandic Arboretum: Background data for Forestry.

EMEP/CORINAIR, 2007: EMEP/CORINAIR Atmospheric Emission Inventory Guidebook – 2007, prepared by the UNECE/EMEP Task Force on Emissions Inventories and Projections. Technical Report No 16/2007. Available at: http://www.eea.europa.eu/publications/EMEPCORINAIR5 (21-02-2014).

EMEP/EEA, 2009: EMEP/EEA air pollutant emission inventory guidebook 2009. Technical guidance to prepare national emission inventories. EEA Technical Report 9/2009. Available at: http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009 (21-02-2014).

Illerup, J.B., Lyck, E., Winther, M. & Rasmussen, E. 2000: Denmark's National Inventory Report – Submitted under the United Nations Framework Convention on Climate Change. Emission Inventories. Research Notes from National Environmental Research Institute, Denmark no. 127, 326 pp. Available at: http://www.dmu.dk/1_viden/2_Publikationer/3_arbrapporter/rapporter/ar127.pdf

IPCC, 2000: Penman, J., Kruger, D., Galbally, I., Hiraishi, T., Nyenzi, B., Emmanuel, S., Buendia, L., Hoppaus, R., Martinsen, T., Meijer, J., Miwa, K. & Tanabe, K. (Eds). Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Published: IPCC/OECD/-IEA/IGES, Hayama, Japan. Available at: http://www.ipcc-nggip.iges.or.jp/public/gp/english/ (15-04-2007).

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. & Tanabe K. (eds). Published: IGES, Japan. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (21-02-2014).

IPCC, 2007: Climate Change 2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z.Chen. M. Marquis, K.B. Averyt, M. Tignor & H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA 996 pp.

Rasmussen, H.E., 1992: Reindeer Management in Southern Greenland (1992). Published in Danish as "Den sydgrønlandske rendrift" (1992).

Statistics Greenland: Energy Consumption in Greenland 2016 published in Danish. Available at: http://www.stat.gl/publ/da/EN/201703/pdf/Grønlands energiforbrug 2016.pdf as "Grønlands energiforbrug 2016" in Danish only (14-12-2017).

Statistics Greenland, 2017: The Greenlandic energy statistics aggregated to SINK categories. Not published.

Statistics Greenland, 2017: Data on waste and ozone depleting substances and greenhouse gases HFCs, PFCs and $SF_6$ (2009-2016)

## 16.2 Trends in Greenhouse Gas Emissions

### 16.2.1 Description and interpretation of emission trends for aggregated greenhouse gas emission

The GHG emissions are estimated according to the IPCC guidelines and are aggregated into five main sectors; Energy incl. Transport, Industrial Processes and Product Use, Agriculture, LULUCF, and Waste, See Figure 16.2.3 and Figure 16.2.4.

The greenhouse gases include $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs and $SF_6$. However, Greenland has no consumption of PFC. In 2018 total emission of greenhouse gases excluding LULUCF was 580.70 Gg $CO_2$ equivalent, and 581.89 Gg $CO_2$ equivalent including LULUCF.

Figure 16.2.1 shows total greenhouse gas emission in $CO_2$ equivalents from 1990 to 2018. The emissions are not corrected for temperature variations. $CO_2$ is the most important greenhouse gas. In 2018 $CO_2$ contributed to the total emission in $CO_2$ equivalent excluding LULUCF with 94.4 %, followed by $CH_4$ with 2.4 %. $N_2O$ and F-gases (HFCs and $SF_6$) contributed with 1.7 % and 1.5 %.

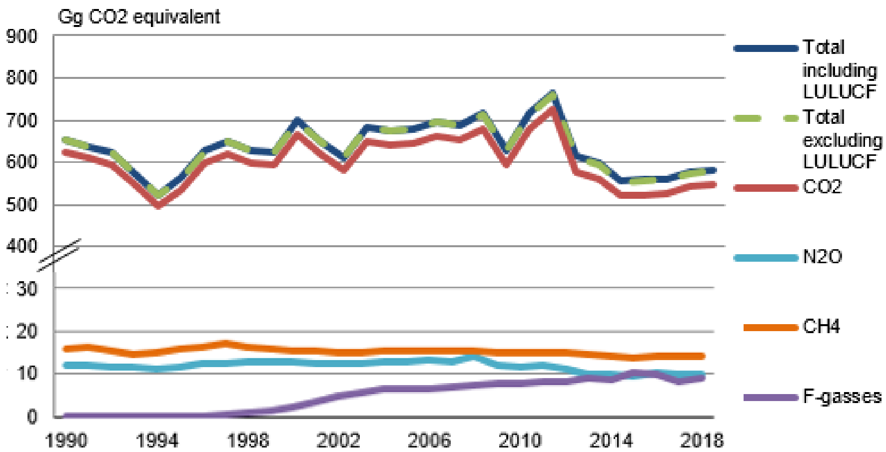



Figure 16.2.1 Greenhouse gas emission in $CO_2$ equivalents, time-series 1990-2018.

Stationary combustion plants and transport represent the largest categories. Energy excluding transport contributed to the total emission in $CO_2$ equivalents excluding LULUCF with 74.5 % in 2018; see Figure 16.2.2. Transport contributed with 19.9 %. Industrial processes and product use, agriculture and waste contributed to the total emission in $CO_2$ equivalents all together with 5.6 %.

The net $CO_2$ emission forestry etc. is 0.2 % of the total emission in $CO_2$ equivalents in 2018. Total GHG emission in $CO_2$ equivalents excluding LULUCF has decreased by 11.0 % from 1990 to 2018 and decreased 10.9% including LULUCF. Comments on the overall trends etc. seen in Figure 16.2.1 and Figure 16.2.2 are given in the sections below on the individual greenhouse gases.

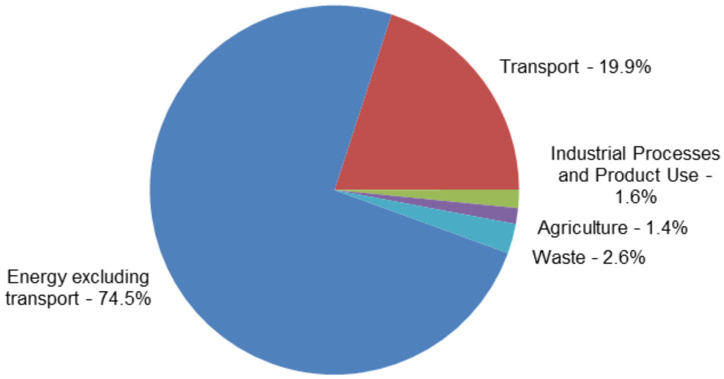



Figure 16.2.2 Greenhouse gas emission in $CO_2$ equivalents distributed on main sectors for 2018.

### 16.2.2 Description and interpretation of emission trends by gas

**Carbon Dioxide**

Emission of $CO_2$ accounted for 94.4 % of the total GHG emission in 2018. The largest source to emission of $CO_2$ is the energy sector comprising Fuel Combustion (Sectoral Approach). In 2018, the energy sector contributed to 99.3 % of the total $CO_2$ emission.

In Figure 16.2.3 and Figure 16.2.4 $CO_2$ emissions are split into several subcategories i.e. Energy Industries, Manufacturing Industries and Construction, Transport, Other energy sectors consisting of the subcategories Commercial and Institutional, Residential, Agriculture and Fishing. All remaining sectors are included in the subcategory *Other* including Agriculture, Industrial Processes and Product Use, and Incineration and Open Burning of waste.

The largest source to the emission of $CO_2$; the energy sector includes combustion of fossil fuels like gasoil, gasoline, jet kerosene etc. From this sector Agriculture, Forestry and Fisheries (AFF) contributes with 26.1 % making AFF the largest contributor in 2018 followed by Transport 20.9 %, Residental 18.5 % and Energy Industries 17.8 %.

Emissions from Energy Industries have been reduced a great deal in later years due to massive investments in hydro power plants. However, in 2010 and 2011 oil explorations were initiated along the west coast increasing fuel combustion and thus caused emissions in the Energy Industries to rise to the highest point ever. Since 2011, there has been a standstill in the oil exploring activities. The standstill in oil exploration combined with a recession in the Greenlandic economy has sent energy combustion in Energy Industries to the lowest level ever in the time series since 1990; see the blue curve in Figure 16.2.3.

Commercial and Institutions contributes with 9.5 % of the total $CO_2$ emission and Manufacturing Industries and Construction with 5.5 %. The category *Other* (containing the remaining sectors) contributed with 1.6 % of the $CO_2$ emissions in 2018.

Overall $CO_2$ emissions excluding LULUCF increased by 1.1 % from 2017 to 2018. However, in 2018, the actual $CO_2$ emission was 12.2 % lower than the emission in 1990 excluding LULUCF.

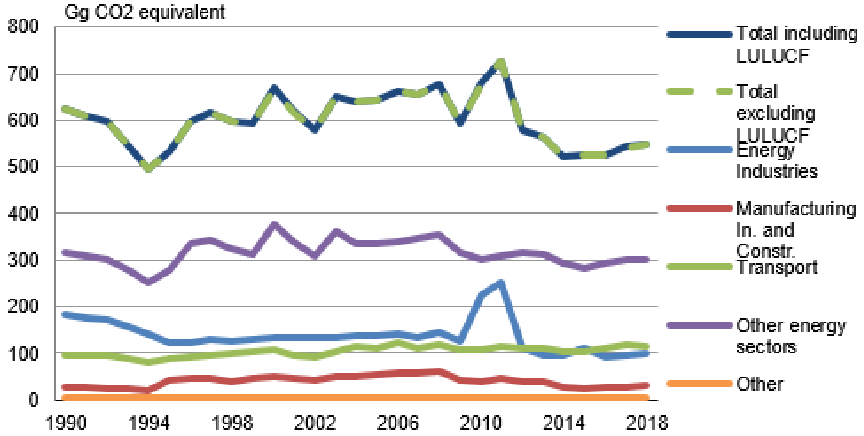


Figure 16.2.3 $CO_2$ emissions, time-series for 1990-2018.

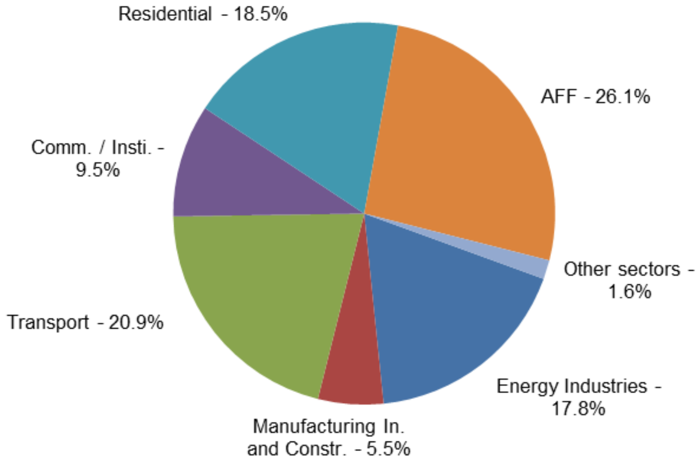


Figure 16.2.4 $CO_2$ emissions, distribution according to the main sectors for 2018.

**Nitrous oxide**

Waste, particularly waste water treatment and discharge is the most important $N_2O$ emission source in 2018 contributing 56.8 % to the total $N_2O$ emissions, see Figure 16.2.6. Agricultural activities contributed 16.4 % to the total $N_2O$ emissions in 2018. Fuel combustion including transport contributed 26.9 %. Since 1990, total emission of $N_2O$ has decreased by 19.0 % excluding LULUCF.

Besides from a temporary increase in 2011 total $N_2O$ emission has been reduced in later years, 2009-2010 and 2011-2015 due to a fall in the amount of waste water from industrial fishing plants and reduced use of inorganic fertilizers in agricultural activities, see Figure 16.2.5.

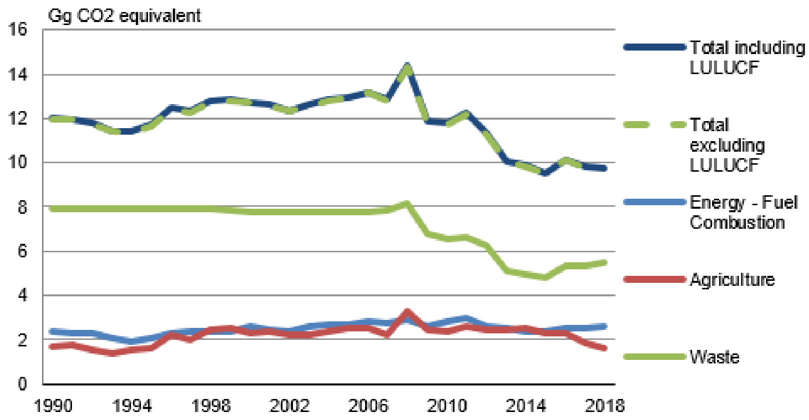



Figure 16.2.5 $N_2O$ emissions, time-series for 1990-2018.

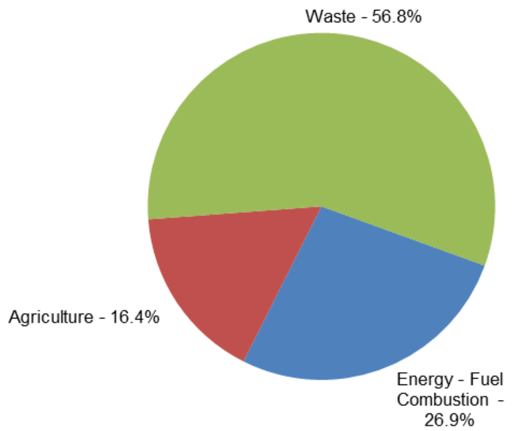



Figure 16.2.6 $N_2O$ emissions, distribution according to the main sectors in 2018.

**Methane**

The largest sources of anthropogenic $CH_4$ emissions are agriculture contributing with 45.6 % of total $CH_4$ emission in 2018 see Figure 16.2.8. Waste contributes to 45.4 % of total emission and the energy sector with 9.1 % of total $CH_4$ emission in 2018.

The emission from agriculture derives from enteric fermentation (97.9 %) and management of animal manure (2.1 %). Since 1990, the number of sheep and reindeer has decreased. From 1990 to 2018, the emission of $CH_4$ from agricultural activities has decreased by 11.9%.

The emission of $CH_4$ from waste derives from solid waste disposal (70.1 %) and incineration and open burning (29.9 %). From 1990 to 2018, the emission of $CH_4$ from solid waste disposal has increased by 4.0 %, while emissions from waste incineration have decreased by 28.8 %. Overall emission of $CH_4$ from waste handling has decreased by 8.6 % from 1990 to 2018.

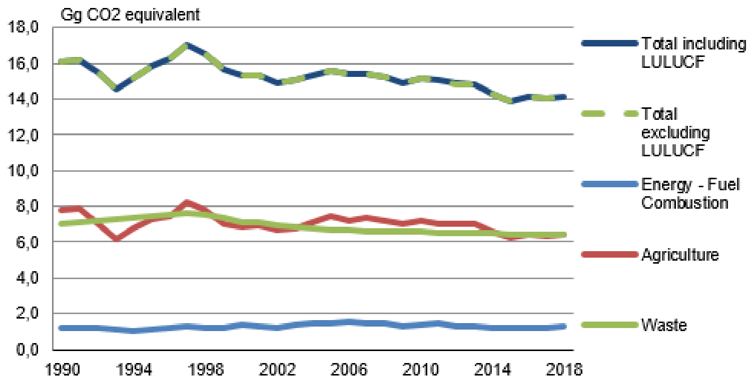



Figure 16.2.7 $CH_4$ emissions, time-series for 1990-2018.

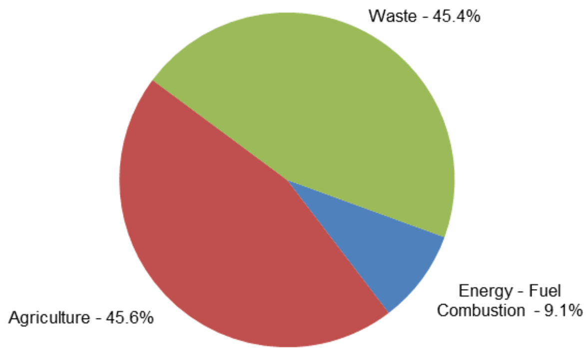



Figure 16.2.8 $CH_4$ emissions, distribution according to the main sectors in 2018.

**HFCs, PFCs and $SF_6$**

This part of the Greenlandic inventory only comprises a full data set for HFCs and $SF_6$ from 1995. Greenland has no consumption that leads to emission of PFCs. Since 1995 there has been a continuous and substantial increase in the contribution from F-gases calculated as the sum of emissions in $CO_2$ equivalents, see Figure 16.2.9.

This increasing emission from 1995 to 2018 is caused by an increase in the emission of HFCs. For the years 2004-2018, the relative increase is lower than for the years 1995 to 2004. The increase from 1995 to 2004 is 10,290 %. From 2004 to 2018 total emission increased by 39.5 %. $SF_6$ contributed to the F-gas sum in 1995 with 55.9 %. Environmental awareness and regulation of this gas under Danish law has reduced its use considerably since 1995. In 2018, the contribution from $SF_6$ to the emission of F-gases was only 0.03 %.

The use of HFCs has increased to a great extent. Today HFCs are by far the dominant F-gas, comprising 44.1 % in 1995, but 99.97 % in 2018. HFCs are mainly used as a refrigerant.

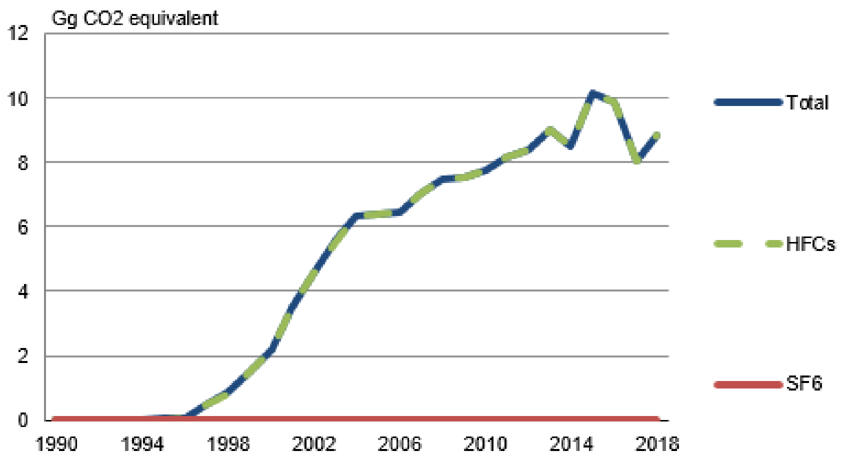


Figure 16.2.9 F-gas emissions, time-series for 1990-2018.

### 16.2.3 Description and interpretation of emission trends by category

#### Energy

The emission of $CO_2$ from energy has decreased by 12.4 % from 1990 to 2018. Emissions decreased from 1990 until 1994 due to the implementation of the first hydro power plant. However, since 1994 combustion of fuel increased continuously causing emissions to increase as well. The reason for this increase was primarily higher demand for transportation and heating. Combustion of fuel may decrease in certain years due to milder temperatures. However, in 2010 and 2011, emissions increased significantly due to the initation of oil exploration, which caused $CO_2$ emission from energy to rise by 14.6 % in 2010 and by 6.9 % in 2011. However, since 2011 oil exploration activities came to a standstill. At the same time, Greenlands fifth hydro power plant went into operation. The rise in hydro power supply combined with an overall recession in the Greenlandic economy caused $CO_2$ emissions from energy to decrease by 20 % in 2012, 3 % in 2013 and 7 % in 2014. In 2015, the economy recovered a little causing $CO_2$ emissions from fuel consumption to rise by 0.6 %. In 2016, the economy recovered even more, but a warm winter – compared to 2015 – reduced the demand for fuel causing $CO_2$ emissions to increase by only 0.2 %. In 2017 the winter was colder compared to 2016 and the waterlevel in the resovoirlake to the hydropowerplant supplying Sisimiut with energy is lower than usual. The national utility company Nukissiorfiit has used more gasoil to produce energy to supplement the energy production from the hydropowerplant. The increased use of gasoil to supplement hydropower in Sisimiut was thus one of the reasons $CO_2$ emissions increased by 3.3 % in 2017.

Overall emission of $CH_4$ from energy has decreased by 3.2 % from 1990 to 2018. However, $CH_4$ emissions from transportation has increased by 109.3 % from 1990 to 2018, mainly due to increasing domestic aviation.

Emission of $N_2O$ has increased by 11.0 % from 1990 to 2018.

#### Industrial processes and product use

Emissions from industrial processes and product use (consumption of halocarbons and $SF_6$) other than fuel combustion amount to 1.6 % of the total emission in $CO_2$ equivalents excluding LULUCF in 2018. The main source is consumptions of HFCs. Emission of F-gases have increased considerable since 1990.

#### Agriculture

The agricultural sector contributes with 1.4 % of the total GHG emissions excluding LULUCF in 2018, 45.5 % of the total $CH_4$ emission and 16.3 % of the total $N_2O$ emission. The total emission from the sector has decreased by 15.5 % from 1990 to 2018. This decrease is due to a fall in the number of reindeer from 6,000 heads in 1990 til 3,000 heads in 2018 and a fall in the number of sheep from 19,929 in 1990 to 18,212 in 2018. The use of inorganic fertilizers has overall increased since 1990. $CH_4$ emission has decreased by 17.3 % from 1990 to 2018, primarily due to the fall in the number of livestock; sheep and reindeer. In the period from 1990 to 2016 $N_2O$ emission has increased by 33.4 % due to a significantly increase in the use of fertilizers. From 2016 to 2018 the $N_2O$ emission has decreased by 30.5 % due to the use of fertilizers has decreased significantly.

#### LULUCF

Emissions from the LULUCF sector amount to just 0.2 % of total emissions in $CO_2$ equivalents in 2018. Forests are assumed to be a sink for the whole period increasing from approximately zero in 1990 to 17.3 tonnes $CO_2$ in 2018. The emission from cropland is estimated to zero in 1990, as there were no cropland in Greenland in 1990 and a net source in 2018 of 48.1 tonnes $CO_2$. The emission from grassland has been estimated to 206 tonnes $CO_2$ in 1990 increasing to 1,124 tonnes $CO_2$ in 2018.

#### Waste

The waste sector contributes with 2.6 % of the total greenhouse gas emissions in 2018, 45.3 % of the total $CH_4$ emission and 56.4 % of the total $N_2O$ emission. Total emission from the sector has decreased by 13.5 % from 1990 to 2018. This decrease is caused by a drop in the $CH_4$ emission from incineration and open burning by 28.8 %, a decrease in the CH4 emission from incineration and open burning by 23.8 % and a decrease in $N_2O$ emission from waste water handling by 31.1 %.

Total GHG emission from waste incineration without energy recovery has decreased by 5.2 % from 1990 to 2017 due to an increasing amount of waste incineration with energy recovery and a continuous decrease in waste water from industrial fishing plants in 2018. Emission from incinerated waste used for heat production is included in the 1A1 IPCC category Energy Industries.

### 16.2.4 Description and interpretation of emission trends for indirect greenhouse gases and $SO_2$

#### $NO_X$

The largest sources to emission of NOx are AFF (Agriculture, Forestry and Fisheries) followed by Transport and combustion in Energy Industries (public power and district heating plants). The AFF-sector is the most contributing sector to the emission of $NO_X$. In 2018, 55 % of the Greenlandic emission of $NO_X$ came from AFF-related activities. The emission of $NO_X$ from AFF varies from year to year. The emissions from transport obtain 28.2 % of total emissions in 2018.

From 1990 to 2018, emission of $NO_X$ from AFF has increased by 36.5 %, while emissions from transport have increased by 22.1 %. In the same period, total emission of $NO_X$ has increased by 12.9 %.

The emissions from energy industries obtain 6.4 % of total emission in 2018. The emission from energy industries have decreased by 45.2 % from 1990 to

2018. The decrease is due to a continuous substitution of fossil fuels with hydro power.

Emission of $NO_X$ from waste handling obtains 1 % of total emission, see Figure 16.2.10.

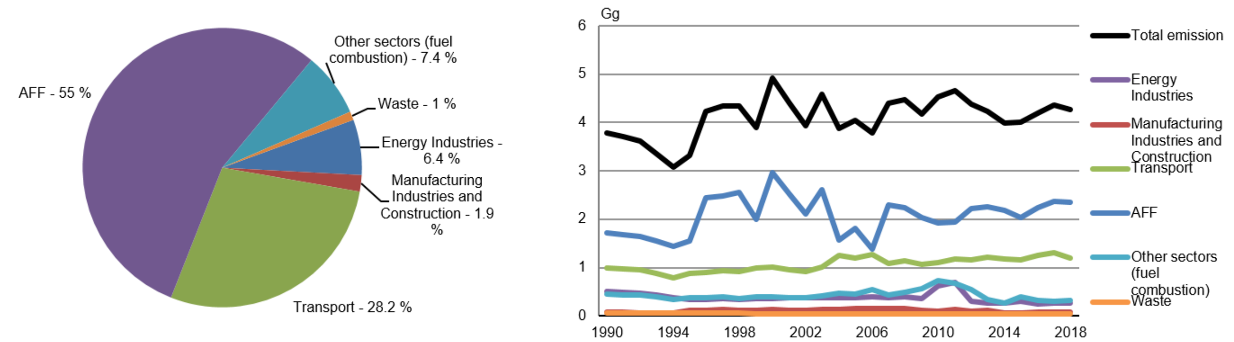



Figure 16.2.10 $NO_X$ emissions. Distribution according to the main sectors (2018) and time series (1990-2018).

**CO**

Mobile sources like transport and AFF (agriculture, forestry and fisheries) contribute significantly to the total emission of this pollutant. Transport is the largest contributor to the total CO emission, see Figure 16.2.11.

Total CO emission has increased by 45.7 % from 1990 to 2018, largely due to increasing emissions from road transportation and civil aviation. Emissions from energy industries have been cut by 46.5 % since 1990, while emissions from transport is increased by 136.7 % since 1990.

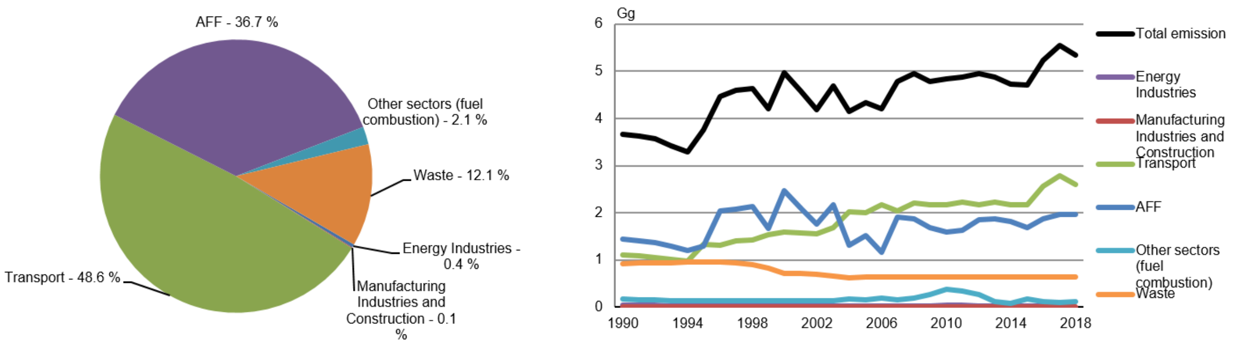



Figure 16.2.11 CO emissions. Distribution according to the main sectors (2018), and time series (1990-2018).

**NMVOC**

The emissions of NMVOC originate from many different sources and can be divided into two main groups: incomplete combustion and evaporation. Road vehicles and other mobile sources such as national navigation vessels fishing vessels and off-road machinery are the main sources of NMVOC emissions from incomplete combustion processes. Road transportation and fishing vessels are the main contributors to this pollutant. Road transportation is included under transportation, which obtain 45.9 % of the total NMVOC emission in 2018. Fishing vessels are included under AFF (agriculture, forestry and fisheries), which obtain 34.8 % of total NMVOC emission in 2018, see Figure 16.2.12.

The evaporative emissions mainly originate from the use of solvents and the extraction, handling and storage of oil. Emissions from solvent and other product use included under Industrial Processes and Product Use. The emission from this sector has increased by 47.1 % from 1990 to 2018.

Total anthropogenic emissions have increased by 59.1 % from 1990 to 2018, largely due to the increase in road transportation and AFF activities.

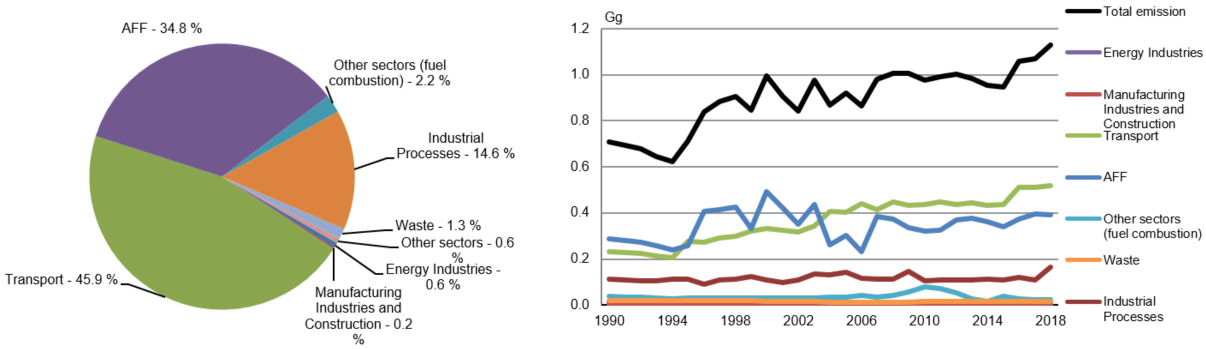



Figure 16.2.12 NMVOC emissions. Distribution according to the main sectors (2018), and time series (1990-2018).

**$SO_2$**

The main part of the $SO_2$ emission originates from the combustion of fossil fuels mainly gasoil in public power and district heating plants. From 1990 to 2018, total emission of $SO_2$ decreased by 5.1 %.

Emissions from AFF (Agriculture, Forestry and Fisheries) obtain 32.0 % of total $SO_2$ emission in 2018 followed by Energy Industries obtaining 19.7 %. Emissions from other industrial combustion plants, non-industrial combustion plants and mobile sources are likewise important. Transportation contributed with 14.3 % of total $SO_2$ emission in 2018.

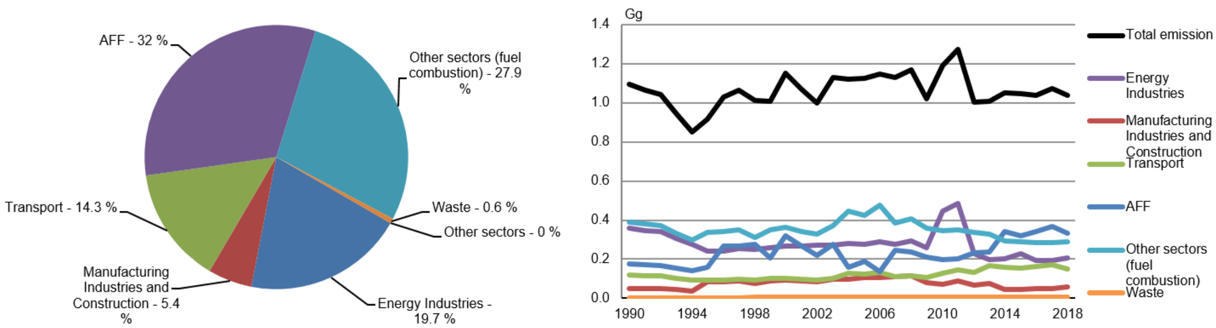



Figure 16.2.13 $SO_2$ emissions. Distribution according to the main sectors (2018), and time series (1990-2018).

## 16.3 Energy (CRF sector 1)

### 16.3.1 Overview of sector

The emission of greenhouse gases from energy activities includes $CO_2$, $CH_4$ and $N_2O$ emission from fuel combustion. In 2010 fugitive emission of $CO_2$, $CH_4$ and $N_2O$ occurred for the first time due to the initiation of well drilling and testing for oil and gas. However, since it has been impossible to obtain any information on the amount of oil and gas picked up during drillings in 2010 and 2011, fugitive emissions has been labelled with the notation key NA.

Emissions from the energy sector are reported in CRF Tables 1.A(a), 1.A(b), 1.A(c), 1.A(d) and 1.B. Furthermore, the emission of non-methane volatile organic compounds (NMVOC), $NO_X$, CO and $SO_2$ from fuel combustion is given in CRF Table 1.

Summary tables for the energy sector are shown in Table 16.3.1.

Table 16.3.1 Emission of $CO_2$ from the Energy Sector.

| Greenhouse gas source and sink categories | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Gg | | | | | |
| 1. Energy | 621.6 | 606.8 | 592.7 | 542.8 | 492.7 | 531.1 | 593.6 | 614.2 | 593.0 | 590.7 |
| A. Fuel Combustion (Sectoral Approach) | 621.6 | 606.8 | 592.7 | 542.8 | 492.7 | 531.1 | 593.6 | 614.2 | 593.0 | 590.7 |
| 1 . Energy Industries | 182.2 | 177.0 | 172.8 | 156.4 | 139.9 | 120.8 | 121.6 | 128.6 | 126.5 | 128.6 |
| 2 . Manufacturing Industries and Construction | 26.5 | 25.7 | 25.1 | 22.6 | 20.2 | 43.8 | 44.5 | 46.2 | 40.0 | 45.8 |
| 3 . Transport | 96.1 | 95.6 | 93.6 | 87.2 | 80.8 | 88.8 | 92.7 | 96.7 | 101.2 | 104.5 |
| 4 . Other Sectors | 308.6 | 300.6 | 293.5 | 269.5 | 245.5 | 271.1 | 328.1 | 336.2 | 318.7 | 305.1 |
| 5 . Other | 8.2 | 8.0 | 7.8 | 7.0 | 6.3 | 6.6 | 6.6 | 6.6 | 6.6 | 6.6 |
| B . Fugitive Emissions from Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| C . $CO_2$ Transport and Storage | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| 1. Energy | 664.0 | 614.5 | 576.2 | 646.2 | 636.4 | 640.5 | 658.8 | 649.7 | 674.3 | 589.4 |
| A. Fuel Combustion (Sectoral Approach) | 664.0 | 614.5 | 576.2 | 646.2 | 636.4 | 640.5 | 658.8 | 649.7 | 674.3 | 589.4 |
| 1 . Energy Industries | 132.1 | 133.2 | 133.9 | 134.4 | 138.5 | 137.1 | 142.3 | 135.1 | 144.0 | 126.0 |
| 2 . Manufacturing Industries and Construction | 48.1 | 45.7 | 43.2 | 49.8 | 50.7 | 55.1 | 55.7 | 57.4 | 59.4 | 43.2 |
| 3 . Transport | 105.9 | 96.1 | 92.4 | 101.4 | 113.6 | 111.9 | 121.2 | 110.4 | 117.1 | 105.9 |
| 4 . Other Sectors | 371.2 | 332.9 | 300.1 | 354.0 | 326.2 | 329.1 | 330.0 | 339.1 | 343.9 | 298.3 |
| 5 . Other | 6.6 | 6.6 | 6.6 | 6.6 | 7.5 | 7.3 | 9.7 | 7.7 | 10.0 | 16.0 |
| B . Fugitive Emissions from Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| C . $CO_2$ Transport and Storage | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| 1. Energy | 675.4 | 721.9 | 575.0 | 557.8 | 517.3 | 520.4 | 521.4 | 538.5 | 544.3 | |
| A. Fuel Combustion (Sectoral Approach) | 675.4 | 721.9 | 575.0 | 557.8 | 517.3 | 520.4 | 521.4 | 538.5 | 544,3 | |
| 1 . Energy Industries | 226.5 | 251.7 | 110.7 | 94.4 | 95.8 | 110.1 | 91.1 | 93.6 | 97,7 | |
| 2 . Manufacturing Industries and Construction | 38.7 | 47.3 | 36.5 | 39.3 | 25.2 | 23.4 | 26.5 | 26.0 | 30,3 | |
| 3 . Transport | 108.5 | 115.5 | 110.7 | 110.1 | 104.7 | 104.1 | 111.8 | 119.1 | 114,3 | |
| 4 . Other Sectors | 277.4 | 286.0 | 301.4 | 309.0 | 289.1 | 273.0 | 286.1 | 295.1 | 297,0 | |
| 5 . Other | 24.4 | 21.3 | 15.6 | 4.9 | 2.4 | 9.7 | 6.0 | 4.7 | 5,1 | |
| B . Fugitive Emissions from Fuels | NA | NA | NO | NO | NO | NO | NO | NO | NO | |
| C . $CO_2$ Transport and Storage | NO | NO | NO | NO | NO | NO | NO | NO | NO | |

Table 16.3.2 Emission of $CH_4$ from the Energy Sector.

| Greenhouse gas source and sink categories | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Gg | | | | | |
| 1. Energy | 0.05 | 0.05 | 0.05 | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 |
| A. Fuel Combustion (Sectoral Approach) | 0.05 | 0.05 | 0.05 | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 |
| 1 . Energy Industries | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 2 . Manufacturing Industries and Construction | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 . Transport | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| 4 . Other Sectors | 0.04 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 | 0.03 | 0.03 |
| 5 . Other | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| B . Fugitive Emissions from Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| *Continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| 1. Energy | 0.06 | 0.05 | 0.05 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.05 |
| A. Fuel Combustion (Sectoral Approach) | 0.06 | 0.05 | 0.05 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.05 |
| 1 . Energy Industries | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 2 . Manufacturing Industries and Construction | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 . Transport | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 4 . Other Sectors | 0.04 | 0.04 | 0.03 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.03 |
| 5 . Other | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| B . Fugitive Emissions from Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| *Continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| 1. Energy | 0.06 | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | |
| A. Fuel Combustion (Sectoral Approach) | 0.06 | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | |
| 1 . Energy Industries | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | |
| 2 . Manufacturing Industries and Construction | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 3 . Transport | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | |
| 4 . Other Sectors | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | |
| 5 . Other | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| B . Fugitive Emissions from Fuels | NA | NA | NO | NO | NO | NO | NO | NO | NO | |

Table 16.3.3 Emission of $N_2O$ from the Energy Sector.

| Greenhouse gas source and sink categories | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Gg | | | | | |
| 1. Energy | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| A. Fuel Combustion (Sectoral Approach) | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 1 . Energy Industries | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 . Manufacturing Industries and Construction | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 . Transport | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 . Other Sectors | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 . Other | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| B . Fugitive Emissions from Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| 1. Energy | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| A. Fuel Combustion (Sectoral Approach) | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 1 . Energy Industries | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 . Manufacturing Industries and Construction | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 . Transport | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 . Other Sectors | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 . Other | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| B . Fugitive Emissions from Fuels | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| 1. Energy | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | |
| A. Fuel Combustion (Sectoral Approach) | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | |
| 1 . Energy Industries | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 2 . Manufacturing Industries and Construction | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 3 . Transport | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 4 . Other Sectors | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 5 . Other | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| B . Fugitive Emissions from Fuels | NA | NA | NO | NO | NO | NO | NO | NO | NO | |

### 16.3.2 Source category description

In this section emission source categories, fuel consumption data and emission data are presented.

Activity data on fuel consumption is based on the same methology that Statistic Greenland has used to the annual statistics on energy previously published by Statistics Greenland and information on waste incineration with energy recovery. The annual statistics on energy is divided into sectors according to the Greenlandic Business Register (GB2000). The register comprises 589 business categories. The official statistics on energy is published by aggregation into 34 categories. From 2018 and onwards data is based on the Danish Business Register CVR, as Greenland Business Register changed early 2018.

In the Greenlandic emission data, all activity rates and emissions are based on the official statistics on energy. However, in order to fit the new CRF format fuel consumption from the official statistics on energy is further aggregated into 19 sectors.

#### Fuel combustion

In 2018, total fuel combustion was 7,591 TJ of which 7,385 TJ was liquid fossil fuels.

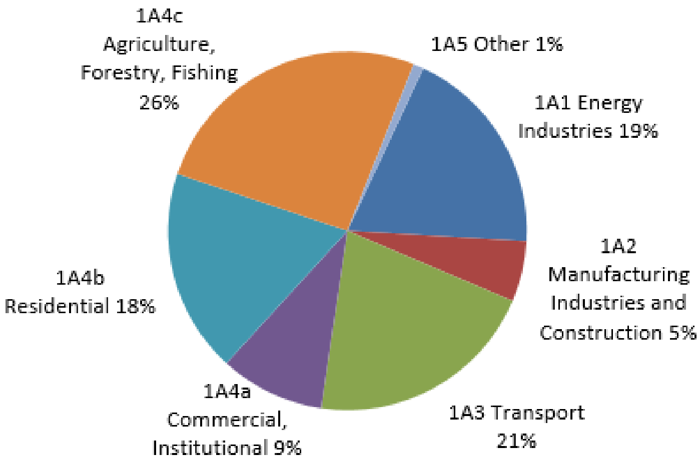
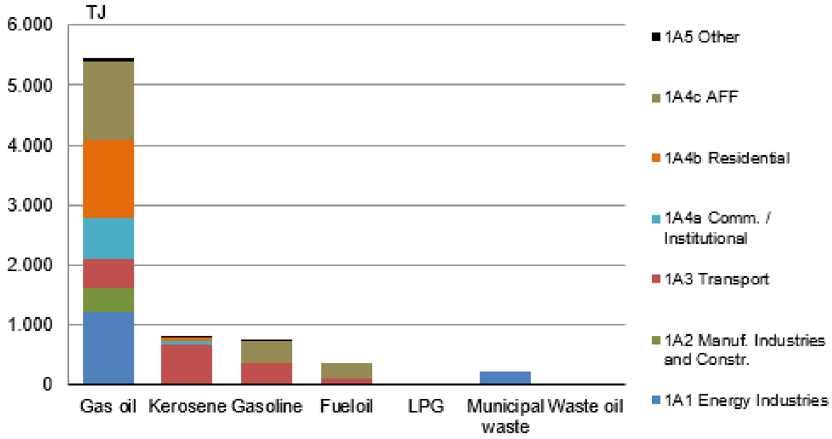



Figure 16.3.1 Fuel combustion rates, fossil fuels 2018.

In Greenland gasoil, kerosene and gasoline are used in fuel combustion. Fueloil has been imported since 2010 and is combusted in ships. Gasoil and kerosene are the most utilised fuels. Gasoil is used in power plants to produce electricity and heat, as well as in district heating, private households, industries and for transportation. In 2010 and 2011 the combustion of gasoil increased significantly due to oil explorations. Due to a standstill in oil explorations total fuel combustion dropped again in 2012.

Kerosene is primarily used in aviation as jetfuel, but also for heating in minor settlements.

A time-series on the consumption of Liquid Petrol Gas (LPG) was introduced for the first time in the 2013 inventory submission. However, the consumption of LPG amount to less than 1 % of the total fuel combustion, see Figure 16.3.2. Prior to the 2017 inventory the time-series on LPG started in 2004. However, with help from the Greenlandic oil importer Polaroil it has been possible to take the time-series on LPG all the way back to 1990. This improvement was implemented in the 2017 inventory and has been used in the inventories since.



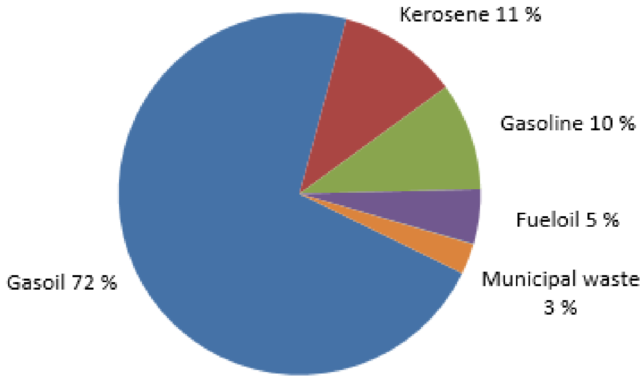




Figure 16.3.2 Fuel combustion, 2017.

Time-series on fuel consumption are presented in Figure 16.3.3. Total fuel consumption has decreased by 11.4 % from 1990 to 2018. This overall decrease in fuel consumption is caused by a drop in the consumption of liquid fossil by 13.4 %. Consumption of renewable waste-energy has increased continuously with a total increase of 356 % from 1990 to 2018. The dropping fuel consumption in 2011-2014 was caused by an overall recession in the Greenlandic economy and the continuous substitution of liquid fuel with electricity from hydro power in the energy sector. In 2016, 2017 and 2018 fuel consumptions increased by, 0.3 %, 3.3 % and 1.2.

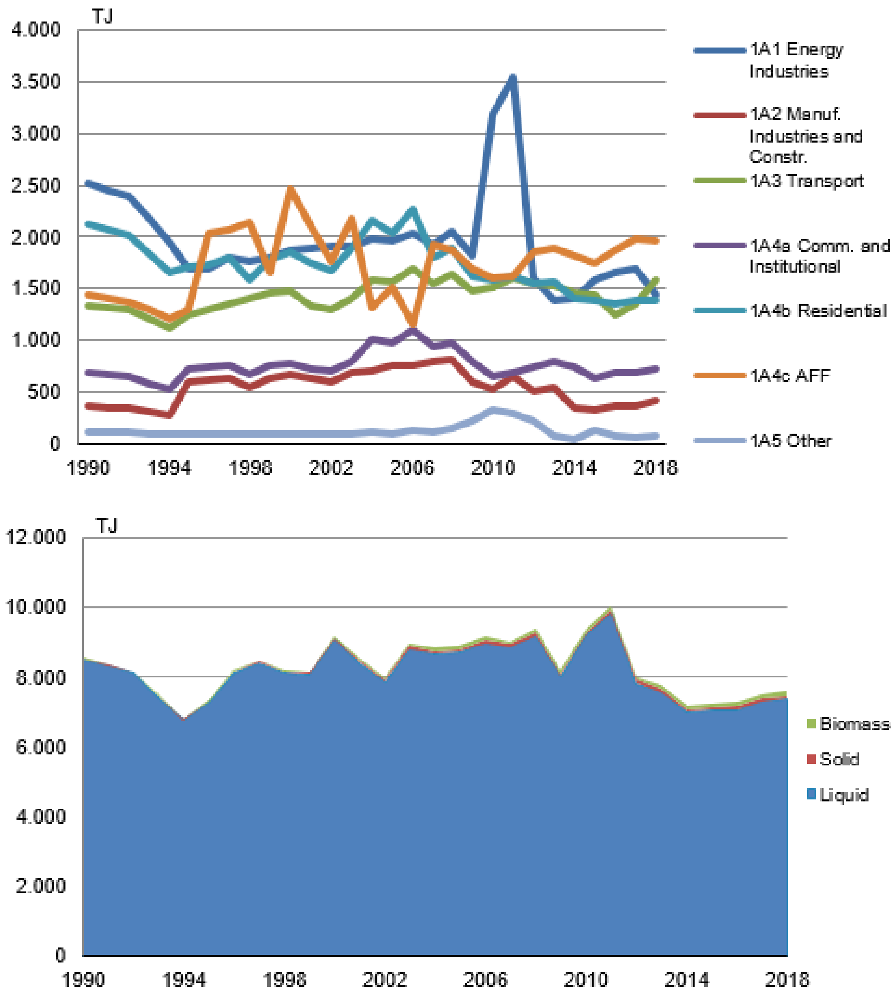



Figure 16.3.3 Fuel consumption time-series 1990-2018.

Fuel consumption is dominated by liquid fuels e.g. gasoil, kerosene and gasoline. In 2018 total fuel consumption consists of 97.3 % liquid fuels, 1.2 % solid fuels and 1.5 % biomass.

In 2018 Energy Industries accounted for 19.0 % of total fuel consumption. From 1990 to 1995 fuel consumption in Energy Industries decreased significantly due to the introduction of the first hydro power plant in 1993, and the introduction of burning waste to produce heat for district heating networks in 1989. Dependence on gasoil decreased immediately. Nevertheless, from 1995 an onwards consumption of gasoil once again increased due to the general economic development. In 2007 fuel consumption in Energy Industries decreased due to a relatively warm winter. Contrary to this, the winter in 2008 was relatively colder, which increased fuel consumption to produce heat. In 2009 hydro power productions increased further when a fourth plant was opened. Together with a relatively warm 2009 winter fuel consumption in Energy Industries decreased additionally. In 2010 and 2011 fuel consumption increased significantly due to oil explorations along the west-coast of Greenland. In 2012-2014 fuel consumption decreased once again due to a standstill in the oil exploration, the opening of the fifth hydro power plant and a general recession in the Greenlandic economy. This all changed in 2015 when the economy improved, which in combination with a very cold winter caused fuel consumptions in Energy Industries to increase as well. In 2016 fuel consumption was reduced in Energy Industries due to a warm winter. In 2017 the fuel consumption increased in Energy Industries due to the combination of colder winter, and the lower waterlevel at the resovoir suppling the hydropower plant in Sisimiut. In 2018 fuel consumption primarily increased a result of an increased consumption in the transport sector.

Fuel consumption regarding Agriculture, Forestry and Fisheries (AFF) accounted for 25.9 % of total fuel sonsumption in 2018 making AFF the largest energy consuming sector. Before 2004, time-series on fuel combustion in this sector varied a great deal due to fluctuations in fishing activities from year to year. However, some uncertainty is expected in the 1990-2003 time-series on fuel consumption in Agriculture, Forestry and Fisheries.

Fuel consumption in Transport accounted for 21.0 % of total fuel consumption in 2018 making Transport the second largest energy consuming sector.

Fuel consumption in Energy Industries accounted for 19.0 % of total fuel consumption in 2018 making Energy Industries the third largest energy consuming sector. Fluctuations in fuel consumption are largely a result of variation in outdoor temperatures from year to year, which also causes fluctuations in fuel consumption in Energy Industries.

Residential fuel consumption accounted for 18.4 % of total fuel consumption in 2018.

For 2004-2016 Statistics Greenland has conducted statistics on energy including detailed information on fuel consumption in businesses and private households; see Section 16.3.3. As of 2017 statistics on energy including detailed information on fuel consumption in businesses and private households are conducted by the Ministry of Industry, Energy, Research and Labour. Compared to the new statistics on energy the historic construction of time-series on fuel consumption in 1990-2003 was based on a much simpler method. Some uncertainty is therefore to be expected in the 1990-2003 time-series on sector-divided fuel consumption.

#### Fugitive Emissions from Fuels

Greenland has no coal mines, no off-shore activities, no oil refineries, no natural gas transmission or distribution. For that reason there have been no fugitive emissions from such activities in 1990-2009. However in 2010 a Scottish company initiated a search for oil along the westcoast of Greenland. Three wells were drilled and tested in 2010. Five wells in 2011. There has been no drilling activitiy since 2011.

In the 2014 National Inventory Report calculation of fugitive emission was based on the annual number of drilled and tested wells and IPCC Guideline emission factors. As from the 2015 National Inventory report fugitive emission is to be based on the amount of drilled oil and gas and IPCC Guideline emission factors.

However, the Scottish company has not been able to provide the Greenland Government with any information on the amount of oil and gas picked up during drillings in 2010 and 2011. To our knowledge the Scottish company only discovered a few minor kicks with some minor inflow of water or gas during drillings.

With no data available, activity data in 2010 and 2011 has been marked with the notation key Not Applicable (NA). Since no amounts could be estimated, all fugitive emissions are assumed to be zeo, and also marked with the notation key Not Applicable (NA). This decision has been made in agreement with the DCE.

Besides energy production some fugitive emission occurs in the distribution of fuel e.g. when refuelling from ships to on-shore tanks, onshore loading of fuel to ships and offshore loading of ships. The emission would only be in the form of NMVOC. The fugitive emission from loading/unloading of ships is currently not estimated.

#### International bunker fuels

##### *International Aviation Bunkers*

Emissions from international aviation bunkers are considered to be of neglible importance. The Greenland Airport Authority has reported the annual amount of jet fuel loaded into foreign aircrafts including Danish aircrafts. However, it is still not possible to distinguish between Danish aircrafts and other aircrafts. Since most foreign aircrafts by far are Danish the annual amount of jet fuel loaded into foreign aircrafts are therefore included as part of the IPCC category 1A3a Domestic aviation.

##### *International Navigation Bunkers*

Emission from international marine bunkers is included from 2004 and onwards. Before 2004 international marine bunkers are considered to be of neglible importance.

#### Feedstocks, reductants and other non-energy use of fuels

At the moment Greenland has no production or use of feedstocks. Emissions from non-energy use of fuels (e.g. bitumen and solvents) are included in the sector Industrial Processes and Product Use (CRF sector 2).

### 16.3.3 Methodological issues

#### Activity data

The Greenlandic emission inventory for fuel combustion has been performed according to the IPCC tier 1 methodology. The inventory is based on activity data from the Greenlandic energy statistics and on emission factors for different fuels, plants and sectors.

Total fuel combustion is based on data from Polaroil, Air Bp (the earlier Statoil) and Malik Supply A/S. Polaroil imports and distributes fuel in all parts of Greenland. Air Bp imports and distributes fuel in Kangerlussuaq. Malik Supply A/S, a Danish company, re-distributes fuel bought from Polaroil to Greenlandic trawlers, ships etc. By using detailed data from Polaroil, Air Bp and Malik Supply A/S it is possible to determine total import, total export, total international bunkers and total domestic fuel combustion.

Next, total domestic fuel combustion is divided into business sectors and private households by using data from a survey on energy consumption, company specific sales data from Polaroil and local fuel distributors, relevant tax accountings, and by estimation.

Since 2008 Statistics Greenland has conducted an annual survey among larger companies. And the Ministry of Industry, Energy, Research and Labour has conducted the annual survey for 2018 data. By completing a questionnaire each company returns detailed information on annual consumption of specific types of fuel. The survey covered 46.3 % of total GHG emission from energy combustion in 2018, see Table 16.3.4.

By using detailed information on sales from Polaroil and local fuel distributors it is possible to determine fuel combustion in private businesses and public offices with an automatic deal on supply. Sales data covered 12.3 % of total GHG emission from energy combustion in 2018, see Table 16.3.4.

Tax accountings in DKK are used to determine annual consumption of fuel in private businesses, in municipalities, and within the Greenland Government. At the moment tax accountings are primarily used for determining fuel combustion in municipalities and public offices in settlements. Accountings cover 14.6 % of total GHG emission from energy combustion in 2018, see Table 16.3.4.

The remaining amount of total inland fuel combustion 26.7 % - is divided into sectors and private households by estimation. This work is carried out by involving statistical material on population, housing, and fisheries and hunting. Danish Business Register CVR (CVR) is used to divide remaining companies into sectors. Information on employees, operating units, vehicles etc. is used to determine the activity in each company.

Fuel combustion in private households is estimated using detailed information from a number of local fuel distributors. Fuel deliveries are registered by buildings. In Greenland each building has a unique number registered in the Greenlandic Area Register (NIN). By combining the NIN-register and the CVR-register (see above) with statistics on housing and population each building is labelled *private household* or located to a sector describing the main activity in the building. This new building-sector register, completed annually, is used extensively to determine the buyer of fuel delivered by Polaroil or local fuel distributors.

Fuel combustion in road traffic is based on a model designed by Statistics Greenland. The model contains data on the vehicle stock obtained from the Greenland Police Department's register on engine data. The vehicles are divided into broad categories of type i.e. personal car, lorry, taxi, truck, ambulance, motorbike etc. Each category is assigned with ratios on fuel type and mileage. Input data on mileage is derived from an annual survey among businesses and private road traffic in 2008-2018. Each vehicle is divided in business categories or labelled *private vehicle* according to the owner. For each group the emissions are estimated by combining vehicle and annual mileage numbers with standard emission factors according to the type of fuel. The model does not take cold start or hot engines into account.

For air traffic annual emissions are based on activity data from Air Greenland A/S and sales data from the Greenland Airport Authority. For navigation, ferries and freight, annual emissions are based on activity data from Royal Arctic Line A/S (freight), Royal Arctic Tankers A/S (freight) and Arctic Umiaq Line A/S (passengers).

Table 16.3.4 shows the part of total $CO_2$ emission divided into sources - survey, specific sales data, tax accountings, and estimation.

Table 16.3.4 Allocation of $CO_2$ emission from fuel combustion into sources to sectoral division (2007-2018).

| | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Pct. | | | | | | | |
| Total | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Survey | 49.6 | 50.3 | 52.8 | 63.0 | 61.3 | 53.2 | 52.2 | 44.8 | 47.5 | 41.4 | 44.0 | 46.3 |
| Sales data from Polaroil | 3.6 | 3.4 | 3.0 | 4.2 | 5.0 | 5.7 | 6.3 | 6.8 | 7.0 | 6.9 | 6.4 | 6.8 |
| Sales data from local fuel distributors | 5.1 | 6.6 | 6.5 | 5.0 | 5.6 | 6.1 | 5.2 | 4.6 | 4.2 | 5.0 | 5.8 | 5.6 |
| Accountings | 12.8 | 12.2 | 12.7 | 10.8 | 11.0 | 13.1 | 15.4 | 15.6 | 16.9 | 20.5 | 13.9 | 14.6 |
| Estimation | 29.0 | 27.5 | 25.0 | 17.0 | 17.0 | 21.8 | 21.0 | 28.3 | 24.4 | 26.2 | 30.0 | 26.7 |

The procedure described above is used to determine fuel combustion in sectors and private households during the period 2004-2018. Formerly, the period 1990-2003, activity data on sectors and private households were estimated using aggregated statistics on population, housing, companies, data on sales from Polaroil, and data on energy consumption in larger companies.

An increasing part of municipal waste incineration is utilised for heat and power production. Thus, incineration with energy-recovery is included in the Energy sector. Table 16.3.5 shows the activity data on fuel combustion for the period 1990-2018.

Table 16.3.5 Activity data on fuel combustion (SINK categories).

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | TJ | | | | | |
| Total | 8 572 | 8 370 | 8 179 | 7 496 | 6 812 | 7 342 | 8 201 | 8 486 | 8 201 | 8 178 |
| Energy industries | 2 519 | 2 447 | 2 393 | 2 169 | 1 944 | 1 685 | 1 698 | 1 794 | 1 766 | 1 805 |
| Manufacturing industries and construction | 363 | 353 | 344 | 311 | 278 | 601 | 610 | 633 | 549 | 628 |
| Domestic aviation | 541 | 556 | 547 | 524 | 500 | 581 | 636 | 660 | 775 | 748 |
| Road transport | 501 | 488 | 476 | 437 | 397 | 370 | 369 | 387 | 361 | 401 |
| Domestic navigation | 288 | 280 | 273 | 248 | 224 | 285 | 285 | 299 | 275 | 308 |
| Commercial/Institutional | 683 | 663 | 647 | 584 | 521 | 726 | 734 | 759 | 669 | 754 |
| Residential | 2 127 | 2 068 | 2 020 | 1 838 | 1 657 | 1 716 | 1 737 | 1 792 | 1 581 | 1 780 |
| AFF | 1 437 | 1 406 | 1 372 | 1 289 | 1 206 | 1 288 | 2 040 | 2 071 | 2 134 | 1 664 |
| Other | 113 | 110 | 107 | 97 | 86 | 91 | 91 | 91 | 91 | 91 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Total | 9 199 | 8 521 | 8 002 | 8 970 | 8 840 | 8 898 | 9 153 | 9 031 | 9 371 | 8 207 |
| Energy industries | 1 868 | 1 885 | 1 900 | 1 915 | 1 972 | 1 955 | 2 028 | 1 928 | 2 045 | 1 795 |
| Manufacturing industries and construction | 660 | 626 | 592 | 682 | 700 | 758 | 768 | 794 | 825 | 610 |
| Domestic aviation | 738 | 632 | 603 | 646 | 608 | 633 | 691 | 701 | 753 | 635 |
| Road transport | 417 | 399 | 388 | 433 | 508 | 504 | 575 | 504 | 535 | 493 |
| Domestic navigation | 321 | 308 | 297 | 334 | 464 | 420 | 421 | 334 | 347 | 350 |
| Commercial/Institutional | 784 | 726 | 700 | 797 | 1 014 | 979 | 1 107 | 939 | 969 | 784 |
| Residential | 1 854 | 1 751 | 1 674 | 1 899 | 2 155 | 2 032 | 2 271 | 1 804 | 1 888 | 1 628 |
| AFF | 2 466 | 2 101 | 1 756 | 2 174 | 1 317 | 1 516 | 1 161 | 1 921 | 1 871 | 1 691 |
| Other | 91 | 91 | 91 | 91 | 103 | 100 | 132 | 105 | 138 | 219 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| Total | 9 387 | 10 026 | 8 014 | 7 773 | 7 199 | 7 244 | 7 266 | 7 501 | 7.591 | |
| Energy industries | 1 551 | 1 522 | 1 578 | 1 343 | 1 379 | 1 566 | 1 323 | 1 352 | 1.413 | |
| Manufacturing and construction | 2 173 | 2 669 | 532 | 583 | 375 | 361 | 386 | 387 | 442 | |
| Domestic aviation | 654 | 723 | 660 | 593 | 555 | 560 | 593 | 673 | 665 | |
| Road transport | 478 | 479 | 469 | 462 | 434 | 427 | 470 | 466 | 481 | |
| National navigation | 378 | 405 | 413 | 471 | 463 | 457 | 491 | 514 | 444 | |
| Commercial/Institutional | 641 | 694 | 742 | 800 | 737 | 647 | 689 | 685 | 717 | |
| Residential | 1 577 | 1 615 | 1 554 | 1 570 | 1 408 | 1 394 | 1 358 | 1 382 | 1 394 | |
| AFF | 1 600 | 1 628 | 1 851 | 1 883 | 1 814 | 1 698 | 1 873 | 1 975 | 1 964 | |
| Other | 335 | 292 | 215 | 67 | 33 | 134 | 82 | 65 | 70 | |

#### Emission factors

The $CO_2$ emission factors applied are presented in Table 16.3.6. For municipal waste and all other fuels the same emission factor is applied for 1990-2018.

In 2013 a technical analysis was conducted on the arctic gasoil that is by far the most dominant type of fuel in Greenland. The analysis was conducted by the Danish Technological Institute in order to gain a country specific emission factor on the Greenlandic gasoil, see Table 16.3.6 and Section 16.3.7 for further details.

In reporting to the Climate Convention, the $CO_2$ emission is aggregated to three fuel types: Liquid fuel, Biomass and Other fuel.

The $CO_2$ emission from incineration of municipal waste with energy-recovery (75.1 + 37.0 kg pr GJ) is divided into two parts: the emission from combustion of the plastic content of waste (which is included in the Greenlandic total) and the emission from combustion of the rest of the waste – the biomass part (which is reported as a memo item). In the IPCC reporting, the fossil part of the waste and the associated emissions from fuel combustion of the plastic content of the waste is reported in the fuel category, *Other fuels*. Greenland uses the Danish emission factors on municipal waste, which have been revised recently due to new information.

Table 16.3.6 $CO_2$ emission factors 1990-2018.

| Fuel | Emission factor | Unit | Reference type | IPCC fuel category |
|---|---|---|---|---|
| Gasoil | 72.967 | kg pr GJ | Country specific | Liquid |
| Kerosene | 71.867 | kg pr GJ | IPCC reference manual | Liquid |
| Jet-Kerosene | 71.500 | kg pr GJ | IPCC reference manual | Liquid |
| Gasoline | 69.300 | kg pr GJ | IPCC reference manual | Liquid |
| Fueloil | 77.367 | kg pr GJ | IPCC reference manual | Liquid |
| LPG | 63.100 | kg pr GJ | IPCC reference manual | Liquid |
| Wasteoil | 77.367 | kg pr GJ | IPCC reference manual | Liquid |
| Municipal waste – biomass | 75.100 | kg pr GJ | Country specific | Biomass |
| Municipal waste – fossil fuel | 37.000 | kg pr GJ | Country specific | Other fuels |

The $CO_2$ emission has been calculated by using the same methodology as described in the IPCC Guidelines (IPCC, 2006). This methodology implies use of C content per fuel type (default) and fraction of carbon oxidised (default); see the equation below.

$$E_{CO_2} = \sum Act_a \times EF_{C,a} \times Ox \times 44/12$$

where:

$Act_a$ = activity; consumption of fuel a

$EF_{C,a}$ = C emission factor for fuel a

Ox = oxidation factor (by default equal to 1)

The emissions of $CH_4$, $N_2O$, $NO_X$, CO and NMVOC have been calculated at sector/fuel level by using IPCC default emission factors combined with measured/Danish EF waste incineration (with energy recovery), see Table 16.3.7 – Table 16.3.9 below.

The equation applied for each pollutant is:

$$E = \sum (EF_{ab} \times Act_{ab})$$

where:

EF = emission factor

Act = activity; fuel input

a = fuel type

b = sector activity

#### $CH_4$

The $CH_4$ emission factors applied for 1990-2018 are presented in Table 16.3.7. Emission factors for municipal waste refer to emission measurements carried out in Danish plants (Nielsen et al., 2010). Other emission factors refer to the IPCC Guidelines (IPCC, 2006).

Table 16.3.7 $CH_4$ emission factors 1990-2018.

| | | Liquid fuel | | | | | | Bio-mass | Other fuel |
|---|---|---|---|---|---|---|---|---|---|
| CRF sector | | Gasoil | Kerosene | Gasoline | Fuel-oil | LPG | Wasteoil | Municipal waste | |
| | | g $CH_4$ per GJ | | | | | | | |
| 1A1 | Energy Industries | 3 | 3 | 3 | 3 | 1 | 3 | 30 | 30 |
| 1A2 | Manufacturing Industries and Construction | 2 | 2 | 2 | 2 | 5 | - | - | - |
| 1A3a | Transport - Domestic aviation | 0.5 | 0.5 | 0.5 | 0.5 | - | - | - | - |
| 1A3b | Transport - Road transportation | 3.9 | 20 | 25 | 5 | 50 | - | - | - |
| 1A3d | Transport - Domestic navigation | 5 | 5 | 5 | 5 | - | - | - | - |
| 1A4a | Other sectors - Commercial, Institutional | 10 | 10 | 10 | 10 | 5 | - | - | - |
| 1A4b | Other sectors - Residential | 10 | 10 | 10 | 10 | 5 | - | - | - |
| 1A4c | Other sectors - AFF stationary | 10 | 10 | 10 | 10 | 5 | - | - | - |
| 1A4c | Other sectors - AFF mobile | 5 | 5 | 5 | 5 | 5 | - | - | - |
| 1A5b | Other - Military mobile | 5 | 5 | 5 | 5 | - | - | - | - |

Source:
- IPCC Guidelines 2006: Gasoil, kerosene, gasoline, fueloil, LPG and waste oil.
- Nielsen et al. (2010): Biomass and other fuel, both municipal waste.

#### $N_2O$

The $N_2O$ emission factors applied for 1990-2018 are presented in Table 16.3.8. Emission factors for municipal waste refer to emission measurements carried out in Danish plants (Nielsen et al., 2010). Other emission factors refer to the IPCC Guidelines (IPCC, 2006).

Table 16.3.8 $N_2O$ emission factors 1990-2018.

| | | Liquid fuel | | | | | | Bio-mass | Other fuel |
|---|---|---|---|---|---|---|---|---|---|
| CRF sector | | Gasoil | Kerosene | Gasoline | Fueloil | LPG | Wasteoil | Municipal waste | |
| | | g $N_2O$ per GJ | | | | | | | |
| 1A1 | Energy Industries | 0.6 | 0.6 | 0.6 | 0.6 | 0.1 | 0.6 | 4 | 4 |
| 1A2 | Manufacturing Industries and Construction | 0.6 | 0.6 | 0.6 | 0.6 | 0.1 | - | - | - |
| 1A3a | Transport - Domestic aviation | 2 | 2 | 2 | 2 | - | - | - | - |
| 1A3b | Transport - Road transportation | 3.9 | 0.6 | 8 | 0.6 | 0.1 | - | - | - |
| 1A3d | Transport - Domestic navigation | 0.6 | 0.6 | 0.6 | 0.6 | - | - | - | - |
| 1A4a | Other sectors | 0.6 | 0.6 | 0.6 | 0.6 | 0.1 | - | - | - |
| 1A5b | Other - Military mobile | 0.6 | 0.6 | 0.6 | 0.6 | 0.1 | - | - | - |

Source:
- IPCC Guidelines 2006: Gasoil, kerosene, gasoline, fueloil, LPG and waste oil.
- Nielsen et al. (2010): Biomass and other fuel, both municipal waste.

#### $SO_2$, $NO_X$, NMVOC and CO

Emission factors for $SO_2$, $NO_X$, NMVOC and CO are listed in Table 16.3.9. The same emission factors have been applied in the period 1990-2018.

Table 16.3.9 $SO_2$, $NO_X$, NMVOC and CO emission factors 1990-2018 (g pr GJ).

| Fuel group | Fuel | CRF sector | | $NO_X$ | CO | NMVOC | $SO_2$ | Ref |
|---|---|---|---|---|---|---|---|---|
| Liquid | Gasoil | 1A1 | Energy Industries | 200 | 15 | 5 | 141 | 1 |
| | | 1A2 | Manufacturing Industries and Construction | 200 | 10 | 5 | 141 | 1 |
| | | 1A3a | Transport – Domestic aviation | 300 | 100 | 50 | 141 | 1 |
| | | 1A3b | Transport – Road transportation | 800 | 1 000 | 200 | 141 | 1 |
| | | 1A3d | Transport – Domestic navigation | 1 500 | 1 000 | 200 | 141 | 1 |
| | | 1A4a,b | Other sectors | 100 | 20 | 5 | 141 | 1 |
| | | 1A4c | Other sectors – AFF stationary | 100 | 20 | 5 | 141 | 1 |
| | | 1A4c | Other sectors – AFF mobile | 1 200 | 1 000 | 200 | 141 | 1 |
| | | 1A5b | Other – Military mobile | 1 500 | 1 000 | 200 | 141 | 1 |
| | Kerosene | 1A1 | Energy Industries | 200 | 15 | 5 | 23 | 1 |
| | | 1A2 | Manufacturing Industries and Construction | 200 | 10 | 5 | 23 | 1 |
| | | 1A3a | Transport – Domestic aviation | 300 | 100 | 50 | 23 | 1 |
| | | 1A3b | Transport – Road transportation | 600 | 8 000 | 1 500 | 23 | 1 |
| | | 1A3d | Transport – Domestic navigation | 1 500 | 1 000 | 200 | 23 | 1 |
| | | 1A4a,b | Other sectors | 100 | 20 | 5 | 23 | 1 |
| | | 1A4c | Other sectors – AFF stationary | 100 | 20 | 5 | 23 | 1 |
| | | 1A4c | Other sectors – AFF mobile | 1 200 | 1 000 | 200 | 23 | 1 |
| | | 1A5b | Other – Military mobile | 1 500 | 1 000 | 200 | 23 | 1 |
| | Gasoline | 1A1 | Energy Industries | 200 | 15 | 5 | 46 | 1 |
| | | 1A2 | Manufacturing Industries and Construction | 200 | 10 | 5 | 46 | 1 |
| | | 1A3a | Transport – Domestic aviation | 300 | 100 | 50 | 46 | 1 |
| | | 1A3b | Transport – Road transportation | 600 | 8 000 | 1 500 | 46 | 1 |
| | | 1A3d | Transport – Domestic navigation | 1 500 | 1 000 | 200 | 46 | 1 |
| | | 1A4a,b | Other sectors | 100 | 20 | 5 | 46 | 1 |
| | | 1A4c | Other sectors – AFF stationary | 100 | 20 | 5 | 46 | 1 |
| | | 1A4c | Other sectors – AFF mobile | 1 200 | 1 000 | 200 | 46 | 1 |
| | | 1A5b | Other – Military mobile | 1 500 | 1 000 | 200 | 46 | 1 |
| | Fueloil | 1A1 | Energy Industries | 200 | 15 | 5 | 492 | 1 |
| | | 1A2 | Manufacturing Industries and Construction | 200 | 10 | 5 | 492 | 1 |
| | | 1A3a | Transport – Domestic aviation | 300 | 100 | 50 | 492 | 1 |
| | | 1A3b | Transport – Road transportation | 600 | 8 000 | 1 500 | 492 | 1 |
| | | 1A3d | Transport – Domestic navigation | 1 500 | 1 000 | 200 | 492 | 1 |
| | | 1A4a,b | Other sectors | 100 | 20 | 5 | 492 | 1 |
| | | 1A4c | Other sectors – AFF stationary | 100 | 20 | 5 | 492 | 1 |
| | | 1A4c | Other sectors – AFF mobile | 1 200 | 1 000 | 200 | 492 | 1 |
| | | 1A5b | Other – Military mobile | 1 500 | 1 000 | 200 | 492 | 1 |
| | LPG | 1A1 | Energy Industries | 150 | 20 | 5 | 0.13 | 1 |
| | | 1A2 | Manufacturing Industries and Construction | 150 | 30 | 5 | 0.13 | 1 |
| | | 1A3a | Transport – Domestic aviation | - | - | - | - | 1 |
| | | 1A3b | Transport – Road transportation | 600 | 400 | 5 | 0.13 | 1 |
| | | 1A3d | Transport – Domestic navigation | - | - | - | - | 1 |
| | | 1A4a,b | Other sectors | 50 | 50 | 5 | 0.13 | 1 |
| | | 1A4c | Other sectors – AFF stationary | 50 | 50 | 5 | 0.13 | 1 |
| | | 1A4c | Other sectors – AFF mobile | 1 000 | 400 | 5 | 0.13 | 1 |
| | | 1A5b | Other – Military mobile | - | - | - | - | 1 |
| | Wasteoil | 1A1 | Energy Industries | 200 | 15 | 5 | 477 | 1 |
| Biomass | Municipal waste | 1A1 | Energy Industries | 134 | 7.4 | 0.98 | 138 | 2 |
| Other fuel | Municipal waste | 1A1 | Energy Industries | 134 | 7.4 | 0.98 | 138 | 2 |

Sources: 1) IPCC Guidelines 2006. 2) Nielsen et al., 2010.

### 16.3.4 Emissions

The greenhouse gas (GHG) emissions are listed in Table 16.3.10. The total emission of greenhouse gases from the energy sector accounts for 93.9 % of total Greenlandic GHG emission in 2016.

$CO_2$ emission from energy accounts for 99.3 % of the Greenlandic $CO_2$ emission (excluding net $CO_2$ emission from Land Use, Land Use Change and Forestry (LULUCF). The $CH_4$ emission from fuel combustion (Sectoral Approach) accounts for 8.8 % of the Greenlandic emission and the $N_2O$ emission from fuel combustion accounts for 24.4 % of the Greenlandic $N_2O$ emission, see Table 16.3.10.

Table 16.3.10 Greenhouse gas emission 2018.

| | | $CO_2$ | $CH_4$ | $N_2O$ |
|---|---|---|---|---|
| | | Gg $CO_2$ equivalent | | |
| 1A1 | Fuel consumption, Energy Industries | 97.7 | 0.2 | 0.5 |
| 1A2 | Fuel consumption, Manufacturing Industries and Construction | 30.3 | 0.0 | 0.1 |
| 1A3 | Fuel consumption, Transport | 114.3 | 0.2 | 1.3 |
| 1A4 | Fuel consumption, Other sectors | 302.1 | 0.8 | 0.7 |
| 1B | Fugitive emissions from fuel, Oil and natural gas | NO | NO | NO |
| Total emission from energy | | 544.3 | 1.3 | 2.6 |
| Greenlandic emission (excluding net emission from LULUCF) | | 548.0 | 14.1 | 9.7 |
| | | | % | |
| Emission share for energy | | 99.3 | 9.1 | 26.9 |

$CO_2$ is the most important GHG pollutant and accounts for 99.3 % of the GHG emission in $CO_2$ equivalents from energy in 2018, see Figure 16.3.4.

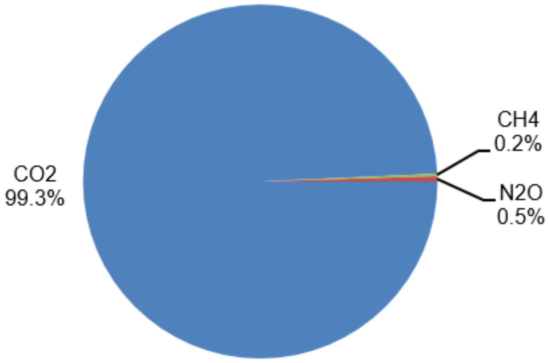



Figure 16.3.4 GHG emissions ($CO_2$ equivalent) from stationary combustion plants 2018.

Figure 16.3.5 depicts the time-series of GHG emission in $CO_2$ equivalents from the energy sector. As shown by the blue curve the development in total GHG emission follows the $CO_2$ emission development very closely. Emission of $CO_2$ and total GHG emission are respectively 12.4 % and 12.3 % lower in 2018 compared to 1990.

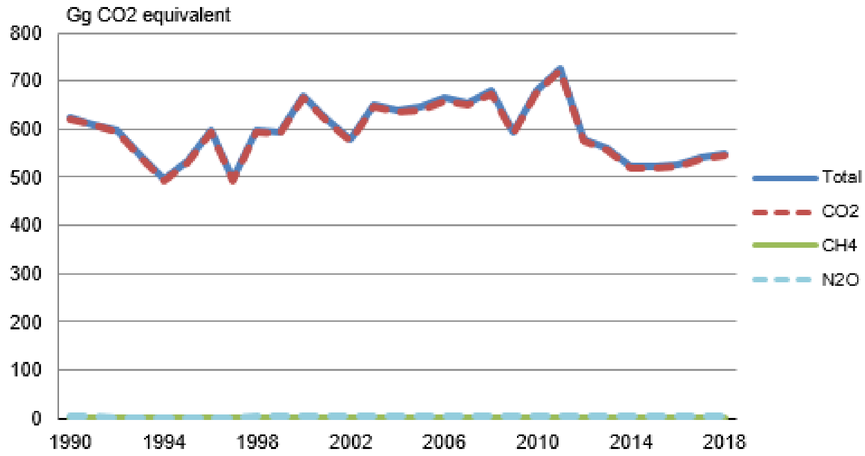


Figure 16.3.5 GHG emission time-series for the Energy Sector.

From 1990 to 1994 total GHG emission was reduced by 21 %. This was primarily due to the introduction of the first hydropower plant in 1993 but also to the introduction of burning waste to produce heat for district heating network in 1989. Dependence on gasoil conversion decreased immediately. Nevertheless, from 1995 an onwards consumption of gasoil once again increased due to the general economic development.

In 2001-2002 total GHG emission decreased due to a minor recession in the economy. However since 1994 GHG emissions have increased in general with some fluctuations from year to year. The fluctuations are largely a result of outdoor temperature variations from year to year i.e. in 2008 the winter was relatively colder than in 2007. As a result fuel consumption increased in 2008 increasing GHG emission from fuel combustion. In 2009 GHG emission decreased due to a significantly substitution in Energy Industries from fuel consumption to hydro power production together with a relatively warmer winter. However, in 2010 and 2011 GHG emission increased by 14.5 % and 6.9 % due to the initiation of oil exploration. In more recent years, 2012-2014 GHG emission has decreased by 20.3 %, 3.0 % and 7.3 % respectively due to the standstill in the oil exploration activities, a drop in fuel combustion in Energy Industries due to the opening of Greenlands fifth hydro power plant, and the overall recession in the Greenlandic economy. In 2015 GHG emission increased once again by 0.6 percent due to an increase in fuel combustion caused by a recovering Greenlandic economy and a very cold winter. Most recently, Greenland was confronted with a warm winter in 2016. Higher winter temperatures reduce the demand for energy. In 2016 the winter was so much warmer than 2015 that the reduced demand for energy on that account seemed too decimate the opposing effects of an economy in continuing recovery.  In 2017 GHG emission increased. One of the reason of the increase of the GHG emission is the colder winter and the challange with the hydropowerplant, which supplies Sisimiut. In 2018 GHG emission increased. The primary reason of the increase of the GHG emission in 2018 was an increased CH4 emission in the transport sector.

### $CO_2$

$CO_2$ emission from fuel combustion accounts for 99.3 % of the total Greenlandic $CO_2$ emission. Table 16.3.11 lists the $CO_2$ emission inventory for the energy sector in 2018 as well as the relative percentage for each category under the sectoral approach.

The table reveals that Agriculture, Forestry and Fisheries (AFF) accounts for 26.3 % of the $CO_2$ emission. Other large $CO_2$ emission sources are Transport with a share of 21.0 % and Residental with 18.7 % as well as Energy Industries with 17.9 %. These are sectors, which also account for a considerable share of fuel consumption.

Table 16.3.11 Emission of $CO_2$ from fuel combustion 2017.

| | | 2017 | |
|---|---|---|---|
| | | Gg | % |
| 1A1 | Energy Industries | 97.7 | 17.9 |
| 1A2 | Manufacturing Industries | 30.3 | 5.6 |
| 1A3 | Transport | 114.3 | 21.0 |
| 1A4a | Commercial / Institutional | 52.3 | 9.6 |
| 1A4b | Residential | 101.6 | 18.7 |
| 1A4c | Agriculture / Forestry / Fisheries | 143.1 | 26.6 |
| 1A5 | Other | 5.1 | 0.9 |
| 1B | Fugitive emissions from fuel | NO | NO |
| 1C | $CO_2$ Transport and Storage | NO | NO |
| Total | | 544.3 | 100.0 |

$CO_2$ emission from combustion of biomass fuels is not included in the total $CO_2$ emission data, since biomass fuels are considered $CO_2$ neutral. The $CO_2$ emission from biomass combustion is reported as a memo item in the Climate Convention reporting. In 2018, the $CO_2$ emission from biomass combustion was 15.4 Gg.

Time-series for $CO_2$ emissions are provided in Figure 16.3.6. Since 1990 emission of $CO_2$ has decreased by 12.4 %. Fluctuations in $CO_2$ emission from AFF primarily regard fluctuations in fishing activities from year to year. Fluctuations in $CO_2$ emission from residential plants are largely a result of outdoor temperature variations from year to year. This also causes fluctuations in $CO_2$ emission from Energy Industries which cover electricity and heat production. However, the significant increase in emission from Energy Industries in 2010 continuing in 2011 is caused by the initiation of oil exploration in 2010, which is reported in the subsector "Manufacture of Solid Fuels and Other Energy Industries". Since 2011 there has been no drilling for oil in Greenland.

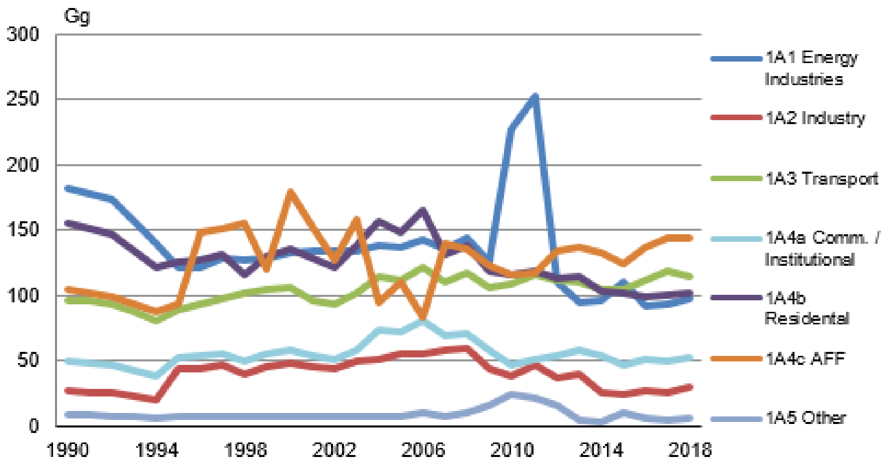



Figure 16.3.6 $CO_2$ Emission time-series for Fuel Combustion (Sectoral Approach).

Detailed trend discussion on CRF category level is available in Section 16.2.

**$CH_4$**

$CH_4$ emission from fuel combustion accounts for 9.1 % of the Greenlandic $CH_4$ emission. Table 16.3.12 lists the $CH_4$ emission inventory for energy in 2018. The table reveals that residental plants accounted for 27.2 % of the $CH_4$ emission from energy in 2018. Energy Industries accounted for 19.3 %, and Agriculture, Forestry and Fisheries for 19.2 %.

Table 16.3.12 Emission of $CH_4$ from fuel combustion 2018.

| | | 2018 | |
|---|---|---|---|
| | | Mg | % |
| 1A1 | Energy Industries | 9.9 | 19.3 |
| 1A2 | Industry | 0.8 | 1.6 |
| 1A3 | Transport | 9.3 | 18.1 |
| 1A4a | Commercial / Institutional | 7.2 | 14.0 |
| 1A4b | Residential | 13.9 | 27.2 |
| 1A4c | Agriculture / Forestry / Fisheries | 9.8 | 19.2 |
| 1A5 | Other | 0.4 | 0. |
| 1B | Fugitive emissions from fuel | NO | NO |
| Total | | 51.3 | 100.0 |

Emission of $CH_4$ from fuel combustion has increased by 3.1 % since 1990. Time-series for $CH_4$ emissions are provided in Figure 16.3.7. Fluctuations in $CH_4$ emission from AFF primarily regard fluctuations in fishing activities from year to year. Fluctuations in $CH_4$ emission from residential plants are largely a result of outdoor temperature variations from year to year. This also causes fluctuations in $CH_4$ emission from Energy Industries, which cover electricity and heat production and manufacture of solid fuels and other Energy Industries.

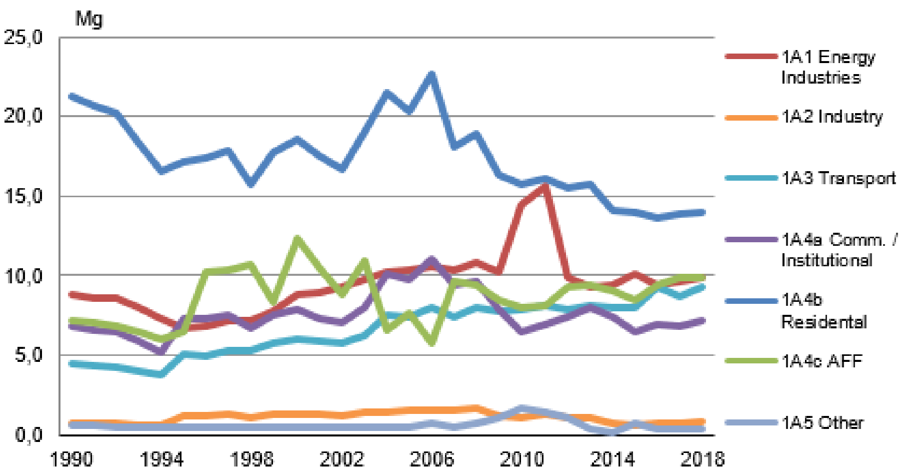



Figure 16.3.7 CH4 emission time-series for energy.

Detailed trend discussion on CRF category level is available in Section 16.2.

**$N_2O$**

Emission of $N_2O$ from fuel combustion accounts for 26.9 % of the Greenlandic $N_2O$ emission. Table 16.3.13 lists the $N_2O$ emission inventory for energy in 2018. The table reveals that Transportations accounted for 50.7 % of the $N_2O$ emission from the energy sector while Energy Industries accounted for 18.0 % of the emissions in 2018.

Table 16.3.13   Emission of $N_2O$ from fuel combustion 2018.

| | | 2017 | |
|---|---|---|---|
| | | Mg | % |
| 1A1 | Energy Industries | 1.6 | 18.0 |
| 1A2 | Industry | 0.2 | 2.9 |
| 1A3 | Transport | 4.4 | 50.7 |
| 1A4a | Commercial / Institutional | 0.4 | 4.9 |
| 1A4b | Residential | 0.8 | 9.6 |
| 1A4c | Agriculture / Forestry / Fisheries | 1.2 | 13.5 |
| 1A5 | Other | 0.0 | 0.5 |
| 1B | Fugitive emissions from fuel | NO | NO |
| Total | | 8.7 | 100.0 |

Figure 16.3.8 shows the time-series for the $N_2O$ emission from energy. $N_2O$ emission has increased by 11.0 % from 1990 to 2018 due to an increase in the use of recovered energy from waste simultaneously to a decrease in the consumption of liquid fuels.

Once again, the 2010 and 2011 increases in $N_2O$ emission from Energy Industries are predominantly caused by the startup of oil explorative activities, while the decrease of $N_2O$ emission since 2011 is due to a continuing standstill in oil explorations.

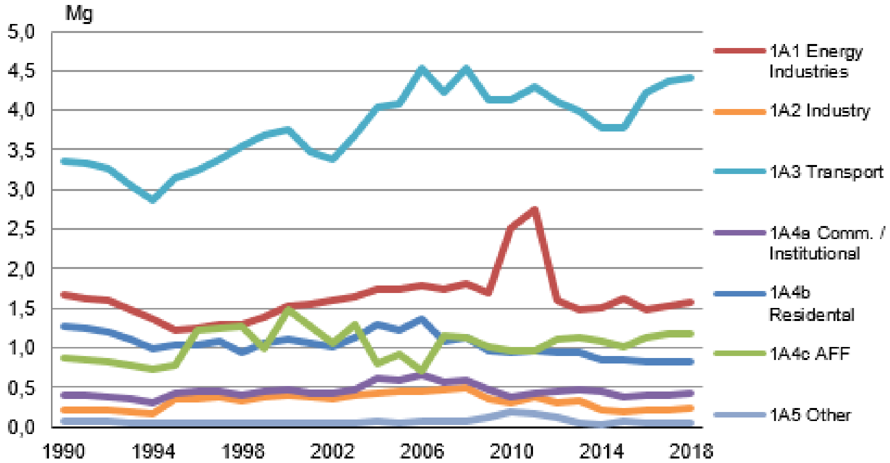


Figure 16.3.8   $N_2O$ emission time-series for energy.

Detailed trend discussion on CRF category level is available in Section 16.2.

**$SO_2$, $NO_X$, NMVOC and CO**

The emissions of $SO_2$, $NO_X$, NMVOC and CO from energy in 2018 are presented in Table 16.3.14. $SO_2$ from energy accounts for 99.4 % of the Greenlandic $SO_2$ emission. $NO_X$, CO and NMVOC account for 99.0 %, 87.9 % and 83.6 % respectively, of the Greenlandic emissions for these substances.

Table 16.3.14 Emission of $SO_2$, $NO_X$, NMVOC and CO from fuel combustion 2018.

| | $NO_X$ | CO | NMVOC | $SO_2$ |
|---|---|---|---|---|
| | Gg | Gg | Gg | Gg |
| 1A1 Fuel consumption, Energy Industries | 0.3 | 0.0 | 0.0 | 0.2 |
| 1A2 Fuel consumption, Manuf. Industries and Constr. | 0.1 | 0.0 | 0.0 | 0.1 |
| 1A3 Fuel consumption, Transport | 1.2 | 2.6 | 0.5 | 0.1 |
| 1A4 Fuel consumption, Other sectors | 2.7 | 2.1 | 0.4 | 0.6 |
| 1B Fugitive emissions from fuel | NO | NO | NO | NO |
| Total emission from fuel consumption and fugitive emissions from fuel | 4.2 | 4.7 | 0.9 | 1.0 |
| Greenlandic emission | 4.3 | 5.3 | 1.1 | 1.0 |
| | | % | | |
| Emission share for fuel consumption | 99.0 | 87.9 | 83.6 | 99.4 |

### 16.3.5 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC Guidelines (IPCC, 2006). The uncertainty has been estimated for all sources included in the reporting for the energy sector. The uncertainties for the activity data and emission factors are shown in Table 16.3.15.

Table 16.3.15 Uncertainties for activity data and emission factors for the energy sector.

| Subsector | Pollutant | Activity data uncertainty | Emission factor uncertainty |
|---|---|---|---|
| 1A Liquid fuels | $CO_2$ | 3 | 2 |
| 1A Municipal waste | $CO_2$ | 3 | 25 |
| 1B2 Oil exploration | $CO_2$ | 3 | 1 000 |
| 1A Liquid fuels | $CH_4$ | 3 | 100 |
| 1A Municipal waste | $CH_4$ | 3 | 100 |
| 1A Biomass | $CH_4$ | 3 | 100 |
| 1B2 Oil exploration | $CH_4$ | 3 | 1 000 |
| 1A Liquid fuels | $N_2O$ | 3 | 500 |
| 1A Municipal waste | $N_2O$ | 3 | 500 |
| 1A Biomass | $N_2O$ | 3 | 200 |
| 1B2 Oil exploration | $N_2O$ | 3 | 1 000 |

With regard to uncertainty, the $CO_2$ emission factors are considered the most certain. Due to a technical analysis a country specific emission factor is available on the Greenlandic gasoil; the dominating liquid fuel. Consequently, the $CO_2$ emission factor uncertainty has been revised from 5 % to 2 % for liquid fuels. This revision was done in the 2014 submission.

To account for the more inhomogeneous nature of municipal waste the emission factor uncertainty has been set to 25 %. For $CH_4$ the emission factor uncertainty has been set to 100 % in accordance with the IPCC Guidelines (IPCC, 2006). For $N_2O$ the emission factor uncertainties have been estimated between 200 % and 500 %. This is based on a first estimate and can be improved upon in the future.

Oil exploration has occurred in 2010 and 2011, but not since. However, fugitive emissions have been set to NA due to the fact that it has been impossible to obtain any information on the amount of oil and gas picked up during drillings in 2010 and 2011.

The resulting uncertainties for the individual greenhouse gases and the total uncertainty on the greenhouse gas emission are shown in Table 16.3.16.

Table 16.3.16 Uncertainties for the emission estimates.

| | Uncertainty % | Trend 1990-2018 % | Trend uncertainty % |
|---|---|---|---|
| GHG | ± 4.2 | -12.3 | ± 3.7 |
| $CO_2$ | ± 3.6 | -12.4 | ± 3.7 |
| $CH_4$ | ± 88 | -3.1 | ± 12.4 |
| $N_2O$ | ± 453 | 11.0 | ± 44.3 |

### 16.3.6 Source specific QA/QC

The elaboration of a formal QA/QC plan is to be completed.

Statistics on fuel consumption is reported by Ministry of Industry, Energy, Research and Labour in form of a spreadsheet. Annual consumption of gasoil, kerosene, gasoline and LPG are divided into business categories and private households. To ensure consistency data are compared with those from previous years and large discrepancies are checked.

All external data used for the emission inventory submission are archived in spreadsheets. Data are archived annually in order to ensure that the basic data for a given report are always available in their original form.

Safely stored and quality checked activity data are then processed by using a methodological approach consistent with international guidelines.

Calculated emission factors are compared with guideline emission factors to ensure that they are reasonable. The calculations follow the principle in international guidelines.

During data processing, it is checked that calculations are being carried out correctly. However, a documentation plan for this is to be elaborated.

Time-series for activity data, emission factors and calculated emissions are used to identify possible errors in the calculation procedure. In fact, during the calculation, numerous controls take place to ensure correctness. Sums are checked of the various stages in the calculation procedure. Implied emission factors are compared to emission factors.

Every single time-series imported to the CRF Reporter is checked for fuel rate, units for fuel rate, emission factor and plant-specific emissions.

#### Reference approach

In addition to the sector-specific $CO_2$ emission inventories (the Greenlandic approach), the $CO_2$ emission is also estimated using the reference approach described in the IPCC Reference manual (IPCC, 2006). The reference approach is based on data for fuel production, import, export and stock change. The $CO_2$ emission inventory based on the reference approach is reported to the Climate Convention and used for verification of the official data in the Greenlandic approach.

Data on import, export and stock change used in the reference approach originate from the annual "basic data" table prepared by Statistics Greenland 2016, and since 2017 the annual "basic data" table prepared by the Ministry of Industy, Energy, Research and Labour. The fraction of carbon oxidised has been assumed to be 1.00. The carbon emission factors are default factors originating from the IPCC Reference Manual (IPCC, 2006). The country-specific emission factors are not used in the reference approach, the approach being for the purposes of verification.

The Climate Convention reporting tables include a comparison of the Greenlandic approach and the reference approach estimates. To make results comparable, the $CO_2$ emission from incineration of the plastic content of municipal waste is added in the reference approach while the fuel consumption is subtracted.

In 2018, fuel consumption rates in the two approaches differ by 0 % and the $CO_2$ emission differs by 0.1 %. In the period 1990-2018 the $CO_2$ emission differs by 0.1 % or less at all times. The differences in energy consumption are 0 % for all years. According to IPCC Good Practice Guidance (IPCC, 2000) the difference should be within 2 %. A comparison of the Greenlandic approach and the reference approach is illustrated in Figure 16.3.9.

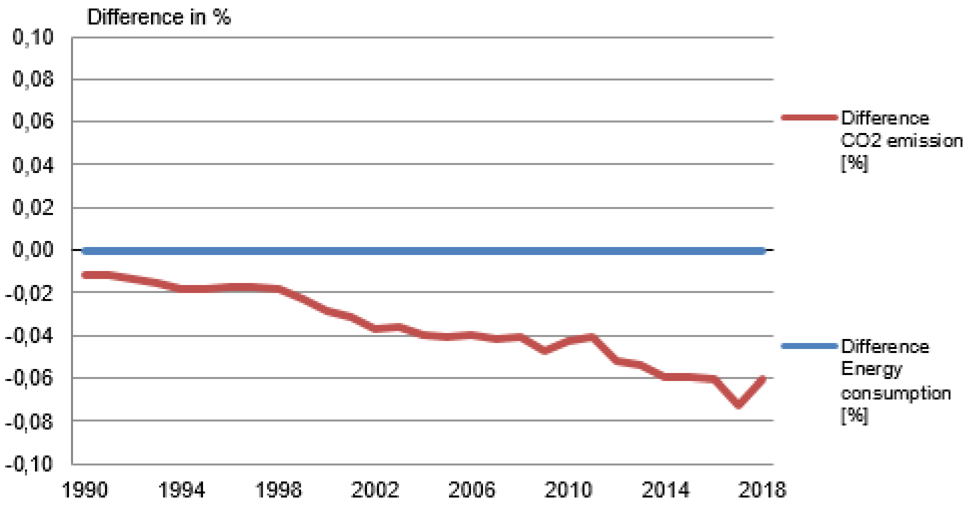



Figure 16.3.9 Comparison of the reference approach and the national approach.

