ANNUAL DANISH INFORMATIVE INVENTORY REPORT

Emission inventories from the base year of the protocols to year 2021

Scientific Report from DCE – Danish Centre for Environment and Energy No. 540 2023

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Ole-Kenneth Nielsen
Marlene S. Plejdrup
Morten Winther
Mette Hjorth Mikkelsen
Malene Nielsen
Steen Gyldenkærne
Patrik Fauser
Rikke Albrektsen
Katja Hossy Hjelgaard
Henrik G. Bruun

Aarhus University, Department of Environmental Science

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

Data sheet

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Authors: Ole-Kenneth Nielsen, Marlene S. Plejdrup, Morten Winther, Mette Hjorth Mikkelsen, Malene Nielsen, Steen Gyldenkærne, Patrik Fauser, Rikke Albrektsen, Katja H. Hjelgaard, Henrik G. Bruun

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Abstract: This report is a documentation report on the emission inventories for Denmark as reported to the UNECE Secretariat under the Convention on Long Range Transboundary Air Pollution and the European Commission under the National Emission Ceilings Directive due by 15 March 2023. The report contains information on Denmark's emission inventories regarding emissions of (1) SO_x for the years 1980-2021, (2) NO_x, CO, NMVOC and NH_3 for the years 1985-2021, (3) Particulate matter: TSP, PM_{10}, $PM_{2.5}$ for the years 1990-2021, (4) Heavy Metals: Pb, Cd, Hg, As, Cr, Cu, Ni, Se and Zn for the years 1990-2021, (5) Polyaromatic hydrocarbons (PAH): Benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene and indeno(1,2,3-cd)pyrene, PCDD/F and HCB for the years 1990-2021. Further, the report contains information on background data for emissions inventory.

Keywords: Emission Inventory; Emissions; Projections; UNECE; EMEP; LRTAP; NO_x; CO; NMVOC; SO_x; NH_3; TSP; PM_{10}; $PM_{2.5}$; Pb; Cd; Hg; As; Cr; Cu; Ni; Se; Zn; Polyaromatic hydrocarbons; Dioxin; Benzo(a)pyrene, Benzo(b)fluoranthene

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Table of Contents

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Summary

I Background information on emission inventories

Annual report

This report is Denmark's Annual Informative Inventory Report (IIR) due March 15, 2023 under the UNECE-Convention on Long-Range Transboundary Air Pollution (LRTAP) and Directive (EU) 2016/2284 on the reduction of national emissions of certain atmospheric pollutants. The report contains information on Denmark's inventories for all years from the base years of the protocols to 2021.

The air pollutants reported are SO_2, NO_X, NMVOC, CO, NH_3, TSP, PM_{10}, $PM_{2.5}$, BC, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn, PCDD/F, HCB, PCBs, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene and indeno(1,2,3-cd)pyrene.

The annual emission inventory for Denmark is reported in the Nomenclature for Reporting (NFR) 2019 format.

The issues addressed in this report are trends in emissions, description of each NFR category, uncertainty estimates, recalculations, planned improvements and procedures for quality assurance and control. The structure of the report follows to the extent possible the proposed outline.

Information contained in this report is available to the public on the Danish Centre for Environment and Energy (DCE), Aarhus University's homepage:

http://envs.au.dk/videnudveksling/luft/emissioner/emissioninventory/

This report and the NFR tables are available on the Eionet central data repository:

http://cdr.eionet.europa.eu/dk/un/clrtap/
&
http://cdr.eionet.europa.eu/dk/eu/nec_revised/

Responsible institute

DCE-Danish Centre for Environment and Energy, Aarhus University, is on behalf of the Danish Ministry of Environment and Food responsible for the annual preparation and submission of the Annual Informative Inventory Report and the inventories in the NFR format to the UNECE-LRTAP Convention and the European Commission. DCE participates in meetings under the UNECE Task Force on Emission Inventories and Projections and the related expert panels, where parties to the convention prepare the guidelines and methodologies on inventories.

II Trends in emissions

Acidifying gases

In 1990, the relative contribution in acid equivalents was almost equal for the three gases SO_2, NO_x and NH_3. In 2021, the most important acidification factor in Denmark is ammonia nitrogen and the relative contributions for SO_2, NO_X and NH_3 were 4 %, 31 % and 65%, respectively. However, with regard to long-range transport of air pollution, SO_2 and NO_X are still the most important pollutants.

Sulphur dioxide (SO_2)

The main part of the sulphur dioxide (SO_2) emission originates from combustion of fossil fuels, i.e. mainly coal and oil, in public power and district heating plants. Since 1990, the total emission has decreased by 95 %. The large reduction is mainly due to installation of desulphurisation and use of fuels with lower content of sulphur in public power and district heating plants. Despite the large reduction of the SO_2 emissions, these plants make up 29 % of the total emission. In addition, emissions from industrial combustion plants, non-industrial combustion plants and other mobile sources are important.

Nitrogen oxide (NO_x)

The largest sources of emissions of nitrogen oxides (NO_x) are road transport followed by other mobile sources and combustion in energy industries (mainly public power and district heating plants). The transport sector is the sector contributing the most to the emission of NO_x and, in 2021, 37 % of the Danish emissions of NO_x stems from road transport, national navigation, railways and civil aviation. In addition, emissions from national fishing and off-road vehicles contribute significantly to the NO_x emission. For non-industrial combustion plants, the main sources are combustion of gas oil, natural gas and wood in residential plants. The emissions from energy industries have decreased by 84 % from 1990 to 2021. In the same period, the total emission decreased by 70 %. The reduction is due to the increasing use of catalyst cars and installation of low-NO_x burners and denitrifying units in power plants and district heating plants.

Ammonia (NH_3)

Almost all atmospheric emissions of ammonia (NH_3) result from agricultural activities. Only a minor part of the total emission originates from stationary combustion (2.0 %), road transport (1.0 %), industrial processes (0.6 %) and waste (1.0 %). The share for road transport was increasing during the 1990's and early 2000's due to increasing use of catalyst cars. In recent years, the share has been decreasing due to more advanced catalysts being implemented. The total ammonia emission has decreased by 50 % since 1990.

The major part of the emission from agriculture stems from livestock manure (40 %) and agricultural soils (55 %). The largest source for manure management is losses of ammonia occur during the handling of the manure in animal housing systems. For agricultural soils, the emissions are mainly stemming from application of mineral fertiliser, application of animal manure and growing crops.

Due to the action plans for the aquatic environment and the Ammonia Action Plan, a series of measures to prevent loss of nitrogen in agricultural production has been initiated. The measures have included demands for improved utilisation of nitrogen in livestock manure, a ban against field application of livestock manure in winter, prohibition of broadspreading of manure, requirements for establishment of catch crops, regulation of the number of livestock per hectare and a ceiling for the supply of nitrogen to crops. As a result, despite an increase in the production of pigs and poultry, the ammonia emission has been reduced considerably.

Other air pollutants

Non-methane volatile organic compounds (NMVOC)

The emissions of Non-Methane Volatile Organic Compounds (NMVOC) originate from many different sources and can be divided into two main groups: incomplete combustion and evaporation. Small combustion plants (e.g. residential wood burning) is a big source of NMVOC originating from combustion. Other sources are road vehicles and other transport sources such as national navigation. NMVOC from road transportation vehicles have been decreasing since 1990, due to the introduction of catalyst cars. The evaporative emissions mainly originate from the agricultural sector, use of solvents, and the extraction, handling and storage of oil and natural gas. The total anthropogenic emissions have decreased by 50 % since 1990, largely due to the increased use of catalyst cars and reduced emissions from use of solvents.

Particulate Matter (PM)

The particulate matter (PM) emission inventory is reported for the years 1990 onwards. The inventory includes the total emission of particles TSP (Total Suspended Particles), emission of particles smaller than 10 µm (PM_{10}) and emission of particles smaller than 2.5 µm ($PM_{2.5}$).

The largest $PM_{2.5}$ emission source is residential plants (51 %), road transport (10 %) and other mobile sources (7 %). Emissions from residential plants increased by 58 % from 1990 to 2007, followed by a decrease of 57 % from 2007 to 2021. The increase was caused by increasing wood consumption while the decrease has been caused by a slightly lower wood consumption (until 2016) combined with legislative demands on new wood stoves and boilers. From 2016, the wood consumption decreased significantly leading to a significant decrease in emissions. For the road transport sector, exhaust emissions account for less than a quarter (18 %) of the emissions, while the remaining emissions come from tyre and brake wear and road abrasion. For other mobile sources, the most important sources are off-road vehicles and machinery in the industrial sector and in the agricultural/forestry sector (16 % and 23 %, respectively). The $PM_{2.5}$ emission decreased by 48 % from 1990 to 2021, but most of the reduction has occurred after 2008.

The largest TSP emission sources are agriculture and non-industrial combustion (76 % and 9 % of total TSP emission in 2021, respectively). Residential plants is the largest source in the non-industrial combustion sector, making up 8 % of the national total TSP emission in 2021.The TSP emissions from transport are also important and include both exhaust emissions and the non-exhaust emissions from brake and tyre wear and road abrasion. The non-exhaust emissions account for 93 % of the TSP emission from road transport in 2021.

Black carbon (BC)

The black carbon (BC) emission inventory is reported for the years 1990 onwards. The main sources are residential plants and road transport contributing 48 % and 18 % in 2021, respectively. From 1990 to 2021, the total BC emission decreased by 66 %. The trend for non-industrial combustion is mainly controlled by the trend for the wood consumption in the residential sector.

BC emissions from the transport sector decreased by 85 % from 1990 to 2021, mainly due to implementing of new EURO norms and improved technology. An important factor is the use of particle filters for heavy-duty vehicles and passenger cars, which reduce the BC emission effectively.

BC emissions from fugitive emissions from fuels, which is mainly due to storage of coal, decreased by 92 % from 1990 to 2021, in line with the decrease in the coal consumption within electricity and heat production.