### 16.3.7 Source specific recalculations and improvements

In this 2020 submission there has been no revisions in the energy sector.

Table 16.3.17 shows recalculations in the energy sector compared to the 2019 submission. No changes occur.

Table 16.3.17 Changes in GHG emission in the energy sector compared to the 2019 submission.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Previous inventory, Gg $CO_2$ eqv. | 625.2 | 610.4 | 596.2 | 545.9 | 495.7 | 534.3 | 597.1 | 617.8 | 596.5 | 594.3 |
| Recalculated, Gg $CO_2$ eqv. | 625.2 | 610.4 | 596.2 | 545.9 | 495.7 | 534.3 | 597.1 | 617.8 | 596.5 | 594.3 |
| Change in Gg $CO_2$ eqv. | - | - | - | - | - | - | - | - | - | - |
| Change in pct. | - | - | - | - | - | - | - | - | - | - |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Previous inventory, Gg $CO_2$ eqv. | 668.0 | 618.2 | 579.8 | 650.2 | 640.5 | 644.6 | 663.1 | 653.9 | 678.7 | 593.3 |
| Recalculated, Gg $CO_2$ eqv. | 668.0 | 618.2 | 579.8 | 650.2 | 640.5 | 644.6 | 663.1 | 653.9 | 678.7 | 593.3 |
| Change in Gg $CO_2$ eqv. | - | - | - | - | - | - | - | - | - | - |
| Change in pct. | - | - | - | - | - | - | - | - | - | - |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| Previous inventory, Gg $CO_2$ eqv. | 679.6 | 726.3 | 578.9 | 561.6 | 520.9 | 524.0 | 525.1 | 542.3 | - | |
| Recalculated, Gg $CO_2$ eqv. | 679.6 | 726.3 | 578.9 | 561.6 | 520.9 | 524.0 | 525.1 | 542.3 | 548.2 | |
| Change in Gg $CO_2$ eqv. | - | - | - | - | 0.0 | 0.0 | - | - | - | |
| Change in pct. | - | - | - | - | 0.0 | 0.0 | - | - | - | |

### 16.3.8 Source specific planned improvements

Some planned improvements to the emission inventories are discussed below. Statistic Greenland had 5 planned improvements in the 2018 submission. The Ministry of Industry, Energy, Research and Labour plans to achieve improvement for the five goals, Statistic Greenland had planned to improve.

#### 1) Memo Items, International Aviation Bunkers

Previously, emissions from international aviation bunkers have been considered to be of neglible importance in terms of Greenland. For that matter the annual amount of jet fuel loaded into foreign aircrafts has been included as part of the IPCC category 1A3a Domestic Aviation. However, some misunderstanding has taken place and this assumption seems to be incorrect! New data has emerged regarding the distinction between domestic and international flights, and it now seems possible that combustion of jet fuel in international bound aircrafts taking off from Greenland can be determined and reported as international aviation bunkers as from this 2021 submission. However, in this 2020 submission jet fuel loaded into foreign aircrafts is still included as part of the IPCC category 1A3a Domestic Aviation.

#### 2) Improved documentation for emission factors

The reporting of, and references for, the applied emission factors have been improved in the current year and will be further developed in future inventories. This will happen on the advice of the Danish National Environmental Research Institute.

#### 3) Improvements in plant specific fuel combustion

Plant specific fuel combustion will be further improved according to the developments made by Statistics Greenland in the energy statistics.

#### 4) Uncertainty estimates

Uncertainty estimates are largely based on the default uncertainty levels for activity rates and emission factors. More country-specific uncertainty estimates will be incorporated in future inventories.

**5) Country specific emission factors**

Statistics Greenland has acquired a technical analysis on the gasoil that is imported to and used in Greenland. The technical analysis conducted by the Danish Techinal Institute has provided a country specific emission factor on the Greenlandic gasoil. Due to this technical analysis a new country specific emission factor on gas oil was implemented as from the 2014 submission. The arctic grade gas oil stands for 3.3 % of all liquid fuels in 2018.

The plan is to obtain additional country specific emission factors on other liquid fuels, but only if the UNFCCC recommend it as in the case of the Greenlandic gasoil.

### 16.3.9 References

Astrup, T., Larsen, A. W., Fuglsang, K. & Pedersen, N. H., 2012: PSO-0213, Biogenic Carbon in Danish Combustable Waste. DTU 2012. In press.

Consulting Company Carl Bro, 1996: Survey on waste from private households and companies in Greenland.

Consulting Company Carl Bro, 2001: Survey on waste from private households and companies in Greenland.

IPCC, 1997: Revised 1996 IPCC Guidelines for National Greenhouse Gas inventories. Available at:
http://www.ipcc-nggip.iges.or.jp/public/gl/invs6.html (15-04-2007).

IPCC, 2000: Penman, J., Kruger, D., Galbally, I., Hiraishi, T., Nyenzi, B., Emmanuel, S., Buendia, L., Hoppaus, R., Martinsen, T., Meijer, J., Miwa, K. & Tanabe, K. (Eds). Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Published: IPCC/OECD/-IEA/IGES, Hayama, Japan. Available at:
http://www.ipcc-nggip.iges.or.jp/public/gp/english/ (15-04-2007).

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. & Tanabe K. (eds). Published: IGES, Japan. Available at:
mhttp://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
(21-02-2014).

EMEP/CORINAIR, 2007: EMEP/CORINAIR Atmospheric Emission Inventory Guidebook – 2007, prepared by the UNECE/EMEP Task Force on Emissions Inventories and Projections. Technical Report No 16/2007. Available at: http://www.eea.europa.eu/publications/EMEPCORINAIR5
(21-02-2014).

European Environment Agency (EEA), 2013: EMEP/EEA air pollutant emission inventory guidebook 2013, Technical Report No 12/2013. Available at:
http://www.eea.europa.eu/publications/emep-eea-guidebook-2013
(13-08-29).

KEMIN, 2008: Ministry of Climate and Energy. Law on $CO_2$ quotas, nr. 348 of 09/05/2008. (Danish legislation). Available (in Danish) at:
https://www.retsinformation.dk/Forms/R0710.aspx?id=117147
(2009-03-01).

Greenland Government, Ministry of Environment and Nature: Data on municipal waste incineration with energy-recovery.

Nielsen M., Nielsen, O.-K. & Thomsen, M. 2010: Emissions from decentralised CHP plants 2007 - Energinet.dk Environmental project no. 07/1882. Project report 5 – Emission factors and emission inventory for decentralised CHP production. National Environmental Research Institute, Aarhus University. 113 pp. – NERI Technical report No. 786. Available at: http://www.dmu.dk/Pub/FR786.pdf (2011-02-28).

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Nielsen, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Thomsen, M., Hjelgaard, K., Fauser, P., Bruun, H.G., Johannsen, V.K., Nord-Larsen, T., Vesterdal, L., Callesen, I., Caspersen, O.H., Rasmussen, E., Petersen, S.B., Baunbæk, L. & Hansen, M.G. 2017. Denmark's National Inventory Report 2017. Emission Inventories 1990-2015 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. 890 pp. – Scientific Report from DCE – Danish Center for Environment and Energy no. 231. Available at: http://dce2.au.dk/pub/SR231.pdf

Pulles, T. & Aardenne, J.v. 2004: Good Practice for CLRTAP Emission Inventories, 24. June 2004. Available at: http://www.eea.europa.eu/publications/EMEPCORINAIR4/BGPG.pdf (2009-02-27).

Statistics Greenland: Energy Consumption in Greenland 2016 published in Danish. Available at: http://www.stat.gl/publ/da/EN/201703/pdf/Grønlands energiforbrug 2016.pdf as "Grønlands energiforbrug 2016" in Danish only (14-12-2017).

## 16.4 Industrial Processes and Product Use (CRF sector 2)

### 16.4.1 Overview of sector

In this chapter the emissions of greenhouse gases from industrial processes and product use, not related to generation of energy, are presented.

The emission of greenhouse gases from industrial processes and product use includes $CO_2$, HFCs and $SF_6$. The emissions are reported in CRF Tables 2(I), 2(I).A, 2(II) and 2(II).B. Furthermore, the emission of non-methane volatile organic compounds (NMVOC) and CO from industrial processes related to asphalt roofing, road paving with asphalt and production of food and drink are given in CRF Table 2(I). This section also includes the emissions of $CO_2$ and NMVOC from use of solvents in industrial processes and households that are related to the former source categories Paint application, degreasing and dry cleaning, chemical products, manufacture and processing and others. Emission of $CO_2$ and NMVOC from solvent use are reported in CRF Tables 2(I) and 2(I).A.

Solvents are chemical compounds that are used on a global scale in industrial processes and as constituents in final products to dissolve e.g. paint, cosmetics, adhesives, ink, rubber, plastic, pesticides, aerosols or are used for cleaning purposes, i.e. degreasing. NMVOCs are main components in solvents - and solvent use in industries and households is typically the dominant source of anthropogenic NMVOC emissions. In industrial processes where solvents are produced or used NMVOC emissions to air and as liquid can be recaptured and either used or destroyed. Solvent containing products are used indoor and outdoor and the majority of solvent sooner or later evaporate. A small fraction of the solvents ends up in waste or as emissions to water and may finally also contribute to air pollution by evaporation from these compartments.

In this section the methodology for the Greenland NMVOC emission inventory for solvent use is presented and the results for the period 1990-2018 are summarised. The method is based on the detailed approach described in EMEP/CORINAIR (2013) and emissions are calculated for the CRF sectors mentioned above.

An overview of sources identified is presented in Table 16.4.1 with an indication of the contribution to the industrial part of the emission of greenhouse gases in 2018. Emissions are extracted from the CRF tables.

Table 16.4.1 Overview of greenhouse gas sources 2018.

| Process | IPCC Code | Substance | Emission tonnes $CO_2$ eqv. | % |
|---|---|---|---|---|
| Mineral Industry | | | | |
| Limestone and Dolomite Use | 2A4 | $CO_2$ | 39.91 | 0.4 |
| Non-Energy Products of Fuels and Solvent use | | | | |
| Paraffin Wax Use | 2D2 | $CO_2$ | 87.52 | 0.9 |
| Solvent Use | 2D3 | $CO_2$ | 393.54 | 4.2 |
| Road Paving with Asphalt | 2D3 | $CO_2$ | 0.10 | 0.0 |
| Asphalt Roofing | 2D3 | $CO_2$ | 0.05 | 0.0 |
| Product uses as substitutes for ODS | | | | |
| Refrigeration and Air Conditioning Equipment | 2F1 | HFCs | 8.861,06 | 94.4 |
| Other product manufacture and use | | | | |
| Electrical Equipment | 2G | $SF_6$ | 2.60 | 0.0 |
| Total emission | | | 9 384.79 | 100.0 |

The subsector *Product uses as substitutes for ODS* (2F) constitutes 94.4 % of the industrial emission of greenhouse gases in 2018. This reflects the emission of HFCs from refrigeration and air conditioning equipment. The subsector *Non-Energy Products of Fuels and Solvent use* (2D) constitutes 5.1 % of the industrial emission of greenhouse gases. In this subsector we find emissions from paraffin wax use and solvents as well as road paving with asphalt and asphalt roofing. There has been an increased import of limestone and dolomite in 2018. Limestone is used e.g. in cement and the production of concrete. Concrete is one of the common building materials in Greenland. The total emission of greenhouse gases (excl. LULUCF) in Greenland is estimated to 580.70 Gg $CO_2$ equivalents in 2018, of which industrial processes contribute with 9,385 Gg $CO_2$ equivalents (1.6 %). The emission of greenhouse gases from industrial processes from 1990-2018 are presented in Figure 16.4.1.

Greenland has no chemical industry, metal production or production of halocarbons or $SF_6$. Greenland has no consumption of PFCs.

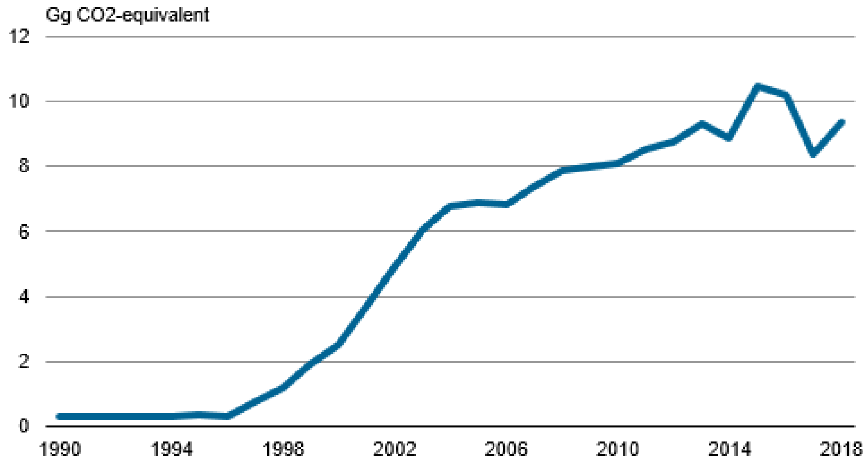


Figure 16.4.1 Emission of greenhouse gases from industrial processes 1990-2018.

The key category in the industrial sector *Consumption of Halocarbons* constitutes 1.5 % of the total emission of greenhouse gases. The trends in greenhouse gases from the industrial sector andsubsectors are presented in Table 16.4.2. The emissions are extracted from the CRF tables.

Table 16.4.2 Emission of GHG from industrial processes and product use in different subsectors from 1990-2018.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ (tonnes $CO_2$) | | | | | | | | | | |
| A. Mineral Industry | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| D. Non-energy products from fuels and solvent use | 306 | 301 | 300 | 310 | 315 | 320 | 242 | 314 | 343 | 392 |
| $CH_4$ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| $N_2O$ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| HFCs (tonnes $CO_2$ eqv.) | | | | | | | | | | |
| F. Product uses as ODS substitutes | NE | NE | NE | NE | 18 | 27 | 88 | 455 | 833 | 1 497 |
| PFCs (tonnes $CO_2$ eqv.) | | | | | | | | | | |
| F. Product uses as ODS substitutes | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| $SF_6$ (tonnes $CO_2$ eqv.) | | | | | | | | | | |
| G. Other product manufacture and use | NE | NE | NE | NE | NE | 34.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| $CO_2$ (tonnes $CO_2$) | | | | | | | | | | |
| A. Mineral Industry | 3.96 | 2.77 | 1.32 | 2.64 | 1.80 | 0.11 | 0.03 | 1.51 | 2.96 | 0.03 |
| D. Non-energy products from fuels and solvent use | 301 | 283 | 320 | 475 | 421 | 489 | 354 | 354 | 355 | 453 |
| $CH_4$ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| $N_2O$ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| HFCs (tonnes $CO_2$ eqv.) | | | | | | | | | | |
| F. Product uses as ODS substitutes | 2 190 | 3 473 | 4 569 | 5 566 | 6 352 | 6 407 | 6 448 | 6 999 | 7 499 | 7 546 |
| PFCs (tonnes $CO_2$ eqv.) | | | | | | | | | | |
| F. Product uses as ODS substitutes | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| $SF_6$ (tonnes $CO_2$ eqv.) | | | | | | | | | | |
| G. Other product manufacture and use | 3.1 | 3.1 | 3.1 | 3.0 | 3.0 | 3.0 | 2.9 | 2.9 | 2.9 | 2.9 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| $CO_2$ (tonnes $CO_2$) | | | | | | | | | | |
| A. Mineral Industry | 4.94 | 0.00 | 19.57 | 0.00 | 6.64 | 0.01 | 0.06 | 3.18 | 39.91 | |
| D. Non-energy products from fuels and solvent use | 329 | 334 | 352 | 316 | 330 | 316 | 324 | 299 | 481 | |
| $CH_4$ | NO | NO | NO | NO | NO | NO | NO | NO | NO | |
| $N_2O$ | NO | NO | NO | NO | NO | NO | NO | NO | NO | |
| HFCs (tonnes $CO_2$ eqv.) | | | | | | | | | | |
| F. Product uses as ODS substitutes | 7 770 | 8 180 | 8 373 | 8 993 | 8 525 | 10 176 | 9 882 | 8 047 | 8.861 | |
| PFCs (tonnes $CO_2$ eqv.) | | | | | | | | | | |
| F. Product uses as ODS substitutes | NO | NO | NO | NO | NO | NO | NO | NO | NO | |
| $SF_6$ (tonnes $CO_2$ eqv.) | | | | | | | | | | |
| G. Other product manufacture and use | 2.8 | 2.8 | 2.8 | 2.7 | 2.7 | 2.7 | 2.7 | 2.6 | 2.6 | |

Greenland has no production of halocarbons or $SF_6$. Data on consumption of F-gases (HFCs and $SF_6$) are obtained from the Statistics Greenland (imports) and by an annual survey on consumption halocarbons and $SF_6$. Information on consumption of F-gases is available from 1995 onwards. Greenland has no consumption of PFCs.

One single plant in Greenland has reported use of $SF_6$ in 1995. The emission of $SF_6$ was 35.9 tonnes $CO_2$ equivalents in 1995. The annual emission from 1996 and onwards is assumed to be 0.5 % of the amount filled into the plant in 1995. This causes a relative high emission of $SF_6$ in 1995 and a much lower emission in the period 1996-2018.

In December 2015 Statistics Greenland aqquired the following information from Nukissiorfiit; the main supplier of electricity and heat in Greenland: Acording to Nukissiorfiit the switchgears in all netstations were changed from regular switches without gas to gaseous switches containing $SF_6$ in 2002-2004. The new gaseous switchgears from Spanish Ormazabal are closed and sealed switches that do not need any filling of gas. For that reason the switchgears are considered to be completely tight with no leaks of gas. When Nukissiorfiit replace the gaseous Ormazabal switches the switchgears are returned directly to Ormazabal in Spain where the $SF_6$ within the switch are recycled.

Due to this information the Greenlandic switchgears in plants and netstations containing $SF_6$ are considered to be completely free from leaks from 2005 an onwards. This consideration is supported by the fact that Nukissiorfiit has not been buying any $SF_6$ for stockpiling or filling for many years and today has no record of any $SF_6$ in stock at all.

However, for the sake of good practice it has been decided to keep the $SF_6$-plant from 1995 within this material for 25 full years, which in 1995 was considered to be the lifetime of that specific switchgear. Due to that decision the plant and the estimated emission of $SF_6$ from that plant will be left in the material until 2020. From 2021 the plant will be deleted from the material as well as all emission from it. We hope that the UNFCCC team of reviewers will approve to this decision.

Energy consumption associated with industrial processes and emissions thereof are included in the Energy sector of the inventory.

### 16.4.2 Source category description

#### Mineral Industry

The subsector *Mineral Industry* (2A) covers the following processes:

- 2A4d Limestone and dolomite use.

Emission from limestone and dolomite use are presented in the CRF sector 2A.4d under 2A.4 Other Process Uses of Carbonates. The time-series for the emission of $CO_2$ from Mineral industry (2A) is presented in Table 16.4.3. The emissions are extracted from the CRF tables and the values are rounded.

Table 16.4.3 Emission of $CO_2$ (tonnes) from Mineral Industry (2A).

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| 4d Limestone and dolomite use | - | - | - | - | - | - | - | - | - | - |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| 4d Limestone and dolomite use | 3.96 | 2.77 | 1.32 | 2.64 | 1.80 | 0.11 | 0.03 | 1.51 | 2.96 | 0.03 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| 4d Limestone and dolomite use | 4.94 | 0.00 | 19.57 | 0.00 | 6.64 | 0.01 | 0.06 | 3.18 | 39.91 | |

The use of limestone and dolomite started in 2000. Hence there is no emission from limestone and dolomite use before 2000. The use of limestone and dolomite has been estimated from the annual import of these products to Greenland. Imports seem to vary a great deal from year to year, which causes the estimated use to vary as well.

The $CO_2$ emission from subsectors under Mineral Industry fluctuates a great deal from year to year, as seen in Figure 16.4.2. This is caused by fluctuations in activities from year to year. However fluctuations in $CO_2$ are primarily caused by the fact that activity data for Mineral Industry are based on import data, which do not allow distinction of imported amount into consumption and stockpiling.

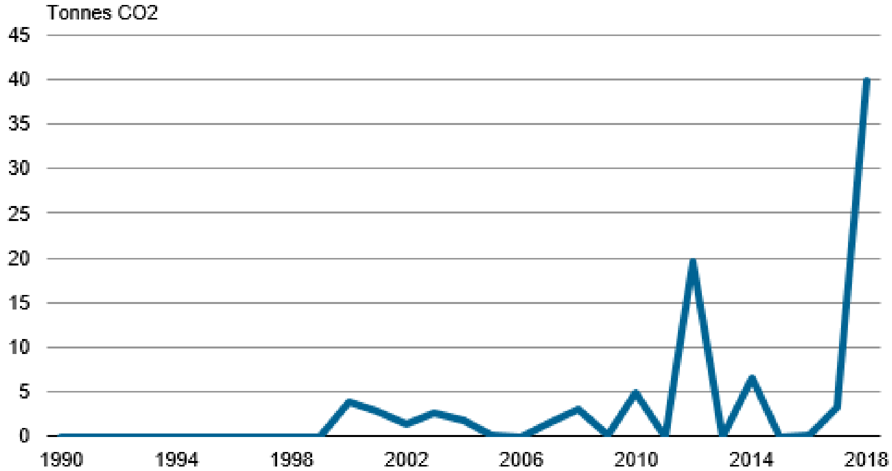



Figure 16.4.2 Emission of $CO_2$ from Mineral Industry.

**Non-energy Products from Fuels and Solvent Use**

The subsector *Non-energy Products from Fuels and Solvent Use* (2D) covers the following processes:

- 2D2 Paraffin Wax Use.
- 2D3a Solvent Use.
- 2D3b Road paving with asphalt.
- 2D3c Roof covering with asphalt materials.

Emissions from paraffin wax use are presented in the CRF 2D.2 subsector Paraffin Wax Use, while emissions from solvent use, road paving with asphalt and roof covering with asphalt materials are specified separately in the CRF 2D.3 subsector Other. The time-series for the emission of $CO_2$ from Non-energy Products from Fuels and Solvent Use (2D) are presented in Table 16.4.4. The emissions are extracted from the CRF tables and the values are rounded.

Table 16.4.4 Emission of $CO_2$ (tonnes) from Non-energy Products from Fuels and Solvent Use (2D).

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2. Paraffin Wax Use | 42.6 | 40.8 | 42.4 | 47.4 | 39.3 | 43.1 | 32.1 | 50.0 | 72.3 | 81.2 |
| 3a. Solvent Use | 263.4 | 259.7 | 257.4 | 262.5 | 275.6 | 276.7 | 209.3 | 263.4 | 271.0 | 310.1 |
| 3b. Asphalt roofing | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 3c. Road paving | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Total | 306.1 | 300.7 | 299.9 | 310.0 | 315.0 | 319.9 | 241.6 | 313.6 | 343.4 | 391.5 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| 2. Paraffin Wax Use | 53.1 | 58.7 | 86.0 | 160.1 | 143.3 | 162.0 | 121.1 | 129.4 | 135.0 | 112.7 |
| 3a. Solvent Use | 247.9 | 223.6 | 233.5 | 314.0 | 277.5 | 326.1 | 232.5 | 224.0 | 219.9 | 339.9 |
| 3b. Asphalt roofing | 0.1 | 0.2 | 0.1 | 0.4 | 0.2 | 0.4 | 0.1 | 0.2 | 0.2 | 0.1 |
| 3c. Road paving | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 |
| Total | 301.2 | 282.5 | 319.7 | 474.5 | 421.0 | 488.5 | 353.7 | 353.6 | 355.2 | 452.8 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| 2. Paraffin Wax Use | 115.8 | 110.8 | 120.3 | 91.3 | 97.1 | 101.4 | 75.5 | 85.8 | 87.5 | |
| 3a. Solvent Use | 213.4 | 223.3 | 231.2 | 224.9 | 232.6 | 214.3 | 248.3 | 212.7 | 393.5 | |
| 3b. Asphalt roofing | 0.1 | 0.3 | 0.1 | 0.2 | 0.1 | 0.4 | 0.4 | 0.3 | 0.1 | |
| 3c. Road paving | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | |
| Total | 329.4 | 334.5 | 351.6 | 316.4 | 329.9 | 316.1 | 324.3 | 298.8 | 481.2 | |

In 2018 the most significant $CO_2$ emission came from the use of solvents which constituted 81.8 % of total $CO_2$ emission from *Non-energy Products from Fuels and Solvent Use* that year. Emission of $CO_2$ from paraffin wax use accounted for 18.2 % of total $CO_2$ emission from this subsector in 2018, while $CO_2$ emission from asphalt roofing and road paving constituted 0.1 and less in 2018.

$CO_2$ emission from subsectors under Non-energy Products from Fuels and Solvent Use fluctuates a great deal from year to year, as seen in Figure 16.4.3. This is among others caused by fluctuations in building activities and road paving. However fluctuations in $CO_2$ are also caused by the fact that activity data for non-energy products and solvent use are based on import data, which do not allow distinction of imported amount into consumption and stockpiling.

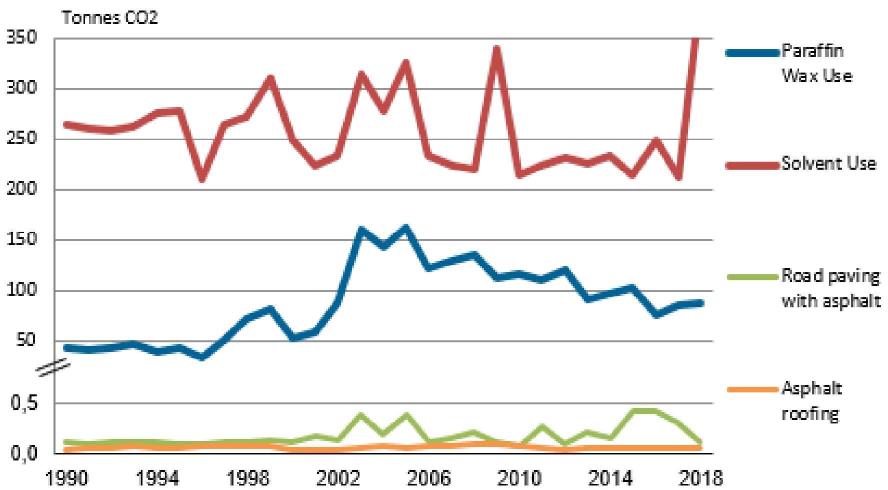



Figure 16.4.3 Emission of $CO_2$ from Non-energy Products from Fuels and Solvent Use.

**Product Uses as Substitutes for ODS – Consumption of Halocarbons**

The subsector *Product Uses as Substitutes for ODS* (2F) includes the following source categories and the following halocarbons of relevance for Greenlandic emissions:

- 2F1 Refrigeration: HFC32, 125, 134a, 143a, unspecified HFCs.

A quantitative overview is given below for each of these source categories and each halocarbon, showing their emissions in tonnes through time. The data is extracted from the CRF tables that form part of this submission and the data presented is rounded values. It must be noticed that the inventories for the years 1990-1994 might not cover emissions of these gases in full. The chosen base-year for these gases is 1995 for Greenland.

Table 16.4.5 Emission of HFCs from refrigeration (t).

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| HFC32 | NE | NE | NE | NE | NE | NA | 0.00 | 0.00 | 0.00 | 0.00 |
| HFC125 | NE | NE | NE | NE | NE | NA | 0.01 | 0.04 | 0.08 | 0.15 |
| HFC134a | NE | NE | NE | NE | 0.01 | 0.02 | 0.03 | 0.06 | 0.10 | 0.17 |
| HFC143a | NE | NE | NE | NE | NE | NA | 0.01 | 0.05 | 0.09 | 0.16 |
| Unspecified HFCs | NE | NE | NE | NE | NE | NA | 0.00 | 0.00 | 0.00 | 0.00 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| HFC32 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| HFC125 | 0.22 | 0.35 | 0.46 | 0.56 | 0.64 | 0.64 | 0.65 | 0.71 | 0.76 | 0.77 |
| HFC134a | 0.24 | 0.35 | 0.45 | 0.55 | 0.63 | 0.65 | 0.65 | 0.68 | 0.67 | 0.64 |
| HFC143a | 0.24 | 0.39 | 0.51 | 0.63 | 0.71 | 0.72 | 0.72 | 0.79 | 0.86 | 0.88 |
| Unspecified HFCs | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| HFC32 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | |
| HFC125 | 0.80 | 0.84 | 0.87 | 0.94 | 0.90 | 1.11 | 1.08 | 0.88 | 0.99 | |
| HFC134a | 0.62 | 0.63 | 0.59 | 0.56 | 0.47 | 0.43 | 0.36 | 0.27 | 0.17 | |
| HFC143a | 0.91 | 0.97 | 1.00 | 1.09 | 1.05 | 1.27 | 1.25 | 1.02 | 1.15 | |
| Unspecified HFCs | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |

HFCs are used in various types of refrigeration in industry, retail, buildings and onboard ships. In 1994 and 1995 consumption of HFC134a was the only reported HFC used for refrigeration. Since 1996 consumption of HFC32, 125, 134A, 143A has been reported continuously. The emission of HFCs has increased a great deal since 1995. Emission of HFCs from refrigeration is shown in Figur 16.4.4.

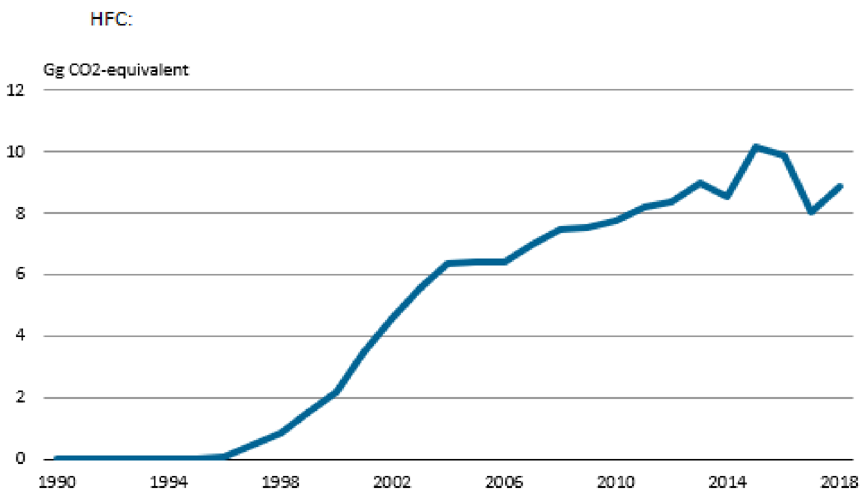



Figure 16.4.4 Emission of HFCs (from refrigeration).

**Other Product Manufacture and Use – Consumption of $SF_6$**

The subsector *Other Product Manufacture and Use* (2G) includes the following source categories and the following F-gases of relevance for Greenlandic emissions:

- 2G1 Electrical Equipment: $SF_6$.

Emissions of $SF_6$ are shown in Table 16.4.6 below. The data is extracted from the CRF tables that form part of this submission and the data presented is rounded values. It must be noticed that the inventories for the years 1990-1994 might not cover emissions of these gases in full. The chosen base-year for these gases is 1995 for Greenland.

Table 16.4.6 Emission of $SF_6$ from Electrical Equipment (kg).

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SF_6$ | NE | NE | NE | NE | NE | 1.50 | 0.14 | 0.14 | 0.14 | 0.14 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| $SF_6$ | 0.14 | 0.14 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| $SF_6$ | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.11 | |

The emission of SF6 was highest in 1995, when one single plant in Greenland reported use of $SF_6$. The emission of $SF_6$ was 1.5 kg in 1995. Since 1995 the annual emission is assumed to be 0.5 % of the amount filled into the plant in 1995. This causes a relative high emission of $SF_6$ in 1995 and a much lower emission in the following years. In 2017 the emission of $SF_6$ was 0.12 kg. Emission of $SF_6$ from electrical equipment is shown in Figur 16.4.5.

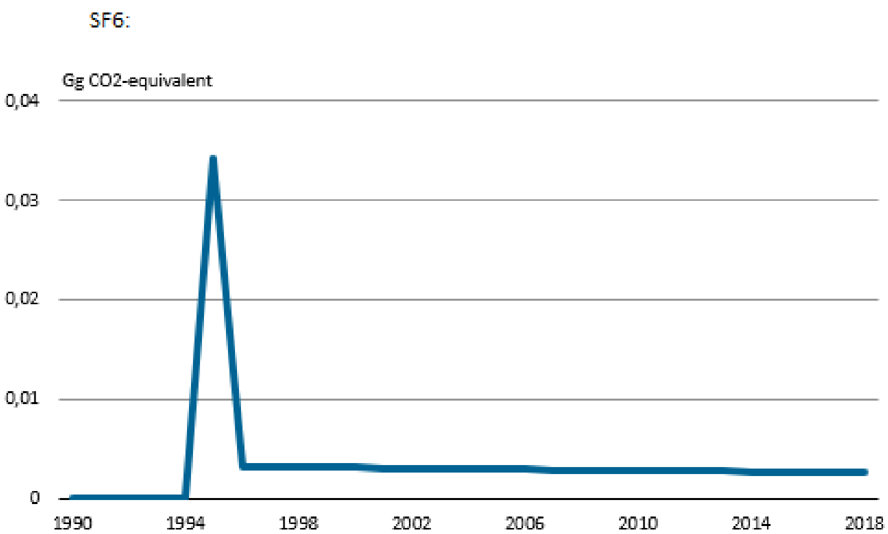



Figure 16.4.5 Emission of $SF_6$ (from electrical equipment).

Table 16.4.7 quantifies an overview of the emissions of the all F-gases in $CO_2$-eqv. from the two subsectors Product Uses as Substitutes for ODS (2F) and Other Product Manufacture and Use (2G). The emissions are extracted from the CRF tables and the values are rounded.

Table 16.4.7 Time-series for emission of HFCs and $SF_6$ (tonnes $CO_2$-eqv.).

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| HFCs | NE | NE | NE | NE | 18 | 27 | 88 | 455 | 833 | 1 497 |
| $SF_6$ | NE | NE | NE | NE | NE | 34.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| HFCs | 2 190 | 3 473 | 4 569 | 5 566 | 6 352 | 6 407 | 6 448 | 6 999 | 7 499 | 7 546 |
| $SF_6$ | 3.1 | 3.1 | 3.1 | 3.0 | 3.0 | 3.0 | 2.9 | 2.9 | 2.9 | 2.9 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| HFCs | 7 770 | 8 180 | 8 373 | 8 993 | 8 525 | 10 176 | 9 882 | 8 047 | 8.861 | |
| $SF_6$ | 2.8 | 2.8 | 2.8 | 2.7 | 2.7 | 2.7 | 2.7 | 2.6 | 2.6 | |

HFCs is by far the most dominant group among the F-gases. HFCs constitute a key category both with regard to the key category level and the trend analysis.

#### Other

The subsector *Other* (2H) covers the following processes:

- 2H2 Food and Beverages Industry.

Emission of NMVOC from food and beverages industry is presented in the CRF sector 2H.2 Other. There is no emission of $CO_2$ from this source.

### 16.4.3 Methodological issues

#### General

Asphalt materials used for roof covering and road paving has been estimated from the annual import of these products to Greenland.

The emissions of HFCs and $SF_6$ have been estimated from data on consumption of F-gases. Activity data includes annual imports and data on consumption of halocarbons and $SF_6$ obtained from an annual survey among importers and consumers of F-gases.

The emission modelling of solvents is done by estimating the amount of (pure) solvents consumed (EMEP/CORINAIR, 2013). All relevant solvents are estimated, or at least those representing more than 90 % of the total NMVOC emission. The estimation and modelling is based on a detailed set of data on imports of chemicals and products to Greenland. Each chemical (NMVOC) and chemical containing product (group) is estimated separately. The sum of emissions of all estimated NMVOCs used as solvents equals the NMVOC emission from solvent use.

The following sections contain a description of activity data and emission factors used for the subsectors under industrial processes. The section is concluded by a description of the emissions of greenhouse gases from industrial processes and product use.

#### Activity data

Activity data for subsectors *Mineral Industry* (2A), *Non-Energy Products of Fuel and Solvent Use* (2D) and *Other* (2H) are presented in Table 16.4.8. Activity data under subsector *Other* (2H) are used for calculation of emission of non-methane volatile organic compounds (NMVOC). Emission of non-methane volatile organic compounds (NMVOC) is also calculated from the use of solvents under subsector 2D.

The activity data are rounded. Notice that production of beer is given in hectolitre (hl). All other activity data are given in tonnes (t).

Statistics on imports are used to estimate annual consumption in mineral industry and the use of non-energy products of fuel and solvents.

The definitions of solvents and VOC that are used are as defined in the solvent directive (Directive 1999/13/EC) of the EU legislation: "Organic solvent shall mean any VOC which is used alone or in combination with other agents, and without undergoing a chemical change, to dissolve raw materials, products or waste materials, or is used as a cleaning agent to dissolve contaminants, or as a dissolver, or as a dispersion medium, or as a viscosity adjuster, or as a surface tension adjuster, or a plasticiser, or as a preservative". VOCs are defined as follows: "Volatile organic compound shall mean any organic compound having at 293.15 K a vapour pressure of 0.01 kPa or more, or having a corresponding volatility under the particular condition of use".

All the import data are collected by Statistics Greenland, the emission calculation based on the import data are performed by the Ministry of Industry, Energy, Research and Labour.

Import figures of chemicals and chemical containing products are obtained from Statistics Greenland. There is no production or export of chemicals and chemical containing products, therefore the import amount is assumed to be equivalent to the used amount.

Statistics on imports of whole coffee beans and yeast for baking are used to estimate annual production of coffee and bread. Statistics on landings of fish and seafood to domestic plants are used to determine domestic processing of fish and seafood. Statistics on imports are produced by Statistics Greenland.

Production of beer including a fermentation process has taken place at the brewery "Godthåb Bryghus" since 2005 (Godthåb Bryghus, 2017). The brewery has reported annual production in rounded hectolitre. The much larger company "Nuuk Imeq" has no production of beer including a fermentation process. As a bottling company the activity at "Nuuk Imeq" only includes diluting of the concentrated quantities imported to Greenland and afterwards bottling of the beer.

Table 16.4.8 Activity data for Mineral Industry, Non-energy Products of Fuel and Solvent Use, and Other.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mineral Industry | | | | | | | | | | |
| 2A4d Limestone and dolomite use (t) | - | - | - | - | - | - | - | - | - | - |
| Non-energy Products from Fuels and Solvent Use | | | | | | | | | | |
| 2D2 Paraffin wax use (t) | 86 | 83 | 86 | 96 | 79 | 87 | 65 | 101 | 146 | 164 |
| 2D3a Solvent use (t) | 190 | 187 | 188 | 195 | 198 | 174 | 141 | 198 | 206 | 254 |
| 2D3b Road paving with asphalt (t) | 591 | 581 | 595 | 604 | 597 | 577 | 532 | 664 | 649 | 752 |
| 2D3c Asphalt roofing (t) | 136 | 210 | 236 | 280 | 234 | 238 | 292 | 249 | 258 | 246 |
| Other Production, Food and Beverage Industry | | | | | | | | | | |
| 2H2 Beans roasted to produce coffee (t) | 0 | 0 | 0 | 0 | - | 0 | - | - | 0 | 0 |
| 2H2 Production of bread (t) | 356 | 346 | 339 | 358 | 501 | 244 | 415 | 500 | 847 | 689 |
| 2H2 Landings of fish and seafood (t) | 81 768 | 72 396 | 65 554 | 59 423 | 64 428 | 67 751 | 60 666 | 62 249 | 67 250 | 63 753 |
| 2H2 Production of beer (hl) | - | - | - | - | - | - | - | - | - | - |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Mineral Industry | | | | | | | | | | |
| 2A4d Limestone and dolomite use (t) | 9 | 6 | 3 | 6 | 4 | 0 | 0 | 3 | 7 | 0 |
| Non-energy Products from Fuels and Solvent Use | | | | | | | | | | |
| 2D2 Paraffin wax use (t) | 107 | 119 | 174 | 324 | 290 | 328 | 245 | 262 | 273 | 228 |
| 2D3a Solvent use (t) | 159 | 155 | 196 | 264 | 271 | 351 | 291 | 258 | 209 | 329 |
| 2D3b Road paving with asphalt (t) | 694 | 988 | 705 | 2 218 | 1 127 | 2 258 | 698 | 912 | 1 206 | 629 |
| 2D3c Asphalt roofing (t) | 136 | 124 | 148 | 187 | 282 | 172 | 242 | 258 | 387 | 322 |
| Other Production, Food and Beverage Industry | | | | | | | | | | |
| 2H2 Beans roasted to produce coffee (t) | 0 | 1 | - | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 2H2 Production of bread (t) | 687 | 566 | 1 020 | 1 048 | 1 338 | 1 014 | 1 134 | 859 | 931 | 587 |
| 2H2 Landings of fish and seafood (t) | 74 105 | 66 929 | 85 970 | 80 667 | 102 570 | 103 642 | 111 351 | 118 260 | 109 420 | 102 393 |
| 2H2 Production of beer (hl) | - | - | - | - | - | 1 000 | 2 000 | 2 000 | 1 850 | 1 650 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Source |
| Mineral Industry | | | | | | | | | | |
| 2A4d Limestone and dolomite use (t) | 11 | 0 | 45 | 0 | 15 | 0 | 0 | 7 | 91 | 1 |
| Non-energy Products from Fuels and Solvent Use | | | | | | | | | | |
| 2D2 Paraffin wax use (t) | 234 | 224 | 243 | 185 | 197 | 205 | 153 | 174 | 177 | 1 |
| 2D3a Solvent use (t) | 225 | 234 | 299 | 275 | 292 | 244 | 233 | 246 | 315 | 1 |
| 2D3b Road paving with asphalt (t) | 443 | 1 529 | 583 | 1 200 | 824 | 2 445 | 2 444 | 1 736 | 617 | 1 |
| 2D3c Asphalt roofing (t) | 292 | 220 | 151 | 169 | 194 | 168 | 238 | 216 | 212 | 1 |
| Other Production, Food and Beverage Industry | | | | | | | | | | |
| 2H2 Beans roasted to produce coffee (t) | 0 | 0 | 1 | 3 | 1 | 1 | 0 | 1 | 4 | 2 |
| 2H2 Production of bread (t) | 790 | 584 | 563 | 567 | 606 | 985 | 433 | 683 | 424 | 2 |
| 2H2 Landings of fish and seafood (t) | 97 955 | 104 020 | 105 511 | 103 445 | 105 358 | 104 230 | 125 077 | 117 161 | 115.659 | 3 |
| 2H2 Production of beer (hl) | 2 010 | 2 115 | 2 080 | 1 985 | 1 628 | 1 800 | 3 810 | 2 450 | 3.430 | 4 |

Sources:

1) Statistics on imports are used to estimate annual consumption.

2) Statistics on imports of whole coffee beans and yeast for baking are used to estimate annual production of coffee and bread.

3) Statistics on landings of fish and seafood to domestic plants are used to determine domestic processing of fish and seafood.

4) Data from the brewery “Godthåb Bryghus” are used to determine annual production of beer.

The activitydata on HFCs and $SF_6$ are obtained by annual registrations on import and export of HFCs and $SF_6$, and by annual surveys among importers, wholesalers and suppliers as well as consumers of HFCs and $SF_6$. This means that the obtaining of acitvitydata includes the quantification and determination of any import and export of HFCs and $SF_6$ contained products and substances in stock form. This is in accordance with IPCC guidelines (IPCC, 2006), as well as the relevant decision trees from the IPCC Good Practice Guidance (IPCC, 2006).

The following sources of information have been used (Statistics Greenland):

- Importers, wholesaler and suppliers
- Statistics Greenland
- Consuming enterprises.

Importers and suppliers provide consumption data of F-gases. Emission factors are defaults from the GPG. Import/export data for sub-source categories where import/export is relevant are quantified on estimates from import/export statistics of products + default values of the amount of gas in the product.

The determination of emissions of F-gases is based on a calculation of the actual emission. The actual emission is the emission in the evaluation year, accounting for the time lapse between consumption and emission. The actual emission includes Greenlandic emissions from production and from products during their lifetimes. Consumption and emissions of F-gases are, whenever possible for individual substances, even though the consumption of certain HFCs has been limited. This has been varied out to ensure transparency of evaluation in the determination of GWP values. However, the continued use for Other HFCs has been necessary since not all importers and suppliers have specified records of sales for individual substances.

Only the actual emission has been calculated. Thus, the potential emission is assumed to be the same as the actual emission in the CRF tables.

Table 16.4.9 Content (w/w%) of "pure" HFC in HFC-mixtures, used as trade names.

| HFC mixtures | HFC32 | HFC125 | HFC134a | HFC143a | Unspecified HFCs |
|---|---|---|---|---|---|
| | % | % | % | % | % |
| HFC-134, total | | | 100 | | |
| HFC-404, total | | 44 | 4 | 52 | |
| HFC-407c, total | 23 | 25 | 52 | | |
| HFC-507a, total | | 50 | | 50 | |
| Unspecified HFCs | | | | | 100 |

The substances have been accounted for in the survey according to their trade names, which are mixtures of HFCs used in the CRF. In the transfer to the "pure" substances used in the CRF reporting schemes, the ratios shown in Table 16.4.9 have been used.

Activity data for the consumption of F-gases is shown in Table 16.4.10. The activity data are rounded and given in kg.

Table 16.4.10 Activity data for the consumption of F-gases by trade-names.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Kg | | | | | |
| HFC-134 | | | | | | | | | | |
| Domestic | NE | NE | NE | 264 | 139 | 91 | 187 | 134 | 453 | 319 |
| Commercial and Industry | NE | NE | NE | - | - | - | 123 | 123 | 247 | 247 |
| Transport | NE | NE | NE | - | - | - | 64 | 64 | 128 | 128 |
| HFC-404a | | | | | | | | | | |
| Commercial and Industry | NE | NE | NE | - | - | - | 488 | 488 | 976 | 976 |
| Transport | NE | NE | NE | - | - | - | 82 | 82 | 164 | 164 |
| HFC-407c | | | | | | | | | | |
| Commercial and Industry | NE | NE | NE | - | - | - | 34 | 34 | 68 | 68 |
| HFC-507a | | | | | | | | | | |
| Transport | NE | NE | NE | - | - | - | 113 | 113 | 225 | 225 |
| Unspecified HFCs | | | | | | | | | | |
| Commercial and Industry | NE | NE | NE | - | - | - | 45 | 45 | 90 | 90 |
| $SF_6$ | | | | | | | | | | |
| Electrical Equipment | NE | NE | NE | - | - | 30 | - | - | - | - |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| HFC-134 | | | | | | | | | | |
| Domestic | 289 | 492 | 774 | 635 | 635 | - | - | - | - | - |
| Commercial and Industry | 493 | 493 | 493 | 493 | 260 | 208 | 680 | 329 | 312 | 195 |
| Transport | 256 | 256 | 256 | 256 | 120 | 120 | 30 | 30 | - | - |
| HFC-404a | | | | | | | | | | |
| Commercial and Industry | 1 952 | 1 952 | 1 952 | 1 952 | 1 324 | 1 041 | 2 033 | 2 069 | 1 950 | 2 089 |
| Transport | 328 | 328 | 328 | 328 | 154 | 222 | 369 | 413 | 384 | 241 |
| HFC-407c | | | | | | | | | | |
| Commercial and Industry | 135 | 135 | 135 | 135 | 68 | 83 | 31 | 4 | 112 | 90 |
| HFC-507a | | | | | | | | | | |
| Transport | 450 | 450 | 450 | 450 | - | - | 120 | 180 | - | 120 |
| Unspecified HFCs | | | | | | | | | | |
| Commercial and Industry | 180 | 180 | 180 | 180 | 326 | 314 | 556 | 698 | 309 | 400 |
| $SF_6$ | | | | | | | | | | |
| Electrical Equipment | - | - | - | - | - | - | - | - | - | - |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| HFC-134 | | | | | | | | | | |
| Domestic | - | - | - | - | - | - | | | | |
| Commercial and Industry | 484 | 340 | 207 | - | 178 | 134 | 338 | 278 | 315 | |
| Transport | - | - | - | - | - | - | | - | | |
| HFC-404a | | | | | | | | | | |
| Commercial and Industry | 2 993 | 2 687 | 4 596 | 2 300 | 3 909 | 4 157 | 3 344 | 3 175 | 4.678 | |
| Transport | 205 | 205 | 479 | 146 | 345 | 512 | 351 | 263 | 371 | |
| HFC-407c | | | | | | | | | | |
| Commercial and Industry | - | 90 | 45 | - | - | 33 | - | 42 | - | |
| HFC-507a | | | | | | | | | | |
| Transport | - | 180 | - | 45 | 2 160 | 270 | 900 | 450 | 450 | |
| Unspecified HFCs | | | | | | | | | | |
| Commercial and Industry | 576 | 600 | 35 | 10 | 40 | 20 | 18 | 39 | 237 | |
| $SF_6$ | | | | | | | | | | |
| Electrical Equipment | - | - | - | - | - | - | - | - | | |

Source: Statistics Greenland

#### Emission factors

The $CO_2$ emission factors applied for products in 2017 are presented in Table 16.4.11. The same emission factor has been applied for 1990-2018.

Table 16.4.11 $CO_2$ emission factors 2018.

| Product | Emission factor | Unit | Reference | IPCC Category |
|---|---|---|---|---|
| Limestone and dolomite use | 440 | kg pr tonne | IPCC, 1997 | 2A4d |
| Paraffin wax use | 494 | kg pr tonne | IPCC, 1997 | 2D2 |
| Asphalt used for road paving | 0.168 | kg pr tonne | Nielsen et al., 2011 | 2D3b |
| Asphalt materials used for roofing | 0.25 | kg pr tonne | Nielsen et al., 2011 | 2D3c |

The CO emission factors applied for the consumption of asphalt products in 2017 are presented in Table 16.4.12. The same emission factor has been applied for 1990-2018.

Table 16.4.12 CO emission factors 2018.

| Product | Emission factor | Unit | Reference | IPCC Category |
|---|---|---|---|---|
| Asphalt used for road paving | 0.075 | kg pr tonnes | Nielsen et al., 2011 | 2D3b |
| Asphalt materials used for roofing | 0.01 | kg pr tonnes | Nielsen et al., 2011 | 2D3c |

The NMVOC emission factors applied for the consumption of asphalt products and products used in the production of food and beverages in 2017 are presented in Table 16.4.13. The same emission factor has been applied for 1990-2018.

Table 16.4.13 NMVOC emission factors 2018.

| Product | Emission factor | Unit | Reference | IPCC Category |
|---|---|---|---|---|
| Asphalt used for road paving | 0.015 | kg pr tonnes | Nielsen et al., 2011 | 2D3b |
| Asphalt materials used for roofing | 0.08 | kg pr tonnes | Nielsen et al., 2011 | 2D3c |
| Food and Beverages Industry - Beans roasted to produce coffee | 0.55 | kg pr tonnes | IPCC, 1997 | 2H2 |
| Food and Beverages Industry - Production of bread | 8 | kg pr tonnes | IPCC, 1997 | 2H2 |
| Food and Beverages Industry - Landings of fish and seafood | 0.3 | kg pr tonnes | IPCC, 1997 | 2H2 |
| Food and Beverages Industry - Production of beer | 0.0625 | kg pr hl | Nielsen et al., 2011 | 2H2 |

For some chemicals, in the calculation of emissions from solvent use, the emission factors are precise. For others they are rough estimates. In the Danish inventory emission factors are divided into four categories: 1) chemical industry (lowest EF), 2) other industry, 3) non-industrial activities, 4) domestic and other diffuse use (highest EF). This implies that high emission factors are applicable for use of solvent containing products and lower emission factors are applicable for use in industrial processes.

The default NMVOC-$CO_2$ conversion factor of 0.85 * 3.667 = 3.11 is used for solvents.

The emission factors used in the Greenlandic inventory are the same as developed for the Danish inventory (please refer to Chapter 5).

### 16.4.4 Emissions

The greenhouse gas (GHG) emissions are listed in Table 16.4.14. The emission from industrial processes and product use accounts for 1.5 % of the Greenlandic GHG emission.

The $CO_2$ emission from industrial processes and product use accounts for just 0.06 % of the Greenlandic $CO_2$ emission (excluding net $CO_2$ emission from Land Use, Land Use Change and Forestry (LULUCF). The HFC emission from industrial processes and product use accounts for 100 % of the Greenlandic emission and the $SF_6$ emission accounts for 100 % of the Greenlandic $SF_6$ emission.

Table 16.4.14 Greenhouse gas emission for the year 2018.

| | | $CO_2$ | HFC | $SF_6$ |
|---|---|---|---|---|
| | | Tonne $CO_2$ equivalent | | |
| 2A4 | Limestone and Dolomite Use | 39.91 | NA | NA |
| 2D2 | Paraffin Wax Use | 87.52 | NA | NA |
| 2D3 | Solvent use | 393.54 | NA | NA |
| 2D3 | Road paving with asphalt | 0.10 | NA | NA |
| 2D3 | Asphalt roofing | 0.05 | NA | NA |
| 2F1 | Refrigeration and air conditioning | NA | 8 861 | NA |
| 2G1 | Electrical Equipment | NA | NA | 2.6 |
| Total emission from industrial processes and product use | | 521.12 | 8 861 | 2.6 |
| Greenlandic emission (excluding net emission from LULUCF) | | 548.015 | 8 861 | 2.6 |
| | | | % | |
| Emission share for industrial processes and product use | | 0.10 | 100.00 | 100.00 |

HFC is the most important GHG pollutant and accounts for 94.4 % of the GHG emission in $CO_2$ equivalents from industrial processes and product use. Illustration of the percentage of share in a figure is omitted due to the large share of HFC, which completely dominates as the most significant GHG pollutant from industrial processes.

**$CO_2$**

Figure 16.4.6 depicts the time-series of $CO_2$ emission from industrial processes. As shown by the blue curve total $CO_2$ emission follows the $CO_2$ emission from solvent use closely. The reason is that solvent use is such a dominat source to $CO_2$ emission with in the sector *Industrial processes and product use*.

Data on imports are used to estimate annual use of paraffin wax use, solvent use, limestone and dolomite as well as asphalt for road paving and roofing. This causes a great deal of fluctuations from year to year. Hence, in years with none or low import of solvents, i.e. 2008, 2010 and onwards, $CO_2$ emission from solvent use are on a lower level.

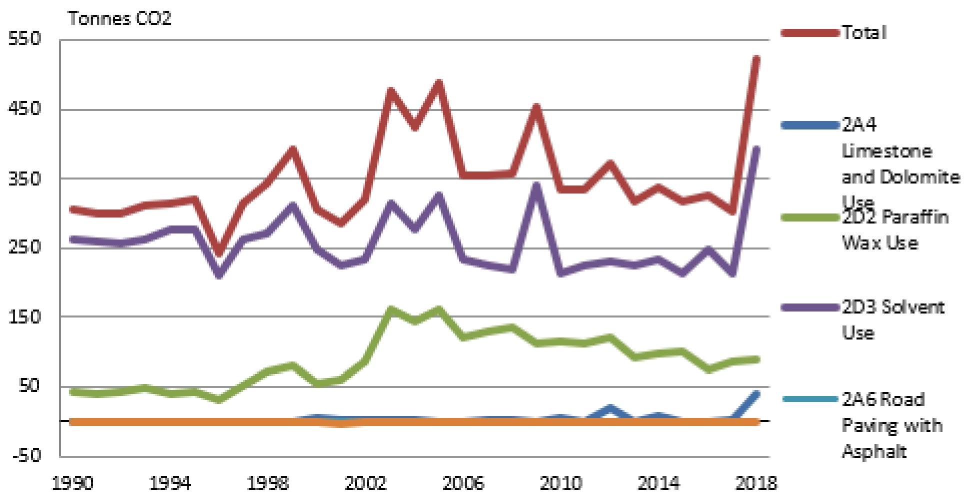



Figure 16.4.6 Emission of $CO_2$ from industrial processes and product use.

Emission of HFCs and $SF_6$ are illustrated in Figure 16.4.4 and Figure 16.4.5.

**NMVOC and CO**

The emissions of NMVOC and CO from industrial processes and product use in 2017 are presented in Table 16.4.15. NMVOC and CO account for 10.21 % and 0.002 % respectively, of the Greenlandic emissions for these substances.

Table 16.4.15 NMVOC and CO emission from industrial processes 2018.

| | | NMVOC | CO |
|---|---|---|---|
| | | Tonnes | |
| 2D3 | Solvent Use | 126.15 | NA |
| 2D3 | Asphalt Roofing | 0.02 | 0.00 |
| 2D3 | Road Paving with Asphalt | 0.01 | 0.05 |
| 2H2 | Food and beverages industry | 38.31 | NA |
| Total emission from industrial processes and product use | | 164.49 | 0.05 |
| Greenlandic emission | | 1 127.590 | 5 348.48 |
| | | % | |
| Emission share for industrial processes and product use | | 14.59 | 0.001 |

### 16.4.5 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC GPG (IPCC, 2006). The uncertainty has been estimated for all sources included in the reporting for industrial processes. The uncertainties for the activity data and emission factors are shown in Table 16.4.16.

Table 16.4.16 Uncertainties for activity data and emission factors for industrial processes.

| Subsector | Pollutant | Activity data uncertainty | Emission factor uncertainty |
|---|---|---|---|
| 2A4 Limestone and dolomite use | $CO_2$ | 5 | 5 |
| 2D2 Paraffin wax use | $CO_2$ | 5 | 25 |
| 2D3 Solvent use | $CO_2$ | 5 | 25 |
| 2D3 Road paving with asphalt | $CO_2$ | 5 | 25 |
| 2D3 Asphalt roofing | $CO_2$ | 5 | 25 |
| 2F Consumption of HFC | HFC | 10 | 50 |
| 2G Consumption of $SF_6$ | $SF_6$ | 10 | 50 |

The activity data comes from the import statistics, which is considered to be of high quality. Thus the uncertainty value of the activity data has been set to 5 % for limestone and dolomite use, paraffin wax use, solvent use and asphalt used for road paving and roofing. For consumption of HFCs and $SF_6$ the uncertainty value of the activity data has been set to 10 %.

With regard to uncertainty, the $CO_2$ emission factor for limestone and dolomite use is considered very certain. It is derived from stoichiometric calculations. Thus an emission factor of 5 % has been assumed. The uncertainty levels for paraffin wax use, solvent use, asphalt roofing and road paving are expert judgements set to 25 % for the emission factor. The emission of F-gases is dominated by emissions from refrigeration equipment and, therefore, the uncertainties assumed for this sector will be used for all the F-gases. The IPCC propose an uncertainty of 30-40 % for regional estimates. However, Greenlandic statistics have been developed over a number of years and, therefore the uncertainty on activity data is assumed to be 10 %.Ministry of Industry and Energy has used the same method. The uncertainty on the emission factor is, on the other hand, assumed to be 50 %. The base year for F-gases for Greenland is 1995.

The resulting uncertainties for the individual greenhouse gases and the total uncertainty on the greenhouse gas emission are shown in Table 16.4.17.

Table 16.4.17 Uncertainties for the emission estimates.

| | Uncertainty % | Trend 1990-2016[1] % | Trend uncertainty % |
|---|---|---|---|
| GHG | ± 48 | 2 456 | ± 1 247 |
| $CO_2$ | ± 20 | 70.3 | ± 10.5 |
| HFC | ± 51 | 32.760 | ± 4 647 |
| $SF_6$ | ± 51 | -92 | ± 1.1 |

[1] For f-gases the base year of 1995 is used.

### 16.4.6 Source specific QA/QC

The elaboration of a formal QA/QC plan is to be completed.

However, the official Greenland import statistics has gone through a great deal of quality work with regard to accuracy, comparability and completeness. Statistics Greenland is responsible for the official Greenlandic import statistics, and as such responsible for the completeness of data. The import statistic are obtained by Statistic Greenland, which are used for emission for Industrial Processes and Product use.

Statistics on imports is reported by Statistics Greenland in form of a spreadsheet. Annual import of limestone and dolomite, paraffin wax use, asphalt materials used for roof covering and road paving, chemicals and chemical containing products, whole coffee beans and yeast for baking are compared with imports in previous years and large discrepancies are checked. The same procedure is used to ensure accuracy in annual use of F-gases and statistics on landings of fish and seafood to domestic plants.

All external data used for the emission inventory submission are archived in spreadsheets. Data are archived annually in order to ensure that the basic data for a given report are always available in their original form.

Safely stored and quality checked activity data are then processes by using a methodological approach consistent with international guidelines.

Calculated emission factors are compared with guideline emission factors to ensure that they are reasonable. The calculations follow the principle in international guidelines.

During data processing, it is checked that calculations are being carried out correctly. However, a documentation plan for this needs to be elaborated.

Time-series for activity data, emission factors and calculated emissions are used to identify possible errors in the calculation procedure. In fact, during the calculation, numerous controls take place to ensure correctness. Sums are checked in the various stages in the calculation procedure. Implied emission factors are compared to emission factors.

Every single time-series imported to the CRF Reporter is checked for annual activity, units for activity, emission factor and emissions. Additional checks are performed on the database. The database encloses every single activity data, emission factors, emission, notation key and comment imported to the CRF Reporter.

### 16.4.7 Source specific recalculations and improvements

In this 2020 submission there has been no revisions in the industrial processes and product use sector.

Table 16.3.18 shows recalculations in the industrial processes and product use sector compared to the 2019 submission. No changes occur.

Table 16.4.18 Changes in GHG emission in Industrial Processes and Product Use compared to the 2019 submission.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Previous inventory, Gg $CO_2$ eqv. | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.3 | 0.8 | 1.2 | 1.9 |
| Recalculated, Gg $CO_2$ eqv. | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.3 | 0.8 | 1.2 | 1.9 |
| Change in Gg $CO_2$ eqv. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Change in pct. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Previous inventory, Gg $CO_2$ eqv. | 2.5 | 3.8 | 4.9 | 6.0 | 6.8 | 6.9 | 6.8 | 7.4 | 7.9 | 8.0 |
| Recalculated, Gg $CO_2$ eqv. | 2.5 | 3.8 | 4.9 | 6.0 | 6.8 | 6.9 | 6.8 | 7.4 | 7.9 | 8.0 |
| Change in Gg $CO_2$ eqv. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Change in pct. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| Previous inventory, Gg $CO_2$ eqv. | 8.1 | 8.5 | 8.7 | 9.3 | 8.9 | 10.5 | 10.2 | 8.4 | - | |
| Recalculated, Gg $CO_2$ eqv. | 8.1 | 8.5 | 8.7 | 9.3 | 8.9 | 10.5 | 10.2 | 8.4 | 9.4 | |
| Change in Gg $CO_2$ eqv. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | - | |
| Change in pct. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | - | |

### 16.4.8 Source specific planned improvements

Some planned improvements to the emission inventories are discussed below. Statistic Greenland had one planned improvement in the 2018 submission. The Ministry of Industry plans to achieve improvement for the one goal, Statistic Greenland had planned to improve

**1) Distribution of unspecified mix of HFCs into single HFCs**

An unspecified mix of HFCs is used in commercials and industries. In future inventories attempts will be made in order to distribute the unspecified mix of HFCs into single substances.

It will be investigated whether use of $N_2O$ from solvents is occurring in Greenland.

### 16.4.9 References

Godthåb Bryghus (Brewery in Nuuk), 2017: Data on production of beer 2006-2016. Not published.

EMEP/EEA Guidebook 2013. EMEP/EEA air pollutant emission in-ventory guidebook 2013. Published by the EEA with the CLRTAP Task Force on Emission Inventories and Projections responsible for the technical content of the chapters. Technical report No 12/2013. Available at: http://www.eea.europa.eu/publications/emep-eea-guidebook-2013 (23/01-2015).

Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations, Brüssel, 1999.

IPCC, 1997: Revised 1996 IPCC Guidelines for National Greenhouse Gas inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/gl/invs6.htm (15-04-2007).

IPCC, 2000: Penman, J., Kruger, D., Galbally, I., Hiraishi, T., Nyenzi, B., Emmanuel, S., Buendia, L., Hoppaus, R., Martinsen, T., Meijer, J., Miwa, K. & Tanabe, K. (Eds). Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Published: IPCC/OECD/-IEA/IGES, Hayama, Japan. Available at: http://www.ipcc-nggip.iges.or.jp/public/gp/english/ (15-04-2007).

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. & Tanabe K. (eds). Published: IGES, Japan. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (21-02-2014).

IPCC, 2007: Climate Change 2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z.Chen. M. Marquis, K.B. Averyt, M. Tignor & H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA 996 pp.

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Nielsen, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Thomsen, M., Hjelgaard, K., Fauser, P., Bruun, H.G., Johannsen, V.K., Nord-Larsen, T., Vesterdal, L., Callesen, I., Caspersen, O.H., Rasmussen, E., Petersen, S.B., Baunbæk, L. & Hansen, M.G. 2017. Denmark's National Inventory Report 2017. Emission Inventories 1990-2015 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. 890 pp. – Scientific Report from DCE – Danish Center for Environment and Energy no. 231. Available at: http://dce2.au.dk/pub/SR231.pdf

## 16.5 Agriculture (CRF sector 3)

The emission of greenhouse gases from agricultural activities includes $CH_4$ emission from enteric fermentation, $CH_4$ and $N_2O$ emission from manure management and $N_2O$ emission from agricultural soils. The emissions are reported in CRF Tables 3.A, 3.B, 3.D and 3.G.

Emission from rice production, burning of agricultural crop residue and burning of savannas does not occur in Greenland and the CRF Tables 3.C, 3.E and 3.F have, consequently, not been completed.

Emission of non-methane volatile organic compounds (NMVOC) from agricultural activities has not been estimated.

### 16.5.1 Overview of sector

In $CO_2$ equivalents, the agricultural sector (without LULUCF) contributes with 1.4 % of the overall greenhouse gas emission (GHG) in 2018. From 1990 to 2018 emissions have decreased from 9.50 Gg $CO_2$ equivalents to 8.03 Gg $CO_2$ equivalents, which correspond to a decrease of 15.5 %, see Table 16.5.1. This emission decrease is primarily caused by a decrease in the number of reindeers.

Table 16.5.1 Emission of GHG in the agricultural sector 1990-2018 in Gg $CO_2$ equivalents.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| $CH_4$ | 7.79 | 7.86 | 7.06 | 6.20 | 6.76 | 7.27 | 7.48 | 8.18 | 7.79 | 7.06 |
| $N_2O$ | 1.71 | 1.73 | 1.56 | 1.40 | 1.52 | 1.62 | 2.24 | 1.98 | 2.46 | 2.55 |
| Total | 9.50 | 9.58 | 8.62 | 7.60 | 8.28 | 8.89 | 9.72 | 10.17 | 10.26 | 9.61 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| $CH_4$ | 6.86 | 6.97 | 6.70 | 6.79 | 7.14 | 7.43 | 7.21 | 7.37 | 7.19 | 7.04 |
| $N_2O$ | 2.27 | 2.33 | 2.19 | 2.23 | 2.38 | 2.49 | 2.52 | 2.22 | 3.27 | 2.41 |
| Total | 9.12 | 9.31 | 8.90 | 9.03 | 9.52 | 9.92 | 9.72 | 9.58 | 10.46 | 9.45 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| $CH_4$ | 7.22 | 7.07 | 7.03 | 6.99 | 6.61 | 6.22 | 6.44 | 6.31 | 6.44 | |
| $N_2O$ | 2.37 | 2.59 | 2.45 | 2.41 | 2.54 | 2.32 | 2.28 | 1.82 | 1.59 | |
| Total | 9.59 | 9.66 | 9.48 | 9.41 | 9.14 | 8.54 | 8.72 | 8.14 | 8.03 | |

As showed in Figure 16.5.1, $CH_4$ emission contributed with 80.2 % of the total GHG emission from the agricultural sector in 2017. $N_2O$ contributed with 19.7 %. The major part of the emission is related to livestock production, which in Greenland particularly means the production of sheep. A smaller part is related to the reindeer production. Concerning the emission from agricultural soils, the main sources are use of inorganic fertilizer, nitrogen leaching from leaching and run-off and emission from grassing animals.

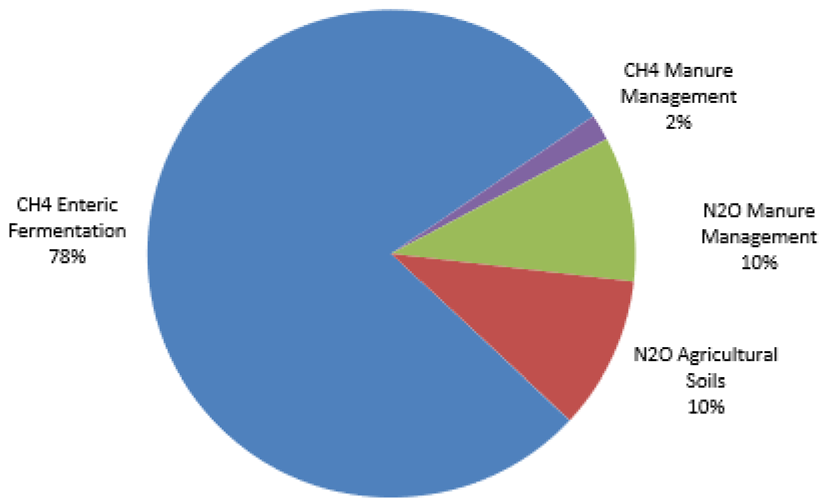



Figure 16.5.1 Emission of greenhouse gases from agriculture in 2018.

### 16.5.2 Source category description

The calculations of the emissions are based on methods described in the IPCC Reference Manual (IPCC, 2006) and the Good Practice Guidance (IPCC, 2000).

Until the data from 2016, Statistics Greenland is responsible for collecting of data, preparation of emission inventory and reporting. Sebsequently the responsibility is on the Ministry of Industry and Energy. Inputs of data are basically obtained from Statistics Greenland and the Greenland Agricultural Consulting Services (ACS). Data on climate are supplied by the Danish Meteorological Institute (DMI) and Greenland Survey (ASIAQ), and published by Statistics Greenland.

Table 16.5.2 List of institutes involved in the emission inventory for the agricultural sector.

| References | Link | Abbreviation | Data/information |
|---|---|---|---|
| Statistics Greenland | *www.stat.gl* | GST | - reporting<br>- data collecting<br>- no. of animal<br>- feed import<br>- use of inorganic fertilizer<br>- spring temperature |
| The Agricultural Consulting Services | *http://nunalerineq.org/* | ACS | - N-excretion<br>- milk yield<br>- feed consumption and composition<br>- stable- and grassing situation<br>- animal growth and weight<br>- land use<br>- crop production |
| The Danish Plant Directorate | *www.pdir.dk* | PD | - N content in different fertilizer types |
| The Danish Agricultural Advisory Centre, Aarhus University | *www.lr.dk* | DAAC | - N content in crop residue<br>- $CO_2$ from liming |

### 16.5.3 $CH_4$ emission from Enteric Fermentation (CRF sector 3A)

**Description**

The major part of the agricultural $CH_4$ emission originates from digestive processes. In 2018, this source accounts for 76 % of the total GHG emission from agricultural activities. The emission is primarily related to ruminants, which in Greenland is sheep. In 2018 sheep contributed with 87 % and the remaining 13 % from reindeer.

#### Methodological issues

The implied emission factors for all animal categories are based on the Tier 2/Country Specific (CS) approach. Feed consumption and composition for sheep and reindeer is based on data from Statistics Greenland and the Agricultural Consulting Services (ACS), which has information concerning the agricultural conditions in practice. Default values for the methane conversion rate ($Y_m$) for sheep given by the IPCC are used, as an average of mature sheep and lambs, which mean an $Y_m$ value of 6.5 % for sheep and 6.0 % for reindeer.

#### Gross energy intake (GE)

The gross energy intake for sheep and reindeer is based on feeding plans for sheep from the Greenland Agricultural Consulting Services supplemented by data on imported feed. For reindeer information on gross energy intake is based on an article on reindeer management in Greenland.

Table 16.5.3 Parameters for calculation of emission from enteric fermentation.

| Animal Category | Gross Energy (GE) | Methane conversion factor ($Y_m$) | Emission factor |
|---|---|---|---|
| | MJ pr head pr day | | Kg $CH_4$ pr head pr yr |
| Sheep | 28.4 | 0.065 | 12.1 |
| Reindeer | 27.5 | 0.060 | 10.7 |

The default $CH_4$ emission factor for sheep Tier 1 methodology is estimated to 8 kg $CH_4$ per animal per year for developed countries. The default GE is given as 20 MJ/head/yr, which is lower than the calculated GE for Greenland, and can explain the lower emission factor. Another reason could be the fact that the national value for feed intake includes lambs. After lambing, ewes and lambs are put out to pasture. Thus lambs only feed through their mother and grass. Lambs are not fed separately before slaughter.

There is no default GE for reindeer. However, Norway, Sweden and Finland have estimated gross energy intake for reindeer to 29.6 – 31.6 MJ/head/day. Based on an article on reindeer management in southern Greenland by H.E. Rasmussen in 1992, the Greenlandic gross energy intake for reindeer has been estimated to 27.5 MJ pr head pr day, which is lower than Norway, Sweden and Finland. However, holding in mind that food conditions for reindeer is more scarcely in Greenland compared to conditions in Norway, Sweden and Finland, which have more forest, and that reindeer in Greenland are not fed separately, the estimated of gross energy intake for reindeer in Greenland seems acceptable.

#### Activity data

Table 16.5.4 shows the development in livestock. The number of sheep is varying slightly. The number of reindeer has decreased considerably since 1990. The reindeer livestock decreased significantly in 1999, when one of two reindeer stations closed. Since 1999 there has been only one reindeer station in Greenland.

Table 16.5.4 Number of animals from 1990-2018 (CRF Table 3.A. 3.B (a) and 3.B (b).

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sheep | 19 929 | 20 134 | 17 900 | 16 256 | 17 818 | 19 464 | 20 163 | 23 134 | 19 929 | 21 007 |
| Reindeer | 6 000 | 6 000 | 5 600 | 4 300 | 4 600 | 4 600 | 4 600 | 3 800 | 6 000 | 2 106 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Sheep | 20 444 | 20 394 | 18 967 | 19 259 | 20 383 | 21 317 | 21 289 | 21 704 | 21 080 | 20 139 |
| Reindeer | 2 000 | 2 480 | 3 100 | 3 100 | 3 100 | 3 100 | 2 318 | 2 441 | 2 500 | 3 000 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| Sheep | 20 729 | 20 232 | 20 107 | 19 994 | 18 738 | 17 501 | 18 190 | 17 785 | 18 212 | |
| Reindeer | 3 000 | 3 000 | 3 000 | 3 000 | 3 000 | 3 000 | 3 000 | 3 000 | 3000 | |

#### Implied emission factor

The implied emission factor (IEF) could vary across years for sheep and reindeer due to changes in feed consumption. However, no existing data can document a change in feed intake. Therefore the same IEF is used for all years.

#### Time-series consistency

The emission from enteric fermentation is given in Table 16.5.5. From 1990 to 2018, the emission has decreased by 17.3 % specifically due to a fall in number of both reindeer and sheep.

Table 16.5.5 Emission of $CH_4$ from Enteric Fermentation 1990-2018, tonnes $CH_4$.

| CRF 3.A | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sheep | 241 | 243 | 216 | 197 | 215 | 235 | 244 | 280 | 241 | 254 |
| Reindeer | 64 | 64 | 60 | 46 | 49 | 49 | 49 | 41 | 64 | 23 |
| Total, tonnes $CH_4$ | 305 | 308 | 276 | 243 | 265 | 284 | 293 | 320 | 305 | 276 |
| Total, tonnes $CO_2$ eqv. | 7 627 | 7 689 | 6 907 | 6 063 | 6 615 | 7 112 | 7 324 | 8 008 | 7 627 | 6 912 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Sheep | 247 | 247 | 229 | 233 | 246 | 258 | 257 | 262 | 255 | 243 |
| Reindeer | 21 | 27 | 33 | 33 | 33 | 33 | 25 | 26 | 27 | 32 |
| Total, tonnes $CH_4$ | 269 | 273 | 262 | 266 | 280 | 291 | 282 | 288 | 282 | 276 |
| Total, tonnes $CO_2$ eqv. | 6 714 | 6 827 | 6 561 | 6 650 | 6 989 | 7 272 | 7 054 | 7 212 | 7 040 | 6 889 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| Sheep | 251 | 245 | 243 | 242 | 227 | 212 | 220 | 215 | 220 | |
| Reindeer | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | |
| Total, tonnes $CH_4$ | 283 | 277 | 275 | 274 | 259 | 244 | 252 | 247 | 252 | |
| Total, tonnes $CO_2$ eqv. | 7 067 | 6 917 | 6 879 | 6 845 | 6 465 | 6 091 | 6 300 | 6 177 | 6 306 | |

### 16.5.4 $CH_4$ and $N_2O$ emission from Manure Management (CRF sector 3B)

#### Description

The emissions of $CH_4$ and $N_2O$ from manure management are given in CRF Table 3.B (a) and 3.B (b). This source contributes with 10.9 % of the total emission from the agricultural sector in 2018. The major part of the emission originates from the production of sheep.

#### Methodological issues

#### $CH_4$ emission

The IPCC Tier 2/CS methodology has been used for the estimation of the $CH_4$ emission from manure management. Calculation of volatile solids, VS is based on national value of gross energy intake (GE). Default values is used for the maximum methane producing capacity ($B_0$), digestibility (DE), the ash content and the methane conversion factor (MCF).

For reindeer no default values exists. Thus DE, ASH and $B_o$ estimates for sheep are used. Sheep and reindeer are similar creatures, both ruminants. Greenlandic reindeer weigh an average of 70 kg. Greenlandic sheep weight approximately 50 kg. However, while sheep are fed relative more intensively, reindeer only feed on what they find in nature all year around. On these arguments the best estimate is to use DE, ASH and $B_0$ estimates for sheep on reindeer as well.

Table 16.5.6 $CH_4$ – Manure management – use of national parameters and IPCC default values.

| Parameter | Unit | Sheep | Reindeer | Default or national value |
|---|---|---|---|---|
| Gross energy intake (GE) | MJ pr head pr day | 28.4 | 27.2 | National |
| Digestibility (DE) | Percent | 60 | 60 | IPCC default |
| Ash content (ASH) | Percent | 8 | 8 | IPCC default |
| Volatile solids (VS) | Kg VS pr head pr day | 0.57 | 0.54 | National |
| Max. methane producing capacity ($B_0$) | $M^3$ pr kg VS | 0.19 | 0.19 | IPCC default |
| $CH_4$ conversion factor (MCF), dry lot | Percent | 1 | 1 | IPCC default |
| $CH_4$ conversion factor (MCF), pasture, range and paddock | Percent | 1 | 1 | IPCC default |
| Emission factor | Kg $CH_4$ pr head pr yr | 0.26 | 0.25 | Tier 2 |

There are no changes in stable conditions or feed intake during the years 1990 to 2017. The implied emission factor is therefore the same for all years.

The default emission factor for sheep is 0.19 kg $CH_4$ per head per year. The higher national value is due to a higher estimate for gross energy intake.

Table 16.5.7 shows a decrease in the $CH_4$ emission from manure management from 1990 to 2018 by 17.9 % related to the fall in the number of both reindeer and sheep.

Table 16.5.7 Emission of $CH_4$ from Manure Management 1990-2018, tonnes $CH_4$.

| CRF 3.A | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sheep | 5.2 | 5.2 | 4.7 | 4.2 | 4.6 | 5.1 | 5.2 | 6.0 | 5.2 | 5.5 |
| Reindeer | 1.5 | 1.5 | 1.4 | 1.1 | 1.2 | 1.2 | 1.2 | 1.0 | 1.5 | 0.5 |
| Total, tonnes $CH_4$ | 6.7 | 6.7 | 6.1 | 5.3 | 5.8 | 6.2 | 6.4 | 7.0 | 6.7 | 6.0 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Sheep | 5.3 | 5.3 | 4.9 | 5.0 | 5.3 | 5.5 | 5.5 | 5.6 | 5.5 | 5.2 |
| Reindeer | 0.5 | 0.6 | 0.8 | 0.8 | 0.8 | 0.8 | 0.6 | 0.6 | 0.6 | 0.8 |
| Total, tonnes $CH_4$ | 5.8 | 5.9 | 5.7 | 5.8 | 6.1 | 6.3 | 6.1 | 6.3 | 6.1 | 6.0 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| Sheep | 5.4 | 5.3 | 5.2 | 5.2 | 4.9 | 4.6 | 4.7 | 4.6 | 4.7 | |
| Reindeer | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | |
| Total, tonnes $CH_4$ | 6.1 | 6.0 | 6.0 | 5.9 | 5.6 | 5.3 | 5.5 | 5.4 | 5.5 | |

**$N_2O$ emission**

Based on information from the Greenland Agricultural Consulting Services it is estimated that for sheep 55 % of the N-excretion is taken place in stable (dry lot) and all manure is handled as solid manure. The IPCC default emission value is applied, which means 2.0 % of the N-excretion for solid manure. Sheep is grassing 45 % of the year. The emission from manure deposits on grass is included in "Pasture, Range and Paddock".

Reindeer is grassing all year. The emission from manure deposits on grass is included in "Pasture, Range and Paddock".

The total nitrogen excretion for sheep has decreased by 19.5 % from 1990 to 2018 (Table 16.5.8) due to a drop in the number of livestock.

Table 16.5.8 Total nitrogen excretion for sheep, 1990-2018, tonnes N.

| CRF table 3.B(b) | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| N-excreted, tonnes in total | 154 | 155 | 140 | 122 | 133 | 143 | 147 | 161 | 154 | 138 |
| N-excretion, tonnes in stable | 66 | 66 | 59 | 54 | 59 | 64 | 67 | 76 | 66 | 69 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| N-excreted, tonnes in total | 134 | 137 | 132 | 133 | 140 | 146 | 141 | 144 | 141 | 138 |
| N-excretion, tonnes in stable | 67 | 67 | 63 | 64 | 67 | 70 | 70 | 72 | 70 | 66 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| N-excreted, tonnes in total | 142 | 139 | 138 | 137 | 130 | 122 | 126 | 124 | 127 | |
| N-excretion, tonnes in stable | 68 | 67 | 66 | 66 | 62 | 58 | 60 | 59 | 60 | |

#### Time-series consistency

As shown in Table 16.5.9 total emission from manure management has decreased by 12.0 % from 1990 to 2018 due to a decrease in the number of sheep and reindeer.

Table 16.5.9 Emissions of $N_2O$ and $CH_4$ from Manure Management 1990-2018.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| $N_2O$ emission, tonnes $CO_2$ eqv. | 869 | 877 | 782 | 704 | 771 | 839 | 867 | 983 | 869 | 882 |
| $CH_4$ emission, tonnes $CO_2$ eqv. | 167 | 168 | 151 | 133 | 145 | 155 | 160 | 174 | 167 | 150 |
| Total, tonnes $CO_2$ eqv. | 1 036 | 1 046 | 933 | 837 | 915 | 994 | 1 027 | 1 158 | 1 036 | 1 032 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| $N_2O$ emission, tonnes $CO_2$ eqv. | 858 | 860 | 806 | 818 | 864 | 903 | 896 | 914 | 888 | 854 |
| $CH_4$ emission, tonnes $CO_2$ eqv. | 145 | 148 | 143 | 145 | 152 | 158 | 153 | 156 | 153 | 150 |
| Total, tonnes $CO_2$ eqv. | 1 004 | 1 008 | 949 | 963 | 1 016 | 1 061 | 1 048 | 1 070 | 1 041 | 1 003 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| $N_2O$ emission, tonnes $CO_2$ eqv. | 878 | 857 | 852 | 848 | 796 | 745 | 773 | 757 | 774 | |
| $CH_4$ emission, tonnes $CO_2$ eqv. | 153 | 150 | 149 | 149 | 141 | 133 | 137 | 134 | 137 | |
| Total, tonnes $CO_2$ eqv. | 1 031 | 1 008 | 1 002 | 996 | 936 | 877 | 910 | 891 | 911 | |

### 16.5.5 $N_2O$ emission from Agricultural Soils (CRF sector 3D)

#### Description

$N_2O$ emissions from agricultural soils contributed with 10.5 % of total emissions from the agricultural sector in 2018. Figure 16.5.2 shows the overall development from 1990 to 2018 and the distribution on different sources. Since 1990 $N_2O$ emissions increased suddenly in 1996, when farmers increased their use of inorganic fertilizer significantly. From 1997 to 2007 the emission of $N_2O$ varied with an increasing trend. In 2008 the emission of $N_2O$ increased considerably due to a considerable increase in the use of inorganic fertilizer caused by a periodical drought in the agricultural part of Greenland. In 2009 the use of inorganic fertilizer returned back to a more normal level, thus the emission of $N_2O$ dropped as well. In 2014 the use of inorganic fertilizer increased by of 26.3 % compared to 2013. In 2015 and 2016 the use of inorganic fertilizers returned to the 2012-2013 level causing emissions to drop as well. In 2018 the use of inorganic fertilizers has drop significantly, more than halved compared to 2016, which causes the emissions to drop.

Emissions from urine and dung depositedby grazing animals is a large part of the total emission from agriculture and contributed with 35.6 % of total in 2018. . Of the remaining sources the greatest part of the emission, by 27.7 %, origins from animal manure applied to soils. Emissions from all sources have increased or remained the same from 1990 to 2018 except from animal manure applied to soils and urine and dung deposited by grazing animals both due to a fall in number of reindeer and sheep.

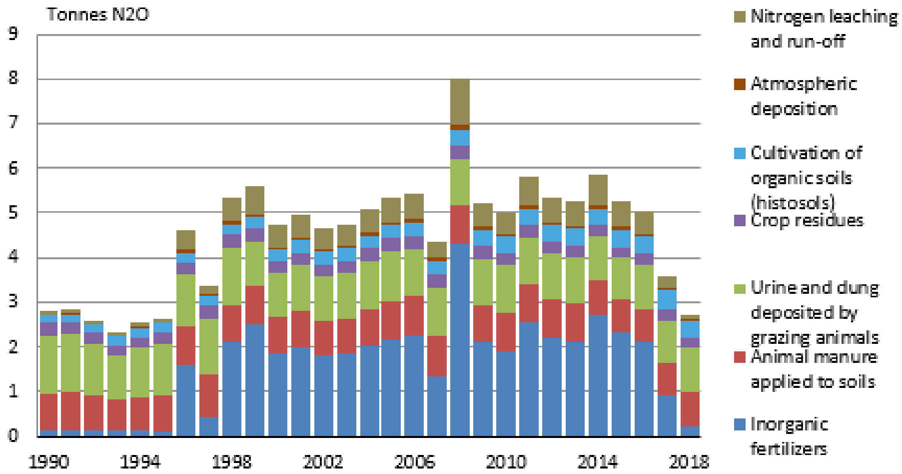



Figure 16.5.2 $N_2O$ emissions from agricultural soils 1990-2018.

**Methodological issues**

To calculate the $N_2O$ emission a combination of IPCC Tier 1a and Tier 1b is used. Tier 1b is used in calculation of emission from crop residues. Emissions of $N_2O$ are closely related to the nitrogen balance. Data concerning the N-excretion, evaporation of ammonia from inorganic fertilizer and grassing animal are based on national values.

The $NH_3$ and $N_2O$ emission factor survey is presented in Table 16.5.10 and shows that except from histosols all $N_2O$ emission factor is based on IPCC default values. The estimated emissions from the different sub-sources are described in the text which follows.

Table 16.5.10 Emissions factor - $N_2O$ emission from Agricultural Soils 1990-2018.

| Agricultural soils – emission sources CRF Table 3.D | Ammonia emission factor | $N_2O$ emission factor (country specific value) | $N_2O$ emission factor (IPCC default value) |
|---|---|---|---|
| | Kg $NH_3$-N pr kg N | kg $N_2O$-N pr ha | kg $N_2O$ -N pr kg N |
| a. Direct $N_2O$ emissions from managed soils | | | |
| 1. Inorganic N fertilizers | 0.03 (CS) | | 0.01 |
| 2. Organic N fertilizers | | | |
| Animal manure applied to soils | 0.20 (IPCC default) | | 0.01 |
| 3. Urine and dung deposited by grazin animals | | | 0.01 |
| 4. Crop residues | | | 0.01 |
| Cultivation of organic soils (i.e. histosols) | | 1.35* | |
| b. Indirect $N_2O$ emissions from managed soils | | | |
| Atmospheric deposition | | | 0.01 |
| Nitrogen leaching and run-off | | | 0.0075 |

CS = country specific value. FracGASF, depending upon the annual mix of inorganic fertilizers.
* Include both emission from cropland and improved grassland. For further details see Section 16.6.

**Direct emissions**

**Inorganic fertilizer**

The calculation of nitrogen (N) applied to soils from use of inorganic fertilizer is based on data on imports from the Statistics Greenland. No data is available before 1994. The consumption for 1990 to 1993 is assumed to be on the same level as 1994. The nitrogen content for each fertilizer type is estimated based on expert judgement from the Danish Plant Directorate (Troels Knudsen, pers. comm.).

Table 16.5.11 shows the consumption of each type of fertilizer in 2018. Furthermore, the ammonia emission factor for each fertilizer is given, based on the values given in EMEP/EEA emission inventory guide book 2013 (Table 3-2). The emission factors are depending on the mean spring temperature estimated to seven degrees in Greenland. The spring temperature has to reflect the time where the fertilizers are applied, which in Greenland normally is June.

Table 16.5.11 Consumption of inorganic fertilizer 2018 and the $NH_3$ emission factors.

| Inorganic fertilizer | Calculation of ammonia emission factor[1] | $NH_3$ emission factor[1] kg $NH_3$-N pr kg N | Consumption[2] t N |
|---|---|---|---|
| Fertilizer type | | | |
| Ammonium sulphate | 0.0013 | 1.30 | NO |
| Ammonium nitrate | 0.0370 | 3.70 | 5.7 |
| Calcium ammonium nitrate | 0.0370 | 3.70 | NO |
| Anhydrous ammonia | 0.0110 | 1.10 | NO |
| Urea | 0.2430 | 24.30 | 1.4 |
| Nitrogen solutions | 0.0481 | 4.81 | NO |
| Ammonium phosphates | 0.1130 | 11.30 | NO |
| Other NK and NPK | 0.0370 | 3.70 | 51.3 |
| Total use of N in inorganic fertilizer | | | 58.4 |
| National emission of $NH_3$-N, tonnes | 0.7 | | |
| Average $NH_3$-N emission (FracGASF) | 0.05 | | |

*ts= means spring temperature=7 degree

[1]) EMEP/EEA (2013).

[2]) Statistics Greenland and the Danish Plant Directorate

The Greenlandic value for the FracGASF is estimated to 0.05 in 2018, which is considerably lower than the recommended default value 0.10 (IPCC 2006. Table 11-3). The major part of the fertilizer types used in Greenland is related to NPK fertilizer where the emission factor is quite low, i.e. 0.0370 kg $NH_3$-N pr kg N. Before 1995 urea accounted for a higher fraction. The value of FracGASF for these years is estimated to 0.16-0.20.

Table 16.5.12 FracGASF, 1990-2018.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| FracGASF | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.16 | 0.04 | 0.06 | 0.03 | 0.03 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| FracGASF | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 | 0.03 | 0.03 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| FracGASF | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.05 | |

Table 16.5.13 shows a general increase in use of fertilizer and a particularl jump upwards in 2008. Due to a relatively small number of farms the individual handling of one farmer has a high effect on the total consumptions. With consumption of fertilizers being based on imports of fertilizers it is not possible to account for fertilizers bought for stockpiling. Thus it is possible that the relative high increase in use of fertilizers in 2008 is due to stockpiling. Another explanation could be that both 2007 and 2008 were relative dry years leading to a considerable decrease in amount of hey harvested. In 2018 the $N_2O$ emission from nitrogen applied as fertilizer decreased by 74.0 %.

Table 16.5.13 Nitrogen applied as fertilizer to agricultural soils 1990-2018.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| N content in inorganic fertilizer, tonnes N | 9 | 9 | 9 | 9 | 9 | 6 | 102 | 28 | 135 | 158 |
| $NH_3$-N emission, tonnes | 2 | 2 | 2 | 2 | 2 | 1 | 4 | 2 | 4 | 5 |
| N in fertilizer applied on soil, tonnes N | 7 | 7 | 7 | 7 | 7 | 5 | 98 | 26 | 131 | 154 |
| $N_2O$ emission, tonnes | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.10 | 1.60 | 0.43 | 2.13 | 2.49 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| N content in inorganic fertilizer, tonnes N | 117 | 126 | 114 | 117 | 128 | 136 | 144 | 86 | 273 | 134 |
| $NH_3$-N emission, tonnes | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 3 | 8 | 4 |
| N in fertilizer applied on soil, tonnes N | 113 | 122 | 111 | 113 | 124 | 132 | 139 | 83 | 265 | 130 |
| $N_2O$ emission, tonnes | 1.84 | 1.97 | 1.79 | 1.84 | 2.01 | 2.14 | 2.26 | 1.36 | 4.29 | 2.10 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| N content in inorganic fertilizer, tonnes N | 120 | 163 | 141 | 136 | 172 | 148 | 134 | 58 | 15 | |
| $NH_3$-N emission, tonnes | 4 | 5 | 4 | 4 | 5 | 5 | 4 | 2 | 1 | |
| N in fertilizer applied on soil, tonnes N | 116 | 158 | 136 | 132 | 166 | 143 | 130 | 56 | 14 | |
| $N_2O$ emission, tonnes | 1.89 | 2.56 | 2.21 | 2.13 | 2.70 | 2.33 | 2.11 | 0.92 | 0.24 | |

#### Manure applied to soil

The amount of nitrogen applied to soils from sheep on stables is estimated as the N-excretion in stables minus the ammonia emission, which occur in stables, under storage and in relation to the application of manure. There are no measurements of ammonia emission from stables in Greenland. Thus IPCC default is used. However, the FracGASM default at 0.20 (IPCC 2006, Table 11-3) match the Danish emission ammonia from sheep, which are estimated to 24 % in 1990 reduced to 19 % in 2008. A lower ammonia emission in Greenland is expected due to the cold climate, but on the other hand no ammonia reducing measures are implemented as in Denmark. The FracGASM at 0.20 are therefore considered as reliable.

Table 16.5.14 shows the development in nitrogen excretion in stables, the estimated amount of N applied on soil and the $N_2O$ emission.

Table 16.5.14 Nitrogen applied as manure to agricultural soils 1990-2018.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| N-excretion in stable, tonnes N | 66 | 66 | 59 | 54 | 59 | 64 | 67 | 76 | 66 | 69 |
| $NH_3$-N emission, tonnes N | 13 | 13 | 12 | 11 | 12 | 13 | 13 | 15 | 13 | 14 |
| N in manure applied on soil, tonnes N | 53 | 53 | 47 | 43 | 47 | 51 | 53 | 61 | 53 | 55 |
| $N_2O$ emission, tonnes $N_2O$ | 0.83 | 0.84 | 0.74 | 0.67 | 0.74 | 0.81 | 0.84 | 0.96 | 0.83 | 0.87 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| N-excretion in stable, tonnes N | 67 | 67 | 63 | 64 | 67 | 70 | 70 | 72 | 70 | 66 |
| $NH_3$-N emission, tonnes N | 13 | 13 | 13 | 13 | 13 | 14 | 14 | 14 | 14 | 13 |
| N in manure applied on soil, tonnes N | 54 | 54 | 50 | 51 | 54 | 56 | 56 | 57 | 56 | 53 |
| $N_2O$ emission, tonnes $N_2O$ | 0.85 | 0.85 | 0.79 | 0.80 | 0.85 | 0.88 | 0.88 | 0.90 | 0.87 | 0.84 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| N-excretion in stable, tonnes N | 68 | 67 | 66 | 66 | 62 | 58 | 60 | 59 | 60 | |
| $NH_3$-N emission, tonnes N | 14 | 13 | 13 | 13 | 12 | 12 | 12 | 12 | 12 | |
| N in manure applied on soil, tonnes N | 55 | 53 | 53 | 53 | 49 | 46 | 48 | 47 | 48 | |
| $N_2O$ emission, tonnes $N_2O$ | 0.86 | 0.84 | 0.83 | 0.83 | 0.78 | 0.73 | 0.75 | 0.74 | 0.76 | |

**Crop residue**

The cultivated area is approximately 1,148 ha with the main part as grass fields, only 10.5 ha are used for potato production. The cultivated area decreased from 2009 to 2012 due to the shutdown of four farms. Since 2012 the cultivated area has increased slightly. To estimate the emission from crop residue, IPCC Tier 1b has been applied. $N_2O$ emissions from crop residues are calculated based on the total above- and belowground N-content in crop residue returned to soil, which in Greenland includes residue of leafs and roots from grass fields and the top and root from potatoes. Harvest of potatoes and grass-clover are calculated based on relatively few observations related to Danish conditions, but are at present the best available data.

Nitrogen content in grass-clover and potatoes is calculated by using IPCC default factors (IPCC 2006, Table 11.2). In the 2016 submission, the dry matter fraction (DRY) of harvested grass-clover was changed from former Danish DRY-factor 0.27 to the IPCC default DRY factor of 0.9.

Table 16.5.15 N-content in crop residues 2018.

| | Husks | Stubble | Top | Leafs | Frequency of ploughing | Nitrogen content in crop residue | |
|---|---|---|---|---|---|---|---|
| Crop type | kg N pr ha | | | | No. of years between ploughing | kg N pr ha | kg N |
| Potatoes | 7.1 | - | 4.8 | - | 1 | 12.0 | 125 |
| Grass-Clover mixtures in rotation | - | 8.9 | - | 5.2 | 5 | 14.1 | 15 971 |
| Total N from crop residue, kg | | | | | | | 16 097 |

Reference: National data and IPCC 2006 (Table 11.2).

To calculate the $N_2O$ emission the IPCC standard emission factor 1.0 % is used. The national emission from crop residues has been relatively stable from 1990 to 2018 (Table 16.5.16).