Heavy metals

In general, the most important sources of heavy metal emissions are combustion of fuels and waste. The heavy metal emissions have decreased substantially in recent years, except for Cu. The reductions span from 15 % to 93 % for Zn and Hg, respectively. The reason for the reduced emissions is mainly increased use of gas cleaning devices at power and district heating plants (including waste incineration plants). The large reduction in the Pb emission is due to a gradual shift towards unleaded gasoline, the latter being essential for catalyst cars. The major source of Cu is automobile tyre and break wear (95 % in 2021) and the 30 % increase in total emission from 1990 to 2021 owe to increasing mileage.

III Recalculations and Improvements

In general, considerable work is being carried out to improve the inventories. Investigations and research carried out in Denmark and abroad produce new results and findings, which are given consideration and, to the extent, which is possible, are included as the basis for emission estimates and as data in the inventory databases. Furthermore, the updates of the EMEP/EEA Guidebook, and the work of the Task Force on Emission Inventories and its expert panels are followed closely in order to be able to incorporate the best scientific information as the basis for the inventories.

The implementation of new results in inventories is made in a way so that improvements, as far as possible, better reflect Danish conditions and circumstances. This is in accordance with good practice. Furthermore, efforts are made to involve as many experts as possible in the reasoning, justification and feasibility of implementation of improvements.

In improving the inventories, care is taken to consider implementation of improvements for the whole time series of inventories to make it consistent. Such efforts lead to recalculation of previously submitted inventories. This submission includes recalculated inventories for the whole time series. A description of the recalculations is provided in Chapter 9 and more detail can be found in the sectoral chapters of this report. For sector specific planned improvements, please also refer to the relevant sectoral chapters.

Sammenfatning

I Baggrund for emissionsopgørelser

Årlig rapport

Denne rapport er Danmarks årlige rapport om emissionsopgørelser rapporteret d. 15. marts 2023 til UNECE-konventionen om langtransporteret grænseoverskridende luftforurening (LRTAP) og Direktiv (EU) 2016/2284 om nedbringelse af nationale emissioner af visse luftforurenende stoffer. Rapporten indeholder oplysninger om Danmarks opgørelser for alle år fra basisårene for protokollerne til 2021.

Luftforureningskomponenterne der rapporteres er SO_2, NO_X, NMVOC, CO, NH_3, TSP, PM_{10}, $PM_{2.5}$, BC, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn, PCDD/F, HCB, PCBs, benzo(a)pyren, benzo(b)fluoranthen, benzo(k)fluoranthen and indeno(1,2,3-cd)pyren.

Den årlige emissionsopgørelse for Danmark rapporteres i NFR 2019-formatet.

Emnerne behandlet i rapporten er: Udvikling i emissioner, beskrivelse af hver NFR-kategori, usikkerheder, genberegninger, planlagte forbedringer og procedure for kvalitetssikring og -kontrol. Strukturen i rapporten følger, så vidt muligt, den foreslåede disposition.

Informationer fra denne rapport er tilgængelige for offentligheden på Aarhus Universitets hjemmeside:

http://envs.au.dk/videnudveksling/luft/emissioner/emissioninventory/

Den fulde rapport samt NFR-skemaer er tilgængelige på Eionets hjemmeside:

http://cdr.eionet.europa.eu/dk/un/clrtap/
&
http://cdr.eionet.europa.eu/dk/eu/nec_revised/

Ansvarlig institution

DCE – Nationalt Center for Miljø og Energi, Aarhus Universitet, er på vegne af Miljø- og Fødevareministeriet ansvarlig for udarbejdelse af den årlige danske emissionsrapport og opgørelserne i NFR. DCE deltager i møder under UNECEs arbejdsgruppe for emissionsopgørelser og –fremskrivninger samt ekspertpaneler, hvor parter i konventionen udarbejder retningslinjer og metoder for emissionsopgørelserne.

II Udviklingen i emissioner

Forsurende gasser

I 1990 var det relative bidrag af syreækvivalenter næsten ens for de tre gasarter. I 2021 var ammoniak den vigtigste forsurende faktor i Danmark og de relative bidrag for SO_2, NO_x og NH_3 var på henholdsvis 4 %, 31 % og 65 %. Med hensyn til langtransporteret luftforurening er det dog stadig SO_2 og NO_x, der er de vigtigste forureningskomponenter.

Svovldioxid (SO_2)

Hovedparten af SO_2-emissionerne stammer fra forbrænding af fossile brændsler, dvs. primært kul og olie, på kraftværker, kraftvarmeværker og fjernvarmeværker. Siden 1990 er den totale udledning reduceret med 95 %. Den store reduktion er primært opnået gennem installation af afsvovlingsanlæg på kraftværker og fjernvarmeværker og brug af brændsler med lavere svovlindhold. Trods den store reduktion er disse værker kilde til 29 % af den samlede udledning. Også emissioner fra industrielle forbrændingsanlæg, ikke-industrielle forbrændingsanlæg, andre mobile kilder samt teglværker og produktion af ekspanderede lerprodukter er væsentlige bidragsydere til emissionen.

Kvælstofilter (NO_x)

Den største kilde til emissioner af NO_x er transportsektoren efterfulgt af andre mobile kilder og forbrænding i energisektoren (hovedsageligt kraftværker og fjernvarmeværker). Transportsektoren er den sektor, der bidrager mest til udledningen af NO_x, og i 2021 stammede 37 % af de danske NO_x-emissioner fra vejtransport, national søfart, jernbaner og civil luftfart. Også emissioner fra nationalt fiskeri og off-road køretøjer (entreprenør-, landbrugsmaskiner, m.m.) bidrager betydeligt til NO_x-emissionen. For ikke-industrielle forbrændingsanlæg er de primære kilder forbrænding af gasolie, naturgas og træ i husholdninger. Emissionerne fra kraftværker og fjernvarmeværker er faldet med 84 % fra 1990 til 2021. I samme periode er den totale emission faldet med 70 %. Reduktionen skyldes øget brug af katalysatorer i biler og installation af lav-NO_x-brændere og de-NO_x-anlæg på kraftværker og fjernvarmeværker.

Ammoniak (NH_3)

Hovedparten af emissioner af NH_3 stammer fra aktiviteter i landbruget. Kun en mindre del skyldes stationær forbrænding (2.0 %), vejtransport (1.0 %), industrielle processer (0.6 %) og affald (1.0 %). Andelen fra transporten var stigende gennem 1990'erne og i starten af 2000'erne pga. den øgede brug af biler med katalysator. I de senere år er andelen igen faldet på grund af implementeringen af mere effektive katalysatorer.

Hovedparten af emissionen fra landbruget stammer fra husdyrgødning (40 %) og landbrugsjorde (55 %). For husdyrgødning, er det største tab af ammoniak under håndtering af gødningen i stalden. For landbrugsjorde stammer emissionen hovedsageligt fra anvendelse af handelsgødning, udbringning af husdyrgødning samt emissioner fra voksende afgrøder.

Den totale ammoniakemission er faldet 50 % fra 1990-2021. Dette skyldes implementeringen af vandmiljøplaner og ammoniakhandlingsplanen som introducerede en række tiltag for at mindske kvælstoftabet i landbruget. Tiltagene har inkluderet krav om forbedret udnyttelse af kvælstof i husdyrgødning, et forbud mod udbringning af husdyrgødning om vinteren, forbud mod bredspredning af gødning, regler for plantning af efterafgrøder, regulering af antallet af tilladte dyr per hektar og et loft for gødningsanvendelsen for afgrøder. På trods af en stigning i produktionen af svin og fjerkræ, så er emissionen faldet betydeligt.

Anden luftforurening

Flygtige organiske forbindelser (NMVOC)

Emissionen af flygtige organiske forbindelser ekskl. metan (NMVOC) stammer fra mange forskellige kilder og kan opdeles i to hovedgrupper: Ufuldstændig forbrænding og fordampning. Hovedkilderne til NMVOC-emissioner fra ufuldstændige forbrændingsprocesser er brændeovne, vejtrafik og andre mobile kilder, som national sejlads og ikke vejgående maskiner. Køretøjer til vejtransport er fortsat den største bidragsyder, selvom emissionerne er faldet siden introduktionen af biler med katalysator i 1990. Emissionerne fra fordampning stammer hovedsageligt fra landbrug, anvendelse af opløsningsmidler og udvinding, lagring og transport af olie og gas. De totale menneskeskabte emissioner er faldet med 50 % siden 1990, primært som følge af øget brug af biler med katalysator, reducerede emissioner fra anvendelse af opløsningsmidler og reducerede emissioner fra træfyring i husholdninger.

Partikler (PM)

Emissionsopgørelsen for partikler (Particulate Matter, forkortet PM) er blevet rapporteret for år 1990 og fremefter. Opgørelsen inkluderer den totale emission af partikler: Total Suspended Particles (TSP), emissionen af partikler mindre end 10 µm (PM_{10}) og emissionen af partikler mindre end 2,5 µm ($PM_{2,5}$).

De største kilder til $PM_{2,5}$-emission er husholdninger (51 %), vejtrafik (10 %) og andre mobile kilder (7 %). Emissionen fra husholdninger steg med 58 % fra 1990 til 2007 efterfulgt af et fald på 57 % fra 2007 til 2021. Stigningen skyldtes et stigende træforbrug, mens reduktionen efter 2007 skyldtes et svagt fald i træforbruget (indtil 2016) kombineret med emissionsgrænseværdier for nye ovne og kedler. Fra 2016 faldt træforbruget væsentligt, hvilket medførte betydelige fald i emissionerne. For andre mobile kilder er off-road-køretøjer i industrien samt landbrugs- og skovbrugsmaskiner de vigtigste kilder (hhv. 16 % og 23 %). I transportsektoren tegner udstødningsemissioner sig for under en fjerdedel (18 %), mens resten udgøres af partikler fra slid på dæk, bremser og vej. $PM_{2.5}$-emissionen er faldet med 48 % fra 1990 til 2021, hovedparten af reduktionen er fundet sted efter 2007.

De største kilder til TSP-emission er landbrugssektoren og husholdningerne med henholdsvis 76 % og 9 %. TSP-emissionen fra transport er også vigtig og inkluderer både udstødningsemissioner og ikke-udstødningsrelaterede emissioner fra slid af bremser, dæk og vej. De ikke-udstødningsrelaterede emissioner udgør 93 % af TSP-emissionen fra transport.

Sod (BC)

Emissionsopgørelsen for sod (Black Carbon – BC) er rapporteret fra år 1990 og fremefter. De vigtigste kilder er husholdninger og vejtransport, der bidrager med henholdsvis 44 % og 18 % i 2021. Fra 1990 til 2021 er den samlede BC-emission faldet med 66 %. Udviklingen indenfor ikke-industriel forbrænding er domineret af udviklingen i træforbruget i husholdninger.

BC-emissionen fra transportsektoren er faldet med 85 % fra 1990 til 2021, hvilket skyldes implementeringen af nye EURO-normer og forbedret teknologi. En vigtig faktor er anvendelsen af partikelfiltre for lastbiler og personbiler, som effektivt begrænser udledningen af partikler og også BC.

BC-emissioner fra udvinding/lagring/transport af kul, olie og gas kommer hovedsageligt fra lagring af kul. Emissionen er faldet med 92 % fra 1990 til 2021 på grund af det faldende kulforbrug til produktion af el og varme.

Tungmetaller

Generelt er de vigtigste kilder til emissioner af tungmetaller forbrænding af fossile brændsler og affald. Emissionerne af tungmetaller er med undtagelse af kobber, faldet betydeligt de seneste år. Reduktionerne spænder fra 15 % til 93 % for henholdsvis Zn og Hg. Årsagen til de reducerede emissioner er hovedsageligt den øgede brug af røggasrensning på kraftværker og fjernvarmeværker (inklusive affaldsforbrændingsanlæg). Den store reduktion i emissionen af Pb skyldes et løbende skift til fordel for blyfri benzin, som er nødvendigt for biler med katalysator. Den største kilde til emission af kobber er slid af køretøjers dæk og bremser (95 % i 2021). Emissionen herfra er steget 30 % fra 1990 til 2021 pga. en stigning i antal kørte kilometer.

III Genberegninger og forbedringer

Generelt pågår der et betydeligt arbejde med at forbedre emissionsopgørelserne. Nye undersøgelser og forskning fra Danmark og udlandet inkluderes så vidt muligt som basis for emissionsestimaterne. Desuden følges arbejdet med opdateringer af EMEP/EEA Guidebook for emissionsopgørelser nøje, med henblik på at indarbejde de bedste videnskabelige informationer som basis for opgørelserne.

Opgørelserne opdateres løbende med ny viden, således at opgørelserne bedst mulig afspejler danske forhold. Ved forbedringer lægges vægt på at opdateringer omfatter hele tidsserier, for at sikre konsistente data. Disse tiltag medfører genberegning af tidligere indberettede opgørelser. Denne aflevering indeholder genberegninger for hele tidsserien. Begrundelserne for genberegningerne er inkluderet i kapitel 9 samt i de enkelte sektorkapitler i denne rapport. For planlagte sektorspecifikke forbedringer henvises der til sektorkapitlerne.

1 Introduction

1.1 Background information on emission inventories

DCE (Danish Centre for Environment and Energy), Aarhus University is contracted by the Ministry of the Environment and Food and the Ministry of Energy, Utilities and Climate to complete emission inventories for Denmark. Department of Environmental Science, Aarhus University is responsible for calculation and reporting of the Danish national emission inventory to the EU (Monitoring Mechanism Regulation & Directive on reduction of national emissions of certain atmospheric pollutants) and the UNFCCC (United Nations Framework Convention on Climate Change) and UNECE CLRTAP (Convention on Long Range Transboundary Air Pollution) conventions.

1.1.1 Annual report

This report is Denmark's Annual Informative Inventory Report due March 15, 2023. The report contains information on Denmark's inventories for all years from the base years of the protocols to 2021.

According to the guidelines for reporting emission data under the Convention on Long-Range Transboundary Air Pollution (ECE/EB.AIR/125) prepared by the Task Force on Emission Inventories and Projections and approved by the Executive Body, countries that are parties to the UNECE-Convention on Long-Range Transboundary Air Pollution should annually submit an informative inventory report to the Secretariat. The current reporting Guidelines (ECE/EB.AIR/125) were accepted at the meeting of the Executive Body in December 2013.

The directive on reduction of national emissions of certain atmospheric pollutants (Directive 2016/2284/EU – the revised NEC directive) entered into force on 31 December 2016. This report is the official submission of the Informative Inventory Report in accordance with Article 8.

The annual emission inventory for Denmark is reported in the Nomenclature for Reporting (NFR) 2019 format.

The issues addressed in this report are trends in emissions, description of each NFR category, uncertainty estimates, recalculations, planned improvements and procedures for quality assurance and control. The outline in annex V of the reporting guidelines is followed as far as possible.

This report and NFR tables are available to the public on the Danish emission inventory webpage:
http://envs.au.dk/videnudveksling/luft/emissioner/emissioninventory/

and on the Eionet central data repository:
http://cdr.eionet.europa.eu/dk/un/clrtap/
&
http://cdr.eionet.europa.eu/dk/eu/nec_revised/

1.2 A description of the institutional arrangement for inventory preparation

DCE (Danish Centre for Environment and Energy, Aarhus University, is responsible for the annual preparation and submission to the UNECE-LRTAP Convention of the Informative Inventory Report, and the inventories in the NFR format in accordance with the guidelines. DCE participates in meetings under the UNECE Task Force on Emission Inventories and Projections and the related expert panels where parties to the convention prepare the guidelines and methodologies on inventories. DCE is also responsible for estimating and reporting emissions under Directive 2016/2284/EU.

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

Danish Energy Agency (DEA), Ministry of Climate, Energy and Utilities:
Annual energy statistics in a format suitable for the emission inventory work and fuel-use data for the large combustion plants.

Danish Environmental Protection Agency (DEPA), Ministry of Environment:
Company reporting to e.g. the PRTR. Database on waste.

Statistics Denmark, Ministry of Digital Government and Gender Equality:
Statistical yearbook, production statistics for manufacturing industries, agricultural statistics and import/export/production figures.

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

The Road Directorate, Ministry of Transport:
Number of vehicles grouped in categories corresponding to the EU classification, mileage (urban, rural, highway), trip speed (urban, rural, highway).

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

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

Danish companies:
Audited environmental reports and direct information gathered from producers and agency enterprises.

Formerly, the provision of data was on a voluntary basis, but now formal agreements are in place with the most important data suppliers, e.g. the Danish Energy Agency and DCA.

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 DCE. The databases are in Access format and handled with software developed by the European Environmental Agency (EEA) and DCE. 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 6. As part of the QA/QC plan (Chapter 1.5), the data structure for data processing support the pathway from collection of raw data, data compilation, modelling and final reporting.

For each submission, databases and additional tools and submodels are archived together with the resulting NFR 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 journal for DCE, for which obligations apply to DCE, as a governmental institute. In this journal system, correspondence, both in-going and out-going, is registered, which in this case involves the registration of submissions and communication on inventories with the UNECE-LRTAP 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 II and for reporting the software tool is developed by DCE. Data files and programme files used in the inventory preparation process are listed in Table 1.1.

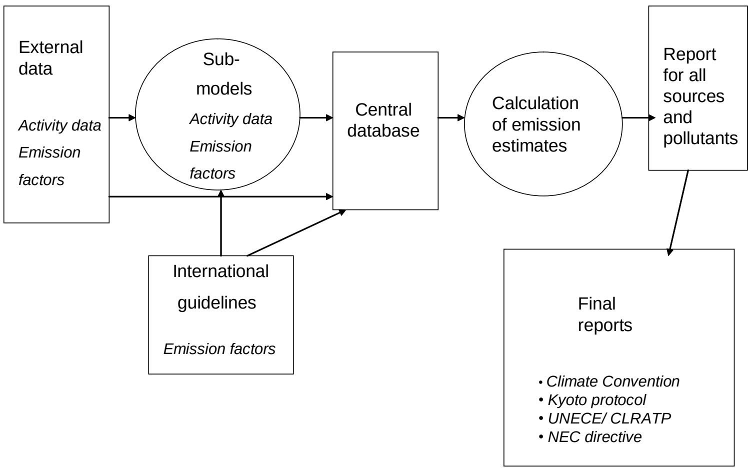


Figure 1.1 Schematic diagram of the process of inventory preparation.

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) NFR Submissions (UNECE and EU)	External report	U:\ST_ENVS-LUFT-EMI\Inventory\AllYears\8_AllSectors\Level_4a_Storage\	MS Excel, xml	CRF Reporter
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)	manual input and Importer2CRF
3 process	Importer2CRF	Help tool	U:\ST_ENVS-LUFT-EMI\Inventory\AllYears\8_AllSectors\Level_3b_Processes	MS Access	CRF Reporter, CollectEr2CRFand excel files
3 process	CollectER2CRF	Help tool	U:\ST_ENVS-LUFT-EMI\Inventory\AllYears\8_AllSectors\Level_3b_Processes	MS Access	NERIRep
2 process 3 store	NERIRep	Help tool	Working path: U:\ST_ENVS-LUFT-EMI\Inventory\AllYears\8_AllSectors\Level_3a_Storage	MS Access	CollectER databases; dk1972.mdb..dkxxxx.mdb
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)	manual input
2 store	dk1980.mdb.dkxxxx.mdb	Datastore	U:\ST_ENVS-LUFT-EMI\Inventory\AllYears\8_AllSectors\Level_2a_Storage	MS Access	CollectER

1.4 Brief description of methodologies and data sources used

Denmark's air emission inventories are based on the EMEP/EEA Guidebook, the CORINAIR methodology as well as the 2006 IPCC Guidelines (IPCC, 2006). 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. In 2019, the latest edition of the EMEP/EEA Guidebook (EEA, 2019) was adopted for use by the EMEP Executive Body. In 2009, the EMEP/CORINAIR Guidebook changed name to the EMEP/EEA Guidebook (EEA, 2009). In this change, the Guidebook switched nomenclature from SNAP to NFR.