Table 16.5.16 Emission from crop residues 1990-2018.

| Crop residue | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Potatoes, kg N | - | - | - | - | - | - | - | - | - | - |
| Grass-Clover, kg N | 17 477 | 17 657 | 15 698 | 14 256 | 15 626 | 17 069 | 17 682 | 20 288 | 17 477 | 18 422 |
| Crop residue total, kg N | 17 477 | 17 657 | 15 698 | 14 256 | 15 626 | 17 069 | 17 682 | 20 288 | 17 477 | 18 422 |
| $N_2O$ emission, kg | 275 | 277 | 247 | 224 | 246 | 268 | 278 | 319 | 275 | 289 |
| *continued* | 2000 | 2001 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
| Potatoes, kg N | - | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 78 |
| Grass-Clover, kg N | 17 929 | 17 885 | 16 633 | 16 889 | 17 875 | 18 694 | 18 670 | 19 034 | 18 486 | 17 661 |
| Crop residue total, kg N | 17 929 | 17 944 | 16 693 | 16 949 | 17 935 | 18 754 | 18 729 | 19 093 | 18 546 | 17 739 |
| $N_2O$ emission, kg | 282 | 282 | 262 | 266 | 282 | 295 | 294 | 300 | 291 | 279 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| Potatoes, kg N | 78 | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 125 | |
| Grass-Clover, kg N | 18 179 | 17 743 | 17 633 | 17 534 | 16 432 | 15 348 | 15 952 | 15 597 | 15 971 | |
| Crop residue total, kg N | 18 256 | 17 868 | 17 759 | 17 659 | 16 558 | 15 473 | 16 077 | 15 722 | 16 097 | |
| $N_2O$ emission, kg | 287 | 281 | 279 | 278 | 260 | 243 | 253 | 247 | 253 | |

**Cultivation of histosols**

$N_2O$ emissions from histosols are based on the area with organic soils multiplied by the emission factor of 1.35 kg $N_2O$-N pr. kg N in 2018. See Section 16.6 on LULUCF for further description on cultivation of histosols.

Table 16.5.17 shows an increase in the $N_2O$ emission from 1990 to 2018 due an increase in the agricultural area.

Table 16.5.17 Activity data and emission from cultivation of histosols 1990-2018.

| CRF – Table 3.D | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Cultivated histosols, ha | 123 | 129 | 136 | 142 | 149 | 155 | 161 | 168 | 174 | 181 |
| $N_2O$ emission, kg | 160 | 169 | 177 | 186 | 194 | 203 | 211 | 220 | 228 | 237 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Cultivated histosols, ha | 187 | 195 | 214 | 220 | 223 | 232 | 242 | 245 | 250 | 274 |
| $N_2O$ emission, kg | 245 | 260 | 285 | 293 | 297 | 308 | 321 | 325 | 332 | 365 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| Cultivated histosols, ha | 268 | 270 | 268 | 270 | 272 | 277 | 280 | 287 | 287 | |
| $N_2O$ emission, kg | 357 | 364 | 361 | 364 | 366 | 372 | 377 | 380 | 386 | |

**Pasture, Range and Paddock**

The amount of nitrogen deposited on grass includes grassing from reindeer 365 days a year and from sheep 164 days a year. An ammonia emission factor of 7 % is used for all animal categories based on investigations from the Netherlands and the United Kingdom (Jarvis et al., 1989a, Jarvis et al., 1989b and Bussink, 1994). EMEP/EEA Emission Inventory Guidebook 2013 use a similar emission factor at 6 % for grassing dairy cattle (calculated from 3B, Appendix B).

Table 16.5.18 shows the estimated values of N-excretion from grassing animals, ammonia emission and $N_2O$ emission. As a consequence of an overall drop in number of reindeer and recently also sheeps $N_2O$ emission has decreased from 1990 to 2018.

Table 16.5.18 Emission from grassing animals 1990-2018.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| N-excretion on grass, tonnes N | 88 | 89 | 81 | 69 | 75 | 79 | 81 | 84 | 88 | 69 |
| $NH_3$-N emission, tonnes | 6 | 6 | 6 | 5 | 5 | 6 | 6 | 6 | 6 | 5 |
| N deposited on grass, tonnes N | 82 | 83 | 75 | 64 | 69 | 73 | 75 | 78 | 82 | 64 |
| $N_2O$ emission, tonnes | 1.29 | 1.30 | 1.18 | 1.00 | 1.09 | 1.15 | 1.18 | 1.23 | 1.29 | 1.01 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| N-excretion on grass, tonnes N | 67 | 69 | 69 | 70 | 73 | 75 | 71 | 73 | 71 | 72 |
| $NH_3$-N emission, tonnes | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| N deposited on grass, tonnes N | 62 | 64 | 64 | 65 | 68 | 70 | 66 | 68 | 66 | 67 |
| $N_2O$ emission, tonnes | 0.97 | 1.01 | 1.01 | 1.02 | 1.06 | 1.10 | 1.03 | 1.06 | 1.04 | 1.05 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| N-excretion on grass, tonnes N | 73 | 72 | 72 | 71 | 68 | 65 | 66 | 65 | 66 | |
| $NH_3$-N emission, tonnes | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| N deposited on grass, tonnes N | 68 | 67 | 67 | 66 | 63 | 60 | 62 | 61 | 62 | |
| $N_2O$ emission, tonnes | 1.07 | 1.05 | 1.05 | 1.04 | 0.99 | 0.94 | 0.97 | 0.95 | 0.97 | |

**Indirect emissions**

**Atmospheric deposition**

Atmospheric deposition includes ammonia emission from manure management, use of inorganic fertilizer and from grassing animals.

$N_2O$ emission from atmospheric deposition has more than doubled from since 1990. Even though the number of reindeer and sheep has decreased, the increasing use of inorganic fertilizer has increased total $N_2O$ emission from atmospheric deposition by 62.2 % from 1990 to 2018.

Table 16.5.19 Emission from atmospheric deposition 1990-2018.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| $NH_3$-N manure management, tonnes | 13 | 13 | 12 | 11 | 12 | 13 | 13 | 15 | 13 | 14 |
| $NH_3$-N inorganic fertlizer, tonnes | 2 | 2 | 2 | 2 | 2 | 1 | 4 | 2 | 4 | 5 |
| $NH_3$-N pasture, tonnes | 6 | 6 | 6 | 5 | 5 | 6 | 6 | 6 | 6 | 5 |
| $NH_3$-N total, tonnes | 21 | 21 | 19 | 17 | 19 | 19 | 23 | 23 | 23 | 24 |
| $N_2O$ emission, tonnes | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.07 | 0.03 | 0.06 | 0.08 |
| *continued* | 2001 | 2002 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| $NH_3$-N manure management, tonnes | 13 | 13 | 13 | 13 | 13 | 14 | 14 | 14 | 14 | 13 |
| $NH_3$-N inorganic fertlizer, tonnes | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 3 | 8 | 4 |
| $NH_3$-N pasture, tonnes | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| $NH_3$-N total, tonnes | 22 | 22 | 21 | 21 | 22 | 23 | 23 | 23 | 27 | 22 |
| $N_2O$ emission, tonnes | 0.06 | 0.06 | 0.05 | 0.06 | 0.06 | 0.07 | 0.07 | 0.05 | 0.13 | 0.06 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| $NH_3$-N manure management, tonnes | 14 | 13 | 13 | 13 | 12 | 12 | 12 | 12 | 12 | |
| $NH_3$-N inorganic fertlizer, tonnes | 4 | 5 | 4 | 4 | 5 | 5 | 4 | 2 | 1 | |
| $NH_3$-N pasture, tonnes | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| $NH_3$-N total, tonnes | 22 | 23 | 23 | 22 | 22 | 21 | 21 | 18 | 17 | |
| $N_2O$ emission, tonnes | 0.06 | 0.08 | 0.07 | 0.08 | 0.08 | 0.08 | 0.06 | 0.03 | 0.01 | |

**Nitrogen leaching and Run-off**

The amount of nitrogen lost by leaching and run-off is calculated by using the IPCC default FracLEACH-(H) at 0.3 (IPCC 2006, Table 11-3).

$N_2O$ emission from N-leaching and runoff more than doubled from 1990 to 2008. However, lately in 2009-2017 total $N_2O$ emission has dropped to a 0.26-0.67 tonnes. In 2018 emission from N-neaching and runoff fell due to a decreased emission of nitrogen from synthetic fertiliser.

From 1990 to 2016 total nitrogen content in manure has decreased due to a fall in the number of reindeer and sheep. However, in the same period the use of inorganic fertilizers has increased significantly causing the overall $N_2O$ emission from N-leaching and runoff to increase. In 2017 the use of inorganic fertilizers has decreased significantly compared to 2016. The decrease in 2017 causing the overall $N_2O$ emission from N-leaching and runoff to decrease. In 2018 the use of inorganic fertilizers further decreased causing the overall $N_2O$ emission from N-leaching and runoff to reduce further.

Table 16.5.20 Emission from N-leaching and runoff 1990-2018.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| N-excretion total, tonnes N | 154 | 155 | 140 | 122 | 133 | 143 | 147 | 161 | 154 | 138 |
| N in inorganic fertilizer, tonnes | 9 | 9 | 9 | 9 | 9 | 6 | 102 | 28 | 135 | 158 |
| $N_2O$ emission, tonnes | 0.09 | 0.10 | 0.09 | 0.08 | 0.09 | 0.08 | 0.42 | 0.17 | 0.54 | 0.63 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| N-excretion total, tonnes N | 134 | 137 | 132 | 133 | 140 | 146 | 141 | 144 | 141 | 138 |
| N in inorganic fertilizer, tonnes | 117 | 126 | 114 | 117 | 128 | 136 | 144 | 86 | 273 | 134 |
| $N_2O$ emission, tonnes | 0.48 | 0.51 | 0.46 | 0.47 | 0.52 | 0.55 | 0.57 | 0.37 | 1.03 | 0.54 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| N-excretion total, tonnes N | 142 | 139 | 138 | 137 | 130 | 122 | 126 | 124 | 127 | |
| N in inorganic fertilizer, tonnes | 120 | 163 | 141 | 136 | 172 | 148 | 134 | 58 | 15 | |
| $N_2O$ emission, tonnes | 0.49 | 0.64 | 0.56 | 0.54 | 0.67 | 0.58 | 0.53 | 0.26 | 0.11 | |

**Activity data**

Table 16.5.21 provides an overview on activity data from 1990 to 2018 used for the estimation of $N_2O$ emission from agricultural soils. For all emission sources the unit tonnes of nitrogen are used except from cultivation of histosols, where the unit is given as hectare.

Table 16.5.21 Activity data - agricultural soils 1990-2018, tonnes N (cultivation of histosols = ha).

| CRF – Table 3.D | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| A. Direct $N_2O$ emissions from managed soils | | | | | | | | | | |
| Inorganic fertilizer | 9 | 9 | 9 | 9 | 9 | 6 | 102 | 28 | 135 | 158 |
| Animal manure applied to soils | 53 | 53 | 47 | 43 | 47 | 51 | 53 | 61 | 53 | 55 |
| Urine and dung deposited by grazing animals | 82 | 83 | 75 | 64 | 69 | 73 | 75 | 78 | 82 | 64 |
| Crop residue | 17 | 18 | 16 | 14 | 16 | 17 | 18 | 20 | 17 | 18 |
| Cultivation of histosols | 123 | 129 | 136 | 142 | 149 | 155 | 161 | 168 | 174 | 181 |
| B. Indirect $N_2O$ emissions from managed soils | | | | | | | | | | |
| Atmospheric deposition | 2 | 2 | 2 | 2 | 2 | 1 | 4 | 2 | 4 | 5 |
| Nitrogen leaching and run-off | 8 | 8 | 7 | 7 | 7 | 7 | 36 | 14 | 46 | 53 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| A. Direct $N_2O$ emissions from managed soils | | | | | | | | | | |
| Inorganic fertilizer | 117 | 126 | 114 | 117 | 128 | 136 | 144 | 86 | 273 | 134 |
| Animal manure applied to soils | 54 | 54 | 50 | 51 | 54 | 56 | 56 | 57 | 56 | 53 |
| Urine and dung deposited by grazing animals | 62 | 64 | 64 | 65 | 68 | 70 | 66 | 68 | 66 | 67 |
| Crop residue | 18 | 18 | 17 | 17 | 18 | 19 | 19 | 19 | 19 | 18 |
| Cultivation of histosols | 187 | 195 | 214 | 220 | 223 | 232 | 242 | 245 | 250 | 274 |
| B. Indirect $N_2O$ emissions from managed soils | | | | | | | | | | |
| Atmospheric deposition | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 3 | 8 | 4 |
| Nitrogen leaching and run-off | 40 | 43 | 39 | 40 | 44 | 46 | 49 | 32 | 88 | 45 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| A. Direct $N_2O$ emissions from managed soils | | | | | | | | | | |
| Inorganic fertilizer | 120 | 163 | 141 | 136 | 172 | 148 | 134 | 58 | 15 | |
| Animal manure applied to soils | 55 | 53 | 53 | 53 | 49 | 46 | 48 | 47 | 48 | |
| Urine and dung deposited by grazing animals | 68 | 67 | 67 | 66 | 63 | 60 | 62 | 61 | 62 | |
| Crop residue | 18 | 18 | 18 | 18 | 17 | 15 | 16 | 16 | 16 | |
| Cultivation of histosols | 268 | 270 | 268 | 270 | 272 | 277 | 280 | 287 | 287 | |
| B. Indirect $N_2O$ emissions from managed soils | | | | | | | | | | |
| Atmospheric deposition | 4 | 5 | 4 | 4 | 5 | 5 | 4 | 2 | 1 | |
| Nitrogen leaching and run-off | 42 | 54 | 48 | 46 | 56 | 49 | 45 | 22 | 9 | |

**Time-series consistency**

$N_2O$ emissions from agricultural soils have increased from 2.8 tonnes $N_2O$ in 1990 to 5.1 tonnes $N_2O$ in 2016 and then decreased to 2.7 in 2018. The decrease in 2018 compared to 2016, is a consequence of a significant reduction in the use of nitrogen in inorganic fertilizer.

Table 16.5.22 Emissions of $N_2O$ from Agricultural Soils 1990–2018, tonnes $N_2O$.

| CRF – Table 3.D | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Total $N_2O$ emission | 2.8 | 2.8 | 2.6 | 2.3 | 2.5 | 2.6 | 4.6 | 3.4 | 5.4 | 5.6 |
| A. Direct $N_2O$ emissions from managed soils | | | | | | | | | | |
| Inorganic fertilizer | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 1.6 | 0.4 | 2.1 | 2.5 |
| Animal manure applied on soil | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 | 0.8 | 0.8 | 1.0 | 0.8 | 0.9 |
| Urine and dung deposited by grazing animals | 1.3 | 1.3 | 1.2 | 1.0 | 1.1 | 1.2 | 1.2 | 1.2 | 1.3 | 1.0 |
| Crop residue | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Cultivation of histosols | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| B. Indirect $N_2O$ emissions from managed soils | | | | | | | | | | |
| Atmospheric deposition | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.1 |
| Nitrogen leaching and run-off | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.4 | 0.2 | 0.5 | 0.6 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Total $N_2O$ emission | 4.7 | 4.9 | 4.7 | 4.7 | 5.1 | 5.3 | 5.4 | 4.4 | 8.0 | 5.2 |
| A. Direct $N_2O$ emissions from managed soils | | | | | | | | | | |
| Inorganic fertilizer | 1.8 | 2.0 | 1.8 | 1.8 | 2.0 | 2.1 | 2.3 | 1.4 | 4.3 | 2.1 |
| Animal manure applied on soil | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.9 | 0.9 | 0.9 | 0.9 | 0.8 |
| Urine and dung deposited by grazing animals | 1.0 | 1.0 | 1.0 | 1.0 | 1.1 | 1.1 | 1.0 | 1.1 | 1.0 | 1.0 |
| Crop residue | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Cultivation of histosols | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 |
| B. Indirect $N_2O$ emissions from managed soils | | | | | | | | | | |
| Atmospheric deposition | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Nitrogen leaching and run-off | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 | 0.4 | 1.0 | 0.5 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| Total $N_2O$ emission | 5.0 | 5.8 | 5.4 | 5.3 | 5.8 | 5.3 | 5.1 | 3.6 | 2.7 | |
| A. Direct $N_2O$ emissions from managed soils | | | | | | | | | | |
| Inorganic fertilizer | 1.9 | 2.6 | 2.2 | 2.1 | 2.7 | 2.3 | 2.1 | 0.9 | 0.2 | |
| Animal manure applied on soil | 0.9 | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 | 0.8 | 0.7 | 0.8 | |
| Urine and dung deposited by grazing animals | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 | 0.9 | 1.0 | 1.0 | 1.0 | |
| Crop residue | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 | 0.2 | 0.3 | |
| Cultivation of histosols | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | |
| B. Indirect $N_2O$ emissions from managed soils | | | | | | | | | | |
| Atmospheric deposition | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | |
| Nitrogen leaching and run-off | 0.5 | 0.6 | 0.6 | 0.5 | 0.7 | 0.6 | 0.5 | 0.3 | 0.1 | |

### 16.5.6 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC Guidelines (IPCC, 2006). The uncertainty has been estimated for all sources included in the reporting for agricultural sector. The uncertainties for the activity data and emission factors are shown in Table 16.5.23.

Table 16.5.23 Uncertainties for activity data and emission factors for agriculture.

| Subsector | Pollutant | Activity data uncertainty | Emission factor uncertainty |
|---|---|---|---|
| 3A Enteric Fermentation | $CH_4$ | 10 | 100 |
| 3B Manure Management | $CH_4$ | 10 | 100 |
| 3B Manure Management | $N_2O$ | 10 | 100 |
| 3D Agricultural soils | $N_2O$ | 20 | 50 |
| 3G Liming | $CO_2$ | 5 | 50 |

The resulting uncertainties for the individual greenhouse gases and the total uncertainty on the greenhouse gas emission are shown in Table 16.5.24.

Table 16.5.24 Uncertainties for the emission estimates.

| | Uncertainty % | Trend 1990-2018 % | Trend uncertainty % |
|---|---|---|---|
| GHG | ± 80 | -15.5 | ± 9.9 |
| $CO_2$ | ± 50 | -50.0 | ± 3.5 |
| $CH_4$ | ± 98 | -17.3 | ± 11.4 |
| $N_2O$ | ± 56 | -7.2 | ± 15.0 |

### 16.5.7 Source specific QA/QC

The elaboration of a formal QA/QC plan is to be completed.

However, data on livestock, land-use categories, inorganic fertilizers and cultivation of histosols has gone through a great deal of quality work with regard to accuracy, comparability and completeness.

All external data used for the emission inventory submission are archived in spreadsheets. Data are archived annually in order to ensure that the basic data for a given report are always available in their original form.

Annual data on livestock, land-use categories, inorganic fertilizers and cultivation of histosols are compared with previous years and large discrepancies are checked.

Safely stored and quality checked activity data are then processes by using a methodological approach consistent with international guidelines.

Calculated emission factors are compared with guideline emission factors to ensure that they are reasonable. The calculations follow the principle in international guidelines.

During data processing, it is checked that calculations are being carried out correctly. However, a documentation plan for this needs to be elaborated.

Time-series for activity data, emission factors and calculated emissions are used to identify possible errors in the calculation procedure. In fact, during the calculation, numerous controls take place to ensure correctness. Sums are checked of the various stages in the calculation procedure. Implied emission factors are compared to emission factors.

Every single time-series imported to the CRF Reporter is checked for annual activity, units for activity, emission factor and emissions. Additional checks are performed on the database. The database encloses every single activity data, emission factors, emission, notation key and comment imported to the CRF Reporter.

### 16.5.8 Source specific recalculations and improvements

In this 2020 submission there has been no revisions in the agricultural sector.

Table 16.5.25 shows recalculations in the waste sector compared to the 2019 submission. No changes occur.

Table 16.5.25 Changes in GHG emission in the agricultural sector compared to the 2019 submission.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Previous inventory, Gg $CO_2$ eqv. | 9.5 | 9.6 | 8.6 | 7.6 | 8.3 | 8.9 | 9.7 | 10.2 | 10.3 | 9.6 |
| Recalculated, Gg $CO_2$ eqv. | 9.5 | 9.6 | 8.6 | 7.6 | 8.3 | 8.9 | 9.7 | 10.2 | 10.3 | 9.6 |
| Change in Gg $CO_2$ eqv. | - | - | - | - | - | - | - | - | - | - |
| Change in pct. | - | - | - | - | - | - | - | - | - | - |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Previous inventory, Gg $CO_2$ eqv. | 9.1 | 9.3 | 8.9 | 9.0 | 9.5 | 9.9 | 9.7 | 9.6 | 10.5 | 9.5 |
| Recalculated, Gg $CO_2$ eqv. | 9.1 | 9.3 | 8.9 | 9.0 | 9.5 | 9.9 | 9.7 | 9.6 | 10.5 | 9.5 |
| Change in Gg $CO_2$ eqv. | - | - | - | - | - | - | - | - | - | - |
| Change in pct. | - | - | - | - | - | - | - | - | - | - |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| Previous inventory, Gg $CO_2$ eqv. | 9.6 | 9.7 | 9.5 | 9.4 | 9.1 | 8.5 | 8.7 | 8.1 | - | |
| Recalculated, Gg $CO_2$ eqv. | 9.6 | 9.7 | 9.5 | 9.4 | 9.1 | 8.5 | 8.7 | 8.1 | 8.0 | |

### 16.5.9 Source specific planned improvements

The Greenlandic emission inventory for the agricultural sector largely meets the request as set down in the IPCC Good Practice Guidance. Thus for the moment improvements especially concern the QA/QC practice.

### 16.5.10 References


Greenland Agricultural Consulting Service: Statistics on livestock (sheep and reindeer) and background data on land use (cropland and grassland).

Bussink, D.W. 1994: Relationship between ammonia volatilisation and nitrogen fertilizer application rate, intake and excretion of herbage nitrogen by cattle on grazed swards. Fertil. Res. 38, 111-121.

Djurhuus, J. & Hansen, E.M. 2003: Notat vedr. tørstof og kvælstof i efterladte planterester for landbrugsjord – af 21. maj 2003. Forskningscenter Foulum, Tjele. (In Danish).

EMEP/EEA Guidebook 2013. EMEP/EEA air pollutant emission in-ventory guidebook 2013. Published by the EEA with the CLRTAP Task Force on Emission Inventories and Projections responsible for the technical content of the chapters. Technical report No 12/2013. Available at: http://www.eea.europa.eu/publications/emep-eea-guidebook-2013 (23/01-2015).

IPCC, 1997: Revised 1996 IPCC Guidelines for National Greenhouse Gas inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/gl/invs6.htm (15-04-2007).

IPCC, 2000: Penman, J., Kruger, D., Galbally, I., Hiraishi, T., Nyenzi, B., Emmanuel, S., Buendia, L., Hoppaus, R., Martinsen, T., Meijer, J., Miwa, K. &

Tanabe, K. (Eds). Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Published: IPCC/OECD/-IEA/IGES, Hayama, Japan. Available at:
http://www.ipcc-nggip.iges.or.jp/public/gp/english/ (15-04-2007).

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. & Tanabe K. (eds). Published: IGES, Japan. Available at:
http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (21-02-2014).

Jarvis, S.C., Hatch, D.J. & Roberts, D.H., 1989a: The effects of grassland management on nitrogen losses from grazed swards through ammonia volatilization; the relationship to extral N returns from cattle. J. Agric. Sci. Camb. 112,205-216.

Jarvis, S.C., Hatch, D.J. & Lockyer, D.R., 1989b: Ammonia fluxes from grazed grassland annual losses form cattle production systems and their relation to nitrogen inputs. J. Agric. Camp. 113, 99-108.

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Nielsen, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Thomsen, M., Hjelgaard, K., Fauser, P., Bruun, H.G., Johannsen, V.K., Nord-Larsen, T., Vesterdal, L., Callesen, I., Caspersen, O.H., Rasmussen, E., Petersen, S.B., Baunbæk, L. & Hansen, M.G. 2017. Denmark's National Inventory Report 2017. Emission Inventories 1990-2015 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. 890 pp. – Scientific Report from DCE – Danish Center for Environment and Energy no. 231. Available at: http://dce2.au.dk/pub/SR231.pdf

Rasmussen, H.E., 1992: Reindeer Management in Southern Greenland (1992). Published in Danish as "Den sydgrønlandske rendrift" (1992).

Statistics Greenland, Stat Bank: Data on average temperature in June in Southern Greenland. Available at:
http://bank.stat.gl/database/Greenland/Energy/Climate/Climate.asp

Statistics Greenland, 1990-2018 Data on livestock (sheep and reindeer).

## 16.6 LULUCF (CRF sector 4)

### 16.6.1 Overview of LULUCF

This LULUCF chapter covers only the territory of Greenland. Greenland is part of the Danish Kingdom.


Figure 16.6.1 Municipalities and major cities in Greenland.

Greenland is the world's largest non-continental island located on the northern American continent between the Arctic Ocean and the North Atlantic Ocean, northeast of Canada. The northernmost point of Greenland, Cape Morris Jesup, is only 740 km from the North Pole. The southernmost point is Cape Farewell, which lies at about the same latitude as Oslo in Norway. Geographical coordinates are 72 00 N, 40 00 W.

Greenland is covering approximately 2,166,086 $km^2$. It has been estimated that 81 % is covered permanently with ice leaving only 410,449 $km^2$ ice free. The distance from the South to the North is 2,670 km, and from East to West 1,050 km.

The terrain is flat to gradually sloping ice cap, which covers all but a narrow, mountainous, barren, rocky coast. The ice cap is up to 3 km thick, and contains 10 per cent of the world's resources of freshwater.

The climate is arctic to sub-arctic with cool winters and cold summers in which the mean temperature does not exceed 10° C.

The mean temperature in January is for Nuuk, -8.6°, Kangerlussuaq, -17.0° and Ilulissat -9.6° (2007) and for July: Nuuk 7.7°, Kangerlussuaq 11.5° and Ilulissat 9.6° (2007).

Greenland is normally defined as having three different climatic zones. For the purpose of reporting is used the definition "Polar and Moist" according to IPCC 2006 Guidelines although some areas may qualify as arctic deserts.

The sparse population is confined to small settlements along the coast, but close to one-quarter of the population lives in the capital, Nuuk. The total population in January 2016 was 55 847 inhabitants.

Due to the cold climate and the small constant population there is almost no land use change occurring. The total area with Forests has been estimated to 218.5 hectares and 10.5 hectares with Cropland. Grassland is divided into improved Grassland covering 1096 hectares and unimproved Grassland covering 240 894 hectares. Wetlands consist of man made water reservoirs – in total 1076 hectares. Settlements cover 5761 hectares. Land classified as "Other Land" is then 99.9 % of the total area.

In the following text the abbreviations are used in accordance with definitions in the IPCC guidelines:

| | |
|---|---|
| A: | Afforestation, areas with forest established after 1990 under Article 3.3. |
| R: | Reforestation, areas which have temporarily been unstocked for less than 10 years - included under Article 3.4. |
| D: | Deforestation, areas where forests are permanently removed to allow for other land use, included under Article 3.3. |
| FF: | Forest remaining Forest, areas remaining forest after 1990. |
| FL: | Forest Land meeting the definition of forests. |
| CL: | Cropland. |
| GL: | Grassland. |
| SE: | Settlements. |
| OL: | Other land, unclassified land. |
| HWP: | Harvested Wood Products. |

The LULUCF sector differs from the other sectors in that it contains both sources and sinks of carbon dioxide. LULUCF are reported in the CRF format. Removals are given as negative figures and emissions are reported as positive figures in accordance with the guidelines.

In total the LULUCF sector has been estimated as a net source of 1.04 kt $CO_2$ equivalents in 2015 equivalent to 0.2 % of the total Greenlandic emission.

The overall land use change from 1990 to 2015 is very small. Afforestation has been made on 14 hectares. No deforestation has occurred and the Cropland area has increased from none to 10.5 hectares.

The emission data are reported in the new CRF format under IPCC categories 4A (Forestry), 4B (Cropland), 4C (Grassland), 4D (Wetlands), 4E (Settlements) and 4F (Other Land).

Fertilisation of forests and other land is not occurring and all fertilizer consumption is therefore reported in the agricultural sector. No drainage of forest soils is made. All liming is reported under Grassland because liming is not occurring in the forests and the very small area with Cropland. Field burning of wooden biomass is not occurring. Wildfires may occur sporadic in the mountains and these are reported as "Other land". Hence, wildfires are reported as NO.

Table 16.6.1 gives an overview of the emission from the LULUCF sector in Greenland. The Forests are a net sink. Cropland is ranging from being zero in 1990 (no Cropland was occurring in 1990) to being a net source in 2015. GL has been estimated to be a net source too. The major emission from CL and GL in 2015 is due to cultivation of organic soils.

Table 16.6.1 Overall emission (kt $CO_2$-eq) from the LULUCF sector in Greenland, 1990-2015.

| GREENHOUSE GAS SOURCE AND SINK CATEGORIES | 1990 | 1995 | 2000 | 2005 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|
| **4. Land use, land-use change and forestry** | 0.21 | 0.38 | 0.52 | 0.63 | 1.42 | 1.21 | 1.32 | 1.12 | 1.13 | 1.04 |
| A. Forest land | IE,NO | -0.02 | -0.03 | -0.05 | -0.04 | -0.04 | -0.04 | -0.05 | -0.05 | -0.05 |
| B. Cropland | NO | NO | NO | 0.02 | 0.03 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| C. Grassland | 0.21 | 0.41 | 0.55 | 0.66 | 1.42 | 1.20 | 1.31 | 1.12 | 1.13 | 1.04 |
| D. Wetlands | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| E. Settlements | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| F. Other land | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| G. Harvested wood products | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |

### 16.6.2 Forest remaining forest (4A1)

**Forests and forest management**

Greenland has virtually no forests and therefore there exist no official forest statistics. All forests are situated in the most southern part of Greenland. In an attempt to introduce trees to Greenland research were carried out to find species adaptable to the Greenlandic climate. This resulted in establishment of the Greenlandic Arboretum, which covers 150 hectares out of the total area of 218.5 hectares, Figure 16.6.2 and Table 16.6.2. Information about the Greenlandic Arboret can be found at
http://ign.ku.dk/om/arboreter/arboret-groenland/skovplantninger

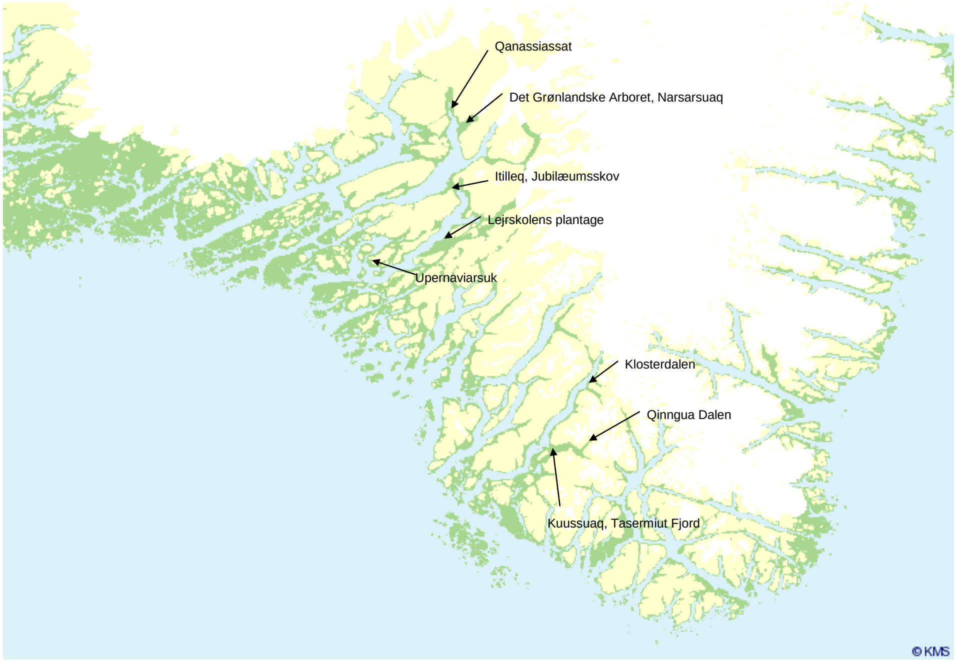



Figure 16.6.2 The position of the Greenlandic forests (Courtesy to Rasmus Enoksen Christensen).

Table 16.6.2 Forests in Greenland 1990 and 2015.

| Location | Established | Dominant tree | Area,ha | 1990 average tree height (m) | 2014 average tree height | Density 1990 (trees pr ha) | Density 2009 |
|---|---|---|---|---|---|---|---|
| Qinngua Valley | Natural | Birch and mountain ash | 45 | n.a | 6 | 100 | 100 |
| Qanassiassat Forest | 1953-63 | Conifer | 1 | 5 | 12.06 | 1500 | 1000 |
| Kuussuaq Forest | 1962-64 -1982 | Conifer | 5 | 3 | 11.5 | 1300 | 900 |
| Kuussuaq Forest | 2008 | Conifer | 3 | *** | < 1 | *** | 3500 |
| Greenland Arboretum | (1976-1980) | Conifer | 3 | 4 | 7 | 300 | 300 |
| Greenland Arboretum | 1980 - | Conifer | 150 | 2 | 3 | 1500 | 1700 |
| Itilleq | 2004-2005 | Conifer | 6 | *** | < 1 | *** | 3500 |
| Upernaviarsuk | 1954 | Conifer | 0,5 | 1,5 | 3 | 200 | 200 |
| Lejrskolen | 1999-2005 | Conifer | 4 | *** | 1 | *** | 2500 |
| Klosterdalen | 2000 | Conifer | 1 | *** | 1 | *** | 2000 |
| Total | | | 218.5 | | | | |

**Forest definition**

The forest definition adopted in Greenland is almost identical to the FAO definition (TBFRA, 2000). It includes "wooded areas larger than 0.5 ha, that are able to form a forest with a height of at least 5 m and crown cover of at least 10 %. The minimum width is 20 m." Temporarily non wooded areas, fire breaks, and other small open areas, that are an integrated part of the forest, are also included. However, due to extreme slow growing rates many of the forests are currently below 5 meters height.

Figure 16.6.3 shows a picture of the best developed forest in Greenland.

Figure 16.6.3 The forest in Kuusuaq. Photo: Rasmus E. Christensen, 2005.

Of special interest is the forest in Qinngua Valley. The Qinngua Valley is situated in a remote area. It consists of natural birch (*Betula pubescens spp. czerepanovii* and *B. glandulosa.)* which develops to forest like trees probably due to an introgressiv hybridisation (Rasmus Enoksen Christensen). This forest will probably not follow the FAO forest definition but are included in the inventory as a sub-division under forests. The Qinngua-valley is not included in the FAO forest statistics.

Figure 16.6.4 Kuussuaq, Tasermiut fjor. Photo: Rasmus Christensen, Juni 2004.

**Methodological issues for forests**

***Estimation of volume, biomass and carbon pools***

Due to lack of precise data and slow growth rates, simple functions are used that only include the height of the trees and the number per hectare.

The height of the trees has been estimated by Rasmus Enoksen Christensen based on data from the Aboretum. It is assumed that the trees are conical and the stem diameter at ground level is based on the general formula for even-aged forests (Vanclay, 2009).

$$D = \beta(H - 1.3)/\ln(N) \qquad \text{(eq.1)}$$

Where:
D = diameter at breast height, cm
ß = slope, species dependent
H = Height of the trees (meters)
N = Number of trees per hectare

Eq. 1 has been simplified by omitting the breast height (1.3 meters) to

$$D = \beta(H)/\ln(N) \qquad \text{(eq.2)}$$

so that D is representing the diameter at ground level. The ß-value used is given in Table 16.6.3.

Table 16.6.3 ß-values for estimating the diameter of trees (from Vanclay, 2009).

| | Betula, spp | Conifers |
|---|---|---|
| ß-values | 6.54 | 7.51 |

In order to estimate the C stock and C stock change is used the average default values from the IPCC 2006 guidelines for BCEF, density, C-content and Root-Shoot ratio for Boreal stands with a growing stock level of 21-50 $m^3$, IPCC table 4.5, pp 4.50. The values are given in Table 16.6.4.

Table 16.6.4 Biomass expansion factors used for Greenland.

| | | Qinngua Walley (Betula, spp.) Birch | Conifers | Orpiuteqarfia (Larix sibirica) Sibirian Larch) |
|---|---|---|---|---|
| BCEF | Dimensionless | 0.7 | 0.66 | 0.78 |
| Density | kg dry matter per litre | 0.51 | 0.4 | 0.46 |
| C-content | kg C per kg dry matter | 0.48 | 0.51 | 0.51 |
| Root-shoot-ratio | Dimensionless | 0.39 | 0.39 | 0.39 |
| Dead Organic Matter | kg per kg aboveground biomass | 0.1 | 0.2 | 0.1 |

Source: IPCC 2006 guidelines.

#### Dead wood volume, biomass and carbon

The volume of dead organic matter (DOM) is estimated as a fraction of the aboveground biomass (Table 16.6.4). It is assumed that litter is included in DOM.

#### Forest soils: forest floors and mineral soil

Following the cold climate and the slow growing rate it is assumed that no changes takes place in C-stock in the soil and hereby following the IPCC 2006 guidelines at Tier 1 level.

#### Uncertainties and time series consistency

The uncertainty in estimation of the C stock changes in the Greenlandic forests is very high. As there are very limited resources to visit and monitor in the remote areas there are very few data available. The current inventory is therefore based on the best knowledge available. It should also be taken into consideration that the importance of the forest sector in Greenland is marginal as only very little thinning is taking place as well as no deforestation and that the effect on the inventory is almost not measurable.

In the overall uncertainty section for the LULUCF is made a Tier 1 uncertainty analysis.

#### QA/QC and verification

Focus on the measurements of carbon pools in forest in Greenland will contribute to QA/QC and verification, but presently there are no plans to a further monitoring of the Greenlandic forests.

#### Recalculations and changes made in response to the review process

No recalculations have been made.

#### Planned improvements

No improvements are planned.

### 16.6.3 Land converted to forests (4A2)

#### Forest area

See Section 16.2.1 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation.

#### Forest definition

See Section 16.2.1 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories (e.g. land use and land-use change matrix).

**Methodological issues for land converted to forest**
See also Section 16.2.1.

Since 1990, there has been a slight increase in the forest area of 14 hectares. This has taken place on land converted from “OL”.

**Uncertainties and time series consistency**
For time series consistency, see Section 16.2.1. For uncertainties, please see Chapter 16.6.15.

**QA/QC and verification**
No QA/QC plan has been made yet. The afforestated area is known.

**Recalculations, including changes made in response to the review process**
None

**Planned improvements**
No improvements are planned.

### 16.6.4 Cropland (4B)

**Cropland and cropland management (4B1)**
In 1990 there were no cropland occurring in Greenland. Due to global warming, it is now possible to have a few crops, which may mature. In 2001, the first five hectares with annual crops were established. These are reported under 5.B.2. A more intensive description of the agriculture in Greenland can be found at
http://nunalerineq.gl/english/landbrug/jord/index-jord.htm

**Land converted to cropland (4B2)**
In 2001, the first annual crops were grown in Greenland. Approximately five hectares with garden crops were grown. Of this is it assumed that 25 % of the area is on organic soils (pers. comm. with Kenneth Høeg, former chief agricultural advisor in Greenland). The area converted to cropland was improved grassland.

Figure 16.6.5 Cropland and Grassland in Greenland.
(Photos from: http://nunalerineq.gl/english/landbrug/landbrug/index-landbrug.htm).

The region is generally characterized by a slightly podsol type of soil with a low pH value and small amounts of accessible plant nutrients. Larger concentrations of clay rarely occur, but considerable quantities of silt are often observable on the surface. Also, a certain amount of brown earth occurs in inland areas.

**Methodological issues**

***Change in carbon stock in living biomass***

For land converted to cropland is used a standard default value of 5,000 kg DM (dry matter) per hectare in above- and below-ground (IPCC 2006).

**Change in carbon stock in dead organic matter**

No organic matter is reported under CL.

**Change in carbon stock in soils**

No C stock changes in mineral soils are assumed. The emission in the 25 % organic soils is estimated by using the IPCC 2006 default value for cropland, Table 5.6 pp 5.19 of 5,000 kg C per ha per year. The emission factors for organic soils in the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC 2014a) are based on expert judgement assumed to be too high for the cold conditions in Greenland.

**Uncertainties and time series consistency**

The time series are complete. For uncertainties, please see Chapter 16.6.15.

**Category-specific QA/QC and verification**

The number of hectares is provided by the Greenlandic Agricultural Consulting Services. As agricultural activities are economically subsidised in Greenland the figures are very accurate.

#### Category-specific recalculation
No recalculations have been made.

#### Category-specific planned improvements
No improvements are planned.

### 16.6.5 Grassland (4C)

#### Grassland remaining grassland (4C1)
Grassland in Greenland is dominated by unimproved grassland where the sheep is grazing. The total area with GL has been estimated to 241,990 hectares. Of these, only approximately 1,100 hectare is improved where stones have been removed combined with sowing of more high yielding species, see Figure 16.6.5.

Since 1990, the area with improved grassland has been extended from 490 hectares to 1096 hectares.

#### Methodological issues for grassland
Grassland is divided into improved and unmanaged Grassland.

#### Change in carbon stock in living biomass
As more GL becomes improved the amount of living biomass at peak is increased. To estimate the amount of living biomass in improved GL is using the same default value as for Cropland, e.g. 5000 kg DM per hectare, IPCC 2006 default value for cropland, Table 5.9 pp 5.28. For unmanaged Grassland is used a default value of 1700 kg DM per hectare according to IPCC 2006 default, Table 6.4 pp 6.27. No estimates for below-ground biomass are given. For conversion from DM to C is used a default value of 0.5 kg C per kg DM.

#### Change in carbon stock in dead organic matter
No changes in dead organic matter are estimated as this is not occurring for this category.

#### Change in carbon stock in soils
No changes in the carbon stock in mineral soils are assumed. For organic soils on improved grassland is used a default EF of 1,250 kg C per ha per year (IPCC, 2006) default value for grassland, Table 6.3 pp 6.17. For unmanaged grassland no carbon stock change is expected. The emission factors for organic soils in the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC 2014a) are based on expert judgement assumed to be too high for the cold conditions in Greenland.

#### Uncertainties and time series consistency
The time series is complete. For uncertainties, please se Chapter 16.6.15.

#### Category-specific QA/QC and verification
The number of hectares is provided by the Greenlandic Agricultural Consulting Services. As the agriculture is subsidised in Greenland the figures are very accurate.

#### Recalculations
No recalculation has been made.

#### Planned improvements
No improvements are planned.

### 16.6.6 Wetlands (4D)

Wetland in Greenland includes only human made water reservoirs and not naturally occurring wetlands. In total 1,076 hectares with ponds and water reservoirs distributed on 48 locations are reported.

No emission estimates from these reservoirs has been made yet.

**Uncertainties and time series consistency**
Not estimated.

**QA/QC and verification**
QA and QC have been made by DCE and Statistics Greenland.

**Recalculations**
No recalculations have been made.

**Category-specific planned improvements**
No improvements are planned.

### 16.6.7 Settlements (4E)

In total there are approximately 56,000 inhabitants in Greenland with about one quarter of the population in the capital, Nuuk.

Table 16.6.5 Inhabitants and the area occupied with houses, hectares.

| | 1990 | 2000 | 2015 |
|---|---|---|---|
| Inhabitants | 55 589 | 56 176 | 55 916 |
| Settlements, total, ha | 4801 | 4891 | 5761 |

The cities are build on the rocky coastline where almost none vegetation occurs. As a consequence, estimates for C stock in living biomass and in soil have been made.

The small increase in the area with Settlements since 1990 has taken place on “Other land”.

Currently, no official data or measurements of the area of villages and settlements are available. Alternatively, land utilized for villages and settlements have been measured by the use of NunaGIS, which is a digital internet atlas displaying maps over villages and settlements in Greenland. NunaGIS is available at www.nunagis.gl.

### 16.6.8 Other land (4F)

The major part of Greenland is covered with snow or rocks. Thus, Other Land consists of 99.9 % of the total area.

No emission estimates have been made for this area.

The global warming can be seen in Greenland with longer and warmer summers, which again increase the amount of living biomass. Especially since the early 1990’s there has been changes observed in the environment, e.g. as given in the area with Cropland and Grassland has increased. However, no methodology exists currently to estimate a proper estimate of the amount of living biomass in the large area classified as “Other land”.

### 16.6.9 Harwested Wood Products (4G)

Due to the very low area with slowgrowing forests and the constant Grenlandic population, is it assumed that no national changes in the carbon stock in Harwested Wood Products (HWP) are taking place.

### 16.6.10 Direct nitrous oxide (N2O) emissions from nitrogen (N) inputs to managed soils– 4(I)

Reported under 3.D.

### 16.6.11 Emissions and removals from drainage and rewetting and other management of organic and mineral soils – 4(II)

Not estimated

### 16.6.12 Direct nitrous oxide (N2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter - 4(III)

Not occurring.

### 16.6.13 Indirect nitrous oxide (N2O) emissions from managed soils– 4(IV)

Reported under 3.D.

### 16.6.14 Biomass burning – 4(V)

No biomass burning takes place in Greenland, and wildfires rarely occur due to the moist climate.

### 16.6.15 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC GPG (IPCC, 2000). The uncertainty has been estimated for all sources included in the reporting for LULUCF. The uncertainties for the activity data and emission factors are shown in Table 16.6.6.

Table 16.6.6 Uncertainties for activity data and emission factors for LULUCF.

| Subsector | Pollutant | Activity data uncertainty | Emission factor uncertainty |
|---|---|---|---|
| 5A Forest | $CO_2$ | 5 | 50 |
| 5B Cropland | $CO_2$ | 5 | 50 |
| 5C Grassland | $CO_2$ | 5 | 50 |

The assumed uncertainties represent expert judgement.

The resulting uncertainties for the individual greenhouse gases and the total uncertainty on the greenhouse gas emission are shown in Table 16.6.7.

Table 16.6.7 Uncertainties for the emission estimates.

| | 1990 Emission/sink, kt $CO_2$ eqv. | 2015 Emission/sink, kt $CO_2$ eqv. | Activity data, % | Emission factor, % | Combined uncertainty | Total kt $CO_2$ eqv |
|---|---|---|---|---|---|---|
| 5. LULUCF | 0.206 | 1.041 | 5 | 50 | 50.2 | ± 50.49 |
| 5.A Forests | 0 | -0.051 | 5 | 50 | 50.2 | ± 2.45 |
| 5.B Cropland | 0 | 0.048 | 5 | 50 | 50.2 | ± 2.32 |
| 5.C.Grassland | 0.206 | 1.044 | 5 | 50 | 50.2 | ± 50.37 |

### 16.6.16 References

Christensen, R.E. 2010: Information on Greenlandic forests. Not published.

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. & Tanabe, K. (eds). Published: IGES, Japan. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

IPCC 2014a, 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds). Published: IPCC, Switzerland.

Vanclay, J.K. 2009: Tree diameter, height and stocking in even-aged forests, Ann. For. Sci. 66. 702 Available online at: EDP Sciences, 2009. Available at: www.afs-journal.org DOI: 10.1051/forest/2009063.

## 16.7 Waste (CRF sector 5)

### 16.7.1 Overview of sector

The waste sector consists of the CRF source category 5.A. Solid Waste Disposal, 5.C. Incineration and Open Burning of Waste and 5.D. Wastewater Treatment and Discharge.

In $CO_2$ equivalents, the waste sector (without LULUCF) contributes with 2.6 % of the overall greenhouse gas emission in 2018. This corresponds to an emission of 15.1 Gg $CO_2$ equivalents.

The Greenlandic inventory includes $CH_4$ emissions from managed and unmanaged waste disposal sites on land, $N_2O$ from wastewater and $CO_2$, $CH_4$, $N_2O$, $NO_x$, CO, NMVOC and $SO_2$ from open burning and waste incineration and open burning. Only emissions from waste incineration without energy recovery are included in the waste sector. Emissions from waste incineration with energy recovery are included in the energy sector.

Table 16.7.1 shows the greenhouse gas emissions from the waste sector. The emissions are taken from the CRF tables and are presented as rounded figures.

Table 16.7.1 Emissions from the waste sector, Gg $CO_2$ equivalents.

| | | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5A Solid waste disposal | $CH_4$ | 4.3 | 4.4 | 4.5 | 4.5 | 4.6 | 4.7 | 4.8 | 4.8 | 4.9 | 4.9 |
| 5B Incineration and open burning | $CO_2$ | 2.6 | 2.6 | 2.6 | 2.6 | 2.7 | 2.7 | 2.9 | 3.1 | 3.5 | 3.4 |
| 5B Incineration and open burning | $CH_4$ | 2.7 | 2.7 | 2.7 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.6 | 2.4 |
| 5B Incineration and open burning | $N_2O$ | 0.7 | 0.7 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 |
| 5C Wastewater treatment and discharge | $N_2O$ | 7.2 | 7.2 | 7.1 | 7.1 | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 |
| 5. Waste total | | 17.5 | 17.6 | 17.7 | 17.8 | 18.0 | 18.2 | 18.4 | 18.6 | 19.0 | 18.7 |
| *continued* | | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| 5A Solid waste disposal | $CH_4$ | 5.0 | 4.9 | 4.9 | 4.9 | 4.9 | 4.8 | 4.8 | 4.8 | 4.7 | 4.7 |
| 5B Incineration and open burning | $CO_2$ | 3.2 | 3.3 | 3.2 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 |
| 5B Incineration and open burning | $CH_4$ | 2.1 | 2.1 | 2.1 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 |
| 5B Incineration and open burning | $N_2O$ | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.6 | 0.6 | 0.5 | 0.6 |
| 5C Wastewater treatment and discharge | $N_2O$ | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 | 7.3 | 7.6 | 6.3 |
| 5. Waste total | | 18.1 | 18.1 | 18.0 | 17.7 | 17.5 | 17.5 | 17.5 | 17.6 | 17.8 | 16.5 |
| *continued* | | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| 5A Solid waste disposal | $CH_4$ | 4.7 | 4.6 | 4.6 | 4.6 | 4.6 | 4.6 | 4.5 | 4.5 | 4.5 | |
| 5B Incineration and open burning | $CO_2$ | 3.1 | 3.1 | 3.1 | 3.1 | 3.2 | 3.1 | 3.2 | 3.2 | 3.2 | |
| 5B Incineration and open burning | $CH_4$ | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | |
| 5B Incineration and open burning | $N_2O$ | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | |
| 5C Wastewater treatment and discharge | $N_2O$ | 6.0 | 6.1 | 5.7 | 4.6 | 4.4 | 4.2 | 4.8 | 4.8 | 4.9 | |
| 5. Waste total | | 16.2 | 16.3 | 15.9 | 14.7 | 14.6 | 14.4 | 14.9 | 15.0 | 15.1 | |

The largest sources of greenhouse gas emission from the waste sector in 2018 are $N_2O$ emission from waste water treatment and discharge (32.6 %) and $CH_4$ emission from solid waste disposal (29.8 %) followed by $CO_2$ from waste incineration and open burning (21.1 %).

Total greenhouse gas emission from the waste sector has decreased by 13.5 % since 1990. In 2018 emissions from all sources were more or less unchanged.

### 16.7.2 Solid waste management

Activity data for waste amounts for solid waste management are shown in Table 16.7.2.

Table 16.7.2 Waste amounts for solid waste management, tonnes.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| 5A1 Managed waste disposal sites | 6 056 | 6 124 | 6 168 | 6 232 | 6 334 | 6 428 | 6 410 | 6 416 | 6 145 | 5 697 |
| 5A2 Unmanaged waste disposal sites | 1 362 | 1 359 | 1 358 | 1 360 | 1 341 | 1 289 | 1 217 | 1 160 | 1 060 | 988 |
| 5C1 Incineration, with energy recovery | 5 519 | 5 578 | 5 618 | 5 733 | 5 918 | 6 072 | 6 178 | 6 275 | 6 398 | 8 200 |
| 5C1 Incineration, without energy rec. | 0 | 0 | 0 | 0 | 56 | 225 | 795 | 1 240 | 2 663 | 2 896 |
| 5C2 Open burning of waste | 16 566 | 16 713 | 16 808 | 16 955 | 17 140 | 17 235 | 17 033 | 16 922 | 16 093 | 14 930 |
| 5. Waste total | 29 503 | 29 775 | 29 952 | 30 280 | 30 788 | 31 249 | 31 633 | 32 014 | 32 360 | 32 712 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| 5A1 Managed waste disposal sites | 4 876 | 4 943 | 4 746 | 4 451 | 4 215 | 4 246 | 4 264 | 4 293 | 4 312 | 4 346 |
| 5A2 Unmanaged waste disposal sites | 910 | 868 | 843 | 835 | 828 | 826 | 818 | 791 | 763 | 746 |
| 5C1 Incineration, with energy recovery | 11 279 | 11 526 | 12 658 | 14 084 | 15 312 | 15 572 | 15 788 | 16 056 | 16 366 | 16 686 |
| 5C1 Incineration, without energy rec. | 3 148 | 3 306 | 3 391 | 3 415 | 3 437 | 3 461 | 3 485 | 3 468 | 3 444 | 3 466 |
| 5C2 Open burning of waste | 12 920 | 12 979 | 12 483 | 11 804 | 11 263 | 11 329 | 11 350 | 11 355 | 11 335 | 11 371 |
| 5. Waste total | 33 132 | 33 623 | 34 121 | 34 589 | 35 055 | 35 435 | 35 705 | 35 964 | 36 220 | 36 614 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| 5A1 Managed waste disposal sites | 4 413 | 4 476 | 4 503 | 4 518 | 4 548 | 4 568 | 4 587 | 4 587 | 4 587 | |
| 5A2 Unmanaged waste disposal sites | 722 | 692 | 658 | 631 | 602 | 579 | 572 | 572 | 572 | |
| 5C1 Incineration, with energy recovery | 17 077 | 17 500 | 17 854 | 18 131 | 18 394 | 18 678 | 18 989 | 19 339 | 19 695 | |
| 5C1 Incineration, without energy rec. | 3 486 | 3 488 | 3 501 | 3 523 | 3 550 | 3 548 | 3 557 | 3 592 | 3 616 | |
| 5C2 Open burning of waste | 11 470 | 11 540 | 11 526 | 11 500 | 11 502 | 11 494 | 11 522 | 11 575 | 11 617 | |
| 5. Waste total | 37 168 | 37 695 | 38 043 | 38 303 | 38 596 | 38 866 | 39 226 | 39 665 | 40 088 | |

Waste amounts are based on municipal data on waste and waste incineration with energy recovery on local incinerator plants in 2004, and a survey by Consulting Company Carl Bro in 1996 and 2001, where waste amounts per person per year was identified as 650 kg and 455 kg for Greenlandic towns and villages, respectively. For the time-series these amounts were regulated by 1 % per year upwards for years after 2004 and by 1 % per year downwards for years before 2004. Further, to construct the time-series statistical data from Statistics Greenland on population in towns and villages were used. Other results of the survey used for the time-series are that it was estimated that (1) 70 % of waste amounts is incinerated and 30 % deposited and (2) 80 % of combustible waste amounts deposited is burned in open burning.

### Solid waste disposal

*Source Category Description*

The category consists of managed and unmanaged disposal sites of waste on land.

#### *Methodological issues, activity data, emission factors and emissions*

In Table 16.7.3 the composition of the waste according to the survey mentioned is shown.

Table 16.7.3 Composition of household and commercial waste before and after open burning.

| Fraction | Household waste[2] | Commercial waste[2] | Household / Commercial Weighted | After open burning | Weighted (after open burning) |
|---|---|---|---|---|---|
| | | | % | | |
| Paper/cardboard, dry | 8.00[1] | 20.00 | 11.84 | 2.37 | 7.66 |
| Paper/cardboard, wet | 10.00[1] | 7.00 | 9.04 | 1.81 | 5.85 |
| Plastics | 7.00[1] | 9.00 | 7.64 | 1.53 | 4.94 |
| Organic waste | 44.00[1] | 34.00 | 40.80 | 8.16 | 26.40 |
| Other combustible | 17.50[1] | 16.00 | 17.02 | 3.40 | 11.00 |
| Glass | 7.50[1] | 3.00[1] | 6.06 | 6.06 | 19.60 |
| Metal | 3.50[1] | 3.00[1] | 3.34 | 3.34 | 10.80 |
| Other, non combustible | 1.00[1] | 5.00 | 2.28 | 2.28 | 7.37 |
| Hazardous waste | 1.50[1] | 3.00[1] | 1.98 | 1.98 | 6.40 |
| Total | 100.00 | 100.00 | 100.00 | 30.93 | 100.00 |
| Pct (%) | 68[3] | 32[3] | | 80[4] | |

Notes:

1 Measured values.

2 Source: Former Environmental and Nature Agency, Ministry of Infrastructure and Environment. Survey from 2004.

3 Distribution of household and commercial waste.

4 Share of combustible waste burned at waste disposal sites.

A Tier 2 approach with a first order decay model is used for estimation of emissions of $CH_4$ from the solid waste disposals. For this purpose the activity data in Table 16.7.2 are estimated back to 1960 (not shown) based on the methodology described in connection to Table 16.7.2. Combining these activity data and the composition data in Table 16.7.3 time-series for 1960-2015 with amounts of waste in waste fractions is calculated.

For these time-series the waste fractions are associated to (1) Dissolved Organic Carbon (DOC) values according to Section 16.7.2 of this NIR and (2) emission factors based on DOC values and values of methane correction factors, fraction of DOC dissimilated and fraction of $CH_4$ in gas emitted according to the IPCC Gudelines and GPG for managed disposals, Table 16.7.4 and unmanaged disposals, Table 16.7.5.

Table 16.7.4 DOC values and emission factors for $CH_4$ for managed disposals.

| | Paper / cardboard, dry | Paper / cardboard, wet | Plastics | Organic waste | Other combustible | Glass | Metal | Other, non com-bustible | Hazardous waste |
|---|---|---|---|---|---|---|---|---|---|
| DOC weighted (after open burning) fraction | 0.40 | 0.20 | 0.00 | 0.20 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 |
| Emission factor kg $CH_4$/tonnes[1] | 133.3 | 66.7 | 0.0 | 66.7 | 66.7 | 0.0 | 0.0 | 0.0 | 0.0 |

[1]) based on:

Methane correction factor: 1

Fraction of DOC dissimilated and emitted: 0.5

Fraction of $CH_4$ in gas emitted: 0.5

Table 16.7.5 DOC values and emission factors for $CH_4$ for unmanaged disposals.

| | Paper/ cardboard dry | Paper/ cardboard wet | Plastics | Organic waste | Other combustible | Glass | Metal | Other, non-com-bustible | Hazardous waste |
|---|---|---|---|---|---|---|---|---|---|
| DOC weighted (after open burn-ing) fraction | 0.40 | 0.20 | 0.00 | 0.20 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 |
| Emission factor kg $CH_4$/tonnes[1] | 53.3 | 26.7 | 0.0 | 26.7 | 26.7 | 0.0 | 0.0 | 0.0 | 0.0 |

[1]) based on:

Methane correction factor: 0.4

Fraction of DOC dissimilated and emitted: 0.5

Fraction of $CH_4$ in gas emitted: 0.5

For managed and unmanaged disposals the default half life time of 14 years and a time lag of 0.5 years are used. For the oxidation factor and according to the GPG for managed disposal 0.1 and for unmanaged 0.0 are used.

In Tables 16.7.6 and 16.7.7 selected data and results are shown for 1990-2018 for managed and unmanaged disposal, respectively. The data in the tables are as follows. The AD for the FOD model as amounts of waste in fractions, the potential emission of $CH_4$ calculated with emission factors on waste amounts in fractions, the annual generated emission of $CH_4$ calculated with the FOD model using the potential emissions, the oxidized $CH_4$ and the actual annual $CH_4$ emission calculated as the annual generated emission minus the $CH_4$ oxidized. Calculations are performed since 1960 and are not shown.

Table 16.7.6 Managed disposal. AD for the FOD model (amount of waste in fractions), potential emission of $CH_4$, oxidized $CH_4$ and annual $CH_4$ emission 1990-2018.

| | Paper /cardboard dry | Paper /cardboard wet | Plastics | Organic waste | Other combustible | Glass | Metal | Other, non combustible | Hazardous waste | Waste total | Potential emission | Annual generated emission | Annual oxidized emission | Annual emission |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unit | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes $CH_4$ | Tonnes $CH_4$ | Tonnes $CH_4$ | Tonnes $CH_4$ |
| 1990 | 464 | 354 | 299 | 1 598 | 667 | 1 187 | 654 | 446 | 388 | 6 056 | 232.7 | 174.8 | 17.5 | 157.3 |
| 1991 | 469 | 358 | 303 | 1 616 | 674 | 1 200 | 661 | 451 | 392 | 6 124 | 236.4 | 177.8 | 17.8 | 160.0 |
| 1992 | 472 | 361 | 305 | 1 627 | 679 | 1 209 | 666 | 455 | 395 | 6 168 | 239.0 | 180.7 | 18.1 | 162.6 |
| 1993 | 477 | 364 | 308 | 1 644 | 686 | 1 221 | 673 | 459 | 399 | 6 232 | 240.8 | 183.6 | 18.4 | 165.3 |
| 1994 | 485 | 370 | 313 | 1 671 | 697 | 1 241 | 684 | 467 | 405 | 6 334 | 243.3 | 186.5 | 18.6 | 167.8 |
| 1995 | 492 | 376 | 318 | 1 696 | 708 | 1 260 | 694 | 474 | 412 | 6 428 | 247.2 | 189.4 | 18.9 | 170.5 |
| 1996 | 491 | 375 | 317 | 1 691 | 705 | 1 256 | 692 | 473 | 410 | 6 410 | 250.9 | 192.4 | 19.2 | 173.2 |
| 1997 | 491 | 375 | 317 | 1 693 | 706 | 1 257 | 693 | 473 | 411 | 6 416 | 250.2 | 195.2 | 19.5 | 175.7 |
| 1998 | 471 | 359 | 304 | 1 621 | 676 | 1 204 | 664 | 453 | 393 | 6 145 | 250.5 | 197.9 | 19.8 | 178.1 |
| 1999 | 436 | 333 | 281 | 1 503 | 627 | 1 116 | 615 | 420 | 365 | 5 697 | 239.9 | 199.9 | 20.0 | 179.9 |
| 2000 | 373 | 285 | 241 | 1 286 | 537 | 955 | 527 | 359 | 312 | 4 876 | 222.4 | 201.0 | 20.1 | 180.9 |
| 2001 | 378 | 289 | 244 | 1 304 | 544 | 969 | 534 | 364 | 316 | 4 943 | 190.3 | 200.5 | 20.0 | 180.4 |
| 2002 | 363 | 277 | 234 | 1 252 | 522 | 930 | 513 | 350 | 304 | 4 746 | 193.0 | 200.1 | 20.0 | 180.1 |
| 2003 | 341 | 260 | 220 | 1 174 | 490 | 872 | 481 | 328 | 285 | 4 451 | 185.3 | 199.4 | 19.9 | 179.4 |
| 2004 | 323 | 246 | 208 | 1 112 | 464 | 826 | 455 | 311 | 270 | 4 215 | 173.7 | 198.1 | 19.8 | 178.3 |
| 2005 | 325 | 248 | 210 | 1 120 | 467 | 832 | 459 | 313 | 272 | 4 246 | 164.5 | 196.5 | 19.7 | 176.9 |
| 2006 | 326 | 249 | 211 | 1 125 | 469 | 836 | 460 | 314 | 273 | 4 264 | 165.7 | 195.0 | 19.5 | 175.5 |
| 2007 | 329 | 251 | 212 | 1 133 | 473 | 841 | 464 | 316 | 275 | 4 293 | 166.4 | 193.6 | 19.4 | 174.3 |
| 2008 | 330 | 252 | 213 | 1 138 | 475 | 845 | 466 | 318 | 276 | 4 312 | 167.6 | 192.4 | 19.2 | 173.2 |
| 2009 | 333 | 254 | 215 | 1 147 | 478 | 852 | 469 | 320 | 278 | 4 346 | 168.3 | 191.2 | 19.1 | 172.1 |
| 2010 | 338 | 258 | 218 | 1 164 | 486 | 865 | 477 | 325 | 283 | 4 413 | 169.6 | 190.2 | 19.0 | 171.2 |
| 2011 | 343 | 262 | 221 | 1 181 | 493 | 877 | 483 | 330 | 287 | 4 476 | 172.3 | 189.3 | 18.9 | 170.4 |
| 2012 | 345 | 263 | 222 | 1 188 | 496 | 882 | 486 | 332 | 288 | 4 503 | 174.7 | 188.6 | 18.9 | 169.8 |
| 2013 | 346 | 264 | 223 | 1 192 | 497 | 885 | 488 | 333 | 289 | 4 518 | 175.8 | 188.0 | 18.8 | 169.2 |
| 2014 | 348 | 266 | 225 | 1 200 | 501 | 891 | 491 | 335 | 291 | 4 548 | 176.4 | 187.4 | 18.7 | 168.7 |
| 2015 | 350 | 267 | 226 | 1 205 | 503 | 895 | 493 | 337 | 292 | 4 568 | 177.5 | 187.0 | 18.7 | 168.3 |
| 2016 | 351 | 268 | 227 | 1 210 | 505 | 899 | 495 | 338 | 294 | 4 587 | 178.3 | 186.5 | 18.7 | 167.9 |
| 2017 | 355 | 271 | 229 | 1 222 | 510 | 907 | 500 | 341 | 296 | 4 631 | 179.0 | 177.5 | 17.8 | 159.8 |
| 2018 | 359 | 274 | 232 | 1 238 | 516 | 919 | 507 | 346 | 300 | 4 691 | 180.8 | 185.9 | 18.6 | 167.3 |

Table 16.7.7 Unmanaged disposal. AD for the FOD model (amount of waste in fractions), potential emission of $CH_4$, oxidized $CH_4$ and annual $CH_4$ emission 1990-2018.

| | Paper /cardboard dry | Paper /cardboard wet | Plastics | Organic waste | Other combustible | Glass | Metal | Other, non combustible | Hazardous waste | Waste total | Potential emission | Annual generated emission | Annual oxidized emission | Annual emission |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unit | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes $CH_4$ | Tonnes $CH_4$ | Tonnes $CH_4$ | Tonnes $CH_4$ |
| 1990 | 104 | 80 | 67 | 359 | 150 | 267 | 147 | 100 | 87 | 1 362 | 21.2 | 15.8 | 0.0 | 15.8 |
| 1991 | 104 | 79 | 67 | 359 | 150 | 266 | 147 | 100 | 87 | 1 359 | 21.3 | 16.1 | 0.0 | 16.1 |
| 1992 | 104 | 79 | 67 | 358 | 149 | 266 | 147 | 100 | 87 | 1 358 | 21.2 | 16.3 | 0.0 | 16.3 |
| 1993 | 104 | 79 | 67 | 359 | 150 | 266 | 147 | 100 | 87 | 1 360 | 21.2 | 16.6 | 0.0 | 16.6 |
| 1994 | 103 | 78 | 66 | 354 | 148 | 263 | 145 | 99 | 86 | 1 341 | 21.2 | 16.8 | 0.0 | 16.8 |
| 1995 | 99 | 75 | 64 | 340 | 142 | 253 | 139 | 95 | 83 | 1 289 | 20.9 | 17.0 | 0.0 | 17.0 |
| 1996 | 93 | 71 | 60 | 321 | 134 | 238 | 131 | 90 | 78 | 1 217 | 20.1 | 17.1 | 0.0 | 17.1 |
| 1997 | 89 | 68 | 57 | 306 | 128 | 227 | 125 | 86 | 74 | 1 160 | 19.0 | 17.2 | 0.0 | 17.2 |
| 1998 | 81 | 62 | 52 | 280 | 117 | 208 | 115 | 78 | 68 | 1 060 | 18.1 | 17.3 | 0.0 | 17.3 |
| 1999 | 76 | 58 | 49 | 261 | 109 | 194 | 107 | 73 | 63 | 988 | 16.6 | 17.2 | 0.0 | 17.2 |
| 2000 | 70 | 53 | 45 | 240 | 100 | 178 | 98 | 67 | 58 | 910 | 15.4 | 17.2 | 0.0 | 17.2 |
| 2001 | 66 | 51 | 43 | 229 | 96 | 170 | 94 | 64 | 56 | 868 | 14.2 | 17.0 | 0.0 | 17.0 |
| 2002 | 65 | 49 | 42 | 222 | 93 | 165 | 91 | 62 | 54 | 843 | 13.6 | 16.8 | 0.0 | 16.8 |
| 2003 | 64 | 49 | 41 | 220 | 92 | 164 | 90 | 62 | 53 | 835 | 13.2 | 16.7 | 0.0 | 16.7 |
| 2004 | 63 | 48 | 41 | 218 | 91 | 162 | 89 | 61 | 53 | 828 | 13.0 | 16.5 | 0.0 | 16.5 |
| 2005 | 63 | 48 | 41 | 218 | 91 | 162 | 89 | 61 | 53 | 826 | 12.9 | 16.3 | 0.0 | 16.3 |
| 2006 | 63 | 48 | 40 | 216 | 90 | 160 | 88 | 60 | 52 | 818 | 12.9 | 16.2 | 0.0 | 16.2 |
| 2007 | 61 | 46 | 39 | 209 | 87 | 155 | 85 | 58 | 51 | 791 | 12.8 | 16.0 | 0.0 | 16.0 |
| 2008 | 58 | 45 | 38 | 201 | 84 | 150 | 82 | 56 | 49 | 763 | 12.4 | 15.8 | 0.0 | 15.8 |
| 2009 | 57 | 44 | 37 | 197 | 82 | 146 | 81 | 55 | 48 | 746 | 11.9 | 15.6 | 0.0 | 15.6 |
| 2010 | 55 | 42 | 36 | 191 | 80 | 142 | 78 | 53 | 46 | 722 | 11.6 | 15.4 | 0.0 | 15.4 |
| 2011 | 53 | 40 | 34 | 183 | 76 | 136 | 75 | 51 | 44 | 692 | 11.3 | 15.2 | 0.0 | 15.2 |
| 2012 | 50 | 38 | 32 | 174 | 72 | 129 | 71 | 48 | 42 | 658 | 10.8 | 15.0 | 0.0 | 15.0 |
| 2013 | 48 | 37 | 31 | 166 | 69 | 124 | 68 | 47 | 40 | 631 | 10.3 | 14.8 | 0.0 | 14.8 |
| 2014 | 46 | 35 | 30 | 159 | 66 | 118 | 65 | 44 | 39 | 602 | 9.9 | 14.6 | 0.0 | 14.6 |
| 2015 | 44 | 34 | 29 | 153 | 64 | 113 | 62 | 43 | 37 | 579 | 9.4 | 14.3 | 0.0 | 14.3 |
| 2016 | 44 | 33 | 28 | 151 | 63 | 112 | 62 | 42 | 37 | 572 | 9.0 | 14.0 | 0.0 | 14.0 |
| 2017 | 42 | 32 | 27 | 146 | 61 | 108 | 60 | 41 | 35 | 552 | 8.9 | 13.4 | 0.0 | 13.4 |
| 2018 | 39 | 30 | 25 | 135 | 56 | 100 | 55 | 38 | 33 | 511 | 8.6 | 12.7 | 0.0 | 12.7 |

### 16.7.3 Incineration and open burning of waste

**Source category description**

In Greenland waste incineration is carried out both with and without energy recovery. According to IPCC Guidelines the emissions associated with waste incineration for energy production is included in the energy sector more specifically in the source category 1.A1a Public Electricity and Heat Production. The emissions from waste incineration without energy recovery is reported in source category 5.C. Waste Incineration. Additionally in Greenland open burning of waste occurs at landfill sites. Emissions associated with this are also reported under sector 5.C. Waste Incineration.

**Methodological issues**

The methodology used follows the IPCC Guidelines (IPCC, 2006). For waste incineration the Danish emission factors are used, as it is trusted that they are also a good representation of Greenlandic conditions.

The emission factors used for both waste incineration and open burning are included in Section 16.7.3.4.

**Activity data**

The amount of waste incinerated without energy recovery is presented in Table 16.7.8. The activity data is provided by the method described in Section 16.7.2.

Table 16.7.8 Activity data for waste incineration without energy recovery, Mg.

| ar | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Incinerated waste without energy recovery, Mg | NO | NO | NO | NO | 56 | 225 | 795 | 1 240 | 2 663 | 2 896 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Incinerated waste without energy recovery, Mg | 3 148 | 3 306 | 3 391 | 3 415 | 3 437 | 3 461 | 3 485 | 3 468 | 3 444 | 3 466 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| Incinerated waste without energy recovery, Mg | 3 486 | 3 488 | 3 501 | 3 523 | 3 550 | 3 548 | 3 557 | 3 592 | 3 616 | |

The open burning of waste is assumed to be 80 % of the waste deposited to landfills (Survey on waste by Carl Bro, 1996 and 2001). The activity data for open burning is presented in Table 16.7.9. The activity data for open burning is provided by the method described in Section 16.7.2.

Table 16.7.9 Activity data for open burning of waste, Mg.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Open burning of waste, Mg | 16 566 | 16 713 | 16 808 | 16 955 | 17 140 | 17 235 | 17 033 | 16 922 | 16 093 | 14 930 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Open burning of waste, Mg | 12 920 | 12 979 | 12 483 | 11 804 | 11 263 | 11 329 | 11 350 | 11 355 | 11 335 | 11 371 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| Open burning of waste, Mg | 11 470 | 11 540 | 11 526 | 11 500 | 11 502 | 11 494 | 11 522 | 11 575 | 11 617 | |

**Emission factors**

**Waste incineration**

For waste incineration without energy recovery the same emission factors have been assumed as for waste incineration with energy recovery. The emission factors refer to the IPCC, 2006 and Danish emission factors (Nielsen et al., 2010). The greenhouse gas emission factors are shown in Table 16.7.10.

Table 16.7.10 Emission factors for greenhouse gases from waste incineration.

| | Emission factor | Unit |
|---|---|---|
| $CO_2$ | 37 | Kg pr GJ |
| $CH_4$ | 30 | g pr GJ |
| $N_2O$ | 4 | g pr GJ |

The emission factors used for the indirect greenhouse gases are shown in table 16.7.11.

Table 16.7.11 Emission factors for indirect greenhouse gases from waste incineration.

| | $NO_x$ | $SO_2$ | NMVOC | CO | Unit |
|---|---|---|---|---|---|
| Waste incineration | 134 | 138 | 0.98 | 7.4 | g pr GJ |

#### Open burning

For open burning emissions are calculated using the methodology, standard parameters and emission factors provided by the IPCC 2006 Guidelines.

The $CH_4$ emission factor used is the recommended and default is 6,500 g per tonne MSW wet weight. This factor refers to US EPA (2001).

For $N_2O$ a default emission factor of 150 g/t MSW dry weight is recommended (IPCC, 2006) this is corrected for the dry matter content to acquire an $N_2O$ emission factor of 214 g per tonne MSW wet weight.

For calculating the $CO_2$ emission the dry matter content, carbon content and the fossil carbon content of the waste fractions are used. The parameters are included in Table 16.7.12.

Table 16.7.12 Parameter used in calculating $CO_2$ emissions from open burning.

| | Dry matter content | Total carbon content, % | Fossil carbon content as percent of total carbon |
|---|---|---|---|
| Paper | 0.90 | 46 | 1 |
| Cardboard | 0.90 | 46 | 1 |
| Plastics | 1.00 | 75 | 100 |
| Organic waste | 0.40 | 38 | 0 |
| Other | 0.85 | 3 | 100 |

Source: IPCC Guidelines 2006, Volume 5, Chapter 2, Table 2.4

An oxidation factor of 58 % is assumed for open burning (IPCC, 2006).

The emission factors for $NO_x$, $SO_2$, NMVOC and CO are presented in Table 16.7.13. The source of these emission factors are EMEP/EEA 2013 (Table 3-1).

Table 16.7.13 Emission factors for indirect greenhouse gases from open burning of waste.

| | $NO_x$ | $SO_2$ | NMVOC | CO | Unit |
|---|---|---|---|---|---|
| Open burning of municipal waste | 3.18 | 0.11 | 1.23 | 55.83 | Kg pr Mg |

#### Emissions

Total emission of greenhouse gases from sector 5.C. Incineration and open burning of waste is shown in Table 16.7.14. Figure 16.7.1 shows total emission of greenhouse gases from sector 5.C. Incineration and open burning.

Table 16.7.14   Greenhouse gas emissions from incineration and open burning.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| $CO_2$, Gg | 2.6 | 2.6 | 2.6 | 2.6 | 2.7 | 2.7 | 2.9 | 3.1 | 3.5 | 3.4 |
| $CH_4$, Mg | 107.7 | 108.6 | 109.2 | 110.2 | 111.4 | 112.1 | 111.0 | 110.4 | 105.4 | 98.0 |
| $N_2O$, Mg | 2.5 | 2.5 | 2.5 | 2.5 | 2.6 | 2.6 | 2.6 | 2.6 | 2.5 | 2.4 |
| $CO_2$ eqv., Gg | 6.0 | 6.0 | 6.1 | 6.1 | 6.2 | 6.3 | 6.5 | 6.6 | 6.9 | 6.6 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| $CO_2$, Gg | 3.2 | 3.3 | 3.2 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 |
| $CH_4$, Mg | 85.0 | 85.4 | 82.2 | 77.8 | 74.3 | 74.7 | 74.9 | 74.9 | 74.8 | 75.0 |
| $N_2O$, Mg | 2.1 | 2.1 | 2.0 | 1.9 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.9 |
| $CO_2$ eqv., Gg | 6.0 | 6.0 | 5.9 | 5.7 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| $CO_2$, Gg | 3.1 | 3.1 | 3.1 | 3.1 | 3.2 | 3.1 | 3.2 | 3.2 | 3.2 | |
| $CH_4$, Mg | 75.7 | 76.1 | 76.0 | 75.9 | 75.9 | 75.8 | 76.0 | 76.4 | 76.7 | |
| $N_2O$, Mg | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | |
| $CO_2$ eqv., Gg | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.7 | |

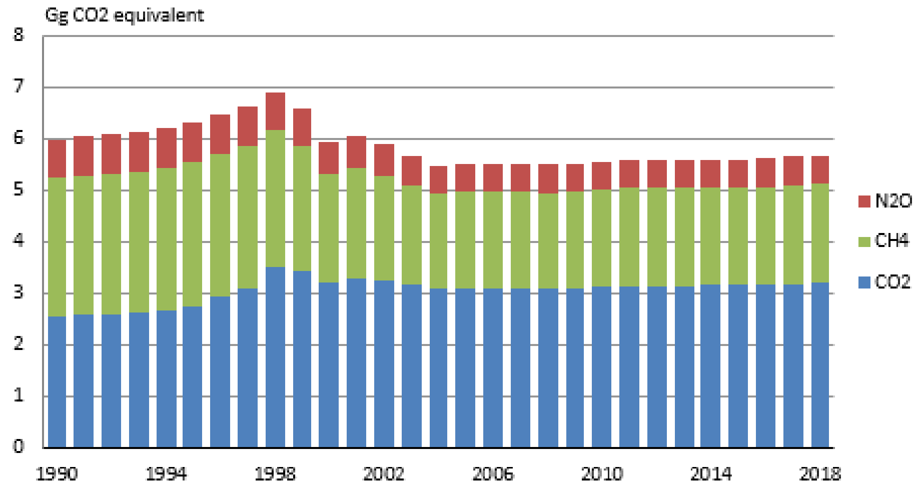



Figure 16.7.1   Emission of greenhouse gases from incineration and open burning.

The emissions of indirect greenhouse gases from incineration and open burning are shown in Table 16.7.15.

Table 16.7.15   Emission of indirect greenhouse gases from incineration and open burning, Mg.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| $NO_x$ | 52.7 | 53.1 | 53.4 | 53.9 | 54.6 | 55.1 | 55.3 | 55.6 | 54.9 | 51.6 |
| $SO_2$ | 1.8 | 1.8 | 1.8 | 1.9 | 2.0 | 2.2 | 3.0 | 3.7 | 5.6 | 5.8 |
| NMVOC | 20.4 | 20.6 | 20.7 | 20.9 | 21.1 | 21.2 | 21.0 | 20.8 | 19.8 | 18.4 |
| CO | 924.9 | 933.1 | 938.4 | 946.6 | 956.9 | 962.3 | 951.0 | 944.8 | 898.7 | 833.8 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| $NO_x$ | 45.5 | 45.9 | 44.5 | 42.3 | 40.7 | 40.9 | 41.0 | 41.0 | 40.9 | 41.0 |
| $SO_2$ | 6.0 | 6.2 | 6.3 | 6.2 | 6.2 | 6.3 | 6.3 | 6.3 | 6.2 | 6.3 |
| NMVOC | 15.9 | 16.0 | 15.4 | 14.6 | 13.9 | 14.0 | 14.0 | 14.0 | 14.0 | 14.0 |
| CO | 721.6 | 724.9 | 697.2 | 659.3 | 629.1 | 632.8 | 634.0 | 634.2 | 633.1 | 635.1 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| $NO_x$ | 41.4 | 41.6 | 41.6 | 41.5 | 41.6 | 41.5 | 41.6 | 41.9 | 42.0 | |
| $SO_2$ | 6.3 | 6.3 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.5 | 6.5 | |
| NMVOC | 14.1 | 14.2 | 14.2 | 14.2 | 14.2 | 14.2 | 14.2 | 14.3 | 14.3 | |
| CO | 640.6 | 644.6 | 643.8 | 642.3 | 642.4 | 642.0 | 643.5 | 646.5 | 648.9 | |

### 16.7.4 Wastewater treatment and discharge

#### Source category description

In Greenland no wastewater treatment occurs; although it should be mentioned some filtering of solid residues from industry may occur and likewise there are ongoing projects focussing on septic tanks at household levels. $N_2O$ emission from human sewage is estimated. It is assumed that no methane emission occurs.

#### Methodological issues

According to the IPCC Guidelines (IPCC, 2006) the important factors for $CH_4$ production from handling of wastewater are: wastewater characteristics; especially the quantity of degradable organic material in the wastewater, handling systems, temperature and BOD vs. COD.

The Guidelines state that production of $CH_4$ generally requires temperatures above 15˚C, and at temperatures below this the lagoon is principally a sedimentation tank (IPCC2006). Temperatures in Greenland rarely exceed 15˚C, and the monthly average temperature has not exceeded 12˚C during the period 1993-2018. Therefore $CH_4$ is reported as Not Applicable in the CRF.

#### $N_2O$ emission from wastewater handling

The IPCC default methodology only includes $N_2O$ emissions from human sewage based on annual per capita protein intake. The methodology account for nitrogen intake ("outcome"), i.e. faeces and urine, only and neither the industrial nitrogen input nor non-consumption protein from kitchen, bath and laundry discharges are included.

Total nitrogen in the effluent discharges is calculated by the following formula from IPCC, 2006 (Equation 6.8):

$$N_{EFFLUENT} = (P \times Protein \times F_{NPR} \times F_{NON-CON} \times F_{IND-CON}) - N_{SLUDGE}$$

where $P$ is the Greenlandic population (source: Statistics Greenland).

*Protein* is the annual per capita protein consumption (kg/person/yr) set contant to 171.5 g/day (see text below).

$F_{NPR}$ is the fraction of nitrogen in protein, default 0.16 kg N/kg protein (IPCC, 2006).

$F_{NON\text{-}CON}$ is the factor for non-consumed protein added to wastewater, default 1.1 (IPCC, 2006).

$F_{IND\text{-}CON}$ is the factor for industrial and commercial co-discharged protein into the sewer system, default 1.25 (IPCC, 2006).

$N_{SLUDGE}$ is nitrogen removed with sludge, default zero kg N/yr.

Thus, total $N_2O$ emission from effluent discharges is calculated by the formula:

$$N_2O_{EFFLUENT} = N_{EFFLUENT} \times EF_{N_2O-N} \times \frac{44}{28}$$

The default IPCC emission factor for $N_2O$ emissions from domestic wastewater nitrogen effluent is 0.005 kg $N_2O$-N/kg N. This emission factor is based on limited field data and on specific assumptions regarding the occurrence of nitrification and denitrification in rivers and in estuaries. To convert total N in effluents to emissions in $N_2O$ the mass ratio 44/28 is used.

#### For households

A large part of the diet originates from seafood, fish or sea mammals, but imported fabricated foods are expected to continue to take over an increasing part of human energy consumption. Due to weather conditions most of fresh food comes from wild animals or fish. Greenland has a production of lamb and a limited supply of vegetables; still most of the produced foods are imported from outside (Mulvad et al., 2007).

In Greenland, the traditional diet based on meat and fish has undergone diversification towards more carbohydrates with the development of a monetary economy; in 1855 the protein content of a mean diet was 377 g protein, whereas 80 years later, in 1935 – 43, the protein content of a mean diet was 257 g protein (Périssé and François, 1981). Today, the majority of young urbanised Greenlandic Inuit have Western dietary habits and consume less meat from marine mammals, terrestrial mammals and birds than Inuit from the hunting districts; Dietary profiles of Canadian Baffin Island Inuit with a high consumption of traditional foods have shown a mean daily protein intake of 144-199 g/day in 41- to 61-year-old (Laursen et al, 2001).

As no data on the protein intake are available a protein intake of 171.5 g/day, i.e. the average of the Canadian Inuit were adopted, as it is assumed that the protein intake has declined even more since 1935 due to increased number of urbanised Greenlandic Inuit. For comparison the Danish yearly protein consumption according to FAOSTAT has increased from 98 g/day in 1990 to 112 g/day in 2005. Using this number, the yearly protein intakes may be derived by multiplying with the population number and days in a year. Based on the above it was decided to set the protein intake to the average value of the Canadian Inuit data, 171.5 g/day. The N-content in effluent wastewater in Greenland was calculated the equation shown above.

#### From industries

The production of residue products from the fish industry in Greenland amounts to around 14,000 tons per year (Nielsen et al, 2005). Overall the waste amount from the Greenland halibut production is around 40 %, while the waste amount from codfish production is 50 %; this governs only the fish production including pre-processing.

According to IPCC, the fraction of nitrogen in protein is 0.16 (IPCC, 2006). The IPCC reports a range of 0.3 to 3.1 kg total N/ton fish referring to effluent loads from cod filleting; i.e. 0.0031. The report also presents values of the total N content of untreated wastewater from the fish industry in the range of 400-1000 mg/l corresponding to a fraction of corresponding. However, as it was not possible to find data for all fish groups, and as it was not possible to determine that fraction of fish, which was pre-processed and how big a fraction that was sold without pre-processing, the below approach was adopted.

From the EC BAT note (EC, 2003) the total N-content of untreated wastewater from the fishing industry was reported to be between 400 and 1000 mg/L with an average value of 700 mg/L. The number was multiplied by the water used within the fishing industry reported for 2004 to 2016 by Statistics Greenland and by Ministry of Industry, Energy, Research and Labour from 2018. The effluent N-content for 1990 to 2002 was set equal to the estimated value for 2003.

#### Emissions

Emission of $N_2O$ from wastewater discharges is shown in Table 16.7.16.

Table 16.7.16 $N_2O$ emissions in wastewater from households and industries 1990-2018.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| $N_2O$ emission, effluents households, Gg | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 |
| $N_2O$ emission, effluents industries, Gg | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 |
| $N_2O$ emission, effluents sum, Gg | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| $N_2O$ emission, effluents households, Gg | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 |
| $N_2O$ emission, effluents industries, Gg | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.020 | 0.021 | 0.016 |
| $N_2O$ emission, effluents sum, Gg | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.025 | 0.021 |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| $N_2O$ emission, effluents households, Gg | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | |
| $N_2O$ emission, effluents industries, Gg | 0.015 | 0.016 | 0.014 | 0.010 | 0.010 | 0.009 | 0.011 | 0.011 | 0.012 | |
| $N_2O$ emission, effluents sum, Gg | 0.020 | 0.020 | 0.019 | 0.015 | 0.015 | 0.014 | 0.016 | 0.016 | 0.017 | |

Total emission of $N_2O$ increased slightly until 2008 due to an increase in the emission from industrial effluents. However, since 2009 total emission of $N_2O$ has decreased to a total level of 0.015-0.020 Gg (which is lower than 1990) due to a temporarily decrease in industrial effluents primaryly caused by a decrease in the catches of shrimps and an overall economic recession.

### 16.7.5 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC Guidelines (IPCC, 2006). The uncertainty has been estimated for all sources included in the reporting for the waste sector. The uncertainties for the activity data and emission factors are shown in Table 16.7.17.

Table 16.7.17 Uncertainties for activity data and emission factors for the waste sector.

| Subsector | Pollutant | Activity data uncertainty | Emission factor uncertainty |
|---|---|---|---|
| 5C Waste incineration | $CO_2$ | 10 | 25 |
| 5A Solid Waste Disposals sites | $CH_4$ | 10 | 100 |
| 5C Waste incineration | $CH_4$ | 10 | 50 |
| 5D Wastewater Handling | $N_2O$ | 30 | 100 |
| 5C Waste incineration | $N_2O$ | 10 | 100 |

The amount of waste incinerated and open burned is relatively well known and the uncertainty is set to 10 %. The same is the case for the waste deposited to landfills. For waste water handling an uncertainty of 30 % on the activity data has been assumed.

Regarding the emission factor uncertainty, a value of 100 % has been used for $CH_4$ from solid waste disposal, $N_2O$ from wastewater treatment and $N_2O$ from waste incineration. This is in the same range as recommended by the IPCC Guidelines (IPCC, 2000). For $CO_2$ and $CH_4$ from waste incineration emission factor uncertainties of 25 % and 50 % respectively have been chosen.

The resulting uncertainties for the individual greenhouse gases and the total uncertainty on the greenhouse gas emission are shown in Table 16.7.18.

Table 16.7.18 Uncertainties for the emission estimates.

| | Uncertainty % | Trend 1990-2016 % | Trend uncertainty % |
|---|---|---|---|
| GHG | ± 46 | -13.5 | ± 15.5 |
| $CO_2$ | ± 27 | 25.2 | ± 17.7 |
| $CH_4$ | ± 72 | -8.6 | ± 13.1 |
| $N_2O$ | ± 94 | -30.4 | ± 26.5 |

### 16.7.6 Source specific QA/QC

The elaboration of a formal QA/QC plan is to be completed.

However, data on solid waste disposals, waste water handling and waste incineration has gone through a great deal of quality work with regard to accuracy, comparability and completeness.

All external data used for the emission inventory submission are archived in spreadsheets. Data are archived annually in order to ensure that the basic data for a given report are always available in their original form.

Annual data on solid waste disposal, waste water handling and waste incineration are compared with previous years and large discrepancies are checked.

Safely stored and quality checked activity data are then processed by using a methodological approach consistent with international guidelines.

Calculated emission factors are compared with guideline emission factors to ensure that they are reasonable. The calculations follow the principle in international guidelines.

During data processing, it is checked that calculations are being carried out correctly.

Time-series for activity data, emission factors and calculated emissions are used to identify possible errors in the calculation procedure. In fact, during the calculation, numerous controls take place to ensure correctness. Sums are checked in the various stages in the calculation procedure. Implied emission factors are compared to emission factors.

Every single time-series imported to the CRF Reporter is checked for annual activity, units for activity, emission factor and emissions. Additional checks are performed on the database. The database encloses every single activity data, emission factors, emission, notation key and comment imported to the CRF Reporter.

### 16.7.7 Source specific recalculations and improvements

In this 2020 submission there has been no revisions in the waste sector.

Table 16.8.19 shows recalculations in the waste sector compared to the 2019 submission. No changes occur.

Table 16.8.19 Changes in GHG emission in the waste sector compared to the 2019 submission.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Previous inventory, Gg $CO_2$ eqv. | 17.5 | 17.6 | 17.7 | 17.8 | 18.0 | 18.2 | 18.4 | 18.6 | 19.0 | 18.7 |
| Recalculated, Gg $CO_2$ eqv. | 17.5 | 17.6 | 17.7 | 17.8 | 18.0 | 18.2 | 18.4 | 18.6 | 19.0 | 18.7 |
| Change in Gg $CO_2$ eqv. | - | - | - | - | - | - | - | - | - | - |
| Change in pct. | - | - | - | - | - | - | - | - | - | - |
| *continued* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Previous inventory, Gg $CO_2$ eqv. | 18.1 | 18.1 | 18.0 | 17.7 | 17.5 | 17.5 | 17.5 | 17.6 | 17.8 | 16.5 |
| Recalculated, Gg $CO_2$ eqv. | 18.1 | 18.1 | 18.0 | 17.7 | 17.5 | 17.5 | 17.5 | 17.6 | 17.8 | 16.5 |
| Change in Gg $CO_2$ eqv. | - | - | - | - | - | - | - | - | - | - |
| Change in pct. | - | - | - | - | - | - | - | - | - | - |
| *continued* | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| Previous inventory, Gg $CO_2$ eqv. | 16.2 | 16.3 | 15.9 | 14.7 | 14.6 | 14.4 | 14.9 | 15.0 | - | |
| Recalculated, Gg $CO_2$ eqv. | 16.2 | 16.3 | 15.9 | 14.7 | 14.6 | 14.4 | 14.9 | 15.0 | 15.1 | |
| Change in Gg $CO_2$ eqv. | - | - | - | - | - | - | - | - | - | |
| Change in pct. | - | - | - | - | - | - | - | - | | |

### 16.7.8 Source specific planned improvements

Some planned improvements to the emission inventories are discussed below.

**1) Improved data on solid waste disposals**

In future inventories attempts will be made in order to improve data on solid waste disposals in general. Statistics Greenland has encouraged the municipal technical departments with responsibility for waste handling to start gathering data on the yearly amounts of waste handled.

**2) Improved data on waste water handling**

In future inventories attempts will be made in order to improve data on waste water handling in general. However, at the moment the municipal technical departments seem to have no data on waste water handling at all.

### 16.7.9 References


EC, 2003: Reference Document on BAT in the food, drink and milk industry. Available at:
http://gasunie.eldoc.ub.rug.nl/FILES/root/2003/2665985/2665985.pdf

European Environment Agency (EEA), 2013: EMEP/EEA air pollutant emission inventory guidebook 2013, Technical Report No 12/2013. Available at: http://www.eea.europa.eu/publications/emep-eea-guidebook-2013 (2013-08-29).

IPCC, 1997: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available at:
http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html

IPCC, 2000: Penman, J., Kruger, D., Galbally, I., Hiraishi, T., Nyenzi, B., Emmanuel, S., Buendia, L., Hoppaus, R., Martinsen, T., Meijer, J., Miwa, K. & Tanabe, K. (Eds). Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Published: IPCC/OECD/-IEA/IGES, Hayama, Japan. Available at:
http://www.ipcc-nggip.iges.or.jp/public/gp/english/ (15-04-2007).

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. & Tanabe K. (eds). Published: IGES, Japan. Available at:
http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (21-02-2014).

Laursen, J., Milman, N., Pedersen, H.S., Mulvad, G., Saaby, H. and Byg, K.-E., 2001: Elements in autopsy liver tissue samples from Greenlandic Inuit and Danes. III. zinc measured by X-ray fluorescence spectrometry. Journal of Trace Elements in Medicine and Biology, 15:209-214.

Mulvad, G., Petersen, H.S.and Olsen, J., 2007: Arctic health problems and environmental challenges in Greenland. In: Ørbæk, J.B., Kallenborn, R., Tombre, I., Hegseth, E.N., Falk-Petersen, S. and Hoel, A.H. Arctic Alpine Ecosystems and People in a Changing Environment. Available at:
http://www.springerlink.com/content/tu377x6715200027/fulltext.pdf

Nielsen M., Nielsen, O.-K. & Thomsen, M. 2010: Emissions from decentralised CHP plants 2007 - Energinet.dk Environmental project no. 07/1882. Project report 5 – Emission factors and emission inventory for decentralised CHP production. National Environmental Research Institute, Aarhus University. 113 pp. – NERI Technical report No. 786. Available at:
http://www.dmu.dk/Pub/FR786.pdf (2011-02-28).

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Nielsen, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Thomsen, M., Hjelgaard, K., Fauser, P., Bruun, H.G., Johannsen, V.K., Nord-Larsen, T., Vesterdal, L., Callesen, I., Caspersen, O.H., Rasmussen, E., Petersen, S.B., Baunbæk, L. & Hansen, M.G. 2017. Denmark's National Inventory Report 2017. Emission Inventories 1990-2015 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. 890 pp. – Scientific Report from DCE – Danish Center for Environment and Energy no. 231. Available at:
http://dce2.au.dk/pub/SR231.pdf

Nielsen, U., Nielsen, K., Mai, P., Frederiksen, O., 2006: Organisk industriaffald i Grønland – Værktøjer til fremme af bedste tilgængelige teknik og nyttiggørelse af restprodukter nr. M. 127/001-0164. Realistiske muligheder for nyttiggørelse/udnyttelse af organisk industriaffald i Grønland. (In Danish)

Périssé, J. and François, P., 1981: Variability of the protein-calorie ratio in diets. FAO/WHO/UNUEPR/81/40. Available at:
http://www.fao.org/docrep/MEETING/004/AA054E/AA054E00.htm

Statistics Greenland, 2017: Statistics on Population 1960-2017. Available at: http://bank.stat.gl/BEEST3

US EPA, 1992: AP 42, Fifth Edition, Volume I Chapter 2.5: Open burning. Available at: http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s05.pdf

US EPA, 2001: US-EPA Emission Inventory Improvement Program. Volume III Chapter 16 Open Burning. United States Environmental Protection Agency (USEPA). Available at: http://www.epa.gov/ttn/chief/eiip/techreport/volume03/iii16_apr2001.pdf

## 16.8 Other

In CRF Sector 7, there are no activities and emissions or removals for the inventory of Greenland.

## 16.9 Recalculations and improvements

The 2020 submission is the tenth year where Greenland on the request of the ERT submits a full CRF.

For recalculations and improvements please refer to Sections 16.3 - 16.7 and Section 16.10.

## 16.10 KP-LULUCF

Greenland does not have a commitment in the second commitment period and therefore is not accounting for KP-LULUCF activities. However, the reporting is still done as Greenland continues to be part of the Kyoto Protocol.

The KP-LULUCF emission estimates are made in accordance with the Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC 2014) and the 2006 IPCC guidelines.

### 16.10.1 General information

In the following text, the abbreviations used are in accordance with definitions in the IPCC guidelines:

| | |
|---|---|
| A: | Afforestation |
| R: | Reforestation |
| D: | Deforestation |
| FF: | Forest remaining Forest, areas remaining forest after 1990 |
| FL: | Forest Land meeting the Danish definition of forests |
| CL: | Cropland |
| GL: | Grassland |
| SE: | Settlements |
| OL: | Other land, unclassified land |
| FM: | Forest Management, areas managed under article 3.4 |
| CM: | Cropland Management, areas managed under article 3.4 |
| GM: | Grazing land Management, areas managed under article 3.4 |
| RE: | Revegetation |
| WDR: | Wetland Drainage and Rewetting |

#### Definition of forest and any other criteria

For the estimation of anthropogenic emissions by sources and removals by sinks associated with afforestation (A), reforestation (R) and deforestation (D) since 1990 under Article 3.3 and forest management (FM) under Article 3.4 of the Kyoto Protocol, the following forest definition will be applied:

- Minimum values for tree crown cover: 10 % tree crown cover for forests.
- Minimum values for land area: 0.5 ha.
- Minimum value for tree height: trees must be able to reach a minimum height of 5 m in the site.

In addition, the forest area includes temporarily unstocked areas, smaller open areas in the forest needed for management purposes and fire breaks.

Forests in national parks, reserves or areas under special protection are included. Windbreaks and groves covering more than 0.5 ha and with a minimum width of 20 m are also considered as forests.

Woody biomass does not exist outside the forest and hence not reported under Cropland and Grassland.

#### Elected activities under Article 3, paragraph 4, of the Kyoto Protocol

As regards the possibility of including in the first commitment period emissions and removals associated with land use, land-use change and forestry activities under Article 3.4 of the Kyoto Protocol, it has been decided to include emissions and removals from forest management (FM), cropland management (CM) and grazing land management (GM).

The national system has identified land areas associated with the activities under Article 3.4 of the Kyoto Protocol in accordance with definitions, modalities, rules and guidelines relating to land use, land-use change and forestry activities under the protocol by satellite monitoring, use of Greenlandic agricultural subsidiary system and forest information.

Inventories of emissions and removals under Article 3.3 and Article 3.4 are prepared and reported annually together with the other greenhouse gas inventory information.

#### Description of how the definitions of each activity under Article 3.3 and each elected activity under Article 3.4 have been implemented and applied consistently over time

The definition of afforestation, reforestation and deforestation is in accordance with the IPCC 2006 and the Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC 2014).

Afforestation or reforestation is identified when areas have wooded treecover and fulfils the forest definition given above. The time of the AF is given by the time of action, i.e. planting of trees. No deforestation and reforestation is reported for Greenland as this is not occurring. All types of establishment of forest (AF or RF) are considered human induced.

As for the forest management (Article 3.4), the forest areas fulfilling the definition given above are included under this activity. All forest areas are considered managed except for the remote Qinngua-valley.

For Cropland and Grassland the area accounted for under Art. 3.4 have been estimated with the best knowledge from the Greenlandic Agricultural Consulting Services. As the agriculture in Greenland is economically subsidized the area is estimated with a high accuracy. Only areas that are reported as CL and GL are included in the accounted area.

#### Description of precedence conditions and/or hierarchy among article 3.4 activities and how they have been consistently applied in determining how land was classified

All Forest activities have precedence, after this Cropland activities and then Grassland activities.

Afforestation has precedence. All land converted to forest are included as afforested area. Deforestated areas are not reported as this is not occurring. The following categories in the Convention reporting are included under afforestation:

- 4A25 OL to A

FM activities are only related to:

- 4A1 Forest remaining Forest

CM activities are related to:

- 4B22 GL to CL

GM activities area related to:

- 4C1 GL remaining GL

No elected land has left land that is not accounted for. Land conversion between elected activities (FM, CM and GM) has been allowed but is currently not occurring. No land elected under article 3.4 activities has been converted to Other Land. Other land converted to elected activities is included in the respective category. As the small increase in CL is made on elected GL areas the total reported area under CL and GL under article 3.4 is constant.

### 16.10.2 Spatial assessment unit used for determining the areas of the units of land under Article 3.3

Afforestation and reforestation are identified as areas which not were covered by forest in 1990. The increase in the forest area is planted.

#### Methodology used to develop the land transition matrix

The land use matrix is based on the best available data. No vector maps exist of the individual forests, cropland and grassland.

#### Maps and/or database to identify the geographical locations, and the system of identification codes for the geographical locations

The forests have been given individual names. For the Cropland and Grassland area no identification has been made.

### 16.10.3 Afforestation, Reforestation & Deforestation (ARD)

#### Methods for carbon stock change and GHG emission and removal estimates

For afforestation the carbon stock change in the period 1990 - 2014 is based both on the area of afforestation and the information on species composition.

#### Description of the methodologies and the underlying assumptions used

See Chapter 16.6.

#### Justification when omitting any carbon pool or GHG emissions/removals from ARD

C stock changes in the soil are not expected due to the cold climate to occur and hence following the guidelines for a Tier 1 approach. As the afforestation is made by hand planting no damages of the existing soil C is expected to take place.

#### Information on whether or not indirect and natural GHG emissions and removals have been factored out

No factoring out has been performed in the emission and removal estimates.

#### Changes in data and methods since the previous submission (recalculations)

No recalculation has been performed.

#### Uncertainty estimates

Not given in the current reporting.

**Information on other methodological issues**
See Chapter 16.6.

**The year of the onset of an activity, if after 2008**
Not applicable.

### 16.10.4 Forest Management (FM)

**Methods for carbon stock change and GHG emission and removal estimates**
See Chapter 16.6 in LULUCF on "Forest remaining forest (4.A.1)".

**Methodologies and the underlying assumptions**
See Chapter 16.6 in LULUCF on "Forest remaining forest (4.A.1)".

**Omission of pools from FM**
C changes in forest soils are omitted and hereby following IPCC 2006 guidelines at a Tier 1 level and the Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC 2014).

**Factoring out**
No factoring out has been performed.

**Recalculations**
No recalculation has been performed.

**Uncertainty estimates**
See Table 16.11.2

**Information on other methodological issues**
See Chapter 16.7 in LULUCF on "Forest remaining forest (4.A.1)".

**The year of the onset of an activity, if after 2008**
Not applicable.

### 16.10.5 Cropland Management (CM)

**Methods for carbon stock change and GHG emission and removal estimates**
Methodologies and the underlying assumptions used

The area with agricultural CM is reported as the area given in Statistics Greenland.

The same methodology as used in the Convention reporting is used in the KP reporting.

**Omission of pool from CM**
Aboveground and belowground living biomass, litter and dead organic are only reported for perennial woody crops in accordance with IPCC 2006 guidelines. No litter and dead organic matter are reported under CM as these are not occurring. Therefore only aboveground living biomasses are reported under CM. Below-ground biomass is included in above-ground biomass.

**Factoring out**
No factoring out has been made.

#### Recalculations
None.

#### Uncertainty estimates
See Table 16.10.1.

#### Information on other methodological issues
None.

#### The year of the onset of an activity, if after 2008
Not applicable.

### 16.10.6 Grazing land management (GM)

#### Methods for carbon stock change and GHG emission and removal estimates
Grazing land is defined as land improved grassland and unmanaged grassland.

#### Description of the methodologies and the underlying assumptions used
The major part of the grassland is unmanaged (241,000 hectare). Only 1078 hectares is improved grassland with occasional reseeding and fertilizer application. The methodology used is the default Tier 1. This is in accordance with IPCC 2006 guidelines as the total emission from LULUCF consists of less than 0.2 % of the total emission from Greenland.

#### Omission of pools from GM
Aboveground and belowground living biomass, litter and dead organic are only reported for perennial woody crops in accordance with IPCC 2006 guidelines. No litter and dead organic matter are reported under GM as these are not occurring. Therefore, only aboveground living biomasses are reported under GM. Below-ground biomass is included in above-ground biomass.

#### Factoring out
No factoring out has been made.

#### Recalculations
No recalculation has been performed.

#### Uncertainty estimates
See Table 16.11.2.

#### Information on other methodological issues
None.

#### The year of the onset of an activity, if after 2008
Not applicable.

### 16.10.7 Revegation

Not elected.

### 16.10.8 Wetland drainage and rewetting

Not elected.

### 16.10.9 Article 3.3

**Information that demonstrates that activities under Article 3.3 began on or after 1 January 1990 and before 31 December 2012 and are direct human-induced**

All forests in Greenland are planted except for the Qinngua valley, which is in a remote area.

**Information on how harvesting or forest disturbance that is followed by the re-establishment of forest is distinguished from deforestation**

No deforestation is occurring and therefore not applicable.

**Information on the size and geographical location of forest areas that have lost forest cover but which are not yet classified as deforested**

Not applicable.

### 16.10.10 Article 3.4

**Information that demonstrates that activities under Article 3.4 have occurred since 1 January 1990 and are human-induced**

**Forest Management**

In Forest Management, all forest areas are under management and changes in carbon stock are hence seen as human induced.

**Cropland Management**

Due to the cold climate and the recent increase in temperature, it has only very recently been possible to grow agricultural crops in Greenland with the first fields established around 2001. Today it is estimated that 10.5 hectares are regularly ploughed.

**Grassland Management**

Due to the cold climate in Greenland and the recent increase in temperature, it has only recently been valuable to introduce management activities in the grassland to increase the crop yield. This is well documented in the Greenlandic subsidiary system to the farmers.

**Information relating to Cropland Management, Grazing Land Management and Revegetation, if elected, for the base year**

No further information is available.

**Information relating to Forest Management**

No further information is available.

### 16.10.11 Other information

**Key category analysis for Article 3.3 activities and any elected activities under Article 3.4**

According to the IPCC Good Practice Guidance for LULUCF a category that is identified as key in the UNFCCC inventory should also be considered key under the Kyoto Protocol (IPCC, 2014).

No LULUCF categories are reported as a key source. The total emission from the LULUCF sector is only 0.2 % of the total emission from Greenland.

### 16.10.12 Information relating to Article 6

There are no Article 6 projects (Joint Implementation) on the Greenlandic territory.

**Literature**

IPCC 2014, 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds). Published: IPCC, Switzerland.

## 16.11 Annex 1 Key categories

A Key Category Analysis (KCA) for year 1990 and 2018 for Greenland has been carried out in accordance with the IPCC Good Practice Guidance. For 1990 a level KCA has been carried out.

The base year in the analysis is the year 1990 for the greenhouse gases $CO_2$, $CH_4$, $N_2O$ and 1995 for the greenhouse F-gases HFC, PFC and $SF_6$. The KCA approach is a Tier 1 quantitative analysis.

The level assessment of the Tier 1 KCA is a ranking of the source categories in accordance to their relative contribution to the national total of greenhouse gases calculated in $CO_2$ equivalents. The level key categories are found from the list of source categories ranked according to their contribution in descending order. Level key categories are those from the top of the list and of which the sum constitutes 95 % of the national total.

The trend assessment of the Tier 1 KCA is a ranking of the source categories according to their contribution to the trend of the national total of greenhouse gases, calculated in $CO_2$ equivalents, from the base year to the year under consideration. The trend of the source category is calculated relative to that of the national totals and the trend is then weighted with the contribution, according to the level assessment. The ranking is in descending order. As for the level assessment, the cut-off point for the sum of contribution to the trend is 95 % and the source categories from the top of the list to the cut-off line are trend key categories.

#### Result of the Key Category Analysis for Greenland for the year 1990 and 2018

The entries in the results of KCA in Tables 16.11.1 to 16.11.3 for the years 1990 and 2018 are composed from CRFs for those years in this report. Note that base-year estimates are not used in the level assessment analysis for year 2018, but are only included in Table 16.11.2 to make it more uniform with Tables 16.11.1 and 16.11.3.

The result of the Tier 1 KCA level assessment for Greenland for 1990 is shown in Table 16.11.1. For the assessment, five categories were identified as key categories and marked as shaded, refer Table 16.11.1.

The result of the Tier 1 KCA level assessment for Greenland for 2018 is shown in Table 16.11.2. For the assessment, seven categories were identified as key categories, refer Table 16.11.2.

The result of the Tier 1 KCA trend assessment for Greenland for 1990/1995-2018 is shown in Table 16.11.3. For the trend assessment, eight categories were identified as key categories, refer Table 16.11.3. Note that according to the GPG, the analysis implies that contributions to the trend are all calculated as mathematically positive to be able to perform the ranking. LULUCF activities are in the table included with their sign, i.e. emissions: +, removals: -.

In Table 16.11.4, a summary of Key Category Analysis for Greenland is given for level assessment for year 1990/95 and 2018 and for trend for years 1990-2018. All the categories are listed by sector and key sources are shown with their ranking.

Table 16.11.1 Key Category Analysis base year 1990/1995, level assessment, Tier 1.

Table 7.A1 (of Good Practice Guidance) Tier 1 Analysis - Level Assessment GRL – inventory

| A | | | B | C | D | E |
|---|---|---|---|---|---|---|
| IPCC Source Categories (LULUCF included) | | | Direct GHG | Base Year Estimate Ex,o Gg $CO_2$ eqv. | Base Year Level Assessment Lx,o | Base Year Cumulative total of Col. D |
| Energy | Combustion excluding transport, Liquid fuels | $CO_2$ | 523.866 | 0.802 | 0.802 | Energy |
| Energy | Domestic aviation | $CO_2$ | 38.709 | 0.059 | 0.862 | Energy |
| Energy | Road transportation | $CO_2$ | 36.423 | 0.056 | 0.918 | Energy |
| Energy | Domestic navigation | $CO_2$ | 20.941 | 0.032 | 0.950 | Energy |
| Agriculture | Enteric fermentation | $CH_4$ | 7.627 | 0.012 | 0.961 | Agriculture |
| Waste | Wastewater treatment and discharge | $N_2O$ | 7.154 | 0.011 | 0.972 | Waste |
| Waste | Solid waste disposal | $CH_4$ | 4.328 | 0.007 | 0.979 | Waste |
| Waste | Incineration and open burning of waste | $CH_4$ | 2.692 | 0.004 | 0.983 | Waste |
| Waste | Incineration and open burning of waste | $CO_2$ | 2.550 | 0.004 | 0.987 | Waste |
| Energy | Combustion excluding transport, other fuels | $CO_2$ | 1.674 | 0.003 | 0.990 | Energy |
| Energy | Combustion excluding transport | $N_2O$ | 1.339 | 0.002 | 0.992 | Energy |
| Energy | Combustion excluding transport | $CH_4$ | 1.133 | 0.002 | 0.993 | Energy |
| Agriculture | Manure management | $N_2O$ | 0.869 | 0.001 | 0.995 | Agriculture |
| Agriculture | Agricultural soils | $N_2O$ | 0.841 | 0.001 | 0.996 | Agriculture |
| Waste | Incineration and open burning of waste | $N_2O$ | 0.741 | 0.001 | 0.997 | Waste |
| Energy | Road transportation | $N_2O$ | 0.627 | 0.001 | 0.998 | Energy |
| Energy | Domestic aviation | $N_2O$ | 0.323 | 0.000 | 0.999 | Energy |
| Industry | Solvent use | $CO_2$ | 0.263 | 0.000 | 0.999 | Industry |
| LULUCF | Grassland remaining grassland | $CO_2$ | 0.206 | 0.000 | 0.999 | LULUCF |
| Agriculture | Manure management | $CH_4$ | 0.167 | 0.000 | 0.999 | Agriculture |
| Energy | Road transportation | $CH_4$ | 0.068 | 0.000 | 1.000 | Energy |
| LULUCF | Forest land | $N_2O$ | 0.052 | 0.000 | 1.000 | LULUCF |
| Energy | Domestic navigation | $N_2O$ | 0.051 | 0.000 | 1.000 | Energy |
| Industry | Paraffin wax use | $CO_2$ | 0.043 | 0.000 | 1.000 | Industry |
| Energy | Domestic navigation | $CH_4$ | 0.036 | 0.000 | 1.000 | Energy |
| Industry | Consumption of $SF_6$ | $SF_6$ | 0.034 | 0.000 | 1.000 | Industry |
| Industry | Consumption of HFC's | HFCs | 0.027 | 0.000 | 1.000 | Industry |
| Agriculture | Liming | $CO_2$ | 0.008 | 0.000 | 1.000 | Agriculture |
| Energy | Domestic aviation | $CH_4$ | 0.007 | 0.000 | 1.000 | Energy |
| LULUCF | Grassland | $CO_2$ | 0.004 | 0.000 | 1.000 | LULUCF |
| LULUCF | Forest land | $CH_4$ | 0.000 | 0.000 | 1.000 | LULUCF |
| Industry | Road paving with asphalt | $CO_2$ | 0.000 | 0.000 | 1.000 | Industry |
| Industry | Asphalt roofing | $CO_2$ | 0.000 | 0.000 | 1.000 | Industry |
| Industry | Limestone and dolomite use | $CO_2$ | 0.000 | 0.000 | 1.000 | Industry |
| LULUCF | Forest land remaining forest land | $CO_2$ | 0.000 | 0.000 | 1.000 | LULUCF |
| LULUCF | Land converted to cropland | $CO_2$ | 0.000 | 0.000 | 1.000 | LULUCF |
| Total | | | | 652.804 | 1.000 | |

Table 16.11.2 Key Category Analysis year 2018, level assessment, Tier 1.

Table 7.A1 (of Good Practice Guidance) Tier 1 Analysis - Level Assessment GRL – inventory

| A | | | B | C | D | E | F |
|---|---|---|---|---|---|---|---|
| IPCC Source Categories (LULUCF included) | | | Direct GHG | Base Year Estimate Ex,o Gg $CO_2$ eqv | Year 2018 Estimate Ex,t Gg $CO_2$ eqv | Year 2018 Level Assessment Lx,t | Year 2018 Cumulative total of Col. E |
| Energy | Combustion excluding transport, Liquid fuels | $CO_2$ | 523.866 | 422.381 | 0.726 | 0.726 | Energy |
| Energy | Domestic aviation | $CO_2$ | 38.709 | 47.564 | 0.082 | 0.808 | Energy |
| Energy | Road transportation | $CO_2$ | 36.423 | 34.274 | 0.059 | 0.866 | Energy |
| Energy | Domestic navigation | $CO_2$ | 20.941 | 32.442 | 0.056 | 0.922 | Energy |
| Industry | Consumption of HFC's | HFCs | 0.027 | 8.861 | 0.015 | 0.937 | Industry |
| Energy | Combustion excluding transport, other fuels | $CO_2$ | 1.674 | 7.635 | 0.013 | 0.951 | Energy |
| Agriculture | Enteric fermentation | $CH_4$ | 7.627 | 6.306 | 0.011 | 0.961 | Agriculture |
| Waste | Wastewater treatment and discharge | $N_2O$ | 7.154 | 4.926 | 0.008 | 0.970 | Waste |
| Waste | Solid waste disposal | $CH_4$ | 4.328 | 4.501 | 0.008 | 0.978 | Waste |
| Waste | Incineration and open burning of waste | $CO_2$ | 2.550 | 3.193 | 0.005 | 0.983 | Waste |
| Waste | Incineration and open burning of waste | $CH_4$ | 2.692 | 1.916 | 0.003 | 0.986 | Waste |
| Energy | Combustion excluding transport | $N_2O$ | 1.339 | 1.281 | 0.002 | 0.989 | Energy |
| LULUCF | Grassland remaining grassland | $CO_2$ | 0.206 | 1.114 | 0.002 | 0.990 | LULUCF |
| Energy | Combustion excluding transport | $CH_4$ | 1.133 | 1.050 | 0.002 | 0.992 | Agriculture |
| Energy | Road transportation | $N_2O$ | 0.627 | 0.840 | 0.001 | 0.994 | Energy |
| Agriculture | Agricultural soils | $N_2O$ | 0.841 | 0.812 | 0.001 | 0.995 | Energy |
| Agriculture | Manure management | $N_2O$ | 0.869 | 0.774 | 0.001 | 0.996 | Agriculture |
| Waste | Incineration and open burning of waste | $N_2O$ | 0.741 | 0.565 | 0.001 | 0.997 | Waste |
| Energy | Domestic aviation | $N_2O$ | 0.323 | 0.397 | 0.001 | 0.998 | Energy |
| Industry | Solvent use | $CO_2$ | 0.263 | 0.394 | 0.001 | 0.999 | Industry |
| Energy | Road transportation | $CH_4$ | 0.068 | 0.168 | 0.000 | 0.999 | Energy |
| Agriculture | Manure management | $CH_4$ | 0.167 | 0.137 | 0.000 | 0.999 | Agriculture |
| Industry | Paraffin wax use | $CO_2$ | 0.043 | 0.088 | 0.000 | 0.999 | Energy |
| Energy | Domestic navigation | $N_2O$ | 0.051 | 0.079 | 0.000 | 1.000 | Industry |
| Energy | Domestic navigation | $CH_4$ | 0.036 | 0.056 | 0.000 | 1.000 | Energy |
| LULUCF | Forest land | $N_2O$ | 0.052 | 0.055 | 0.000 | 1.000 | LULUCF |
| LULUCF | Land converted to cropland | $CO_2$ | 0.000 | 0.048 | 0.000 | 1.000 | LULUCF |
| Industry | Limestone and dolomite use | $CO_2$ | 0.000 | 0.040 | 0.000 | 1.000 | LULUCF |
| LULUCF | Forest land remaining forest land | $CO_2$ | 0.000 | -0.038 | 0.000 | 1.000 | LULUCF |
| LULUCF | Grassland | $CO_2$ | 0.004 | 0.010 | 0.000 | 1.000 | Energy |
| Energy | Domestic aviation | $CH_4$ | 0.007 | 0.008 | 0.000 | 1.000 | Agriculture |
| Agriculture | Liming | $CO_2$ | 0.008 | 0.004 | 0.000 | 1.000 | Industry |
| Industry | Consumption of SF6 | $SF_6$ | 0.034 | 0.003 | 0.000 | 1.000 | Industry |
| LULUCF | Forest land | $CH_4$ | 0.000 | 0.000 | 0.000 | 1.000 | Industry |
| Industry | Road paving with asphalt | $CO_2$ | 0.000 | 0.000 | 0.000 | 1.000 | LULUCF |
| Industry | Asphalt roofing | $CO_2$ | 0.000 | 0.000 | 0.000 | 1.000 | Industry |
| Total | | | | 652.804 | 581.886 | 1.000 | |

Table 16.11.3 Key Category Analysis years 1990/1995-2018, trend assessment, Tier 1.

Table 7.A1 (of Good Practice Guidance) Tier 1 Analysis - Trend Assessment GRL – inventory

| A | | | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| IPCC Source Categories (LULUCF included) | | | Direct GHG | Base Year Estimate Ex,o Gg $CO_2$ eq | Year 2018 Estimate Ex,t Gg $CO_2$ eq | Trend Assess-ment Tx,t | Contri-Bution To Trend | Cumul. total of Col. F |
| Energy | Combustion excluding transport, Liquid fuels | $CO_2$ | 523.866 | 422.381 | 0.068 | 0.472 | 0.472 | Energy |
| Energy | Domestic navigation | $CO_2$ | 20.941 | 32.442 | 0.021 | 0.146 | 0.618 | Energy |
| Energy | Domestic aviation | $CO_2$ | 38.709 | 47.564 | 0.020 | 0.138 | 0.757 | Energy |
| Industry | Consumption of HFC's | HFCs | 0.027 | 8.861 | 0.014 | 0.094 | 0.851 | Industry |
| Energy | Combustion excluding transport, other fuels | $CO_2$ | 1.674 | 7.635 | 0.009 | 0.065 | 0.916 | Energy |
| Energy | Road transportation | $CO_2$ | 36.423 | 34.274 | 0.003 | 0.019 | 0.935 | Waste |
| Waste | Wastewater treatment and discharge | $N_2O$ | 7.154 | 4.926 | 0.002 | 0.015 | 0.950 | Energy |
| LULUCF | Grassland remaining grassland | $CO_2$ | 0.206 | 1.114 | 0.001 | 0.010 | 0.960 | LULUCF |
| Waste | Incineration and open burning of waste | $CO_2$ | 2.550 | 3.193 | 0.001 | 0.010 | 0.970 | Waste |
| Waste | Solid waste disposal | $CH_4$ | 4.328 | 4.501 | 0.001 | 0.007 | 0.977 | Waste |
| Agriculture | Enteric fermentation | $CH_4$ | 7.627 | 6.306 | 0.001 | 0.005 | 0.982 | Agriculture |
| Waste | Incineration and open burning of waste | $CH_4$ | 2.692 | 1.916 | 0.001 | 0.005 | 0.987 | Waste |
| Energy | Road transportation | $N_2O$ | 0.627 | 0.840 | 0.000 | 0.003 | 0.990 | Agriculture |
| Industry | Solvent use | $CO_2$ | 0.263 | 0.394 | 0.000 | 0.002 | 0.992 | Energy |
| Energy | Domestic aviation | $N_2O$ | 0.323 | 0.397 | 0.000 | 0.001 | 0.993 | Energy |
| Energy | Road transportation | $CH_4$ | 0.068 | 0.168 | 0.000 | 0.001 | 0.994 | Waste |
| Waste | Incineration and open burning of waste | $N_2O$ | 0.741 | 0.565 | 0.000 | 0.001 | 0.995 | Energy |
| Energy | Combustion excluding transport | $N_2O$ | 1.339 | 1.281 | 0.000 | 0.001 | 0.996 | Energy |
| Agriculture | Agricultural soils | $N_2O$ | 0.841 | 0.812 | 0.000 | 0.001 | 0.996 | Industry |
| Industry | Paraffin wax use | $CO_2$ | 0.043 | 0.088 | 0.000 | 0.001 | 0.997 | LULUCF |
| LULUCF | Land converted to cropland | $CO_2$ | 0.000 | 0.048 | 0.000 | 0.001 | 0.998 | Energy |
| Energy | Combustion excluding transport | $CH_4$ | 1.133 | 1.050 | 0.000 | 0.000 | 0.998 | LULUCF |
| Industry | Limestone and dolomite use | $CO_2$ | 0.000 | 0.040 | 0.000 | 0.000 | 0.998 | Energy |
| LULUCF | Forest land remaining forest land | $CO_2$ | 0.000 | -0.038 | 0.000 | 0.000 | 0.999 | Energy |
| Energy | Domestic navigation | $N_2O$ | 0.051 | 0.079 | 0.000 | 0.000 | 0.999 | Industry |
| Industry | Consumption of SF6 | $SF_6$ | 0.034 | 0.003 | 0.000 | 0.000 | 0.999 | Industry |
| Energy | Domestic navigation | $CH_4$ | 0.036 | 0.056 | 0.000 | 0.000 | 1.000 | Agriculture |
| Agriculture | Manure management | $CH_4$ | 0.167 | 0.137 | 0.000 | 0.000 | 1.000 | LULUCF |
| LULUCF | Forest land | $N_2O$ | 0.052 | 0.055 | 0.000 | 0.000 | 1.000 | Agriculture |
| LULUCF | Grassland | $CO_2$ | 0.004 | 0.010 | 0.000 | 0.000 | 1.000 | LULUCF |
| Agriculture | Liming | $CO_2$ | 0.008 | 0.004 | 0.000 | 0.000 | 1.000 | Agriculture |
| Energy | Domestic aviation | $CH_4$ | 0.007 | 0.008 | 0.000 | 0.000 | 1.000 | Industry |
| Agriculture | Manure management | $N_2O$ | 0.869 | 0.774 | 0.000 | 0.000 | 1.000 | Energy |
| LULUCF | Forest land | $CH_4$ | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | Industry |
| Industry | Asphalt roofing | $CO_2$ | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | Industry |
| Industry | Road paving with asphalt | $CO_2$ | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | LULUCF |
| Total | | | | 652.804 | 581.886 | | 1.000 | |

Table 16.11.4 Summary of Key Category Analysis for Greenland for level assessment for year 1990/95 and 2018 and for trend for years 1990-2018.

| IPCC Source Categories (LULUCF included) | | | GHG | | |
|---|---|---|---|---|---|
| | | | Level Tier1 1990 | Level Tier1 2018 | Trend Tier1 1990-2018 |
| Energy | Combustion excluding transport, Liquid fuels | $CO_2$ | 1 | 1 | 1 |
| Energy | Combustion excluding transport, other fuels | $CO_2$ | 6 | 6 | 5 |
| Energy | Combustion excluding transport | $CH_4$ | | | |
| Energy | Combustion excluding transport | $N_2O$ | | | |
| Energy | Domestic aviation | $CO_2$ | 2 | 2 | 3 |
| Energy | Domestic aviation | $CH_4$ | | | |
| Energy | Domestic aviation | $N_2O$ | | | |
| Energy | Road transportation | $CO_2$ | 3 | 3 | 6 |
| Energy | Road transportation | $CH_4$ | | | |
| Energy | Road transportation | $N_2O$ | | | |
| Energy | Domestic navigation | $CO_2$ | 4 | 4 | 2 |
| Energy | Domestic navigation | $CH_4$ | | | |
| Energy | Domestic navigation | $N_2O$ | | | |
| Industry | Limestone and dolomite use | $CO_2$ | | | |
| Industry | Paraffin wax use | $CO_2$ | | | |
| Industry | Solvent use | $CO_2$ | | | |
| Industry | Road paving with asphalt | $CO_2$ | | | |
| Industry | Asphalt roofing | $CO_2$ | | | |
| Industry | Consumption of HFC's | HFCs | 5 | 5 | 4 |
| Industry | Consumption of SF6 | $SF_6$ | | | |
| Agriculture | Enteric fermentation | $CH_4$ | 5 | | |
| Agriculture | Manure management | $CH_4$ | | | |
| Agriculture | Manure management | $N_2O$ | | | |
| Agriculture | Agricultural soils | $N_2O$ | | | |
| Agriculture | Liming | $CO_2$ | | | |
| Waste | Solid waste disposal | $CH_4$ | | | |
| Waste | Incineration and open burning of waste | $CO_2$ | | | |
| Waste | Incineration and open burning of waste | $CH_4$ | | | |
| Waste | Incineration and open burning of waste | $N_2O$ | | | |
| Waste | Wastewater treatment and discharge | $N_2O$ | | | 7 |
| LULUCF | Forest land remaining forest land | $CO_2$ | | | |
| LULUCF | Forest land | $CH_4$ | | | |
| LULUCF | Forest land | $N_2O$ | | | |
| LULUCF | Land converted to cropland | $CO_2$ | | | |
| LULUCF | Grassland remaining grassland | $CO_2$ | | | |
| LULUCF | Grassland | $CO_2$ | | | |

## 16.12 Annex 2 Detailed discussion of methodology and data for estimating $CO_2$ emission from fossil fuel combustion

Detailed information regarding the methodology and input data used to calculate $CO_2$ emissions from fossil fuel combustion is included in Section 16.3.

## 16.13 Annex 3 Other detailed methodological descriptions for individual source or sink categories

All methodological descriptions are included in Sections 16.3 – 16.7 and Section 16.10.

## 16.14 Annex 4 $CO_2$ reference approach and comparison with sectoral approach, and relevant information on the national energy balance

See Section 16.3.6 of this annex for the results of the comparison between the sectoral and reference approach.

## 16.15 Annex 5 Assessment of completeness and (potential) sources and sinks of greenhouse gas emissions and removals excluded

### 16.15.1 GHG inventory

The Greenlandic greenhouse gas emission inventories for 1990-2018 include all sources identified by the 2006 IPCC Guidelines and the 2000 IPCC Good Practice Guidance except the following:

In the Industrial Processes and Product Use sector no $N_2O$ emissions are included in (CRF category 2D3) Solvent Use. With regard to $N_2O$ from fire extinguishers (CRF category 2G3b) the notation key NE was priorily used. However, a Danish research on the matter has showed that $N_2O$ is not used in fire extinguishers. Since Greenland imports all fireextinguishers from Denmark, the notation key on $N_2O$ in fire extinguishers has been changed from NE to NO concerning every year in the time-series 1990-2018. With regard to aerosol cans, we are aware that $N_2O$ is found in the products. However, since we cannot find any activity data on aerosol cans, we continue to report the notation key NE for $N_2O$ in aerosol cans.

Direct and indirect $CH_4$ emissions from agricultural soils are not estimated. Direct and indirect soil emissions are considered of minor importance for $CH_4$.

In the LULUCF sector emissions/removals from wetlands, settlements and other land are currently not estimated due to the lack of available data. The lack of data availability is also an issue for other aspects of LULUCF, e.g. harvested wood products. For more detail, please see Section 16.6.

In the Waste sector $CO_2$ emissions from managed waste disposal on land are not estimated. According to the 2006 IPCC Guidelines: "Decomposition of organic material deriving from biomass sources (e.g., crops, wood) is the primary source of $CO_2$ release from waste. These $CO_2$ emissions are not included in national totals, because the carbon is of biogenic origin and net emissions are accounted for under the AFOLU Sector."

### 16.15.2 KP-LULUCF inventory

The KP-LULUCF inventory is considered complete. The carbon pools not estimated has been documented as not being sources, please see Section 16.10 for further documentation.

## 16.16 Annex 6 Additional information to be considered as part of the annual inventory submission and the supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol or other useful reference information

No additional information for Greenland is deemed relevant.

## 16.17 Annex 7 Tables 6.1 and 6.2 of the IPCC good practice guidance

| IPCC Source category | Gas | Base year emission | Year t emission | Activity data uncertainty | Emission factor uncertainty | Combined uncertainty | Combined uncertainty as % of total national emissions in year t | Type A sensitivity | Type B sensitivity | Uncertainty in trend in national emissions introduced by emission factor uncertainty | Uncertainty in trend in national emissions introduced by activity data uncertainty | Uncertainty introduced into the trend in total national emissions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Input data | Input data | Input data | Input data | | | | | | | |
| | | Gg $CO_2$ eq | Gg $CO_2$ eq | % | % | % | % | % | % | % | % | % |
| 1A Liquid fuels | $CO_2$ | 620 | 531 | 3 | 2 | 3.606 | 11.086 | 0.023 | 0.813 | 0.046 | 3.451 | 11.912 |
| 1A Municipal waste | $CO_2$ | 2 | 8 | 3 | 25 | 25.179 | 0.108 | 0.009 | 0.011 | 0.231 | 0.049 | 0.056 |
| 1A Liquid fuels | $CH_4$ | 1 | 1 | 3 | 100 | 100.045 | 0.036 | 0.000 | 0.002 | 0.004 | 0.007 | 0.000 |
| 1A Municipal waste | $CH_4$ | 0 | 0 | 3 | 100 | 100.045 | 0.000 | 0.000 | 0.000 | 0.008 | 0.000 | 0.000 |
| 1A Biomass | $CH_4$ | 0 | 0 | 3 | 100 | 100.045 | 0.000 | 0.000 | 0.000 | 0.010 | 0.001 | 0.000 |
| 1A Liquid fuels | $N_2O$ | 2 | 2 | 3 | 500 | 500.009 | 4.033 | 0.000 | 0.004 | 0.227 | 0.015 | 0.052 |
| 1A Municipal waste | $N_2O$ | 0 | 0 | 3 | 500 | 500.009 | 0.009 | 0.000 | 0.000 | 0.067 | 0.001 | 0.004 |
| 1A Biomass | $N_2O$ | 0 | 0 | 3 | 200 | 200.022 | 0.002 | 0.000 | 0.000 | 0.033 | 0.001 | 0.001 |
| 1B2 Oil exploration | $CO_2$ | 0 | 0 | 3 | 1000 | 1,000.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1B2 Oil exploration | $CH_4$ | 0 | 0 | 3 | 1000 | 1,000.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1B2 Oil exploration | $N_2O$ | 0 | 0 | 3 | 1000 | 1,000.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2A4 Limestone and dolomite use | $CO_2$ | 0 | 0 | 5 | 5 | 7.071 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2D2 Paraffin wax use | $CO_2$ | 0 | 0 | 5 | 25 | 25.495 | 0.000 | 0.000 | 0.000 | 0.002 | 0.001 | 0.000 |
| 2D3 Solvent use | $CO_2$ | 0 | 0 | 5 | 25 | 25.495 | 0.000 | 0.000 | 0.000 | 0.001 | 0.002 | 0.000 |
| 2D3 Road paving with asphalt | $CO_2$ | 0 | 0 | 5 | 25 | 25.495 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2D3 Asphalt roofing | $CO_2$ | 0 | 0 | 5 | 25 | 25.495 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2F Consumption of HFC | HFC | 0 | 8 | 10 | 50 | 50.990 | 0.509 | 0.012 | 0.012 | 0.615 | 0.174 | 0.408 |
| 2G Consumption of $SF_6$ | $SF_6$ | 0 | 0 | 10 | 50 | 50.990 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 |
| 3A Enteric Fermentation | $CH_4$ | 8 | 6 | 10 | 100 | 100.499 | 1.166 | 0.001 | 0.009 | 0.083 | 0.134 | 0.025 |
| 3B Manure Management | $CH_4$ | 0 | 0 | 10 | 100 | 100.499 | 0.001 | 0.000 | 0.000 | 0.002 | 0.003 | 0.000 |
| 3B Manure Management | $N_2O$ | 1 | 1 | 10 | 100 | 100.499 | 0.017 | 0.000 | 0.001 | 0.001 | 0.016 | 0.000 |
| 3D Agricultural soils | $N_2O$ | 1 | 1 | 20 | 50 | 53.852 | 0.010 | 0.001 | 0.002 | 0.025 | 0.046 | 0.003 |
| 3G Liming | $CO_2$ | 0 | 0 | 5 | 50 | 50.249 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

| IPCC Source category | Gas | Base year emission | Year t emission | Activity data uncertainty | Emission factor uncertainty | Combined uncertainty | Combined uncertainty as % of total national emissions in year t | Type A sensitivity | Type B sensitivity | Uncertainty in trend in national emissions introduced by emission factor uncertainty | Uncertainty in trend in national emissions introduced by activity data uncertainty | Uncertainty introduced into the trend in total national emissions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Input data Gg $CO_2$ eq | Input data Gg $CO_2$ eq | Input data % | Input data % | % | % | % | % | % | % | % |
| *continued* | | | | | | | | | | | | |
| 4A Forest | $CO_2$ | 0 | 0 | 5 | 50 | 50.249 | 0.000 | 0.000 | 0.000 | 0.003 | 0.000 | 0.000 |
| 4A Forest | $CH_4$ | 0 | 0 | 5 | 50 | 50.249 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4A Forest | $N_2O$ | 0 | 0 | 5 | 50 | 50.249 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 |
| 4B Cropland | $CO_2$ | 0 | 0 | 5 | 50 | 50.249 | 0.000 | 0.000 | 0.000 | 0.004 | 0.001 | 0.000 |
| 4C Grassland | $CO_2$ | 0 | 1 | 5 | 50 | 50.249 | 0.010 | 0.001 | 0.002 | 0.074 | 0.012 | 0.006 |
| 4C Grassland | $CH_4$ | 0 | 0 | 5 | 50 | 50.249 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5A Solid Waste Disposal | $CH_4$ | 4 | 5 | 10 | 100 | 100.499 | 0.632 | 0.001 | 0.007 | 0.113 | 0.099 | 0.022 |
| 5C Incineration and open burning of waste | $CO_2$ | 3 | 3 | 10 | 25 | 26.926 | 0.022 | 0.001 | 0.005 | 0.036 | 0.069 | 0.006 |
| 5C Incineration and open burning of waste | $CH_4$ | 3 | 2 | 10 | 50 | 50.990 | 0.029 | 0.001 | 0.003 | 0.035 | 0.041 | 0.003 |
| 5C Incineration and open burning of waste | $N_2O$ | 1 | 1 | 10 | 100 | 100.499 | 0.010 | 0.000 | 0.001 | 0.014 | 0.012 | 0.000 |
| 5D Wastewater treatment and discharge | $N_2O$ | 7 | 5 | 30 | 100 | 104.403 | 0.758 | 0.002 | 0.007 | 0.231 | 0.312 | 0.150 |
| Total | | 653 | 575 | | | | 18,438 | | | | | 12,649 |
| Total uncertainties | | | | Overall uncertainty in the year (%): | | | 4.294 | | | | Trend uncertainty (%): | 3.557 |

## 16.18 Annex 8 Results of a technical analysis conducted on the Greenlandic gasoil

In 2013, a technical analysis has been conducted on the arctic gasoil that is by far the most dominant type of fuel in Greenland. The analysis was conducted by the Danish Technological Institute in order to gain a country specific emission factor on the Greenlandic gasoil.

Table 16.18.1 shows the results of the technological analysis on the Greenlandic gasoil. The $CO_2$ emission factor was revised in the 2015 submission due to an increase in the recommended oxidation factor from 0.99 to 1.0.

Table 16.18.1 Results on the technical analysis on the Greenlandic gasoil

| | Test result | Method |
|---|---|---|
| C, % | 85.4 | Elementaranalyse |
| Upper calorific, J/g | 45860 | DS/CEN/TS 14918 |
| Lower calorific, J/g | 42900 | Calculation |
| $CO_2$ emission factor, kg $CO_2$/GJ | 72.967 | Calculation |

# 17 Information regarding the aggregated submission for Denmark and Greenland

This chapter contains information on the aggregated submission for Denmark and Greenland submitted under the Kyoto Protocol. This chapter contains a trend discussion, an approach 1 uncertainty analysis, information on the aggregated reference approach, information relating to key categories and information on recalculations. Sector specific information is included for Denmark in Chapter 3-10 and for Greenland in Chapter 16.

The institutional arrangements and the overall QA/QC plan are described in Chapter 1. This description covers all the Danish submissions to the European Union, the UNFCCC and the Kyoto Protocol, and therefore information regarding the national system is not presented in this chapter. Information on the specific QA/QC activities concerning the aggregated submission is presented in Chapter 17.7.

In Chapter 17.6, a description of the aggregation process is provided. The chapter explains the technical issues in aggregating two CRF submissions, including the software used in the process and the handling of background data.

## 17.1 Trends in emissions

Due to the small emission originating from Greenland, the trends for Denmark and Greenland are practically identical to the trends for Denmark presented in Chapter 2. Therefore, they are not further described here.

## 17.2 The reference approach

In addition to the sector-specific $CO_2$ emission inventories (the national approach), the $CO_2$ emission is also estimated using the reference approach described in the 2006 IPCC Guidelines. The reference approach is based on data for fuel production, import, export and stock change. The $CO_2$ emission inventory based on the reference approach is reported to the Climate Convention and used for verification of the official data in the national approach.

The reference approach for Denmark and Greenland is an aggregation of the individual reference approaches for the two. The reference approach for Denmark is described in Chapter 3.4 and the reference approach for Greenland is included in Chapter 16.

The difference between the two methods is almost exclusively caused by the difference between the Danish sectoral and reference approach. Please refer to Chapter 3.4 for more information.

## 17.3 Uncertainties

An uncertainty estimate has been calculated for Denmark and Greenland. The uncertainty estimate for Denmark is included in Chapter 1.7 and for Greenland in Chapter 16.

The uncertainty estimates are based on the Approach 1 methodology in the 2006 IPCC Guidelines. Uncertainty estimates cover 100 % of the total net greenhouse gas emissions and removals. The emissions from Greenland have been treated separately due to the uncertainties being different than the uncertainties in the Danish inventory. The uncertainty of the Greenlandic emissions has almost no effect on the overall uncertainty estimate, due to the low emissions originating from Greenland.

The estimated uncertainties for total GHG and for $CO_2$, $CH_4$, $N_2O$ and F-gases are shown in Table 17.1. The base year for F-gases is 1995 and for all other sources the base year is 1990. The total net GHG emission from Denmark and Greenland is estimated with an uncertainty of ±5.7 % and the trend in net GHG emission since 1990/1995 has been estimated to be -28.7 % ± 1.8 %-age points. The GHG uncertainty estimates do not take into account the uncertainty of the GWP factors.

Table 17.1 Uncertainties 1990-2018.

| | Uncertainty [%] | Trend [%] | Uncertainty in trend [%-age points] |
|---|---|---|---|
| GHG | 5.6 | -28.5 | 1.8 |
| GHG ex. LULUCF | 4.9 | -30.9 | 1.8 |
| $CO_2$ | 5.2 | -31.3 | 1.5 |
| $CH_4$ | 14.2 | -6.4 | 11.6 |
| $N_2O$ | 36 | -34 | 10 |
| F-gases | 43 | 44 | 66 |

The uncertainties shown in Table 17.1 are practically identical to the values for Denmark only presented in Chapter 1. The uncertainties for the activity rates and emission factors are shown in Table 17.2.

Table 17.2 Uncertainties for activity rates and emission factors.

| | IPCC Source category | Gas | Base year emission Input data Gg $CO_2$ eqv. | 2018 emission Input data Gg $CO_2$ eqv. | Activity data uncertainty Input data % | Emission factor uncertainty Input data % |
|---|---|---|---|---|---|---|
| Denmark | 1A Stationary combustion, Coal, ETS data | $CO_2$ | 0.0 | 6107.0 | 0.5 | 0.3 |
| Denmark | 1A Stationary combustion, Coal, no ETS data | $CO_2$ | 23826.7 | 210.9 | 1.5 | 1.0 |
| Denmark | 1A Stationary combustion, BKB | $CO_2$ | 11.3 | 0.0 | 2.9 | 5.0 |
| Denmark | 1A Stationary combustion, Coke oven coke | $CO_2$ | 136.5 | 43.5 | 1.5 | 5.0 |
| Denmark | 1A Stationary combustion, Fossil waste, ETS data | $CO_2$ | 0.0 | 1340.3 | 2.0 | 3.0 |
| Denmark | 1A Stationary combustion, Fossil waste, no ETS data | $CO_2$ | 573.5 | 431.5 | 5.0 | 10.0 |
| Denmark | 1A Stationary combustion, Petroleum coke, ETS data | $CO_2$ | 0.0 | 631.7 | 0.5 | 0.5 |
| Denmark | 1A Stationary combustion, Petroleum coke, no ETS data | $CO_2$ | 414.7 | 20.6 | 1.9 | 5.0 |
| Denmark | 1A Stationary combustion, Residual oil, ETS data | $CO_2$ | 0.0 | 231.1 | 0.5 | 0.5 |
| Denmark | 1A Stationary combustion, Residual oil, no ETS data | $CO_2$ | 2526.6 | 20.2 | 1.0 | 2.0 |
| Denmark | 1A Stationary combustion, Gas oil | $CO_2$ | 4738.4 | 688.6 | 2.6 | 1.3 |
| Denmark | 1A Stationary combustion, Kerosene | $CO_2$ | 367.6 | 13.2 | 2.0 | 3.0 |
| Denmark | 1A Stationary combustion, LPG | $CO_2$ | 187.9 | 140.6 | 2.0 | 4.0 |
| Denmark | 1A1b Stationary combustion, Petroleum refining, Refinery gas | $CO_2$ | 816.1 | 832.1 | 1.0 | 0.5 |
| Denmark | 1A Stationary combustion, Natural gas, onshore | $CO_2$ | 3790.5 | 5194.1 | 1.3 | 0.4 |
| Denmark | 1A1c_ii Stationary combustion, Oil and gas extraction, Off shore gas turbines, Natural gas | $CO_2$ | 544.9 | 1253.6 | 0.5 | 0.5 |
| Denmark | 1A1 Stationary Combustion, Solid fuels | $CH_4$ | 5.3 | 1.4 | 1.0 | 100.0 |
| Denmark | 1A1 Stationary Combustion, Liquid fuels | $CH_4$ | 0.7 | 0.5 | 1.0 | 100.0 |
| Denmark | 1A1 Stationary Combustion, not engines, gaseous fuels | $CH_4$ | 0.8 | 1.6 | 1.0 | 100.0 |
| Denmark | 1A1 Stationary Combustion, Waste | $CH_4$ | 0.2 | 0.3 | 3.0 | 100.0 |
| Denmark | 1A1 Stationary Combustion, not engines, Biomass | $CH_4$ | 3.6 | 13.0 | 3.0 | 100.0 |

| | IPCC Source category | Gas | Base year emission Input data Gg $CO_2$ eqv. | 2018 emission Input data Gg $CO_2$ eqv. | Activity data uncertainty Input data % | Emission factor uncertainty Input data % |
|---|---|---|---|---|---|---|
| Denmark | 1A2 Stationary Combustion, solid fuels | $CH_4$ | 3.8 | 1.3 | 2.0 | 100.0 |
| Denmark | 1A2 Stationary Combustion, Liquid fuels | $CH_4$ | 0.9 | 0.6 | 2.0 | 100.0 |
| Denmark | 1A2 Stationary Combustion, not engines, gaseous fuels | $CH_4$ | 0.6 | 0.8 | 2.0 | 100.0 |
| Denmark | 1A2 Stationary Combustion, Waste | $CH_4$ | 0.0 | 2.9 | 3.0 | 100.0 |
| Denmark | 1A2 Stationary Combustion, not engines, Biomass | $CH_4$ | 1.6 | 2.3 | 3.0 | 100.0 |
| Denmark | 1A4 Stationary Combustion, Solid fuels | $CH_4$ | 6.2 | 0.1 | 3.0 | 100.0 |
| Denmark | 1A4 Stationary Combustion, Liquid fuels | $CH_4$ | 3.0 | 0.4 | 3.0 | 100.0 |
| Denmark | 1A4 Stationary Combustion, not engines, gaseous fuels | $CH_4$ | 0.6 | 0.8 | 3.0 | 100.0 |
| Denmark | 1A4 Stationary Combustion, Waste | $CH_4$ | 0.7 | 0.0 | 3.0 | 100.0 |
| Denmark | 1A4 Stationary Combustion, not engines, not residential wood and not residential/agricultural straw, Biomass | $CH_4$ | 0.1 | 0.6 | 3.0 | 100.0 |
| Denmark | 1A4b_i Stationary combustion, Residential wood combustion | $CH_4$ | 72.3 | 70.1 | 10.0 | 150.0 |
| Denmark | 1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion | $CH_4$ | 63.6 | 36.9 | 10.0 | 150.0 |
| Denmark | 1A Stationary combustion, Natural gas fuelled engines, gaseous fuels | $CH_4$ | 5.5 | 72.4 | 1.0 | 2.0 |
| Denmark | 1A Stationary combustion, Biogas fuelled engines, Biomass | $CH_4$ | 2.2 | 57.9 | 3.0 | 10.0 |
| Denmark | 1A1 Stationary Combustion, Solid fuels | $N_2O$ | 57.4 | 14.8 | 1.0 | 400.0 |
| Denmark | 1A1 Stationary Combustion, Liquid fuels | $N_2O$ | 2.8 | 1.5 | 1.0 | 1000.0 |
| Denmark | 1A1 Stationary Combustion, Gaseous fuels | $N_2O$ | 11.8 | 14.3 | 1.0 | 750.0 |
| Denmark | 1A1 Stationary Combustion, Waste | $N_2O$ | 5.2 | 13.0 | 3.0 | 400.0 |
| Denmark | 1A1 Stationary Combustion, Biomass | $N_2O$ | 8.4 | 42.4 | 3.0 | 400.0 |
| Denmark | 1A2 Stationary Combustion, Solid fuels | $N_2O$ | 6.7 | 24.6 | 2.0 | 400.0 |
| Denmark | 1A2 Stationary Combustion, Liquid fuels | $N_2O$ | 28.7 | 6.2 | 2.0 | 1000.0 |
| Denmark | 1A2 Stationary Combustion, Gaseous fuels | $N_2O$ | 7.2 | 8.9 | 2.0 | 750.0 |
| Denmark | 1A2 Stationary Combustion, Waste | $N_2O$ | 0.0 | 4.6 | 3.0 | 400.0 |
| Denmark | 1A2 Stationary Combustion, Biomass | $N_2O$ | 6.9 | 10.6 | 3.0 | 400.0 |
| Denmark | 1A4 Stationary Combustion, Solid fuels | $N_2O$ | 1.5 | 0.2 | 3.0 | 400.0 |
| Denmark | 1A4 Stationary Combustion, Liquid fuels | $N_2O$ | 11.4 | 1.4 | 3.0 | 1000.0 |
| Denmark | 1A4 Stationary Combustion, Gaseous fuels | $N_2O$ | 7.7 | 9.8 | 3.0 | 750.0 |
| Denmark | 1A4 Stationary Combustion, Waste | $N_2O$ | 1.1 | 0.0 | 3.0 | 400.0 |
| Denmark | 1A4 Stationary Combustion, not residential wood and not residential/agricultural straw, Biomass | $N_2O$ | 0.5 | 3.8 | 3.0 | 400.0 |
| Denmark | 1A4b_i Stationary Combustion, Residential wood combustion | $N_2O$ | 10.7 | 49.0 | 10.0 | 500.0 |
| Denmark | 1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion | $N_2O$ | 10.1 | 5.9 | 10.0 | 500.0 |
| Denmark | 1.A.2.g Industry (mobile) | $CO_2$ | 629.3 | 604.8 | 41.0 | 5.0 |
| Denmark | 1.A.3.a Civil aviation | $CO_2$ | 204.8 | 133.2 | 10.0 | 5.0 |
| Denmark | 1.A.3.b Road Transport | $CO_2$ | 9356.6 | 12306.7 | 2.0 | 5.0 |
| Denmark | 1.A.3.c Railways | $CO_2$ | 296.7 | 224.0 | 2.0 | 5.0 |
| Denmark | 1.A.3.d Navigation (large vessels) | $CO_2$ | 714.4 | 621.1 | 11.0 | 5.0 |
| Denmark | 1.A.4.a Commercial/Institutional (mobile) | $CO_2$ | 44.6 | 83.0 | 35.0 | 5.0 |
| Denmark | 1.A.4.b Residential (mobile) | $CO_2$ | 18.8 | 23.2 | 35.0 | 5.0 |
| Denmark | 1.A.4.c ii Agriculture (mobile) | $CO_2$ | 1272.3 | 1041.7 | 24.0 | 5.0 |
| Denmark | 1.A.4.c ii Forestry (mobile) | $CO_2$ | 35.7 | 15.3 | 30.0 | 5.0 |
| Denmark | 1.A.4.c iii Fisheries | $CO_2$ | 619.6 | 269.2 | 2.0 | 5.0 |
| Denmark | 1.A.5.b Other (military) | $CO_2$ | 47.9 | 97.4 | 41.0 | 5.0 |
| Denmark | 1.A.5.b Other (small boats) | $CO_2$ | 119.0 | 117.6 | 2.0 | 5.0 |
| Denmark | 1.A.2.g Industry (mobile) | $CH_4$ | 1.5 | 0.5 | 41.0 | 100.0 |
| Denmark | 1.A.3.a Civil aviation | $CH_4$ | 0.1 | 0.0 | 10.0 | 100.0 |
| Denmark | 1.A.3.b Road Transport | $CH_4$ | 78.5 | 9.3 | 2.0 | 40.0 |
| Denmark | 1.A.3.c Railways | $CH_4$ | 0.3 | 0.1 | 2.0 | 100.0 |
| Denmark | 1.A.3.d Navigation (large vessels) | $CH_4$ | 0.4 | 0.9 | 11.0 | 100.0 |

| | IPCC Source category | Gas | Base year emission Input data Gg $CO_2$ eqv. | 2018 emission Input data Gg $CO_2$ eqv. | Activity data uncertainty Input data % | Emission factor uncertainty Input data % |
|---|---|---|---|---|---|---|
| Denmark | 1.A.4.a Commercial/Institutional (mobile) | $CH_4$ | 0.6 | 0.8 | 35.0 | 100.0 |
| Denmark | 1.A.4.b Residential (mobile) | $CH_4$ | 0.9 | 0.4 | 35.0 | 100.0 |
| Denmark | 1.A.4.c ii Agriculture (mobile) | $CH_4$ | 2.3 | 1.4 | 24.0 | 100.0 |
| Denmark | 1.A.4.c ii Forestry (mobile) | $CH_4$ | 4.0 | 0.4 | 30.0 | 100.0 |
| Denmark | 1.A.4.c iii Fisheries | $CH_4$ | 0.3 | 0.2 | 2.0 | 100.0 |
| Denmark | 1.A.5.b Other (military) | $CH_4$ | 1.9 | 0.2 | 41.0 | 100.0 |
| Denmark | 1.A.5.b Other (small boats) | $CH_4$ | 0.1 | 0.1 | 2.0 | 100.0 |
| Denmark | 1.A.2.g Industry (mobile) | $N_2O$ | 7.4 | 8.3 | 41.0 | 1000.0 |
| Denmark | 1.A.3.a Civil aviation | $N_2O$ | 2.9 | 2.0 | 10.0 | 1000.0 |
| Denmark | 1.A.3.b Road Transport | $N_2O$ | 87.8 | 132.5 | 2.0 | 50.0 |
| Denmark | 1.A.3.c Railways | $N_2O$ | 2.7 | 2.0 | 2.0 | 1000.0 |
| Denmark | 1.A.3.d Navigation (large vessels) | $N_2O$ | 5.3 | 4.6 | 11.0 | 1000.0 |
| Denmark | 1.A.4.a Commercial/Institutional (mobile) | $N_2O$ | 0.4 | 0.6 | 35.0 | 1000.0 |
| Denmark | 1.A.4.b Residential (mobile) | $N_2O$ | 0.1 | 0.1 | 35.0 | 1000.0 |
| Denmark | 1.A.4.c ii Agriculture (mobile) | $N_2O$ | 14.7 | 14.7 | 24.0 | 1000.0 |
| Denmark | 1.A.4.c ii Forestry (mobile) | $N_2O$ | 0.2 | 0.2 | 30.0 | 1000.0 |
| Denmark | 1.A.4.c iii Fisheries | $N_2O$ | 4.7 | 2.0 | 2.0 | 1000.0 |
| Denmark | 1.A.5.b Other (military) | $N_2O$ | 0.4 | 1.0 | 41.0 | 1000.0 |
| Denmark | 1.A.5.b Other (small boats) | $N_2O$ | 1.1 | 1.4 | 2.0 | 1000.0 |
| Denmark | 1.B.2.a.1 Exploration | $CO_2$ | 4.7 | 0.0 | 2.0 | 10.0 |
| Denmark | 1.B.2.a.2 Production | $CO_2$ | 0.0 | 0.0 | 2.0 | 100.0 |
| Denmark | 1.B.2.a.4 Refining/storage | $CO_2$ | 0.0 | 0.0 | 2.0 | 40.0 |
| Denmark | 1.B.2.b.1 Exploration | $CO_2$ | 8.2 | 0.0 | 2.0 | 10.0 |
| Denmark | 1.B.2.b.2 Production | $CO_2$ | 0.1 | 0.1 | 2.0 | 100.0 |
| Denmark | 1.B.2.b.4 Transmission and storage | $CO_2$ | 0.0 | 0.0 | 15.0 | 2.0 |
| Denmark | 1.B.2.b.5 Distribution | $CO_2$ | 0.0 | 0.0 | 25.0 | 10.0 |
| Denmark | 1.B.2.c.1.ii Venting | $CO_2$ | 0.0 | 0.0 | 15.0 | 2.0 |
| Denmark | 1.B.2.c.2.i Flaring, oil | $CO_2$ | 22.9 | 17.9 | 11.0 | 2.0 |
| Denmark | 1.B.2.c.2.ii Flaring, gas | $CO_2$ | 2.1 | 1.4 | 7.5 | 2.0 |
| Denmark | 1.B.2.c.2.iii Flaring, combined | $CO_2$ | 302.8 | 213.1 | 7.5 | 2.0 |
| Denmark | 1.B.2.a.1 Exploration | $CH_4$ | 0.0 | 0.0 | 2.0 | 125.0 |
| Denmark | 1.B.2.a.2 Production | $CH_4$ | 0.1 | 0.1 | 2.0 | 100.0 |
| Denmark | 1.B.2.a.3 Transport | $CH_4$ | 0.8 | 1.4 | 2.0 | 100.0 |
| Denmark | 1.B.2.a.4 Refining/storage | $CH_4$ | 30.5 | 21.4 | 1.0 | 200.0 |
| Denmark | 1.B.2.b.1 Exploration | $CH_4$ | 0.8 | 0.0 | 2.0 | 125.0 |
| Denmark | 1.B.2.b.2 Production | $CH_4$ | 48.8 | 38.3 | 2.0 | 100.0 |
| Denmark | 1.B.2.b.4 Transmission and storage | $CH_4$ | 4.8 | 0.7 | 15.0 | 2.0 |
| Denmark | 1.B.2.b.5 Distribution | $CH_4$ | 6.4 | 4.2 | 25.0 | 10.0 |
| Denmark | 1.B.2.c.1.ii Venting | $CH_4$ | 1.5 | 0.9 | 15.0 | 2.0 |
| Denmark | 1.B.2.c.2.i Flaring, oil | $CH_4$ | 0.2 | 0.1 | 11.0 | 15.0 |
| Denmark | 1.B.2.c.2.ii Flaring, gas | $CH_4$ | 0.3 | 0.0 | 7.5 | 2.0 |
| Denmark | 1.B.2.c.2.iii Flaring, combined | $CH_4$ | 28.6 | 22.8 | 7.5 | 125.0 |
| Denmark | 1.B.2.a.1 Exploration, oil | $N_2O$ | 1.4 | 0.0 | 2.0 | 1000.0 |
| Denmark | 1.B.2.c.2.i Flaring, oil | $N_2O$ | 0.1 | 0.0 | 11.0 | 1000.0 |
| Denmark | 1.B.2.c.2.ii Flaring, gas | $N_2O$ | 0.0 | 0.0 | 7.5 | 1000.0 |
| Denmark | 1.B.2.c.2.iii Flaring, combined | $N_2O$ | 51.6 | 41.2 | 7.5 | 1000.0 |
| Denmark | 2A1 Cement production | $CO_2$ | 882.4 | 1159.7 | 1.6 | 2.0 |
| Denmark | 2A2 Lime production | $CO_2$ | 105.4 | 36.8 | 1.4 | 4.0 |
| Denmark | 2A3 Glass production | $CO_2$ | 16.5 | 10.4 | 1.0 | 2.0 |
| Denmark | 2A4a Ceramics | $CO_2$ | 46.1 | 46.4 | 5.0 | 2.0 |
| Denmark | 2A4b Other uses of soda ash | $CO_2$ | 13.8 | 18.6 | 5.0 | 2.0 |
| Denmark | 2A4d Other process uses of carbonates | $CO_2$ | 17.5 | 26.1 | 4.0 | 2.0 |

| | IPCC Source category | Gas | Base year emission Input data Gg $CO_2$ eqv. | 2018 emission Input data Gg $CO_2$ eqv. | Activity data uncertainty Input data % | Emission factor un-certainty Input data % |
|---|---|---|---|---|---|---|
| Denmark | 2B10 Production of catalysts | $CO_2$ | 0.6 | 1.4 | 5.0 | 5.0 |
| Denmark | 2C1a Steel | $CO_2$ | 30.3 | 0.0 | 5.0 | 10.0 |
| Denmark | 2C5 Lead production | $CO_2$ | 0.2 | 0.1 | 10.0 | 50.0 |
| Denmark | 2D1 Lubricant use | $CO_2$ | 49.7 | 31.7 | 5.0 | 10.0 |
| Denmark | 2D2 Paraffin wax use | $CO_2$ | 21.7 | 58.5 | 10.0 | 20.0 |
| Denmark | Paint Application | $CO_2$ | 12.9 | 5.4 | 10.0 | 15.0 |
| Denmark | Degreasing, dry cleaning and electronics | $CO_2$ | 0.0 | 0.0 | 10.0 | 15.0 |
| Denmark | Chemical products manufacturing or processing | $CO_2$ | 19.4 | 12.6 | 10.0 | 15.0 |
| Denmark | Other use of solvents and related activities | $CO_2$ | 52.0 | 29.4 | 10.0 | 20.0 |
| Denmark | Printing industry | $CO_2$ | 0.0 | 0.0 | 10.0 | 15.0 |
| Denmark | Domestic solvent use (other than paint application) | $CO_2$ | 9.4 | 13.4 | 10.0 | 15.0 |
| Denmark | 2D3 Road paving with asphalt | $CO_2$ | 0.6 | 0.9 | 5.0 | 75.0 |
| Denmark | 2D3 Asphalt roofing | $CO_2$ | 0.0 | 0.0 | 5.0 | 75.0 |
| Denmark | 2D3 Urea based catalysts | $CO_2$ | 0.0 | 8.9 | 5.0 | 10.0 |
| Denmark | 2G4 Fireworks | $CO_2$ | 0.1 | 0.3 | 5.0 | 50.0 |
| Denmark | 2D2 Paraffin wax use | $CH_4$ | 0.0 | 0.1 | 10.0 | 20.0 |
| Denmark | 2D3 Road paving with asphalt | $CH_4$ | 0.3 | 0.4 | 5.0 | 75.0 |
| Denmark | 2G4 Fireworks | $CH_4$ | 0.0 | 0.1 | 5.0 | 50.0 |
| Denmark | 2G4 Tobacco | $CH_4$ | 1.0 | 0.5 | 5.0 | 50.0 |
| Denmark | 2G4 Charcoal | $CH_4$ | 1.1 | 1.2 | 5.0 | 100.0 |
| Denmark | 2B2 Nitric acid production | $N_2O$ | 1002.5 | 0.0 | 2.0 | 25.0 |
| Denmark | 2D2 Paraffin wax use | $N_2O$ | 0.1 | 0.1 | 10.0 | 20.0 |
| Denmark | 2G3a Medical application of $N_2O$ | $N_2O$ | 11.3 | 11.3 | 25.0 | 20.0 |
| Denmark | 2G3b $N_2O$ as propellant for pressure and aerosol products | $N_2O$ | 5.3 | 4.9 | 100.0 | 150.0 |
| Denmark | 2G4 Fireworks | $N_2O$ | 0.7 | 3.6 | 5.0 | 50.0 |
| Denmark | 2G4 Tobacco | $N_2O$ | 0.3 | 0.1 | 5.0 | 50.0 |
| Denmark | 2G4 Charcoal | $N_2O$ | 0.1 | 0.1 | 5.0 | 100.0 |
| Denmark | 2E Electronics industry | HFCs | 0.0 | 0.0 | 0.0 | 0.0 |
| Denmark | 2F1 Refrigeration and air conditioning | HFCs | 47.6 | 473.8 | 10.0 | 50.0 |
| Denmark | 2F2 Foam blowing agents | HFCs | 210.3 | 0.8 | 10.00 | 50.00 |
| Denmark | 2F4 Aerosols | HFCs | 0.0 | 12.8 | 10.00 | 50.00 |
| Denmark | 2E Electronics industry | PFCs | 0.0 | 0.0 | 10.00 | 50.00 |
| Denmark | 2F1 Refrigeration and air conditioning | PFCs | 0.6 | 0.0 | 10.00 | 50.00 |
| Denmark | 2C4 Magnesium production | $SF_6$ | 34.2 | 0.0 | 10.00 | 30.00 |
| Denmark | 2G1 Electrical equipment | $SF_6$ | 3.7 | 13.2 | 10.00 | 50.00 |
| Denmark | 2G2 $SF_6$ and PFCs from other product use | $SF_6$ | 65.9 | 60.0 | 10.00 | 50.00 |
| Denmark | 3A Enteric Fermentation | $CH_4$ | 4039.5 | 3767.4 | 2.00 | 20.00 |
| Denmark | 3B Manure Management | $CH_4$ | 1853.6 | 2219.3 | 5.00 | 20.00 |
| Denmark | 3F Field Burning of Agricultural Residues | $CH_4$ | 2.2 | 3.4 | 25.00 | 50.00 |
| Denmark | 3B Manure Management | $N_2O$ | 780.7 | 596.7 | 25.00 | 100.00 |
| Denmark | 3B5 Atmospheric deposition | $N_2O$ | 198.1 | 136.4 | 16.00 | 100.00 |
| Denmark | 3Da1 Inorganic N fertilizer | $N_2O$ | 1875.0 | 1049.8 | 3.00 | 100.00 |
| Denmark | 3Da2a Animal manure applied to soils | $N_2O$ | 991.0 | 1016.3 | 25.00 | 100.00 |
| Denmark | 3Da2b Sewage sludge applied to soils | $N_2O$ | 14.6 | 19.0 | 15.00 | 100.00 |
| Denmark | 3Da2c Other organic fertilizer applied to soils | $N_2O$ | 7.2 | 22.4 | 20.00 | 100.00 |
| Denmark | 3Da3 Urine and dung deposited by grazing animals | $N_2O$ | 297.9 | 175.3 | 10.00 | 100.00 |
| Denmark | 3Da4 Crop Residues | $N_2O$ | 569.3 | 473.4 | 25.00 | 100.00 |
| Denmark | 3Da5 Mineralization | $N_2O$ | 147.8 | 135.1 | 50.00 | 100.00 |
| Denmark | 3Da6 Cultivation of organic soils | $N_2O$ | 856.3 | 652.0 | 20.00 | 100.00 |
| Denmark | 3Db1 Atmospheric deposition | $N_2O$ | 359.4 | 200.1 | 16.00 | 100.00 |
| Denmark | 3Db2 Leaching | $N_2O$ | 549.3 | 329.5 | 20.00 | 100.00 |
| Denmark | 3F Field Burning of Agricultural Residues | $N_2O$ | 0.7 | 1.1 | 25.00 | 50.00 |

| | IPCC Source category | Gas | Base year emission Input data Gg $CO_2$ eqv. | 2018 emission Input data Gg $CO_2$ eqv. | Activity data uncertainty Input data % | Emission factor uncertainty Input data % |
|---|---|---|---|---|---|---|
| Denmark | 3G Liming | $CO_2$ | 565.5 | 239.9 | 5.00 | 100.00 |
| Denmark | 3H Urea applicaton | $CO_2$ | 14.7 | 1.4 | 3.00 | 100.00 |
| Denmark | 3I Other carbon-containing fertilizers | $CO_2$ | 38.4 | 2.9 | 3.00 | 100.00 |
| Denmark | 4.A.1 Forest land remaining forest land, Living biomass | $CO_2$ | -738.3 | -2607.2 | 5.00 | 2.00 |
| Denmark | 4.A.1 Forest land remaining forest land, Dead organic matter | $CO_2$ | -5.8 | 2977.9 | 5.00 | 3.29 |
| Denmark | 4.A.1 Forest land remaining forest land, Mineral soils | $CO_2$ | 0.0 | 0.0 | 5.00 | 2.00 |
| Denmark | 4.A.1 Forest land remaining forest land, Organic soils | $CO_2$ | 189.8 | 141.4 | 10.00 | 50.00 |
| Denmark | 4.A.2 Land converted to forest land | $CO_2$ | -19.8 | -163.4 | 10.00 | 8.74 |
| Denmark | 4.B.1 Cropland remaining cropland, Living biomass | $CO_2$ | -19.7 | 48.3 | 2.50 | 15.00 |
| Denmark | 4.B.1 Cropland remaining cropland, Mineral soils | $CO_2$ | 460.9 | 795.6 | 2.50 | 75.00 |
| Denmark | 4.B.1 Cropland remaining cropland, Organic soils | $CO_2$ | 4704.2 | 3525.0 | 3.30 | 50.00 |
| Denmark | 4.B.2 Forest land converted to cropland | $CO_2$ | 2.3 | 74.5 | 10.00 | 50.00 |
| Denmark | 4.B.2 Other land uses converted to cropland | $CO_2$ | -1.6 | -28.0 | 10.00 | 50.00 |
| Denmark | 4(II) Cropland on organic soils | $CO_2$ | 34.6 | 27.6 | 3.30 | 40.00 |
| Denmark | 4.C.1 Grassland remaining grassland, Living biomass | $CO_2$ | 14.3 | 99.2 | 2.50 | 7.00 |
| Denmark | 4.C.1 Grassland remaining grassland, Organic soils | $CO_2$ | 1420.9 | 1206.4 | 3.30 | 50.00 |
| Denmark | 4.C.2 Forest land converted to grassland | $CO_2$ | 1.4 | 47.3 | 10.00 | 50.00 |
| Denmark | 4.C.2 Other land uses converted to grassland | $CO_2$ | 0.9 | 24.0 | 10.00 | 50.00 |
| Denmark | 4(II) Grassland on organic soils | $CO_2$ | 14.3 | 12.3 | 3.30 | 40.00 |
| Denmark | 4.D.1.1 Peat extraction remaining peat extraction | $CO_2$ | 99.5 | 52.6 | 10.00 | 75.00 |
| Denmark | 4.D.1.2 Flooded land remaining flooded land | $CO_2$ | 0.0 | 0.0 | 10.00 | 75.00 |
| Denmark | 4.D.2. Land converted to wetlands | $CO_2$ | -1.3 | 0.0 | 10.00 | 75.00 |
| Denmark | 4.E.2 Forest land converted to settlements | $CO_2$ | 4.8 | 35.5 | 10.00 | 75.00 |
| Denmark | 4.E.2 Other land uses converted to settlements | $CO_2$ | 13.8 | 144.2 | 10.00 | 75.00 |
| Denmark | 4.G Harvested wood products | $CO_2$ | -2.4 | -162.1 | 25.00 | 75.00 |
| Denmark | 4(II) Cropland on organic soils | $CH_4$ | 162.5 | 141.0 | 10.00 | 90.00 |
| Denmark | 4(II) Grassland on organic soils | $CH_4$ | 85.6 | 73.5 | 10.00 | 90.00 |
| Denmark | 4(II) A. Forest land, organic soils | $CH_4$ | 4.0 | 29.4 | 10.00 | 90.00 |
| Denmark | 4(II) Land converted to wetlands | $CH_4$ | 2.2 | 56.6 | 10.00 | 90.00 |
| Denmark | 4(II) Peatland | $CH_4$ | 1.3 | 0.7 | 10.00 | 90.00 |
| Denmark | 4(V) Biomass Burning | $CH_4$ | 0.7 | 0.0 | 10.00 | 30.00 |
| Denmark | 4(III) Mineralization/immobilization, Forest land | $N_2O$ | 0.0 | 0.0 | 10.00 | 90.00 |
| Denmark | 4(III) Mineralization/immobilization, Cropland | $N_2O$ | 0.1 | 2.0 | 10.00 | 90.00 |
| Denmark | 4(III) Mineralization/immobilization, Grassland | $N_2O$ | 0.0 | 0.8 | 10.00 | 90.00 |
| Denmark | 4(III) Mineralization/immobilization, Land converted to Settlements | $N_2O$ | 0.3 | 14.3 | 10.00 | 90.00 |
| Denmark | 4(V) Biomass burning | $N_2O$ | 0.4 | 0.0 | 10.00 | 30.00 |
| Denmark | 4(II) Drainage and rewetting, Forest soils | $N_2O$ | 26.5 | 24.0 | 10.00 | 50.00 |
| Denmark | 4(II) Peat extraction remaining peat extraction | $N_2O$ | 0.2 | 0.1 | 10.00 | 50.00 |
| Denmark | 5.E Accidental fires | $CO_2$ | 20.3 | 18.0 | 10.00 | 300.00 |
| Denmark | 5.A Solid waste disposal | $CH_4$ | 1536.3 | 560.4 | 10.00 | 104.52 |
| Denmark | 5.B.1 Composting | $CH_4$ | 34.7 | 106.8 | 20.00 | 100.00 |
| Denmark | 5.B.2. Anaerobic digestion at biogas facilities | $CH_4$ | 5.6 | 252.1 | 5.00 | 20.00 |
| Denmark | 5.C.1 Incineration of corpses | $CH_4$ | 0.0 | 0.0 | 1.00 | 150.00 |
| Denmark | 5.C.2 Incineration of carcasses | $CH_4$ | 0.0 | 0.0 | 40.00 | 150.00 |
| Denmark | 5.D.1 Domestic wastewater | $CH_4$ | 41.1 | 50.8 | 24.00 | 32.00 |
| Denmark | 5.E Accidental fires | $CH_4$ | 2.4 | 2.1 | 10.00 | 500.00 |
| Denmark | 5.B.1 Composting | $N_2O$ | 12.1 | 83.5 | 20.00 | 100.00 |
| Denmark | 5.C.1 Incineration of corpses | $N_2O$ | 0.2 | 0.2 | 1.00 | 150.00 |
| Denmark | 5.C.2 Incineration of carcasses | $N_2O$ | 0.0 | 0.1 | 40.00 | 150.00 |
| Denmark | 5.D.1 Domestic wastewater | $N_2O$ | 61.4 | 58.5 | 30.00 | 50.00 |
| Denmark | 5.D.2 Industrial wastewater | $N_2O$ | 47.8 | 6.9 | 30.00 | 50.00 |

| IPCC Source category | | Gas | Base year emission Input data Gg $CO_2$ eqv. | 2018 emission Input data Gg $CO_2$ eqv. | Activity data uncertainty Input data % | Emission factor uncertainty Input data % |
|---|---|---|---|---|---|---|
| Greenland | 1A Liquid fuels | $CO_2$ | 619.9 | 536.7 | 3.0 | 2.0 |
| Greenland | 1A Municipal waste | $CO_2$ | 1.7 | 7.6 | 3.0 | 25.0 |
| Greenland | 1A Liquid fuels | $CH_4$ | 1.2 | 1.1 | 3.0 | 100.0 |
| Greenland | 1A Municipal waste | $CH_4$ | 0.0 | 0.1 | 3.0 | 100.0 |
| Greenland | 1A Biomass | $CH_4$ | 0.0 | 0.1 | 3.0 | 100.0 |
| Greenland | 1A Liquid fuels | $N_2O$ | 2.3 | 2.4 | 3.0 | 500.0 |
| Greenland | 1A Municipal waste | $N_2O$ | 0.0 | 0.1 | 3.0 | 500.0 |
| Greenland | 1A Biomass | $N_2O$ | 0.0 | 0.1 | 3.0 | 200.0 |
| Greenland | 1B2 Oil exploration | $CO_2$ | 0.0 | 0.0 | 3.0 | 1000.0 |
| Greenland | 1B2 Oil exploration | $CH_4$ | 0.0 | 0.0 | 3.0 | 1000.0 |
| Greenland | 1B2 Oil exploration | $N_2O$ | 0.0 | 0.0 | 3.0 | 1000.0 |
| Greenland | 2A4 Limestone and dolomite use | $CO_2$ | 0.0 | 0.0 | 5.0 | 5.0 |
| Greenland | 2D2 Paraffin wax use | $CO_2$ | 0.0 | 0.1 | 5.0 | 25.0 |
| Greenland | 2D3 Solvent use | $CO_2$ | 0.3 | 0.4 | 5.0 | 25.0 |
| Greenland | 2D3 Road paving with asphalt | $CO_2$ | 0.0 | 0.0 | 5.0 | 25.0 |
| Greenland | 2D3 Asphalt roofing | $CO_2$ | 0.0 | 0.0 | 5.0 | 25.0 |
| Greenland | 2F Consumption of HFC | HFC | 0.0 | 8.9 | 10.0 | 50.0 |
| Greenland | 2G Consumption of $SF_6$ | $SF_6$ | 0.0 | 0.0 | 10.0 | 50.0 |
| Greenland | 3A Enteric Fermentation | $CH_4$ | 7.6 | 6.3 | 10.0 | 100.0 |
| Greenland | 3B Manure Management | $CH_4$ | 0.2 | 0.1 | 10.0 | 100.0 |
| Greenland | 3B Manure Management | $N_2O$ | 0.9 | 0.8 | 10.0 | 100.0 |
| Greenland | 3D Agricultural soils | $N_2O$ | 0.8 | 0.8 | 20.0 | 50.0 |
| Greenland | 3G Liming | $CO_2$ | 0.0 | 0.0 | 5.0 | 50.0 |
| Greenland | 4A Forest | $CO_2$ | 0.0 | 0.0 | 5.0 | 50.0 |
| Greenland | 4A Forest | $CH_4$ | 0.0 | 0.0 | 5.0 | 50.0 |
| Greenland | 4A Forest | $N_2O$ | 0.1 | 0.1 | 5.0 | 50.0 |
| Greenland | 4B Cropland | $CO_2$ | 0.0 | 0.0 | 5.0 | 50.0 |
| Greenland | 4C Grassland | $CO_2$ | 0.2 | 1.1 | 5.0 | 50.0 |
| Greenland | 4C Grassland | $CH_4$ | 0.0 | 0.0 | 5.0 | 50.0 |
| Greenland | 5A Solid Waste Disposal | $CH_4$ | 4.3 | 4.5 | 10.0 | 100.0 |
| Greenland | 5C Incineration and open burning of waste | $CO_2$ | 2.6 | 3.2 | 10.0 | 25.0 |
| Greenland | 5C Incineration and open burning of waste | $CH_4$ | 2.7 | 1.9 | 10.0 | 50.0 |
| Greenland | 5C Incineration and open burning of waste | $N_2O$ | 0.7 | 0.6 | 10.0 | 100.0 |
| Greenland | 5D Wastewater treatment and discharge | $N_2O$ | 7.2 | 4.9 | 30.0 | 100.0 |

## 17.4 Key category analysis

A tier 1 key category analysis (KCA) has been carried out on emissions from Denmark and Greenland. The key category analysis for Denmark is included in Chapter 1.5 and Annex 1, and the key category analysis for Greenland is included in Chapter 16.

The KCA for 1990 and 2018 has been carried out in accordance with the IPCC Guidelines 2006. The KCA is based on data available in CRF and thus slightly more aggregated than the KCA carried out for Denmark. The categorisation used results in a total of 141 source categories of which 22 are LULUCF categories.

The KCA for Denmark and Greenland includes a total of six different analyses:

- Base year, reporting year and trend,
- Including and excluding LULUCF.

The six different KCA for Denmark and Greenland point out 19-28 key source categories each and a total of 33 different key source categories. The number of key categories in each of the main sectors are Energy 17, Industrial processes and product use 4, Agriculture 5, LULUCF 5 and Waste 2.

The KCA for Denmark and Greenland are shown in Annex 8. An overview for all KCA is given in Table 17.3.

Table 17.3 Key Category Analysis for Denmark and Greenland, overview.

| IPCC Source Categories | | GHG | Level Tier 1 1990 Excl. LULUCF | Level Tier 1 2018 Excl. LULUCF | Trend Tier 1 1990/1995 - 2018 Excl. LULUCF | Level Tier 1 1990 Incl. LULUCF | Level Tier 1 2018 Incl. LULUCF | Trend Tier 1 1990/1995 - 2018 Incl. LULUCF |
|---|---|---|---|---|---|---|---|---|
| Energy | 1A1 Energy industries, Liquid Fuels | $CO_2$ | 7 | 13 | 10 | 8 | 15 | 11 |
| Energy | 1A1 Energy industries, Solid Fuels | $CO_2$ | 1 | 2 | 1 | 1 | 2 | 1 |
| Energy | 1A1 Energy industries, Gaseous Fuels | $CO_2$ | 10 | 5 | 5 | 11 | 6 | 5 |
| Energy | 1A1 Energy industries, Other Fuels | $CO_2$ | 19 | 10 | 7 | 22 | 11 | 8 |
| Energy | 1A2 Manufacturing industries and construction, Liquid Fuels | $CO_2$ | 6 | 11 | 6 | 7 | 12 | 6 |
| Energy | 1A2 Manufacturing industries and construction, Solid Fuels | $CO_2$ | 12 | 17 | 11 | 14 | 20 | 12 |
| Energy | 1A2 Manufacturing industries and construction, Gaseous Fuels | $CO_2$ | 13 | 9 | 14 | 15 | 10 | 16 |
| Energy | 1A2 Manufacturing industries and construction, Other Fuels | $CO_2$ | | | | | 27 | 25 |
| Energy | 1A4 Other sectors , Liquid Fuels | $CO_2$ | 3 | 6 | 2 | 3 | 7 | 2 |
| Energy | 1A4 Other sectors , Solid Fuels | $CO_2$ | | | 17 | | | 20 |
| Energy | 1A4 Other sectors , Gaseous Fuels | $CO_2$ | 11 | 8 | 13 | 12 | 9 | 15 |
| Energy | 1A4 Other sectors , Other Fuels | $CO_2$ | | | | | | |
| Energy | 1A5 Non-specified, Mobile | $CO_2$ | | | | | 26 | |
| Energy | 1A1 Energy industries, Liquid Fuels | $CH_4$ | | | | | | |
| Energy | 1A1 Energy industries, Solid Fuels | $CH_4$ | | | | | | |
| Energy | 1A1 Energy industries, Gaseous Fuels | $CH_4$ | | | | | | |
| Energy | 1A1 Energy industries, Other Fuels | $CH_4$ | | | | | | |
| Energy | 1A1 Energy industries, Biomass | $CH_4$ | | | | | | |
| Energy | 1A2 Manufacturing industries and construction, Liquid Fuels | $CH_4$ | | | | | | |
| Energy | 1A2 Manufacturing industries and construction, Solid Fuels | $CH_4$ | | | | | | |
| Energy | 1A2 Manufacturing industries and construction, Gaseous Fuels | $CH_4$ | | | | | | |
| Energy | 1A2 Manufacturing industries and construction, Other Fuels | $CH_4$ | | | | | | |
| Energy | 1A2 Manufacturing industries and construction, Biomass | $CH_4$ | | | | | | |
| Energy | 1A4 Other sectors , Liquid Fuels | $CH_4$ | | | | | | |
| Energy | 1A4 Other sectors , Solid Fuels | $CH_4$ | | | | | | |
| Energy | 1A4 Other sectors , Gaseous Fuels | $CH_4$ | | | | | | |
| Energy | 1A4 Other sectors , Other Fuels | $CH_4$ | | | | | | |
| Energy | 1A4 Other sectors , Biomass | $CH_4$ | | | | | | |
| Energy | 1A5 Non-specified, Mobile | $CH_4$ | | | | | | |
| Energy | 1A1 Energy industries, Liquid Fuels | $N_2O$ | | | | | | |
| Energy | 1A1 Energy industries, Solid Fuels | $N_2O$ | | | | | | |
| Energy | 1A1 Energy industries, Gaseous Fuels | $N_2O$ | | | | | | |
| Energy | 1A1 Energy industries, Other Fuels | $N_2O$ | | | | | | |
| Energy | 1A1 Energy industries, Biomass | $N_2O$ | | | | | | |
| Energy | 1A2 Manufacturing industries and construction, Liquid Fuels | $N_2O$ | | | | | | |

| IPCC Source Categories | | GHG | Level Tier 1 1990 Excl. LULUCF | Level Tier 1 2018 Excl. LULUCF | Trend Tier 1 1990/1995 - 2018 Excl. LULUCF | Level Tier 1 1990 Incl. LULUCF | Level Tier 1 2018 Incl. LULUCF | Trend Tier 1 1990/1995 - 2018 Incl. LULUCF |
|---|---|---|---|---|---|---|---|---|
| Energy | 1A2 Manufacturing industries and construction, Solid Fuels | $N_2O$ | | | | | | |
| Energy | 1A2 Manufacturing industries and construction, Gaseous Fuels | $N_2O$ | | | | | | |
| Energy | 1A2 Manufacturing industries and construction, Other Fuels | $N_2O$ | | | | | | |
| Energy | 1A2 Manufacturing industries and construction, Biomass | $N_2O$ | | | | | | |
| Energy | 1A4 Other sectors , Liquid Fuels | $N_2O$ | | | | | | |
| Energy | 1A4 Other sectors , Solid Fuels | $N_2O$ | | | | | | |
| Energy | 1A4 Other sectors , Gaseous Fuels | $N_2O$ | | | | | | |
| Energy | 1A4 Other sectors , Other Fuels | $N_2O$ | | | | | | |
| Energy | 1A4 Other sectors , Biomass | $N_2O$ | | | | | | |
| Energy | 1A5 Non-specified, Mobile | $N_2O$ | | | | | | |
| Energy | 1A3. Transport, a Domestic aviation | $CO_2$ | | | | | 28 | |
| Energy | 1A3. Transport, a Domestic aviation | $CH_4$ | | | | | | |
| Energy | 1A3. Transport, a Domestic aviation | $N_2O$ | | | | | | |
| Energy | 1A3. Transport, b Road transportation | $CO_2$ | 2 | 1 | 3 | 2 | 1 | 3 |
| Energy | 1A3. Transport, b Road transportation | $CH_4$ | | | | | | |
| Energy | 1A3. Transport, b Road transportation | $N_2O$ | | | | | | |
| Energy | 1A3. Transport, c Railways | $CO_2$ | | | | | 25 | |
| Energy | 1A3. Transport, c Railways | $CH_4$ | | | | | | |
| Energy | 1A3. Transport, c Railways | $N_2O$ | | | | | | |
| Energy | 1A3. Transport, d Domestic navigation | $CO_2$ | 17 | 15 | | 19 | 17 | |
| Energy | 1A3. Transport, d Domestic navigation | $CH_4$ | | | | | | |
| Energy | 1A3. Transport, d Domestic navigation | $N_2O$ | | | | | | |
| Energy | 1B Fugitive emissions from fuels, 2a Oil | $CO_2$ | | | | | | |
| Energy | 1B Fugitive emissions from fuels, 2a Oil | $CH_4$ | | | | | | |
| Energy | 1B Fugitive emissions from fuels, 2a Oil | $N_2O$ | | | | | | |
| Energy | 1B Fugitive emissions from fuels, 2b Natural gas | $CO_2$ | | | | | | |
| Energy | 1B Fugitive emissions from fuels, 2b Natural gas | $CH_4$ | | | | | | |
| Energy | 1B Fugitive emissions from fuels, 2c Venting gas | $CO_2$ | | | | | | |
| Energy | 1B Fugitive emissions from fuels, 2c Venting gas | $CH_4$ | | | | | | |
| Energy | 1B Fugitive emissions from fuels, 2c, Flaring | $CO_2$ | | 21 | | | 24 | |
| Energy | 1B Fugitive emissions from fuels, 2c, Flaring | $CH_4$ | | | | | | |
| Energy | 1B Fugitive emissions from fuels, 2c, Flaring | $N_2O$ | | | | | | |
| Industrial processes | 2A. Mineral industry, 1 Cement production | $CO_2$ | 16 | 12 | 18 | 18 | 14 | 21 |
| Industrial processes | 2A. Mineral industry, 2 Lime production | $CO_2$ | | | | | | |
| Industrial processes | 2A. Mineral industry, 3 Glass production | $CO_2$ | | | | | | |
| Industrial processes | 2A. Mineral industry, 4 Other process uses of carbonates | $CO_2$ | | | | | | |

| IPCC Source Categories | | GHG | Level Tier 1 1990 Excl. LULUCF | Level Tier 1 2018 Excl. LULUCF | Trend Tier 1 1990/1995 - 2018 Excl. LULUCF | Level Tier 1 1990 Incl. LULUCF | Level Tier 1 2018 Incl. LULUCF | Trend Tier 1 1990/1995 - 2018 Incl. LULUCF |
|---|---|---|---|---|---|---|---|---|
| Industrial processes | 2B. Chemical Industry, 2 Nitric acid production | $N_2O$ | 14 | | 8 | 16 | | 9 |
| Industrial processes | 2B. Chemical Industry, 10 Other | $CO_2$ | | | | | | |
| Industrial processes | 2C. Metal industry, 1 Iron and steel production | $CO_2$ | | | | | | |
| Industrial processes | 2C. Metal industry, 1 Iron and steel production | $CH_4$ | | | | | | |
| Industrial processes | 2C. Metal industry, 4 Magnesium production | SF6 | | | | | | |
| Industrial processes | 2C. Metal industry, 5 Lead production | $CO_2$ | | | | | | |
| Industrial processes | 2D. Non-energy products from fuels and solvent use, 1 Lubricant use | $CO_2$ | | | | | | |
| Industrial processes | 2D. Non-energy products from fuels and solvent use, 2 Paraffin wax use | $CO_2$ | | | | | | |
| Industrial processes | 2D. Non-energy products from fuels and solvent use, 2 Paraffin wax use | $CH_4$ | | | | | | |
| Industrial processes | 2D. Non-energy products from fuels and solvent use, 2 Paraffin wax use | $N_2O$ | | | | | | |
| Industrial processes | 2D. Non-energy products from fuels and solvent use, 3 Other | $CO_2$ | | | | | | |
| Industrial processes | 2D. Non-energy products from fuels and solvent use, 3 Other | $CH_4$ | | | | | | |
| Industrial processes | 2E. Electronics industry, 5 Other | HFCs | | | | | | |
| Industrial processes | 2E. Electronics industry, 5 Other | PFCs | | | | | | |
| Industrial processes | 2F. Product uses as substitutes for ODS, 1 Refrigeration and air conditioning | HFCs | | 18 | 12 | | 21 | 14 |
| Industrial processes | 2F. Product uses as substitutes for ODS, 1 Refrigeration and air conditioning | PFCs | | | | | | |
| Industrial processes | 2F. Product uses as substitutes for ODS, 2 Foam blowing agents | HFCs | | | | | | 24 |
| Industrial processes | 2F. Product uses as substitutes for ODS, 4 Aerosols | HFCs | | | | | | |
| Industrial processes | 2G. Other product manufacture and use, 1 Electrical equipment | $SF_6$ | | | | | | |
| Industrial processes | 2G. Other product manufacture and use, 2 SF6 and PFCs from other product use | $SF_6$ | | | | | | |
| Industrial processes | 2G. Other product manufacture and use, 3 N2O from product uses | $N_2O$ | | | | | | |
| Industrial processes | 2G. Other product manufacture and use, 4 Other | $CO_2$ | | | | | | |
| Industrial processes | 2G. Other product manufacture and use, 4 Other | $CH_4$ | | | | | | |
| Industrial processes | 2G. Other product manufacture and use, 4 Other | $N_2O$ | | | | | | |
| Agriculture | 3A. Enteric fermentation, - | $CH_4$ | 5 | 4 | 19 | 6 | 5 | 18 |
| Agriculture | 3B. Manure management, - | $CH_4$ | 8 | 7 | 15 | 9 | 8 | 17 |
| Agriculture | 3B. Manure management, - | $N_2O$ | 15 | 14 | 21 | 17 | 16 | 22 |
| Agriculture | 3D. Agricultural soils, - | $N_2O$ | 4 | 3 | 4 | 4 | 4 | 4 |
| Agriculture | 3F. Field burning of agricultural residues, - | $CH_4$ | | | | | | |
| Agriculture | 3F. Field burning of agricultural residues, - | $N_2O$ | | | | | | |
| Agriculture | 3G. Liming, - | $CO_2$ | 18 | 20 | 16 | 20 | 23 | 19 |
| Agriculture | 3H. Urea application, - | $CO_2$ | | | | | | |
| Agriculture | 3I. Other carbon-containing fertilizers, - | $CO_2$ | | | | | | |
| Waste | 5A. Solid waste disposal, - | $CH_4$ | 9 | 16 | 9 | 10 | 18 | 10 |
| Waste | 5B. Biological treatment of solid waste, 1. Composting | $CH_4$ | | | | | | |
| Waste | 5B. Biological treatment of solid waste, 1. Composting | $N_2O$ | | | | | | |

| IPCC Source Categories | | GHG | Level Tier 1 1990 Excl. LULUCF | Level Tier 1 2018 Excl. LULUCF | Trend Tier 1 1990/1995 - 2018 Excl. LULUCF | Level Tier 1 1990 Incl. LULUCF | Level Tier 1 2018 Incl. LULUCF | Trend Tier 1 1990/1995 - 2018 Incl. LULUCF |
|---|---|---|---|---|---|---|---|---|
| Waste | 5B. Biological treatment of solid waste, 2. Anaerobic digestion at biogas facilities | $CH_4$ | | 19 | 20 | | 22 | 23 |
| Waste | 5C. Incineration and open burning of waste, 1. Waste incineration | $CO_2$ | | | | | | |
| Waste | 5C. Incineration and open burning of waste, 1. Waste incineration | $CH_4$ | | | | | | |
| Waste | 5C. Incineration and open burning of waste, 1. Waste incineration | $N_2O$ | | | | | | |
| Waste | 5C. Incineration and open burning of waste, 2. Open burning of waste | $CO_2$ | | | | | | |
| Waste | 5C. Incineration and open burning of waste, 2. Open burning of waste | $CH_4$ | | | | | | |
| Waste | 5C. Incineration and open burning of waste, 2. Open burning of waste | $N_2O$ | | | | | | |
| Waste | 5D. Wastewater treatment and discharge, 1. Domestic wastewater | $CH_4$ | | | | | | |
| Waste | 5D. Wastewater treatment and discharge, 1. Domestic wastewater | $N_2O$ | | | | | | |
| Waste | 5D. Wastewater treatment and discharge, 2. Industrial wastewater | $N_2O$ | | | | | | |
| Waste | 5E. Other (please specify), - | $CO_2$ | | | | | | |
| Waste | 5E. Other (please specify), - | $CH_4$ | | | | | | |
| LULUCF | 4A. Forest land, - | $CH_4$ | | | | | | |
| LULUCF | 4A. Forest land, - | $N_2O$ | | | | | | |
| LULUCF | 4A. Forest land, 1. Forest land remaining forest land | $CO_2$ | | | | 21 | 19 | 7 |
| LULUCF | 4A. Forest land, 2. Land converted to forest land | $CO_2$ | | | | | | |
| LULUCF | 4B. Cropland, 1. Cropland remaining cropland | $CO_2$ | | | | 5 | 3 | 13 |
| LULUCF | 4B. Cropland, 2. Land converted to cropland | $CO_2$ | | | | | | |
| LULUCF | 4B. Cropland, - | $CH_4$ | | | | | | |
| LULUCF | 4B. Cropland, 2. Land converted to cropland | $N_2O$ | | | | | | |
| LULUCF | 4B. Cropland, Drained organic soils | $CO_2$ | | | | | | |
| LULUCF | 4C. Grassland, - | $CH_4$ | | | | | | |
| LULUCF | 4C. Grassland, 1. Grassland remaining grassland | $CO_2$ | | | | 13 | 13 | |
| LULUCF | 4C. Grassland, 1. Grassland remaining grassland | $N_2O$ | | | | | | |
| LULUCF | 4C. Grassland, 2. Land converted to grassland | $CO_2$ | | | | | | |
| LULUCF | 4C. Grassland, 2. Land converted to grassland | $N_2O$ | | | | | | |
| LULUCF | 4C. Grassland, Drained organic soils | $CO_2$ | | | | | | |
| LULUCF | 4D. Wetlands, - | $CH_4$ | | | | | | |
| LULUCF | 4D. Wetlands, - | $N_2O$ | | | | | | |
| LULUCF | 4D. Wetlands, 1. Wetlands remaining wetlands | $CO_2$ | | | | | | |
| LULUCF | 4D. Wetlands, 2. Land converted to wetlands | $CO_2$ | | | | | | |
| LULUCF | 4E. Settlements, 2. Land converted to settlements | $CO_2$ | | | | | | 26 |
| LULUCF | 4E. Settlements, 2. Land converted to settlements | $N_2O$ | | | | | | |
| LULUCF | 4G. Harvested wood products, - | $CO_2$ | | | | | | 27 |

### 17.4.1 Key category analysis for KP-LULUCF

The contribution from Greenland to the KP-LULUCF inventory is miniscule the same categories are therefore identified as key as for the submission from Denmark, see Chapter 11.9 for more information.