The Danish inventory is prepared at the more detailed SNAP level rather than at the NFR level that is only suitable for reporting. 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.

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 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 The specific methodologies regarding stationary combustion

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 former CORINAIR system. 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 1A2 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.

A number of large plants, e.g. power plants, municipal waste incineration plants and large industrial plants are registered individually as large point sources. This enables use of plant-specific emission factors that refer to emission measurements stated in annual environmental reports. Emission factors of SO_2, NO_X, HM and PM are often plant specific.

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

1.4.2 Specific methodologies regarding 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 NFR categories; 1A3b (Road transport), 1A2f (Industry-other), 1A3a (Civil aviation), 1A3c (Railways), 1A3d (Navigation), 1A4c (Agriculture/forestry/-fisheries), 1A4a (Commercial/institutional), 1A4b (Residential) and 1A5 (Other).

An internal DCE model with a structure similar to the European COPERT IV emission model (EEA, 2019) 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.

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.

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 The specific methodologies regarding fugitive emissions

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, 2019). The sources include offshore extraction of oil and gas, onshore oil tanks, onshore and offshore loading of ships, and gasoline distribution. Activity data are 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 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 from the national transmission company.

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 national studies and the EMEP/EEA Guidebook (EEA, 2017).

Please refer to Chapter 3.4 for further information on fugitive emissions from fuels.

1.4.4 Specific methodologies regarding industrial processes and product use

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

Mineral industry

The sub-sector includes production of cement, lime, container glass/glass wool, mineral wool, other production (consumption of lime), and roofing and road paving with asphalt. The activity data as well as emission data are primarily based on information from Environmental Reports (In Danish: "Grønne regnskaber") prepared by companies according to obligations under Danish law. Also, data on production and import/export from Statistics Denmark are used. The published information is supplemented with information obtained directly from companies or by use of standard emission factors. The distribution of TSP between PM_{10} and $PM_{2.5}$ is based on European average data.

Chemical industry

The sub-sector includes production of nitric and sulphuric acid (ceased in 1997 and 2004, respectively), catalysts, fertilisers and pesticides. The activity data as well as emission data are based on information from the companies as accounted for and published in the Environmental Reports combined with information obtained by contact to the companies. The distribution of TSP between PM_{10} and $PM_{2.5}$ is based on European average data.

Metal industry

The sub-sector includes electro steelwork, production of steel sheets and bars (electro steelwork until 2005 and thereafter, only rolling mills), cast iron, aluminium (ceased in 2008), lead and lead products and various other metal products. The activity data as well as emission data for the steelworks are based on information from the companies as accounted for and published in the Environmental Reports, combined with information obtained through contact with the companies. The activity data for the other processes are based on information from Statistics Denmark combined with Danish average emission factors and standard emission factors. The particle size distribution of TSP (PM_{10} and $PM_{2.5}$) is based on European average data.

Other production

The sub-sector includes breweries, production of spirits and other activities within the food sector e.g. sugar production, meat curing and production of margarine and solid cooking fats. The activity data are obtained from Statistics Denmark and the emission factors are obtained from the EMEP/EEA Guidebook combined with emission factors (EF) derived from specific emission measurements at the companies.

Solvent and other product use

The approach for calculating the emissions of Non-Methane Volatile Organic Carbon (NMVOC) from industrial and household use in Denmark focuses on single chemicals rather than activities. This leads to a clearer picture of the influence from each specific chemical, which enables a more detailed differentiation on products and the influence of product use on emissions. The procedure is to quantify the use of the chemicals and estimate the fraction of the chemicals that is emitted as a consequence of use.

The detailed approach in EMEP/EEA Guidebook (2019) is used. Here all relevant consumption data on all relevant solvents must be inventoried or at least those together representing more than 90 % of the total NMVOC emission. Simple mass balances for calculating the use and emissions of chemicals are set up 1) use = production + import – export, 2) emission = use emission factor. Production, import and export figures are extracted from Statistics Denmark, from which a list of more than 400 single chemicals, a few groups and products is generated. For each of these, a "use" amount in tonnes per year is calculated. For some chemicals and/or products, e.g. propellants used in aerosol cans and ethanol used in windscreen washing agents, use amounts are obtained from the industry as the information from Statistics Denmark does not comply with required specificity. It is found that approximately 40 different NMVOCs comprise over 95 % of the total use and these 40 chemicals are thus investigated further. The "use" amounts are distributed across industrial activities according to the Nordic SPIN (Substances in Preparations in Nordic Countries) database, where information on industrial use categories is available in a NACE coding system. The chemicals are also related to specific products according to the Use Category (UCN) system. Emission factors are obtained from regulators, literature or the industry.

The same method is used for calculating emissions from the use of fireworks, tobacco, candles and charcoal for barbeques (BBQ). These activities lead to emissions of SO_2, NO_x, CO, NH_3, particles, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn, dioxins/furans and PAHs.

Please refer to Chapter 4 and Annex 3C for further information on industrial processes and product use.

1.4.5 Specific methodologies regarding agriculture

The emission from agricultural activities covers NH_3, NO_x, NMVOC and particles from animal husbandry/manure management and agricultural soils. Furthermore, the inventory includes emissions from field burning of straw which covers NH_3, PM, NO_x, CO, NMVOC, SO_2, heavy metals, dioxin and PAH.

Emissions from agricultural activities are estimated according to the methodology described in the EMEP/EEA air pollutant emission inventory guidebook (EEA, 2019). Activity data and national data regarding emission factors are collected, evaluated and discussed in cooperation with Statistics Denmark, DCA-Danish Centre for Food and Agriculture (Aarhus University), the Danish Agricultural Advisory Service, Danish Environmental Protection Agency and the Danish AgriFish Agency. It means that data are evaluated continuously according to the latest knowledge and information.

The Danish agricultural emissions are calculated and managed in a comprehensive model complex called IDA (Integrated Database model for Agricultural emissions), which is used to calculate both air pollutants compounds and greenhouse gas related emissions. The livestock production has a great influence on the Danish agricultural emissions. IDA works with approximately 40 different livestock categories, dependent on livestock category, weight class and age. Each of these subcategories is subdivided according to housing type and manure type, which results in about 200 different combinations of subcategories and housing type, and the emissions are calculated from each of these combinations and aggregated to relevant main categories in the reporting format.

Most of the emissions from agricultural activities are directly related to livestock production. The remaining part comes from the use of synthetic fertiliser, growing crops, NH_3 treated straw, field burning of agricultural residues and sewage sludge applied to fields as fertiliser. The number of animals can be considered as the most important activity data in estimation of the agricultural emissions.

The number of animals is mainly based on data from Statistics Denmark. For data covering pigs, bulls and poultry, the number is based on slaughter data also collected from the Agricultural Statistics. The production of sheep, goats and horses typically takes place on small farms below five hectare, which are not included in the annual statistics and the production of these categories as well as for deer and ostriches are therefore based on the Central House-animal farm Register (CHR) managed by the Ministry of Food, Agriculture and Fisheries.

Data concerning nitrogen excretion, distribution of housing types until 2004 and handling of manure is based on data and information from DCA-Danish Centre for Food and Agriculture at Aarhus University and the Danish Agricultural Advisory Service. From 2005, annual statistics covering housing types are available from the Danish Agricultural Agency.

Data related to use of synthetic fertiliser, both the amount of fertiliser and the nitrogen content is based on statistics published by the Danish Agricultural Agency.

Please refer to Chapter 5 and Appendix 3D for further information on emission inventories for agriculture.

1.4.6 Specific methodologies regarding waste

The waste sector consists of the four main NFR categories 5A Solid waste disposal, 5B Biological treatment of solid waste, 5C Waste incineration, 5D Wastewater treatment and discharge and 5E Other waste.

Composting includes four types of biological waste; garden and park waste, organic waste from households and other sources, sludge and home composting of garden and vegetable food waste. Individual emission factors are found for each waste category.

Waste incineration covers the cremation of human bodies and animal carcasses. Both are calculated as an activity multiplied by an emission factor.

The Other waste category includes accidental building- and vehicle fires.

Please refer to Chapter 6 and Annex 3E for further information on emission inventories for agriculture.

1.5 Key categories

Denmark has estimated key categories using Approach 1 for level and trend. The results of the analysis are provided in Annex 1.

1.6 Information on the Quality Control and Quality Assurance plan including verification and treatment of confidential issues where relevant

In the Danish National Inventory Report to UNFCCC (Nielsen et al., 2022) as well as in the QA/QC manual for the Danish Greenhouse gas inventory (Nielsen et al., 2020), the plan for Quality Control (QC) and Quality Assurance (QA) for greenhouse gas emission inventories prepared by the DCE is outlined. The plan is in accordance with the guidelines provided by the UNFCCC (IPCC, 2006). The ISO 9000 standards are also used as important input for the plan. The plan also, to a limited extent, includes air pollutants. Due to a lack of resources, it has not been possible to extend the QA/QC system for the greenhouse gas inventory to also cover the air pollutants.

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

The uncertainty estimates are based on the simple Tier 1 approach in the EMEP/CorinAir *Good Practice Guidance for LRTAP Emission Inventories* (Pulles & Aardenne, 2004).

The uncertainty estimates are based on emission data for the base year and year 2021, and on uncertainties for activity rates and emission factors for each of the main SNAP sectors. For all pollutants, 1990 is used as the base year.

Uncertainty estimates include uncertainty of the total emission as well as uncertainty of the trend. The estimated uncertainties are shown in Table 1.2. The uncertainty estimates include all sectors.

Table 1.2 Danish uncertainty estimates, 2021.