## 17.5 Recalculations

### 17.5.1 Implications for emission levels

The impact of recalculations in the Greenlandic inventory is insignificant compared to the recalculations in the Danish inventory. Therefore, the explanations and justifications are not repeated in this Chapter. Detailed information on the recalculations in the Danish inventory is provided in Chapter 9 and in the sectoral Chapters 3-7. The recalculations carried out for the Greenlandic inventory are described in Chapter 16.

## 17.6 Technical description of the aggregation of the emission inventories of Denmark and Greenland

In order to accommodate the request of the ERT of full inclusion of the Greenlandic emission data in the full CRF format, Denmark operates separate installations for Denmark and Greenland (and the Faroe Islands). The country identification codes provided by the UNFCCC secretariat are DNM for Denmark and GRL for Greenland (FRO for the Faroe Islands). Two additional installations are necessary to enable the submission of aggregated submissions under the Kyoto Protocol (Denmark and Greenland) and under UNFCCC (Denmark, Greenland and the Faroe Islands). The country identification codes provided by the UNFCCC secretariat are DKE for the aggregated submission for Denmark and Greenland, and DNK for the UNFCCC submission (Denmark, Greenland and the Faroe Islands).

For the aggregation of the submissions two IT tools are used; 'CRF Aggregator DKE' and 'CRF Aggregator DNK' developed by DCE.

The three main work processes in connection with the aggregation of the submissions are:

- In the CRF Aggregator DKE/DNK the following work processes take place:
    - Aggregation of variables; sum of emissions and activity data, notation keys and comments.
    - As input data the xml submission files from the CRF Reporter installations for DNM (Denmark), GRL (Greenland) and FRO (Faroe Islands) are used.
    - As output file, a CRF Reporter xml import file is generated. This file is then imported into the CRF Reporter website, DKE (KP-CP1) or DNK (UNFCCC).

## 17.7 QA/QC of the aggregated submission for Denmark and Greenland

The QA/QC procedures for the Danish inventory are described in Chapter 1.6 and the sectoral chapters. Please refer to Chapter 1.6 for a general description of the QA/QC system, and the structural setup of the Danish QA/QC system for the greenhouse gas inventory. The QA/QC procedures carried out by Greenlandic authorities for the Greenlandic inventory are described in Chapter 16. The following focuses on the specific QA/QC measures carried out at DCE both on the data (CRF tables and documentation) received from Greenland and the QC checks carried out for the aggregated versions of the inventory for reporting to the Kyoto Protocol and the UNFCCC. The PM's relevant for this are listed in Table 17.5.

Table 17.5 PM's specific to the handling of Greenlandic emission data and the aggregated submissions.

| | | | |
|---|---|---|---|
| Data Storage level 4 | 3.Completeness | DS.4.3.3 | Check that no sources where methodology exists in the IPCC guidelines are reported as NE by Greenland. |
| | 4.Consistency | DS.4.4.2 | Check time series consistency of the reporting by Greenland prior to aggregating the final submissions. |
| | 5.Correctness | DS.4.5.1 | Check that the aggregated submissions for Denmark under the Kyoto Protocol and the UNFCCC match the sum of the individual submissions. |
| | | DS.4.5.2 | Check that additional information and information related to land-use changes has been correctly aggregated compared to the individual submissions of Denmark and Greenland. |
| | 7.Transparency | DS.4.7.2 | Perform QA on the documentation report provided by the Government of Greenland. |

| | | | |
|---|---|---|---|
| Data Storage level 4 | 3.Completeness | DS.4.3.3 | Check that no sources where a methodology exists in the IPCC guidelines or good practice guidance are reported as NE by Greenland |

A check is made to filter any NE's from the CRF tables. If any greenhouse gas emissions are reported as NE, it is checked whether methodologies exist in the IPCC guidelines or the IPCC good practice guidance. If methodologies do exist, efforts are made to quickly estimate and report emissions. No categories where methodology exists were identified for the submission of Denmark and Greenland.

| | | | |
|---|---|---|---|
| Data Storage level 4 | 4.Consistency | DS.4.4.2 | Check time series consistency of the reporting of Greenland and the Faroe Islands prior to aggregating the final submissions |

The time series for all pollutants in the submissions from Greenland and the Faroe Islands are checked at the CRF 3 level for large variations in the time series. Any large variations are explained or corrected in cooperation with the authorities in Greenland and the Faroe Islands.

| | | | |
|---|---|---|---|
| Data Storage level 4 | 5.Correctness | DS.4.5.1 | Check that the aggregated submissions for Denmark under the Kyoto Protocol and the UNFCCC matches the sum of the individual submissions |

To ensure that the submission for Denmark under the Kyoto Protocol matches the sum of the submissions of Denmark and Greenland a spreadsheet check has been implemented to ensure complete correctness of the submitted inventory. The same procedure is followed for the submission under the UNFCCC, where it is ensured that the submitted emissions equate to the sum of Denmark, Greenland and the Faroe Islands. Special attention is paid to the additional information provided in the CRF, e.g. for the agricultural sector. Certain parameters cannot simply be added, e.g. animal weights. In these cases, a weighted average is reported in the CRF tables.

The check has since the 2012 submission, been extended to also cover area information reported in the KP-LULUCF tables (NIR-2).

| | | | |
|---|---|---|---|
| Data Storage level 4 | 5.Correctness | DS.4.5.2 | Check that additional information and information related to land-use changes has been correctly aggregated compared to the individual submissions of Denmark and Greenland. |

The CRF submission for Denmark and Greenland is checked to see if the additional information has been aggregated correctly. The additional information is mainly related to the agricultural and waste sectors.

| | | | |
|---|---|---|---|
| Data Storage level 4 | 7.Transparency | DS.4.7.2 | Perform QA on the documentation report provided by the Government of Greenland |

The documentation report is received by DCE from the Government of Greenland in the early spring every year. The documentation report is included in the NIR as Chapter 16. DCE experts read and provide comments on the report to the Government of Greenland, so that any questions are resolved prior to the UNFCCC reporting deadline of April 15.

# Annexes

**Annex 1 – Key category analysis**

**Annex 2 – Assessment of uncertainty**

**Annex 3 – Other detailed methodological descriptions for individu7al source or sink categories (where relevant)**

Annex 3A – Stationary combustion

Annex 3B – Transport and other mobile sources

Annex 3C – Industrial processes and product use

Annex 3D - Agriculture

Annex 3E – LULUCF

Annex 3F - Waste

**Annex 4 – Information on the energy statistics**

**Annex 5 – Assessment of completeness and (potential) sources and sinks of greenhouse gas emissions and removals excluded**

**Annex 6 – Additional information to be considered as part of the annual inventory submission and the supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol or other useful reference information**

**Annex 7 – Methodology applied for the greenhouse gas inventory for the Faroe Islands**

## Annex 1 - Key category analysis

### Description of the methodology used for identifying key categories

Key Category Analysis (KCA) approach 1 and 2 for year 1990 and 2018 for Denmark (excluding Greenland and Faroe Islands) has been carried out in accordance with the IPCC Guidelines (2006). The KCA has been carried out excluding and including the LULUCF sector. An approach 1 KCA has also been worked out for Greenland and for Denmark and Greenland; refer to Chapter 16 and Chapter 17, respectively.

The base year in the analysis is the year 1990 for the greenhouse gases $CO_2$, $CH_4$, $N_2O$ and 1995 for the F-gases HFC, PFC and $SF_6$. The KCA approaches are:

- A quantitative analysis, approach 1 KCA.
- An analysis based on uncertainties, approach 2 KCA.

The level assessment of the approach 1 KCA is a ranking of the source categories in accordance to their relative contribution to the national total of greenhouse gases calculated in $CO_2$ equivalent units. The level key categories are found from the list of source categories ranked according to their contribution in descending order. Level key categories are those from the top of the list and of which the sum constitutes 95 % of the national total.

The trend assessment of the approach 1 KCA is a ranking of the source categories according to their contribution to the trend of the national total of greenhouse gases, calculated in $CO_2$ equivalents, from the base year to the latest year. The trend of the source category is calculated relative to that of the national totals and the trend is then weighted with the contribution, according to the level assessment. The ranking is in descending order. As for the level assessment, the cut-off point for the sum of contribution to the trend is 95 % and the source categories from the top of the list to the cut-off line are trend key categories.

In addition, an approach 2 KCA has been carried out to provide additional insight into categories being key sources. The categorisation used is as for the approach 1 analysis and the uncertainties used are approach 1 uncertainties as listed in Annex 2.

The level approach 2 KCA is a ranking of the categories according to their relative contribution to the national total multiplied by the uncertainty of the emission of the category as the combined uncertainty on activity data and on emission factor. Chosen for cut of for key categories in the analysis is 90 %.

The trend approach 2 KCA is a ranking of the categories according to their relative contribution to the trend 1990-2018 of the national total multiplied by the uncertainty of the emission of the category. Chosen for cut of for key categories in the analysis is 90 %.

Since the level KCA is carried out for 1990, 2018 and trend, for data exclusive and inclusive LULUCF and based on approach 1 and approach 2 a total of 12 KCA tables for Denmark (excluding Greenland and Faroe Islands) has been worked out.

In addition, two[1] overview tables based on the Guidebook (2006), Vol. 1, Table 4.4 are shown. The overview tables show summary results of the KCAs for 1990, for 2018, and for the trend 1990-2018.

The inclusion of the LULUCF sector in the level analysis implies that the emissions in this sector are all calculated positive, i.e. the absolute value of removals are included. Note also that according to the Guidebook, the analysis implies that contributions to the trend are all calculated as mathematically positive to be able to perform the ranking.

### Emission source categories

The emission source categories are identical to the emission source categories applied in the uncertainty analysis. The categorisation has been somewhat revised compared to last year. The KCA is based on 224 emission source categories including 35 LULUCF source categories.

### Result of the Key Category Analysis for Denmark

An overview of results of the KCA excluding LULUCF is shown in Table A1-1 and results of the KCA including LULUCF is shown in Table A1-2. The number of key source categories for each of the KCA are shown in Table A1-3.

The 12 different KCA for Denmark point out 24-55 key source categories each and a total of 75 different key source categories. The number of key categories in each of the main sectors is: energy 38, IPPU 4, agriculture 14, LULUCF 14 and waste 5.

Approach 1 point out mainly the large emission sources as key categories and thus $CO_2$ emission from stationary and mobile combustion are important key categories. Approach 2 point out some of the sources with larger uncertainty rates.

The list below gives an overview of the different KCA for Denmark (not including Greenland and Faroe Islands) that are presented in Table A1-4 – Table A1-15.

Table A1-4 KCA for Denmark, level assessment, base year excl. LULUCF, approach 1.
Table A1-5 KCA for Denmark, level assessment base year incl. LULUCF, approach 1.
Table A1-6 KCA for Denmark, level assessment 2018 excl. LULUCF, approach 1.
Table A1-7 KCA for Denmark, level assessment 2018 incl. LULUCF, approach 1.
Table A1-8 KCA for Denmark, trend assessment 1990-2018 excl. LULUCF, approach 1.
Table A1-9 KCA for Denmark, trend assessment 1990-2018 incl. LULUCF, approach 1.
Table A1-10 KCA for Denmark, level assessment base year excl. LULUCF, approach 2.
Table A1-11 KCA for Denmark, level assessment base year incl. LULUCF, approach 2.
Table A1-12 KCA for Denmark, level assessment 2018 excl. LULUCF, approach 2.
Table A1-13 KCA for Denmark, level assessment 2018 incl. LULUCF, approach 2.
Table A1-14 KCA for Denmark, trend assessment 1990-2018 excl. LULUCF, approach 2.
Table A1-15 KCA for Denmark, trend assessment 1990-2018 incl. LULUCF, approach 2.

[1] Including and excluding LULUCF.

Table A1-1 Summary of KCA for Denmark, level and trend for 1990-2018, excl. LULUCF, approach 1 and approach 2.

| **IPCC Source Categories (LULUCF excluded)** | | **GHG** | **Key categories with number according to ranking in analysis** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Level Approach 1 1990** | **Level Approach 1 2018** | **Trend Approach 1 1990-2018** | **Level Approach 2 1990** | **Level Approach 2 2018** | **Trend Approach 2 1990-2018** |
| Energy | 1A Stationary combustion, Coal, ETS data, $CO_2$ | $CO_2$ | | 2 | 2 | | | 37 |
| Energy | 1A Stationary combustion, Coal, no ETS data, $CO_2$ | $CO_2$ | 1 | 30 | 1 | 12 | | 4 |
| Energy | 1A Stationary combustion, BKB, $CO_2$ | $CO_2$ | | | | | | |
| Energy | 1A Stationary combustion, Coke oven coke, $CO_2$ | $CO_2$ | | | | | | |
| Energy | 1A Stationary combustion, Fossil waste, ETS data, $CO_2$ | $CO_2$ | | 6 | 7 | | | 27 |
| Energy | 1A Stationary combustion, Fossil waste, no ETS data, $CO_2$ | $CO_2$ | 20 | 22 | | 32 | | |
| Energy | 1A Stationary combustion, Petroleum coke, ETS data, $CO_2$ | $CO_2$ | | 15 | 12 | | | |
| Energy | 1A Stationary combustion, Petroleum coke, no ETS data, $CO_2$ | $CO_2$ | 25 | | 18 | | | |
| Energy | 1A Stationary combustion, Residual oil, ETS data, $CO_2$ | $CO_2$ | | 27 | 22 | | | |
| Energy | 1A Stationary combustion, Residual oil, no ETS data, $CO_2$ | $CO_2$ | 6 | | 6 | | | 33 |
| Energy | 1A Stationary combustion, Gas oil, $CO_2$ | $CO_2$ | 3 | 13 | 5 | 24 | | 19 |
| Energy | 1A Stationary combustion, Kerosene, $CO_2$ | $CO_2$ | 26 | | 20 | | | |
| Energy | 1A Stationary combustion, LPG, $CO_2$ | $CO_2$ | | 33 | | | | |
| Energy | 1A1b Stationary combustion, Petroleum refining, Refinery gas, $CO_2$ | $CO_2$ | 15 | 12 | 17 | | | |
| Energy | 1A Stationary combustion, Natural gas, onshore, $CO_2$ | $CO_2$ | 5 | 3 | 4 | | 31 | 38 |
| Energy | 1A1c_ii Stationary combustion, Oil and gas extraction, Off shore gas turbines, Natural gas, $CO_2$ | $CO_2$ | 24 | 7 | 10 | | | |
| Energy | 1A1 Stationary Combustion, Solid fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A1 Stationary Combustion, Liquid fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A1 Stationary Combustion, not engines, gaseous fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A1 Stationary Combustion, Waste, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A1 Stationary Combustion, not engines, Biomass, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A2 Stationary Combustion,solid fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A2 Stationary Combustion,Liquid fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A2 Stationary Combustion, not engines, gaseous fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A2 Stationary Combustion, Waste, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A2 Stationary Combustion, not engines, Biomass, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A4 Stationary Combustion, Solid fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A4 Stationary Combustion, Liquid fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A4 Stationary Combustion, not engines, gaseous fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A4 Stationary Combustion, Waste, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A4 Stationary Combustion, not engines, not residential wood and not residential/agricultural straw, Biomass, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A4b_i Stationary combustion, Residential wood combustion, $CH_4$ | $CH_4$ | | | | 26 | 25 | 41 |
| Energy | 1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion, $CH_4$ | $CH_4$ | | | | 28 | 36 | |

| IPCC Source Categories (LULUCF excluded) | | GHG | Key categories with number according to ranking in analysis | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Level Approach 1 1990** | **Level Approach 1 2018** | **Trend Approach 1 1990-2018** | **Level Approach 2 1990** | **Level Approach 2 2018** | **Trend Approach 2 1990-2018** |
| Energy | 1A Stationary combustion, Natural gas fuelled engines, gaseous fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A Stationary combustion, Biogas fuelled engines, Biomass, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A1 Stationary Combustion, Solid fuels, $N_2O$ | $N_2O$ | | | | 20 | 35 | 14 |
| Energy | 1A1 Stationary Combustion, Liquid fuels, $N_2O$ | $N_2O$ | | | | | | |
| Energy | 1A1 Stationary Combustion, Gaseous fuels, $N_2O$ | $N_2O$ | | | | 29 | 24 | 31 |
| Energy | 1A1 Stationary Combustion, Waste, $N_2O$ | $N_2O$ | | | | | | 34 |
| Energy | 1A1 Stationary Combustion, Biomass, $N_2O$ | $N_2O$ | | | | | 19 | 12 |
| Energy | 1A2 Stationary Combustion, Solid fuels, $N_2O$ | $N_2O$ | | | | | 26 | 17 |
| Energy | 1A2 Stationary Combustion, Liquid fuels, $N_2O$ | $N_2O$ | | | | 17 | 34 | 13 |
| Energy | 1A2 Stationary Combustion, Gaseous fuels, $N_2O$ | $N_2O$ | | | | | 32 | 42 |
| Energy | 1A2 Stationary Combustion, Waste, $N_2O$ | $N_2O$ | | | | | | |
| Energy | 1A2 Stationary Combustion, Biomass, $N_2O$ | $N_2O$ | | | | | | |
| Energy | 1A4 Stationary Combustion, Solid fuels, $N_2O$ | $N_2O$ | | | | | | |
| Energy | 1A4 Stationary Combustion, Liquid fuels, $N_2O$ | $N_2O$ | | | | 25 | | 23 |
| Energy | 1A4 Stationary Combustion, Gaseous fuels, $N_2O$ | $N_2O$ | | | | | 30 | 39 |
| Energy | 1A4 Stationary Combustion, Waste, $N_2O$ | $N_2O$ | | | | | | |
| Energy | 1A4 Stationary Combustion, not residential wood and not residential/agricultural straw, Biomass, $N_2O$ | $N_2O$ | | | | | | |
| Energy | 1A4b_i Stationary Combustion, Residential wood combustion, $N_2O$ | $N_2O$ | | | | | 14 | 7 |
| Energy | 1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion, $N_2O$ | $N_2O$ | | | | | | |
| Energy | 1.A.2.g Industry (mobile) | $CO_2$ | 18 | 17 | 23 | 18 | 13 | 21 |
| Energy | 1.A.3.a Civil aviation | $CO_2$ | | | | | | |
| Energy | 1.A.3.b Road Transport | $CO_2$ | 2 | 1 | 3 | 11 | 5 | 3 |
| Energy | 1.A.3.c Railways | $CO_2$ | | 28 | | | | |
| Energy | 1.A.3.d Navigation (large vessels) | $CO_2$ | 17 | 16 | | 30 | 29 | |
| Energy | 1.A.4.a Commercial/Institutional (mobile) | $CO_2$ | | | | | | |
| Energy | 1.A.4.b Residential (mobile) | $CO_2$ | | | | | | |
| Energy | 1.A.4.c ii Agriculture (mobile) | $CO_2$ | 10 | 10 | 24 | 15 | 12 | 32 |
| Energy | 1.A.4.c ii Forestry (mobile) | $CO_2$ | | | | | | |
| Energy | 1.A.4.c iii Fisheries | $CO_2$ | 19 | 24 | | | | |
| Energy | 1.A.5.b Other (military) | $CO_2$ | | | | | | |
| Energy | 1.A.5.b Other (small boats) | $CO_2$ | | | | | | |
| Energy | 1.A.2.g Industry (mobile) | $CH_4$ | | | | | | |
| Energy | 1.A.3.a Civil aviation | $CH_4$ | | | | | | |
| Energy | 1.A.3.b Road Transport | $CH_4$ | | | | | | |
| Energy | 1.A.3.c Railways | $CH_4$ | | | | | | |

| IPCC Source Categories (LULUCF excluded) | | GHG | Key categories with number according to ranking in analysis | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Level Approach 1 1990 | Level Approach 1 2018 | Trend Approach 1 1990-2018 | Level Approach 2 1990 | Level Approach 2 2018 | Trend Approach 2 1990-2018 |
| Energy | 1.A.3.d Navigation (large vessels) | $CH_4$ | | | | | | |
| Energy | 1.A.4.a Commercial/Institutional (mobile) | $CH_4$ | | | | | | |
| Energy | 1.A.4.b Residential (mobile) | $CH_4$ | | | | | | |
| Energy | 1.A.4.c ii Agriculture (mobile) | $CH_4$ | | | | | | |
| Energy | 1.A.4.c ii Forestry (mobile) | $CH_4$ | | | | | | |
| Energy | 1.A.4.c iii Fisheries | $CH_4$ | | | | | | |
| Energy | 1.A.5.b Other (military) | $CH_4$ | | | | | | |
| Energy | 1.A.5.b Other (small boats) | $CH_4$ | | | | | | |
| Energy | 1.A.2.g Industry (mobile) | $N_2O$ | | | | 31 | 28 | 40 |
| Energy | 1.A.3.a Civil aviation | $N_2O$ | | | | | | |
| Energy | 1.A.3.b Road Transport | $N_2O$ | | | | | 33 | 36 |
| Energy | 1.A.3.c Railways | $N_2O$ | | | | | | |
| Energy | 1.A.3.d Navigation (large vessels) | $N_2O$ | | | | | | |
| Energy | 1.A.4.a Commercial/Institutional (mobile) | $N_2O$ | | | | | | |
| Energy | 1.A.4.b Residential (mobile) | $N_2O$ | | | | | | |
| Energy | 1.A.4.c ii Agriculture (mobile) | $N_2O$ | | | | 23 | 21 | 30 |
| Energy | 1.A.4.c ii Forestry (mobile) | $N_2O$ | | | | | | |
| Energy | 1.A.4.c iii Fisheries | $N_2O$ | | | | | | |
| Energy | 1.A.5.b Other (military) | $N_2O$ | | | | | | |
| Energy | 1.A.5.b Other (small boats) | $N_2O$ | | | | | | |
| Energy | 1.B.2.a.1 Exploration | $CO_2$ | | | | | | |
| Energy | 1.B.2.a.2 Production | $CO_2$ | | | | | | |
| Energy | 1.B.2.a.4 Refining/storage | $CO_2$ | | | | | | |
| Energy | 1.B.2.b.1 Exploration | $CO_2$ | | | | | | |
| Energy | 1.B.2.b.2 Production | $CO_2$ | | | | | | |
| Energy | 1.B.2.b.4 Transmission and storage | $CO_2$ | | | | | | |
| Energy | 1.B.2.b.5 Distribution | $CO_2$ | | | | | | |
| Energy | 1.B.2.c.1.ii Venting | $CO_2$ | | | | | | |
| Energy | 1.B.2.c.2.i Flaring, oil | $CO_2$ | | | | | | |
| Energy | 1.B.2.c.2.ii Flaring, gas | $CO_2$ | | | | | | |
| Energy | 1.B.2.c.2.iii Flaring, combined | $CO_2$ | 28 | 29 | | | | |
| Energy | 1.B.2.a.1 Exploration | $CH_4$ | | | | | | |
| Energy | 1.B.2.a.2 Production | $CH_4$ | | | | | | |
| Energy | 1.B.2.a.3 Transport | $CH_4$ | | | | | | |
| Energy | 1.B.2.a.4 Refining/storage | $CH_4$ | | | | | | |
| Energy | 1.B.2.b.1 Exploration | $CH_4$ | | | | | | |
| Energy | 1.B.2.b.2 Production | $CH_4$ | | | | | | |

| IPCC Source Categories (LULUCF excluded) | | GHG | Key categories with number according to ranking in analysis | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Level Approach 1 1990** | **Level Approach 1 2018** | **Trend Approach 1 1990-2018** | **Level Approach 2 1990** | **Level Approach 2 2018** | **Trend Approach 2 1990-2018** |
| Energy | 1.B.2.b.4 Transmission and storage | $CH_4$ | | | | | | |
| Energy | 1.B.2.b.5 Distribution | $CH_4$ | | | | | | |
| Energy | 1.B.2.c.1.ii Venting | $CH_4$ | | | | | | |
| Energy | 1.B.2.c.2.i Flaring, oil | $CH_4$ | | | | | | |
| Energy | 1.B.2.c.2.ii Flaring, gas | $CH_4$ | | | | | | |
| Energy | 1.B.2.c.2.iii Flaring, combined | $CH_4$ | | | | | | |
| Energy | 1.B.2.a.1 Exploration, oil | $N_2O$ | | | | | | |
| Energy | 1.B.2.c.2.i Flaring, oil | $N_2O$ | | | | | | |
| Energy | 1.B.2.c.2.ii Flaring, gas | $N_2O$ | | | | | | |
| Energy | 1.B.2.c.2.iii Flaring, combined | $N_2O$ | | | | 10 | 10 | 25 |
| IPPU | 2A1 Cement production | $CO_2$ | 13 | 8 | 13 | | | |
| IPPU | 2A2 Lime production | $CO_2$ | | | | | | |
| IPPU | 2A3 Glass production | $CO_2$ | | | | | | |
| IPPU | 2A4a Ceramics | $CO_2$ | | | | | | |
| IPPU | 2A4b Other uses of soda ash | $CO_2$ | | | | | | |
| IPPU | 2A4d Other process uses of carbonates | $CO_2$ | | | | | | |
| IPPU | 2B10 Production of catalysts | $CO_2$ | | | | | | |
| IPPU | 2C1a Steel | $CO_2$ | | | | | | |
| IPPU | 2C5 Lead production | $CO_2$ | | | | | | |
| IPPU | 2D1 Lubricant use | $CO_2$ | | | | | | |
| IPPU | 2D2 Paraffin wax use | $CO_2$ | | | | | | |
| IPPU | Paint Application | $CO_2$ | | | | | | |
| IPPU | Degreasing, dry cleaning and electronics | $CO_2$ | | | | | | |
| IPPU | Chemical products manufacturing or processing | $CO_2$ | | | | | | |
| IPPU | Other use of solvents and related activities | $CO_2$ | | | | | | |
| IPPU | Printing industry | $CO_2$ | | | | | | |
| IPPU | Domestic solvent use (other than paint application) | $CO_2$ | | | | | | |
| IPPU | 2D3 Road paving with asphalt | $CO_2$ | | | | | | |
| IPPU | 2D3 Asphalt roofing | $CO_2$ | | | | | | |
| IPPU | 2D3 Urea based catalysts | $CO_2$ | | | | | | |
| IPPU | 2G4 Fireworks | $CO_2$ | | | | | | |
| IPPU | 2D2 Paraffin wax use | $CH_4$ | | | | | | |
| IPPU | 2D3 Road paving with asphalt | $CH_4$ | | | | | | |
| IPPU | 2G4 Fireworks | $CH_4$ | | | | | | |
| IPPU | 2G4 Tobacco | $CH_4$ | | | | | | |
| IPPU | 2G4 Charcoal | $CH_4$ | | | | | | |
| IPPU | 2B2 Nitric acid production | $N_2O$ | 11 | | 11 | 19 | | 10 |

| IPCC Source Categories (LULUCF excluded) | | GHG | Key categories with number according to ranking in analysis | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Level Approach 1 1990 | Level Approach 1 2018 | Trend Approach 1 1990-2018 | Level Approach 2 1990 | Level Approach 2 2018 | Trend Approach 2 1990-2018 |
| IPPU | 2D2 Paraffin wax use | $N_2O$ | | | | | | |
| IPPU | 2G3a Medical application of $N_2O$ | $N_2O$ | | | | | | |
| IPPU | 2G3b $N_2O$ as propellant for pressure and aerosol products | $N_2O$ | | | | | | |
| IPPU | 2G4 Fireworks | $N_2O$ | | | | | | |
| IPPU | 2G4 Tobacco | $N_2O$ | | | | | | |
| IPPU | 2G4 Charcoal | $N_2O$ | | | | | | |
| IPPU | 2E Electronics industry | HFCs | | | | | | |
| IPPU | 2F1 Refrigeration and air conditioning | HFCs | | 20 | 15 | | 15 | 6 |
| IPPU | 2F2 Foam blowing agents | HFCs | | | | 27 | | 20 |
| IPPU | 2F4 Aerosols | HFCs | | | | | | |
| IPPU | 2E Electronics industry | PFCs | | | | | | |
| IPPU | 2F1 Refrigeration and air conditioning | PFCs | | | | | | |
| IPPU | 2C4 Magnesium production | $SF_6$ | | | | | | |
| IPPU | 2G1 Electrical equipment | $SF_6$ | | | | | | |
| IPPU | 2G2 SF6 and PFCs from other product use | $SF_6$ | | | | | | |
| Agriculture | 3A Enteric Fermentation | $CH_4$ | 4 | 4 | 8 | 5 | 3 | 8 |
| Agriculture | 3B Manure Management | $CH_4$ | 8 | 5 | 9 | 13 | 9 | 9 |
| Agriculture | 3F Field Burning of Agricultural Residues | $CH_4$ | | | | | | |
| Agriculture | 3B Manure Management | $N_2O$ | 16 | 18 | | 6 | 6 | 24 |
| Agriculture | 3B5 Atmospheric deposition | $N_2O$ | | 34 | | 21 | 22 | |
| Agriculture | 3Da1 Inorganic N fertilizer | $N_2O$ | 7 | 9 | 21 | 1 | 1 | 5 |
| Agriculture | 3Da2a Animal manure applied to soils | $N_2O$ | 12 | 11 | 16 | 3 | 2 | 2 |
| Agriculture | 3Da2b Sewage sludge applied to soils | $N_2O$ | | | | | | |
| Agriculture | 3Da2c Other organic fertilizer applied to soils | $N_2O$ | | | | | | |
| Agriculture | 3Da3 Urine and dung deposited by grazing animals | $N_2O$ | 29 | 32 | | 16 | 18 | 43 |
| Agriculture | 3Da4 Crop Residues | $N_2O$ | 21 | 21 | | 7 | 8 | 15 |
| Agriculture | 3Da5 Mineralization | $N_2O$ | | | | 22 | 20 | 35 |
| Agriculture | 3Da6 Cultivation of organic soils | $N_2O$ | 14 | 14 | | 4 | 4 | 22 |
| Agriculture | 3Db1 Atmospheric deposition | $N_2O$ | 27 | 31 | | 14 | 17 | 29 |
| Agriculture | 3Db2 Leaching | $N_2O$ | 23 | 23 | | 9 | 11 | 28 |
| Agriculture | 3F Field Burning of Agricultural Residues | $N_2O$ | | | | | | |
| Agriculture | 3G Liming | $CO_2$ | 22 | 26 | | 8 | 16 | 11 |
| Agriculture | 3H Urea applicaton | $CO_2$ | | | | | | |
| Agriculture | 3I Other carbon-containing fertilizers | $CO_2$ | | | | | | |
| Waste | 5.E Accidental fires | $CO_2$ | | | | 33 | 37 | |
| Waste | 5.A Solid waste disposal | $CH_4$ | 9 | 19 | 14 | 2 | 7 | 1 |
| Waste | 5.B.1 Composting | $CH_4$ | | | | | 23 | 16 |

| IPCC Source Categories (LULUCF excluded) | | GHG | Key categories with number according to ranking in analysis | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Level Approach 1 1990 | Level Approach 1 2018 | Trend Approach 1 1990-2018 | Level Approach 2 1990 | Level Approach 2 2018 | Trend Approach 2 1990-2018 |
| Waste | 5.B.2. Anaerobic digestion at biogas facilities | $CH_4$ | | 25 | 19 | | | 26 |
| Waste | 5.C.1 Incineration of corpses | $CH_4$ | | | | | | |
| Waste | 5.C.2 Incineration of carcasses | $CH_4$ | | | | | | |
| Waste | 5.D.1 Domestic wastewater | $CH_4$ | | | | | | |
| Waste | 5.E Accidental fires | $CH_4$ | | | | | | |
| Waste | 5.B.1 Composting | $N_2O$ | | | | | 27 | 18 |
| Waste | 5.C.1 Incineration of corpses | $N_2O$ | | | | | | |
| Waste | 5.C.2 Incineration of carcasses | $N_2O$ | | | | | | |
| Waste | 5.D.1 Domestic wastewater | $N_2O$ | | | | | | |
| Waste | 5.D.2 Industrial wastewater | $N_2O$ | | | | | | |

Table A1-2 Summary of KCA for Denmark, level and trend for 1990-2018, incl. LULUCF, approach 1 and approach 2.

| **IPCC Source Categories (LULUCF included)** | | **GHG** | **Key categories with number according to ranking in analysis** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Level Approach 1 1990** | **Level Approach 1 2018** | **Trend Approach 1 1990-2018** | **Level Approach 2 1990** | **Level Approach 2 2018** | **Trend Approach 2 1990-2018** |
| Energy | 1A Stationary combustion, Coal, ETS data, $CO_2$ | $CO_2$ | | 2 | 2 | | | 44 |
| Energy | 1A Stationary combustion, Coal, no ETS data, $CO_2$ | $CO_2$ | 1 | 35 | 1 | 14 | | 4 |
| Energy | 1A Stationary combustion, BKB, $CO_2$ | $CO_2$ | | | | | | |
| Energy | 1A Stationary combustion, Coke oven coke, $CO_2$ | $CO_2$ | | | | | | |
| Energy | 1A Stationary combustion, Fossil waste, ETS data, $CO_2$ | $CO_2$ | | 9 | 9 | | | 34 |
| Energy | 1A Stationary combustion, Fossil waste, no ETS data, $CO_2$ | $CO_2$ | 23 | 27 | | | | |
| Energy | 1A Stationary combustion, Petroleum coke, ETS data, $CO_2$ | $CO_2$ | | 20 | 14 | | | |
| Energy | 1A Stationary combustion, Petroleum coke, no ETS data, $CO_2$ | $CO_2$ | 29 | | 21 | | | |
| Energy | 1A Stationary combustion, Residual oil, ETS data, $CO_2$ | $CO_2$ | | 32 | 25 | | | |
| Energy | 1A Stationary combustion, Residual oil, no ETS data, $CO_2$ | $CO_2$ | 7 | | 7 | | | 40 |
| Energy | 1A Stationary combustion, Gas oil, $CO_2$ | $CO_2$ | 3 | 18 | 5 | 28 | | 24 |
| Energy | 1A Stationary combustion, Kerosene, $CO_2$ | $CO_2$ | 30 | | 23 | | | |
| Energy | 1A Stationary combustion, LPG, $CO_2$ | $CO_2$ | | 43 | | | | |
| Energy | 1A1b Stationary combustion, Petroleum refining, Refinery gas, $CO_2$ | $CO_2$ | 17 | 16 | 22 | | | |
| Energy | 1A Stationary combustion, Natural gas, onshore, $CO_2$ | $CO_2$ | 6 | 3 | 6 | | 40 | 46 |
| Energy | 1A1c_ii Stationary combustion, Oil and gas extraction, Off shore gas turbines, Natural gas, $CO_2$ | $CO_2$ | 27 | 10 | 12 | | | |
| Energy | 1A1 Stationary Combustion, Solid fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A1 Stationary Combustion, Liquid fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A1 Stationary Combustion, not engines, gaseous fuels, CH4 | $CH_4$ | | | | | | |
| Energy | 1A1 Stationary Combustion, Waste, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A1 Stationary Combustion, not engines, Biomass, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A2 Stationary Combustion,solid fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A2 Stationary Combustion,Liquid fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A2 Stationary Combustion, not engines, gaseous fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A2 Stationary Combustion, Waste, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A2 Stationary Combustion, not engines, Biomass, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A4 Stationary Combustion, Solid fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A4 Stationary Combustion, Liquid fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A4 Stationary Combustion, not engines, gaseous fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A4 Stationary Combustion, Waste, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A4 Stationary Combustion, not engines, not residential wood and not residen-tial/agricultural straw, Biomass, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A4b_i Stationary combustion, Residential wood combustion, $CH_4$ | $CH_4$ | | | | 30 | 33 | 52 |
| Energy | 1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw com-bustion, $CH_4$ | $CH_4$ | | | | 33 | | |

| IPCC Source Categories (LULUCF included) | | GHG | Key categories with number according to ranking in analysis | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Level Approach 1 1990** | **Level Approach 1 2018** | **Trend Approach 1 1990-2018** | **Level Approach 2 1990** | **Level Approach 2 2018** | **Trend Approach 2 1990-2018** |
| Energy | 1A Stationary combustion, Natural gas fuelled engines, gaseous fuels, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A Stationary combustion, Biogas fuelled engines, Biomass, $CH_4$ | $CH_4$ | | | | | | |
| Energy | 1A1 Stationary Combustion, Solid fuels, $N_2O$ | $N_2O$ | | | | 23 | 45 | 17 |
| Energy | 1A1 Stationary Combustion, Liquid fuels, $N_2O$ | $N_2O$ | | | | | | |
| Energy | 1A1 Stationary Combustion, Gaseous fuels, $N_2O$ | $N_2O$ | | | | 34 | 32 | 36 |
| Energy | 1A1 Stationary Combustion, Waste, $N_2O$ | $N_2O$ | | | | | | 42 |
| Energy | 1A1 Stationary Combustion, Biomass, $N_2O$ | $N_2O$ | | | | | 23 | 14 |
| Energy | 1A2 Stationary Combustion, Solid fuels, $N_2O$ | $N_2O$ | | | | | 34 | 23 |
| Energy | 1A2 Stationary Combustion, Liquid fuels, $N_2O$ | $N_2O$ | | | | 20 | 44 | 15 |
| Energy | 1A2 Stationary Combustion, Gaseous fuels, $N_2O$ | $N_2O$ | | | | | 42 | 51 |
| Energy | 1A2 Stationary Combustion, Waste $N_2O$ | $N_2O$ | | | | | | |
| Energy | 1A2 Stationary Combustion, Biomass, $N_2O$ | $N_2O$ | | | | | | |
| Energy | 1A4 Stationary Combustion, Solid fuels, $N_2O$ | $N_2O$ | | | | | | |
| Energy | 1A4 Stationary Combustion, Liquid fuels, $N_2O$ | $N_2O$ | | | | 29 | | 28 |
| Energy | 1A4 Stationary Combustion, Gaseous fuels $N_2O$ | $N_2O$ | | | | | 38 | 49 |
| Energy | 1A4 Stationary Combustion, Waste, $N_2O$ | $N_2O$ | | | | | | |
| Energy | 1A4 Stationary Combustion, not residential wood and not residential/agricultural straw, Biomass, $N_2O$ | $N_2O$ | | | | | | |
| Energy | 1A4b_i Stationary Combustion, Residential wood combustion, $N_2O$ | $N_2O$ | | | | | 17 | 8 |
| Energy | 1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion, $N_2O$ | $N_2O$ | | | | | | |
| Energy | 1.A.2.g Industry (mobile) | $CO_2$ | 21 | 22 | 31 | 21 | 16 | 29 |
| Energy | 1.A.3.a Civil aviation | $CO_2$ | | | | | | |
| Energy | 1.A.3.b Road Transport | $CO_2$ | 2 | 1 | 3 | 13 | 6 | 5 |
| Energy | 1.A.3.c Railways | $CO_2$ | 34 | 33 | | | | |
| Energy | 1.A.3.d Navigation (large vessels) | $CO_2$ | 20 | 21 | | 35 | 37 | |
| Energy | 1.A.4.a Commercial/Institutional (mobile) | $CO_2$ | | | | | | |
| Energy | 1.A.4.b Residential (mobile) | $CO_2$ | | | | | | |
| Energy | 1.A.4.c ii Agriculture (mobile) | $CO_2$ | 12 | 14 | | 18 | 15 | 48 |
| Energy | 1.A.4.c ii Forestry (mobile) | $CO_2$ | | | | | | |
| Energy | 1.A.4.c iii Fisheries | $CO_2$ | 22 | 29 | 27 | | | |
| Energy | 1.A.5.b Other (military) | $CO_2$ | | | | | | 53 |
| Energy | 1.A.5.b Other (small boats) | $CO_2$ | | | | | | |
| Energy | 1.A.2.g Industry (mobile) | $CH_4$ | | | | | | |
| Energy | 1.A.3.a Civil aviation | $CH_4$ | | | | | | |
| Energy | 1.A.3.b Road Transport | $CH_4$ | | | | | | |
| Energy | 1.A.3.c Railways | $CH_4$ | | | | | | |

| IPCC Source Categories (LULUCF included) | | GHG | Key categories with number according to ranking in analysis | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Level Approach 1 1990** | **Level Approach 1 2018** | **Trend Approach 1 1990-2018** | **Level Approach 2 1990** | **Level Approach 2 2018** | **Trend Approach 2 1990-2018** |
| Energy | 1.A.3.d Navigation (large vessels) | $CH_4$ | | | | | | |
| Energy | 1.A.4.a Commercial/Institutional (mobile) | $CH_4$ | | | | | | |
| Energy | 1.A.4.b Residential (mobile) | $CH_4$ | | | | | | |
| Energy | 1.A.4.c ii Agriculture (mobile) | $CH_4$ | | | | | | |
| Energy | 1.A.4.c ii Forestry (mobile) | $CH_4$ | | | | | | |
| Energy | 1.A.4.c iii Fisheries | $CH_4$ | | | | | | |
| Energy | 1.A.5.b Other (military) | $CH_4$ | | | | | | |
| Energy | 1.A.5.b Other (small boats) | $CH_4$ | | | | | | |
| Energy | 1.A.2.g Industry (mobile) | $N_2O$ | | | | | 36 | 50 |
| Energy | 1.A.3.a Civil aviation | $N_2O$ | | | | | | |
| Energy | 1.A.3.b Road Transport | $N_2O$ | | | | | 43 | 45 |
| Energy | 1.A.3.c Railways | $N_2O$ | | | | | | |
| Energy | 1.A.3.d Navigation (large vessels) | $N_2O$ | | | | | | |
| Energy | 1.A.4.a Commercial/Institutional (mobile) | $N_2O$ | | | | | | |
| Energy | 1.A.4.b Residential (mobile) | $N_2O$ | | | | | | |
| Energy | 1.A.4.c ii Agriculture (mobile) | $N_2O$ | | | | 27 | 25 | 37 |
| Energy | 1.A.4.c ii Forestry (mobile) | $N_2O$ | | | | | | |
| Energy | 1.A.4.c iii Fisheries | $N_2O$ | | | | | | |
| Energy | 1.A.5.b Other (military) | $N_2O$ | | | | | | |
| Energy | 1.A.5.b Other (small boats) | $N_2O$ | | | | | | |
| Energy | 1.B.2.a.1 Exploration | $CO_2$ | | | | | | |
| Energy | 1.B.2.a.2 Production | $CO_2$ | | | | | | |
| Energy | 1.B.2.a.4 Refining/storage | $CO_2$ | | | | | | |
| Energy | 1.B.2.b.1 Exploration | $CO_2$ | | | | | | |
| Energy | 1.B.2.b.2 Production | $CO_2$ | | | | | | |
| Energy | 1.B.2.b.4 Transmission and storage | $CO_2$ | | | | | | |
| Energy | 1.B.2.b.5 Distribution | $CO_2$ | | | | | | |
| Energy | 1.B.2.c.1.ii Venting | $CO_2$ | | | | | | |
| Energy | 1.B.2.c.2.i Flaring, oil | $CO_2$ | | | | | | |
| Energy | 1.B.2.c.2.ii Flaring, gas | $CO_2$ | | | | | | |
| Energy | 1.B.2.c.2.iii Flaring, combined | $CO_2$ | 32 | 34 | | | | |
| Energy | 1.B.2.a.1 Exploration | $CH_4$ | | | | | | |
| Energy | 1.B.2.a.2 Production | $CH_4$ | | | | | | |
| Energy | 1.B.2.a.3 Transport | $CH_4$ | | | | | | |
| Energy | 1.B.2.a.4 Refining/storage | $CH_4$ | | | | | | |
| Energy | 1.B.2.b.1 Exploration | $CH_4$ | | | | | | |
| Energy | 1.B.2.b.2 Production | $CH_4$ | | | | | | |

| IPCC Source Categories (LULUCF included) | | GHG | Key categories with number according to ranking in analysis | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Level Approach 1 1990** | **Level Approach 1 2018** | **Trend Approach 1 1990-2018** | **Level Approach 2 1990** | **Level Approach 2 2018** | **Trend Approach 2 1990-2018** |
| Energy | 1.B.2.b.4 Transmission and storage | $CH_4$ | | | | | | |
| Energy | 1.B.2.b.5 Distribution | $CH_4$ | | | | | | |
| Energy | 1.B.2.c.1.ii Venting | $CH_4$ | | | | | | |
| Energy | 1.B.2.c.2.i Flaring, oil | $CH_4$ | | | | | | |
| Energy | 1.B.2.c.2.ii Flaring, gas | $CH_4$ | | | | | | |
| Energy | 1.B.2.c.2.iii Flaring, combined | $CH_4$ | | | | | | |
| Energy | 1.B.2.a.1 Exploration, oil | $N_2O$ | | | | | | |
| Energy | 1.B.2.c.2.i Flaring, oil | $N_2O$ | | | | | | |
| Energy | 1.B.2.c.2.ii Flaring, gas | $N_2O$ | | | | | | |
| Energy | 1.B.2.c.2.iii Flaring, combined | $N_2O$ | | | | 12 | 13 | 35 |
| IPPU | 2A1 Cement production | $CO_2$ | 15 | 12 | 16 | | | |
| IPPU | 2A2 Lime production | $CO_2$ | | | | | | |
| IPPU | 2A3 Glass production | $CO_2$ | | | | | | |
| IPPU | 2A4a Ceramics | $CO_2$ | | | | | | |
| IPPU | 2A4b Other uses of soda ash | $CO_2$ | | | | | | |
| IPPU | 2A4d Other process uses of carbonates | $CO_2$ | | | | | | |
| IPPU | 2B10 Production of catalysts | $CO_2$ | | | | | | |
| IPPU | 2C1a Steel | $CO_2$ | | | | | | |
| IPPU | 2C5 Lead production | $CO_2$ | | | | | | |
| IPPU | 2D1 Lubricant use | $CO_2$ | | | | | | |
| IPPU | 2D2 Paraffin wax use | $CO_2$ | | | | | | |
| IPPU | Paint Application | $CO_2$ | | | | | | |
| IPPU | Degreasing, dry cleaning and electronics | $CO_2$ | | | | | | |
| IPPU | Chemical products manufacturing or processing | $CO_2$ | | | | | | |
| IPPU | Other use of solvents and related activities | $CO_2$ | | | | | | |
| IPPU | Printing industry | $CO_2$ | | | | | | |
| IPPU | Domestic solvent use (other than paint application) | $CO_2$ | | | | | | |
| IPPU | 2D3 Road paving with asphalt | $CO_2$ | | | | | | |
| IPPU | 2D3 Asphalt roofing | $CO_2$ | | | | | | |
| IPPU | 2D3 Urea based catalysts | $CO_2$ | | | | | | |
| IPPU | 2G4 Fireworks | $CO_2$ | | | | | | |
| IPPU | 2D2 Paraffin wax use | $CH_4$ | | | | | | |
| IPPU | 2D3 Road paving with asphalt | $CH_4$ | | | | | | |
| IPPU | 2G4 Fireworks | $CH_4$ | | | | | | |
| IPPU | 2G4 Tobacco | $CH_4$ | | | | | | |
| IPPU | 2G4 Charcoal | $CH_4$ | | | | | | |
| IPPU | 2B2 Nitric acid production | $N_2O$ | 13 | | 13 | 22 | | 10 |

| IPCC Source Categories (LULUCF included) | | GHG | Key categories with number according to ranking in analysis | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Level Approach 1 1990** | **Level Approach 1 2018** | **Trend Approach 1 1990-2018** | **Level Approach 2 1990** | **Level Approach 2 2018** | **Trend Approach 2 1990-2018** |
| IPPU | 2D2 Paraffin wax use | $N_2O$ | | | | | | |
| IPPU | 2G3a Medical application of $N_2O$ | $N_2O$ | | | | | | |
| IPPU | 2G3b $N_2O$ as propellant for pressure and aerosol products | $N_2O$ | | | | | | |
| IPPU | 2G4 Fireworks | $N_2O$ | | | | | | |
| IPPU | 2G4 Tobacco | $N_2O$ | | | | | | |
| IPPU | 2G4 Charcoal | $N_2O$ | | | | | | |
| IPPU | 2E Electronics industry | HFCs | | | | | | |
| IPPU | 2F1 Refrigeration and air conditioning | HFCs | | 25 | 18 | | 18 | 7 |
| IPPU | 2F2 Foam blowing agents | HFCs | | | 32 | 31 | | 26 |
| IPPU | 2F4 Aerosols | HFCs | | | | | | |
| IPPU | 2E Electronics industry | PFCs | | | | | | |
| IPPU | 2F1 Refrigeration and air conditioning | PFCs | | | | | | |
| IPPU | 2C4 Magnesium production | $SF_6$ | | | | | | |
| IPPU | 2G1 Electrical equipment | $SF_6$ | | | | | | |
| IPPU | 2G2 $SF_6$ and PFCs from other product use | $SF_6$ | | | | | | |
| Agriculture | 3A Enteric Fermentation | $CH_4$ | 5 | 4 | 11 | 6 | 4 | 12 |
| Agriculture | 3B Manure Management | $CH_4$ | 9 | 8 | 10 | 15 | 12 | 9 |
| Agriculture | 3F Field Burning of Agricultural Residues | $CH_4$ | | | | | | |
| Agriculture | 3B Manure Management | $N_2O$ | 18 | 23 | | 7 | 7 | 39 |
| Agriculture | 3B5 Atmospheric deposition | $N_2O$ | | 44 | | 24 | 27 | |
| Agriculture | 3Da1 Inorganic N fertilizer | $N_2O$ | 8 | 13 | 20 | 2 | 2 | 6 |
| Agriculture | 3Da2a Animal manure applied to soils | $N_2O$ | 14 | 15 | 19 | 4 | 3 | 3 |
| Agriculture | 3Da2b Sewage sludge applied to soils | $N_2O$ | | | | | | |
| Agriculture | 3Da2c Other organic fertilizer applied to soils | $N_2O$ | | | | | | |
| Agriculture | 3Da3 Urine and dung deposited by grazing animals | $N_2O$ | 33 | 37 | | 19 | 22 | 41 |
| Agriculture | 3Da4 Crop Residues | $N_2O$ | 24 | 26 | | 9 | 11 | 27 |
| Agriculture | 3Da5 Mineralization | $N_2O$ | | | | 25 | 24 | 47 |
| Agriculture | 3Da6 Cultivation of organic soils | $N_2O$ | 16 | 19 | | 5 | 5 | 38 |
| Agriculture | 3Db1 Atmospheric deposition | $N_2O$ | 31 | 36 | | 16 | 20 | 31 |
| Agriculture | 3Db2 Leaching | $N_2O$ | 26 | 28 | | 11 | 14 | 30 |
| Agriculture | 3F Field Burning of Agricultural Residues | $N_2O$ | | | | | | |
| Agriculture | 3G Liming | $CO_2$ | 25 | 31 | 29 | 10 | 19 | 13 |
| Agriculture | 3H Urea applicaton | $CO_2$ | | | | | | |
| Agriculture | 3I Other carbon-containing fertilizers | $CO_2$ | | | | | | 54 |
| LULUCF | 4.A.1 Forest land remaining forest land, Living biomass | $CO_2$ | 19 | 7 | 8 | | 26 | 20 |
| LULUCF | 4.A.1 Forest land remaining forest land, Dead organic matter | $CO_2$ | | 6 | 4 | | 21 | 11 |
| LULUCF | 4.A.1 Forest land remaining forest land, Mineral soils | $CO_2$ | | | | | | |

| IPCC Source Categories (LULUCF included) | | GHG | Key categories with number according to ranking in analysis | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Level Approach 1 1990 | Level Approach 1 2018 | Trend Approach 1 1990-2018 | Level Approach 2 1990 | Level Approach 2 2018 | Trend Approach 2 1990-2018 |
| LULUCF | 4.A.1 Forest land remaining forest land, Organic soils | $CO_2$ | | 41 | | 32 | 39 | |
| LULUCF | 4.A.2 Land converted to forest land | $CO_2$ | | 38 | 33 | | | |
| LULUCF | 4.B.1 Cropland remaining cropland, Living biomass | $CO_2$ | | | | | | |
| LULUCF | 4.B.1 Cropland remaining cropland, Mineral soils | $CO_2$ | 28 | 17 | 17 | 17 | 9 | 2 |
| LULUCF | 4.B.1 Cropland remaining cropland, Organic soils | $CO_2$ | 4 | 5 | 28 | 1 | 1 | 21 |
| LULUCF | 4.B.2 Forest land converted to cropland | $CO_2$ | | | | | | 43 |
| LULUCF | 4.B.2 Other land uses converted to cropland | $CO_2$ | | | | | | |
| LULUCF | 4(II) Cropland on organic soils | $CO_2$ | | | | | | |
| LULUCF | 4.C.1 Grassland remaining grassland, Living biomass | $CO_2$ | | | | | | |
| LULUCF | 4.C.1 Grassland remaining grassland, Organic soils | $CO_2$ | 11 | 11 | 26 | 8 | 8 | 19 |
| LULUCF | 4.C.2 Forest land converted to grassland | $CO_2$ | | | | | | |
| LULUCF | 4.C.2 Other land uses converted to grassland | $CO_2$ | | | | | | |
| LULUCF | 4(II) Grassland on organic soils | $CO_2$ | | | | | | |
| LULUCF | 4.D.1.1 Peat extraction remaining peat extraction | $CO_2$ | | | | | | |
| LULUCF | 4.D.1.2 Flooded land remaining flooded land | $CO_2$ | | | | | | |
| LULUCF | 4.D.2. Land converted to wetlands | $CO_2$ | | | | | | |
| LULUCF | 4.E.2 Forest land converted to settlements | $CO_2$ | | | | | | 55 |
| LULUCF | 4.E.2 Other land uses converted to settlements | $CO_2$ | | 40 | | | 30 | 18 |
| LULUCF | 4.G Harvested wood products | $CO_2$ | | 39 | 30 | | 28 | 16 |
| LULUCF | 4(II) Cropland on organic soils | $CH_4$ | | 42 | | 26 | 29 | |
| LULUCF | 4(II) Grassland on organic soils | $CH_4$ | | | | 36 | 41 | |
| LULUCF | 4(II) A. Forest land, organic soils | $CH_4$ | | | | | | |
| LULUCF | 4(II) Land converted to wetlands | $CH_4$ | | | | | | 33 |
| LULUCF | 4(II) Peatland | $CH_4$ | | | | | | |
| LULUCF | 4(V) Biomass Burning | $CH_4$ | | | | | | |
| LULUCF | 4(III) Mineralization/immobilization, Forest land | $N_2O$ | | | | | | |
| LULUCF | 4(III) Mineralization/immobilization, Cropland | $N_2O$ | | | | | | |
| LULUCF | 4(III) Mineralization/immobilization, Grassland | $N_2O$ | | | | | | |
| LULUCF | 4(III) Mineralization/immobilization, Land converted to Settlements | $N_2O$ | | | | | | |
| LULUCF | 4(V) Biomass burning | $N_2O$ | | | | | | |
| LULUCF | 4(II) Drainage and rewetting, Forest soils | $N_2O$ | | | | | | |
| LULUCF | 4(II) Peat extraction remaining peat extraction | $N_2O$ | | | | | | |
| Waste | 5.E Accidental fires | $CO_2$ | | | | | | |
| Waste | 5.A Solid waste disposal | $CH_4$ | 10 | 24 | 15 | 3 | 10 | 1 |
| Waste | 5.B.1 Composting | $CH_4$ | | | | | 31 | 22 |
| Waste | 5.B.2. Anaerobic digestion at biogas facilities | $CH_4$ | | 30 | 24 | | | 32 |
| Waste | 5.C.1 Incineration of corpses | $CH_4$ | | | | | | |

| IPCC Source Categories (LULUCF included) | | GHG | Key categories with number according to ranking in analysis | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Level Approach 1 1990 | Level Approach 1 2018 | Trend Approach 1 1990-2018 | Level Approach 2 1990 | Level Approach 2 2018 | Trend Approach 2 1990-2018 |
| Waste | 5.C.2 Incineration of carcasses | $CH_4$ | | | | | | |
| Waste | 5.D.1 Domestic wastewater | $CH_4$ | | | | | | |
| Waste | 5.E Accidental fires | $CH_4$ | | | | | | |
| Waste | 5.B.1 Composting | $N_2O$ | | | | | 35 | 25 |
| Waste | 5.C.1 Incineration of corpses | $N_2O$ | | | | | | |
| Waste | 5.C.2 Incineration of carcasses | $N_2O$ | | | | | | |
| Waste | 5.D.1 Domestic wastewater | $N_2O$ | | | | | | |
| Waste | 5.D.2 Industrial wastewater | $N_2O$ | | | | | | |

Table A1-3 Summary of KCA for Denmark, number of key source categories in each of the KCA.

| | Level Approach 1 1990 | Level Approach 1 2018 | Trend Approach 1 1990-2018 | Level Approach 2 1990 | Level Approach 2 2018 | Trend Approach 2 1990-2018 |
|---|---|---|---|---|---|---|
| Excluding LULUCF | 29 | 34 | 24 | 33 | 37 | 43 |
| Including LULUCF | 34 | 44 | 33 | 36 | 45 | 55 |

Table A1-4 KCA for Denmark, level assessment, base year excl. LULUCF, approach 1. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A1-5 KCA for Denmark, level assessment base year incl. LULUCF, approach 1. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A1-6 KCA for Denmark, level assessment 2018 excl. LULUCF, approach 1. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A1-7 KCA for Denmark, level assessment 2018 incl. LULUCF, approach 1. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A1-8 KCA for Denmark, trend assessment 1990-2018 excl. LULUCF, approach 1. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A1-9 KCA for Denmark, trend assessment 1990-2018 incl. LULUCF, approach 1. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A1-10 KCA for Denmark, level assessment base year excl. LULUCF, approach 2. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A1-11 KCA for Denmark, level assessment base year incl. LULUCF, approach 2. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A1-12 KCA for Denmark, level assessment 2018 excl. LULUCF, approach 2. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A1-13 KCA for Denmark, level assessment 2018 incl. LULUCF, approach 2. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A1-14 KCA for Denmark, trend assessment 1990-2018 excl. LULUCF, approach 2. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A1-15 KCA for Denmark, trend assessment 1990-2018 incl. LULUCF, approach 2. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

# Annex 2 - Assessment of uncertainty

## Description of methodology used for identifying uncertainties

For the inventory of Denmark, the uncertainties are estimated using Approach 1 of the 2006 IPCC Guidelines.

More information and the results are provided in Chapter 1.7.

The underlying table, corresponding to Table 3.3 of volume 1 of the 2006 IPCC Guidelines, is very large and not suitable for incorporation in a text document. The table in Excel format can be found at https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

## Annex 3 - Other detailed methodological descriptions for individual source or sink categories (where relevant)

Annex 3A – Stationary Combustion

Annex 3B – Transport and other mobile sources

Annex 3C – Industrial Processes

Annex 3D – Agriculture

Annex 3E – LULUCF

Annex 3F – Waste

## Annex 3A - Stationary combustion

| | |
|---|---|
| Annex 3A-1: | Correspondence list between SNAP and CRF source categories |
| Annex 3A-2: | Fuel rate |
| Annex 3A-3: | Default Lower Calorific Value (LCV) of fuels and fuel correspondence list |
| Annex 3A-4: | Emission factors |
| Annex 3A-5: | Large point sources |
| Annex 3A-6: | Adjustment of $CO_2$ emission |
| Annex 3A-7: | Uncertainty estimates |
| Annex 3A-8: | Emission inventory 2018 based on SNAP sectors |
| Annex 3A-9: | EU ETS data |

## Annex 3A-1 Correspondence list between SNAP and CRF source categories

Table 3A-1.1 Correspondence list between SNAP and CRF source categories for stationary combustion.

| | snap_name | CRF id | CRF name |
|---|---|---|---|
| 010100 | Public power | 1A1a | Public electricity and heat production |
| 010101 | Combustion plants >= 300 MW (boilers) | 1A1a | Public electricity and heat production |
| 010102 | Combustion plants >= 50 and < 300 MW (boilers) | 1A1a | Public electricity and heat production |
| 010103 | Combustion plants < 50 MW (boilers) | 1A1a | Public electricity and heat production |
| 010104 | Gas turbines | 1A1a | Public electricity and heat production |
| 010105 | Stationary engines | 1A1a | Public electricity and heat production |
| 010200 | District heating plants | 1A1a | Public electricity and heat production |
| 010201 | Combustion plants >= 300 MW (boilers) | 1A1a | Public electricity and heat production |
| 010202 | Combustion plants >= 50 and < 300 MW (boilers) | 1A1a | Public electricity and heat production |
| 010203 | Combustion plants < 50 MW (boilers) | 1A1a | Public electricity and heat production |
| 010204 | Gas turbines | 1A1a | Public electricity and heat production |
| 010205 | Stationary engines | 1A1a | Public electricity and heat production |
| 010300 | Petroleum refining plants | 1A1b | Petroleum refining |
| 010301 | Combustion plants >= 300 MW (boilers) | 1A1b | Petroleum refining |
| 010302 | Combustion plants >= 50 and < 300 MW (boilers) | 1A1b | Petroleum refining |
| 010303 | Combustion plants < 50 MW (boilers) | 1A1b | Petroleum refining |
| 010304 | Gas turbines | 1A1b | Petroleum refining |
| 010305 | Stationary engines | 1A1b | Petroleum refining |
| 010306 | Process furnaces | 1A1b | Petroleum refining |
| 010400 | Solid fuel transformation plants | 1A1c | Oil and gas extraction |
| 010401 | Combustion plants >= 300 MW (boilers) | 1A1c | Oil and gas extraction |
| 010402 | Combustion plants >= 50 and < 300 MW (boilers) | 1A1c | Oil and gas extraction |
| 010403 | Combustion plants < 50 MW (boilers) | 1A1c | Oil and gas extraction |
| 010404 | Gas turbines | 1A1c | Oil and gas extraction |
| 010405 | Stationary engines | 1A1c | Oil and gas extraction |
| 010406 | Coke oven furnaces | 1A1c | Oil and gas extraction |
| 010407 | Other (coal gasification, liquefaction) | 1A1c | Oil and gas extraction |
| 010500 | Coal mining, oil / gas extraction, pipeline compressors | 1A1c | Oil and gas extraction |
| 010501 | Combustion plants >= 300 MW (boilers) | 1A1c | Oil and gas extraction |
| 010502 | Combustion plants >= 50 and < 300 MW (boilers) | 1A1c | Oil and gas extraction |
| 010503 | Combustion plants < 50 MW (boilers) | 1A1c | Oil and gas extraction |
| 010504 | Gas turbines | 1A1c | Oil and gas extraction |
| 010505 | Stationary engines | 1A1c | Oil and gas extraction |
| 010506 | Pipeline compressors | 1A3e i | Pipeline transport |
| 020100 | Commercial and institutional plants | 1A4a i | Commercial/institutional: Stationary |
| 020101 | Combustion plants >= 300 MW (boilers) | 1A4a i | Commercial/institutional: Stationary |
| 020102 | Combustion plants >= 50 and < 300 MW (boilers) | 1A4a i | Commercial/institutional: Stationary |
| 020103 | Combustion plants < 50 MW (boilers) | 1A4a i | Commercial/institutional: Stationary |
| 020104 | Stationary gas turbines | 1A4a i | Commercial/institutional: Stationary |
| 020105 | Stationary engines | 1A4a i | Commercial/institutional: Stationary |
| 020106 | Other stationary equipments | 1A4a i | Commercial/institutional: Stationary |
| 020200 | Residential plants | 1A4b i | Residential: Stationary |
| 020201 | Combustion plants >= 50 MW (boilers) | 1A4b i | Residential: Stationary |
| 020202 | Combustion plants < 50 MW (boilers) | 1A4b i | Residential: Stationary |
| 020203 | Gas turbines | 1A4b i | Residential: Stationary |
| 020204 | Stationary engines | 1A4b i | Residential: Stationary |
| 020205 | Other equipments (stoves, fireplaces, cooking) | 1A4b i | Residential: Stationary |
| 020300 | Plants in agriculture, forestry and aquaculture | 1A4c i | Agriculture/Forestry/Fishing: Stationary |
| 020301 | Combustion plants >= 50 MW (boilers) | 1A4c i | Agriculture/Forestry/Fishing: Stationary |
| 020302 | Combustion plants < 50 MW (boilers) | 1A4c i | Agriculture/Forestry/Fishing: Stationary |
| 020303 | Stationary gas turbines | 1A4c i | Agriculture/Forestry/Fishing: Stationary |
| 020304 | Stationary engines | 1A4c i | Agriculture/Forestry/Fishing: Stationary |
| 020305 | Other stationary equipments | 1A4c i | Agriculture/Forestry/Fishing: Stationary |
| 030100 | Comb. in boilers, gas turbines and stationary | 1A2g viii | Other manufacturing industry |
| 030101 | Combustion plants >= 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 030102 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 030103 | Combustion plants < 50 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 030104 | Gas turbines | 1A2g viii | Other manufacturing industry |
| 030105 | Stationary engines | 1A2g viii | Other manufacturing industry |

| | snap_name | CRF id | CRF name |
|---|---|---|---|
| 030106 | Other stationary equipments | 1A2g viii | Other manufacturing industry |
| 030200 | Process furnaces without contact (a) | 1A2g viii | Other manufacturing industry |
| 030203 | Blast furnace cowpers | 1A2a | Iron and steel |
| 030204 | Plaster furnaces | 1A2g viii | Other manufacturing industry |
| 030205 | Other furnaces | 1A2g viii | Other manufacturing industry |
| 030400 | Iron and Steel | 1A2a | Iron and steel |
| 030401 | Combustion plants >= 300 MW (boilers) | 1A2a | Iron and steel |
| 030402 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2a | Iron and steel |
| 030403 | Combustion plants < 50 MW (boilers) | 1A2a | Iron and steel |
| 030404 | Gas turbines | 1A2a | Iron and steel |
| 030405 | Stationary engines | 1A2a | Iron and steel |
| 030406 | Other stationary equipments | 1A2a | Iron and steel |
| 030500 | Non-Ferrous Metals | 1A2b | Non-ferrous metals |
| 030501 | Combustion plants >= 300 MW (boilers) | 1A2b | Non-ferrous metals |
| 030502 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2b | Non-ferrous metals |
| 030503 | Combustion plants < 50 MW (boilers) | 1A2b | Non-ferrous metals |
| 030504 | Gas turbines | 1A2b | Non-ferrous metals |
| 030505 | Stationary engines | 1A2b | Non-ferrous metals |
| 030506 | Other stationary equipments | 1A2b | Non-ferrous metals |
| 030600 | Chemical and Petrochemical | 1A2c | Chemicals |
| 030601 | Combustion plants >= 300 MW (boilers) | 1A2c | Chemicals |
| 030602 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2c | Chemicals |
| 030603 | Combustion plants < 50 MW (boilers) | 1A2c | Chemicals |
| 030604 | Gas turbines | 1A2c | Chemicals |
| 030605 | Stationary engines | 1A2c | Chemicals |
| 030606 | Other stationary equipments | 1A2c | Chemicals |
| 030700 | Non-Metallic Minerals | 1A2f | Non-metallic minerals |
| 030701 | Combustion plants >= 300 MW (boilers) | 1A2f | Non-metallic minerals |
| 030702 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2f | Non-metallic minerals |
| 030703 | Combustion plants < 50 MW (boilers) | 1A2f | Non-metallic minerals |
| 030704 | Gas turbines | 1A2f | Non-metallic minerals |
| 030705 | Stationary engines | 1A2f | Non-metallic minerals |
| 030706 | Other stationary equipments | 1A2f | Non-metallic minerals |
| 030800 | Mining and Quarrying | 1A2g viii | Other manufacturing industry |
| 030801 | Combustion plants >= 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 030802 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 030803 | Combustion plants < 50 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 030804 | Gas turbines | 1A2g viii | Other manufacturing industry |
| 030805 | Stationary engines | 1A2g viii | Other manufacturing industry |
| 030806 | Other stationary equipments | 1A2g viii | Other manufacturing industry |
| 030900 | Food and Tobacco | 1A2e | Food processing, beverages and tobacco |
| 030901 | Combustion plants >= 300 MW (boilers) | 1A2e | Food processing, beverages and tobacco |
| 030902 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2e | Food processing, beverages and tobacco |
| 030903 | Combustion plants < 50 MW (boilers) | 1A2e | Food processing, beverages and tobacco |
| 030904 | Gas turbines | 1A2e | Food processing, beverages and tobacco |
| 030905 | Stationary engines | 1A2e | Food processing, beverages and tobacco |
| 030906 | Other stationary equipments | 1A2e | Food processing, beverages and tobacco |
| 031000 | Textile and Leather | 1A2g viii | Other manufacturing industry |
| 031001 | Combustion plants >= 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 031002 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 031003 | Combustion plants < 50 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 031004 | Gas turbines | 1A2g viii | Other manufacturing industry |
| 031005 | Stationary engines | 1A2g viii | Other manufacturing industry |
| 031006 | Other stationary equipments | 1A2g viii | Other manufacturing industry |
| 031100 | Paper, Pulp and Print | 1A2d | Pulp, Paper and Print |
| 031101 | Combustion plants >= 300 MW (boilers) | 1A2d | Pulp, Paper and Print |
| 031102 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2d | Pulp, Paper and Print |
| 031103 | Combustion plants < 50 MW (boilers) | 1A2d | Pulp, Paper and Print |
| 031104 | Gas turbines | 1A2d | Pulp, Paper and Print |
| 031105 | Stationary engines | 1A2d | Pulp, Paper and Print |
| 031106 | Other stationary equipments | 1A2d | Pulp, Paper and Print |
| 031200 | Transport Equipment | 1A2g viii | Other manufacturing industry |
| 031201 | Combustion plants >= 300 MW (boilers) | 1A2g viii | Other manufacturing industry |

| | snap_name | CRF id | CRF name |
|---|---|---|---|
| 031202 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 031203 | Combustion plants < 50 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 031204 | Gas turbines | 1A2g viii | Other manufacturing industry |
| 031205 | Stationary engines | 1A2g viii | Other manufacturing industry |
| 031206 | Other stationary equipments | 1A2g viii | Other manufacturing industry |
| 031300 | Machinery | 1A2g viii | Other manufacturing industry |
| 031301 | Combustion plants >= 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 031302 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 031303 | Combustion plants < 50 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 031304 | Gas turbines | 1A2g viii | Other manufacturing industry |
| 031305 | Stationary engines | 1A2g viii | Other manufacturing industry |
| 031306 | Other stationary equipments | 1A2g viii | Other manufacturing industry |
| 031400 | Wood and Wood Products | 1A2g viii | Other manufacturing industry |
| 031401 | Combustion plants >= 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 031402 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 031403 | Combustion plants < 50 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 031404 | Gas turbines | 1A2g viii | Other manufacturing industry |
| 031405 | Stationary engines | 1A2g viii | Other manufacturing industry |
| 031406 | Other stationary equipments | 1A2g viii | Other manufacturing industry |
| 031500 | Construction | 1A2g viii | Other manufacturing industry |
| 031501 | Combustion plants >= 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 031502 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 031503 | Combustion plants < 50 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 031504 | Gas turbines | 1A2g viii | Other manufacturing industry |
| 031505 | Stationary engines | 1A2g viii | Other manufacturing industry |
| 031506 | Other stationary equipments | 1A2g viii | Other manufacturing industry |
| 031600 | Cement production | 1A2f | Non-metallic minerals |
| 031601 | Combustion plants >= 300 MW (boilers) | 1A2f | Non-metallic minerals |
| 031602 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2f | Non-metallic minerals |
| 031603 | Combustion plants < 50 MW (boilers) | 1A2f | Non-metallic minerals |
| 031604 | Gas turbines | 1A2f | Non-metallic minerals |
| 031605 | Stationary engines | 1A2f | Non-metallic minerals |
| 031606 | Other stationary equipments | 1A2f | Non-metallic minerals |
| 032000 | Non-specified (Industry) | 1A2g viii | Other manufacturing industry |
| 032001 | Combustion plants >= 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 032002 | Combustion plants >= 50 and < 300 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 032003 | Combustion plants < 50 MW (boilers) | 1A2g viii | Other manufacturing industry |
| 032004 | Gas turbines | 1A2g viii | Other manufacturing industry |
| 032005 | Stationary engines | 1A2g viii | Other manufacturing industry |
| 032006 | Other stationary equipments | 1A2g viii | Other manufacturing industry |

## Annex 3A-2 Fuel rate

Table 3A-2.1 Fuel consumption rate for stationary combustion plants 1990-2018, PJ.

| Sum of Fuel_rate_PJ | | | Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **fuel_type** | **fuel_id** | **fuel_gr_abbr** | **1990** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** |
| SOLID | 101A | Other solid fossil | | | | | | | | | | |
| | 102A | Coal | 253.4 | 344.3 | 286.8 | 300.8 | 323.4 | 270.3 | 371.9 | 276.3 | 234.3 | 196.5 |
| | 103A | Fly ash (fossil) | | | | | | | | | | |
| | 106A | BKB | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 |
| | 107A | Coke oven coke | 1.3 | 1.4 | 1.2 | 1.2 | 1.2 | 1.3 | 1.2 | 1.3 | 1.3 | 1.4 |
| LIQUID | 110A | Petroleum coke | 4.5 | 4.4 | 4.3 | 5.7 | 7.5 | 5.3 | 5.9 | 6.0 | 5.3 | 6.8 |
| | 203A | Residual oil | 32.1 | 37.0 | 37.3 | 32.5 | 46.6 | 33.3 | 38.1 | 26.7 | 29.5 | 23.0 |
| | 204A | Gas oil | 63.9 | 67.6 | 58.7 | 64.7 | 56.7 | 56.5 | 60.9 | 54.1 | 51.5 | 50.6 |
| | 206A | Kerosene | 5.1 | 1.0 | 0.8 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.4 | 0.3 |
| | 225A | Orimulsion | | | | | | 19.9 | 36.8 | 40.5 | 32.6 | 34.2 |
| | 303A | LPG | 3.0 | 2.8 | 2.5 | 2.6 | 2.6 | 2.8 | 3.1 | 2.6 | 2.8 | 2.5 |
| | 308A | Refinery gas | 14.2 | 14.5 | 14.9 | 15.4 | 16.4 | 20.8 | 21.4 | 16.9 | 15.2 | 15.7 |
| GAS | 301A | Natural gas | 76.1 | 86.1 | 90.5 | 102.5 | 114.6 | 132.7 | 156.3 | 164.5 | 178.7 | 187.9 |
| WASTE | 114A | Waste | 15.5 | 16.7 | 17.8 | 19.4 | 20.3 | 22.9 | 25.0 | 26.8 | 26.6 | 29.1 |
| | 115A | Industrial waste | | | | | | | | | | |
| BIOMASS | 111A | Wood | 16.7 | 17.9 | 18.6 | 20.1 | 19.7 | 19.5 | 20.7 | 20.5 | 19.7 | 20.3 |
| | 117A | Straw | 12.5 | 13.3 | 13.9 | 13.4 | 12.7 | 13.1 | 13.5 | 13.9 | 13.9 | 13.7 |
| | | Wood pellets | 1.6 | 2.1 | 2.5 | 2.1 | 2.1 | 2.3 | 2.7 | 2.9 | 3.2 | 4.0 |
| | 215A | Bio oil | 0.7 | 0.7 | 0.7 | 0.8 | 0.2 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 |
| | 309A | Biogas | 0.8 | 0.9 | 0.9 | 1.1 | 1.3 | 1.8 | 2.0 | 2.4 | 2.7 | 2.7 |
| | 310A | Bio gasification gas | | | | | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 315A | Bio natural gas | | | | | | | | | | |
| **Total** | | | 501.4 | 611.0 | 551.5 | 583.1 | 626.2 | 603.5 | 760.1 | 655.9 | 617.8 | 588.8 |

| Sum of Fuel_rate_PJ | | | Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **fuel_type** | **fuel_id** | **fuel_gr_abbr** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
| SOLID | 101A | Other solid fossil | | | | | | | | | | 0.0 |
| | 102A | Coal | 164.7 | 174.3 | 174.7 | 239.0 | 182.5 | 154.0 | 232.0 | 194.1 | 170.5 | 167.7 |
| | 103A | Fly ash (fossil) | | | | | | | | | | |
| | 106A | BKB | 0.0 | 0.0 | 0.0 | 0.0 | | | | | 0.0 | 0.0 |
| | 107A | Coke oven coke | 1.2 | 1.1 | 1.1 | 1.0 | 1.1 | 1.0 | 1.0 | 1.1 | 1.0 | 0.8 |
| LIQUID | 110A | Petroleum coke | 6.8 | 7.8 | 7.8 | 8.0 | 8.4 | 8.1 | 8.5 | 9.2 | 6.9 | 5.9 |
| | 203A | Residual oil | 18.0 | 20.2 | 24.8 | 27.3 | 23.5 | 21.1 | 25.4 | 19.3 | 15.3 | 14.2 |
| | 204A | Gas oil | 44.2 | 46.5 | 41.4 | 41.6 | 38.4 | 34.4 | 29.8 | 25.5 | 25.2 | 27.6 |
| | 206A | Kerosene | 0.2 | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 |
| | 225A | Orimulsion | 34.1 | 30.2 | 23.8 | 1.9 | 0.0 | | | | | |
| | 303A | LPG | 2.4 | 2.1 | 2.0 | 2.0 | 2.1 | 2.1 | 2.2 | 1.8 | 1.6 | 1.5 |
| | 308A | Refinery gas | 15.6 | 15.8 | 15.2 | 16.6 | 15.9 | 15.3 | 16.1 | 15.9 | 14.1 | 15.0 |
| GAS | 301A | Natural gas | 186.1 | 193.8 | 193.6 | 195.9 | 195.1 | 187.4 | 191.1 | 171.0 | 173.3 | 166.1 |
| WASTE | 114A | Waste | 29.8 | 31.3 | 33.3 | 35.1 | 35.3 | 35.8 | 36.9 | 38.1 | 39.6 | 37.6 |
| | 115A | Industrial waste | 0.5 | 1.4 | 1.9 | 1.5 | 2.0 | 2.0 | 1.5 | 1.6 | 2.0 | 1.7 |
| BIOMASS | 111A | Wood | 22.3 | 23.7 | 23.7 | 29.1 | 31.1 | 33.7 | 36.5 | 43.8 | 45.1 | 45.9 |
| | 117A | Straw | 12.2 | 13.7 | 15.7 | 16.9 | 17.9 | 18.5 | 18.5 | 18.8 | 15.9 | 17.4 |
| | | Wood pellets | 5.1 | 7.1 | 7.9 | 9.8 | 12.8 | 16.1 | 15.6 | 16.5 | 18.5 | 20.1 |
| | 215A | Bio oil | 0.0 | 0.2 | 0.1 | 0.4 | 0.6 | 0.8 | 1.1 | 1.2 | 1.8 | 1.7 |
| | 309A | Biogas | 2.9 | 3.0 | 3.4 | 3.6 | 3.7 | 3.8 | 3.9 | 3.9 | 3.9 | 4.2 |
| | 310A | Bio gasification gas | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.3 |
| | 315A | Bio natural gas | | | | | | | | | | |
| **Total** | | | 546.5 | 572.7 | 570.5 | 630.1 | 570.7 | 534.4 | 620.4 | 562.1 | 535.0 | 527.8 |

| Sum of Fuel_rate_PJ | | | Year | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **fuel_type** | **fuel_id** | **fuel_gr_abbr** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** |
| SOLID | 101A | Other solid fossil | 0.0 | 0.0 | 0.0 | 0.0 | | | | | |
| | 102A | Coal | 163.0 | 135.5 | 106.2 | 135.0 | 107.0 | 76.0 | 88.2 | 65.8 | 67.2 |
| | 103A | Fly ash (fossil) | | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 |
| | 106A | BKB | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 0.0 | | |
| | 107A | Coke oven coke | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.5 | 0.3 | 0.3 | 0.4 |
| LIQUID | 110A | Petroleum coke | 5.1 | 6.5 | 6.7 | 6.1 | 6.6 | 6.6 | 7.6 | 7.9 | 6.9 |
| | 203A | Residual oil | 12.8 | 7.8 | 7.2 | 5.5 | 4.5 | 4.2 | 4.1 | 4.1 | 3.2 |
| | 204A | Gas oil | 27.2 | 21.2 | 17.7 | 15.8 | 9.5 | 9.8 | 9.5 | 8.7 | 9.3 |
| | 206A | Kerosene | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| | 225A | Orimulsion | | | | | | | | | |
| | 303A | LPG | 1.5 | 1.5 | 1.7 | 1.5 | 1.2 | 1.8 | 2.0 | 2.2 | 2.2 |
| | 308A | Refinery gas | 14.3 | 13.7 | 14.8 | 14.8 | 15.4 | 16.2 | 14.4 | 15.6 | 15.0 |
| GAS | 301A | Natural gas | 186.0 | 157.5 | 147.3 | 139.5 | 119.4 | 120.7 | 122.5 | 116.5 | 113.0 |
| WASTE | 114A | Waste | 36.8 | 36.7 | 35.9 | 35.7 | 36.9 | 37.7 | 37.8 | 37.8 | 36.4 |
| | 115A | Industrial waste | 1.4 | 1.7 | 1.5 | 1.8 | 1.8 | 2.5 | 2.9 | 3.0 | 3.9 |
| BIOMASS | 111A | Wood | 51.3 | 48.8 | 48.6 | 46.4 | 45.0 | 53.1 | 53.9 | 57.2 | 61.6 |
| | 117A | Straw | 23.3 | 20.2 | 18.3 | 20.3 | 18.6 | 19.8 | 19.7 | 20.2 | 17.6 |
| | 122A | Wood pellets | 29.9 | 30.0 | 33.2 | 34.6 | 36.3 | 36.5 | 44.3 | 57.4 | 55.2 |
| | 215A | Bio oil | 2.0 | 0.8 | 1.1 | 0.9 | 0.7 | 0.6 | 0.3 | 0.2 | 0.2 |
| | 309A | Biogas | 4.3 | 4.1 | 4.4 | 4.6 | 5.2 | 5.3 | 5.9 | 5.9 | 6.4 |
| | 310A | Bio gasification gas | 0.2 | 0.3 | 0.4 | 0.4 | 0.4 | 0.5 | 0.5 | 1.0 | 1.4 |
| | 315A | Bio natural gas | | | | | 0.3 | 1.0 | 3.1 | 5.1 | 7.1 |
| **Total** | | | 559.9 | 487.2 | 445.7 | 463.6 | 409.7 | 392.8 | 417.0 | 409.1 | 407.3 |

Table 3A-2.2 Detailed fuel consumption data for stationary combustion plants, 1990-2018, PJ.
This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

# Annex 3A-3 Default Lower Calorific Value (LCV) of fuels and fuel correspondence list

Table 3A-3.1 Time series for calorific values of fuels (DEA, 2019a).

| | | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Crude Oil, Average | GJ per tonne | 42.40 | 42.40 | 42.40 | 42.70 | 42.70 | 42.70 | 42.70 | 43.00 | 43.00 | 43.00 |
| Crude Oil, Golf | GJ per tonne | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 |
| Crude Oil, North Sea | GJ per tonne | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 43.00 | 43.00 | 43.00 |
| Refinery Feedstocks | GJ per tonne | 41.60 | 41.60 | 41.60 | 41.60 | 41.60 | 41.60 | 41.60 | 42.70 | 42.70 | 42.70 |
| Refinery Gas | GJ per tonne | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 |
| LPG | GJ per tonne | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 |
| Naphtha (LVN) | GJ per tonne | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 |
| Motor Gasoline | GJ per tonne | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 |
| Aviation Gasoline | GJ per tonne | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 |
| JP4 | GJ per tonne | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 |
| Other Kerosene | GJ per tonne | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 |
| JP1 | GJ per tonne | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 |
| Gas/Diesel Oil | GJ per tonne | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 |
| Fuel Oil | GJ per tonne | 40.40 | 40.40 | 40.40 | 40.40 | 40.40 | 40.40 | 40.70 | 40.65 | 40.65 | 40.65 |
| Orimulsion | GJ per tonne | 27.60 | 27.60 | 27.60 | 27.60 | 27.60 | 28.13 | 28.02 | 27.72 | 27.84 | 27.58 |
| Petroleum Coke | GJ per tonne | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 |
| Waste Oil | GJ per tonne | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 |
| White Spirit | GJ per tonne | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 |
| Bitumen | GJ per tonne | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 |
| Lubricants | GJ per tonne | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 |
| Natural Gas | GJ per 1000 $Nm^3$ | 39.00 | 39.00 | 39.00 | 39.30 | 39.30 | 39.30 | 39.30 | 39.60 | 39.90 | 40.00 |
| Town Gas | GJ per 1000 $m^3$ | | | | | | | 17.00 | 17.00 | 17.00 | 17.00 |
| Electricity Plant Coal | GJ per tonne | 25.30 | 25.40 | 25.80 | 25.20 | 24.50 | 24.50 | 24.70 | 24.96 | 25.00 | 25.00 |
| Other Hard Coal | GJ per tonne | 26.10 | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 |
| Coke | GJ per tonne | 31.80 | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 |
| Brown Coal Briquettes | GJ per tonne | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 |
| Straw | GJ per tonne | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 |
| Wood Chips | GJ per Cubic metre | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 |
| Wood Chips | GJ per $m^3$ | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 |
| Firewood, Hardwood | GJ per $m^3$ | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 |
| Firewood, Conifer | GJ per tonne | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 |
| Wood Pellets | GJ per tonne | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 |
| Wood Waste | GJ per Cubic metre | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 |
| Wood Waste | GJ per 1000 $m^3$ | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 |
| Biogas | GJ per tonne | | | | | | | | 23.00 | 23.00 | 23.00 |
| Wastes | GJ per tonne | 8.20 | 8.20 | 9.00 | 9.40 | 9.40 | 10.00 | 10.50 | 10.50 | 10.50 | 10.50 |
| Bioethanol | GJ per tonne | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 |
| Liquid Biofuels | GJ per tonne | 37.60 | 37.60 | 37.60 | 37.60 | 37.60 | 37.60 | 37.60 | 37.60 | 37.60 | 37.60 |
| Bio Oil | GJ per tonne | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 |

| *Continued* | | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Crude Oil, Average | GJ per tonne | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 |
| Crude Oil, Golf | GJ per tonne | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 |
| Crude Oil, North Sea | GJ per tonne | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 |
| Refinery Feedstocks | GJ per tonne | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 |
| Refinery Gas | GJ per tonne | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 |
| LPG | GJ per tonne | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 |
| Naphtha (LVN) | GJ per tonne | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 |
| Motor Gasoline | GJ per tonne | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 |
| Aviation Gasoline | GJ per tonne | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 |
| JP4 | GJ per tonne | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 |
| Other Kerosene | GJ per tonne | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 |
| JP1 | GJ per tonne | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 |
| Gas/Diesel Oil | GJ per tonne | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 |
| Fuel Oil | GJ per tonne | 40.65 | 40.65 | 40.65 | 40.65 | 40.65 | 40.65 | 40.65 | 40.65 | 40.65 | 40.65 |
| Orimulsion | GJ per tonne | 27.62 | 27.64 | 27.71 | 27.65 | 27.65 | 27.65 | 27.65 | 27.65 | 27.65 | 27.65 |
| Petroleum Coke | GJ per tonne | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 |
| Waste Oil | GJ per tonne | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 |
| White Spirit | GJ per tonne | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 |
| Bitumen | GJ per tonne | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 |
| Lubricants | GJ per tonne | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 |
| Natural Gas | GJ per 1000 $Nm^3$ | 40.15 | 39.99 | 40.06 | 39.94 | 39.77 | 39.67 | 39.54 | 39.59 | 39.48 | 39.46 |
| Town Gas | GJ per 1000 $m^3$ | 17.01 | 16.88 | 17.39 | 16.88 | 17.58 | 17.51 | 17.20 | 17.14 | 15.50 | 21.29 |
| Electricity Plant Coal | GJ per tonne | 24.80 | 24.90 | 25.15 | 24.73 | 24.60 | 24.40 | 24.80 | 24.40 | 24.30 | 24.60 |
| Other Hard Coal | GJ per tonne | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 | 25.81 | 25.13 |
| Coke | GJ per tonne | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 |
| Brown Coal Briquettes | GJ per tonne | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 |
| Straw | GJ per tonne | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 |
| Wood Chips | GJ per Cubic metre | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 |
| Wood Chips | GJ per $m^3$ | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 |
| Firewood, Hardwood | GJ per $m^3$ | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 |
| Firewood, Conifer | GJ per tonne | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 |
| Wood Pellets | GJ per tonne | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 |
| Wood Waste | GJ per Cubic metre | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 |
| Wood Waste | GJ per 1000 $m^3$ | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 |
| Biogas | GJ per tonne | 23.00 | 23.00 | 23.00 | 23.00 | 23.00 | 23.00 | 23.00 | 23.00 | 23.00 | 23.00 |
| Wastes | GJ per tonne | 10.50 | 10.50 | 10.50 | 10.50 | 10.50 | 10.50 | 10.50 | 10.50 | 10.50 | 10.50 |
| Bioethanol | GJ per tonne | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 |
| Liquid Biofuels | GJ per tonne | 37.60 | 37.60 | 37.60 | 37.60 | 37.60 | 37.60 | 37.60 | 37.60 | 37.50 | 37.50 |
| Bio Oil | GJ per tonne | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 |

| *Continued* | | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| Crude Oil, Average | GJ per tonne | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 |
| Crude Oil, Golf | GJ per tonne | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 | 41.80 |
| Crude Oil, North Sea | GJ per tonne | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 |
| Refinery Feedstocks | GJ per tonne | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 |
| Refinery Gas | GJ per tonne | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 |
| LPG | GJ per tonne | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 | 46.00 |
| Naphtha (LVN) | GJ per tonne | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 | 44.50 |
| Motor Gasoline | GJ per tonne | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 |
| Aviation Gasoline | GJ per tonne | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 |
| JP4 | GJ per tonne | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 | 43.80 |
| Other Kerosene | GJ per tonne | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 |
| JP1 | GJ per tonne | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 |
| Gas/Diesel Oil | GJ per tonne | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 | 42.70 |
| Fuel Oil | GJ per tonne | 40.65 | 40.65 | 40.65 | 40.65 | 40.65 | 40.65 | 40.65 | 40.65 | 40.65 |
| Orimulsion | GJ per tonne | 27.65 | 27.65 | 27.65 | 27.65 | 27.65 | 27.65 | 27.65 | 27.65 | 27.65 |
| Petroleum Coke | GJ per tonne | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 | 31.40 |
| Waste Oil | GJ per tonne | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 |
| White Spirit | GJ per tonne | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 | 43.50 |
| Bitumen | GJ per tonne | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 | 39.80 |
| Lubricants | GJ per tonne | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 | 41.90 |
| Natural Gas | GJ per 1000 $Nm^3$ | 39.46 | 39.51 | 39.55 | 38.99 | 39.53 | 39.64 | 39.63 | 39.66 | 39.59 |
| Town Gas | GJ per 1000 $m^3$ | 21.35 | 21.37 | 19.30 | 19.31 | 20.20 | 19.80 | 20.28 | 20.80 | 20.82 |
| Electricity Plant Coal | GJ per tonne | 24.44 | 24.38 | 24.23 | 24.49 | 24.70 | 24.10 | 24.29 | 24.33 | 24.13 |
| Other Hard Coal | GJ per tonne | 24.44 | 24.38 | 24.23 | 24.49 | 24.70 | 24.10 | 26.10 | 26.88 | 26.64 |
| Coke | GJ per tonne | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 | 29.30 |
| Brown Coal Briquettes | GJ per tonne | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 | 18.30 |
| Straw | GJ per tonne | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 | 14.50 |
| Wood Chips | GJ per Cubic metre | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 | 2.80 |
| Wood Chips | GJ per $m^3$ | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 | 9.30 |
| Firewood, Hardwood | GJ per $m^3$ | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 |
| Firewood, Conifer | GJ per tonne | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 |
| Wood Pellets | GJ per tonne | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 |
| Wood Waste | GJ per Cubic metre | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 |
| Wood Waste | GJ per 1000 $m^3$ | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 |
| Biogas | GJ per tonne | 23.00 | 23.00 | 23.00 | 23.00 | 23.00 | 23.00 | 23.00 | 23.00 | 23.00 |
| Wastes | GJ per tonne | 10.50 | 10.50 | 10.50 | 10.60 | 10.60 | 10.60 | 10.60 | 10.60 | 10.60 |
| Bioethanol | GJ per tonne | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 | 26.70 |
| Liquid Biofuels | GJ per tonne | 37.50 | 37.50 | 37.50 | 37.50 | 37.50 | 37.50 | 37.50 | 37.50 | 37.50 |
| Bio Oil | GJ per tonne | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 | 37.20 |

Table 3A-3.2 Fuel category correspondence list, DEA, DCE and Climate Convention reporting (CRF).

| **Danish Energy Agency** | **DCE Emission database** | **IPCC fuel category** |
|---|---|---|
| Other Hard Coal | Coal | Solid |
| Coke | Coke oven coke | Solid |
| Electricity Plant Coal | Coal | Solid |
| Brown Coal Briquettes | BKB | Solid |
| - | Other solid fossil | Solid |
| - | Fly ash fossil | Solid |
| Orimulsion | Orimulsion | Liquid |
| Petroleum Coke | Petroleum coke | Liquid |
| Fuel Oil | Residual oil | Liquid |
| Waste Oil | Residual oil | Liquid |
| Gas/Diesel Oil | Gas oil | Liquid |
| Other Kerosene | Kerosene | Liquid |
| LPG | LPG | Liquid |
| Refinery Gas | Refinery gas | Liquid |
| Town Gas | Natural gas | Gas |
| Natural Gas | Natural gas | Gas |
| Straw | Straw | Biomass |
| Wood Waste | Wood | Biomass |
| Wood Pellets | Wood pellets | Biomass |
| Wood Chips | Wood | Biomass |
| Firewood, Hardwood & Conifer | Wood | Biomass |
| Waste Combustion (biomass) | Municipal wastes | Biomass |
| Bio fuels | Liquid biofuels | Biomass |
| Biogas | Biogas | Biomass |
| Biogas, other | Biogas | Biomass |
| Biogas, landfill | Biogas | Biomass |
| Biogas, sewage sludge | Biogas | Biomass |
| (Wood applied in gas engines) | Biomass gasification gas | Biomass |
| Biogas upgraded for distribution in the natural gas grid | Bio natural gas | Biomass |
| Biogas distributed in the town gas grid | Biogas | Biomass |
| Waste Combustion (fossil) | Fossil waste | Other fuel |

## Annex 3A-4 Emission factors

Table 3A-4.1 $CO_2$ emission factors, 2018.

| Fuel | Emission factor, kg per GJ | | Reference type | IPCC fuel category |
|---|---|---|---|---|
| | Biomass | Fossil fuel | | |
| Coal | | 94.04 1) | Country specific | Solid |
| Brown coal briquettes | | 97.5 | IPCC (2006) | Solid |
| Coke oven coke | | 107 3) | IPCC (2006) | Solid |
| Other solid fossil fuels 6) | | 118 1) | Country specific | Solid |
| Fly ash fossil (from coal) | | 94.04 | Country specific | Solid |
| Petroleum coke | | 93 3) | Country-specific | Liquid |
| Residual oil | | 79.42 1) | Country-specific | Liquid |
| Gas oil | | 74.1 1) | Country-specific | Liquid |
| Kerosene | | 71.9 | IPCC (2006) | Liquid |
| Orimulsion | | 80 2) | Country-specific | Liquid |
| LPG | | 63.1 | IPCC (2006) | Liquid |
| Refinery gas | | 56.144 | Country-specific | Liquid |
| Natural gas, offshore gas turbines | | 57.639 | Country-specific | Gas |
| Natural gas, other | | 56.89 | Country-specific | Gas |
| Waste | 63.3 3)4) | + 42.5 1)3)4) | Country-specific | Biomass and Other fuels |
| Straw | 100 | | IPCC (2006) | Biomass |
| Wood | 112 | | IPCC (2006) | Biomass |
| Wood pellets | 112 | | IPCC (2006) | Biomass |
| Bio oil | 70.8 | | IPCC (2006) | Biomass |
| Biogas | 84.1 | | Country-specific | Biomass |
| Biomass gasification gas | 142.9 5) | | Country-specific | Biomass |
| Bio natural gas | 55.55 | | Country-specific | Biomass |

1) Plant specific data from EU ETS incorporated for individual plants.

2) Not applied in 2018. Orimulsion was applied in Denmark in 1995 – 2004.

3) Plant specific data from EU ETS incorporated for cement industry and sugar, lime and mineral wool production.

4) The emission factor for waste is (42.5+63.3) kg $CO_2$ per GJ waste. The fuel consumption and the $CO_2$ emission have been disaggregated to the two IPCC fuel categories Biomass and Other fossil fuels in CRF. The corresponding IEF for $CO_2$, Other fuels is 94.44 kg $CO_2$ per GJ fossil waste (not including plant specific data).

5) Includes a high content of $CO_2$ in the gas.

6) Anodic carbon. Not applied in Denmark in 2018.

Time series have been estimated for:

- Coal
- Residual oil
- Refinery gas
- Natural gas applied in offshore gas turbines
- Natural gas, other
- Waste, fossil part
- Industrial waste, biomass part

For all other fuels the same emission factor has been applied for 1990-2018.

Table 3A-4.2 $CO_2$ emission factors, time series.

| Year | Coal, kg per GJ | Residual oil, kg per GJ | Refinery gas, kg per GJ | Natural gas, offshore gas turbines, kg per GJ | Natural gas, other, kg per GJ | Waste, fossil part | Industrial waste, biomass part |
|---|---|---|---|---|---|---|---|
| 1990 | 94 | 78.7 | 57.6 | 57.469 | 56.9 | 37 | 86.7 |
| 1991 | 94 | 78.7 | 57.6 | 57.469 | 56.9 | 37 | 86.7 |
| 1992 | 94 | 78.7 | 57.6 | 57.469 | 56.9 | 37 | 84.2 |
| 1993 | 94 | 78.7 | 57.6 | 57.469 | 56.9 | 37 | 83.0 |
| 1994 | 94 | 78.7 | 57.6 | 57.469 | 56.9 | 37 | 83.0 |
| 1995 | 94 | 78.7 | 57.6 | 57.469 | 56.9 | 37 | 81.1 |
| 1996 | 94 | 78.7 | 57.6 | 57.469 | 56.9 | 37 | 79.6 |
| 1997 | 94 | 78.7 | 57.6 | 57.469 | 56.9 | 37 | 79.6 |
| 1998 | 94 | 78.7 | 57.6 | 57.469 | 56.9 | 37 | 79.6 |
| 1999 | 94 | 78.7 | 57.6 | 57.469 | 56.9 | 37 | 79.6 |
| 2000 | 94 | 78.7 | 57.6 | 57.469 | 57.1 | 37 | 79.6 |
| 2001 | 94 | 78.7 | 57.6 | 57.469 | 57.25 | 37 | 79.6 |
| 2002 | 94 | 78.7 | 57.6 | 57.469 | 57.28 | 37 | 79.6 |
| 2003 | 94 | 78.7 | 57.6 | 57.469 | 57.19 | 37 | 79.6 |
| 2004 | 94 | 78.7 | 57.6 | 57.469 | 57.12 | 37 | 79.6 |
| 2005 | 94 | 78.7 | 57.6 | 57.469 | 56.96 | 37 | 79.6 |
| 2006 | 94.4 | 78.6 | 57.812 | 57.879 | 56.78 | 37 | 79.6 |
| 2007 | 94.3 | 78.5 | 57.848 | 57.784 | 56.78 | 37 | 79.6 |
| 2008 | 94.0 | 78.5 | 57.948 | 56.959 | 56.77 | 37 | 79.6 |
| 2009 | 93.6 | 78.9 | 56.817 | 57.254 | 56.69 | 37 | 79.6 |
| 2010 | 93.6 | 79.2 | 57.134 | 57.314 | 56.74 | 37 | 79.6 |
| 2011 | 94.73 | 79.25 | 57.861 | 57.379 | 56.97 | 37.5 | 79.6 |
| 2012 | 94.25 | 79.21 | 58.108 | 57.423 | 57.03 | 40.0 | 79.6 |
| 2013 | 93.95 | 79.28 | 58.274 | 57.295 | 56.79 | 42.5 | 79.6 |
| 2014 | 94.17 | 79.49 | 57.620 | 57.381 | 56.95 | 42.5 | 79.6 |
| 2015 | 94.46 | 79.17 | 57.508 | 57.615 | 57.06 | 42.5 | 79.6 |
| 2016 | 94.95 | 79.29 | 57.335 | 57.704 | 57.01 | 42.5 | 79.6 |
| 2017 | 94.37 | 79.19 | 57.109 | 57.628 | 57.00 | 42.5 | 79.6 |
| 2018 | 94.04 | 79.42 | 56.144 | 57.639 | 56.89 | 42.5 | 79.6 |

Table 3A-4.3 $CH_4$ emission factors and references, 2018.

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| SOLID | Coal | 1A1a | Public electricity and heat production | 0101 0102 | 0.9 | IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Pulverised bituminous coal combustion, Wet bottom. |
| | | 1A2 a-g | Industry | 03 | 10 | IPCC (2006), Tier 1, Table 2-3, Manufacturing industries. |
| | | 1A4b i | Residential | 0202 | 300 | IPCC (2006), Tier 1, Table 2.5, Residential, Bituminous coal. |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 10 | IPCC (2006), Tier 1, Table 2-4, Commercial, coal.[1)] |
| | BKB | 1A4b i | Residential | 0202 | 300 | IPCC (2006), Tier 1, Table 2-5, Residential, brown coal briquettes |
| | Coke oven coke | 1A2 a-g | Industry | 03 | 10 | IPCC (2006), Tier 1, Table 2-4, Commercial, coke oven coke. |
| | | 1A4b i | Residential | 0202 | 300 | IPCC (2006), Tier 1, Table 2-5, Residential, coke oven coke. |
| | Anodic carbon | 1A2 a-g | Industry | 03 | 10 | IPCC (2006), Tier 1, Table 2-3, Manufacturing industries. |
| | Fossil fly ash | 1A1a | Public electricity and heat production | 0101 | 0.9 | IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Pulverised bituminous coal combustion, Wet bottom. |
| LIQUID | Petroleum coke | 1A2 a-g | Industry | 03 | 3 | IPCC (2006), Tier 1, Table 2-3, Industry, petroleum coke. |
| | | 1A4a | Commercial/ Institutional | 0201 | 10 | IPCC (2006), Tier 1, Table 2-4, Commercial, Petroleum coke. |
| | | 1A4b | Residential | 0202 | 10 | IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, Petroleum coke. |
| | | 1A4c | Agriculture/ Forestry | 0203 | 10 | IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, Petroleum coke. |
| | Residual oil | 1A1a | Public electricity and heat production | 010101 | 0.8 | IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Residual fuel oil. |
| | | | | 010102 010103 | 1.3 | Nielsen et al. (2010a) |
| | | | | 010104 | 3 | IPCC (2006), Tier 1, Table 2-2, Energy industries, residual oil. |
| | | | | 010105 | 4 | IPCC (2006), Tier 3, Table 2-6, Utility, Large diesel engines |
| | | | | 010203 | 0.8 | IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Residual fuel oil. |
| | | 1A1b | Petroleum refining | 010306 | 3 | IPCC (2006), Tier 1, Table 2-2, Energy industries, residual fuel oil. |
| | | 1A2 a-g | Industry | 03 | 1.3 | Nielsen et al. (2010a) |
| | | | | Engines | 4 | IPCC (2006), Tier 3, Table 2-6, Utility, Large diesel engines |
| | | 1A4a | Commercial/ Institutional | 0201 | 1.4 | IPCC (2006), Tier 3, Table 2-10, Commercial, residual fuel oil boilers. |
| | | 1A4b | Residential | 0202 | 1.4 | IPCC (2006), Tier 3, Table 2-9, Residential, residual fuel oil. |
| | | 1A4c | Agriculture/ Forestry | 0203 | 1.4 | IPCC (2006), Tier 3, Table 2-10, Commercial, residual fuel oil boilers.[1)]. |
| | Gas oil | 1A1a | Public electricity and heat production | 010101 010102 010103 | 0.9 | IPCC (2006), Tier 3, Table 2-6, Utility, gas oil, boilers. |
| | | | | 010104 | 3 | IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil. |
| | | | | 010105 | 24 | Nielsen et al. (2010a) |
| | | | | 010202 010203 | 0.9 | IPCC (2006), Tier 3, Table 2-6, Utility, gas oil, boilers. |
| | | 1A1b | Petroleum refining | 010306 | 3 | IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil. |
| | | 1A1c | Oil and gas extraction | 010504 | 3 | IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil. |
| | | 1A2 a-g | Industry | 03 | 0.2 | IPCC (2006), Tier 3, Table 2-7, Industry, gas oil, boilers. |
| | | | | Turbines | 3 | IPCC (2006), Tier 1, Table 2-3, Industry, gas oil. |
| | | | | Engines | 24 | Nielsen et al. (2010a) |

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| | | 1A4a | Commercial/ Institutional | 0201 | 0.7 | IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil. |
| | | | | 020105 | 24 | Nielsen et al. (2010a) |
| | | 1A4b i | Residential | 0202 | 0.7 | IPCC (2006), Tier 3, Table 2.9, Residential, gas oil. |
| | | | | 020204 | 24 | Nielsen et al. (2010a) |
| | | 1A4c | Agriculture/ Forestry | 0203 | 0.7 | IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil[1). |
| | | | | 020304 | 24 | Nielsen et al. (2010a) |
| | Kerosene | 1A2 a-g | Industry | 03 | 3 | IPCC (2006), Tier 1, Table 2-3, Industry, other kerosene. |
| | | 1A4a | Commercial/ Institutional | 0201 | 10 | IPCC (2006), Tier 1, Table 2-4, Commercial, other kerosene. |
| | | 1A4b i | Residential | 0202 | 10 | IPCC (2006), Tier 1, Table 2-5, Residential/agricultural, other kerosene. |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 10 | IPCC (2006), Tier 1, Table 2-5, Residential/agricultural, other kerosene. |
| | LPG | 1A1a | Public electricity and heat production | 0101<br>0102 | 1 | IPCC (2006), Tier 1, Table 2-2, Energy Industries, LPG. |
| | | 1A1b | Petroleum refining | 0103 | 1 | IPCC (2006), Tier 1, Table 2-2, Energy Industries, LPG. |
| | | 1A2 a-g | Industry | 03 | 1 | IPCC (2006), Tier 1, Table 2-3, Industry, LPG |
| | | 1A4a | Commercial/ Institutional | 0201 | 5 | IPCC (2006), Tier 1, Table 2-4, Commercial, LPG. |
| | | 1A4b i | Residential | 0202 | 5 | IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, LPG. |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 5 | IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, LPG. |
| | Refinery gas | 1A1b | Petroleum refining | 010304 | 1.7 | Assumed equal to natural gas fuelled gas turbines. Nielsen et al. (2010a) |
| | | | | 010306 | 1 | IPCC (2006), Tier 1, Table 2-2, refinery gas. |
| GAS | Natural gas | 1A1a | Public electricity and heat production | 010101<br>010102<br>010103 | 1 | IPCC (2006), Tier 3, Table 2-6, Utility, natural gas, boilers. |
| | | | | 010104 | 1.7 | Nielsen et al. (2010a) |
| | | | | 010105 | 481 | Nielsen et al. (2010a) |
| | | | | 010202<br>010203 | 1 | IPCC (2006), Tier 3, Table 2-6, Utility, natural gas, boilers. |
| | | 1A1b | Petroleum refining | 010306 | 1 | Assumed equal to industrial boilers. |
| | | 1A1c | Oil and gas extraction | 010503 | 1 | Assumed equal to industrial boilers. |
| | | | | 010504 | 1.7 | Nielsen et al. (2010a) |
| | | 1A2 a-g | Industry | Other | 1 | IPCC (2006), Tier 3, Table 2-7, Industry, natural gas boilers. |
| | | | | Gas turbines | 1.7 | Nielsen et al. (2010a) |
| | | | | Engines | 481 | Nielsen et al. (2010a) |
| | | 1A4a | Commercial/ Institutional | 0201 | 1 | IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers. |
| | | | | 020105 | 481 | Nielsen et al. (2010a) |
| | | 1A4b i | Residential | 0202 | 1 | IPCC (2006), Tier 3, Table 2-9. Residential, natural gas boilers. |
| | | | | 020204 | 481 | Nielsen et al. (2010a) |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 1 | IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers[1). |
| | | | | 020304 | 481 | Nielsen et al. (2010a) |
| WASTE | Waste | 1A1a | Public electricity and heat production | 0101<br>0102 | 0.34 | Nielsen et al. (2010a) |
| | | 1A2 a-g | Industry | 03 | 30 | IPCC (2006), Tier 1, Table 2-3, Industry, municipal wastes. |
| | | 1A4a | Commercial/ Institutional | 0201 | 30 | IPCC (2006), Tier 1, Table 2-3, Industry, municipal wastes [2). |
| | Industrial waste | 1A2f | Industry | 0316 | 30 | IPCC (2006), Tier 1, Table 2-3, Industry, industrial wastes. |
| BIO-MASS | Wood | 1A1a | Public electricity and heat production | 0101 | 3.1 | Nielsen et al. (2010a) |

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| | | | | 0102 | 11 | IPCC (2006), Tier 3, Table 2-6, Utility boilers, wood |
| | | 1A2 a-g | Industry | 03 | 11 | IPCC (2006), Tier 3, Table 2-7, Industry, wood, boilers. |
| | | 1A4a | Commercial/ Institutional | 0201 | 11 | IPCC (2006), Tier 3, Table 2-10, Commercial, wood. |
| | | 1A4b i | Residential | 0202 | 110.77 | DCE estimate based on technology distribution, Nielsen et al. (2020) [3] |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 11 | IPCC (2006), Tier 3, Table 2-10, Commercial, wood.[1]. |
| | Straw | 1A1a | Public electricity and heat production | 0101 | 0.47 | Nielsen et al. (2010a) |
| | | | | 0102 | 30 | IPCC (2006), Tier 1, Table 2-2, Energy industries, other primary solid biomass |
| | | 1A4b i | Residential | 0202 | 300 | IPCC (2006), Tier 1, Table 2-5, Residential, other primary solid biomass. |
| | | 1A4c i | Agriculture/ Forestry | 020300 | 300 | IPCC (2006), Tier 1, Table 2-5, Agriculture, other primary solid biomass. |
| | | | | 020302 | 30 | IPCC (2006), Tier 1, Table 2-2, Energy industries, other primary solid biomass (large agricultural plants considered equal to this plant category) |
| | Wood pellets | 1A1a | Public electricity and heat production | 0101 | 3.1 | Nielsen et al. (2010a) |
| | | | | 0102 | 11 | IPCC (2006), Tier 3, Table 2-6, Utility boilers, wood |
| | | 1A2 a-g | Industry | 03 | 11 | IPCC (2006), Tier 3, Table 2-7, Industry, wood, boilers. |
| | | 1A4a | Commercial/ Institutional | 0201 | 11 | IPCC (2006), Tier 3, Table 2-10, Commercial, wood. |
| | | 1A4b i | Residential | 0202 | 3 | Paulrud et al. (2005) |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 11 | IPCC (2006), Tier 3, Table 2-10, Commercial, wood.[1]. |
| | Bio oil | 1A1a | Public electricity and heat production | 010102 | 3 | IPCC (2006), Tier 1, Table 2-2, Energy industries, biodiesels. |
| | | | | 010105 | 24 | Nielsen et al. (2010a) assumed same emission factor as for gas oil fuelled engines. |
| | | | | 0102 | 3 | IPCC (2006), Tier 1, Table 2-2, Energy industries, biodiesels. |
| | | 1A2 a-g | Industry | 03 | 3 | IPCC (2006), Tier 1, Table 2-3, Industry, biodiesels. |
| | | | | 030902 | 0.2 | - |
| | | 1A4b i | Residential | 0202 | 10 | IPCC (2006), Tier 1, Table 2-5, Residential, biodiesels. |
| | Biogas | 1A1a | Public electricity and heat production | 0101 | 1 | IPCC (2006), Tier 1, Table 2-2, Energy industries, other biogas. |
| | | | | 010105 | 434 | Nielsen et al. (2010a) |
| | | | | 0102 | 1 | IPCC (2006), Tier 1, Table 2-2, Energy industries, other biogas. |
| | | 1A2 a-g | Industry | 03 | 1 | IPCC (2006), Tier 1, Table 2-3, Industry, other biogas. |
| | | | | Engines | 434 | Nielsen et al. (2010a) |
| | | 1A4a | Commercial/ Institutional | 0201 | 5 | IPCC (2006), Tier 1, Table 2-4, Commercial, other biogas. |
| | | | | 020105 | 434 | Nielsen et al. (2010a) |
| | | 1A4b | Residential | 0202 | 1 | Assumed equal to natural gas. |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 5 | IPCC (2006), Tier 1, Table 2-5, Agriculture, other biogas. |
| | | | | 020304 | 434 | Nielsen et al. (2010a) |
| | Bio gasification gas | 1A1a | Public electricity and heat production | 010101 | 1 | Assumed equal to biogas. |
| | | | | 010105 | 13 | Nielsen et al. (2010a) |
| | | 1A4a | Commercial/Institutional | 020105 | 13 | Nielsen et al. (2010a) |
| | Bio natural gas | 1A1a | Public electricity and heat production | 0101<br>0102 | 1 | Assumed equal to natural gas. |

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| | | 1A2 a-g | Industry | 03 | 1 | Assumed equal to natural gas. |
| | | 1A4a | Commercial/ Institutional | 0201 | 1 | Assumed equal to natural gas. |
| | | 1A4b | Residential | 0202 | 1 | Assumed equal to natural gas. |
| | | 1A4c | Agriculture/ Forestry | 0203 | 1 | Assumed equal to natural gas. |

1) Assumed same emission factors as for commercial plants. Plant capacity and technology are similar for Danish plants.

2) Assumed same emission factor as for industrial plants. Plant capacity and technology is similar to industrial plants rather than to residential plants.

3) Aggregated emission factor based on the technology distribution in the sector (Nielsen et al., 2020) and technology specific emission factors that refer to Paulrud et al. (2005), Johansson et al. (2004) and Olsson & Kjällstrand (2005). The emission factor is within the IPCC (2006) interval for residential wood combustion (100-900 g per GJ).

In general, the same $CH_4$ emission factors have been applied for 1990-2018. However, time series have been estimated for both natural gas fuelled engines and biogas fuelled engines, residential wood combustion, natural gas fuelled gas turbines[1] and waste incineration plants**Error! Bookmark not defined.**.

[1] A minor emission source.

Table 3A-4.4 $CH_4$ emission factors, time series.

| Year | Natural gas fuelled engines Emission factor, g per GJ | Biogas fuelled engines Emission factor, g per GJ | Residential wood combustion, g per GJ | Waste incineration g per GJ | Natural gas fuelled gas turbines, g per GJ |
|---|---|---|---|---|---|
| 1990 | 266 | 239 | 327 | 0.59 | 1.5 |
| 1991 | 309 | 251 | 321 | 0.59 | 1.5 |
| 1992 | 359 | 264 | 314 | 0.59 | 1.5 |
| 1993 | 562 | 276 | 308 | 0.59 | 1.5 |
| 1994 | 623 | 289 | 302 | 0.59 | 1.5 |
| 1995 | 632 | 301 | 296 | 0.59 | 1.5 |
| 1996 | 616 | 305 | 289 | 0.59 | 1.5 |
| 1997 | 551 | 310 | 283 | 0.59 | 1.5 |
| 1998 | 542 | 314 | 276 | 0.59 | 1.5 |
| 1999 | 541 | 318 | 270 | 0.59 | 1.5 |
| 2000 | 537 | 323 | 263 | 0.59 | 1.5 |
| 2001 | 522 | 342 | 256 | 0.59 | 1.5 |
| 2002 | 508 | 360 | 248 | 0.59 | 1.6 |
| 2003 | 494 | 379 | 240 | 0.59 | 1.6 |
| 2004 | 479 | 397 | 227 | 0.51 | 1.7 |
| 2005 | 465 | 416 | 215 | 0.42 | 1.7 |
| 2006 | 473 | 434 | 206 | 0.34 | 1.7 |
| 2007 | 481 | 434 | 197 | 0.34 | 1.7 |
| 2008 | 481 | 434 | 188 | 0.34 | 1.7 |
| 2009 | 481 | 434 | 178 | 0.34 | 1.7 |
| 2010 | 481 | 434 | 167 | 0.34 | 1.7 |
| 2011 | 481 | 434 | 160 | 0.34 | 1.7 |
| 2012 | 481 | 434 | 152 | 0.34 | 1.7 |
| 2013 | 481 | 434 | 145 | 0.34 | 1.7 |
| 2014 | 481 | 434 | 138 | 0.34 | 1.7 |
| 2015 | 481 | 434 | 131 | 0.34 | 1.7 |
| 2016 | 481 | 434 | 124 | 0.34 | 1.7 |
| 2017 | 481 | 434 | 117 | 0.34 | 1.7 |
| 2018 | 481 | 434 | 111 | 0.34 | 1.7 |

Table 3A-4.5 $N_2O$ emission factors and references, 2018.

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| SOLID | Coal | 1A1a | Public electricity and heat production | 0101 | 0.8 | Henriksen (2005) |
| | | | | 0102 | 1.4 | IPCC (2006), Tier 3, Table 2.6, Utility source, pulverised bituminous coal, wet bottom boiler. |
| | | 1A2 a-g | Industry | 03 | 1.5 | IPCC (2006), Tier 1, Table 2-3, Manufacturing industries, coal |
| | | 1A4b i | Residential | 0202 | 1.5 | IPCC (2006), Tier 1, Table 2-5, Residential, coal |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 1.5 | IPCC (2006), Tier 1, Table 2-4, Commercial, coal[1)] |
| | BKB | 1A4b i | Residential | 0202 | 1.5 | IPCC (2006), Tier 1, Table 2-5, Residential, brown coal briquettes |
| | Coke oven coke | 1A2 a-g | Industry | 03 | 1.5 | IPCC (2006), Tier 1, Table 2-3, Industry, coke oven coke |
| | | 1A4b i | Residential | 020200 | 1.5 | IPCC (2006), Tier 1, Table 2-5, Residential, coke oven coke |
| | Anodic carbon | 1A2 a-g | Industry | 03 | 1.5 | IPCC (2006), Tier 1, Table 2-3, manufacturing industries, other bituminous coal |
| | Fossil fly ash | 1A1a | Public electricity and heat production | 0101 | 0.8 | Assumed equal to coal. |
| LIQUID | Petroleum coke | 1A2 a-g | Industry – other | 03 | 0.6 | IPCC (2006), Tier 1, Table 2-3, Industry, petroleum coke |
| | | | | 031600 | 1.5 | - |
| | | 1A4a | Commercial/ Institutional | 0201 | 0.6 | IPCC (2006), Tier 1, Table 2-4, Commercial, petroleum coke |
| | | 1A4b i | Residential | 0202 | 0.6 | IPCC (2006), Tier 1, Table 2-5, Residential, petroleum coke |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 0.6 | IPCC (2006), Tier 1, Table 2-5, Residential/Agricultural, petroleum coke |
| | Residual oil | 1A1a | Public electricity and heat production | 010101 | 0.3 | IPCC (2006), Tier 3, Table 2-6, Utility, residual fuel oil |
| | | | | 010102<br>010103 | 5 | Nielsen et al. (2010a) |
| | | | | 010104<br>010105 | 0.6 | IPCC (2006), Tier 1, Table 2-2, Energy industries, residual fuel oil |
| | | | | 010203 | 0.3 | IPCC (2006), Tier 3, Table 2-6, Utility, residual fuel oil |
| | | 1A1b | Petroleum refining | 010306 | 0.6 | IPCC (2006), Tier 1, Table 2-2, Energy industries, residual fuel oil |
| | | 1A2 a-g | Industry | 03 | 5 | Nielsen et al. (2010a) |
| | | | | Engines | 0.6 | IPCC (2006), Tier 1, Table 2-3, manufacturing industries and construction, residual fuel oil. |
| | | 1A4a | Commercial/ Institutional | 0201 | 0.3 | IPCC (2006), Tier 3, Table 2-10, Commercial, fuel oil boilers |
| | | 1A4b i | Residential | 0202 | 0.6 | IPCC (2006), Tier 1, Table 2-5, Residential, residual fuel oil |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 0.3 | IPCC (2006), Tier 3, Table 2-10, Commercial, fuel oil boilers[1)] |
| | Gas oil | 1A1a | Public electricity and heat production | 010101<br>010102<br>010103 | 0.4 | IPCC (2006), Tier 3, Table 2-6, Utility, gas oil boilers |
| | | | | 010104 | 0.6 | IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil |
| | | | | 010105 | 2.1 | Nielsen et al. (2010a) |
| | | | | 0102 | 0.4 | IPCC (2006), Tier 3, Table 2-6, Utility, gas oil boilers |

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| | | 1A1b | Petroleum refining | 010306 | 0.6 | IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil |
| | | 1A1c | Oil and gas extraction | 010504 | 0.6 | IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil |
| | | 1A2 a-g | Industry | 03 | 0.4 | IPCC (2006), Tier 3, Table 2-7, Industry, gas oil boilers |
| | | | | Tur-bines | 0.6 | IPCC (2006), Tier 1, Table 2-3, Industry, gas oil |
| | | | | Engines | 2.1 | Nielsen et al. (2010a) |
| | | 1A4a | Commercial/ Institutional | 0201 | 0.4 | IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil boilers |
| | | | | Engines | 2.1 | Nielsen et al. (2010a) |
| | | 1A4b i | Residential | 0202 | 0.6 | IPCC (2006), Tier 1, Table 2-5, Residen-tial, gas oil |
| | | | | Engines | 2.1 | Nielsen et al. (2010a) |
| | | 1A4c | Agriculture/ Forestry | 0203 | 0.4 | IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil boilers[1)] |
| | | | | Engines | 2.1 | Nielsen et al. (2010a) |
| | Kerosene | 1A2 a-g | Industry | 03 | 0.6 | IPCC (2006), Tier 1, Table 2-3, Industry, other kerosene |
| | | 1A4a | Commercial/ Institutional | 0201 | 0.6 | IPCC (2006), Tier 1, Table 2-4, Commercial, other kerosene |
| | | 1A4b i | Residential | 0202 | 0.6 | IPCC (2006), Tier 1, Table 2-5, Residential, other kerosene |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 0.6 | IPCC (2006), Tier 1, Table 2-4, Commercial, other kerosene [1)] |
| | LPG | 1A1a | Public electricity and heat production | 0101<br>0102 | 0.1 | IPCC (2006), Tier 1, Table 2-2, Energy industries, LPG |
| | | 1A1b | Petroleum refining | 010306 | 0.1 | IPCC (2006), Tier 1, Table 2-2, Energy industries, LPG |
| | | 1A2 a-g | Industry | 03 | 0.1 | IPCC (2006), Tier 1, Table 2-3, Industry, LPG |
| | | 1A4a | Commercial/ Institutional | 0201 | 0.1 | IPCC (2006), Tier 1, Table 2-4, Commercial, LPG |
| | | 1A4b i | Residential | 0202 | 0.1 | IPCC (2006), Tier 1, Table 2-5, Residential, LPG |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 0.1 | IPCC (2006), Tier 1, Table 2-5, Residential/Agricultural, LPG |
| | Refinery gas | 1A1b | Petroleum refining | 010304 | 1 | Assumed equal to natural gas fuelled tur-bines. Based on Nielsen et al. (2010a). |
| | | | | 010306 | 0.1 | IPCC (2006), Tier 1, Table 2-2, Energy industries, refinery gas |
| GAS | Natural gas | 1A1a | Public electricity and heat production | 010101<br>010102<br>010103 | 1 | IPCC (2006), Tier 3, Table 2-6, Natural gas, Utility, boiler |
| | | | | 010104 | 1 | Nielsen et al. (2010a) |
| | | | | 010105 | 0.58 | Nielsen et al. (2010a) |
| | | | | 0102 | 1 | IPCC (2006), Tier 3, Table 2-6, Natural gas, Utility, boiler |
| | | 1A1b | Petroleum refining | 010306 | 1 | IPCC (2006), Tier 3, Table 2-6, Natural gas, Utility, boiler |
| | | 1A1c | Oil and gas extraction | 010504 | 1 | Nielsen et al. (2010a) |
| | | 1A2 a-g | Industry | 03 | 1 | IPCC (2006), Tier 3, Table 2-7, Industry, natural gas boilers |
| | | | | Gas tur-bines | 1 | Nielsen et al. (2010a) |
| | | | | Engines | 0.58 | Nielsen et al. (2010a) |
| | | 1A4a | Commercial/ Institutional | 020100<br>020103 | 1 | IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers |

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| | | | | Engines | 0.58 | Nielsen et al. (2010a) |
| | | 1A4b i | Residential | 0202 | 1 | IPCC (2006), Tier 3, Table 2-9, Residential, natural gas boilers |
| | | | | Engines | 0.58 | Nielsen et al. (2010a) |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 1 | IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers [1)] |
| | | | | Engines | 0.58 | Nielsen et al. (2010a) |
| WASTE | Waste | 1A1a | Public electricity and heat production | 0101 0102 | 1.2 | Nielsen et al. (2010a) |
| | | 1A2 a-g | Industry | 03 | 4 | IPCC (2006), Tier 1, Table 2-3, Industry, wastes |
| | | 1A4a | Commercial/ Institutional | 0201 | 4 | IPCC (2006), Tier 1, Table 2-4, Commercial, municipal wastes |
| | Industrial waste | 1A2 a-g | Industry | 03 | 4 | IPCC (2006), Tier 1, Table 2-3, Industry, industrial wastes |
| BIO-MASS | Wood | 1A1a | Public electricity and heat production | 0101 | 0.8 | Nielsen et al. (2010a) |
| | | | | 0102 | 4 | IPCC (2006), Tier 1, Table 2-2, Energy industries, wood |
| | | 1A2 a-g | Industry | 03 | 4 | IPCC (2006), Tier 1, Table 2-3, Industry, wood |
| | | 1A4a | Commercial/ Institutional | 0201 | 4 | IPCC (2006), Tier 1, Table 2-4, Commercial, wood |
| | | 1A4b i | Residential | 0202 | 4 | IPCC (2006), Tier 1, Table 2-5, Residential, wood |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 4 | IPCC (2006), Tier 1, Table 2-5, Agriculture, wood |
| | Straw | 1A1a | Public electricity and heat production | 0101 | 1.1 | Nielsen et al. (2010a) |
| | | | | 0102 | 4 | IPCC (2006), Tier 1, Table 2-2, Energy industries, other primary solid biomass |
| | | 1A4b i | Residential | 0202 | 4 | IPCC (2006), Tier 1, Table 2-5, Residential, other primary solid biomass |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 4 | IPCC (2006), Tier 1, Table 2-5, Agriculture, other primary solid biomass |
| | Wood pellets | 1A1a | Public electricity and heat production | 0101 | 0.8 | Nielsen et al. (2010a) |
| | | | | 0102 | 4 | IPCC (2006), Tier 1, Table 2-2, Energy industries, wood |
| | | 1A2 a-g | Industry | 03 | 4 | IPCC (2006), Tier 1, Table 2-3, Industry, wood |
| | | 1A4a | Commercial/ Institutional | 0201 | 4 | IPCC (2006), Tier 1, Table 2-4, Commercial, wood |
| | | 1A4b i | Residential | 0202 | 4 | IPCC (2006), Tier 1, Table 2-5, Residential, wood |
| | Bio oil | 1A1a | Public electricity and heat production | 0101 0102 | 0.6 | IPCC (2006), Tier 3, Table 2-2, Utility, biodiesels |
| | | | | Engines | 2.1 | Assumed equal to gas oil. Based on Nielsen et al. (2010a) |
| | | 1A2 a-g | Industry | 03 | 0.4 | Assumed equal to gas oil. |
| | | 1A4b i | Residential | 0202 | 0.6 | IPCC (2006), Tier 1, Table 2-5, Residential, biodiesels |
| | Biogas | 1A1a | Public electricity and heat production | 0101 0102 | 0.1 | IPCC (2006), Tier 1, Table 2-2, Energy industries, other biogas |
| | | | | Engines | 1.6 | Nielsen et al. (2010a) |
| | | 1A2 a-g | Industry | 03 | 0.1 | IPCC (2006), Tier 1, Table 2-3, Industry, other biogas |
| | | | | Engines | 1.6 | Nielsen et al. (2010a) |

| Fuel group | Fuel | CRF source category | CRF source category | SNAP | Emission factor, g per GJ | Reference |
|---|---|---|---|---|---|---|
| | | 1A4a | Commercial/ Institutional | 0201 | 0.1 | IPCC (2006), Tier 1, Table 2,4, Commercial, other biogas |
| | | | | Engines | 1.6 | Nielsen et al. (2010a) |
| | | 1A4b | Residential | 0202 | 1 | Assumed equal to natural gas. |
| | | 1A4c i | Agriculture/ Forestry | 0203 | 0.1 | IPCC (2006), Tier 1, Table 2-5, Agriculture, other biogas |
| | | | | Engines | 1.6 | Nielsen et al. (2010a) |
| | Bio gasification gas | 1A1a | Public electricity and heat production | 010101 | 0.1 | Assumed equal to biogas. |
| | | | | 010105 | 2.7 | Nielsen et al. (2010a) |
| | | 1A4a | Commercial/ Institutional | 020105 | 2.7 | Nielsen et al. (2010a) |
| | Bio natural gas | 1A1a | Public electricity and heat production | 0101 or 0102 | 1 | Assumed equal to natural gas. |
| | | 1A2 a-g | Industry | 03 | 1 | Assumed equal to natural gas. |
| | | 1A4a | Commercial/ Institutional | 0201 | 1 | Assumed equal to natural gas. |
| | | 1A4b | Residential | 0202 | 1 | Assumed equal to natural gas. |
| | | 1A4c | Agriculture/ Forestry | 0203 | 1 | Assumed equal to natural gas. |

1) In Denmark, plants in Agriculture/Forestry are similar to Commercial plants.

Time series have been estimated for natural gas fuelled gas turbines and refinery gas fuelled turbines. All other emission factors have been applied unchanged for 1990-2018.

Table 3A-4.6 $N_2O$ emission factors, time series.

| Year | Natural gas fuelled gas turbines. Emission factor, g per GJ | Refinery gas fuelled gas turbines. Emission factor, g per GJ |
|---|---|---|
| 1990 | 2.2 | 2.2 |
| 1991 | 2.2 | 2.2 |
| 1992 | 2.2 | 2.2 |
| 1993 | 2.2 | 2.2 |
| 1994 | 2.2 | 2.2 |
| 1995 | 2.2 | 2.2 |
| 1996 | 2.2 | 2.2 |
| 1997 | 2.2 | 2.2 |
| 1998 | 2.2 | 2.2 |
| 1999 | 2.2 | 2.2 |
| 2000 | 2.2 | 2.2 |
| 2001 | 2.0 | 2.0 |
| 2002 | 1.9 | 1.9 |
| 2003 | 1.7 | 1.7 |
| 2004 | 1.5 | 1.5 |
| 2005 | 1.4 | 1.4 |
| 2006 | 1.2 | 1.2 |
| 2007 | 1.0 | 1.0 |
| 2008 | 1.0 | 1.0 |
| 2009 | 1.0 | 1.0 |
| 2010 | 1.0 | 1.0 |
| 2011 | 1.0 | 1.0 |
| 2012 | 1.0 | 1.0 |
| 2013 | 1.0 | 1.0 |
| 2014 | 1.0 | 1.0 |
| 2015 | 1.0 | 1.0 |
| 2016 | 1.0 | 1.0 |
| 2017 | 1.0 | 1.0 |
| 2018 | 1.0 | 1.0 |

Table 3A-4.15 Technology specific $CH_4$ emission factors for residential wood combustion.

| Technology | Emission factor, g per GJ | Reference |
|---|---|---|
| Stoves (-1989) | 430 | Methane emissions from residential biomass combustion, Paulrud et al. (2005) (SMED report, Sweden) |
| Stoves (1990-2007) | 215 | Assumed ½ the emission factor for old stoves. |
| Stoves (2008-2014) | 125 | Estimated based on the emission factor for new stoves and the emission factors for NMVOC. |
| Stoves (2015-2016) | 125 | Same as modern stove (2008-2015) |
| Stoves (2017-) | 125 | Same as modern stove (2008-2015) |
| Eco labelled stoves / new advanced stoves (-2014) | 2 | Low emissions from wood burning in an ecolabelled residential boiler. Olsson & Kjällstrand (2005). |
| Eco labelled stoves / new advanced stoves (2015-2016) | 2 | Same as advanced / ecolabelled stoves |
| Eco labelled stoves / new advanced stoves (2017-) | 2 | Same as advanced / ecolabelled stoves |
| Open fireplaces and similar | 430 | Assumed equal to old stove. |
| Masonry heat accumulating stoves and similar | 215 | Assumed equal to old stove. |
| Boilers with accumulation tank (-1979) | 211 | Methane emissions from residential biomass combustion, Paulrud et al 2005 (SMED report, Sweden) |
| Boilers without accumulation tank (-1979) | 256 | Methane emissions from residential biomass combustion, Paulrud et al 2005 (SMED report, Sweden) |
| Boilers with accumulation tank (1980-) | 50 | Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004) |
| Boilers without accumulation tank (1980-) | 50 | Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004) |

## Annex 3A-5 Large point sources

Table 3A-5.1 Large point sources, 2018 (stationary combustion).

| Large point sources |
|---|
| AffaldPlus+, Naestved Forbraendingsanlaeg |
| Affaldplus+, Slagelse Forbr. and DONG Slagelse KVV |
| Affaldscenter aarhus - Forbraendsanlaegget |
| Amagerforbraending |
| Amagervaerket |
| Ardagh Glass Holmegaard A/S |
| Asnaesvaerket |
| Avedoerevaerket |
| AVV Forbraendingsanlaeg |
| Bofa I/S |
| Centralkommunernes Transmissionsselskab F_berg |
| Cheminova |
| Dalum Kraftvarmevaerk |
| Danisco Grindsted Dupont |
| DanSteel |
| Enstedvaerket |
| Esbjergvaerket |
| Faxe Kalk |
| Fjernvarme Fyn, Centrum Varmecentral |
| Frederikshavn Affaldskraftvarmevaerk |
| Fynsvaerket |
| H.C.Oerstedsvaerket |
| Haldor Topsoee |
| Hammel Fjernvarmeselskab |
| Helsingoer Kraftvarmevaerk |
| Herningvaerket |
| Hilleroed Kraftvarmevaerk |
| I/S Faelles Forbraending |
| I/S Kara Affaldsforbraendingsanlaeg |
| I/S Kraftvarmevaerk Thisted |
| I/S Reno Nord |
| I/S Reno Syd |
| I/S Vestforbraending |
| Koege Kraftvarmevaerk |
| Kolding Forbraendingsanlaeg TAS |
| Kommunekemi |
| Kyndbyvaerket |
| L90 Affaldsforbraending |
| Maricogen |
| Nordic Sugar Nakskov |
| Nordic Sugar Nykoebing |
| Nordjyllandsvaerket |
| Nybro Gasbehandlingsanlaeg |
| Odense Kraftvarmevaerk |
| Oestkraft |
| Randersvaerket Verdo |
| Rensningsanlaegget Lynetten |
| Rockwool A/S Doense |
| Rockwool A/S Vamdrup |
| Saint-Gobain Isover A/S |
| Shell Raffinaderi |
| Silkeborg Kraftvarmevaerk |

| Large point sources |
|---|
| Skaerbaekvaerket |
| Soenderborg Kraftvarmevaerk |
| Statoil Raffinaderi |
| Studstrupvaerket |
| Svanemoellevaerket |
| Svendborg Kraftvarmevaerk |
| Viborg Kraftvarme |
| Vordingborg Kraftvarme |
| Aalborg Portland |
| AarhusKarlshamn Denmark A/S |

Table 3A-5.2 Large point sources, aggregated fuel consumption in 2018.

| nfr_id_EA | fuel_id | fuel_gr_abbr | Sum of Fuel_TJ |
|---|---|---|---|
| 1A1a | 102A | COAL | 61849 |
| | 103A | SUB-BITUMINOUS | 31 |
| | 111A | WOOD | 16250 |
| | 114A | WASTE | 36436 |
| | 117A | STRAW | 4792 |
| | 122A | Wood Pellets | 33888 |
| | 203A | RESIDUAL OIL | 707 |
| | 204A | GAS OIL | 502 |
| | 215A | BIO OIL | 23 |
| | 301A | NATURAL GAS | 14084 |
| | 303A | LPG | 1 |
| | 309A | BIOGAS | 113 |
| 1A1a Total | | | 168677 |
| 1A1b | 203A | RESIDUAL OIL | 376 |
| | 204A | GAS OIL | 4 |
| | 301A | NATURAL GAS | 513 |
| | 303A | LPG | 0 |
| | 308A | REFINERY GAS | 14981 |
| 1A1b Total | | | 15875 |
| 1A1c | 204A | GAS OIL | 0 |
| | 301A | NATURAL GAS | 108 |
| 1A1c Total | | | 108 |
| 1A2a | 204A | GAS OIL | 0 |
| | 301A | NATURAL GAS | 1654 |
| | 303A | LPG | 2 |
| 1A2a Total | | | 1656 |
| 1A2c | 204A | GAS OIL | 0 |
| | 301A | NATURAL GAS | 1208 |
| | 303A | LPG | 1 |
| 1A2c Total | | | 1209 |
| 1A2e | 102A | COAL | 452 |
| | 107A | COKE OVEN COKE | 100 |
| | 111A | WOOD | 538 |
| | 203A | RESIDUAL OIL | 2043 |
| | 204A | GAS OIL | 25 |
| | 215A | BIO OIL | 2 |
| | 301A | NATURAL GAS | 387 |
| | 303A | LPG | 11 |
| | 309A | BIOGAS | 95 |
| 1A2e Total | | | 3654 |
| 1A2f | 102A | COAL | 2257 |
| | 110A | PETROLEUM COKE | 6695 |
| | 115A | INDUSTR. WASTES | 3891 |
| | 203A | RESIDUAL OIL | 83 |
| | 204A | GAS OIL | 117 |
| | 215A | BIO OIL | 0 |
| | 301A | NATURAL GAS | 7 |
| 1A2f Total | | | 13050 |
| 1A2g viii | 102A | COAL | 388 |
| | 107A | COKE OVEN COKE | 266 |
| | 204A | GAS OIL | 0 |
| | 301A | NATURAL GAS | 1334 |
| | 303A | LPG | 1 |

| | | | |
|---|---|---|---|
| 1A2g viii Total | | | 1989 |
| 1A4a i | 111A | WOOD | 245 |
| | 114A | WASTE | 0 |
| | 309A | BIOGAS | 0 |
| 1A4a i Total | | | 245 |
| Grand Total | | | 206463 |

## Annex 3A-6 Adjustment of $CO_2$ emission

Table 3A-6.1 Adjustment of $CO_2$ emission (DEA, 2019a).

| | | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Actual Degree Days | Degree days | 2857 | 3284 | 3022 | 3434 | 3148 | 3297 | 3837 | 3236 | 3217 | 3056 |
| Normal Degree Days | Degree days | 0 | 0 | 0 | 6603 | 3285 | 394 | -1117 | -2135 | -427 | 427 |
| Net electricity import | PJ | 25.4 | -7.1 | 13.5 | 4.3 | -17.4 | -2.9 | -55.4 | -26.1 | -15.6 | -8.3 |
| Actual $CO_2$ emission | 1 000 000 tonnes | 0.0 | 0.0 | Total | 38.3 | 47.9 | 42.1 | 44.4 | 48.1 | 45.0 | 58.3 |
| Adjusted $CO_2$ emission | 1 000 000 tonnes | 0.0 | 0.0 | 0.0 | 44.5 | 46.3 | 45.0 | 45.5 | 44.3 | 44.3 | 45.2 |
| ***Continued*** | | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
| Actual Degree Days | Degree days | 2902 | 3279 | 3011 | 3150 | 3113 | 3068 | 2908 | 2807 | 2853 | 3061 |
| Normal Degree Days | Degree days | 886.95 | 391.572 | 3360.99 | 4401.9 | 3055.05 | 2463.75 | 1642.5 | 1642.5 | 1642.5 | 821.25 |
| Net electricity import | PJ | 2.4 | -2.1 | -7.5 | -30.8 | -10.3 | 4.9 | -25.0 | -3.4 | 5.2 | 1.2 |
| Actual $CO_2$ emission | 1 000 000 tonnes | 48.4 | 44.5 | 41.3 | 37.3 | 38.9 | 38.4 | 43.2 | 37.2 | 33.4 | 41.1 |
| Adjusted $CO_2$ emission | 1 000 000 tonnes | 42.4 | 40.8 | 39.4 | 38.0 | 38.6 | 36.8 | 36.4 | 34.9 | 34.6 | 35.5 |
| ***Continued*** | | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | |
| Actual Degree Days | Degree days | 3742 | 2970 | 3234 | 3207 | 2664 | 2921 | 2998 | 2970 | 2900 | |
| Normal Degree Days | Degree days | 0 | 0 | 0 | 1807 | 1807 | 2070 | 1511 | 2595 | 2300 | |
| Net electricity import | PJ | -4.1 | 4.7 | 18.8 | 3.9 | 10.3 | 21.3 | 18.2 | 16.4 | 18.8 | |
| Actual CO2 emission | 1 000 000 tonnes | 35.6 | 32.9 | 32.0 | 32.5 | 27.7 | 24.0 | 25.9 | 21.6 | 19.1 | |
| Adjusted CO2 emission | 1 000 000 tonnes | 34.9 | 34.0 | 32.3 | 31.6 | 28.7 | 28.2 | 26.6 | 23.4 | 22.6 | |

## Annex 3A-7 Uncertainty estimates

Table 3A-7.1 Uncertainty estimation, approach 1, GHG

This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table 3A-7.2 Uncertainty estimation, approach 1, $CO_2$

This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table 3A-7.3 Uncertainty estimation, approach 1, $CH_4$

This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table 3A-7.4 Uncertainty estimation, approach 1, $N_2O$

This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

## Annex 3A-8 Emission inventory 2018 based on SNAP sectors

Table 3A-8.1 Emission inventory 2018 based on SNAP sectors.

| CRF | SNAP | $CO_2$, kt | $CH_4$, t | $N_2O$, t |
|---|---|---|---|---|
| 1A1a | 010100 | 0.000 | 1.161 | 1.161 |
| | 010101 | 6215.530 | 116.580 | 69.783 |
| | 010102 | 918.511 | 47.011 | 39.022 |
| | 010103 | 496.130 | 8.877 | 15.641 |
| | 010104 | 570.047 | 76.077 | 29.994 |
| | 010105 | 298.546 | 3805.547 | 11.516 |
| | 010200 | 0.000 | 0.975 | 0.975 |
| | 010201 | 0.000 | 0.000 | 0.000 |
| | 010202 | 79.901 | 1.467 | 1.382 |
| | 010203 | 534.063 | 348.002 | 93.044 |
| | 010205 | 0.000 | 0.000 | 0.000 |
| 1A1b | 010304 | 111.027 | 3.334 | 1.961 |
| | 010306 | 780.396 | 14.673 | 2.043 |
| 1A1c | 010503 | 6.119 | 0.108 | 0.108 |
| | 010504 | 1253.580 | 36.973 | 21.749 |
| | 010505 | 0.000 | 0.000 | 0.000 |
| 1A2a | 030400 | 12.353 | 0.214 | 0.179 |
| | 030402 | 94.259 | 1.656 | 1.654 |
| 1A2b | 030500 | 0.000 | 0.000 | 0.000 |
| 1A2c | 030600 | 282.062 | 15.823 | 7.048 |
| | 030602 | 34.819 | 0.612 | 0.611 |
| | 030603 | 0.000 | 0.000 | 0.000 |
| | 030604 | 33.943 | 1.014 | 0.597 |
| | 030605 | 0.000 | 58.298 | 0.215 |
| 1A2d | 031100 | 60.342 | 10.733 | 4.524 |
| | 031102 | 0.000 | 0.000 | 0.000 |
| | 031103 | 0.000 | 0.000 | 0.000 |
| | 031104 | 18.968 | 0.567 | 0.333 |
| 1A2e | 030900 | 719.852 | 18.904 | 12.289 |
| | 030902 | 143.468 | 11.170 | 9.602 |
| | 030903 | 97.468 | 3.547 | 4.087 |
| | 030904 | 55.252 | 1.651 | 0.971 |
| | 030905 | 14.897 | 465.489 | 1.404 |
| 1A2f | 030700 | 341.058 | 11.219 | 5.972 |
| | 030703 | 22.070 | 2.361 | 0.360 |
| | 030705 | 0.424 | 3.587 | 0.004 |
| | 031600 | 1030.964 | 157.169 | 29.101 |
| | 031604 | 0.000 | 0.000 | 0.000 |
| | 031605 | 0.000 | 0.000 | 0.000 |
| 1A2gviii | 030104 | 0.000 | 0.000 | 0.000 |
| | 030105 | 0.000 | 0.000 | 0.000 |
| | 030106 | 3.991 | 0.070 | 0.070 |
| | 030800 | 51.502 | 10.602 | 4.396 |
| | 031000 | 12.313 | 0.555 | 0.337 |
| | 031005 | 0.000 | 0.000 | 0.000 |
| | 031200 | 9.938 | 0.300 | 0.217 |
| | 031205 | 0.000 | 0.000 | 0.000 |
| | 031300 | 60.471 | 7.799 | 3.377 |
| | 031305 | 1.691 | 14.301 | 0.017 |
| | 031400 | 5.511 | 4.386 | 1.652 |
| | 031403 | 0.000 | 2.494 | 0.907 |
| | 031405 | 0.594 | 5.023 | 0.006 |
| | 031500 | 23.598 | 0.423 | 0.313 |
| | 032000 | 56.515 | 44.429 | 18.238 |
| | 032002 | 86.031 | 6.907 | 76.162 |
| | 032004 | 0.017 | 0.001 | 0.000 |
| | 032005 | 0.801 | 16.790 | 0.047 |
| 1A4ai | 020100 | 607.108 | 29.835 | 14.941 |
| | 020103 | 3.885 | 2.869 | 1.037 |

| | | | | |
|---|---|---|---|---|
| | 020105 | 4.234 | 343.307 | 1.213 |
| 1A4bi | 020200 | 1837.898 | 3723.228 | 205.314 |
| | 020202 | 5.253 | 0.106 | 0.111 |
| | 020204 | 5.391 | 45.250 | 0.056 |
| 1A4ci | 020300 | 137.934 | 598.278 | 10.878 |
| | 020302 | 0.007 | 0.630 | 0.084 |
| | 020303 | 0.001 | 0.000 | 0.000 |
| | 020304 | 18.262 | 473.493 | 1.363 |
| | 020305 | 0.000 | 0.000 | 0.000 |
| Grand Total | | 17158.999 | 10555.877 | 708.070 |

## Annex 3A-9 EU ETS data for coal

EU ETS data are available for the years 2006-2018. Corresponding values for lower calorific value (LCV) and implied emission factor (IEF) for $CO_2$ for 2006-2009 are shown in Figure 3A-10.1. The IEF factors include the oxidation factors.

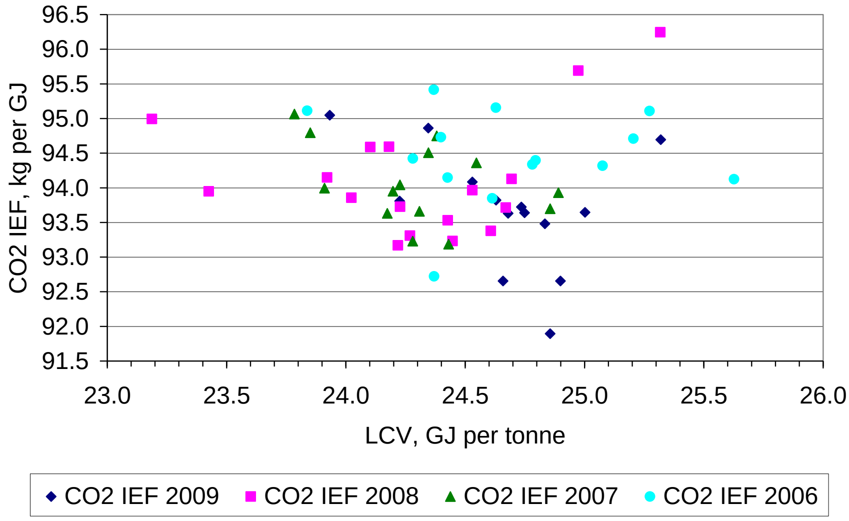



Figure 3A-9.1 EU ETS data for LCV and $CO_2$ IEF (including oxidation factor) for coal. Data for the years 2006-2009.

## Annex 3B - Transport and other mobile sources

Annex 3B-12-1: Annual traffic data (no. of round trips) for Danish ferries 1990-2018

Annex 3B-12-2: Annual traffic data (no. of round trips) per ferry for Danish ferries 1990-2018

Annex 3B-12-3: Ferry service, ferry name, engine year, main engine MCR (kW), engine type, specific fuel consumption (sfc), $NO_x$, VOC, CO emission factors (g/kWh), aux. engine (kW)

Annex 3B-12-3: Ferry service, ferry name, engine type, engine year, fuel type, main engine MCR (kW), aux. engine (kW), specific fuel consumption (g/kWh), SO2, NOx, NMVOC, CH4, VOC, CO, CO2, N2O, NH3, TSP, PM10, PM2.5 and BC emission factors for 2018 (g/kWh, g/GJ, g/kg fuel).

Annex 3B-12-4: Sailing time (single trip) for Danish ferries

Annex 3B-12-5: Engine load factor (% MCR) for Danish ferries

Annex 3B-12-6: Round trip shares for Danish ferries

Annex 3B-13-1: Specific fuel consumption, $NO_x$, CO, VOC, NMVOC and $CH_4$ emission factors (g pr kWh) per engine year for ship engines

Annex 3B-13-2: Fuel consumption (PJ and tonnes), S-%, $SO_2$ , $NO_x$, NMVOC, $CH_4$, CO, $CO_2$, $N_2O$, TSP, $PM_{10}$, $PM_{2.5}$ and BC emission factors (g/kg fuel and g/GJ) per fuel type for ship traffic

Annex 3B-13-3: Engine load adjustment functions for sfc, $NO_x$, VOC, CO, $N_2O$ and TSP emission factors for ferries

Annex 3B-14-1: Fuel sales figures from DEA, and further processed fuel consumption data suited for the Danish inventory

Annex 3B-14-2: Fuel sulphur legislation limits, fuel sulphur content and lower heating values used in the Danish inventory

Annex 3B-15-1: Emission factors for 1990 in CollectER format

Annex 3B-15-2: Emission factors for 2018 in CollectER format

Annex 3B-15-3: Emissions for 1990 in CollectER format

Annex 3B-15-4: Emissions for 2018 in CollectER format

Annex 3B-15-5: Non-exhaust emission factors, activity data and total non-exhaust emissions of TSP, PM, $PM_{2.5}$, BC and heavy metals in 2018

Annex 3B-16-1: Fuel consumption 1985-2018 in CRF format

Annex 3B-16-2: Emissions 1985-2018 in CRF format

Annex 3B-16-3: Fuel consumption 1985-2018 in NFR format

Annex 3B-16-4: Emissions 1985-2018 in NFR format

Annex 3B-17-1: Uncertainty estimates for greenhouse gases

Annex 3B-17-2: Uncertainty estimates for emission components reported to the CLRTAP Convention

All annexes are available at: [http://envs.au.dk/videnudveksling/luft/emissioner/supporting-documentation/air-pollution-iir/](http://envs.au.dk/videnudveksling/luft/emissioner/supporting-documentation/air-pollution-iir/)

## Annex 3C - Industrial processes and product use

| | |
|---|---|
| Annex 3C-26: | Use of paraffin wax candles, kt |
| Annex 3C-27: | Emissions from the use of paraffin wax candles |
| Annex 3C-28: | Activity data for solvent use, kt |
| Annex 3C-29: | $CO_2$ emission factors for solvent use |
| Annex 3C-30: | $CO_2$ emissions from solvent use |
| Annex 3C-31: | Activity data for road paving with asphalt, kt |
| Annex 3C-32: | Emissions from road paving with asphalt, t |
| Annex 3C-33: | Activity data for asphalt roofing, kt |
| Annex 3C-34: | Emissions from asphalt roofing, t |
| Annex 3C-35: | Activity data for urea used in catalysts, kt |
| Annex 3C-36: | Emissions from urea used in catalysts, kt |
| Annex 3C-37: | Consumption of F-gasses in other electronic industry, t |
| Annex 3C-38: | Emissions from other electronic industry, kt $CO_2$ equivalents |
| Annex 3C-39: | Consumption of cream in Denmark, t |
| Annex 3C-40: | Emissions from the use of canned whipped cream, kt |
| Annex 3C-41: | Activity data for other product uses, kt |
| Annex 3C-42: | Emissions from other product uses, kt |

All annexes are available at:

https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Please note that data found via this link are updated annually. This means that data in the annexes always matches the newest version of the NIR report.

## Annex 3D - Agriculture

Table 3D-1 Changes in housing type 1990 – 2018https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/ (most recently submitted values)

Table 3D-2 Number of animals allocated on subcategories for 1990-2018, 1 000 head. https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/ (most recently submitted values)

Table 3D-3 (a-d) $NH_3$ emission factors for housing units, 2018.

a) **Cattle**

| | | Urine | Slurry | Solid manure | Deep litter manure |
|---|---|---|---|---|---|
| | | TAN | TAN | Total N | Total N |
| Housing type | | pct. loss of TAN ex animal | | pct. loss of N ex animal | |
| Tethered | urine and solid manure | 10 | - | 5 | - |
| | slurry manure | - | 6 | - | - |
| Loose-housing with beds | slatted floor | - | 13.5 | - | - |
| | slatted floor and scrape | - | 12 | - | - |
| | solid floor | - | 20 | - | - |
| | drained floor | - | 10.4 | - | - |
| | solid floor with tilt and scrape | - | 10.4 | - | - |
| | solid floor with tilt | - | 10.4 | - | - |
| Deep litter | All | - | - | - | 6 |
| | solid floor | - | - | - | 6 |
| | slatted floor | - | 13.5 | - | 6 |
| | slatted floor and scrape | - | 12 | - | 6 |
| | solid floor and scrape | - | 20 | - | 6 |
| Boxes | sloping bedded floor | - | 16 | - | - |
| | slatted floor | - | 16 | - | - |

*Continued…*

b) **Swine**

| | Housing type | Floor or manure type | Urine TAN | Slurry TAN | Solid manure Total N | Deep litter Total N |
|---|---|---|---|---|---|---|
| | | | Pct. loss of TAN ex animal | | pct. loss of N ex animal | |
| Sows | Individual, mating and gestation | Partly slatted floor | - | 13 | - | - |
| | | Full slatted floor | - | 19 | - | - |
| | | Solid floor | 21 | - | 16 | - |
| | Group, mating and gestation | Deep litter | - | - | - | 15 |
| | | Deep litter + slatted floor | - | 16 | - | 15 |
| | | Deep litter + solid floor | - | 19 | - | 15 |
| | | Partly slatted floor | - | 16 | - | - |
| | Farrowing crate | Full slatted floor | - | 13 | - | - |
| | | Partly slatted floor | - | 26 | - | - |
| | Farrowing pen | Solid floor | 20 | - | 15 | - |
| | | Partly slatted floor | - | 22 | 15 | - |
| Weaners | | Full slatted floor | - | 24 | - | - |
| | | Drained + partly slatted floor | - | 21 | - | - |
| | | Deep litter (to-climate housings) | - | 10 | - | 15 |
| | | Solid floor | 37 | - | 25 | - |
| | | Deep litter | - | - | - | 15 |
| Fattening pigs | | Partly slatted floor (50-75 % solid) | - | 13 | - | - |
| | | Partly slatted floor (25-49% solid) | - | 17 | - | - |
| | | Drained + partly slatted floor | - | 21 | - | - |
| | | Full slatted floor | - | 24 | - | - |
| | | Solid floor | 27 | - | 18 | - |
| | | Deep litter, divided | - | 18 | - | 15 |
| | | Deep litter | - | - | - | 15 |

c) **Poultry**

| | Housing type | Floor or manure type | Solid manure Total N | Deep litter Total N |
|---|---|---|---|---|
| | | | pct. loss of N ex animal | |
| Hens and pullets | Free-range, organic and barn | Deep pit | 40 | 25 |
| | | Deep litter | - | 28 |
| | | Manure belt | 10 | 25 |
| | Battery | Deep pit | 12 | - |
| | | Manure belt | 10 | - |
| Broilers | Conventional | Deep litter | - | 10 |
| | Organic and barn | Deep litter | - | 9 |
| Turkeys, ducks and geese | | Deep litter | - | 20 |

d) **Other**

| | Slurry TAN | Deep litter Total N |
|---|---|---|
| | Pct. loss of TAN ex animal | pct. loss of N ex animal |
| Fur animals | 30-67 | 40 |
| Horses, sheep and goats | - | 15 |

Table 3D-4 $NH_3$ emission factors for storage units, 2018.

| | | | Urine | Slurry | Solid manure | Deep litter | Pct. of solid manure stored in heap on field |
|---|---|---|---|---|---|---|---|
| Cattle | | Total N | 2.2 | 2 | 4 | 1 | 35 |
| | | TAN | 2.2 | 3.4 | - | - | - |
| Pigs | Sows | Total N | 2.2 | 2.1 | 19 | 6.5 | 50 |
| | | TAN | 2.2 | 2.7 | - | - | - |
| | Weaners | Total N | 2.2 | 2.1 | 19 | 9.8 | - |
| | | TAN | 2.2 | 2.7 | - | - | - |
| | Fattening pigs | Total N | 2.2 | 2.1 | 19 | 9,8 | 75 |
| | | TAN | 2.2 | 2.7 | - | - | - |
| Poultry | Hens and pullets | Total N | - | 2 | 7.5 | 4.8 | 95 |
| | Broilers | Total N | - | - | 11.5 | 6.8 | 85 |
| | Turkeys, ducks, and geese | Total N | - | - | - | 6.8, 8(Turkeys) | - |
| Ostric | | Total N | | | | 4.8 | |
| Fur animals | | Total N | 0 | 1.9 | - | 8 | - |
| | | TAN | 0 | 2.7 | - | - | - |
| Sheep and goats | | Total N | - | - | - | 3 | - |
| Horses | | Total N | - | - | - | 3 | - |

Table 3D-5 EF for poultry for $CH_4$ from enteric fermentation, kg $CH_4$ per 100 or 1000 heads

| | Number of heads | $CH_4$ EF |
|---|---|---|
| Hens | 100 | 0.021 |
| Pullets (consumption), 112 days | 100 | 0.285 |
| Pullets (hatching), 119 days | 100 | 0.303 |
| Broilers: | | |
| 30 days | 1 000 | 0.011 |
| 32 days | 1 000 | 0.012 |
| 35 days | 1 000 | 0.013 |
| 40 days | 1 000 | 0.015 |
| 45 days | 1 000 | 0.017 |
| 56 days | 1 000 | 0.021 |
| 81 days (organic) | 1 000 | 0.075 |
| Other poultry | | |
| Turkeys, male | 100 | 0.014 |
| Turkeys, hen | 100 | 0.007 |
| Ducks | 100 | 0.003 |
| Geese | 100 | 0.005 |
| Pheasant, chicken | 1 000 | 0.003 |
| Pheasant, hen | 100 | 0.472 |
| Ostrich, chicken | 1 | 0.001 |
| Ostrich, hen | 1 | 0.660 |

Table 3D-6 Parameters for winter feeding plans.

| | | Feeding code* PDIR (2002) | % dm* | % Crude protein* | % Raw fat* | % Raw ashes* | % Carbo-hydrates | FU/kg dm* | kg dm/day** | MJ/day | $GE_{FU}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Heifers: | Straw | 781 | 85.0 | 4.0 | 1.9 | 4.5 | 89.6 | 0.2 | 33.4 | 571.8 | |
| | Maize silage | 593 | 31.0 | 8.7 | 2.2 | 4.2 | 84.9 | 0.9 | 57.5 | 1 009.0 | |
| | Toasted soya | 155 | 87.5 | 49.1 | 3.2 | 7.4 | 40.3 | 1.4 | 8.1 | 161.7 | |
| | Total | - | - | - | - | - | - | - | 99.0 | 1 742.4 | 25.8 |
| Suckling cows: | Straw | 781 | 85.0 | 4.0 | 1.9 | 4.5 | 89.6 | 0.2 | 1.6 | 119.1 | |
| Period 1 (2 mth) | Toasted soya | 155 | 87.5 | 49.1 | 3.2 | 7.4 | 40.3 | 1.4 | 3.4 | 49.6 | |
| | Barley | 201 | 85.0 | 11.2 | 2.9 | 2.2 | 83.7 | 1.1 | 1.8 | 29.2 | |
| Period 2 (4 mth) | Straw | 781 | 85.0 | 4.0 | 1.9 | 4.5 | 89.6 | 0.2 | 3.2 | 238.2 | |
| | Toasted soya | 155 | 87.5 | 49.1 | 3.2 | 7.4 | 40.3 | 1.4 | 3.0 | 29.1 | |
| | Barley | 202 | 85.0 | 11.2 | 2.9 | 2.2 | 83.7 | 1.1 | 3.2 | 52.0 | |
| | Total | - | - | - | - | - | - | - | 15.2 | 517.1 | 34.0 |
| Horses: | Straw | 781 | 85.0 | 4.0 | 1.9 | 4.5 | 89.6 | 0.2 | 4.0 | 58.2 | |
| | Hay | 665 | 85.0 | 12.1 | 2.6 | 7.7 | 77.6 | 0.6 | 3.0 | 44.0 | |
| | Oat | 202 | 86.0 | 12.1 | 5.7 | 2.7 | 79.5 | 0.9 | 2.5 | 40.1 | |
| | Supplemental | | 86.4 | 15.4 | 4.3 | 6.6 | 73.7 | 1.0 | 1.0 | 15.5 | |
| | Total | - | - | - | - | - | - | - | - | 157.7 | 29.8 |
| Sheep and Goats: | Straw | 781 | 85.0 | 4.0 | 1.9 | 4.5 | 89.6 | 0.2 | 1.0 | 14.6 | |
| | Toasted soya | 155 | 87.5 | 49.1 | 3.2 | 7.4 | 40.3 | 1.4 | 0.1 | 1.8 | |
| | Barley | 202 | 85.0 | 11.2 | 2.9 | 2.2 | 83.7 | 1.1 | 0.4 | 6.2 | |
| | Grass pills (dried) | 707 | 92.0 | 17.0 | 3.1 | 11.0 | 68.9 | 0.6 | 1.0 | 15.7 | |
| | Total | - | - | - | - | - | - | - | - | 38.2 | 30.0 |
| Summer grazing | | | | | | | | | | | |
| Grazing | Clover grass, 2 weeks old | 422 | 18.0 | 22.0 | 4.1 | 9.4 | 64.5 | 1.0 | 1.0 | 18.8 | |
| | Total | - | - | - | - | - | - | - | 1.0 | 18.8 | 18.8 |
| Swine: | Full feeding | | | | | | | | | | |
| | Sows | - | 87.1 | 16.1 | 5.2 | 5.5 | 73.2 | 1.2 | - | 64.2 | 17.5 |
| | Weaners | - | 87.4 | 18.8 | 5.7 | 5.5 | 70.0 | 1.3 | - | 2.1 | 16.5 |
| | Fattening pigs | - | 86.9 | 17.0 | 4.7 | 5.1 | 73.3 | 1.2 | - | 9.6 | 17.3 |

Table 3D-7 Energy factors used for GE.

| | MJ per kg dm |
|---|---|
| $E_{Crude\ protein}$ | 24.237 |
| $E_{Raw\ fat}$ | 34.116 |
| $E_{Carbonhydrates}$ | 17.3 |

Table 3D-8 Feed intake 1990-2018, Dairy cattle; kg DM per cow per year, Others; FU per animal per year. https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/ (most recently submitted values)

Table 3D-9 Grazing animals 1990 – 2018, number of days on grass per year. https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/ (most recently submitted values)

Table 3D-10 Gross energy per kg DM for dairy cattle, 1990-2018, MJ per kg DM. https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/ (most recently submitted values)

Table 3D-11 Average gross energy intake (GE) 1990 – 2018, MJ per head per day. https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/ (most recently submitted values)

Table 3D-12 Implied Emission Factor of CH4 from enteric fermentation, 1990 – 2018, https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/ (most recently submitted values)

Table 3D-13 Emission of $CH_4$ from enteric fermentation, 1990 – 2018. https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/ (most recently submitted values)

Table 3D-14 VS daily excretion 1990 – 2018, kg DM per head per day. https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/ (most recently submitted values)

Table 3D-15 National manure management system and MCF vs. IPCC manure management system and MCFhttps://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table 3D-16 MCF for liquid manure, 1990 – 2018. https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/ (most recently submitted values)

Table 3D-17 Implied Emission Factor of CH4 from manure management, 1990 – 2018, https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/ (most recently submitted values)

Table 3D-18 Emission of $CH_4$ from manure management, 1990 – 2018. https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/ (most recently submitted values)

Table 3D-19 Area of agricultural land, 1990 – 2018, ha. https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/ (most recently submitted values)

Table 3D-20 Above-ground residue dry matter $AG_{DM(T)}$ 1990-2018, kg DM per ha. https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/ (most recently submitted values)

### Nitrogen leaching and Run-off

Calculations of nitrogen lost by leaching from groundwater are based on two models described in Børgesen and Grant (2003) (in Danish). The model SKEP/DAISY is a dynamic model, N-LES is an empirical model and SKEP is an up scaling model. The SKEP/DAISY calculations were done for 10 scenarios (the years 1984, 1989 and 1995-2002) and the N-LES calculations were done for an 11-year period (1990-2000). Both calculations were up-scaled nationwide. The key parameters for the models were land use, nitrogen from synthetic fertilizer and manure, application practice for manure and $NH_3$ evaporation at application of manure (SKEP/DAISY only). The calculations were normalised to an average climate. A schematic overview of the models is seen below.

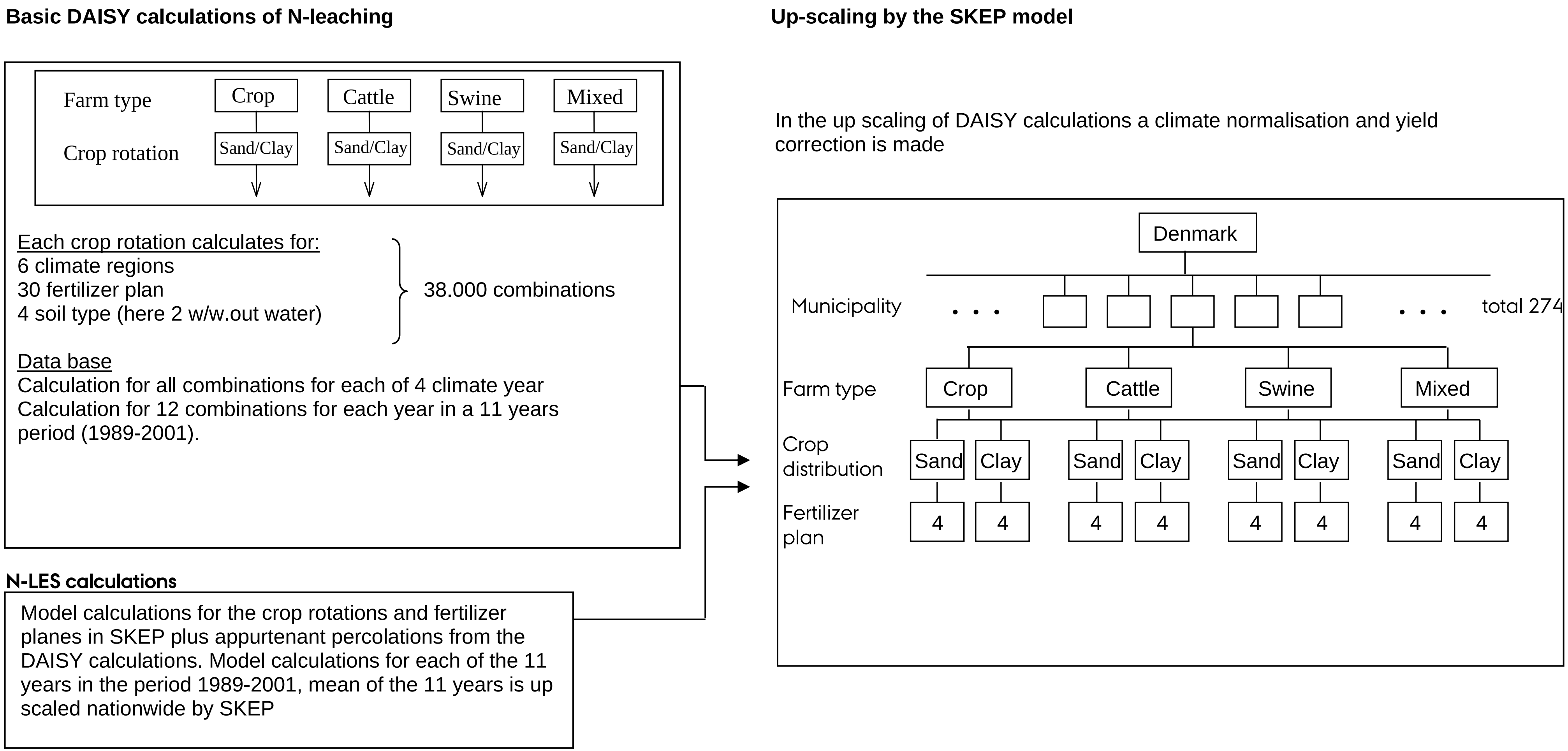



Figure 3D-1 Model calculation of nitrogen leaching from groundwater nationwide by SKEP/DAISY and N-LES.

Table 3D-21 QA/QC procedure, stage I – III.

| Stage I: Check of input data | Variable | Reference |
|---|---|---|
| Livestock production | - number of animal<br>- slaughter data | DSt |
| Normative figures | - N-excretion<br>- use of straw<br>- amount of manure<br>- feed intake<br>- milk yield | DCA |
| Housing types | - distribution | DAAS + DAFA |
| Grazing days | | DAAS |
| Crops | - land use<br>- crop yield<br>- crop production | DSt |
| Synthetic fertiliser | - N-content<br>- fertiliser types | DAFA |
| N-leaching | - amount of nitrogen leached | DCE |
| Atmospheric deposition | - all $NH_3$ emission sources | DCE – $NH_3$ inventory |
| Sewage sludge and industrial waste | - Amount of sludge applied to soils | EPA + DAFA |
| **Stage II: Check of IDA data – overall** | **Emission source** | **Variable** |
| Recalculation | - $CO_2$ eqv. total emission<br>- $CH_4$, $N_2O$, NMVOC<br>- emission from field burning | - compared with latest submission |
| Time series | - $CO_2$ eqv. total emission<br>- $CH_4$, $N_2O$, NMVOC<br>- emission from field burning | - trends<br>- jumps and dips |
| **Stage III: Check of IDA data – specific** | **Emission source** | **Variable** |
| $CH_4$ | - enteric fermentation | - IEF (jumps and dips)<br>- Ym (dairy cattle + heifer)<br>- GE |
| $CH_4$ | - manure management | - IEF (jumps and dips)<br>- VS<br>- biogas |
| $N_2O$ | - manure management | - trends (jumps and dips)<br>- IEF<br>- biogas |
| $N_2O$ | - synthetic fertiliser | - trends (jumps and dips)<br>- IEF |
| $N_2O$ | - animal waste applied to soil | - trends (jumps and dips)<br>- IEF |
| $N_2O$ | - N-fixing crops | - trends (jumps and dips)<br>- IEF |
| $N_2O$ | - crop residue | - trends (jumps and dips)<br>- IEF |
| $N_2O$ | - pasture, range and paddock | - trends (jumps and dips)<br>- IEF |
| $N_2O$ | - atmospheric deposition | - trends (jumps and dips)<br>- IEF |
| $N_2O$ | - N-leaching and run-off | - trends (jumps and dips)<br>- IEF |
| $N_2O$ | - sewage sludge + industrial waste | - trends (jumps and dips)<br>- IEF |
| NMVOC | - crops | - trends (jumps and dips) |

## Chapter 3D-1 Biogas treatment of manure

### Introduction

A significant and growing part of the Danish animal slurry is being used for production of biogas. The production uses anaerobic digestion of animal manure in combination with other biodegradable products, e.g. agricultural waste and slaughterhouse waste. Biogas treatment is important to include in the inventory, because the anaerobic digested slurry produces lower $CH_4$ emission from storage and from applied slurry on cultivated soils.

$CH_4$ emission from manure management depends, among other variables, on the $CH_4$ conversion factor (MCF), which depends on the actual temperature and storage conditions. The 2006 IPCC Guidelines Tier 2 approach recommends a MCF at 10 % for covered and a MCF at 17% for uncovered manure- cool climate – for swine and cattle. Based on study activities in 2015-2016 a national MCF has been estimated for raw untreated slurry and for anaerobic digested slurry, from cattle and swine slurry respectively. Focus has been on cattle and swine slurry, which cover >96 % of the total $CH_4$ emission from manure management in the 2017 submission.

The result of the national MCF estimated will first be presented. Following is an overview of the biogas production in Denmark and the estimation of the amount of treated slurry. Finally a description and documentation of the estimation of the national MCF is provided.

**National estimated MCF for cattle- and swine slurry**

In 2015-2016 national studies were conducted covering e.g. manure storage time in Danish barns (Kai et al., 2015) and the emissions from anaerobically digested material (Petersen et al., 2016).

During the work with estimating the $CH_4$ emission from anaerobic digested cattle and swine slurry, it became apparent that the currently used MCF for cattle and swine slurry (the default values from the 2006 IPCC Guidelines) were not properly reflecting the Danish conditions. The analyses based on new measurements showed that the emission from untreated swine slurry was underestimated. It was therefore decided also to estimate a country specific MCF for untreated cattle and swine slurry.

The national estimates of MCF are based on temperature dependent degradation functions, which take into account the different temperature conditions inside the barns and during outdoor storage. The storage time and the related $CH_4$ emission inside the barns, outdoor storage and storage of anaerobic digested biomass is also taken into account. The approach use temperature dependent functions adapted to Danish conditions. The emissions are estimated separately from the barns and pre-tanks at the farm. After the manure has left the barn, it is split in two fractions. The major fraction of 90 % is left on the farms as untreated raw liquid manure and currently 10 % is brought to anaerobic digestion either on the farms or at large-scale biogas plants. The digested material is returned for storage on the farms until field application. In Table 3D-22 the MCF values used in previous emission inventories are compared to the new national estimated values.

Table 3D-22 National methane conversion factor (MCF) values

| MCF, % | 2018<br>Liquid system | 2018<br>Anaerobic digesters |
|---|---|---|
| Untreated cattle slurry | 12.40 | |
| Untreated swine slurry | 13.37 | |
| Biogas treated cattle slurry | | 7.48 |
| Biogas treated swine slurry | | 10.28 |

The national estimated MCF for untreated swine- and cattleslurry is higher than the 2006 IPCC Guidelines default. The national study shows a very fast turnover of VS in the swine slurry, and especially inside the barns caused by the relatively high temperatures (Møller, 2013), which leading to a high emission of methane per kg of VS.

Table 3D-23 shows the trend 1990 – 2018 for the national estimated MCF for cattle and swine slurry both digested and not digested. The national estimated MCF for not digested slurry for cattle is changing slightly over time, form 12.00 in 1990 and 12.40 in 2018. The MCF for not digested slurry for swine is reduced from 15.25 in 1990 to 13.37 in 2018 due to changes in housing system. The MCF depends on storage time in housing, which differ from system to system. The development from housing systems with fully slatted floor towards systems with partly slatted floor, shorter than storage time for slurry and thus reduces the MCF.

The MCF for non digested cattle slurry in 2018 is estimated to 12.40 % and the MCF for digested cattle slurry is 7.48 %, which corresponds to a 40 % reduction of $CH_4$ emission. The MCF for not digested swine slurry in 2018 is estimated to 13.37 % and the MCF for digested swine slurry to 10.38 %, which corresponds to a 23 % reduction. The changes over time is mainly due to changes in housing types.

Table 3D-23 Estimated methane conversion factor (MCF) for digested and not digested cattle and swine slurry from 1990 to 2018, %.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cattle | | | | | | | | | | | |
| MCF for digested cattle slurry | 6.49 | 6.45 | 7.34 | 7.33 | 7.60 | 8.12 | 8.00 | 7.85 | 7.53 | 7.50 | 7.48 |
| MCF for not digested cattle slurry | 12.00 | 11.89 | 12.70 | 12.55 | 12.56 | 12.79 | 12.61 | 12.59 | 12.53 | 12.49 | 12.40 |
| Swine | | | | | | | | | | | |
| MCF for digested swine slurry | 12.08 | 11.90 | 11.60 | 10.87 | 11.08 | 11.11 | 11.15 | 10.98 | 10.51 | 10.34 | 10.38 |
| MCF for not digested swine slurry | 15.25 | 15.11 | 14.86 | 14.03 | 13.93 | 13.74 | 13.69 | 13.67 | 13.57 | 13.42 | 13.37 |

### Estimation of slurry treated in biogas plants in Denmark

In Denmark, the biogas plants are divided in five facility types; wastewater, industrial, landfills, large-scale plants (centralised multi farms) and farm-level plants. Large-scale biogas plants are larger facilities, where slurry is received from several farms and farm-level plants are characterised by receiving manure from one or a few farms. In 2018, the Energy Statistics estimated the total energy production based on biogas to 13 414 TJ (DEA, 2019a), and out of this, the manure based biogas plants account for 91 % produced at approximately 30 large-scale plants and 60 farm-level plants. The Energy Statistic provides data annually and thus data from all years 1990 – 2018 is available.

Table 3D-24 Biogas production, 2018 (DEA, 2019a).

| Facility type | Biogas production, TJ | % |
|---|---|---|
| Wastewater treatment | 1002 | 7 |
| Industrial | 169 | 1 |
| Large-scale and farm-scale* | 12244 | 91 |
| Total | 13 414 | 100 |

*Include Landfill, which only accounts for approximately 200 TJ (less than 2 % of total biogas production).

The livestock production mainly takes place in the western parts of Denmark in Jutland and consequently the majority of manure based biogas plants are located here.

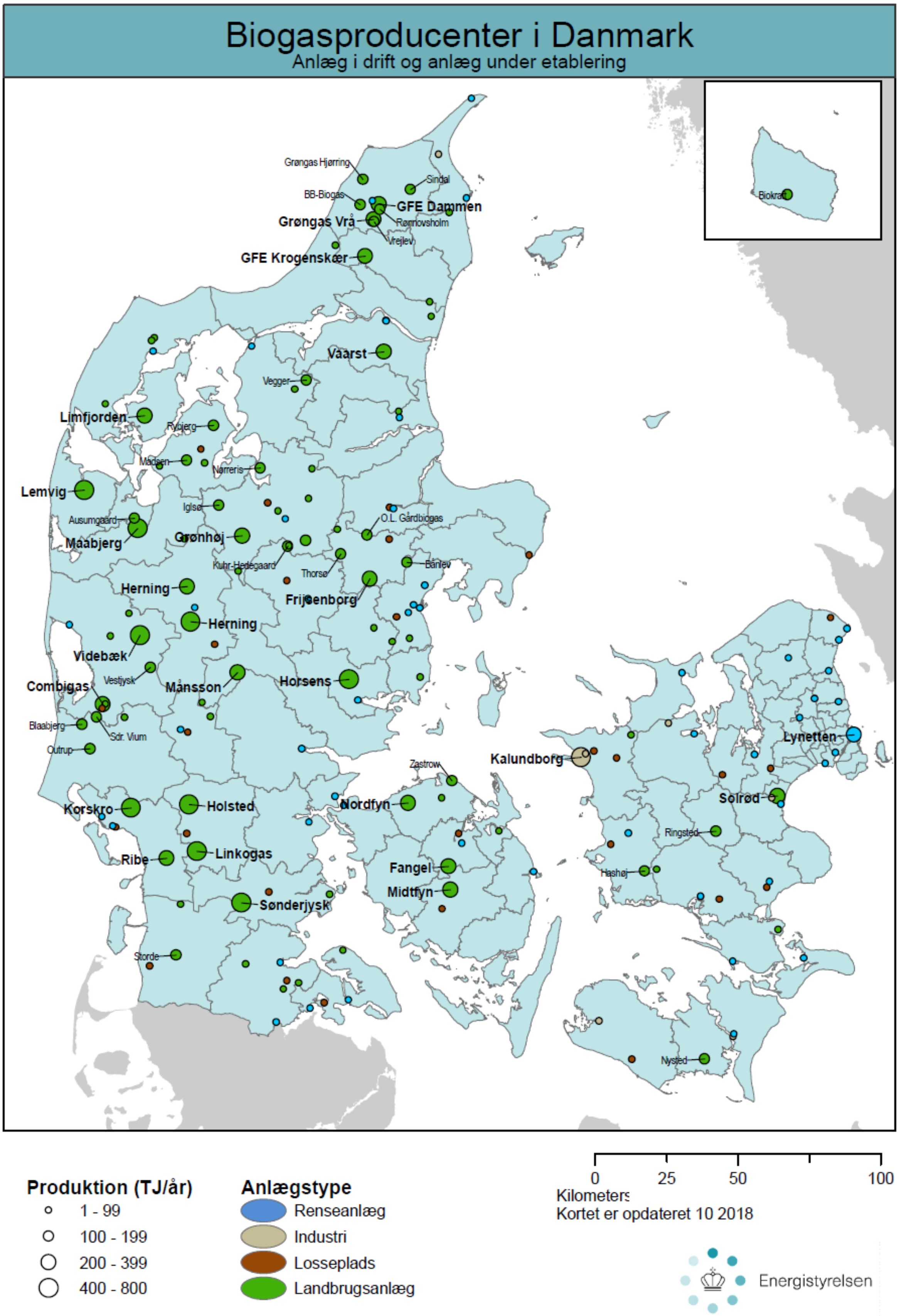



Figure 3D-2 Biogas producers in Denmark, 2018 (DEA, 2018c). WWT – waste water treatment.

For year 2015-2018, data for the actual amount and different types of biomass delivered to the biogas plants is available. Data is collected by the Danish Energy Agency (DEA, 2019b), based on reporting from each biogas plant and covers data from all the biggest biogas plants. In the following, these data are referenced as the BIB-register; Biomass Input to Biogas production. The BIB register does not fully cover all biogas plants, but the most important biogas producers, and thus it covers 80-90 % of the total biogas production.

Data regarding the amount of slurry delivered to biogas plants is available for the years 2001, 2015, 2016, 2017 and 2018. Data for year 2001 is based on a single investigation provided by the DEA – the Danish Energy Agency, while the data for year 2015-2018 is based on the BIB – register. For the intervening years, 1990-1999 and 2002-2014, the data for amount of slurry delivered to the biogas production is based on an interpolation, by using the relation between the amount of slurry delivered and the total energy production produced at the biogas plants. The total energy production from biogas plants for all years is based on the Energy Statistics (DEA, 2019a).

In 1990, the biogas production at the large-scale, farm-level and industrial biogas plants is 266 TJ, which correspond to slurry input of 220 kt, increasing to 12 244 TJ and 5 739 kt slurry in 2018.

In 2018, around 15 % of total amount of slurry is delivered to biogas production, 21 % of the total amount of cattle slurry and 11 % for swine slurry.

Table 3D-25 Biogas production, 1990-2018.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Biogas production, TJ**[1] | | | | | | | | | | | |
| Total | 752 | 1758 | 2912 | 3830 | 4337 | 4588 | 5561 | 6285 | 9048 | 11053 | 13414 |
| Large-scale, farm-level and industrial biogas plants | 266 | 746 | 1442 | 2375 | 3184 | 3434 | 4359 | 5199 | 7795 | 9882 | 12244 |
| **Slurry delivered to biogas plants, kt**[2] | | | | | | | | | | | |
| Cattle, swine and mixed | 220 | 617 | 1192 | 1779 | 2076 | 2038 | 2503 | 2884 | 4142 | 5263 | 5739 |
| Percent of total produced slurry | 1 | 2 | 4 | 5 | 6 | 5 | 7 | 8 | 11 | 14 | 15 |

[1]DEA, 2019a.

[2]DEA, 2019b.

The anaerobic digestion process is complicated and sensitive to several factors, such as different biomass types and different combination of biomass input, nutrients concentration, species and concentration of bacteria, operational conditions for each biogas plants, etc. Uses of current data from the BIB register will to some extend take these variations from biogas plant to biogas plant into account, because the data is based on existing production.

### Calculation method for the national MCF

MCF is estimated by using the Tier 2 equation for estimating $CH_4$ emission factor from manure management from IPCC 2006:

$$\mathrm{MCF}_{not\ digested} = \left(\frac{E_{barns} + E_{storage,not\ digested}}{VS_{barns}}\right) / (0.67 \cdot B_0) \qquad \text{(Eq. 3D-1)}$$

Where:

$MCF_{not\ digested}$ = methane conversion factor for not digested slurry, %
$E_{barns}$ = emission of $CH_4$ from barns, kg $CH_4$, see Equation 3D-3
$E_{storage,\ not\ digested}$ = emission of $CH_4$ from storage of not digested slurry, kg $CH_4$, see Equation 3D-4
$VS_{barns}$ = amount of volatile solids, kg VS, based on VS excreted, see Table 3D-27
$B_0$ = maximum methane producing capacity, $m^3$ $CH_4$ per VS
0.67 = conversion factor, $CH_4$ per $m^3$ $CH_4$

$$\mathrm{MCF}_{digested} = \left(\frac{E_{barns}+E_{storage,digested}}{VS_{barns}}\right)/(0.67 \cdot B_0) \qquad \text{(Eq. 3D-2)}$$

Where:

$MCF_{digested}$ = methane conversion factor for digested slurry, %
$E_{barns}$ = emission of $CH_4$ from barns, kg $CH_4$, see Equation 3D-3
$E_{storage,\ digested}$ = emission of $CH_4$ from storage of not digested slurry, kg $CH_4$, see Equation 3D-4
$VS_{barns}$ = amount of volatile solids, kg VS, based on VS excreted, see Table 3D-27
$B_0$ = maximum methane producing capacity, $m^3$ $CH_4$ per VS
0.67 = conversion factor, $CH_4$ per $m^3$ $CH_4$

**Estimation of methane emission from raw cattle and swine slurry and anaerobic digested animal manure**

The $CH_4$ emission from liquid cattle and swine manure is based on $CH_4$ emission from barns, from outdoor stored raw cattle and swine slurry, from anaerobic digesters and from anaerobically digested biomass/primarily animal manure.

**Emission of $CH_4$ from barns**

$$\mathrm{E}_{barns} = \mathrm{VS}_{barns} \cdot \mathrm{EF}_{barns} \cdot \mathrm{HRT}/365 \qquad \text{(Eq. 3D-3)}$$

Where:

$E_{barns}$ = emission of $CH_4$ from barns, kg $CH_4$
$VS_{barns}$ = amount of volatile solids, kg VS, based on VS excreted, see Table 3D-27
$EF_{barns}$ = emission factor for $CH_4$, based on measurements see Table 3D-26
HRT = Hydraulic Retention Time, days, see Table 3D-27

**Emission of $CH_4$ from storage of not digested slurry**

$CH_4$ emission from storage of slurry is estimated as VS multiplied by EF where VS is divided in VS degradable (VSd) and VS non-degradable[1] (VSnd).

$$\mathrm{E}_{Storage,not\ digested} = \mathrm{VSd}_{storage,not\ digested} \cdot \mathrm{EFd}_{storage,not\ digested} + \mathrm{VSnd}_{storage,not\ digested} \cdot \mathrm{EFnd}_{storage,not\ digested} \qquad \text{(Eq. 3D-4)}$$

Where:

[1] Non-degradable could also be refed to as low-degradable because a small decomposition is possible.

| | |
|---|---|
| $E_{storage, not digested}$ | = emission of $CH_4$ from storage of not digested slurry, kg $CH_4$ |
| $VSd_{storage, not digested}$ | = amount of degradable volatile solids in the slurry not digested, see Table 3D-27 |
| $EFd_{storage, not digested}$ | = emission factor for $CH_4$ for degradable VS, see Table 3D-26 |
| $VSnd_{storage, not digested}$ | = amount of non-degradable volatile solids in the slurry not digested, see Table 3D-27 |
| $EFnd_{storage, not digested}$ | = emission factor for $CH_4$ for degradable VS, see Table 3D-26 |

**Emission of $CH_4$ from storage of digested slurry**

$$E_{Storage,digested} = VS_{storage,digested} \cdot EF_{storage,digested} \quad \text{(Eq. 3D-5)}$$

Where:

| | |
|---|---|
| $E_{storage, digested}$ | = emission of $CH_4$ from storage of digested slurry, kg $CH_4$ |
| $VS_{storage, digested}$ | = amount of volatile solids in the slurry digested, see Table 3D-27 |
| $EF_{storage, digested}$ | = emission factor for $CH_4$ for VS, see Table 3D-26 |

Table 3D-26 Estimated emission factors.

| Cattle | |
|---|---|
| $EF_{barns}$, g $CH_4$ per kg VS per year | 179.79 |
| $EFd_{storage, not digested}$, g $CH_4$ per kg VSd per year | 28.08 |
| $EFnd_{storage, not digested}$, g $CH_4$ per kg VSnd per year | 0.51 |
| $EF_{storage, digested}$, g $CH_4$ per kg VS per year | 1.76 |
| **Swine** | |
| $EF_{barns}$, g $CH_4$ per kg VS per year | 563.22 |
| $EFd_{storage, not digested}$, g $CH_4$ per kg VSd per year | 29.58 |
| $EFnd_{storage, not digested}$, g $CH_4$ per kg VSnd per year | 0.56 |
| $EF_{storage, digested}$, g $CH_4$ per kg VS per year | 1.76 |

Table 3D-27a-c shows the estimated $CH_4$ emission from liquid cattle and swine slurry for the years 1990-2018. Table 3D-27a-c shows the total amount of liquid VS excreted by cattle and swine, the average HRT, the estimated g $CH_4$ per kg VS and the total emission of $CH_4$ from that category.

For cattle slurry, the total emission in barns in 1990 has been estimated to 10.32 kt $CH_4$ increasing to 13.69 kt $CH_4$ in 2018. The increase in this emission is due to change in housing systems where the slurry is kept in the housings longer and more slurry. In addition to this comes an emission from outdoor storage, estimated to 10.29 kt $CH_4$ in 1990 and decreased to 9.64 kt $CH_4$ in 2018. To this comes a small amount from digested manure (Table 3D-27c).

For swine slurry has the total emission inside the barns in 1990 been estimated to 18.71 kt $CH_4$ in 1990 increasing to 26.37 kt $CH_4$ in 2018, due to a growing swine production until 2011. To this comes an emission from outdoor storage. This has been estimated to 6.51 kt $CH_4$ in 1990 and an increase to 10.68 kt $CH_4$ in 2018. The increase in this emission is due to increase in the share of degradable volatile solids in the slurry. In addition, a small amount is realised from the digested manure (Table 3D-27c).

Table 3D-27a Emission estimates for cattle slurry inside the barns and not digested stored liquid manure.

| Cattle | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Barns | | | | | | | | | | | |
| Slurry, tonnes VS per year | 1 140 939 | 1 044 346 | 1 014 726 | 1 160 046 | 1 204 501 | 1 286 630 | 1 284 391 | 1 281 868 | 1 305 683 | 1 321 646 | 1 342 416 |
| EF, g $CH_4$ per kg VS per year | 179.79 | 179.79 | 179.79 | 179.79 | 179.79 | 179.79 | 179.79 | 179.79 | 179.79 | 179.79 | 179.79 |
| Average HRT, days | 18.36 | 18.48 | 21.47 | 21.25 | 21.17 | 21.82 | 21.27 | 21.21 | 21.07 | 20.97 | 20.70 |
| EF, g $CH_4$ per kg VS per year | 9.04 | 9.10 | 10.58 | 10.47 | 10.43 | 10.75 | 10.48 | 10.44 | 10.38 | 10.33 | 10.20 |
| Emission, kt $CH_4$ per year | 10.32 | 9.51 | 10.73 | 12.14 | 12.56 | 13.83 | 13.46 | 13.39 | 13.55 | 13.65 | 13.69 |
| Storage, not digested | | | | | | | | | | | |
| Slurry, not digested, tonnes VSd ab barn | 352 702 | 315 688 | 293 571 | 327 969 | 339 836 | 368 904 | 362 316 | 356 196 | 345 984 | 331 472 | 330 611 |
| Slurry, not digested, tonnes VSnd ab barn | 755 765 | 676 715 | 635 045 | 708 967 | 734 449 | 798 852 | 783 264 | 769 883 | 747 513 | 715 923 | 713 487 |
| EF, g $CH_4$ per kg VSd per year | 28.08 | 28.08 | 28.08 | 28.08 | 28.08 | 28.08 | 28.08 | 28.08 | 28.08 | 28.08 | 28.08 |
| EF, g $CH_4$ per kg VSnd per year | 0.51 | 0.51 | 0.51 | 0.51 | 0.51 | 0.51 | 0.51 | 0.51 | 0.51 | 0.51 | 0.51 |
| Emission, kt $CH_4$ per year | 10.29 | 9.21 | 8.56 | 9.57 | 9.91 | 10.76 | 10.57 | 10.39 | 10.09 | 9.67 | 9.64 |

Table 3D-27b Emission estimates for swine slurry inside the barns and not digested stored liquid manure.

| Swine | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Barns | | | | | | | | | | | |
| Slurry, tonnes VS per year | 549 494 | 720 278 | 819 274 | 944 522 | 950 766 | 901 919 | 935 067 | 930 091 | 922 126 | 920 921 | 950 925 |
| EF, g $CH_4$ per kg VS per year | 563.22 | 563.22 | 563.22 | 563.22 | 563.22 | 563.22 | 563.22 | 563.22 | 563.22 | 563.22 | 563.22 |
| Average HRT, days | 22.06 | 21.76 | 21.22 | 19.41 | 19.19 | 18.77 | 18.68 | 18.62 | 18.42 | 18.08 | 17.97 |
| EF, g $CH_4$ per kg VS per year | 34.04 | 33.58 | 32.75 | 29.95 | 29.62 | 28.97 | 28.83 | 28.74 | 28.42 | 27.90 | 27.73 |
| Emission, kt $CH_4$ per year | 18.71 | 24.19 | 26.83 | 28.29 | 28.16 | 26.13 | 26.95 | 26.73 | 26.21 | 25.69 | 26.37 |
| Storage, not digested | | | | | | | | | | | |
| Slurry, not digested, tons VSd ab barn | 215 034 | 280 411 | 317 300 | 371 345 | 372 827 | 355 101 | 365 648 | 361 046 | 348 648 | 343 780 | 353 321 |
| Slurry, not digested, tons VSnd ab barn | 266 669 | 346 385 | 389 186 | 444 931 | 445 491 | 422 055 | 434 079 | 428 311 | 412 520 | 405 037 | 415 700 |
| EF, g $CH_4$ per kg VSd per year | 29.58 | 29.58 | 29.58 | 29.58 | 29.58 | 29.58 | 29.58 | 29.58 | 29.58 | 29.58 | 29.58 |
| EF, g $CH_4$ per kg VSnd per year | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 |
| Emission, kt $CH_4$ per year | 6.51 | 8.49 | 9.60 | 11.23 | 11.28 | 10.74 | 11.06 | 10.92 | 10.54 | 10.40 | 10.68 |

Table 3D-27c Emission estimates for digested biomass.

| Digested biomass | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| VSd, tonnes | 10 697 | 29 950 | 57 893 | 108 744 | 168 171 | 195 860 | 254 739 | 262 836 | 286 129 | 359 253 | 428 335 |
| EF, g $CH_4$ per kg VS per year | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 |
| Emission, kt $CH_4$ per year | 0.02 | 0.05 | 0.10 | 0.19 | 0.30 | 0.34 | 0.45 | 0.46 | 0.50 | 0.63 | 0.75 |

### Documentation for estimation of the national MCF

$CH_4$ formation in manure is mainly formed by microorganisms that produce methane as a metabolic by-product in anoxic conditions. They are classified as archaea, a domain distinct from bacteria. The metabolism is temperature dependent, and actual temperatures are therefore the main driver for the methanogenesis. The overall methodology for estimating the $CH_4$ emission from liquid animal manure and anaerobically digested biomass is based on the available amount of volatile substance (VS) in the biomass and the temperature dependent $CH_4$ formation functions (Van't-Hoof/Arrhenius equation) (Sommer et al., 2004). The model by Sommer et al. (2004) uses a 2-pooled concept for estimating the $CH_4$ emission from degradable VS (VSd) and from non-degradable[2] VS (VSnd). The emission from VSnd has been set to 1 % of VS (Sommer et al., 2001, 2004). During storage inside the barns, in outdoor storages and in the anaerobic digesters VS is degraded. To take into haccount a "decreasing" emission due to depletion of the VS in the manure in up to 8-9 months a degradation model has been developed.