Pollutant	Uncertainty Total emission [%]	Trend 1990-2021 [%]	Uncertainty Trend [%-age points]
SO_2	34	-95	1.5
NO_x	62	-70	11
NMVOC	110	-50	26
CO	39	-73	8
NH_3	18	-50	6
TSP	211	-23	24
PM_{10}	100	-36	19
$PM_{2.5}$	83	-48	14
BC	346	-66	76
Arsenic	231	-78	35
Cadmium	372	-45	172
Chromium	227	-73	54
Copper	953	30	56
Mercury	114	-93	9
Nickel	518	-84	54
Lead	583	-89	28
Selenium	162	-89	15
Zinc	502	-15	221
PCDD/F	336	-56	144
Benzo(b)fluoranthene	666	-54	65
Benzo(k)fluoranthene	667	-64	80
Benzo(a)pyrene	738	-63	46
Indeno(1,2,3-c,d)pyrene	642	-76	44
HCB	498	-83	60
PCBs	580	-85	74

1.8 General assessment of the completeness

Annex 4 provides a full and comprehensive explanation on the use of notation keys in the Danish inventory.

The NFR as reported by Denmark makes use of five notation keys: NO (Not Occurring), NA (Not Applicable), NE (Not Estimated), IE (Included Elsewhere) and NR (Not Reported).

NO is used in instances where the activity does not occur in Denmark, e.g. adipic acid production, buffaloes, etc.

NA is used in instances where the activity occurs in Denmark but the emission of a certain pollutant is not believed to be relevant, e.g. heavy metals from dairy cattle.

NE is used in instances where the activity occurs in Denmark and emissions of a certain pollutant are thought to occur but the emission has not been estimated; see Annex 4.

IE is used where emissions of a certain pollutant or the whole source category are reported under another source category; see Annex 4.

NR is used for pollutants prior to the base year, e.g. HM emissions prior to the year 1990.

1.9 Emission reduction commitments

The amended Gothenburg Protocol under the UNECE established emission reduction commitments (ERCs) for 2020 for five pollutants: NO_x, SO_2, NMVOC, NH_3 and $PM_{2.5}$. The same ERCs for 2020 were agreed in Directive 2016/2284/EU (NECD). The ERCs were expressed as a percentage reduction commitment in 2020 compared to the emission level in 2005.

The definitions for what counts towards compliance is different between the Gothenburg Protocol and the NECD. For the NECD, NO_x and NMVOC emissions from NFR categories 3B and 3D are excluded when determining compliance. For reporting to the UNECE, NO_x emissions from NFR category 3D are excluded from the reduction commitment. Table 1.3 and 1.4 below shows the emissions in 2005 and 2020, the achieved emission reduction in comparison with the targets under the UNECE and NECD, respectively.

It should be noted that the current NFR template (Annex 1 to the reporting guidelines) does not calculate the compliance total for NO_x correctly under the UNECE as it does not take into account that NO_x from NFR category 3D should be excluded for some Parties. Therefore, the numbers for NO_x presented in Table 1.3 differs from the compliance total calculated in the NFR template.

Table 1.3 Emissions and achieved reduction under the UNECE.

Pollutant	2005 emission	2020 emission	2021 emission	Reduction 2020, %	Reduction 2021, %	ERC, %
SO_2	26.44	9.30	8.58	64.8	67.5	35
NO_x	181.59	70.27	71.77	61.3	60.5	56
NH_3	93.09	78.91	70.80	15.2	23.9	24
NMVOC	153.60	106.47	106.62	30.7	30.6	35
NMVOC incl. adjustment	133.57	82.54	82.17	38.2	38.5	35
$PM_{2.5}$	21.08	11.98	11.98	43.2	43.2	33

Table 1.3 shows that Denmark has not met the ERCs under the UNECE for NH_3. For NMVOC, Denmark applied for an adjustment in 2022 that was accepted. Taking into account the approved adjustment, Denmark is in compliance for NMVOC. For more information on the adjustment, please refer to Chapter 12.

Table 1.4 Emissions and achieved reduction under the NECD.

Pollutant	2005 emission	2020 emission	2021 emission	Reduction 2020, %	Reduction 2021, %	ERC, %
SO_2	26.44	9.30	8.58	64.8	67.5	35
NO_x	180.78	69.51	71.01	61.5	60.7	56
NH_3	93.09	78.91	70.80	15.2	23.9	24
NMVOC	110.63	60.18	60.19	45.6	45.6	35
$PM_{2.5}$	21.08	11.98	11.98	43.2	43.2	33

Table 1.4 shows, that Denmark under the NECD has met the ERCs for all pollutants with the exception of NH_3.

1.10 References

Directive 2016/2284/EU on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016L2284&from=EN (02-03-2020).

EEA, 2009: EMEP/EEA air pollutant emission inventory guidebook — 2009 prepared by the UNECE/EMEP Task Force on Emissions Inventories and Projections. Available at: http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009 (02-03-2020).

EEA, 2019: EMEP/EEA air pollutant emission inventory guidebook — 2019 prepared by the UNECE/EMEP Task Force on Emissions Inventories and Projections. Available at: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (02-03-2020).

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. Samfund og Miljø – 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 (21-01-2017).

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Gyldenkærne, S., Thomsen, M., Nielsen, M, Mikkelsen, M.H., Albrektsen, R., Hjelgaard, K. & Bruun, H.G. 2020: Quality manual for the Danish greenhouse gas inventory. Version 3. Aarhus University, DCE – Danish Centre for Environment and Energy, 44 pp. Scientific Report No. 406 http://dce2.au.dk/pub/SR406.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., Stupak, I., Scott-Bentsen, N., Rasmussen, E., Petersen, S.B., Baunbæk, L., & Hansen, M.G. 2022: Denmark's National Inventory Report 2022. Emission Inventories 1990-2020 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Aarhus University, DCE – Danish Centre for Environment and Energy, 969 pp. Scientific Report No. 494 http://dce2.au.dk/pub/SR494.pdf

Pulles, T. & Aardenne, J.v., 2004: Good Practice Guidance for LRTAP Emission Inventories, 24. June 2004.

2 Trends in Emissions

2.1 Acidifying gases

Acid deposition of sulphur and nitrogen compounds mainly derives from emissions of SO_2, NO_X and NH_3. The effects of acidification may appear in a number of ways, including defoliation and reduced vitality of trees, and declining fish stocks in acid-sensitive lakes and rivers.

SO_2 and NO_X can be oxidised into sulphate (SO_4^{--}) and nitrate (NO_3^-) - either in the atmosphere or after deposition - resulting in the formation of two and one H^+, respectively. NH_3 may react with H^+ to form ammonium (NH_4^+) and, by nitrification in soil, NH_4^+ is oxidised to NO_3^- and H^+ ions are formed.

Weighting the individual substances according to their acidification effect, total emissions in terms of acid equivalents can be calculated as:

$$A = \frac{m_{SO_2}}{M_{SO_2}} \cdot 2 + \frac{m_{NO_x}}{M_{NO_x}} + \frac{m_{NH_3}}{M_{NH_3}} = \frac{m_{SO_2}}{64} \cdot 2 + \frac{m_{NO_x}}{46} + \frac{m_{NH_3}}{17}$$

where A is the acidification index in Mmole

m_i is the emission of pollutant *i* in tonnes

M_i is the mole weight [tonne/Mmole] of pollutant *i*

The actual effect of the acidifying substances depends on a combination of two factors: the amount of acid deposition and the natural capacity of the terrestrial or aquatic ecosystem to counteract the acidification. In areas where the soil minerals easily weather or have a high lime content, acid deposition will be neutralised relatively easy.

Figure 2.1 shows the emission of Danish acidifying gases in terms of acid equivalents. In 1990, the relative contribution in acid equivalents was almost equal for the three gases. In 2021, the most important acidification factor in Denmark is ammonia nitrogen and the relative contributions for SO_2, NO_X and NH_3 were 4 %, 31 % and 65 %, respectively. However, with regard to long-range transport of air pollution, SO_2 and NO_X are still the most important pollutants.

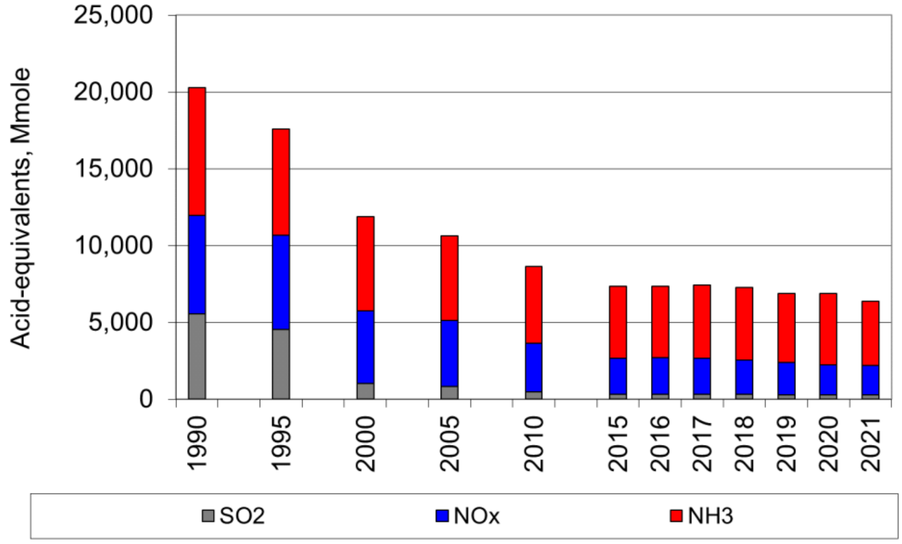


Figure 2.1 Emissions of NH_3, NO_X and SO_2 over time in acid equivalents.

2.2 Description and interpretation of emission trends by gas

2.2.1 Sulphur dioxide (SO_2)

The main part of the sulphur dioxide (SO_2) emission originates from combustion of fossil fuels, i.e. mainly coal and oil, in public power and district heating plants. Since 1990, the total emission has decreased by 95 %. The large reduction is mainly due to installation of desulphurisation plant and use of fuels with lower content of sulphur in public power and district heating plants. Despite the large reduction of the SO_2 emissions, these plants make up 29 % of the total emission. In addition, emissions from industrial combustion plants, non-industrial combustion plants and other mobile sources are important.