For the purpose of documenting the emission estimate in the inventories the following tasks have been performed:

- a thorough literature search
- estimation of temperature functions for animal manure stored
  - inside the barns for swine and cattle barns
  - outdoor storage for untreated liquid manure
  - anaerobically digested manure
- estimation of storage time, HRT (Hydraulic Retention Time) in the barns (Kai et al., 2015)
- temperature dependent $CH_4$ formation from 20 samples of different types of liquid swine manure and 12 samples of different type of liquid dairy cattle manure (Petersen et al., 2016)
- developing a model to estimate the storage time in outdoor liquid manure stores
- compilation of data from BIB. The BIB include information on suppliers, amount and types of manure and other biomass used in the Danish anaerobic digesters
- developing an emission model based on time steps of 10 days

### Dry matter excretion and VS, VSd and VSnd

The amount of excreted dry matter is taken from the Danish Normative System for animal manure (data included in IDA). The share of VS of dry matter is set as a default to 80 % as used in the agricultural inventories.

In the model for estimating the $CH_4$ emission a 2-pooled model is used, dividing the VS in VSd and VSnd (Tong et al., 1990, Sommer et al., 2004). The share of VSd and VSnd has for the purpose of the inventories been estimated by Petersen et al. (2016) for swine (sow, weaners and fattening pigs) and cattle slurry (mainly dairy cattle slurry). The manure samples were taken in barns in full production and can thus be seen as normal farming practise. Petersen et al. (2016) estimated the average age of the swine slurry to 13-15 days and the cattle slurry to around 20-30 days. The slurry samples can therefore be seen as quite fresh manure with only little degradation.

[2] Non-degradable could also be refed to as low-degradable because a small decomposition is possible.

Petersen et al. (2016) sampled 20 swine slurry samples and 12 dairy cattle slurry samples and estimated the VSd. For swine manure they found an average VSd of 51 % (95 % Confidence Interval: 44 – 57 %) and for slurry for dairy cattle a VSd of 33 % (95 % Confidence Interval: 29 – 37 %).

Møller and Moset (2015) has measured dry matter and VS in digested manure from eight biogas plants. They found an average dry matter in the digested manure of 4.88 % were VS of dry matter in average were 3.32 %. Møller (2016) has measured the B0-value of the digestate from the continuous biogasplants to 13.8 indicating that the major part of the digestate is non-degradeable. Based on the model, which take storage time and temperature into account, the emission factor for $VS_{digested}$ were estimated to 1.76 g $CH_4$ per kg VS per year.

**Parameters for Arrhenius function**

Estimation of the parameters for Arrhenius function is based on Petersen et al. (2016) with a *lnA* based on degadeable VS (VSd) for undigested slurry combined on data from Elsgaard et al. (2016) and  et al. (2018) with a lnA for digested manure based on total VS (VSd and VSnd).

The determination of methane production rates largely followed the description of Petersen et al. (2016). Two temperatures were selected at approximately 10 and 20°C (Petersen et al., 2016). To estimate the parameters 20 samples from swine slurry and 11 samples from cattle slurry were used. In effect, cattle slurry was always incubated at around 10 °C, and swine slurry around 20 °C.

Methane production rates observed, corrected to the ambient temperature in slurry pits and channels at sampling time, were compared with predictions based on the model presented by Sommer et al. (2001):

$$F(T) = \left(VS_d * b_1 * \exp\left(lnA - E_a * \left(\frac{1}{RT}\right)\right) + VS_{nd} * b_2 * \exp(lnA - E_a * \left(\frac{1}{RT}\right))\right) \cdot 24 \quad \text{(Eq. 3D-6)}$$

Where:

| | |
|---|---|
| F(T) | = g $CH_4$ per day |
| VSd | = volatile solids, degradable, kg |
| VSnd | = volatile solids, non-degradable, kg |
| b1 and b2 | = scaling factors, 1 for VSd and 0.01 for VSnd (dimension-less) |
| *lnA* | = Arrhenius parameter, g $CH_4$ per kg $VS_d$ per h or g $CH_4$ per kg VS per h (digestate) |
| Ea | = the apparent activation energy, J per mol |
| R | = the gas constant, 8.314 J per mol per K |
| T | = temperature, K |
| 24 | = conversion from hour to day |

An activation energy, Ea, of 81  kJ per mol was recently proposed by Elsgaard et al. (2016) which represented the temperature response of a cattle slurry, a swine slurry, fresh digestate and stored digestate (no significant differences).

In Table 3D-28 is shown the used parameters.

Table 3D-28 $CH_4$ emission estimate parameters. Petersen et al. (2016) combined with Elsgaard et al. (2016) and Maldanera et al. (2018).

| | Ea, kJ per mol | Ln(A), g $CH_4$ per kg VS per hour | VSd, % | VSnd, % |
|---|---|---|---|---|
| Liquid cattle manure | 81.0 | 31.2 | 33 | 67 |
| Liquid swine manure | 81.0 | 31.3 | 51 | 49 |
| Digestate | 81.0 | 27.9 | 100[a] | 0 |

[a]For digesgtate is the model parameter set to 100 mimicking that all VS is degradeable

### Degradation function

Based on literature data and unpublished research data it was estimated that the C loss from manure stores constitutes roughly of 20 % $CH_4$-C and 80 % $CO_2$-C (Dinuccion et al., 2008). In the emission estimate a conservative figure of 25 % is used. Beside this Patni and Jui (1987) found 10-25 % losses of dry matter during storage of dairy cattle slurry supporting that a high share of loss of VS is taken place as $CO_2$ as this is not lost as $CH_4$. For effluent from digested animal manure, Wang et al. (2016) found very low $CH_4/CO_2$ ratios at around 3-4 % (unpublished data received from Yue Wang). For the digestate, an estimate for $CH_4$-C/$CO_2$-C fraction of 10 % is used (Dong, 2013, Pers. Comm.).

The $CH_4$/degradation model was built in an excel spreadsheet with a time step of 10 days.

### Danish animal housing systems and Hydraulic Retention Time (HRT)

The most common housing systems for swine in Denmark are partly plug-systems with slatted floors and a depth of the slurry channels of 40-60 cm. The storage capacity inside the barns in these systems is around 40 days. After 40 days the farmers pull the plugs and the slurry under the slats are flushed to the outdoor storage tanks. During the production cycle of weaners and fattening pigs it is normally only needed to flush once during the production, and once after the pigs have been moved and the barn is washed and cleaned. In these systems the average storage time is therefore app. 40 days/2 = 20 days. The average storage time is named the Hydraulic Retention Time (HRT).

For the purpose of the Danish inventories Kai et al. (2015) have investigated/measured the storage capacity in swine and cattle barns and estimated the HRT for all barn types mentioned in the Danish Normative System for animal manure.

Animal housing systems change over time. To take into account changes in the HRT inside the barns over time since 1990, the shares of the different barn types have been multiplied with the HRT for each barn type and summed for swine and cattle slurry to get the average HRT for swine and cattle slurry (Table 3D.29). The HRT for liquid cattle manure has increased since 1990. This is mainly because in the 1990'ies there was a high share of tied-up dairy cattle with liquid handling and frequent removal of the slurry. These were later replaced by cubicles combined with slats. In recent years cubicles with scrapers are becoming more common so a decrease in the HRT for cattle is expected in the future. The most common housing system for swine has until recently been fully slatted floors. A ban on fully slatted floors forced the farmers to build partly slatted floors/drained floors. This has reduced the storage capacity below the slats and thus reduced the average HRT for swine slurry.

Table 3D-29 Average Hydraulic Retention Time (HRT) in cattle and swine barns from 1990 to 2018.

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cattle | 18.36 | 18.48 | 21.47 | 21.25 | 21.17 | 21.82 | 21.27 | 21.21 | 21.07 | 20.97 | 20.70 |
| Swine | 22.06 | 21.76 | 21.22 | 19.41 | 19.19 | 18.77 | 18.68 | 18.62 | 18.42 | 18.08 | 17.97 |

In the emission estimate, it is assumed that all manure regardless of whether it is used for anaerobic digestion or not is having the same HRT. The data collected by Kai et al. (2015) do not prove that farms delivering manure to anaerobic digestion are empting their slurry channels more frequently than farmers who are not.

#### Temperatures

Based on average air temperature for the period 2001-2010, measured temperatures and literature data temperature functions have been developed.

#### Insulated swine barns

Only few measured slurry temperatures inside the barns can be found in the literature. Some measurements have been made by SEGES (Holm, 2015). Besides this, Petersen et al. (2016) have measured slurry temperatures in 27 different swine barns in November and December 2014 in connection with the $CH_4$ emission parameterisation. Holm (2015, Pers. Comm.) has made 48 measurements in barns with fattening pigs at different times of the year and found an average slurry temperature of 18.6 °C (16.0-21.8 °C) with a standard deviation of 1.29. The highest temperatures were measured in summer. When the average outdoor temperature was 16-17 °C the slurry temperature tended to be around 19 °C. In winter when the average outdoor temperature was around 2-5 °C the slurry temperature was 17-18 °C (Figure 3D-5). The dots represent different combinations of slurry height and temperatures. Petersen et al. (2016) found an average temperature of 18.7 °C in their measurements in November and December. In the inventories are used the average data of 18.6 °C from SEGES throughout as the data are not sufficient qualified to distinguish between winter and summer. Figure 3D-3 shows the measured data by SEGES.

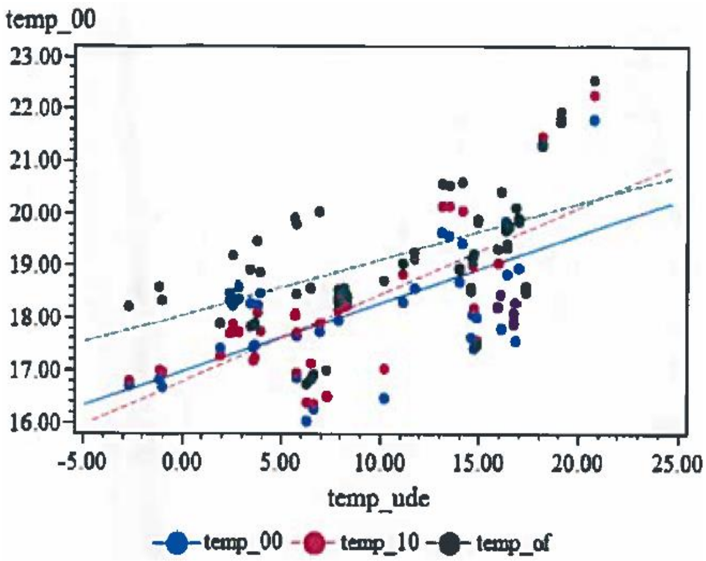



Figure 3D-3 Measured slurry temperature in fattening pig slurry channel in different times during the production cycle. The different colours indicate different slurry heights in the slurry channel (Holm, 2015).

### Open cattle barns

Most cattle barns in Denmark are naturally ventilated. Inside the barns the air temperature is generally 5-6 °C higher than the outdoor temperature. The manure temperature inside the slurry channels do not follow the air temperature closely (Andersen and Grønkjær, 2020). In 2017 and 2018 temperature measurements were carried out in one cattle barn in the Southern Denmark and one in the Northern Denmark with logging 2-5 times per day. As Denmark is quite small these data were combined and converted to a sine-wave representing whole Denmark (Figure 3D-4).

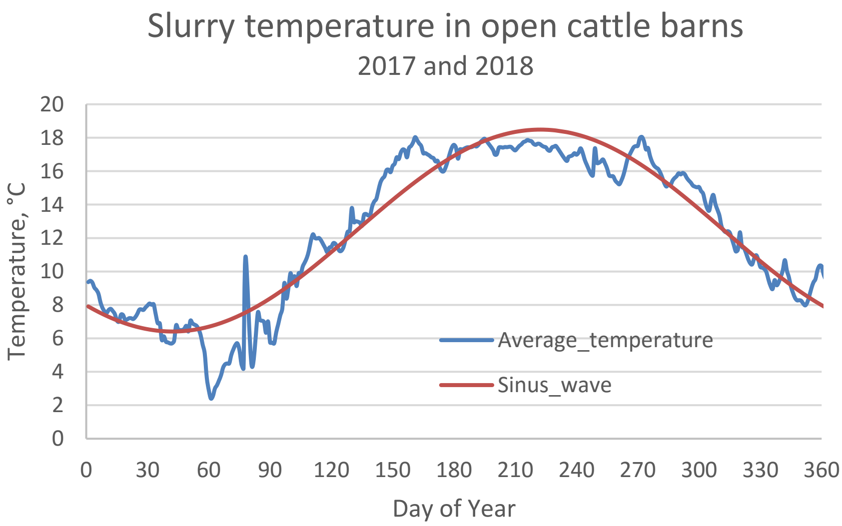



Figure 3D-4 Average daily measured slurry temperature in two cattle barns in 2017 and 2018 (Andersen and Grønkjær, 2020).

In Table 3D-30 is given the parameters for the Sine-function which estimates the daily average air temperatures.

Table 3D-30 Parameters for the Sine-function (y=a+ b sin (2πx/d+c)) for air temperature. $R^2$ = 0.92

| Parameter | Value | Std Error | t-value | 95% confidence limits | |
|---|---|---|---|---|---|
| a | 12.45 | 0.087 | 142.64 | 12.28 | 12.62 |
| b | 6.04 | 0.098 | 61.55 | 5.84 | 6.23 |
| c | 3.97 | 0.046 | 86.73 | 3.89 | 4.07 |
| d | 360.08 | 4.209 | 85.55 | 351.80 | 368.35 |

### Outdoor storage temperatures

The temperature in outdoor slurry tanks is expected to follow the outdoor temperature to a great extent. As with indoor storage only few data can be found in the literature. The temperature is a function of the loading with slurry, the actual amount stored and the solar radiation. If data from other climatic conditions is used they therefore have to be converted to Danish conditions. E.g. Park et al. (2006) found a linear relation between air temperature and slurry temperature in Canada with the following model parameters: Slurry_temperature = Air_temperature * 0.879 + 4.24 (Figure 3D-5). However, the locations used for this study is far more southern than Denmark and are thus not suited for Danish conditions, especially not during summer where a higher solar radiation is occurring. Hansen et al. (2006) measured the slurry temperatures in slurry tanks throughout a year on three farms receiving digestate from anaerobic digesters. They found also a linear relation similar to Park et al. (2006) with the parameters Slurry_temperature = Air_temperature * 0.75 + 6.23 (Figure 3D-5). The measurements by Hansen et al. (2006) cannot be seen as representative for raw liquid manure as the digestate as a starting point is having a higher temperature than raw slurry due to the exothermic process in the anaerobic digesters. The model by Hansen et al. (2006) is used for anaerobic digested manure as this is likely a normal temperature profile for digestate returned to the farms for continued storage.

For raw slurry a linear model has been constructed with data from Husted (1994) and Rodhe et al. (2009, 2012, 2015) with the following parameters Slurry_temperature = Air_temperature * 0.5011 + 5.1886 ($r^2 = 0.75$).

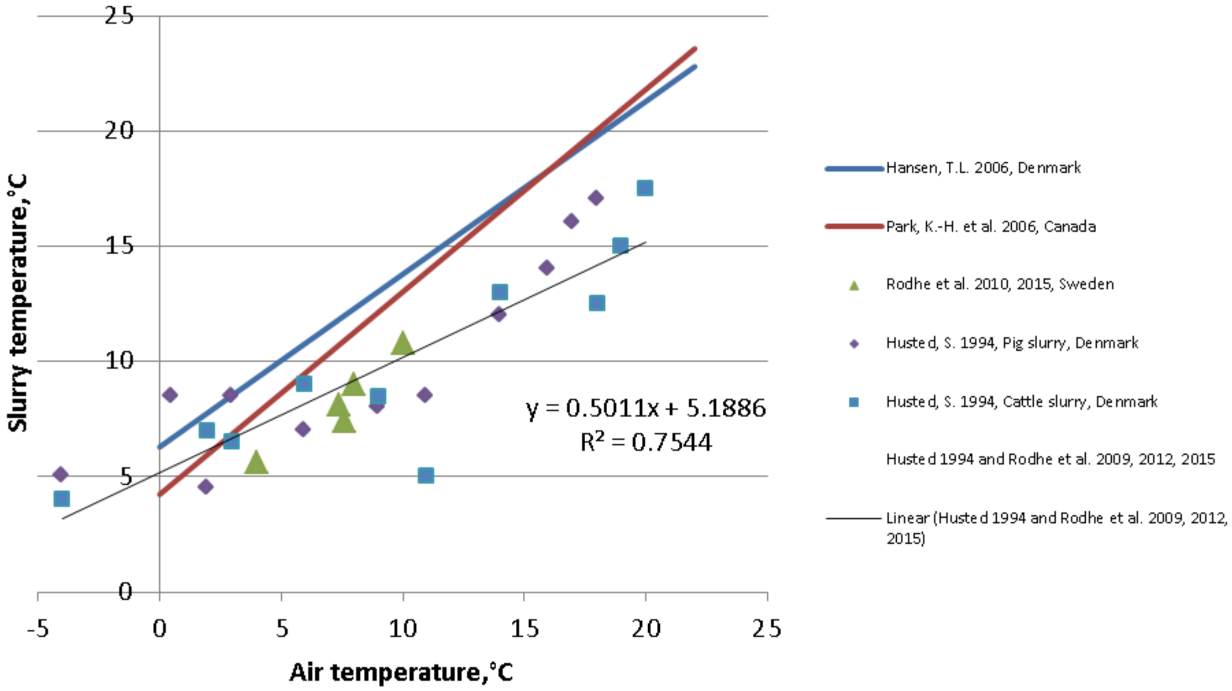



Figure 3D-5 Measured and modelled slurry temperatures in outdoor storage tanks.

**Manure storage and application to fields**

The Ministry of Environment and Food of Denmark regulate the storage time and the secondary field application of raw biomass and digested biomass. The general rule is that manure is only allowed to be applied to crops, which have a nitrogen norm and is harvested the same calendar year. Only crops with an official nitrogen norm are allowed to be fertilised.

It means that autumn application is not allowed as these crops are not harvested within the calendar year. The storage manure capacity is therefore 8-10 months including eventually storage capacity inside the barns.

Field application of manure is not allowed before February 1st and not on frozen or snow covered areas. Because of difficulties for driving in the fields the optimum application time is March and April, plus some application to grass cuttings during summer. In cooperation with the Danish Agricultural Advisory Centre (SEGES), a general storage profile for animal manure storages has been developed, Figure 3D-6. The figure shows that the maximum storage is in February and the minimum in end April. Slurry is generally stored in four meter deep concrete tanks where two meters are above ground and two meters below ground. As it is not possible to empty the tanks completely (crust cover) it is assumed that 10 % of the annual production is the minimum amount stored by end of April.

No reduction in the $CH_4$ emission due to microbial degradation in the crust cover (IPCC 2006) is implemented in the emission estimate so far.

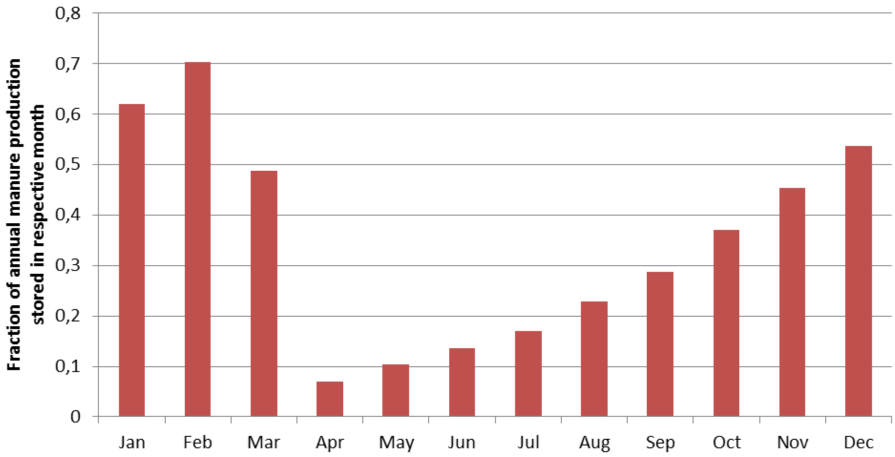



Figure 3D-6 The fraction of animal manure stored during different month of the year. The fraction is the share of the total annual manure production corrected for grazing. Small amounts are applied to grass during summer giving a lower increase in the summer months than in the winter period.

**The model**

The model estimates methane emission for slurry from cattle and swine. Estimations of $CH_4$, VSd and VSnd is based on measurements (Petersen et al., 2016). The measurements are not made on the exact time for excretion of the manure and the $CH_4$ emission is therefore calculated as a constant emission per day, even though some degrading of VS in the barn will take place. The $CH_4$ emission in barns for swine at 18.6 °C is estimated to 563.22 g $CH_4$ per kg VS per year, corresponding to 1.54 g $CH_4$ per kg VS per day. VS from barns are not divided in VSd and VSnd because the measured emission relate to the total amount of VS. The total $CH_4$ emission from barns is calculated as excreted VS multiplied by 1.54 g $CH_4$ per kg VS per day and average storage time (HRT) in the barn.

For cattle barns the temperature varies through the year. The emission factor of 179.79 g $CH_4$ per kg VS per year given in Table 3D-26 is an average for a year. For cattle total $CH_4$ emission from barns is also calculated as VS multiplied with average store time (HRT). It is assumed that excretion of VS in barns is constant. The period in which the cattle is on grass gives less manure in the barns, but this is not taken in to account. It is assumed that the effect of grazing is very small because the majority of dairy cattle in Denmark spend most of the time in the barns.

Methane emission from outdoor storage of not digested slurry is estimated in a matrix, where slurry is supplied and taken away with a time step of 10 days. The matrix sums the total methane emission until the decomposition of VS is almost null (around 2 years). The amount of VS supplied the storage is the total VS excretion from the animals and the straw used for bedding, subtracted VS-loss from barns. Removal of VSd and VSnd from storage is estimated for every time step and a new methane emission is calculated. For cattle slurry the estimation gives an emission of 0.51 g $CH_4$ per kg and for swine slurry the estimation gives 0.56 g $CH_4$ per kg VS (Table 3D-26).

For estimation of methane emission from outdoor storage of digested slurry, the amount of digested slurry delivered to the biogas plants based on the BIB register is used. Same model as used for not digested slurry is used for digested slurry, though with a higher temperature in the storage after biogas treatment. The stored digested slurry has a high content of VSnd and the emission of methane is therefore low. Due to the low activity of the decomposition, a lower $CH_4$:$CO_2$-ratio (of 0.1) is assumed for digested slurry compared to not digested slurry (Dong, 2013, Pers. Comm.).

**References**


Andersen, M and Grønkjær, A., 2020: Personal communication. Unpublished data on slurry temperatures in two cattle barns measured in 2017 and 2018. Danish Technological Institute, DTI.

DEA, 2019a: Energy Statistics received from DEA Nov. 2019.

DEA, 2019b: BIB register, covering data for biomass delivered to the biogas plants and the biogas production. Data received from DEA, Nov 2019.

DEA, 2018c: Available at: https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/energy-infomaps (2020).

Dinuccio, E, Berg, W. & Balsari, P. 2008: Gaseous emissions from the storage of untreated slurries and the fractions obtained after mechanical separation. Atm. Env. 42, 2448-2459.

Dong, H. 2013: Pers. Comm. Dr. Hongmin Dong, medforfatter til IPCC Guidelines og ansat i CAAS - Chinese Academy Of Agricultural sciences, Beijing.

Elsgaard, L., Olsen, A.B. & Petersen, S.O. 2016: Temperature response of methane production in liquid manures and co-digestates, Sci. of the Total Env. 539, pp 78-84.

Hansen, T.L., Sommer, S.G., Gabriel, S. & Christensen, T.H. 2006: Methane production during storage of anaerobically digested municipal organic waste. J. Environ. Qual., 35, 830-836.

Holm, M. 2015: Personal Communication. Unpublished data recorded in SEGESs Pig Research Centre, Vinkelvej 11, 8620 Kjellerup, Denmark.

Husted, S. 1994: Seasonal variation in methane emission from stored slurry and solid manures. J Environ Qual. 23:585–592.

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. & Tanabe K. (eds). Published: IGES, Japan. Available at:
http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (Jan. 2020).

Kai, P., Birkmose, T. & Petersen, S. 2015: Slurry in Danish livestock Buildings. Report by AgroTech to the Danish Energy Agency, pp 32.

Maldanera, L., Wagner-Riddle, C., Van derZaag, A. C., Gordon, R.,Duked, C., 2018: Methane emissions from storage of digestate at a dairy manure biogas facility, Agricultural and Forest Meteorology, Volume 258, 15 August 2018, Pages 96-107. Available at: https://www.sciencedirect.com/science/article/pii/S0168192317305981?via%3Dihub

Møller, H.B. 2013: Final Report: Biogas potentials in manure and effects of pretreatment (2009-1-010294). Report to the Danish Energy Agency.

Møller, Henrik Bjarne. 2016: Personal communication. Department of Engineering - Anaerobe Digestion Technologies, Aarhus University.

Møller, H.B. & Moset, V. 2015: Methane emissions from liquid manure storage – influence of temperature, storage time, substrate type and anaerobic digestion. Draft Final report 2015, Biogas Taskforce. Aarhus University, Department of Engineering.

Sommer, S.G., Møller, H.B. & Petersen, S.O. 2001: Reduktion af drivhusgasemission fra gylle og organisk affald ved Biogasbehandling. DJF rapport - Husdyrbrug, 31, 53 pp. (In Danish).

Sommer S.G., Petersen S.O. & Møller H.B. 2004: Algorithms for calculating methane and nitrous oxide emissions from manure management. Nutrient Cycling in Agroecosystems. 69, 143-154.

Park, K.-H., Thompson, A.G., Marinier, M., Clark, K. & Wagner-Riddle, C. 2006: Greenhous gas emissions from stored liquid swine manure in a cold climate. Atm. Env. 618-627.

Patni, N.K. & Jui, P.Y, 1987: Changes in solids and carbon content of dairy-cattle slurry in farm tanks. Bio. Wastes, 20, 11-34.

Petersen, S.O., Olsen, A.B., Elsgaard, L., Triolo, J.M.& Sommer, S.G. 2016: Estimation of Methane Emissions from Slurry Pits below Pig and Cattle Confinements. PLoS ONE 11(8): e0160968. doi:10.1371/journal.pone.0160968

Rodhe, L.K.K., Ascue, J., Willén, A., Persson, B.V. & Nordberg, Å. 2015: Greenhouse gas emissions from storage and field application of anaerobically digested and non-digested cattle slurry.

Rodhe, L., Ascue, J. & Nordberg, Å. 2009: Emissions of greenhouse gases (methane and nitrous oxide) from cattle slurry storage in Northern Europe. IOP Conf. Ser. Earth Environ. Sci. 8, 012019. doi:http://dx.doi.org/10.1088/1755-1315/8/1/012019

Rodhe, L.K.K., Abubaker, J., Ascue, J., Pell, M. & Nordberg, Å. 2012: Greenhouse gas emissions from pig slurry during storage and after field application in northern European conditions. Biosyst. Eng. 113, 379–394. doi:http://dx.doi.org/10.1016/ j.biosystemseng.2012.09.010

Tong, X., Smith, L.H. & McCarty, P.L. 1990: Methane fermentation of selected lignocellulosic materials. Biomass 21: 239–255.

Wang, P.R., 2012: Referenceværdier: Døgn-, måneds-og årsværdier for regioner og hele landet 2001-2010, Danmark for temperatur, relativ luftfugtighed, vindhastighed, globalstråling og nedbør. Teknisk rapport 12-24 DMI.

Wang, Y., Dong, H., Zhu, Z., Li, L. Zhou, T., Jiang, B. & Xin, H. 2016: $CH_4$, $NH_3$, $N_2O$ and NO emissions from stored biogas digester effluent of pig manure at different temperatures, Agr. Eco. Env. 217, 1-12.

## Annex 3E - LULUCF



### List of figures

Table 3E.1 Estimation of forest percentage and forest area.

| Equation | Description |
|---|---|
| $X_j = \frac{A_j}{A_{15,j}}$ | The forest percentage ( $X$ ) of the *j*th sample plot (SSU) is estimated as the forested area (*A*) divided by the total area of the 15 m radius sample plot ($A_{15,j}$). |
| $\bar{X}_Z = \frac{1}{n_Z}\sum_Z X_j R_j$ | Average forest percentage ( $\bar{X}$ ) of all inventoried plots (SSU) with forest status *Z* based on aerial photos. $R_j$ is an indicator variable that is 1 for inventoried plots and 0 otherwise. $n_Z$ is the number of inventoried plots identified as forest or OWL from the air photos. |
| $\bar{\bar{X}} = \frac{1}{n}\left(\sum_{j=1}^{n} X_j R_j + N_{21}\bar{X}_1 + N_{22}\bar{X}_2\right)$ | Overall average forest percentage ( $\bar{\bar{X}}$ ). *n* is the total number of inventoried and non-inventoried sample plots. $N_{21}$ and $N_{22}$ is the number of non-inventoried sample plots with forest and OWL, respectively. |
| $A_{Forest} = \bar{\bar{X}} \cdot A_{Total}$ | Total forest area. $A_{Total}$ is the total land area, $\bar{\bar{X}}$ is the estimated forest percentage and $A_{Forest}$ is the total forest area. |

Table 3E.2 Estimation of forest area with a specific characteristic.

| Equation | Description |
|---|---|
| $\bar{X}_k = \frac{\sum_{j=1}^{n} R_{jk} A_j}{\sum_{j=1}^{n} A_j}$ | Proportion of the forest area with a given characteristic ( $\bar{X}_k$ ). $R_{jk}$ is an indicator variable which is 1 if the the forest area on the *j*'th sample plots has the *k*'th characteristic and 0 otherwise. $A_j$ is the sample plot area and *n* is the total number of inventoried sample plots with forest cover. |
| $A_k = \bar{X}_k \cdot A_{Forest}$ | Total area with a given characteristic ($A_k$). $\bar{X}_k$ is the estimated proportion of the forest area with the *k*'th characteristic and $A_{Forest}$ is the total forest area. |

Table 3E.3 Estimation of diameter-height equations.

| Equation | Description |
|---|---|
| $h_{ij} = 13 + \left(\bar{h}_j - 13\right) \cdot \exp\left(\alpha_1 \cdot \left(1 - \frac{\bar{d}_j}{d_{ij}}\right) + \alpha_2 \cdot \left(\frac{1}{\bar{d}_j} - \frac{1}{d_{ij}}\right)\right)$ | Site specific dh-regression for calculating height of trees not measured for height. $h_{ij}$ and $d_{ij}$ is the height and diameter of the i'th tree on the j'th sample plot. $\bar{h}_j$ and $\bar{d}_j$ are the average height and diameter of trees measured for height on the *j*th sample plot. $\alpha_1$ and $\alpha_2$ are species and growth-region specific parameters |
| $h_{ij} = 13 + \beta_1 \cdot \exp(-\frac{\beta_2}{d_{ij}})$ | General dh-regression for calculating height of trees not measured for height. $h_{ij}$ and $d_{ij}$ is the height and diameter of the i'th tree on the j'th sample plot. $\beta_1$ and $\beta_2$ are species and growth-region specific parameters |

Table 3E.4 Estimation of quadratic mean diameter.

| Equation | Description |
|---|---|
| $g_{ij} = \frac{\pi}{4} d_{ij}^2$ | Basal area (*g*) of the *i*th tree on the *j*th plot is calculated from the diameter at breast height (*d*) (1.3 m above ground) assuming a circular stem form. |
| $G_j = \sum_{i=1}^{m} \frac{1}{A_{c,ij}} g_{ij}$ | Basal area per hectare (*G*) the jth sample plot is calculated as the scaled sum of individual tree basal areas. Basal area (*g*) of the *i*th tree on the *j*th sample plot is scaled according to the plot area ($A_{c,ij}$) of the *c*'th concentric circle (c=3,5; 10; 15 m). |
| $N_j = \sum_{i=1}^{m} \frac{1}{A_{c,ij}}$ | Stem number per hectare (*N*) the *j*th sample plot is calculated as the scaled number of individual trees. The *i*th tree on the *j*th sample plot is scaled according to the plot area ($A_{c,ij}$) of the *c*'th concentric circle (c=3,5; 10; 15 m). |
| $D_{g,j} = \sqrt{\frac{4}{\pi} \frac{G_j}{N_J}}$ | The mean squared diameter is calculated from the calculated basal area and stem number for each plot. |

Table 3E.5 Estimation of biomass and carbon of trees.

| Equation | Description |
|---|---|
| $v_{ij} = F\left(d_{ij}, h_{ij}, D_{g,j}\right)$ | The volume (*v*) of the *i*'th tree on the *j*th sample plots is calculated using the existing volume functions (*F*) using the tree diameter and height and the quadratic mean diameter. |
| $B_{ij} = V_{ij} \cdot Density_{ij}$ | Biomass (*B*) of the *i*th tree on the *j*th sample plot is estimated as the total volume ($V_{Tot}$) times the species-specific density. |
| $E_{ij} = F\left(d_{ij}, h_{ij}\right)$ | Expansion factor model for beech and Norway spruce |
| $v_{tot,ij} = B_{ij} \cdot E_{ij}$ | The total above and below ground volume ($v_{tot}$) of the ith tree on the jth sample plot. $B_{ij}$ is the calculated aboveground biomass of the tree and *E* is the expansion factor. |
| $C_{ij} = B_{ij} \cdot 0.5$ | Carbon of the *i*th tree on the *j*th sample plot is calculated as the biomass (*B*) times 0.5. |

Table 3E.6 Estimation of total biomass and carbon pools.

| Equation | Description |
|---|---|
| $V_{cj} = \frac{1}{A_{cj}} \sum_{i=1}^{m} R_{c,i} v_{ij}$ | Volume, biomass or carbon per hectare (*V*) of the *c*th concentric circle on the *j*th sample plot (*c*=3,5; 10; 15 m). $R_c$ is an indicator variable that is 1 if the *i*th tree is measured on the *c*th circle and 0 otherwise. $A_{c,ij}$ is the area of the *j*th sample plot and *c*th concentric circle; *m* is the number of trees on the *jth* sample plot. |
| $\bar{V}_c = \frac{\sum_{j=1}^{n} A_{cj} V_{cj}}{\sum_{j=1}^{n} A_{cj}}$ | The average area weighted volume, biomass or carbon per hectare ($\bar{V}$) of the *c*th concentric circle. $A_{c,ij}$ is the area of the *j*th sample plot and *c*th concentric circle; *n* is the number of sample plots. |
| $\bar{\bar{V}} = \bar{V}_{3,5} + \bar{V}_{10} + \bar{V}_{15}$ | The overall average volume, biomass or carbon per hectare ($\bar{\bar{V}}$) is estimated as the sum of the average volume, biomass or carbon per hectare ($\bar{V}_c$) for the three concentric circles (*c*=3.5, 10 and 15) |
| $V = \bar{\bar{V}} \cdot A_{Skov}$ | Total volume, biomass or carbon *V* is the overall average volume, biomass or carbon per hectare ($\bar{\bar{V}}$) times the forest area $A_{Forest}$. |

Table 3E.7 Estimation of biomass and carbon with a given characteristic.

| Equation | Description |
|---|---|
| $V_{cj,k} = \frac{1}{A_{cj}} \sum_{i=1}^{m} R_{c,ij} R_{k,ij} v_{ij}$ | Volume, biomass or carbon per hectare (*V*) with the *k*th characteristic of the *c*th concentric circle on the *j*th sample plot (c=3,5; 10; 15 m). $R_c$ is an indicator variable that is 1 if the *i*th tree is measured on the *c*th circle and 0 otherwise. $R_k$ is an indicator variable that is 1 if the tree has *k*th characteristic and 0 otherwise. $A_{c,ij}$ is the area of the *j*th sample plot and *c*th concentric circle; *m* is the number of trees on the *j*th sample plot. |
| $\bar{V}_{c,k} = \frac{\sum_{j=1}^{n} A_{cj} V_{cj,k}}{\sum_{j=1}^{n} A_{cj}}$ | The average area weighted volume, biomass or carbon per hectare ($\bar{V}$) with the *k*th characteristic of the cth concentric circle. $A_{c,ij}$ is the area of the *j*th sample plot and *c*th concentric circle; *m* is the number of trees on the *j*th sample plot. |
| $\bar{\bar{V}}_k = \bar{V}_{3,5,k} + \bar{V}_{10,k} + \bar{V}_{15,k}$ | The overall average volume, biomass or carbon per hectare with the *k*th characteristic ($\bar{\bar{V}}$) is estimated as the sum of the average volume, biomass or carbon per hectare ($\bar{V}_{c,k}$) for the three concentric circles (*c*=3.5, 10 and 15) |
| $V_k = \bar{\bar{V}}_k \cdot A_{Forest}$ | Total volume, biomass or carbon with the $k^{th}$ characteristic ($V_k$) is the overall average volume, biomass or carbon per hectare ($\bar{\bar{V}}_k$) times the forest area $A_{Forest}$. |

Table 3E.8 Estimation of biomass and carbon content of dead wood.

| Equation | Description |
|---|---|
| $v_{s,ij} = F\left(d_{s,ij}, h_{s,ij}, D_{g,j}\right)$ | The volume ($v_s$) of the *i*th standing, dead tree on the *j*th sample plots is calculated using the existing volume functions (*F*) using the tree diameter and height and the squared mean diameter. |
| $v_{l,ij} = \frac{\pi}{4} d_{l,ij}^2 \cdot l_{l,ij}$ | Volume of lying dead trees ($v_l$) is calculated as the length ($l$) and the ith tree on the jth sample plot times the cross sectional area. The cross sectional area is calculated from the mid-diameter ($d_l$) of the dead wood. |
| $B_{s,ij} = v_{s,ij} \cdot D_{ij} \cdot r_{k,ij}$<br>$B_{l,ij} = v_{l,ij} \cdot D_{ij} \cdot r_{k,ij}$ | Biomass of the *i*th standing ($B_s$) or lying ($B_l$) tree on the jth sample plot is calculated as the volume ($v_s$ or $v_l$) times the species specific density (*D*) and a the *k*th reduction factor according to the structural decay of the wood observed in the field. |
| $B_{s,tot,ij} = B_{s,ij} \cdot E_{ij}$ | The total above and below ground volume ($B_{s,tot}$) of the *i*th standing, dead tree on the *j*th sample plot. $v_s$ is the calculated biomass of the tree and *E* is the expansion factor. |
| $K_{s,ij} = B_{s,ij} \cdot 0.5$<br>$K_{l,ij} = B_{l,ij} \cdot 0.5$ | Carbon in standing or lying dead wood ($C_s$ or $C_l$) is calculated as the biomass ($B_s$ or $B_l$) times 0.5. |

Table 3E.9 Estimation of total biomass and carbon pools of dead wood.

| Equation | Description |
|---|---|
| $V_{D,cj} = \frac{1}{A_{cj}} \sum_{i=1}^{m} R_c v_{s,ij} + R_c v_{l,ij}$ | Deadwood volume, biomass or carbon pools per hectare ($V_D$) for the *c*th circle and the *j*th sample plot. $v_s$ and $v_l$ is the volume of standing and lying deadwood respectively. $R_c$ is an indicator variable that is 1 if the tree is measured in the *c*th circle and 0 otherwise. $A_C$ is the sample plot area of the *c*th circle. *m* is the number of trees within the *j*th sample plot. |
| $\overline{V}_{D,c} = \frac{\sum_{j=1}^{n} A_{cj} V_{cj}}{\sum_{j=1}^{n} A_{cj}}$ | The average area weighted deadwood volume, biomass or carbon per hectare ($\overline{V}_D$) of the cth concentric circle. $A_{c,ij}$ is the area of the jth sample plot and cth concentric circle; *n* is the number of sample plots. |
| $\overline{\overline{V}}_D = \overline{V}_{D,3,5} + \overline{V}_{D,10} + \overline{V}_{D,15}$ | The overall average deadwood volume, biomass or carbon per hectare ( $\overline{\overline{V}}_D$ ) is estimated as the sum of the average volume, biomass or carbon per hectare ($\overline{V}_{D,c}$) for the three concentric circles (c=3.5, 10 and 15) |
| $V_D = \overline{\overline{V}}_D \cdot A_{Forest}$ | Total deadwood volume, biomass or carbon $V_D$ is the overall average deadwood volume, biomass or carbon per hectare ($\overline{\overline{V}}_D$) times the forest area $A_{Forest}$. |

Table 3E.10 Estimation of forest floor carbon.

| Equation | Description |
|---|---|
| $C_{floor,s,j} = Depth_j \cdot A_j \cdot B_s \cdot F_{s,j}$ | Forest floor carbon ($C_{floor,s,j}$) of the *s*th species, on the *j*th plot with an area of *A*. $B_s$ is the species specific forest floor density and *F* is the fraction of species *s*. |
| $C_{floor,j} = \sum_{s=1}^{k} C_{floor,s,j}$ | Total forest floor carbon on the jth plot. |
| $C_{floor} = \frac{\sum_{j=1}^{n} C_{floor,j}}{\sum_{j=1}^{n} A_j} \cdot A_{Forest}$ | Total forest floor carbon is estimated as the area weighted average forest floor carbon content times the total forest area. |

Table 3E.11 Crops grown from Statistics Denmark in 2018 distributed regions, ha.

| | Denmak | Copenhagen area | Bornholm | Zealand | Funen | Southern Jutland | Eastern Jutland | Western Jutland | Northern Jutland |
|---|---|---|---|---|---|---|---|---|---|
| Agriculture and horticulture total | 2632453 | 73890 | 37435 | 495019 | 228955 | 532374 | 348799 | 434107 | 481874 |
| 1. Cereals for the production of grain | 1420173 | 36141 | 23052 | 292800 | 129335 | 254867 | 219308 | 215209 | 249462 |
| 1.1 Common wheat | 439567 | 14351 | 11948 | 102416 | 58767 | 56260 | 75654 | 44180 | 75992 |
| 1.1.1 Common winter | 406774 | 13389 | 10493 | 95861 | 55847 | 47578 | 71127 | 40917 | 71561 |
| 1.1.2 Common spring wheat | 32793 | 962 | 1454 | 6555 | 2920 | 8682 | 4526 | 3263 | 4431 |
| 1.2 Barley | 789621 | 17411 | 10149 | 176481 | 61846 | 150701 | 115989 | 133817 | 123227 |
| 1.2.1 Winter barley | 81931 | 1642 | 1743 | 6861 | 9140 | 14203 | 20834 | 11858 | 15651 |
| 1.2.2 Spring barley | 707690 | 15769 | 8406 | 169620 | 52706 | 136498 | 95156 | 121958 | 107576 |
| 1.3 Rye | 89981 | 2598 | 514 | 5147 | 4238 | 18724 | 13183 | 21071 | 24504 |
| 1.4 Oats | 80153 | 1514 | 246 | 5422 | 3308 | 24716 | 10282 | 12187 | 22480 |
| 1.5 Triticale | 7331 | .. | .. | 751 | 301 | 1003 | 2262 | 911 | 2055 |
| 1.6 Grain maize and corn-cob mix | 6158 | 156 | .. | 959 | 530 | 1921 | 1307 | 1040 | 241 |
| 1.7 Mixed grains and other cereals | 7361 | .. | 180 | 1624 | 345 | 1541 | 630 | 2004 | 962 |
| 2. Pulses | 33983 | 1176 | 1353 | 5742 | 2025 | 7297 | 5141 | 3908 | 7342 |
| 2.1 Pulses for the production of grain | 7102 | 181 | .. | 2966 | 520 | 580 | 1148 | 580 | 1090 |
| 2.2 Horse beans | 26577 | 933 | 1315 | 2776 | 1482 | 6656 | 3953 | 3209 | 6252 |
| 2.3 Other pulses | 305 | 63 | .. | .. | .. | .. | .. | 119 | .. |
| 3. Root crops | 92009 | 896 | .. | 40844 | 2080 | 11980 | 2361 | 21983 | 11849 |
| 3.1 Potatoes | 48635 | 825 | .. | 2333 | 1029 | 11419 | 2013 | 21098 | 9900 |
| 3.1.1 Seed potatoes | 7048 | .. | .. | 870 | 100 | 1376 | 297 | 3533 | 841 |
| 3.1.2 Potatoes for manufacturing | 28786 | .. | .. | .. | .. | 7169 | 637 | 14320 | 6615 |
| 3.1.3 Potatoes for human consumption | 12801 | 795 | .. | 1462 | 884 | 2874 | 1079 | 3245 | 2445 |
| 3.2 Sugar beets | 39369 | .. | .. | 38419 | 950 | .. | .. | .. | .. |
| 3.3 Beets and other root crops for fodder | 4006 | 71 | .. | 92 | 100 | 560 | 348 | 885 | 1949 |
| 4. Industrial crops | 146471 | 6199 | 2500 | 37492 | 18206 | 19786 | 24478 | 15661 | 22149 |
| 4.1 Rape | 145347 | 6131 | 2500 | 37085 | 18201 | 19608 | 24050 | 15631 | 22142 |
| 4.1.1 Winter rape | 144254 | 6131 | 2500 | 36827 | 18054 | 19276 | 24029 | 15525 | 21914 |
| 4.1.2 Spring rape | 1094 | .. | .. | 258 | 147 | 332 | .. | 106 | 228 |
| 4.2 Flax | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 4.3 Other industrial crops | 1123 | .. | .. | 407 | 6 | 178 | 428 | 30 | .. |
| 5. Seeds for sowing | 102860 | 2274 | 2060 | 42776 | 21914 | 6015 | 10334 | 9278 | 8210 |
| 6. Temporary grass and green fodder | 494075 | 7249 | 5857 | 24136 | 24408 | 167728 | 42048 | 109771 | 112878 |
| 6.1 Lucerne | 1372 | .. | .. | 355 | 101 | 786 | 30 | .. | 67 |
| 6.2 Green maize | 177678 | 1048 | 3073 | 6814 | 10595 | 74654 | 12188 | 37678 | 31628 |
| 6.3 Cereals and pulses harvested green | 50878 | 522 | 255 | 1088 | 1592 | 15127 | 3391 | 14309 | 14594 |
| 6.4 Temporary grass and clover | 264146 | 5653 | 2529 | 15879 | 12120 | 77161 | 26439 | 57775 | 66589 |
| 7. Horticultural crops | 20576 | 972 | 60 | 5613 | 5462 | 1387 | 2704 | 2877 | 1501 |
| 7.1 Vegetables grown outdoors | 9779 | 539 | 37 | 1517 | 2003 | 221 | 2208 | 2208 | 1045 |
| 7.2 Peas for human consumption | 3136 | 133 | .. | 1899 | 998 | .. | 19 | 37 | .. |
| 7.3 fruits and berries | 5633 | 195 | 21 | 1866 | 1890 | 751 | 358 | 207 | 347 |
| 7.3.1 Apples | 1677 | 66 | .. | 479 | 683 | 288 | 87 | 38 | 32 |
| 7.3.2 Pears | 305 | .. | .. | 111 | 142 | 11 | 18 | .. | .. |
| 7.3.3 Strawberries | 1269 | 66 | .. | 462 | 224 | 134 | 133 | 81 | 168 |
| 7.3.4 Cherries | 639 | .. | .. | 388 | 228 | 11 | 3 | .. | .. |
| 7.3.5 Blackcurrants | 541 | .. | .. | 133 | 202 | 49 | 47 | 51 | .. |
| 7.3.6 Redcurrants | 394 | .. | .. | 99 | 130 | 123 | 12 | .. | .. |
| 7.3.7 Other fruits and berries | 809 | 12 | 11 | 194 | 281 | 136 | 57 | 27 | 91 |
| 7.4 Bulbs and flowers | 55 | .. | .. | 43 | 7 | .. | .. | .. | .. |
| 7.5 Nursery area | 1974 | 102 | .. | 289 | 564 | 410 | 119 | 425 | 64 |
| 8. Permanent grassland | 212657 | 14436 | 1932 | 30076 | 15836 | 44838 | 25810 | 37533 | 42197 |
| 9. Christmas trees & decorative greenery | 23693 | 373 | 30 | 2226 | 3145 | 4186 | 4745 | 3854 | 5134 |
| 10. Fallow land | 76377 | 3734 | 574 | 12797 | 6141 | 12160 | 10682 | 12510 | 17780 |
| 10.1 Fallow land with subsidies | 9253 | 61 | 87 | 2594 | 911 | 2555 | 1215 | 1172 | 659 |
| 10.2 Fallow land without subsidies | 67124 | 3672 | 487 | 10204 | 5230 | 9605 | 9467 | 11338 | 17121 |
| 11. Other crops | 9578 | 440 | .. | 517 | 405 | 2130 | 1190 | 1523 | 3373 |
| A. Irrigable area | 299027 | 2899 | .. | 6952 | 7625 | 108846 | 40150 | 115323 | 17089 |
| A 1. Irrigated area in the past year | 228794 | 1713 | .. | 2831 | 4665 | 78527 | 36062 | 94244 | 10716 |
| B. Area with zero or low tillage | 357590 | 9038 | 5254 | 86158 | 39266 | 56562 | 41246 | 59875 | 60191 |
| B 1 Zero tillage (direct seeding) | 319006 | 7851 | 5104 | 79706 | 36234 | 51145 | 36026 | 50371 | 52568 |
| B 2 Conservation tillage (low tillage) | 38585 | 1187 | .. | 6452 | 3032 | 5417 | 5220 | 9503 | 7623 |
| C. Forest belonging to agricultural farms | 217241 | 2402 | 3859 | 42205 | 21498 | 27766 | 46284 | 40660 | 32567 |

Table 3E.12 Crop yield from Statistics Denmark in 2018 distributed regions, Hhg crop ha$^{-1}$.

| | Copenhagen and North Zealand | Bornholm | Zealand | Funen | Southern Jutland | Eastern Jutland | Western Jutland | Northern Jutland |
|---|---|---|---|---|---|---|---|---|
| Winter wheat | 53.4 | 56.6 | 67.3 | 69.3 | 63.3 | 62 | 62 | 63.1 |
| Spring wheat | 23.1 | 26.6 | 38.6 | 38.6 | 40.9 | 38.5 | 38.8 | 43.1 |
| Rye | 55.1 | 39.5 | 54.7 | 64.4 | 47.3 | 52.1 | 49.2 | 54.8 |
| Triticale | 55.2 | 55.2 | 36.3 | 55.2 | 54.7 | 72.7 | 47 | 55.8 |
| Winter barley | 39.7 | 52.2 | 57.8 | 54.3 | 53.1 | 53.1 | 48.9 | 52 |
| Spring barley | 35.5 | 32.4 | 44 | 42.5 | 42.3 | 43 | 43.9 | 42.4 |
| Oats and dredge corn | 32.8 | 34.2 | 30.5 | 34.8 | 35.7 | 35.7 | 35.8 | 32.6 |
| Grain maize | 59 | 59 | 30.6 | 43.5 | 77.9 | 57.6 | 48.6 | 59 |
| Field peas | 27.7 | 27.7 | 28.9 | 27.7 | 28.3 | 27.2 | 30.8 | 25.5 |
| Straw from cereals | 24.3 | 25.2 | 29.3 | 31.2 | 26.6 | 28.9 | 27.6 | 28.8 |
| Seed potatoes | 200 | 0 | 200 | 200 | 200 | 200 | 200 | 202 |
| Potatoes for flour manufacturing | 0 | 0 | 0 | 433 | 433 | 425 | 450 | 391 |
| Potatoes for human consumption | 245.7 | 230.4 | 246.3 | 243.5 | 243.5 | 248.2 | 244.2 | 200.6 |
| Beets for sugar production | 0 | 0 | 614 | 614 | 0 | 0 | 0 | 0 |
| Fodder beets | 759 | 751 | 667 | 700 | 706 | 400 | 407 | 625 |
| Lucerne | 317.7 | 303.5 | 484.8 | 411.4 | 355.8 | 358.5 | 356 | 357.7 |
| Maize for green fodder | 326.4 | 326.4 | 322 | 328.4 | 382.1 | 296.6 | 331 | 336.3 |
| Cereals for green fodder | 115.6 | 124.4 | 127.6 | 122.7 | 123.5 | 131.1 | 112.7 | 182.6 |
| Grass and clover in rotation | 312.3 | 308.5 | 291.7 | 340.5 | 397.7 | 317.4 | 372 | 380.2 |
| Permanent grassland out of rotation | 159.2 | 119.2 | 108.6 | 126 | 129.5 | 209 | 118.3 | 173.2 |
| Aftermath, cereals silage and silage | 26.1 | 27.2 | 29 | 30.8 | 48.2 | 27.9 | 42.9 | 51.3 |

Table 3E.13 Area input format to C-TOOL in 2018 in hectares. Soil Group 1 represents sandy soils, 2 is sandy loam and 3 is loamy sand. Soil Group 4 is organic soils with >6% SOC. Organic soils are NOT included in the estimation of changes in SOC in mineral soils.

| Crop type | Soil Group | Bornholm | Copenhagen and North Zealand | Funen | Southern Jutland | Western Jutland | Eastern Jutland | Northern Jutland | Zealand |
|---|---|---|---|---|---|---|---|---|---|
| Flax | 1 | | | | 0 | 32 | 0 | | |
| Flax | 2 | | | 0 | 1 | 11 | 0 | 8 | 1 |
| Flax | 3 | 0 | 1 | 0 | | | 0 | | 32 |
| Flax | 4 | | | 0 | | 1 | 0 | 1 | |
| Grass and clover fields in rotation | 1 | | | | 34007 | 27751 | 5167 | 10592 | |
| Grass and clover fields in rotation | 2 | 443 | 3623 | 4873 | 23339 | 18238 | 10963 | 41963 | 7031 |
| Grass and clover fields in rotation | 3 | 1854 | 2456 | 4311 | 14234 | 3706 | 4267 | 3359 | 8039 |
| Grass and clover fields in rotation | 4 | 78 | 693 | 1599 | 10677 | 8275 | 3780 | 11296 | 3063 |
| Green cereals for silage | 1 | | | | 8597 | 6983 | 1017 | 2242 | |
| Green cereals for silage | 2 | 35 | 342 | 427 | 5572 | 5368 | 1948 | 12476 | 422 |
| Green cereals for silage | 3 | 173 | 108 | 620 | 1692 | 981 | 513 | 681 | 561 |
| Green cereals for silage | 4 | 13 | | 2 | 1344 | 880 | 217 | 1515 | 87 |
| Green maize for silage | 1 | | | | 43863 | 23132 | 2757 | 4603 | |
| Green maize for silage | 2 | 300 | 453 | 4565 | 26461 | 15348 | 6422 | 23496 | 1613 |
| Green maize for silage | 3 | 1739 | 241 | 5812 | 4393 | 1545 | 1590 | 1634 | 3498 |
| Green maize for silage | 4 | 20 | 12 | 147 | 3002 | 1023 | 261 | 942 | 256 |
| Oat and mixed cereals | 1 | | | | 8426 | 5860 | 1752 | 2181 | |
| Oat and mixed cereals | 2 | 49 | 1179 | 1691 | 8824 | 5248 | 5407 | 17813 | 892 |
| Oat and mixed cereals | 3 | 267 | 507 | 1713 | 6117 | 1102 | 2759 | 1996 | 3142 |
| Oat and mixed cereals | 4 | | 42 | 31 | 1530 | 1056 | 437 | 1780 | 397 |
| Other crops and fallow land | 1 | 0 0 | 0 | | 6648 | 6821 | 3478 | 3201 | 0 |
| Other crops and fallow land | 2 | 9 | 2209 | 1808 | 4225 | 4490 | 5215 | 14985 | 2792 |
| Other crops and fallow land | 3 | 565 | 626 | 2973 | 889 | 923 | 1753 | 976 | 8160 |
| Other crops and fallow land | 4 | | 258 | 66 | 1727 | 1132 | 838 | 2414 | 404 |
| Other seeds for industrial use | 1 | | | | 49 | 31 | 83 | 24 | |
| Other seeds for industrial use | 2 | | 3 | 8 | 6 | 5 | 64 | 40 | 112 |
| Other seeds for industrial use | 3 | | 0 | 3 | 156 | 0 | 114 | | 339 |
| Other seeds for industrial use | 4 | | | | | 2 | | 1 | 2 |
| Permanent grass outside rotation | 1 | | | | 16475 | 16984 | 5804 | 10837 | |
| Permanent grass outside rotation | 2 | 282 | 8717 | 6050 | 13198 | 7470 | 10858 | 25142 | 9253 |
| Permanent grass outside rotation | 3 | 1479 | 4086 | 5237 | 10865 | 1802 | 5290 | 1613 | 13780 |
| Permanent grass outside rotation | 4 | 36 | 1581 | 2460 | 10505 | 10401 | 7435 | 12974 | 5185 |
| Potatoes for consumption | 1 | | | | 2948 | 2723 | 98 | 390 | |
| Potatoes for consumption | 2 | 17 | 352 | 757 | 586 | 618 | 675 | 863 | 630 |
| Potatoes for consumption | 3 | 6 | 74 | 232 | 104 | 15 | 147 | 4 | 865 |
| Potatoes for consumption | 4 | | 7 | 2 | 109 | 23 | 34 | 957 | 9 |
| Potatoes for seed | 1 | | | | 980 | 2118 | 71 | 119 | |
| Potatoes for seed | 2 | | 17 | 99 | 585 | 1301 | 317 | 906 | 13 |
| Potatoes for seed | 3 | | | 79 | 65 | 192 | 53 | 24 | 726 |
| Potatoes for seed | 4 | | | | 41 | 117 | 3 | 52 | |
| Potatoes for starch production | 1 | | | | 6859 | 12356 | 332 | 387 | |
| Potatoes for starch production | 2 | | | 67 | 1320 | 2306 | 741 | 5205 | |
| Potatoes for starch production | 3 | | | 17 | 82 | 34 | 2 | 83 | |
| Potatoes for starch production | 4 | | | | 275 | 333 | 41 | 521 | |
| Pulses for maturity | 1 | | | | 2144 | 1483 | 359 | 301 | |
| Pulses for maturity | 2 | 37 | 406 | 477 | 2028 | 1406 | 2058 | 5077 | 811 |
| Pulses for maturity | 3 | 1210 | 290 | 1627 | 2801 | 593 | 2582 | 962 | 4782 |
| Pulses for maturity | 4 | | 29 | 36 | 149 | 65 | 68 | 205 | 38 |
| Pulses, fodder cabbage etc | 1 | | | | 0 | 0 | 0 | 0 | |
| Pulses, fodder cabbage etc | 2 | | | 0 | 0 | 0 | 0 | 0 | 0 |
| Pulses, fodder cabbage etc | 3 | | 0 | 0 | 0 | | | 0 | 0 |
| Pulses, fodder cabbage etc | 4 | | 0 | | | 0 | 0 | 0 | 0 |
| Rye | 1 | | | | 11095 | 14191 | 4866 | 3309 | |
| Rye | 2 | 104 | 1763 | 4188 | 5658 | 7185 | 7411 | 18820 | 2461 |
| Rye | 3 | 257 | 344 | 1226 | 1025 | 567 | 1155 | 968 | 2884 |
| Rye | 4 | | 46 | 105 | 736 | 749 | 326 | 1006 | 253 |
| Seeds for sowing | 1 | | | | 1579 | 3709 | 938 | 581 | |
| Seeds for sowing | 2 | 37 | 856 | 5646 | 1620 | 4467 | 5177 | 6985 | 4835 |
| Seeds for sowing | 3 | 2175 | 600 | 16152 | 3137 | 1469 | 3655 | 854 | 36028 |
| Seeds for sowing | 4 | 17 | 14 | 204 | 61 | 281 | 265 | 233 | 393 |
| Set aside with grass | 1 | | | | 417 | 350 | 199 | 93 | |

| Crop type | Soil Group | Bornholm | Copenha-gen and North Zealand | Funen | Southern Jutland | Western Jutland | Eastern Jutland | Northern Jutland | Zealand |
|---|---|---|---|---|---|---|---|---|---|
| Set aside with grass | 2 | 18 | 214 | 323 | 330 | 177 | 522 | 512 | 975 |
| Set aside with grass | 3 | 135 | 121 | 322 | 523 | 33 | 340 | 58 | 1365 |
| Set aside with grass | 4 | 5 | 88 | 79 | 335 | 145 | 250 | 298 | 506 |
| Spring barley | 1 | | | | 65259 | 68065 | 13361 | 9612 | |
| Spring barley | 2 | 422 | 8351 | 18666 | 49389 | 44971 | 48734 | 82093 | 22511 |
| Spring barley | 3 | 7863 | 5460 | 34449 | 23837 | 9532 | 27763 | 11593 | 134051 |
| Spring barley | 4 | 60 | 391 | 857 | 7069 | 5245 | 2652 | 8021 | 3094 |
| Spring rape | 1 | | | | 101 | 92 | | 19 | |
| Spring rape | 2 | | 3 | 32 | 108 | 24 | 68 | 107 | 13 |
| Spring rape | 3 | | | 147 | 88 | 2 | 13 | 42 | 212 |
| Spring rape | 4 | | | | 27 | | | | |
| Spring wheat | 1 | | | | 3400 | 1019 | 363 | 375 | |
| Spring wheat | 2 | 50 | 384 | 551 | 3073 | 942 | 1865 | 2899 | 1287 |
| Spring wheat | 3 | 550 | 230 | 2570 | 2360 | 353 | 1980 | 549 | 4478 |
| Spring wheat | 4 | | 26 | 69 | 567 | 411 | 500 | 1403 | 736 |
| Sugar beet for sugar production | 1 | | | | 0 | | | | |
| Sugar beet for sugar production | 2 | | 62 | 96 | | | 1 | 0 | 2581 |
| Sugar beet for sugar production | 3 | | | 669 | | | | | 30791 |
| Sugar beet for sugar production | 4 | | | | | | | | 182 |
| Sugar beets for feeding | 1 | | | | | 747 | | | |
| Sugar beets for feeding | 2 | | | 65 | | | | 2191 | |
| Sugar beets for feeding | 3 | | | | | | 302 | | 74 |
| Sugar beets for feeding | 4 | | | | | | | | 32 |
| Triticale | 1 | | | | 2285 | 1574 | 779 | 349 | |
| Triticale | 2 | 38 | 238 | 705 | 1506 | 1231 | 1890 | 2596 | 931 |
| Triticale | 3 | 122 | 111 | 541 | 1088 | 176 | 778 | 196 | 1508 |
| Triticale | 4 | | 5 | 15 | 235 | 161 | 236 | 167 | 185 |
| Vegetables grown in the open, total | 1 | | | | 96 | 1284 | 472 | 110 | |
| Vegetables grown in the open, total | 2 | 0 | 336 | 1648 | 91 | 637 | 878 | 651 | 636 |
| Vegetables grown in the open, total | 3 | 30 | 220 | 1188 | 27 | 69 | 218 | 33 | 2813 |
| Vegetables grown in the open, total | 4 | | 32 | 79 | 29 | 262 | 282 | 172 | 240 |
| Winter barley | 1 | | | | 3578 | 4765 | 1632 | 1127 | |
| Winter barley | 2 | 97 | 1072 | 3252 | 4260 | 6103 | 10122 | 12121 | 1519 |
| Winter barley | 3 | 1442 | 528 | 5527 | 7270 | 1443 | 8184 | 2628 | 5369 |
| Winter barley | 4 | | 51 | 82 | 272 | 176 | 229 | 401 | 71 |
| Winter rape | 1 | | | | 3185 | 4025 | 1649 | 1598 | |
| Winter rape | 2 | 142 | 2862 | 5971 | 5741 | 8760 | 12943 | 16640 | 5983 |
| Winter rape | 3 | 2328 | 2024 | 12335 | 10394 | 2767 | 9743 | 2881 | 28338 |
| Winter rape | 4 | | 64 | 78 | 374 | 242 | 214 | 592 | 473 |
| Winter wheat | 1 | | | | 6501 | 9911 | 3220 | 3163 | |
| Winter wheat | 2 | 445 | 5546 | 15478 | 11174 | 18950 | 31359 | 46400 | 12813 |
| Winter wheat | 3 | 9308 | 4397 | 37810 | 28969 | 9037 | 33355 | 15071 | 79059 |
| Winter wheat | 4 | 23 | 143 | 415 | 1084 | 1317 | 1652 | 5075 | 1444 |

Table 3E.14 Average annual temperatures for Denmark, 1977-2018, °C.

| Year | Average | Year | Average |
|---|---|---|---|
| 1977 | 7.7 | 2000 | 9.2 |
| 1978 | 7.7 | 2001 | 8.2 |
| 1979 | 7.7 | 2002 | 9.2 |
| 1980 | 7.2 | 2003 | 8.7 |
| 1981 | 7.2 | 2004 | 8.7 |
| 1982 | 8.0 | 2005 | 8.8 |
| 1983 | 8.4 | 2006 | 9.4 |
| 1984 | 8.0 | 2007 | 9.4 |
| 1985 | 6.5 | 2008 | 9.4 |
| 1986 | 7.0 | 2009 | 8.8 |
| 1987 | 6.6 | 2010 | 6.9 |
| 1988 | 8.5 | 2011 | 8.9 |
| 1989 | 9.2 | 2012 | 8.3 |
| 1990 | 9.2 | 2013 | 8.3 |
| 1991 | 8.1 | 2014 | 10.0 |
| 1992 | 9.0 | 2015 | 9.1 |
| 1993 | 7.6 | 2016 | 9.0 |
| 1994 | 8.6 | 2017 | 8.9 |
| 1995 | 8.2 | 2018 | 9.5 |
| 1996 | 6.8 | | |
| 1997 | 8.5 | | |
| 1998 | 8.2 | | |
| 1999 | 8.9 | | |

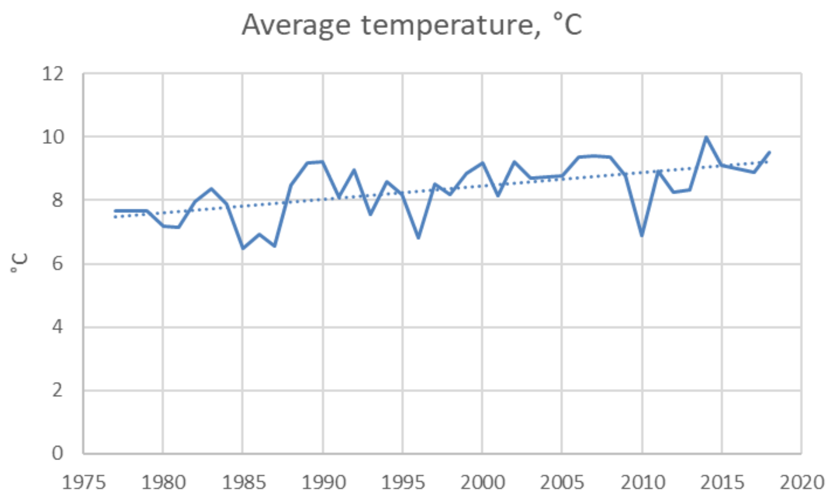


Figure 3E.1 Average annual temperatures for Denmark, 1977-2018, °C.

### Hedgerows

Since the beginning of the early 1930s, governmental subsidiaries have been given to increase the area with hedgerows to reduce soil erosion. In the 1950-60'ies annually was planted 6-9 million single rowed confers, mainly white spruce *(Picea glauca)*. From around 1965, the annual rate decreased sharply to almost zero. Instead new hedges were made of broad leave trees/plants but only to around 2-3 million trees. This can be converted to annually financial support given to approximately 400-800 km of hedgerow in the latter years only financial support has been given to app. 100 ha. From 2014 only minor subsidized areas has been erected. Currently there is a small annual governmental subsidy available for approximately 100 ha per year.

The new updated LiDAR-model for hedges and biotopes not qualifying for forest is based on LiDAR measurements in 2006 and 2014/15. Information on the exact location of subsidized hedge planting and some of the removal is available from 2007 and onwards. In the period from 2006 to 2014/15 is the area with removed hedges estimated from what is missing in the 2014/15 LiDAR measurements compared to 2006.

Future updates with this technology will be available because the Danish Government has decided to make new LiDAR measurements in a five years rotation for the whole country starting 2019.

#### Transition period and effect on eventual on under- or overestimation of the C source/sink in the period up to 1990

The Danish inventory has so far only developed an annual Land Use Matrix from 1990 and onwards and are not using a 20 years transition period for estimating emissions from Land Use Change (LUC) as mentioned in the 2006 IPCC Guidelines. There are several reasons for that:

- For all living and dead biomass Denmark is using instant oxidation. No carrying over model of living biomass is used, except for hedges where an area based Tier 3 carbon stock model is developed. Thus the emission/sink from living and dead biomass has no impact on the emission estimate for the base year. An eventual over- or underestimation of the emission will therefore only occur from mineral soils in transition.
- The current default transition period of 20 years when land use change is taking place is not appropriate under the cold temperate conditions in Denmark where the average annual temperature is around 8 °C.

The main LUC in Denmark is from

- Cropland (CL) to Settlement (SE) with an indicative loss of carbon stock/ha
- CL to Forest land (FL) with an indicative increase in the carbon stock/ha

In Figure 3E.2 is shown the apparent Land Use Change from 1888 to 2018 (Statistics Denmark 1896, 1919, 1952, 1990). As can be seen has the area with FL increased substantially as well as the SE area. The total area with CL is more or less constant but the GL has decreased substantially. Approximately half of the 900 000 ha GL in 1888 were heathland. Of this is only 70 000 ha left today. The remaining heathland has been turned into agricultural soils. According to our forest statistics from 1954 (Vivian Kvist Johannesen, pers. com) has about 55 % of the afforestation from 1954 to now taken place on CL and 32 % on which we consider as GL. The afforestation on CL has mainly taken place on the fertile land around the cities and the afforestation on GL were mainly on the sandy heathland with Norwegian spruce.

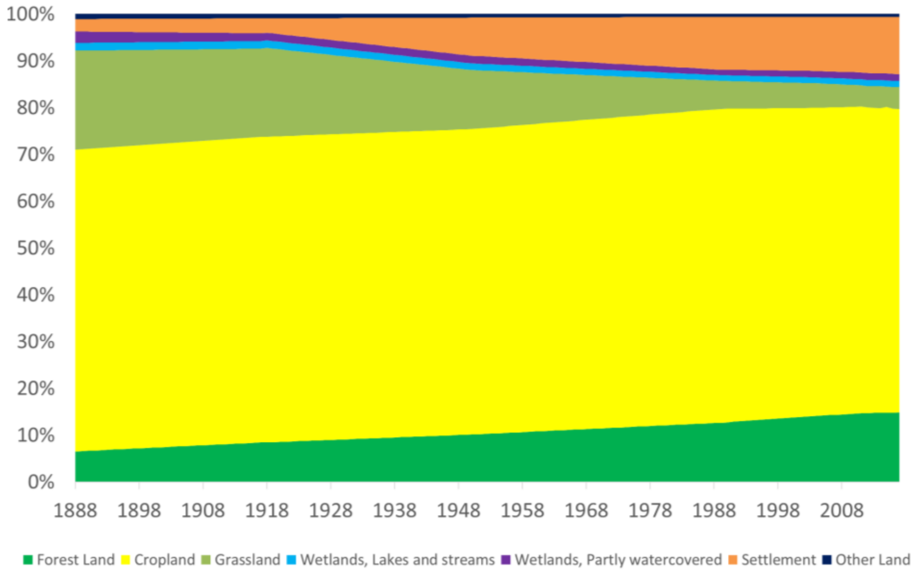



Figure 3E.2 Land Use Change 1888-2018.

Very few data is available on the carbon stock in the different soil types and it is therefore very difficult to estimate Danish default reference carbon stocks. The earliest representative data we have on agricultural land is from the beginning of the 1960'ies from our agricultural research stations (Lamm, 1971). 49 of these soil samples can be considered as mineral. They had an average C stock (0-100 cm) of 103.3 ton C/ha (SE ±33.8). The sandy soils showed both low and high values, depending on its podsolization. In Danish soil sampling grid from 1986 (approximately 500 samples) the weighted average C stock were 120.8 ton C/ha indication a build-up in the period from the 1960 to the 1980'ies. This coincided with the increased fertilization in agriculture leading to higher yields.

Long-term agricultural experiments at Rothhamsted in the United Kingdom has shown that >95 % of the Soil Organic Matter (SOM) has a half-life (t½) of more than 49 years (Jenkinson and Rayner, 1977), Table 1. Both the Roth-C model and C-TOOL (Petersen et al., 2002) is based on the long-term experiments. All models are using prediction of the age of the soil carbon. Basically, the models are operating with fast pools (crop residue), medium reacting pools and slow acting pools. Within the time frame of the inventories submitted to UNFCCC is it mainly the medium pools which are important for understanding the carbon sink/source from LUC. The fast pools are normally considered as crop residues or litter and the slow reacting pools is of minor interest for inventory purposes because of t½ >> 100 years. Hence, the medium pools is the single most important factor for the reporting obligation. According to the data from Rothhamstedt (Jenkinson and Rayner 1977) and Denmark (Petersen et al. 2002) account the medium pool to approximately 45 % of the total C stock. New unpublished data in Denmark has estimated that on sandy soils (former heathland) is the medium pool even lower (Arezoo T., Pers. comm).

Table 3E.17 Modelled half-lives and pool sizes in Rothamstedt (Jenkinson and Rayner, 1977).

| | t½, yr | t ha-1 (0-23 cm) | Fraction |
|---|---|---|---|
| Decomposable Plant Material, DPM | 0.165 | 0.01 | 0.0004 |
| Resistant Plant Material, RPM | 2.31 | 0.47 | 0.0194 |
| Soil Biomass | 1.69 | 0.28 | 0.0115 |
| Physically stabilized Organic Matter POM | 49.5 | 11.3 | 0.4658 |
| Chemically Stabilized Organic Matter, COM | 1980 | 12.2 | 0.5029 |
| Total | | 24.3 | 1.0000 |

The Danish inventory are using C-TOOL to estimate the C turnover in agricultural soils. As the major Land Use Conversion is from agricultural land to SE, this model may be able to predict loss from agricultural soils when land is transferred to SE. When looking on the large Danish conversion from unfertile sandy heathland to fertile CL and the afforestation on this land it is currently a difficult task to come with any conclusive figures on the loss and gain from mineral soils combined with LUC.

### Technical documentation for C-TOOL

C-TOOL is a simple tool for simulation of soil carbon turnover. The technical documentation for C-TOOL with parameterization is provided and documented by Taghizadeh-Toosi et al., 2015.

### Literature

Jenkinson, D.S. & Rayner, J.H., 1977: The turnover of soil organic matter in some of the Rothamsted classical experiments. *Soil Science* 123: 298–305.

Lamm, C.G., 1971: The Danish soil library, Tidskrift for Planteavl, 75, 703-720.

Petersen, B.M., Olesen, J.E. & Heidmann, T., 2002: A flexible tool for simulation of soil carbon turnover. Ecol. Model. 151, 1–14

Taghizadeh-Toosi, A., Christensen, B.T., Hutchings, N.J., Vejlin, J. Kätterer, T. Glendining, M. & Olesen, J.E., 2014: C-TOOL: A simple model for simulating whole-profile carbon storage in temperate agricultural soils, Ecological Modelling, 292, pp 11-25. Available at: https://agro.au.dk/fileadmin/DJF/Agro/Medarbejderportal_AGRO/Sektioner/KLIMA/C-TOOL_Documentation.pdf

Vivian Kvist Johannesen, pers. Com. University of Copenhagen, Department of Geosciences and Natural Resource Management.

## Annex 3F - Waste

## Annex 3F-1 Emissions from the waste sector, 1990-2018

Table 3F-1.1 Emissions for the waste sector, kt $CO_2$ equivalents.

See:
https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

## Annex 3F-2 Solid Waste Disposal on Land, 6A

Table 3F-2.1 All nationally produced waste categorised after handling method, collected for the ISAG database 1994-2009 and the new waste reporting system for 2010-2018.

Table 3F-2.2 Annual amounts of deposited waste, gross methane emission, recovered methane collected for biogas production, oxidised methane in the top layer and resulting net emission for the Danish SWDS.

Table 3F-2.3 Annual amounts of deposited inert and decomposable waste allocated according to 18 identified waste types characterised according to their DOCi and decomposition rate quantified by their half-life times, t½.

Table 3F.2.4 European waste codes allocated according to 18 characterised waste types.

Table 3F-2.5 Fractional distribution of waste types for the whole time series 1990-2018.

See:
https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

## Annex 3F-3 Biological Treatment of Solid Waste, 5.B

Table 3F-3.1 National emissions from composting – 1990 to 2018, tonnes.

Table 3F-3.2 Activity data composting, kt.

Table 3F-3.3 Activity data and methane emissions from anaerobic digestion at manure-based biogas plants.

See:
https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

## Annex 3F-4 Incineration and open burning of waste, 5. C

Table 3F-4.1 presents the greenhouse gas emissions from 5.C Incineration and open burning of waste for 1990-2018.

Table 3F-4.2 presents the activity data for human cremation for 1990-2018.

Table 3F-4.3 presents the activity data for animal cremation for 1990-2018.

See:
https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

## Annex 3F-5 Wastewater treatment and discharge, 5.D

Table 3F-5.1 Produced, recovered and emitted CH4 from wastewater treatment, kt, 1990-2018.

Table 3F-5.2 $N_2O$ emissions from wastewater, tonnes, 1990-2018.

Table 3F-5.3 Time series for the contribution from industrial wastewater to the influent TOW at Danish wastewater treatment plants, population number, measured BOD and COD data and resulting COD/BOD ratio, 1990-2018.

Table 3F-5.4 Nitrogen content in the influent and effluent wastewater, tonnes.

See:
https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

## Annex 3F-6 Other. 5.E.1 Accidental fires

Table 3F-6.1 Overall emission of greenhouse gasses from accidental fires, 1990-2018.

Table 3F-6.2 Occurrence of accidental fires, 1990-2018.

Table 3F-6.3 Accidental building fires full scale equivalent activity data.

Table 3F-6.4a Emission factors for accidental detached building fires, 1990-2014 and the average emission factor, used for alle years.

Table 3F-6.4b Emission factors for accidental undetached building fire, 1990-2014 and the average emission factor, used for alle years.

Table 3F-6.4c Emission factors for accidental apartment building fires, 1990-2014 and the average emission factor, used for alle years.

Table 3F-6.5 Average floor space in building types, 1990-2014. Used to estimate average emission factors for building fires.

Table 3F-6.6a Number of nationally registered vehicles and full scale equivalent vehicle fires.

Table 3F-6.6b Number of nationally registered vehicles and full scale equivalent vehicle fires.

Table 3F-6.6c Number of nationally registered vehicles and full scale equivalent vehicle fires.

Table 3F-6.7 Average weight of different vehicle categories, kg, 1990-2018.

Table 3F-6.8 Burnt mass of different vehicle and machine categories, tonnes.

See:
https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

## Annex 3F-7 Recalculations to the waste sector

Table 3F-7.1 Changes in emissions from Solid Waste Disposal compared with the CRF reported last year.
Table 3F-7.2a Changes in emissions from Biological treatment of Solid Waste compared with the CRF reported last year.Table 3F-7.3 Changes in emissions from Incineration and open burning of waste compared with the CRF reported last year.

Table 3F-7.2b Changes in emissions from sub-category 5.B.1 Composting compared with the CRF reported last year.

Table 3F-7.2b Changes in emissions from sub-category 5.B.2 Manure-based biogas with the CRF reported last year.

Table 3F-7.3 Changes in emissions from Incineration and open burning of waste compared with the CRF reported last year.

Table 3F-7.4 Changes in emissions from Wastewater Treatment and Discharge compared with the CRF reported last year.

Table 3F-7.5 Changes in emissions from Waste Other compared with the CRF reported last year.

Table 3F-7.6 Changes in emissions from the waste sector compared with the CRF reported last year.

See:
https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

# Annex 4 - Information on the energy statistics

This description of the Danish energy statistics has been prepared by DCE in cooperation with the Danish Energy Agency (DEA) as background information to the Danish National Inventory Report (NIR).

## The Danish energy statistics system

DEA is responsible for the Danish energy balance. Main contributors to the energy statistics outside DEA are Statistics Denmark and Danish Energy Association (before Association of Danish Energy Companies). The statistics is performed using an integrated statistical system building on an Access database and Excel spreadsheets.

The DEA follows the recommendations of the International Energy Agency as well as Eurostat.

The national energy statistics is updated annually and all revisions are immediately included in the published statistics, which can be found on the DEA homepage[1]. It is an easy task to check for breaks in a series because the statistics is 100 % time-series oriented.

The national energy statistics does not include Greenland and the Faroe Islands.

For historical reasons, DEA receive monthly information from the Danish oil companies regarding Danish deliveries of oil products to Greenland and Faroe Islands. However, the monthly (MOS) and annual (AOS) reporting of oil statistics to Eurostat and IEA exclude Greenland and Faroe Islands. For all other energy products, the Danish figures are also excluding Greenland and Faroe Islands.

## Reporting to the Danish Energy Agency

The Danish Energy Agency receives monthly statistics for the following fuel groups:

- Crude oil and oil products
    - Monthly data from 46 oil companies, the main purpose is monitoring oil stocks according to the oil preparedness system
- Natural gas
    - Fuel/flare from platforms in the North Sea
    - Natural gas balance from the regulator Energinet.dk (National monopoly)
- Coal and coke
    - Power plants (94 %)
    - Industry companies (4 %)
    - Coal and coke traders (2 %)
- Electricity

[1] https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics

- Monthly reporting by e-mail from the regulator Energinet.dk (National monopoly)
    - The statistics covers:
        - Production by type of producer
        - Own use of electricity
        - Import and export by country
        - Domestic supply (consumption + distribution loss)
- Town gas (quarterly) from two town gas producers
- The large central power plants also report monthly consumption of biomass

Annual data includes renewable energy including waste. The DEA conducts a biannual survey on wood pellets and wood fuel. Statistics Denmark conducts biannual surveys on the energy consumption in the service and industrial sectors. Statistics Denmark prepares annual surveys on forest (wood fuel) & straw.

Other annual data sources include:

- DEA
    - Survey on production of electricity and heat and fuels used
    - Survey on end use of oil
    - Survey on end use of natural gas
    - Survey on end use of coal and coke
- DCE, Aarhus University
    - Energy consumption for domestic air transport
- Danish Energy Association (Association of Danish Energy companies)
    - Survey on electricity consumption
- Ministry of Taxation
    - Border trade
- Centre for Biomass Technology
    - Annual estimates of final consumption of straw and wood chips

### Annual revisions

In general, DEA follows the same procedures as in the Danish national account. This means that normally only figures for the last two years are revised.

### Aggregating the energy statistics on SNAP level

The sectors used in the official energy statistics have been mapped to SNAP categories, used in the Danish emission database. DCE aggregates the official energy statistics to SNAP level based on a source correspondence table.

In cooperation between DEA and DCE, a fuel correspondence table has been developed mapping the fuels used by the DEA in the official energy statistics with the fuel codes used in the Danish national emission database. The fuel correspondence table between fuel categories used by the DEA, DCE and IPCC is presented in Annex 3A-3.

The mapping between the energy statistics and the SNAP and fuel codes used by DCE can be seen in the table below.

Table 3A-9.1 Correspondence between the Danish national energy statistics and the SNAP nomenclature (only stationary combustion part shown).

| Unit: TJ | End-use | | Transformation | |
|---|---|---|---|---|
| | SNAP | Fuel | SNAP | Fuel |
| **Energy Sector** | | | | |
| **Extraction and Gasification** | | | | |
| **- Extraction** | | | | |
| - - Natural Gas | 010504 | 301A | | |
| **- Gasification** | | | | |
| - - Biogas, Landfill | | | | |
| - - Biogas, Other | | | | |
| - - Electricity | | | | |
| **Refineries** | | | | |
| **- Used for Refining** | | | | |
| - - Crude Oil | | | | |
| - - Refinery Feedstocks | | | | |
| - - Electricity | | | | |
| - - District Heating | | | | |
| **- Own Use** | | | | |
| - - Refinery Gas | 010306 | 308A | | |
| - - LPG | 010306 | 303A | | |
| - - Gas-/Diesel Oil | 010306 | 204A | | |
| - - Fuel Oil | 010306 | 203A | | |
| **- Net Production** | | | | |
| - - Refinery Gas | | | | |
| - - LPG | | | | |
| - - Naphtha (LVN) | | | | |
| - - Aviation Gasoline | | | | |
| - - Motor Gasoline | | | | |
| - - JP4 | | | | |
| - - Other Kerosene | | | | |
| - - JP1 | | | | |
| - - Gas-/Diesel Oil | | | | |
| - - Fuel Oil | | | | |
| - - Petroleum Coke | | | | |
| - - White Spirit | | | | |
| - - Lubricants | | | | |
| - - Bitumen | | | | |
| - - Biodiesel | | | | |
| **Distribution** | | | | |
| **- Electricity Used in Distribution** | | | | |
| - - Electricity Distribution | | | | |
| - - District Heating Distribution | | | | |
| - - Gas Distribution | | | | |
| **Transformation Sector** | | | | |
| **Large-scale Power Units** | | | | |
| **- Fuels Used for Power Production** | | | | |
| - - Gas-/Diesel Oil | | | 010100 | 204A |
| - - Fuel Oil | | | 010100 | 203A |
| - - Electricity Plant Coal | | | 010100 | 102A |
| - - Straw | | | 010100 | 117A |
| **- Own Use** | | | | |
| - - Electricity | | | | |
| **- Gross Production** | | | | |
| - - Electricity | | | | |
| **Large-Scale CHP Units** | | | | |
| **- Fuels Used for Power Production** | | | | |
| - - Refinery Gas | | | 010300 | 308A |
| - - LPG | | | 010100 | 303A |
| - - Naphtha (LVN) | | | 010100 | 210A |
| - - Gas-/Diesel Oil | | | 010100 | 204A |
| - - Fuel Oil | | | 010100 | 203A |
| - - Petroleum Coke | | | 010100 | 110A |
| - - Orimulsion | | | 010100 | 225A |
| - - Natural Gas | | | 010100 | 301A |
| - - Electricity Plant Coal | | | 010100 | 102A |
| - - Straw | | | 010100 | 117A |
| - - Wood Chips | | | 010100 | 111A |
| - - Wood Pellets | | | 010100 | 111A |
| - - Wood Waste | | | 010100 | 111A |
| - - Biogas, Landfill | | | 010100 | 309A |
| - - Biogas, Sludge | | | 010100 | 309A |

| *Continued* | | | |
|---|---|---|---|
| - - Biogas, Others | | 010100 | 309A |
| - - Bio Natural Gas | | 010100 | 315A |
| - - Waste, Non-renewable | | 010100 | 114A |
| - - Wastes, Renewable | | 010100 | 114A |
| **- Fuels Used for Heat Production** | | | |
| - - Refinery Gas | | 010300 | 308A |
| - - LPG | | 010100 | 303A |
| - - Naphtha (LVN) | | 010100 | 210A |
| - - Gas-/Diesel Oil | | 010100 | 204A |
| - - Fuel Oil | | 010100 | 203A |
| - - Petroleum Coke | | 010100 | 110A |
| - - Orimulsion | | 010100 | 225A |
| - - Natural Gas | | 010100 | 301A |
| - - Electricity Plant Coal | | 010100 | 102A |
| - - Straw | | 010100 | 117A |
| - - Wood Chips | | 010100 | 111A |
| - - Wood Pellets | | 010100 | 111A |
| - - Wood Waste | | 010100 | 111A |
| - - Biogas, Landfill | | 010100 | 309A |
| - - Biogas, Sludge | | 010100 | 309A |
| - - Biogas, Other | | 010100 | 309A |
| - - Bio Natural Gas | | 010100 | 315A |
| - - Wastes, Non-renewable | | 010100 | 114A |
| - - Wastes, Renewable | | 010100 | 114A |
| **- Own Use** | | | |
| - - Electricity | | | |
| - - District Heating | | | |
| **- Production** | | | |
| - - Electricity, Gross | | | |
| - - District Heating, Net | | | |
| **Small-Scale CHP Units** | | | |
| **- Fuels Used for Power Production** | | | |
| - - Gas-/Diesel Oil | | 010100 | 204A |
| - - Fuel Oil | | 010100 | 203A |
| - - Natural Gas | | 010100 | 301A |
| - - Electricity Plant Coal | | 010100 | 102A |
| - - Straw | | 010100 | 117A |
| - - Wood Chips | | 010100 | 111A |
| - - Wood Pellets | | 010100 | 111A |
| - - Wood Waste | | 010100 | 111A |
| - - Biogas, Landfill | | 010100 | 309A |
| - - Biogas, Sludge | | 010100 | 309A |
| - - Biogas, Other | | 010100 | 309A |
| - - Bio Natural Gas | | 010100 | 315A |
| - - Waste, Non-renewable | | 010100 | 114A |
| - - Wastes, Renewable | | 010100 | 114A |
| **- Fuels Used for Heat Production** | | | |
| - - Gas-/Diesel Oil | | 010100 | 204A |
| - - Fuel Oil | | 010100 | 203A |
| - - Natural Gas | | 010100 | 301A |
| - - Electricity Plant Coal | | 010100 | 102A |
| - - Straw | | 010100 | 117A |
| - - Wood Chips | | 010100 | 111A |
| - - Wood Pellets | | 010100 | 111A |
| - - Wood Waste | | 010100 | 111A |
| - - Biogas, Landfill | | 010100 | 309A |
| - - Biogas, Sludge | | 010100 | 309A |
| - - Biogas, Other | | 010100 | 309A |
| - - Bio Natural Gas | | 010100 | 315A |
| - - Wastes, Non-renewable | | 010100 | 114A |
| - - Wastes, Renewable | | 010100 | 114A |
| **- Own Use** | | | |
| - - Electricity | | | |
| - - District Heating | | | |
| **- Production** | | | |
| - - Electricity, Gross | | | |
| - - District Heating, Net | | | |
| **Wind Turbines** | | | |
| **- Used for Power Production** | | | |
| - - Wind Power | | | |
| **- Gross Production** | | | |
| - - Electricity | | | |

| *Continued* | | | |
|---|---|---|---|
| **Hydro Power Units** | | | |
| **- Used for Power Production** | | | |
| - - Hydro Power | | | |
| **- Gross Production** | | | |
| - - Electricity | | | |
| **District Heating Units** | | | |
| **- Fuels Used for Heat Production** | | | |
| - - Refinery Gas | | 010300 | 308A |
| - - LPG | | 010200 | 303A |
| - - Gas-/Diesel Oil | | 010200 | 204A |
| - - Fuel Oil | | 010200 | 203A |
| - - Waste Oil | | 010200 | 203A |
| - - Petroleum Coke | | 010200 | 110A |
| - - Natural Gas | | 010200 | 301A |
| - - Electricity Plant Coal | | 010200 | 102A |
| - - Coal | | 010200 | 102A |
| - - Solar Energy | | | |
| - - Geothermal Energy | | | |
| - - Straw | | 010200 | 117A |
| - - Wood Chips | | 010200 | 111A |
| - - Wood Pellets | | 010200 | 111A |
| - - Wood Waste | | 010200 | 111A |
| - - Biogas, Landfill | | 010200 | 309A |
| - - Biogas, Sludge | | 010200 | 309A |
| - - Biogas, Other | | 010200 | 309A |
| - - Bio Natural Gas | | 010200 | 315A |
| - - Wastes, Non-renewable | | 010200 | 114A |
| - - Wastes, Renewable | | 010200 | 114A |
| - - Bio Oil | | 010200 | 215A |
| - - Electricity for Heat Pumps | | | |
| **- Own Use** | | | |
| - - District Heating | | | |
| **- Net Production** | | | |
| - - District Heating | | | |
| **Auto producers, Electricity Only** | | | |
| **- Fuels Used for Power Production** | | | |
| - - Natural Gas | | 030100 | 301A |
| - - Solar Energy | | | |
| - - Biogas, Landfill | | 030100 | 309A |
| - - Biogas, Sewage Sludge | | 030100 | 309A |
| - - Biogas, Other | | 030100 | 309A |
| - - Bio Natural Gas | | 030100 | 315A |
| **- Gross Production** | | | |
| - - Electricity | | | |
| **Auto producers, CHP Units** | | | |
| **- Fuels Used for Power Production** | | | |
| - - Refinery Gas | | 010300 | 308A |
| - - Gas-/Diesel Oil | | 030100 | 204A |
| - - Fuel Oil | | 030100 | 203A |
| - - Waste Oil | | 030100 | 203A |
| - - Natural Gas | | 030100 | 301A |
| - - Coal | | 030100 | 102A |
| - - Straw | | 030100 | 117A |
| - - Wood Chips | | 030100 | 111A |
| - - Wood Pellets | | 030100 | 111A |
| - - Wood Waste | | 030100 | 111A |
| - - Biogas, Landfill | | 030100 | 309A |
| - - Biogas, Sludge | | 030100 | 309A |
| - - Biogas, Other | | 030100 | 309A |
| - - Bio Natural Gas | | 030100 | 315A |
| - - Bio Oil | | 030100 | 215A |
| - - Wastes, Non-renewable | | 010100 | 114A |
| - - Wastes, Renewable | | 010100 | 114A |
| **- Fuels Used for Heat Production** | | 030100 | 114A |
| - - Refinery Gas | | 010300 | 308A |
| - - Gas-/Diesel Oil | | 030100 | 204A |
| - - Fuel Oil | | 030100 | 203A |
| - - Waste Oil | | 030100 | 203A |
| - - Natural Gas | | 030100 | 301A |
| - - Coal | | 030100 | 102A |
| - - Wood Chips | | 030100 | 111A |
| - - Wood Waste | | 030100 | 111A |

| | | | | |
|---|---|---|---|---|
| *Continued* | | | | |
| - - Biogas, Landfill | | | 030100 | 309A |
| - - Biogas, Sludge | | | 030100 | 309A |
| - - Biogas, Other | | | 030100 | 309A |
| - - Bio Natural Gas | | | 030100 | 315A |
| - - Wastes, Non-renewable | | | 010100 | 114A |
| - - Wastes, Renewable | | | 010100 | 114A |
| **- Production** | | | | |
| - - Electricity, Gross | | | | |
| - - District Heating, Net | | | | |
| **Auto producers, Heat Only** | | | | |
| **- Fuels Used for Heat Production** | | | | |
| - - Gas-/Diesel Oil | | | 030100 | 204A |
| - - Fuel Oil | | | 030100 | 203A |
| - - Waste Oil | | | 030100 | 203A |
| - - Natural Gas | | | 030100 | 301A |
| - - Straw | | | 030100 | 117A |
| - - Wood Chips | | | 030100 | 111A |
| - - Wood Pellets | | | 030100 | 111A |
| - - Wood Waste | | | 030100 | 111A |
| - - Biogas, Landfill | | | 030100 | 309A |
| - - Biogas, Sludge | | | 030100 | 309A |
| - - Biogas, Other | | | 030100 | 309A |
| - - Bio Natural Gas | | | 030100 | 315A |
| - - Wastes, Non-renewable | | | 010200 | 114A |
| - - Wastes, Renewable | | | 010200 | 114A |
| - - Heat Pumps | | | | |
| **- Net Production** | | | | |
| - - District Heating | | | | |
| **Gas Works Gas Units** | 030106 | 301A | | |
| **- Fuels Used for Gas Works Gas** | | | | |
| - - Refinery Gas | | | | |
| - - LPG | | | | |
| - - Naphtha (LVN) | | | | |
| - - Gas-/Diesel Oil | | | | |
| - - Natural Gas | | | | |
| - - Hard Coal | | | | |
| **- Production** | | | | |
| - - Gas Works Gas | | | | |
| - - Coke | | | | |
| **Distribution Losses** | | | | |
| **- Distribution Losses etc.** | | | | |
| - - Natural Gas | | | | |
| - - Electricity | | | | |
| - - District Heating | | | | |
| - - Gas Works Gas | | | | |
| **Consumption Sector** | | | | |
| **- Non-energy Use** | | | | |
| - - White Spirit | | | | |
| - - Lubricants | | | | |
| - - Bitumen | | | | |
| **Transport** | | | | |
| **Military Transport** | | | | |
| - Aviation Gasoline | Transport | 209A | | |
| - Motor Gasoline | Transport | 208A | | |
| - JP4 | Transport | 207A | | |
| - JP1 | Transport | 207A | | |
| - Gas-/Diesel Oil | Transport | 205A | | |
| **Road** | | | | |
| - LPG | Transport | 303A | | |
| - Motor Gasoline | Transport | 208A | | |
| - Other Kerosene | 020200 | 206A | | |
| - Gas-/Diesel Oil | Transport | 205A | | |
| - Fuel Oil | Transport | 203A | | |
| - Natural gas | Transport | 301A | | |
| - Bio Natural Gas | Transport | 315A | | |
| - Bioethanol | Transport | 223A | | |
| - Biodiesel | Transport | 215A | | |
| **Rail** | | | | |
| - Motor Gasoline | Transport | 208A | | |
| - Other Kerosene | Transport | 206A | | |
| - Gas-/Diesel Oil | Transport | 205A | | |

| | | | |
|---|---|---|---|
| *Continued* | | | |
| - Electricity | | | |
| **Domestic Sea Transport** | | | |
| - LPG | Transport | 303A | |
| - Other Kerosene | Transport | 206A | |
| - Gas-/Diesel Oil | Transport | 205A | |
| - Fuel Oil | Transport | 203A | |
| **Domestic Aviation** | | | |
| - LPG | Transport | 303A | |
| - Aviation Gasoline | Transport | 209A | |
| - Motor Gasoline | Transport | 208A | |
| - Other Kerosene | 020100 | 206A | |
| - JP1 | Transport | 207A | |
| **International Aviation** | | | |
| - Aviation Gasoline | Transport | 209A | |
| - JP1 | Transport | 207A | |
| **Agriculture and Forestry and Horticulture** | | | |
| - LPG | Transport | 303A | |
| - Motor Gasoline | Transport | 208A | |
| - Other Kerosene | 020300 | 206A | |
| - Gas-/Diesel Oil | Transport | 205A | |
| - Fuel Oil | 020300 | 203A | |
| - Petroleum Coke | 020300 | 110A | |
| - Natural Gas | 020300 | 301A | |
| - Coal | 020300 | 102A | |
| - Brown Coal Briquettes | 020300 | 106A | |
| - Straw | 020300 | 117A | |
| - Wood Chips | 020300 | 111A | |
| - Wood Waste | 020300 | 111A | |
| - Biogas, Other | 020300 | 309A | |
| - Bio Natural Gas | 020300 | 315A | |
| - Heat Pumps | | | |
| - Electricity | | | |
| - District Heating | | | |
| **Fishing** | | | |
| - LPG | Transport | 303A | |
| - Motor Gasoline | Transport | 208A | |
| - Other Kerosene | Transport | 206A | |
| - Gas-/Diesel Oil | Transport | 205A | |
| - Fuel Oil | Transport | 203A | |
| **Manufacturing Industry** | | | |
| - Refinery Gas | 030100 | 308A | |
| - LPG | Transport | 303A | |
| - Naphtha (LVN) | Transport | 210A | |
| - Motor Gasoline | Transport | 208A | |
| - Other Kerosene | 030100 | 206A | |
| - Gas-/Diesel Oil | Transport | 205A | |
| - Fuel Oil | 030100 | 203A | |
| - Waste Oil | 030100 | 203A | |
| - Petroleum Coke | 030100 | 110A | |
| - Natural Gas | 030100 | 301A | |
| - Coal | 030100 | 102A | |
| - Coke | 030100 | 107A | |
| - Brown Coal Briquettes | 030100 | 106A | |
| - Wood Chips | 030100 | 111A | |
| - Wood Pellets | 030100 | 111A | |
| - Wood Waste | 030100 | 111A | |
| - Biogas, Landfill | 030100 | 111A | |
| - Biogas, Other | 030100 | 309A | |
| - Bio Natural Gas | 030100 | 315A | |
| - Wastes, Non-renewable | 030100 | 114A | |
| - Wastes, Renewable | 030100 | 114A | |
| - Heat Pumps | | | |
| - Electricity | | | |
| - District Heating | | | |
| - Gas Works Gas | 030100 | 301A | |
| **Construction** | | | |
| - LPG | 031500 | 303A | |
| - Motor Gasoline | Transport | | |
| - Other Kerosene | 031500 | 206A | |
| - Gas-/Diesel Oil | Transport | | |
| - Fuel Oil | 031500 | 203A | |
| - Natural Gas | 031500 | 301A | |

| | | | |
|---|---|---|---|
| *Continued* | | | |
| - Bio Natural Gas | 031500 | 315A | |
| - Electricity | | | |
| **Wholesale** | | | |
| - LPG | 020100 | 303A | |
| - Other Kerosene | 020100 | 206A | |
| - Gas-/Diesel Oil | 020100 | 204A | |
| - Petroleum Coke | 020100 | 110A | |
| - Natural Gas | 020100 | 301A | |
| - Wood Waste | 020100 | 111A | |
| - Bio Natural Gas | 020100 | 315A | |
| - Electricity | | | |
| - District Heating | | | |
| **Retail Trade** | | | |
| - LPG | 020100 | 303A | |
| - Other Kerosene | 020100 | 206A | |
| - Gas-/Diesel Oil | 020100 | 204A | |
| - Fuel Oil | 020100 | 203A | |
| - Petroleum Coke | 020100 | 110A | |
| - Natural Gas | 020100 | 301A | |
| - Electricity | | | |
| - District Heating | | | |
| **Private Service** | | | |
| - LPG | 020100 | 303A | |
| - Other Kerosene | 020100 | 206A | |
| - Gas-/Diesel Oil | 020100 | 204A | |
| - Fuel Oil | 020100 | 203A | |
| - Waste Oil | 020100 | 203A | |
| - Petroleum Coke | 020100 | 110A | |
| - Natural Gas | 020100 | 301A | |
| - Wood Chips | 020100 | 111A | |
| - Wood Waste | 020100 | 111A | |
| - Biogas, Landfill | 020100 | 309A | |
| - Biogas, Sludge | 020100 | 309A | |
| - Biogas, Other | 020100 | 309A | |
| - Bio Natural Gas | 020100 | 315A | |
| - Wastes, Non-renewable | 020100 | 114A | |
| - Wastes, Renewable | 020100 | 114A | |
| - Electricity | | | |
| - District Heating | | | |
| - Gas Works Gas | 020100 | 301A | |
| **Public Service** | | | |
| - LPG | 020100 | 303A | |
| - Other Kerosene | 020100 | 206A | |
| - Gas-/Diesel Oil | 020100 | 204A | |
| - Fuel Oil | 020100 | 203A | |
| - Petroleum Coke | 020100 | 110A | |
| - Natural Gas | 020100 | 301A | |
| - Coal | 020100 | 102A | |
| - Brown Coal Briquettes | 020100 | 106A | |
| - Solar Energy | | | |
| - Wood Chips | 020100 | 111A | |
| - Wood Pellets | 020100 | 111A | |
| - Bio Natural Gas | 020100 | 315A | |
| - Electricity | | | |
| - District Heating | | | |
| - Gas Works Gas | 020100 | 301A | |
| **Single Family Houses** | | | |
| - LPG | 020200 | 303A | |
| - Motor Gasoline | Transport | 208A | |
| - Other Kerosene | 020200 | 206A | |
| - Gas-/Diesel Oil | 020200 | 204A | |
| - Fuel Oil | 020200 | 203A | |
| - Petroleum Coke | 020200 | 110A | |
| - Natural Gas | 020200 | 301A | |
| - Coal | 020200 | 102A | |
| - Coke | 020200 | 107A | |
| - Brown Coal Briquettes | 020200 | 106A | |
| - Solar Energy | | | |
| - Straw | 020200 | 117A | |
| - Firewood | 020200 | 111A | |
| - Wood Chips | 020200 | 111A | |
| - Wood Pellets | 020200 | 111A | |

| *Continued* | | | |
|---|---|---|---|
| - Bio Natural Gas | 020200 | 315A | |
| - Biodiesel | 020200 | 215A | |
| - Heat Pumps | | | |
| - Electricity | | | |
| - District Heating | | | |
| - Gas Works Gas | 020200 | 301A | |
| **Multi-family Houses** | | | |
| - LPG | 020200 | 303A | |
| - Other Kerosene | 020200 | 206A | |
| - Gas-/Diesel Oil | 020200 | 204A | |
| - Fuel Oil | 020200 | 203A | |
| - Petroleum Coke | 020200 | 110A | |
| - Natural Gas | 020200 | 301A | |
| - Coal | 020200 | 102A | |
| - Coke | 020200 | 107A | |
| - Brown Coal Briquettes | 020200 | 106A | |
| - Solar Energy | | | |
| - Bio Natural Gas | 020200 | 315A | |
| - Electricity | | | |
| - District Heating | | | |
| - Gas Works Gas | 020200 | 301A | |

# Annex 5 - Assessment of completeness and (potential) sources and sinks of greenhouse gas emissions and removals excluded

## GHG inventory

The Danish greenhouse gas emission inventories for 1990-2018 include all sources identified by the 2006 IPCC Guidelines where methodologies and default emission factors exist. Some very minor sources have not been estimated due to lack of methodology, activity data or emission factors, i.e.:

- $N_2O$ emissions from gaseous fuels in shipping;
- Direct and indirect $CH_4$ emissions from agricultural soils.