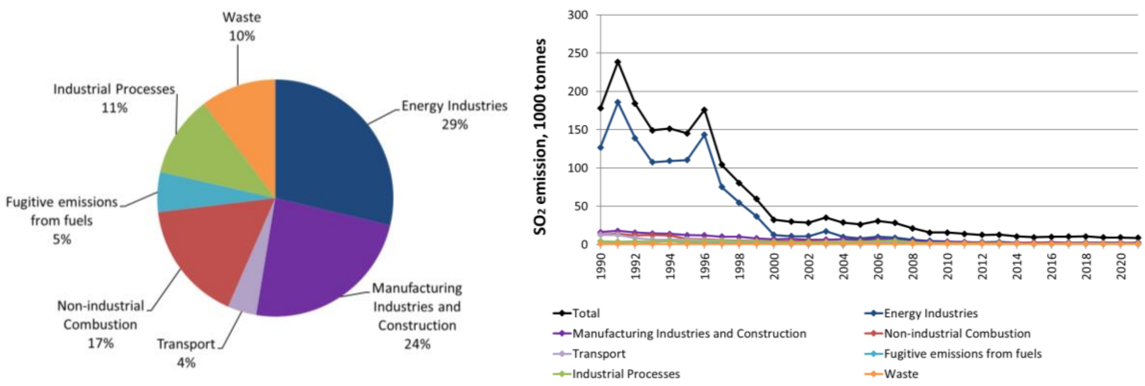


Figure 2.2 SO_2 emissions. Distribution according to the main sectors (2021) and time series for 1990 to 2021.

2.2.2 Nitrogen oxides (NO_x)

The largest sources of emissions of nitrogen oxides (NO_x) are road transport followed by other mobile sources and combustion in energy industries (mainly public power and district heating plants). The transport sector is the sector contributing the most to the emission of NO_x and, in 2021, 37 % of the Danish emissions of NO_x stems from road transport, national navigation, railways and civil aviation. In addition, emissions from national fishing and off-road vehicles contribute significantly to the NO_x emission. For non-industrial combustion plants, the main sources are combustion of gas oil, natural gas and wood in residential plants. The emissions from energy industries have decreased by 84 % from 1990 to 2021. In the same period, the total emission decreased by 70 %. The reduction is due to the increasing use of catalyst cars and installation of low-NO_x burners and denitrifying units in power plants and district heating plants.

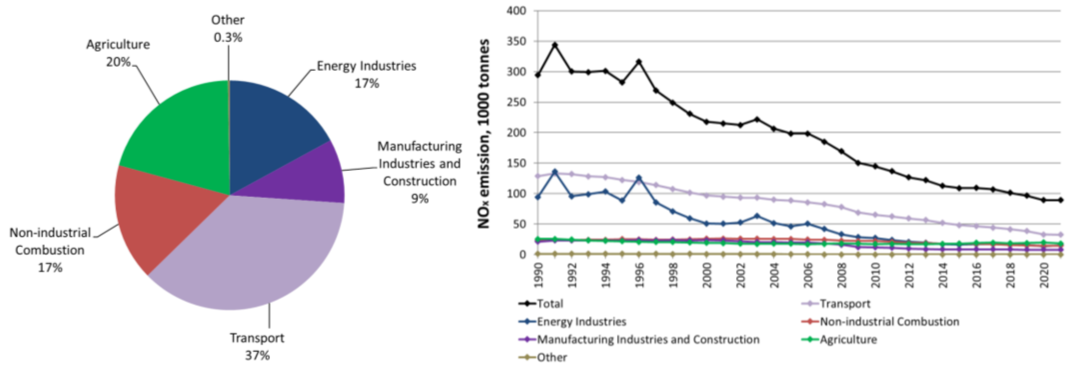


Figure 2.3 NO_X emissions. Distribution according to the main sectors (2021) and time series for 1990 to 2021.

2.2.3 Ammonia (NH_3)

Almost all atmospheric emissions of ammonia (NH_3) result from agricultural activities. Only a minor part of the total emission originates from stationary combustion (2.0 %), road transport (1.0 %), industrial processes (0.6 %) and waste (1.0 %). The share for road transport was increasing during the 1990’s and early 2000’s due to increasing use of catalyst cars. In recent years, the share has been decreasing due to more advanced catalysts being implemented. The total ammonia emission has decreased by 50 % since 1990.

The major part of the emission from agriculture stems from livestock manure (40 %) and agricultural soils (55 %). The largest source for manure management is losses of ammonia occurring during the handling of the manure in animal housing systems. For agricultural soils, the emissions are mainly stemming from application of mineral fertiliser, application of animal manure and growing crops.

Due to the action plans for the aquatic environment and the Ammonia Action Plan, a series of measures to prevent loss of nitrogen in agricultural production has been initiated. The measures have included demands for improved utilisation of nitrogen in livestock manure, a ban against field application of livestock manure in winter, prohibition of broad-spreading of manure, requirements for establishment of catch crops, regulation of the number of livestock per hectare and a ceiling for the supply of nitrogen to crops. As a result, despite an increase in the production of pigs and poultry, the ammonia emission has been reduced considerably.

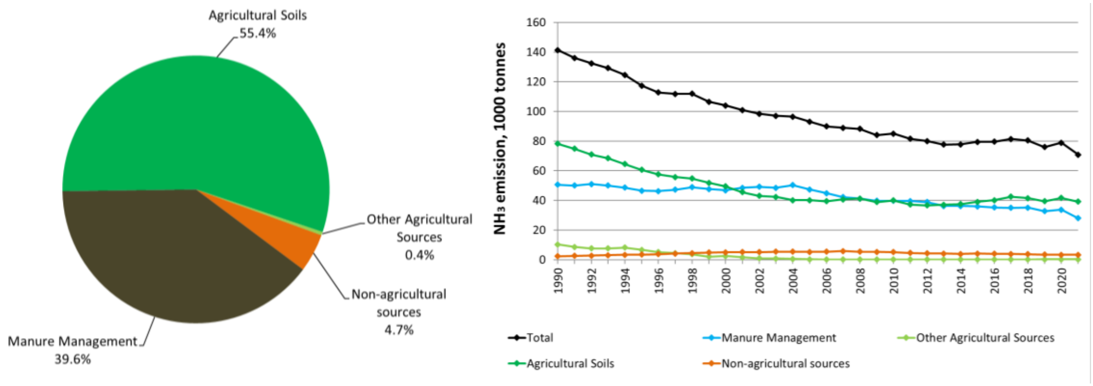


Figure 2.4 NH_3 emissions. Distribution on the main sectors (2021) and time series for 1990 to 2021.

2.3 Other air pollutants

2.3.1 Non-Methane Volatile Organic Compounds (NMVOC)

The emissions of Non-Methane Volatile Organic Compounds (NMVOC) originate from many different sources and can be divided into two main groups: incomplete combustion and evaporation. Small combustion plants (e.g. residential wood burning) is a big source of NMVOC originating from combustion. Other important sources are road vehicles and other transport sources such as national navigation. NMVOC from road transportation vehicles have been decreasing since 1990, due to the introduction of catalyst cars. The evaporative emissions mainly originate from the agricultural sector, use of solvents, and the extraction, handling and storage of oil and natural gas. The total anthropogenic emissions have decreased by 50 % since 1990, largely due to the increased use of catalyst cars and reduced emissions from use of solvents.

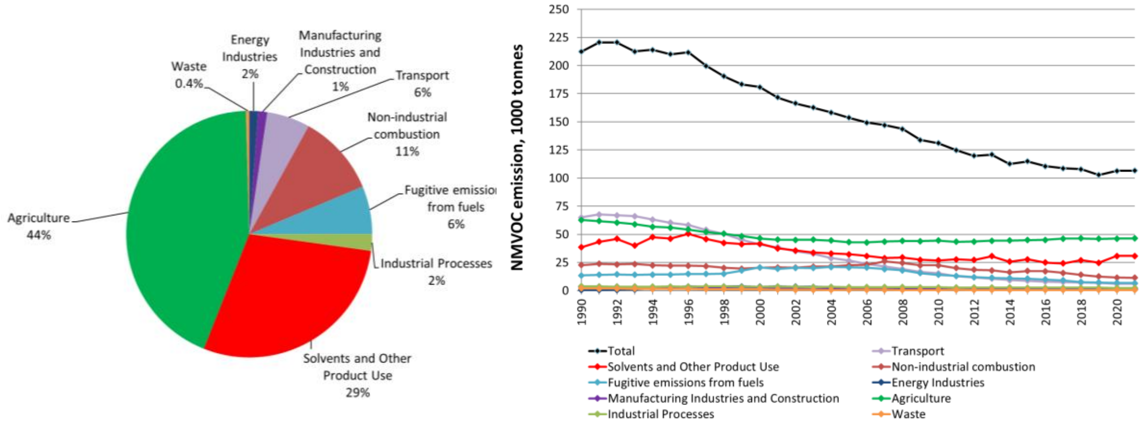


Figure 2.5 NMVOC emissions. Distribution according to the main sectors (2021) and time series for 1990 to 2021.

2.3.2 Carbon monoxide (CO)

Non-industrial combustion plants are the main source to the total CO emission. For the non-industrial sector, emissions from the residential sector is dominating and has decreased due to newer technologies but fluctuates with the wood consumption. Transport is the second largest contributor to the total CO emission in 2021 (28 %), showing a decrease of 89 % from 1990 to 2021. The major transport source is passenger cars, which made up 59 % in 1990, but has decreased to 22 % in 2021. The main driver is the increase of catalyst cars. In 1990, a law forbidding the burning of agricultural crop residues on fields was implemented, which caused a significant reduction in CO emission. The total CO emission decreased further by 73 % from 1990 to 2021, largely because of decreasing emissions from road transport and residential combustion.

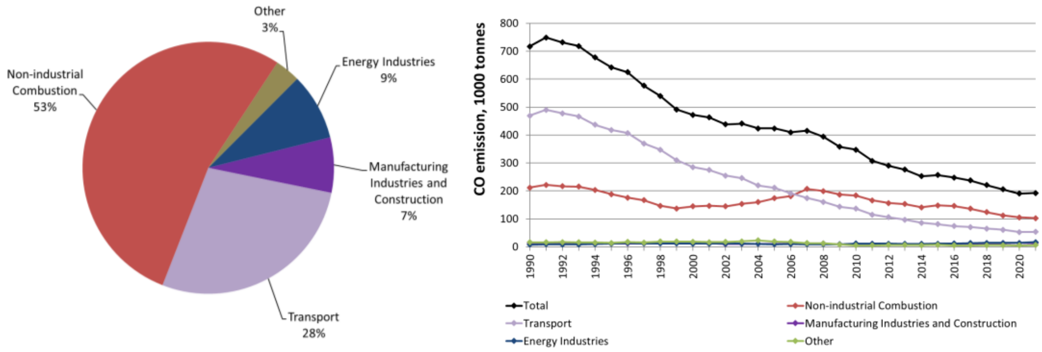


Figure 2.6 CO emissions. Distribution according to the main sectors (2021) and time series for 1990 to 2021.

2.3.3 Particulate matter (PM)

The particulate matter (PM) emission inventory is reported for the years 1990 onwards. The inventory includes the total emission of particles TSP (Total Suspended Particles), emission of particles smaller than 10 µm (PM_{10}) and emission of particles smaller than 2.5 µm ($PM_{2.5}$).

The largest $PM_{2.5}$ emission source is residential plants (51 %), road transport (10 %) and other mobile sources (7 %). Emissions from residential plants have increased by 58 % from 1990 to 2007, followed by a decrease of 57 % from 2007 to 2021. The increase was caused by increasing wood consumption while the decrease has been caused by a slightly lower wood consumption (until 2016) combined with legislative demands on new wood stoves and boilers. From 2016, the wood consumption decreased significantly leading to a significant decrease in emissions. For the road transport sector, exhaust emissions account for less than a quarter (18 %) of the emissions, while the remaining emissions come from tyre and brake wear and road abrasion. For other mobile sources, the most important sources are off-road vehicles and machinery in the industrial sector and in the agricultural/forestry sector (16 % and 23 %, respectively). The $PM_{2.5}$ emission decreased by 48 % from 1990 to 2021, but most of the reduction has occurred after 2008.

The largest TSP emission sources are agriculture and non-industrial combustion (76 % and 9 % of total TSP emission in 2021, respectively). Residential plants is the largest source in the non-industrial combustion sector, making up 8 % of the national total TSP emission in 2021.The TSP emissions from transport are also important and include both exhaust emissions and the non-exhaust emissions from brake and tyre wear and road abrasion. The non-exhaust emissions account for 93 % of the TSP emission from road transport in 2021.

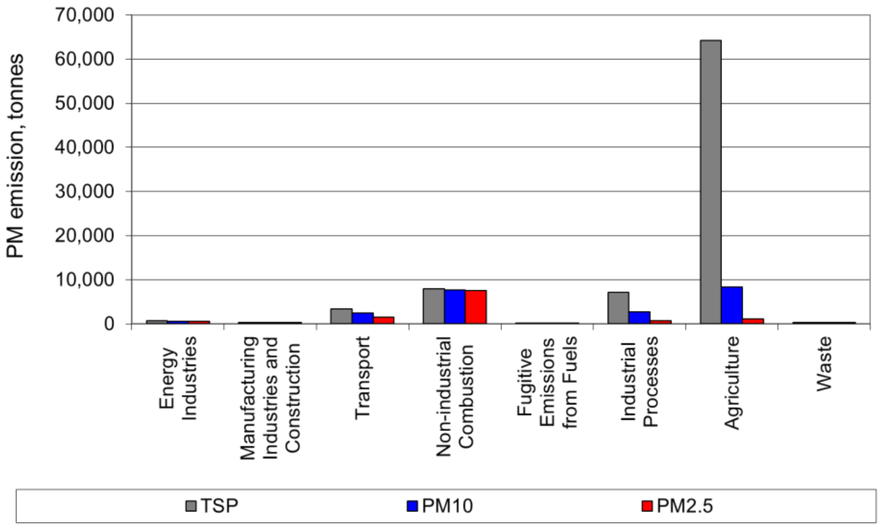


Figure 2.7 PM emissions per sector for 2021.

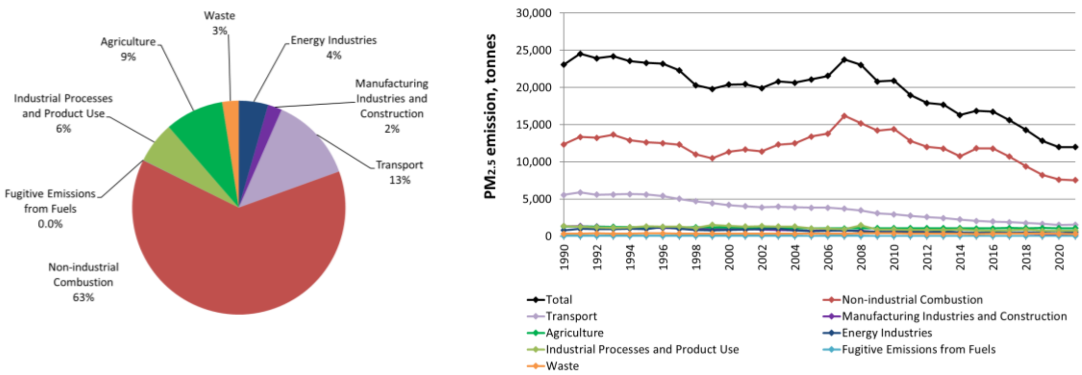


Figure 2.8 $PM_{2.5}$ emissions. Distribution according to the main sectors (2021) and time series for 1990 to 2021.

2.3.4 Black carbon (BC)

The black carbon (BC) emission inventory is reported for the years 1990 onwards. The main sources are residential plants and road transport contributing 44 % and 18 % in 2021, respectively. From 1990 to 2021, the total BC emission decreased by 66 %. The trend for non-industrial combustion is mainly controlled by the trend for the wood consumption in the residential sector.

BC emissions from the transport sector decreased by 85 % from 1990 to 2021, mainly due to implementing of new EURO norms and improved technology. An important factor is the use of particle filters for heavy-duty vehicles and passenger cars, which reduce the BC emission effectively.

BC emissions from fugitive emissions from fuels, which is mainly due to storage of coal, decreased by 92 % from 1990 to 2021, in line with the decrease of the coal consumption in electricity and heat production.

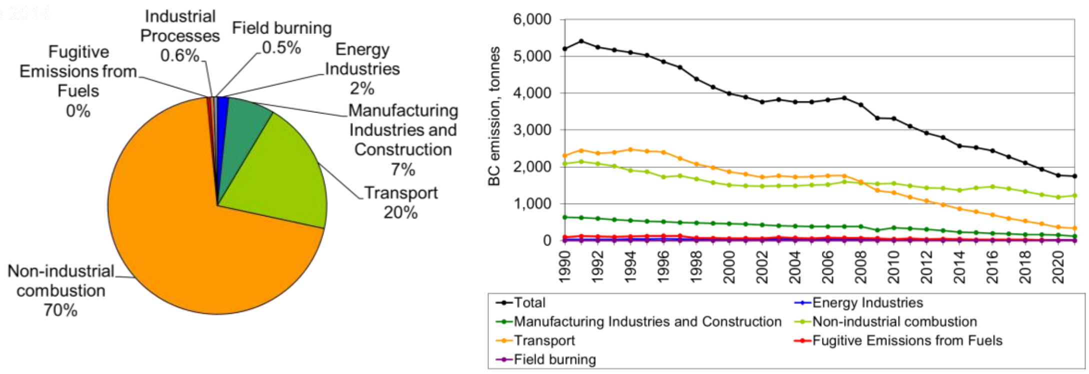


Figure 2.9 BC emissions. Distribution according to the main sectors (2021) and time series for 1990 to 2021.

2.3.5 Heavy metals

In general, the most important sources of heavy metal emissions are combustion of fuels and waste. The heavy metal emissions have decreased substantially in recent years, except for Cu. The reductions span from 15 % to 93 % for Zn and Hg, respectively. The reason for the reduced emissions is mainly increased use of gas cleaning devices at power and district heating plants (including waste incineration plants). The large reduction in the Pb emission is due to a gradual shift towards unleaded gasoline, the latter being essential for catalyst cars. The major source of Cu is automobile tyre and break wear (95 % in 2021) and the 30 % increase in total emission from 1990 to 2021 owe to increasing mileage.

Table 2.1 Emissions of heavy metals.

Heavy metals, kilogramme	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
1990	1370	1209	6046	49 396	3164	18 646	132 489	4245	74 626
2019	298	667	1,641	64 193	237	3002	14 553	486	63 598
Reduction, %	78	45	73	-30	93	84	89	89	15

According to the UNECE Heavy Metal Protocol, the priority metals are Pb, Cd and Hg and the objective is to reduce emissions of these heavy metals.

Cadmium (Cd)

The main sources of emissions of cadmium (Cd) to air are mainly combustion of wood, wood waste and municipal waste. Non-industrial combustion contributes 71 % in 2021, of which 93 % comes from residential plants. Emissions from residential plants have increased by 140 % from 1990 to 2021 due to increasing wood consumption. Emissions from energy industries, manufacturing industries and construction, and industrial processes have decreased by 87 % since 1990. The decreasing emission from energy industries is mainly related to the decreasing combustion of coal and better flue gas cleaning. In the transport sector emissions from passenger cars is the main source contributing with 54 % of the sectoral emission in 2021.