## KP-LULUCF inventory

The KP-LULUCF inventory is considered complete. Please see Chapter 11 for further documentation.

## Annex 6 - Additional information to be considered as part of the annual inventory submission and the supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol or other useful reference information

Tables A6.1 to A6.5 below contain the information publically available in this report. Table A6.6 includes the list of discrepancies identified by the ITL (no discrepancies in this submission).

Table A6.1 Total quantities of Kyoto Protocol units by account type at beginning of reported year.

| Account type | Unit type | | | | | |
|---|---|---|---|---|---|---|
| | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
| Party holding accounts | NO | NO | NO | 283 191 | NO | NO |
| Entity holding accounts | NO | NO | NO | 788 | NO | NO |
| Retirement account | NO | NO | NO | NO | NO | NO |
| Previous period surplus reserve account | NO | | | | | |
| Article 3.3/3.4 net source cancellation accounts | NO | NO | NO | NO | | |
| Non-compliance cancellation account | NO | NO | NO | NO | | |
| Voluntary cancellation account | NO | NO | NO | 11 164 | NO | NO |
| Cancellation account for remaining units after carry-over | NO | NO | NO | NO | NO | NO |
| Article 3.1 ter and quater ambition increase cancellation account | NO | | | | | |
| Article 3.7 ter cancellation account | NO | | | | | |
| tCER cancellation account for expiry | | | | | NO | |
| lCER cancellation account for expiry | | | | | | NO |
| lCER cancellation account for reversal of storage | | | | | | NO |
| lCER cancellation account for non-submission of certification report | | | | | | NO |
| tCER replacement account for expiry | NO | NO | NO | NO | NO | |
| lCER replacement account for expiry | NO | NO | NO | NO | | |
| lCER replacement account for reversal of storage | NO | NO | NO | NO | | NO |
| lCER replacement account for non-submission of certification report | NO | NO | NO | NO | | NO |
| Total | NO | NO | NO | 295 143 | NO | NO |

Table A6.2a Annual internal transactions.

| Transaction type | Additions | | | | | | Subtractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AAUs | ERUs | RMUs | CERs | tCERs | lCERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
| Art6 issuance and conversion | | | | | | | | | | | | |
| Party verified projects | | NO | | | | | NO | | NO | | | |
| Independently verified projects | | NO | | | | | NO | | NO | | | |
| Art3.3 and 3.4 issuance or cancellation | | | | | | | | | | | | |
| 3.3 Afforestation refor-estation | | | NO | | | | NO | NO | NO | NO | | |
| 3.3 Deforestation | | | NO | | | | NO | NO | NO | NO | | |
| 3.4 Forest management | | | NO | | | | NO | NO | NO | NO | | |
| 3.4 Cropland manage-ment | | | NO | | | | NO | NO | NO | NO | | |
| 3.4 Grazing land man-agement | | | NO | | | | NO | NO | NO | NO | | |
| 3.4 Revegetation | | | NO | | | | NO | NO | NO | NO | | |
| 3.4 Wetland drainage and rewetting | | | NO | | | | NO | NO | NO | NO | | |
| Art 12 afforestation and reforestation | | | | | | | | | | | | |
| Replacement of expired tCERs | | | | | | | NO | NO | NO | NO | NO | |
| Replacement of expired lCERs | | | | | | | NO | NO | NO | NO | | |
| Replacement for rever-sal of storage | | | | | | | NO | NO | NO | NO | | NO |
| Cancellation for reversal of storage | | | | | | | | | | | | NO |
| Replacement for non-submission of certifica-tion report | | | | | | | NO | NO | NO | NO | | NO |
| Cancellation for non-submission of certifica-tion report | | | | | | | | | | | | NO |
| Other cancelation | | | | | | | | | | | | |
| Voluntary cancellation | | | | | | | NO | NO | NO | NO | NO | NO |
| Article 3.1 ter and quater ambition increase cancellation | | | | | | | NO | | | | | |
| Subtotal | | NO | NO | | | | NO | NO | NO | NO | NO | NO |

Table A6.2ab Annual internal transactions.

| Transaction type | Retirement | | | | | |
|---|---|---|---|---|---|---|
| | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
| Retirement | NO | NO | NO | NO | NO | NO |
| Retirement from PPSR | NO | | | | | |
| Total | NO | NO | NO | NO | NO | NO |

Table A6.2b Annual external transactions.

| | Additions | | | | | | Subtractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total transfers and acquisitions | AAUs | ERUs | RMUs | CERs | tCERs | lCERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
| CDM | NO | NO | NO | 3 380 834 | NO | NO | NO | NO | NO | NO | NO | NO |
| EU | NO | NO | NO | 299 | NO | NO | NO | NO | NO | 1199 | NO | NO |
| Subtotal | NO | NO | NO | 3 381 133 | NO | NO | NO | NO | NO | 1199 | NO | NO |

Table A6.2c Annual transactions between PPSR accounts.

| | AAUs | ERUs | RMUs | CERs | tCERs | lCERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subtotal | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |

Table A6.2d Share of proceeds transactions under decision 1/CMP.8, paragraph 21 - Adaptation Fund.

| | AAUs | ERUs | RMUs | CERs | tCERs | lCERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| First international transfers of AAUs | NO | | | | | | NO | | | | | |
| Issuance of ERU from Party-verified projects | | NO | | | | | | NO | | | | |
| Issuance of independently verified ERUs | | NO | | | | | | NO | | | | |

Table A6.2f Total annual transactions.

| | Additions | | | | | | Subtractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AAUs | ERUs | RMUs | CERs | tCERs | lCERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
| Total<br>(Sum of sub-totals in table 2a and table 2b) | NO | NO | NO | 3 381 133 | NO | NO | NO | NO | NO | 1 199 | NO | NO |

Table A6.3 Expiry, cancellation and replacement.

| Transaction or event type | Requirement to replace or cancel | | | Replacement | | | | | | Cancellation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transaction or event type | tCERs | lCERs | CERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
| Temporary CERs | | | | | | | | | | | | | | | |
| Expired in retirement and replacement accounts | NO | | | NO | NO | NO | NO | NO | | | | | | | |
| Expired in holding accounts | NO | | | | | | | | | | | | | NO | |
| Long-term CERs | | | | | | | | | | | | | | | |
| Expired in retirement and replacement accounts | | NO | | NO | NO | NO | NO | | | | | | | | |
| Expired in holding accounts | | NO | | | | | | | | | | | | | NO |
| Subject to reversal of Storage | | NO | | NO | NO | NO | NO | | NO | | | | | | NO |
| Subject to non submission of certification Report | | NO | | NO | NO | NO | NO | | NO | | | | | | NO |
| Carbon Capture and Storage CERs | | | | | | | | | | | | | | | |
| Subject to net reversal of storage | | | NO | | | | | | | NO | NO | NO | NO | | |
| Subject to non submission of certification report | | | NO | | | | | | | NO | NO | NO | NO | | |
| Total | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |

Table A6.4 Total quantities of Kyoto Protocol units by account type at end of reported year.

| Account type | Unit type | | | | | |
|---|---|---|---|---|---|---|
| | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
| Party holding accounts | NO | NO | NO | 284 392 | NO | NO |
| Entity holding accounts | NO | NO | NO | 3 379 521 | NO | NO |
| Retirement account | NO | NO | NO | NO | NO | NO |
| Previous period surplus reserve account | NO | | | | | |
| Article 3.3/3.4 net source cancellation accounts | NO | NO | NO | NO | | |
| Non-compliance cancellation account | NO | NO | NO | NO | | |
| Voluntary cancellation account | NO | NO | NO | 11 164 | NO | NO |
| Cancellation account for remaining units after carry-over | NO | NO | NO | NO | NO | NO |
| Article 3.1 ter and quater ambition increase cancellation account | NO | | | | | |
| Article 3.7 ter cancellation account | NO | | | | | |
| tCER cancellation account for expiry | | | | | NO | |
| lCER cancellation account for expiry | | | | | | NO |
| lCER cancellation account for reversal of storage | | | | | | NO |
| lCER cancellation account for non-submission of certification report | | | | | | NO |
| tCER replacement account for expiry | NO | NO | NO | NO | NO | |
| lCER replacement account for expiry | NO | NO | NO | NO | | |
| lCER replacement account for reversal of storage | NO | NO | NO | NO | | NO |
| lCER replacement account for non-submission of certification report | NO | NO | NO | NO | | NO |
| Total | NO | NO | NO | 3 675 077 | NO | NO |

Table A6.5(a) Summary information on additions and subtractions.

| | Additions | | | | | | Subtractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AAUs | ERUs | RMUs | CERs | tCERs | lCERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
| Assigned amount units issued | NO | | | | | | | | | | | |
| Article 3 Paragraph 7 ter cancellations | | | | | | | NO | | | | | |
| Cancellation following increase in ambition | | | | | | | NO | | | | | |
| Cancellation of remaining units after carry over | | | | | | | NO | NO | NO | NO | NO | NO |
| Non-compliance cancellation | | | | | | | NO | NO | NO | NO | | |
| Carry-over | | NO | | NO | | | | | | | | |
| Carry-over to PPSR | NO | | | | | | NO | | | | | |
| Total | NO | NO | | NO | | | NO | NO | NO | NO | NO | NO |

Table A6.5(b) Summary information on annual transactions.

| | Additions | | | | | | Subtractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AAUs | ERUs | RMUs | CERs | tCERs | lCERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
| Year 1 (2013) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 2 (2014) | NO | NO | NO | 37 361 | NO | NO | NO | NO | NO | 3 142 | NO | NO |
| Year 3 (2015) | NO | NO | NO | 815 943 | NO | NO | NO | NO | NO | 56 320 | NO | NO |
| Year 4 (2016) | NO | NO | NO | 60 795 | NO | NO | NO | NO | NO | 634 856 | NO | NO |
| Year 5 (2017) | NO | NO | NO | 77 456 | NO | NO | NO | NO | NO | 16 155 | NO | NO |
| Year 6 (2018) | NO | NO | NO | 5 456 | NO | NO | NO | NO | NO | 2 559 | NO | NO |
| Year 7 (2019) | NO | NO | NO | 3 381 133 | NO | NO | NO | NO | NO | 1 199 | NO | NO |
| Year 8 (2020) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 2021 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 2022 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 2023 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Total | NO | NO | NO | 4 378 144 | NO | NO | NO | NO | NO | 714 231 | NO | NO |

Table A6.5(c) Summary information on annual transactions between PPSR accounts.

| | Additions | | | | | | Subtractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AAUs | ERUs | RMUs | CERs | tCERs | lCERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
| Year 1 (2013) | NO | | | | | | NO | | | | | |
| Year 2 (2014) | NO | | | | | | NO | | | | | |
| Year 3 (2015) | NO | | | | | | NO | | | | | |
| Year 4 (2016) | NO | | | | | | NO | | | | | |
| Year 5 (2017) | NO | | | | | | NO | | | | | |
| Year 6 (2018) | NO | | | | | | NO | | | | | |
| Year 7 (2019) | NO | | | | | | NO | | | | | |
| Year 8 (2020) | NO | | | | | | NO | | | | | |
| Year 2021 | NO | | | | | | NO | | | | | |
| Year 2022 | NO | | | | | | NO | | | | | |
| Year 2023 | NO | | | | | | NO | | | | | |
| Total | NO | | | | | | NO | | | | | |

Table A6.5(d) Summary information on expiry, cancellation and replacement.

| | Requirement to replace or cancel | | | Replacement | | | | | | Cancellation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | tCERs | lCERs | CERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
| Year 1 (2013) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 2 (2014) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 3 (2015) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 4 (2016) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 5 (2017) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 6 (2018) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 7 (2019) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 8 (2020) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 2021 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 2022 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 2023 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Total | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |

Table A6.5(e) Summary information on retirement.

| | Retirement – Unit type | | | | | |
|---|---|---|---|---|---|---|
| Year | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
| Year 1 (2013) | NO | NO | NO | NO | NO | NO |
| Year 2 (2014) | NO | NO | NO | NO | NO | NO |
| Year 3 (2015) | NO | NO | NO | NO | NO | NO |
| Year 4 (2016) | NO | NO | NO | NO | NO | NO |
| Year 5 (2017) | NO | NO | NO | NO | NO | NO |
| Year 6 (2018) | NO | NO | NO | NO | NO | NO |
| Year 7 (2019) | NO | NO | NO | NO | NO | NO |
| Year 8 (2020) | NO | NO | NO | NO | NO | NO |
| Year 2021 | NO | NO | NO | NO | NO | NO |
| Year 2022 | NO | NO | NO | NO | NO | NO |
| Year 2023 | NO | NO | NO | NO | NO | NO |

## Annex 7 - Information related to the greenhouse gas inventory for the Faroe Islands

### Introduction

This report covers the Faroese part of the National Inventory Report for the Kingdom of Denmark.

The report is made by Umhvørvisstovan, the Faroese Environment Agency (FEA) www.us.fo.

#### Background information on greenhouse gas inventories and climate change

Each year the Faroe Islands is obligated to report its emission of greenhouse gases (GHG), according to the requirements of the United Nations Framework Convention on Climate Change (UNFCCC). The Kingdom of Denmark (which includes Denmark, Greenland and the Faroe Islands as geographical areas) has signed the UNFCCC. The Faroese emission figures are part of the emission total for the Kingdom of Denmark.

When Denmark ratified the Kyoto Protocol, it was with territorial reservation for the Faroe Islands. Since the reservation has not been lifted, the requirements for reporting are only those related to the Convention.

The first emission inventories for the Faroe Islands were made using an average method based upon the total use of fossil fuels in the Faroe Islands and consequently the inventories have only included total estimates of $CO_2$ emissions. Later, the inventories were done according to IPCC guidelines. The FEA has since 2008 yearly reported GHG emissions to Danish Centre for Environment and Energy (DCE), Dep. of Environmental Science (ENVS), Aarhus University.

The GHGs reported are:

- Carbon dioxide $CO_2$
- Methane $CH_4$
- Nitrous Oxide $N_2O$
- Hydrofluorocarbons HFCs
- Perfluorocarbons PFCs
- Sulphur hexaflouride $SF_6$
- Nitrogen triflouride $NF_3$

#### A description of the institutional arrangement for inventory preparation

FEA, an agency under the Ministry of Environment, Industry and Trade (www.uvmr), is responsible for the annual preparation and submission to the UNFCCC of the Faroe Islands' contribution to the Kingdom of Denmark's National Inventory Report and the GHG inventories in the Common Reporting Format in accordance with the UNFCCC Guidelines. The inventory is done with guidance from and in co-operation with DCE.

The work concerning the annual greenhouse gas emission inventory is carried out in co-operation with other Faroese ministries, research institutes, organisations and companies:

- *Statistics Faroe Islands (Ministry of Finance)* www.hagstova.fo Annual statistics on liquid fuel sale, fuel usage for electricity and heat production, and statistics on livestock (sheep and cows).
- *Municipal Waste Plants* Data on amount of incinerated waste.
- *Electricity producing company* www.sev.fo Data on import of F-gases ($SF_6$).
- *Airline Company* www.atlantic.fo Data for fuel bunkers for domestic flights and international flights to and from the Faroe Islands.
- *Refrigeration companies* Data on import of F-gases (HFCs).
- *Oil companies – license holders* Data on use of fuel oil in connection with exploration (deep water) drilling in Faroese territorial waters.

In January 2010, DCE and FEA made a formal agreement about data delivery.

**Brief description of the process of inventory preparation. Data collection and processing, data storage and archiving**

The activity data for fuel sale and for fuel usage by combustion plants, as well as for the number of livestock (sheep and cows) are collected and stored at Statistics Faroe Islands. Each year, FEA receives new data for fuel sale and fuel usage for the previous year. Numbers of livestock and other data is accessible on the homepage of Statistics Faroe Islands.

Other activity data are delivered by plants owned by municipalities or private companies.

After receiving the data, the material is placed on servers at FEA. The servers are subject to routine backup services. Material that has been backed up is archived safely. All collected data is also archived in the electronic journal of the agency.

The emission factors are yearly received from DCE Denmark, sent by email to the FEA as Excel files. In addition to copying the factors to spread sheet files, the e-mails are archived in the electronic journal.

Since the 2008 submission, all subsequent submissions have been reported in the Common Reporting Format of UNFCCC (CRF). The new format has meant improvements, higher data security and limited the potential for errors in the reporting.

**Brief general description of methodologies and data sources used**

The GHG inventory for the Faroe Islands includes the following sectors:

- Energy (CRF sector 1)
- Industrial Processes and Product Use (CRF sector 2)
- Agriculture (CRF sector 3)
- Waste (CRF sector 5)

Since the emissions in the Waste sector all are allocated to the Energy sector, table 1 also includes methods applied and emission factors for calculating GHG emissions related to the Waste sector.

The applied methodologies follow the IPCC Guidelines and IPCC Good Practice Guidance, and the Tier 1 method is always applied.

The methods and the emission factors used in the inventory are shown in Table 1 (emission factors for $CO_2$, $CH_4$ and $N_2O$ in the Energy and Agriculture sector) and in Table 2 (emission factors for HFCs and $SF_6$ in the sector for Industrial Processes and Product Use). A brief general description of methodologies is included below for the different sectors.

Table 1 Methods applied, and emission factors used for calculating $CO_2$, $CH_4$ and $N_2O$ emissions in the Energy and Agriculture sectors.

| | $CO_2$ | | $CH_4$ | | $N_2O$ | |
|---|---|---|---|---|---|---|
| GHG CATEGORIES | Method applied | Emission factor | Method applied | Emission factor | Method applied | Emission factor |
| 1. Energy | T1 | CS | T1 | CS | T1 | CS |
| A. Fuel Combustion | T1 | CS | T1 | CS | T1 | CS |
| 1. Energy Industries | T1 | CS | T1 | CS | T1 | CS |
| 2. Manufacturing Industries and Construction | T1 | CS | T1 | CS | T1 | CS |
| 3. Transport | T1 | CS | T1 | CS | T1 | CS |
| 4. Other Sectors | T1 | CS | T1 | CS | T1 | CS |
| 3. Agriculture | | | T1 | D | T1 | D |
| A. Enteric Fermentation | | | T1 | D | | |
| B. Manure Management | | | T1 | D | T1 | D |

Table 2 Methods and Emission factors used for calculating HFCs and $SF_6$ emissions in the Industrial Processes sector.

| | HFCs | | $SF_6$ | |
|---|---|---|---|---|
| GHG CATEGORIES | Method applied | Emission factor | Method applied | Emission factor |
| 2. Industrial Processes and Product Use | T1 | D | T1 | D |
| F. Product Uses as Substitutes of ODS | T1 | D | T1 | D |

Energy sector

All emissions in the Energy sector are from Fuel combustion (1.A.A), and in these categories:

- 1.A.1 Energy Industries
    - 1A1a Public Electricity and Heat Production (incl. Waste)
    - 1A1c Manufacture of Solid Fuels and Other Energy Industries
- 1.A.2 Manufacturing Industries and Construction
- 1.A.3 Transport
    - 1.A.3.a Domestic Aviation
    - 1.A.3.b Road Transportation
    - 1.A.3.d Domestic Navigation
- 1.A.4 Other Sectors
    - 1.A.4.a Commercial/Institutional
    - 1.A.4.b Residential
    - 1.A.4.c Agriculture/Forestry/Fishing
        - iii Fishing

Statistics Faroe Islands provides the information on fuel sales by fuel type (in $m^3$) and divided into eight main groups (original titles: Fishing vessels, Other ships, Transportation, Industry, Trading and Service, Residential and Communities, Institutions and Public Power), each group again divided into subgroups.

The fuel data delivered by Statistics Faroe Islands originate from several sources. The main data sources are the two main oil companies in the Faroe Islands. Fuel data not included in sales information from the oil companies are delivered by the industry to FEA.

Since the delivered data on fuel sale are not fully arranged according to IPCC guidelines, the FEA rearranges the data to comply with the guidelines.

### Emission factors

Emissions from fuel combustion can be divided into two main sources: stationary and mobile combustion. Stationary combustion is fuel combustion related to e.g. industry on land, house heating and oil exploration. Mobile combustion includes the combustion in engines used for propulsion in the various modes of transport such as road transport, marine activities and aviation. The emission factors used for stationary, transport, waste and aviation are country specific and provided by DCE. All emissions factors used in the inventory are found in Annex 1.

Emissions are calculated by multiplying fuel consumption data with an emission factor (e.g. in tonnes emission per GJ fuel).

### Public Electricity and Heat Production (1A1a)

The activity data used for calculations of emissions of GHG from Public Electricity and Heat Production are the consumption of residual oil and diesel oil at electricity producing plants on the Faroe Islands. The emission factors are calculated and delivered by DCE, see Table 5 in Annex 1.a.

### Manufacture of Solid Fuels and Other Energy Industries (1A1c)

This category only covers the emissions of GHG from activities related to exploration drilling in Faroese territory. The operators deliver the activity data (usage of diesel on the rigs). The emission factors are calculated and delivered by DCE, see Table 5 in Annex 1.a.

### Manufacturing Industries and Construction (1A2)

Statistics Faroe Islands deliver the activity data for oil usage. The emission factors are calculated and delivered by DCE, see Table 5 in Annex 1.a.

### Domestic Aviation (1A3a)

The Faroese airline company, Atlantic Airways, www.atlantic.fo delivers data for jet fuel bunkered in the Faroe Islands. Since the Faroe Islands has accepted the United Nations Framework Convention on Climate Change as a part of the Kingdom of Denmark, aviation between Denmark and the Faroe Islands is to be reported as Domestic Aviation. The jet fuel data is thus divided by destination: flights to destinations inside the Kingdom of Denmark, i.e., Denmark and Greenland (Domestic Aviation), and outside the Danish Kingdom, e.g., Iceland, Norway and Great Britain (International Aviation). Fuel refuelled outside the Faroe Islands is not included in the Faroese inventory. The emission factors for aviation are calculated and delivered by DCE, see Table 7 in Annex 1.b.

### Road Transportation (1A3b)

The activity data for road transportation is data for sale of gasoline and diesel to all types of vehicle at all filling stations in the Faroe Islands. The data is delivered by the Statistics Faroe Islands. The emission factors for road traffic are calculated and delivered by DCE. The Danish results are modified for Faroese traffic conditions such as other gross vehicle weights for heavy-duty vehicles and no highway driving conditions. The emissions factors are also modified because biofuel is not used in the Faroe Islands, unlike in Denmark. The emission factors are shown in Table 8 in Annex 1.b.

### Domestic Navigation (1A3d)

Statistics Faroe Islands deliver the activity data for oil used in navigation. The emission factors are calculated and delivered by DCE, see Table 9 in Annex 1.b.

### Other sectors (1A4)

The activity data for oil usage used to calculate the GHG emissions from the Commercial/Institutional (1A4a) and Residential (1A4b) sectors are delivered by Statistics Faroe Islands. The emission factors calculated and delivered by DCE are found in Table 5 in Annex 1.a.

### Fishing (1A4ciii)

Statistics Faroe Islands deliver the activity data (sale of oil to fishing vessels). The emission factors are calculated and delivered by DCE and are found in Table 9 in Annex 1.b.

Until the 2014 delivery of data, it had not been possible to rearrange the data for foreign fishing vessels to fully comply with the IPCC guidelines. According to the guidelines, all emissions resulting from fuel used in both coastal and deep-sea fishing should be allocated to the country delivering the fuel. When oil has been sold to foreign vessels, the oil companies do not always, or have not always, registered whether the ship is a fishing vessel or another type of vessel. Even though most foreign vessels today bunkering in the Faroe Islands are fishing vessels, the emission from foreign vessels have been allocated to International Bunkers. This means that the emission from fishing vessels in reality were higher than in the inventory and emission from International bunkering were lower. This is not so anymore, since it was changed in the 2014 delivery. Through direct communication with the oil companies, the Environmental Agency has received more detailed information about sale of oil to foreign fishing vessels, enough to make a fairly good estimation of the amount of oil sold to foreign fishing vessels in the years 2001-2011. This has resulted in higher emissions from fishing vessels and lower emissions in International Bunkers for the year 2001-2011. The same new estimations for the years 1990-2000 remain to be done.

The inventory includes all oil bunkered on Faroese territory, though excluding oil bunkered by international companies, i.e., from a foreign supplier to a foreign customer at open sea or on near-coast sites.

### Industrial Processes and Product Use

Emissions from Industrial processes and Product Use are allocated to these categories:

- 2.F Product Uses as Substitutes for ODS
    - 2.F.1 Refrigeration and Air conditioning
- 2.G Other Product Manufacture and Use
    - 2.G.1 Electrical Equipment

The inventory follows the principles in the IPCC Guidelines and the IPCC Good Practice Guidance, with a Tier 1 methodology. The emissions factors are IPPC default.

The activity data origin from FEA surveys on the consumption (import) of HFCs and $SF_6$ that have been conducted annually since 2003. An estimate of the consumption has been done for the years 1990-2002.

There has not been any consumption of PFCs nor $NF_3$ in the Faroe Islands.

### Solvent and other product use

Since no data are available, emissions from solvent and other product use are not calculated.

### Agriculture

GHG emissions from agriculture are calculated for following categories:

- 3.1 Livestock
  - 3.A Enteric Fermentation
  - 3.B Manure Management
- 3.D Agricultural Soils

The inventory follows the principles in the IPCC Guidelines and the IPCC Good Practice Guidance. Tier 1 method is always used. All emission factors used for agriculture are IPCC standard values. The emissions are calculated with support from DCE. Activity data is accessible on the homepage of Statistics Faroe Islands (number of cows and sheep).

### Waste

The GHG emission from waste incineration is calculated with IPCC default values. All emissions in the Waste sector are allocated to the Energy sector. Emission factors relative to emissions of $CO_2$, $N_2O$ and $CH_4$ from waste incineration in 1990-2018 are listed in Table 6 in Annex 1.a. Heating values for waste incineration are listed in Table 3.

Table 3 Heating values (GJ/t) for waste.

| Year | Heating values |
|---|---|
| 1990-91 | 8,2 |
| 1992 | 9,0 |
| 1993-94 | 9,4 |
| 1995 | 10,0 |
| 1996-2012 | 10,5 |
| 2013-2018 | 10,6 |

### Brief description of key categories

No key category analysis (KCA) has been carried out for the Faroe Islands GHG inventory.

### Information on QA/QC plan including verification and treatment of confidential issues where relevant

A number of measures are in place to ensure the quality of the greenhouse gas inventory for the Faroe Islands.

The general QC activities include:

- Check that data from Statistics Faroe Islands and other data deliverers are correctly transferred to emissions spreadsheets.
- Check that data are correctly transferred between data processing steps, e.g., it is ensured that the data are imported correctly from the emission spread sheets /databases to the CRF Reporter.
- The time series are analysed. Any large fluctuations are investigated and explained /corrected.
- The completeness of the inventory is checked utilising the completeness checker incorporated in the CRF Reporter.

These types of QC checks are recommended as Tier 1 QC checks in the IPCC Good Practice Guidance (IPCC, 2000).

No confidential issues are relevant.

#### General uncertainty evaluation, including data on the overall uncertainty for the inventory totals

Uncertainty evaluation has not been made for the Faroese inventory.

#### General assessment of the completeness

In general, the inventory is complete.

#### References

Lastein, L. & Winther, M. 2003: Emissions of greenhouse gases and long-range transboundary air pollutants in the Faroe Islands 1990-2001. National Environmental Research Institute, Denmark. 62 p. NERI Technical Report no. 477. http://www2.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR477.pdf

Winther, M. 2001: 1998 Fuel Use and Emissions for Danish IFR Flights. Environmental Project no. 628, 2001. 112 p. Danish EPA. Prepared by the National Environmental Research Institute (NERI), Denmark. Electronic report at homepage of Danish EPA. Available at :
https://www2.mst.dk/udgiv/publications/2001/87-7944-661-2/pdf/87-7944-662-0.pdf

### Trends in Greenhouse Gas Emissions

The trends present in this Chapter cover the emissions from the Faroe Islands.

The whole inventory, including trend tables and emission trend summary tables, can be found on the homepage of EIONET https://cdr.eionet.europa.eu/dk/Air_Emission_Inventories/Submission_UNFCCC/

#### Description and interpretation of emission trends for aggregated greenhouse gas emissions

The greenhouse gas emissions are estimated according to the IPCC guidelines and are aggregated into four main sectors: Energy, Industrial Processes and Product Use, Agriculture and Waste. All emissions from the Waste sector are allocated to the Energy sector. The main part, 90 %, of the emissions is from the fuel consumption in the energy sector. Figure 1 shows the estimated total greenhouse gas emissions in $CO_2$ equivalents from 1990 to 2018. The total greenhouse gas emission in $CO_2$ equivalents has increased by 66.4 % from 1990 to 2018. Comments on the overall trends etc. are given in the sections below.

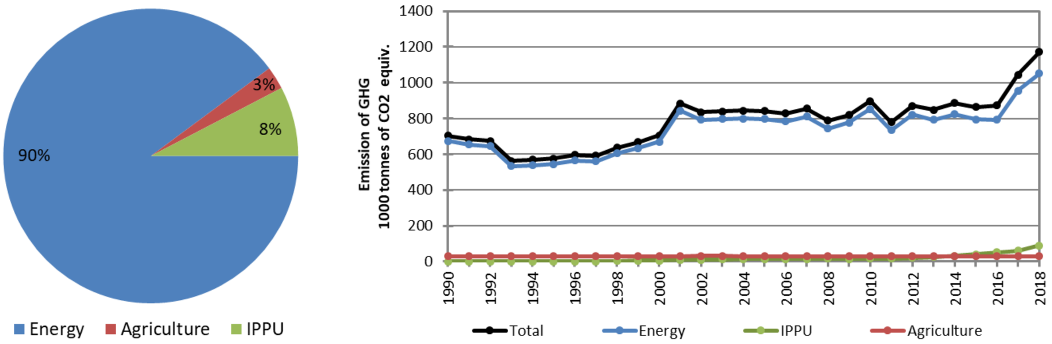



Figure 1 Greenhouse gas emissions in $CO_2$ equivalents distributed on main sectors for 2018 and time series for 1990 to 2018.

The greenhouse gases include $CO_2$, $CH_4$, $N_2O$, HFCs and $SF_6$. Figure 2 shows the composition of greenhouse gas emissions ($CO_2$, $N_2O$, $CH_4$ and F-gases) in 2018, calculated in GWP values. $CO_2$ is the most important greenhouse gas contributing with 89 %, followed by F-gases (HFCs and $SF_6$) with 8 %, $CH_4$ with 2 % and $N_2O$ with 1 %.

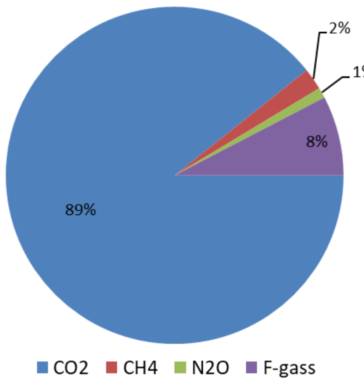



Figure 2 Emissions of GHG in $CO_2$ equivalents in 2018, distributed on type of gas.

Figure 3 shows the total emissions of greenhouse gases and the emission of $CO_2$, $N_2O$, $CH_4$ and F-gases (in $CO_2$ equivalents) in the time period 1990-2018. From 1990 to 1993, a decrease is observed, due to an economic crisis in the Faroe Islands, which lasts for 6-8 years. From 2001 to 2007, the emissions were rather stabile. In 2008-2011, the emissions from Faroese fishing ship were significantly lower than previous years, especially due to rising oil prices and lower prices on fish. The decrease is concealed by emissions related to new bunkering activity starting in 2009 that has led to a substantial increase in the number of foreign fishing vessels bunkering in the Faroe Island. In general, the total emission of greenhouse gases on the Faroe Islands were relative stabile from 2001 until 2016, around and above 800 thousand tonnes of $CO_2$ equivalents pr. year. A significant and step rise in the emission was seen in 2017 and as well in 2018.

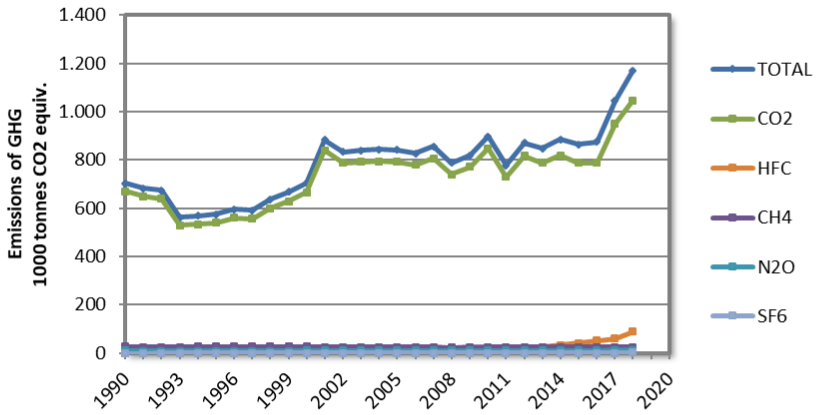



Figure 3 GHG emission by gas in $CO_2$ equivalents, time series 1990-2018.

### Description and interpretation of emission trends by gas

Carbon dioxide

The emission of $CO_2$ on the Faroe Islands is from fuel consumption only. The trend in the total emission of $CO_2$ (Figure 4) is nearly identical with the trend of the total emission of GHG in the Faroe Islands (Figure 3) showing the trends in $CO_2$ emissions in the period from 1990 to 2018. After the economic decline in the 1990's, the emissions rose and were rather constant until 2007. From 2008 to 2011, the effort in the Faroese fishing fleet was significantly lower than previous years, also meaning a significant reduction in oil consumption. The reduction in the emissions for fisheries in 2009 and 2011 is not visible because a new oil bunkering activity (mostly used by foreign fishing vessels) started up in 2009, increasing the emissions. As seen in figure 4, the rise in the total emission in 2017 and 2018 is due to more energy usage on fishing vessels.

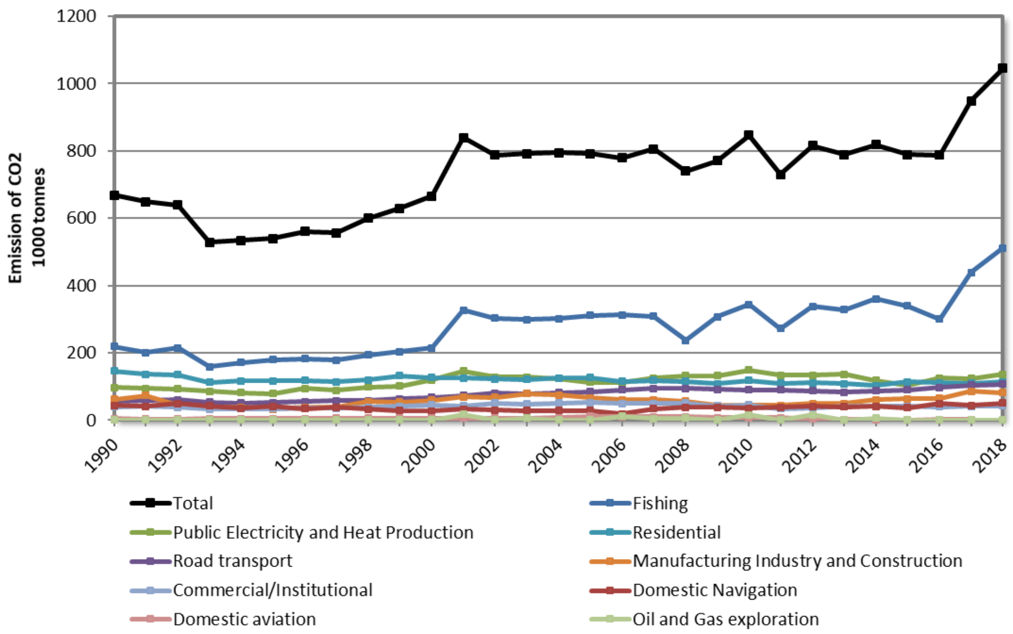



Figure 4 Total $CO_2$ emissions, by sector, time series for 1990-2018.

Figure 5 shows how the emissions are distributed between categories. In 2018, 49 %of the emissions of $CO_2$ came from fishing vessels. Public Electricity and Heat Production, Residential and Road Transportation accounted for 13 %, 11 % and 10 % of the total $CO_2$ emission.

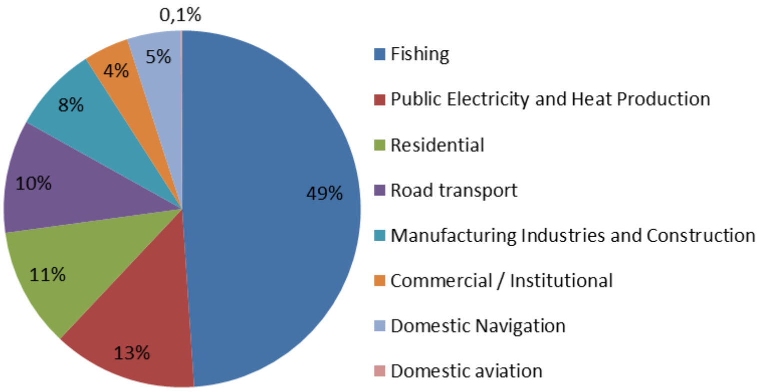



Figure 5 Emissions of $CO_2$ in the Energy sector, divided in fuel consumption categories, in CO2 equivalents, 2018.

### Nitrous oxide

Figure 6 shows the emissions of nitrous oxide in the Faroe Islands 1990-2018. Most of the $N_2O$ emissions are from the energy sector, but much $N_2O$ also comes from the agricultural sector, from animals grazing on agricultural soils.

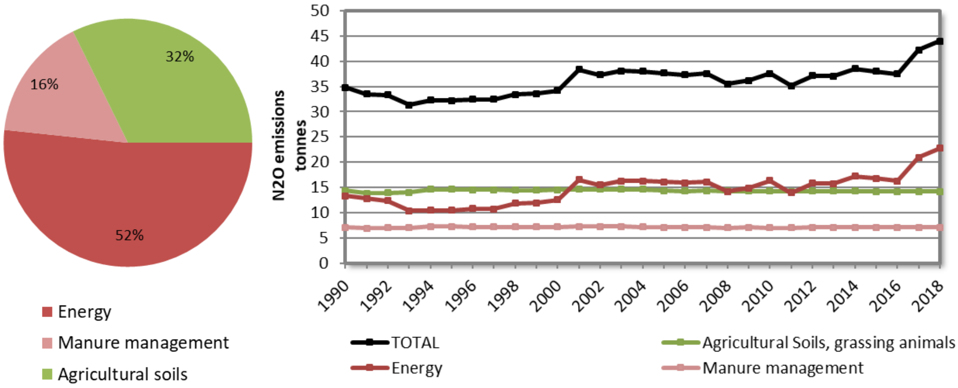



Figure 6 $N_2O$ emissions in tonnes distributed on sector and time series for 1990-2018.

### Methane

Figure 7 shows the emissions of methane in the Faroe Islands 1990-2018. Almost all methane emission is from the agriculture sector, especially from enteric fermentation (93 %). Most of the emission of $CH_4$ in the energy sector is due to aviation activity.

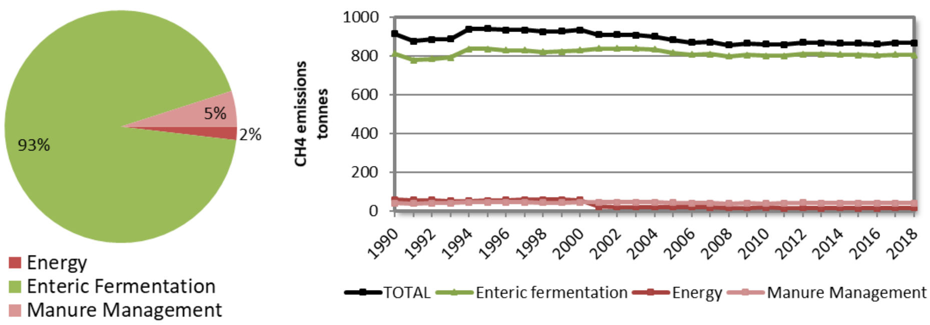



Figure 7 $CH_4$ emissions in tonnes distributed on sectors and time series for 1990-2018.

### HFCs, PFCs, $SF_6$ and $NF_3$

Figure 8 shows the emissions of F-gases, HFCs and $SF_6$ respectively, in the years 1990-2018. Most of the emission is HFCs, used for refrigeration purposes, as substitutes for HCFCs. After the emissions increased in the period 1996-2005, the emissions were rather stable at around 14,000 tonnes of $CO_2$ equivalents pr. year until 2011. Since then the emission has increased each year, and in 2018, the emissions of HFC has six folded since 2012, to in total around 90,000 tonnes of $CO_2$ equivalents. This is due to higher use of HFC-125 and HFC-143a, both components in the HFC-blend HFC-507a, which in recent years has been used as a substitute when phasing out HCFC-22 (ozone depleting freezing agent) on fishing vessels. See also Table 4.

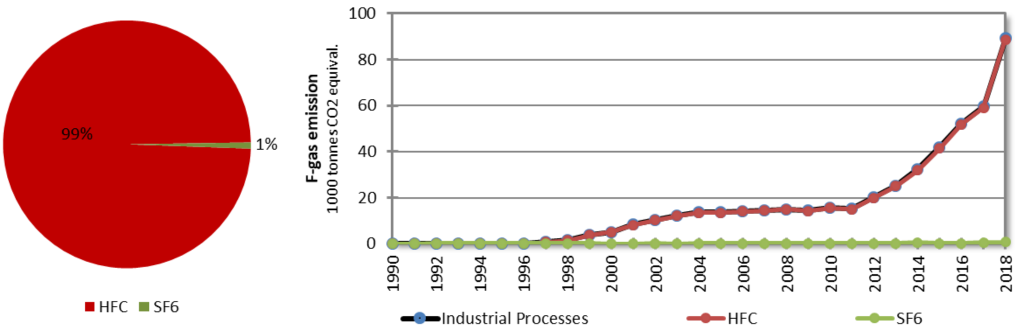



Figure 8 F-gas emissions in $CO_2$ equivalents, contribution from type of F-gas and time series for 1990-2018.

PFC nor $NF_3$ have been in use in the Faroe Islands.

#### Description and interpretation of emission trends by source

In 2018, 90 % of all GHG emissions were from the Energy sector, including waste incineration. Nearly 8 % were from Industrial Processes and Product Use, and 2.5 % from Agriculture, see Figure 1.

The fluctuations in the GHG emissions in the Energy sector are decisive for the fluctuations in the total GHG emissions, see Figure 9. The emissions from the Agriculture sector and from Industrial processes and Product Use are relatively small and constant.

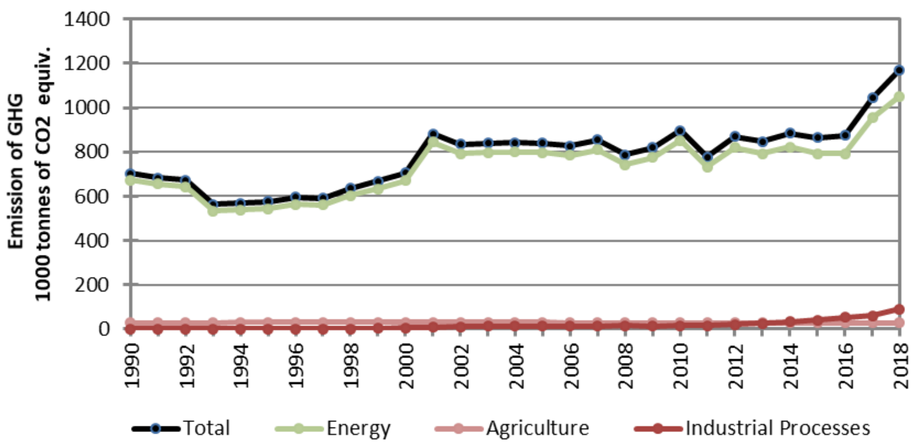



Figure 9 GHG emissions in $CO_2$ equivalents, main sectors, time series 1990-2018.

#### Description and interpretation of emission trends for indirect greenhouse gases and $SO_2$

Emission trends for indirect greenhouse gases and $SO_2$ have not been made for the Faroe Islands.

## Energy (CRF sector 1)

#### Overview of the sector

Fuel consumption on the Faroe Islands, 1990-2018, can be seen in Figure 10. Most of the fuel is used by fishing vessels.

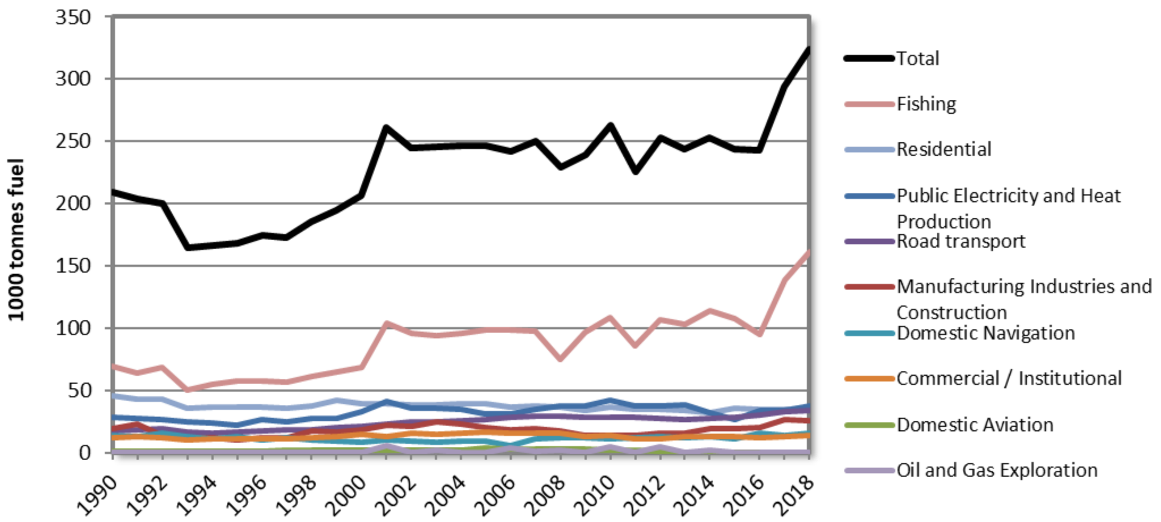



Figure 10 Fuel consumption (tonnes) in the Energy sector, including waste incineration, 1990-2018.

Figure 11 shows the GHG emissions in the Energy sector on the Faroe Islands 1990-2018. The trend is just the same as in Figure 10.

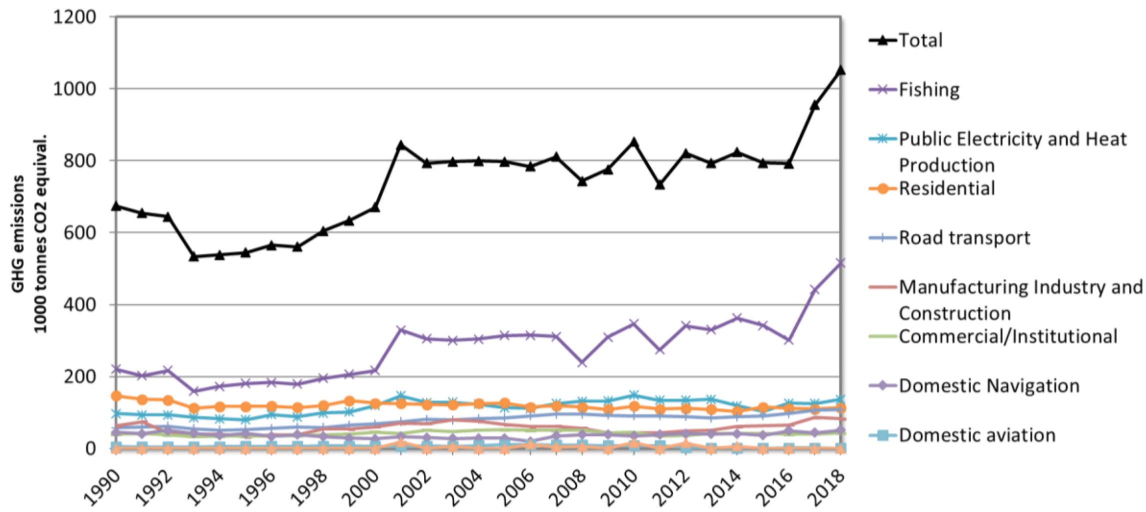



Figure 11 GHG emissions in $CO_2$ equivalents, categories in the Energy sector, 1990-2018.

Figure 12 shows how the emission of GHG in 2018 was distributed between groups of fuel users. Fishing vessels, Public Electricity and Heat Production, Residential and Road transportation had 44, 12, 10 and 9 %, respectively, of the emissions in the Energy sector in 2018.

Waste Incineration has been included under category 1A1a (Public Electricity and Heat Production), comprising 12 % of the total emissions in the category and 1.4 % of the total emissions in the Faroe Islands in 2018.

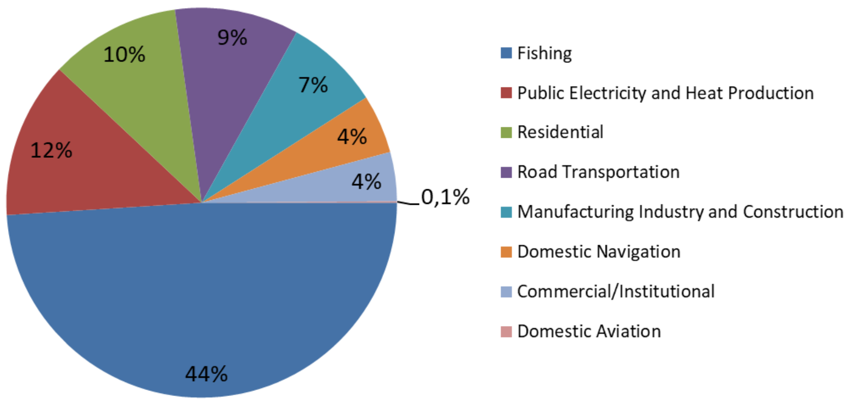



Figure 12 GHG emissions in $CO_2$ equivalents; Energy sector divided in categories, 2018.

**Fugitive emissions (CRF sector 1B)**

Fugitive emissions of GHG gases are estimated to be very limited on the Faroe Islands. These emissions have not been estimated.

## Industrial Processes and Product Use (CRF Sector 2)

There is no chemical industry, no metal production, no production of F-gases and no mineral production (other than road paving with asphalt) on the Faroe Islands.

### Overview of the sector

The only industrial processes leading to GHG emissions on the Faroe Islands is the use of f-gases. Of the total emissions in 2018, 7.6 % are emissions related to Industrial Processes and Product Use, of this nearly all (99 %) of the emission is from Product Uses as Substitutes for ODS (2.F), while the rest (1 %) of the emission is from use of Electrical equipment (2.G.1).

Figure 13 shows the f-gas emissions from Industrial Processes and Product Use sector on the Faroe Islands 1990-2018. The increase in f-gas emissions, starting in 1996, is due to use of HFCs in refrigeration, as substitute for ODS. See also Figure 8.

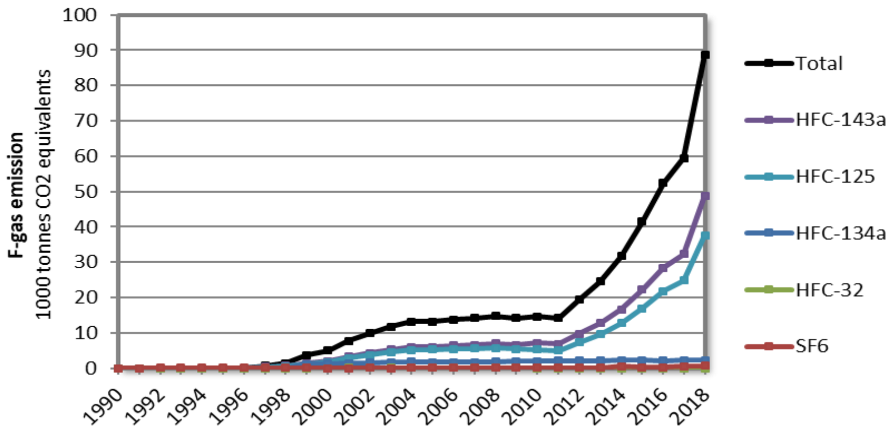



Figure 13 Emissions of f-gases, in $CO_2$ equivalents, Industrial processes and Product Use, 1990-2018.

Mineral Industry (2A)

There is no mineral production in the Faroe Islands, other than paving roads with asphalt.

Chemical Industry (2B)

No chemical industry with GHG emission is in the Faroe Islands.

### Metal Industry (2C)

No metal production industry is in the Faroe Islands.

### Production of Halocarbons and $SF_6$ (2E)

There is no production of halocarbons and $SF_6$ in the Faroe Islands.

### Product Uses as Substitutes for ODS (2F)

Of the total emissions of f-gases, nearly all (99 %) is HFC gasses used as substitutes for ozone depleting substance HCFC-22, used for refrigeration purposes domestically, commercially and in the industry. Four different types of HFCs are used on the Faroe Islands, mostly in HFC gas blends, such as HFC-507. Time series of the emission (tonnes) of the four different HFC for the years 1990, 2000, 2005, 2010-2018, are seen in Table 4.

The HFC emissions are reported with the following assumptions:

- Domestic refrigeration is use in freezers and refrigerators.
- Commercial refrigeration is use in land-based units.
- Industrial refrigeration is use on ships.
- Mobile air conditioning is use in cars, buses and trucks.

Table 4 Emissions of HFCs from refrigeration and air conditioning, 1990, 2000, 2005, 2010-2018 (tonnes).

| | 1990 | 2000 | 2005 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Domestic refrigeration | | | | | | | | | | | | |
| HFC-134a | 0,00 | 0,003 | 0,007 | 0,012 | 0,012 | 0,012 | 0,012 | 0,012 | 0,011 | 0,010 | 0,010 | 0,009 |
| Commercial refrigeration | | | | | | | | | | | | |
| HFC-134a | 0,00 | 0,04 | 0,14 | 0,15 | 0,19 | 0,17 | 0,19 | 0,25 | 0,28 | 0,26 | 0,23 | 0,20 |
| HFC-32 | 0,00 | 0,09 | 0,32 | 0,08 | 0,08 | 0,08 | 0,08 | 0,07 | 0,06 | 0,04 | 0,03 | 0,02 |
| HFC-125 | 0,00 | 0,15 | 0,51 | 0,55 | 0,58 | 0,68 | 0,77 | 0,87 | 1,00 | 1,11 | 1,19 | 1,23 |
| HFC-143a | 0,00 | 0,06 | 0,19 | 0,51 | 0,56 | 0,67 | 0,77 | 0,89 | 1,04 | 1,15 | 1,25 | 1,32 |
| Industrial refrigeration | | | | | | | | | | | | |
| HFC-134a | 0,00 | 0,16 | 0,43 | 0,35 | 0,35 | 0,29 | 0,30 | 0,28 | 0,27 | 0,25 | 0,30 | 0,31 |
| HFC-125 | 0,00 | 0,34 | 1,00 | 0,96 | 0,87 | 1,43 | 1,97 | 2,77 | 3,84 | 5,11 | 5,91 | 9,53 |
| HFC-143a | 0,00 | 0,40 | 1,17 | 1,10 | 0,99 | 1,53 | 2,08 | 2,85 | 3,93 | 5,19 | 5,98 | 9,59 |
| Mobile Air Conditioning | | | | | | | | | | | | |
| HFC-134a | 0,00 | 0,70 | 0,59 | 0,94 | 0,97 | 1,00 | 1,02 | 1,03 | 1,04 | 1,04 | 1,05 | 1,08 |

### Other Product Manufacture and Use (2G)

Figure 14 shows the emissions of $SF_6$ from Electrical Equipment on the Faroe Islands 1990-2018.

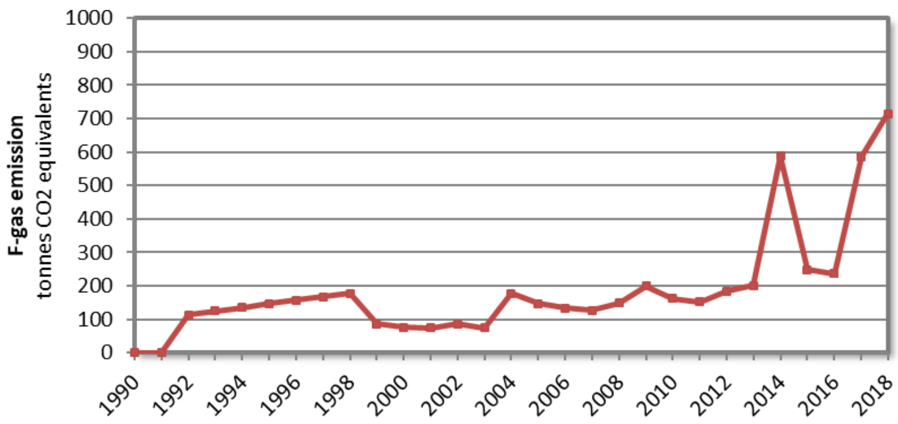



Figure 14 Emission of $SF_6$, in $CO_2$ equivalents, time series for Electrical Equipment, 1990-2018.

In 2014, a significant increase was in the actual emission of $SF_6$. The increase was due to establishment of a new windmill park in Húsahagi, just outside the capital Tórshavn, owned by SEV, the public electricity company. The high usage in 2017 was due to establishment of a new switchyard "innan Eið", near Fuglafjørð.

### Uncertainty

Estimations of the uncertainties for emission calculations in the sector Industrial processes and Product Use have not been done.

## Agriculture (CRF Sector 3)

### Overview

The emission of greenhouse gases from agricultural activities includes:

- $CH_4$ emission from manure management and enteric fermentation.
- $N_2O$ emission from manure management and agricultural soil.

2.5 % of the total GHG emissions on the Faroe Islands in 2018 are due to agriculture. The sources are cattle and sheep.

Figure 15 shows the number of cattle in the Faroe Islands from 1990 to 2018. The number of sheep is around 78,940, which corresponds to the carrying capacity for sheep on the islands. There are no data on the exact number of sheep nor on the number of sheep slaughtered.

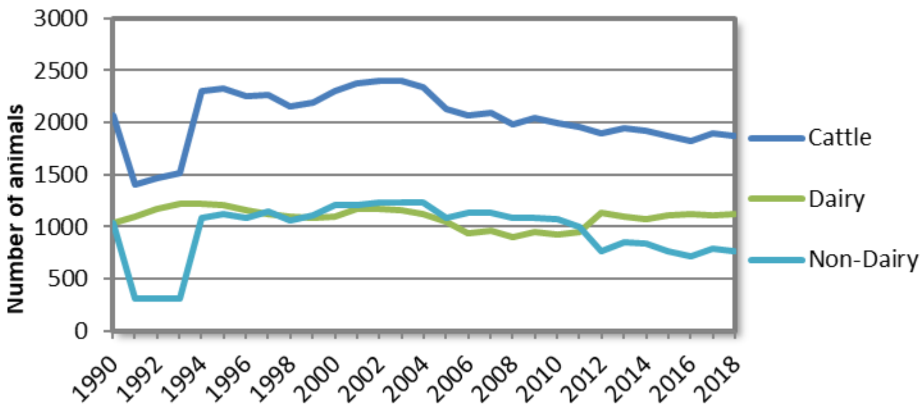



Figure 15 Number of cattle (dairy and non-dairy), time series for 1990-2018.

Figure 16 shows the total emissions from the Agriculture sector. The emissions are very constant.

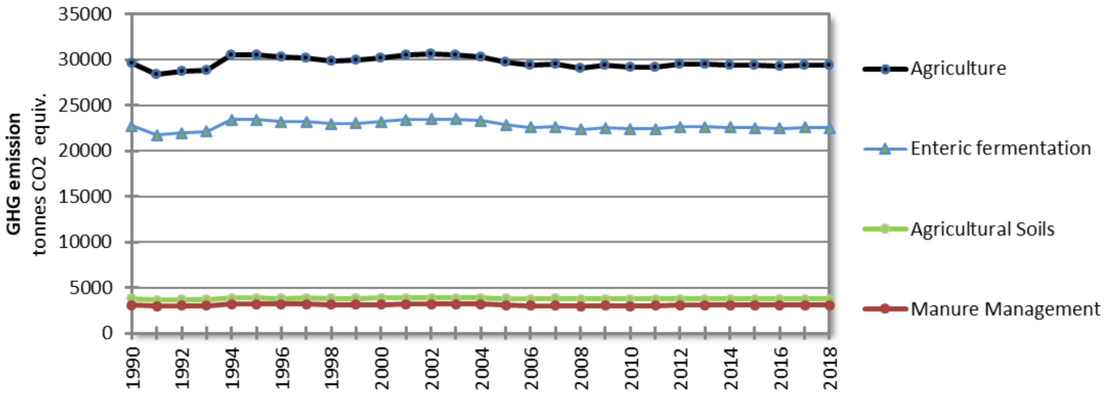



Figure 16 GHG emissions in $CO_2$ equivalents, in the Agriculture sector, 1990-2018.

### $CH_4$ emission from Enteric Fermentation (CRF Sector 3A)

Figure 17 shows emissions of $CH_4$ from enteric fermentation in livestock on the Faroe Islands, 1990-2018.

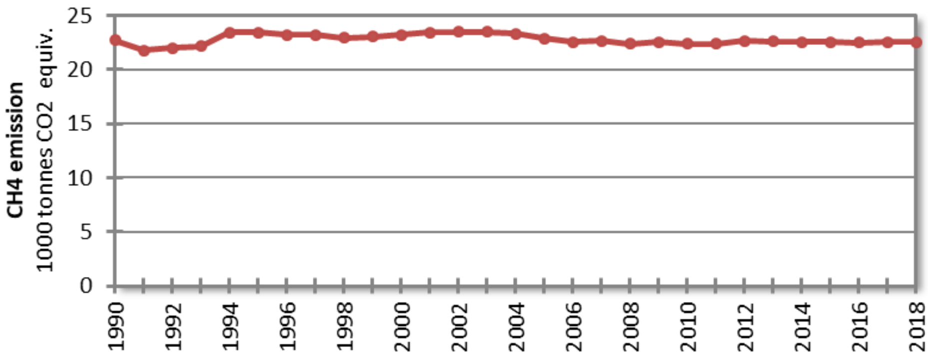



Figure 17 $CH_4$ emissions in $CO_2$ equivalents from enteric fermentation, 1990-2018.

### $CH_4$ and $N_2O$ emission from Manure Management (CRF Sector 3B)

Figure 18 shows emissions of $N_2O$ and $CH_4$ from manure management on the Faroe Islands, 1990-2018, in $CO_2$ equivalents. The emissions are very stable. The total yearly emission is around 3000 tonnes of $CO_2$ equiv. Around one third is $CH_4$ and two thirds is $N_2O$, in $CO_2$ equiv.

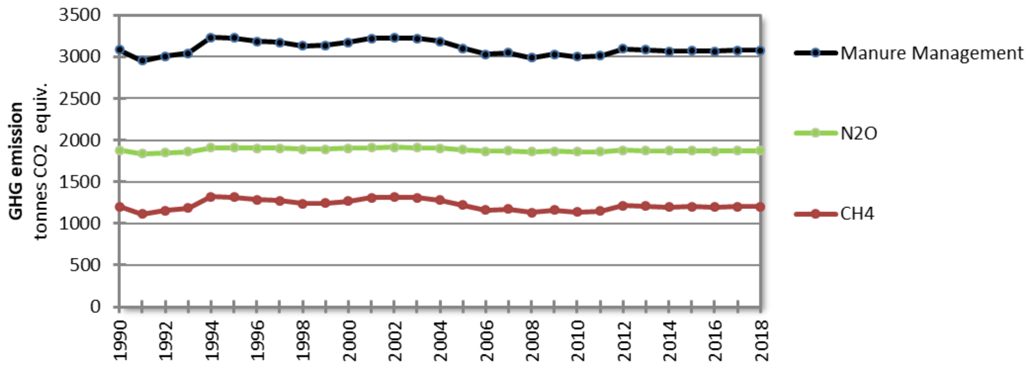



Figure 18 $N_2O$ and $CH_4$ emission in $CO_2$ equivalents from Manure management, time series 1990-2018.

### $N_2O$ emission from Agricultural Soils (CRF Sector 3D)

The $N_2O$ emission from sheep and cows grazing on agricultural soil is about 14.2 tonnes $N_2O$ per year. This corresponds to 3,770 tonnes of $CO_2$ equivalents.

Figure 19 shows the $N_2O$ emissions from agricultural soil. Since the number of animals is constant, the emissions are also constant.

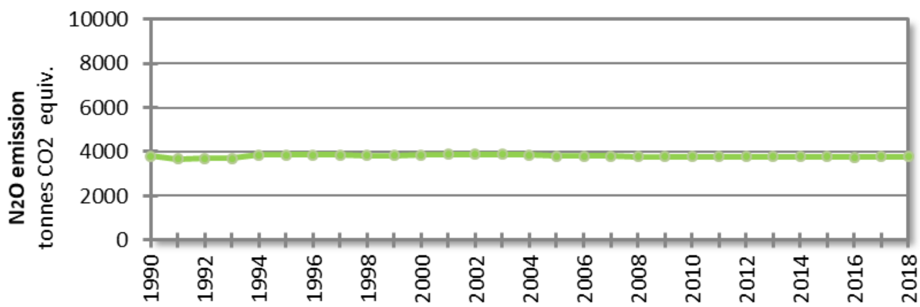



Figure 19 $N_2O$ emissions (tonnes $CO_2$ equiv.) from Agricultural Soils, time series 1990-2018.

#### NMVOC emission
The emission of NMVOC is not calculated.

#### Uncertainties
The uncertainties have not been calculated.

#### Recalculation
No recalculations were made in the Agriculture section in 2018.

#### Planned improvements
- To go through all data in the Agricultural sector, including an assessment of whether emission factors, other than default, and methods, other than Tier 1, should be used.
- To include emissions from animal categories other than cattle and sheep. Try to get better data on number of sheep.

## Land Use, Land-Use Change and Forestry (CRF Sector 4)

No emissions are calculated for land use, land-use change and forestry.

## Waste Sector (CRF Sector 5)

#### Overview of the Waste sector
Waste incineration is the only source in the Waste sector with significant emission. The emissions have been allocated to the energy sector in accordance with the IPCC Guidelines.

#### Solid Waste Disposal (CRF Source Category 5A)
Several land-based solid waste disposals facilities are located on the Faroe Islands. The GHG emissions from these depots have not been calculated.

#### Biological Treatment of Solid Waste (CRF Source Category 5B)
The first biogas facility on the Faroe Island will open in Hoyvík in 2020. Primarily receiving organic waste from the aquaculture industry and from agriculture.

Composting in the Faroes is primarily a small-scale activity in private households only. In recent years though, some Faroese municipalities, are about to establish compost sites where people can deliver their organic household waste, fx the municipality of Vágur in Suðuroy.

#### Incineration and Open Burning of Waste (CRF Source Category 5C)
There are two waste incineration plants on the Faroe Islands, one in Hoyvík and one in Leirvík. Both plants perform energy recovery operations and therefore the emissions from the plants have been allocated to the energy sector (Public Electricity and Heat Production, 1A1a) in accordance with the IPCC Guidelines. Figure 20 shows the amounts of waste incinerated on the Faroe Islands 1990-2018.

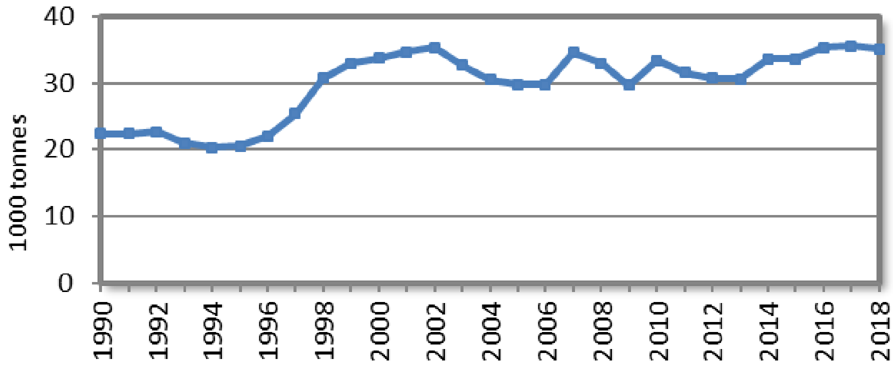


Figure 20 Incineration of municipal waste on the Faroe Islands, 1990-2018.

Open burning of waste is prohibited and is also not occurring in the Faroes.

#### Wastewater Treatment and Discharge (CRF Source Category 5D)

In the Faroe Islands, most households have a septic tank through which domestic wastewater (sewage) flows for basic mechanical treatment. Industrial wastewater, e.g. from the fishing industry, is treated mechanically (oil/fat separation). Only a very few wastewater handling plants are treating the wastewater chemically and/or biologically.

GHG emissions from wastewater treatment or discharge in the Faroes have not been calculated.

#### Waste Other (CRF Source Category 5E)

There are no activities and emissions in the category Waste Other.

## Other (CRF sector 6)

There are no activities, emissions or removals for the Other category in the inventory of the Faroe Islands.

## Recalculations and improvements

Most of the recalculations in the 2020 submission for the Faroe Islands are due to changes in emissions factors, and in all these cases, the changes are the same as in the inventory for Denmark, and thus explained in the main part of the report. Some minor correction have been made, with no substantial effect on the emissions trends or levels.

#### Explanations and justifications for recalculations

The following recalculations and improvements to the emission inventory have been made since the reporting in 2019.

#### Energy

Public Electricity and Heat Production

The emission factors for heavy fuel, $CO_2$, 1990-2005 have been updated.

Manufacturing Industries and Construction

The emission factors for heavy fuel, $CO_2$, 1990-2005, 2007-2017 have been updated.

Domestic Aviation

The emission factors for aviation, Jet fuel, $N_2O$ and $CH_4$, has been updated for the year 2006.

### Road Transportation

The emission factors for road transportation, diesel and gasoline, $N_2O$ and $CH_4$, has been updated for the whole time series, 1990-2017.

### Domestic Navigation

The emission factors for diesel, $N_2O$ and $CH_4$, has been updated for the whole time-series.

The emission factors for residual oil, $N_2O$ and $CH_4$, has been updated for 2009-2017.

### Commercial/Institutional

No changes.

### Residential

No changes.

**International bunkers**

No changes in the emission factors.

**International aviation**

AD for jet fuel for the whole time-series have been corrected.

These emission factors for International aviation, Jet fuel, have been updated for $CH_4$ and $N_2O$, 2001-2016.

**Waste**

The $CO_2$ emission factor for the period 2015-18 have been updated.

**Agriculture**

No changes.

**Industrial Processes and Product Use**

No changes.

**Implications for emission levels**

Most of the recalculations have only had small implication for the emissions levels. It was observed, that the total emissions of GHG for the years 1990-2006 increased, but not more than around 200 tonnes of $CO_2$ equivalents. A decrease was observed in 2007 and 2008, around 40 tonnes of $CO_2$ equivalents pr. year. Again, an increase in the yearly emission due to updated emissions factors was observed from 2009 to 2017, mostly around 75-350 tonnes of $CO_2$ equivalents yearly. In 2017, the increase due to updated emission factors was around 2500 tonnes of $CO_2$ equivalents.

**Implications for emission trends, including time series consistency**

No significant changes.

## Improvements

Improvement to implement in next year's delivery:

### Fishing vessels

In the 2014 delivery, the recalculation made for fishing vessels for certain reasons only could be done for the time-series 2001-2012. Therefor the time series for fishing vessels, 2001-2018, is inconsistent with the time series 1990-2000.

Oil sold to foreign fishing vessels for 1990-2000 will be estimated, and the activity data will be corrected correspondently.

### Agriculture

Improvements regarding emission factors and methods are planned.

## Annexes

All emissions factors used in the inventory are found in this Annex.

### Annex 1.a. Emissions factors – Stationary combustion

The emissions factors used for calculating the Faroese emission of GHG in following stationary combustion categories are found in Table 5 :

- 1A1a Public Electricity and Heat Production
- 1A2 Manufacturing Industry and Construction
- 1A4a Commercial/Institutional
- 1A4b Residential

Table 5 Emission Factors for Stationary Combustion, 1990-2018.

| Category | Fuel | Pollutant | 1990-2006 | 2007-2018 |
|---|---|---|---|---|
| Public Electricity and Heat Production | Gas/diesel oil | $CH_4$ (g/GJ) | 0.9 | 0.9 |
| | | $CO_2$ (kg/GJ) | 74.1 | 74.1 |
| | | $N_2O$ (g/GJ) | 0.4 | 0.4 |
| | Heavy fuel oil | $CH_4$ (g/GJ) | 0.8 | 0.8 |
| | | $CO_2$ (kg/GJ) | 78.7 | 78.6-79.4 |
| | | $N_2O$ (g/GJ) | 0.3 | 0.3 |
| Manufacturing Industries and Construction | Gas/diesel oil | $CH_4$ (g/GJ) | 0.2 | 0.2 |
| | | $CO_2$ (kg/GJ) | 74.1 | 74.1 |
| | | $N_2O$ (g/GJ) | 0.4 | 0.4 |
| | Heavy fuel oil | $CH_4$ (g/GJ) | 1.3 | 1.3 |
| | | $CO_2$ (kg/GJ) | 78.7 | 78.6 |
| | | $N_2O$ (g/GJ) | 5 | 5 |
| | Kerosene | $CH_4$ (g/GJ) | 3 | 3 |
| | | $CO_2$ (kg/GJ) | 71.9 | 71.9 |
| | | $N_2O$ (g/GJ) | 0.6 | 0.6 |
| Commercial/Institutional | Gas/diesel oil | $CH_4$ (g/GJ) | 0.7 | 0.7 |
| | | $CO_2$ (kg/GJ) | 74.1 | 74.1 |
| | | $N_2O$ (g/GJ) | 0.4 | 0.4 |
| | Kerosene | $CH_4$ (g/GJ) | 10 | 10 |
| | | $CO_2$ (kg/GJ) | 71.9 | 71.9 |
| | | $N_2O$ (g/GJ) | 0.6 | 0.6 |
| Residential | Gas/diesel oil | $CH_4$ (g/GJ) | 0.7 | 0.7 |
| | | $CO_2$ (kg/GJ) | 74.1 | 74.1 |
| | | $N_2O$ (g/GJ) | 0.6 | 0.6 |
| | Kerosene | $CH_4$ (g/GJ) | 10 | 10 |
| | | $CO_2$ (kg/GJ) | 71.9 | 71.9 |
| | | $N_2O$ (g/GJ) | 0.6 | 0.6 |

The emissions factors for calculating the Faroese emissions from the Waste sector are found in Table 6.

Table 6 Emission factors for Waste Incineration, 1990-2018.

| Year | Fossil Waste *%* | $CO_2$ EMF-fossil *kg/GJ* | $CO_2$ EMF-biogen *kg/GJ* | $CH_4$ EMF-total *g/GJ* | $N_2O$ EMF-total *g/GJ* |
|---|---|---|---|---|---|
| 1990 | 32,2 | 37 | 86,7 | 0,59 | 1,2 |
| 1991 | 32,2 | 37 | 86,7 | 0,59 | 1,2 |
| 1992 | 35,4 | 37 | 84,2 | 0,59 | 1,2 |
| 1993 | 36,9 | 37 | 83 | 0,59 | 1,2 |
| 1994 | 36,9 | 37 | 83 | 0,59 | 1,2 |
| 1995 | 39,3 | 37 | 81,1 | 0,59 | 1,2 |
| 1996 | 41,2 | 37 | 79,6 | 0,59 | 1,2 |
| 1997 | 41,2 | 37 | 79,6 | 0,59 | 1,2 |
| 1998 | 41,2 | 37 | 79,6 | 0,59 | 1,2 |
| 1999 | 41,2 | 37 | 79,6 | 0,59 | 1,2 |
| 2000 | 41,2 | 37 | 79,6 | 0,59 | 1,2 |
| 2001 | 41,2 | 37 | 79,6 | 0,59 | 1,2 |
| 2002 | 41,2 | 37 | 79,6 | 0,59 | 1,2 |
| 2003 | 41,2 | 37 | 79,6 | 0,59 | 1,2 |
| 2004 | 41,2 | 37 | 79,6 | 0,51 | 1,2 |
| 2005 | 41,2 | 37 | 79,6 | 0,42 | 1,2 |
| 2006 | 41,2 | 37 | 79,6 | 0,34 | 1,2 |
| 2007 | 41,2 | 37 | 79,6 | 0,34 | 1,2 |
| 2008 | 41,2 | 37 | 79,6 | 0,34 | 1,2 |
| 2009 | 41,2 | 37 | 79,6 | 0,34 | 1,2 |
| 2010 | 41,2 | 37 | 79,6 | 0,34 | 1,2 |
| 2011 | 41,2 | 37,5 | 79,6 | 0,34 | 1,2 |
| 2012 | 41,2 | 40 | 79,6 | 0,34 | 1,2 |
| 2013 | 41,2 | 42,5 | 79,6 | 0,34 | 1,2 |
| 2014 | 41,2 | 42,5 | 79,6 | 0,34 | 1,2 |
| 2015 | 41,2 | 42,5 | 79,6 | 0,34 | 1,2 |
| 2016 | 41,2 | 42,5 | 79,6 | 0,34 | 1,2 |
| 2017 | 41,2 | 42,5 | 79,6 | 0,34 | 1,2 |
| 2018 | 41,2 | 42,5 | 79,6 | 0,34 | 1,2 |

## Annex 1.b. Emissions factors – Mobile combustion

The emissions factors used for calculating the Faroese emission of GHG in following mobile combustion categories are found in Table 7, Table 8 and Table 9:

- 1A3a Domestic Aviation
- 1A3b Road Transportation
- 1A3d Domestic Navigation
- 1A4c Agriculture, Forestry and Fishing

Table 7 Emission factors for Domestic Aviation, 1990-2018.

| | $CH_4$ g/GJ | $CO_2$ kg/GJ | $N_2O$ g/GJ |
|---|---|---|---|
| 1990 | 485.3 | 72.0 | 2.680 |
| 1991 | 485.3 | 72.0 | 2.680 |
| 1992 | 485.3 | 72.0 | 2.680 |
| 1993 | 485.3 | 72.0 | 2.680 |
| 1994 | 485.3 | 72.0 | 2.680 |
| 1995 | 485.3 | 72.0 | 2.680 |
| 1996 | 485.3 | 72.0 | 2.680 |
| 1997 | 485.3 | 72.0 | 2.680 |
| 1998 | 485.3 | 72.0 | 2.680 |
| 1999 | 485.3 | 72.0 | 2.680 |
| 2000 | 485.3 | 72.0 | 2.680 |
| 2001 | 0.136 | 72.0 | 2.597 |
| 2002 | 0.139 | 72.0 | 2.601 |
| 2003 | 0.140 | 72.0 | 2.600 |
| 2004 | 0.144 | 72.0 | 2.612 |
| 2005 | 0.165 | 72.0 | 2.657 |
| 2006 | 0.165 | 72.0 | 2.653 |
| 2007 | 0.166 | 72.0 | 2.661 |
| 2008 | 0.167 | 72.0 | 2.660 |
| 2009 | 0.167 | 72.0 | 2.660 |
| 2010 | 0.167 | 72.0 | 2.661 |
| 2011 | 0.165 | 72.0 | 2.657 |
| 2012 | 0.213 | 72.0 | 2.637 |
| 2013 | 0.241 | 72.0 | 2.624 |
| 2014 | 0.261 | 72.0 | 2.613 |
| 2015 | 0.272 | 72.0 | 2.608 |
| 2016 | 0.268 | 72.0 | 2.606 |
| 2017 | 0.240 | 72.0 | 2.561 |
| 2018 | 0.2468 | 72.0 | 2.570 |

Table 8 Emission factors for Road Transportation, Diesel and Gasoline, 1990-2018.

| | Diesel | | | Gasoline | | |
|---|---|---|---|---|---|---|
| | $CH_4$ g/GJ | $CO_2$ kg/GJ | $N_2O$ g/GJ | $CH_4$ g/GJ | $CO_2$ kg/GJ | $N_2O$ g/GJ |
| 1990 | 6,448 | 74,000 | 1,732 | 40,872 | 73,000 | 2,839 |
| 1991 | 6,354 | 74,000 | 1,678 | 39,992 | 73,000 | 2,860 |
| 1992 | 6,334 | 74,000 | 1,666 | 38,297 | 73,000 | 2,930 |
| 1993 | 6,279 | 74,000 | 1,622 | 36,668 | 73,000 | 2,982 |
| 1994 | 6,336 | 74,000 | 1,581 | 34,286 | 73,000 | 3,069 |
| 1995 | 6,418 | 74,000 | 1,502 | 31,795 | 73,000 | 3,151 |
| 1996 | 6,413 | 74,000 | 1,399 | 29,354 | 73,000 | 3,231 |
| 1997 | 6,305 | 74,000 | 1,324 | 27,038 | 73,000 | 3,286 |
| 1998 | 6,133 | 74,000 | 1,281 | 24,821 | 73,000 | 3,240 |
| 1999 | 5,913 | 74,000 | 1,260 | 22,732 | 73,000 | 3,217 |
| 2000 | 5,584 | 74,000 | 1,255 | 21,097 | 73,000 | 3,210 |
| 2001 | 5,360 | 74,000 | 1,257 | 19,582 | 73,000 | 3,160 |
| 2002 | 5,104 | 74,000 | 1,277 | 18,006 | 73,000 | 3,075 |
| 2003 | 4,917 | 74,000 | 1,306 | 16,500 | 73,000 | 2,967 |
| 2004 | 4,706 | 74,000 | 1,341 | 14,916 | 73,000 | 2,846 |
| 2005 | 4,429 | 74,000 | 1,383 | 13,471 | 73,000 | 2,666 |
| 2006 | 4,082 | 74,000 | 1,453 | 12,080 | 73,000 | 2,476 |
| 2007 | 3,399 | 74,000 | 1,640 | 10,920 | 73,000 | 2,285 |
| 2008 | 2,650 | 74,000 | 1,895 | 10,033 | 73,000 | 2,111 |
| 2009 | 2,130 | 74,000 | 2,098 | 9,332 | 73,000 | 1,993 |
| 2010 | 1,902 | 74,000 | 2,251 | 8,971 | 73,000 | 1,878 |
| 2011 | 1,539 | 74,000 | 2,567 | 8,249 | 73,000 | 1,698 |
| 2012 | 1,214 | 74,000 | 2,788 | 7,778 | 73,000 | 1,511 |
| 2013 | 0,988 | 74,000 | 2,990 | 7,354 | 73,000 | 1,340 |
| 2014 | 0,848 | 74,000 | 3,158 | 6,907 | 73,000 | 1,181 |
| 2015 | 0,709 | 74,000 | 3,254 | 6,518 | 73,000 | 1,036 |
| 2016 | 0,595 | 74,000 | 3,330 | 6,140 | 73,000 | 0,910 |
| 2017 | 0,500 | 74,000 | 3,363 | 5,815 | 73,000 | 0,806 |
| 2018 | 0,422 | 74,000 | 3,376 | 5,518 | 73,000 | 0,721 |

Table 9 Emission factors for Domestic Navigation (diesel and residual) and Fisheries (diesel), 1990-2018.

| | Navigation - diesel | | | Navigation and Fisheries - Residual | | | Fisheries - diesel | | |
|---|---|---|---|---|---|---|---|---|---|
| | $CH_4$ g/GJ | $CO_2$ kg/GJ | $N_2O$ g/GJ | $CH_4$ g/GJ | $CO_2$ kg/GJ | $N_2O$ g/GJ | $CH_4$ g/GJ | $CO_2$ kg/GJ | $N_2O$ kg/GJ |
| 1990 | 1,545 | 74,000 | 1,852 | 1,632 | 78,000 | 1,932 | 1,519 | 74,000 | 1,874 |
| 1991 | 1,554 | 74,000 | 1,854 | 1,636 | 78,000 | 1,936 | 1,530 | 74,000 | 1,874 |
| 1992 | 1,562 | 74,000 | 1,855 | 1,637 | 78,000 | 1,936 | 1,541 | 74,000 | 1,874 |
| 1993 | 1,562 | 74,000 | 1,855 | 1,632 | 78,000 | 1,935 | 1,553 | 74,000 | 1,874 |
| 1994 | 1,566 | 74,000 | 1,855 | 1,619 | 78,000 | 1,930 | 1,565 | 74,000 | 1,874 |
| 1995 | 1,580 | 74,000 | 1,854 | 1,621 | 78,000 | 1,930 | 1,578 | 74,000 | 1,874 |
| 1996 | 1,648 | 74,000 | 1,857 | 1,631 | 78,000 | 1,925 | 1,592 | 74,000 | 1,874 |
| 1997 | 1,594 | 74,000 | 1,860 | 1,657 | 78,000 | 1,917 | 1,606 | 74,000 | 1,874 |
| 1998 | 1,604 | 74,000 | 1,861 | 1,693 | 78,000 | 1,923 | 1,622 | 74,000 | 1,874 |
| 1999 | 1,589 | 74,000 | 1,864 | 1,709 | 78,000 | 1,922 | 1,639 | 74,000 | 1,874 |
| 2000 | 1,664 | 74,000 | 1,867 | 1,725 | 78,000 | 1,924 | 1,656 | 74,000 | 1,874 |
| 2001 | 1,671 | 74,000 | 1,867 | 1,746 | 78,000 | 1,928 | 1,673 | 74,000 | 1,874 |
| 2002 | 1,710 | 74,000 | 1,867 | 1,773 | 78,000 | 1,934 | 1,689 | 74,000 | 1,874 |
| 2003 | 1,698 | 74,000 | 1,868 | 1,805 | 78,000 | 1,934 | 1,704 | 74,000 | 1,874 |
| 2004 | 1,678 | 74,000 | 1,867 | 1,811 | 78,000 | 1,930 | 1,718 | 74,000 | 1,874 |
| 2005 | 1,685 | 74,000 | 1,869 | 1,854 | 78,000 | 1,942 | 1,731 | 74,000 | 1,874 |
| 2006 | 1,673 | 74,000 | 1,868 | 1,886 | 78,000 | 1,950 | 1,743 | 74,000 | 1,874 |
| 2007 | 1,673 | 74,000 | 1,867 | 1,898 | 78,000 | 1,950 | 1,753 | 74,000 | 1,874 |
| 2008 | 1,697 | 74,000 | 1,868 | 1,905 | 78,000 | 1,950 | 1,762 | 74,000 | 1,874 |
| 2009 | 1,700 | 74,000 | 1,868 | 1,918 | 78,000 | 1,949 | 1,770 | 74,000 | 1,874 |
| 2010 | 1,691 | 74,000 | 1,868 | 1,927 | 78,000 | 1,949 | 1,775 | 74,000 | 1,874 |
| 2011 | 1,663 | 74,000 | 1,868 | 1,936 | 78,000 | 1,949 | 1,780 | 74,000 | 1,874 |
| 2012 | 1,783 | 74,000 | 1,868 | 1,945 | 78,000 | 1,949 | 1,785 | 74,000 | 1,874 |
| 2013 | 1,816 | 74,000 | 1,868 | 1,954 | 78,000 | 1,949 | 1,791 | 74,000 | 1,874 |
| 2014 | 1,794 | 74,000 | 1,867 | 1,962 | 78,000 | 1,949 | 1,797 | 74,000 | 1,874 |
| 2015 | 1,802 | 74,000 | 1,868 | 1,957 | 78,000 | 1,946 | 1,803 | 74,000 | 1,874 |
| 2016 | 1,798 | 74,000 | 1,869 | 1,962 | 78,000 | 1,946 | 1,810 | 74,000 | 1,874 |
| 2017 | 1,843 | 74,000 | 1,869 | 1,974 | 78,000 | 1,947 | 1,817 | 74,000 | 1,874 |
| 2018 | 1,829 | 74,000 | 1,869 | 1,980 | 78,000 | 1,947 | 1,823 | 74,000 | 1,874 |

# Annex 8 - Key category analysis for Denmark and Greenland

The KCAs for Denmark and Greenland includes 6 KCAs shown in Table A8-1 – A8-6 below.

Table A8-1 KCA for Denmark+Greenland, level assessment, base year excl. LULUCF. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A8-2 KCA for Denmark+Greenland, level assessment, base year incl. LULUCF. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A8-3 KCA for Denmark+Greenland, level assessment, 2018 excl. LULUCF. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A8-4 KCA for Denmark+Greenland, level assessment, 2018 incl. LULUCF. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A8-5 KCA for Denmark+Greenland, trend assessment 1990-2018, excl. LULUCF. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Table A8-6 KCA for Denmark+Greenland, trend assessment 1990-2018, incl. LULUCF. This table is available at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

# DENMARK'S NATIONAL INVENTORY REPORT 2020

Emission Inventories 1990-2018 – Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol

This report is Denmark's National Inventory Report 2020, which serves as documentation for the Danish greenhouse gas inventories submitted to the European Union and the United Nations. The report contains information on Denmark's emission inventories for all years' from 1990 to 2018 for $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs and $SF_6$.

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