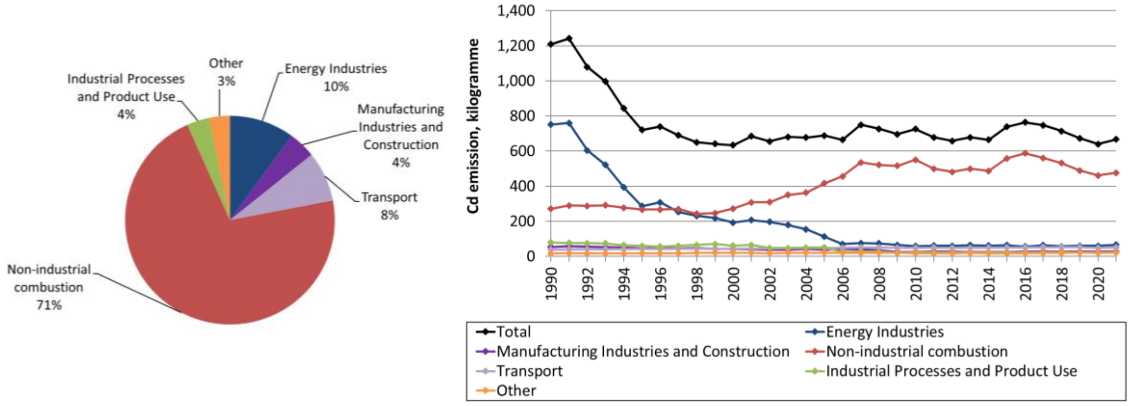


Figure 2.10 Cd emissions. Distribution by main sectors (2021) and time series for 1990 to 2021.

Mercury (Hg)

The largest sources of mercury (Hg) emissions to air are waste incineration and coal combustion in energy industries. Due to improved flue gas cleaning and decreasing coal combustion the emissions from Energy industries decreased by 76 % from 1990-2000. The trend has continued in the following years and the corresponding decrease from 1990-2021 is 95 %. Non-industrial combustion is dominated by wood combustion in residential plants while the main contributions to emissions from manufacturing industries and construction are food processing, beverages and tobacco, and non-metallic minerals. The variations in emissions from industrial processes owe to the closure in 2002 followed by re-opening and a second shut down in 2005 of the only Danish electro-steelwork.

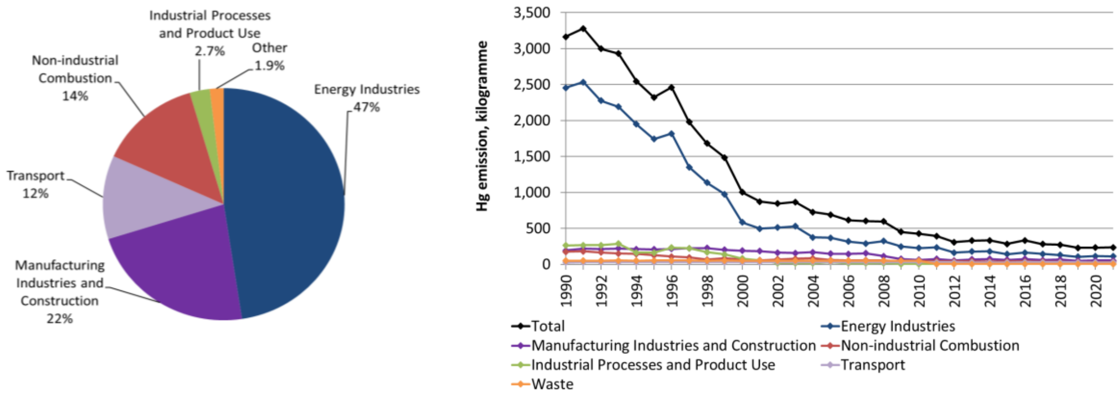


Figure 2.11 Hg emissions. Distribution by main sectors (2021) and time series for 1990 to 2021.

Lead (Pb)

The main lead (Pb) emission sources are transport, waste, non-industrial combustion and industrial processes. In earlier years combustion of leaded gasoline was the major contributor to Pb emissions to air but the shift toward use of unleaded gasoline for transport have decreased the Pb emission from transport by 95 % from 1990-2021. The trend in the Pb emission from non-industrial combustion from 1990 to 2021 is a decrease of 39 %. In the non-industrial combustion sector the dominant source is wood combustion in residential plants, which has been increasing from 1990 to 2021, but counterbalanced by decreasing emissions from stationary combustion in commercial/institutional and in agriculture/forestry/fishing. The decreasing emission from energy industries (97 % from 1990 to 2021) is caused by the deceasing coal combustion and more efficient particle abatement.

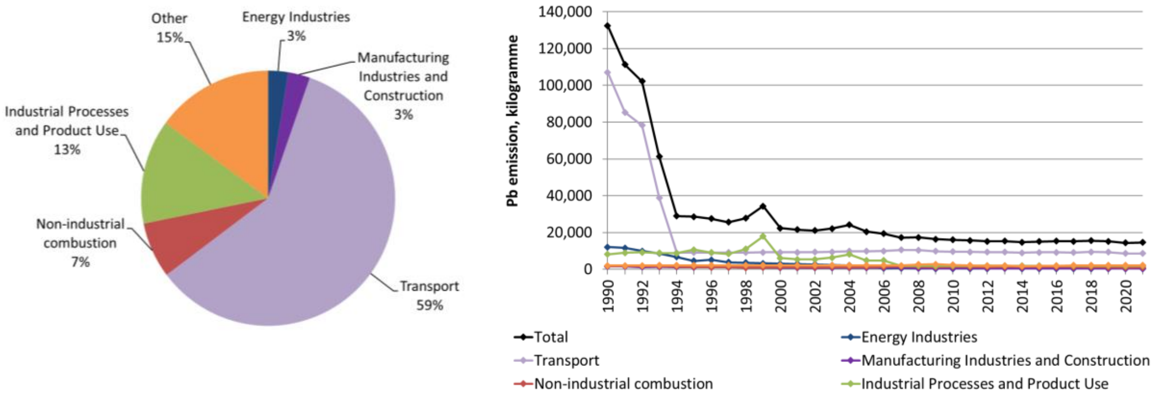


Figure 2.12 Pb emissions. Distribution by main sectors (2021) and time series for 1990 to 2021.

2.3.6 Polycyclic aromatic hydrocarbons (PAHs)

The present emission inventory for polycyclic aromatic hydrocarbons (PAH) includes four PAHs: benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene and indeno(1,2,3-cd)pyrene. The major part of the total PAH emission is benzo(b)fluoranthene and benzo(a)pyrene, which contribute by 32 % and 30 %, respectively in 2021.

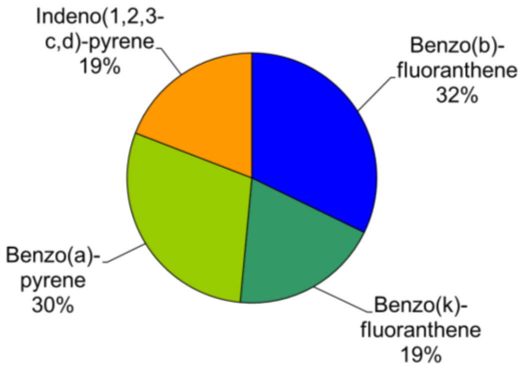


Figure 2.13 PAH emissions. Distribution according to reported PAHs in 2021.

The most important source of PAHs emissions is combustion in the residential sector (mostly wood burning) making up 70 % of the total emission in 2021. The decreasing emission trend from 1990 is due to decreasing emissions from the residential sector caused by newer technologies with more complete combustion and a decrease in wood consumption, especially after 2016. The PAH emission from combustion in residential plants has decreased by 71 % from 1990 to 2021.

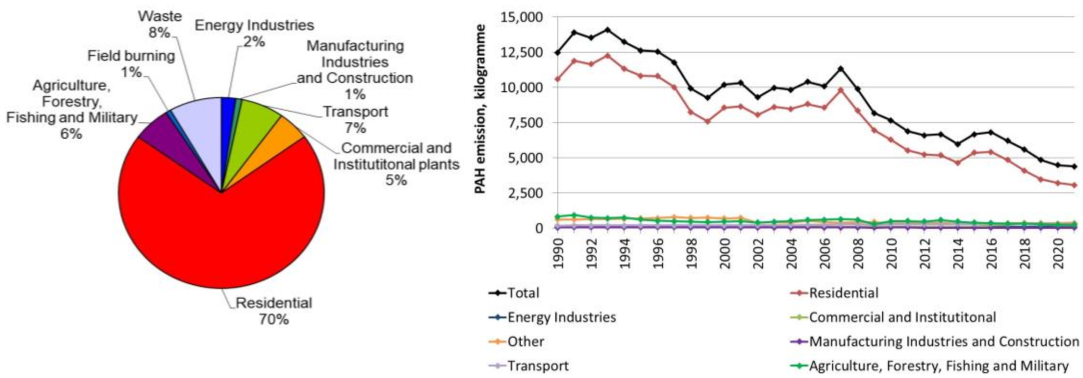


Figure 2.14 PAH emissions. Distribution according to the main sectors (2021) and time series for 1990 to 2021.

2.3.7 Dioxins and furans

The major part of the dioxin emission owes to wood combustion in the residential sector, mainly in wood stoves and ovens without flue gas cleaning. Residential plants (mainly wood combustion) accounts for 60 % of the national dioxin emission in 2021. The contribution to the total dioxin emission from the waste sector (26 % in 2021) mainly owes to accidental fires, especially building fires. The emissions of dioxins from energy industries are dominated by emissions from combustion of biomass as wood, wood waste and to a lesser extend agricultural waste. In total, the emission has decreased by 56 % since 1990, mainly due to a decrease from energy industries caused by improved abatement at coal fired power plants and waste incineration plants. However, most of the reduction took place from 1990 to 1999. Emissions from non-industrial combustion (mainly wood combustion in residential plants) have increased as newer technologies has higher emission factors compared to older technologies. However, in later years the reduced wood consumption has led to falling emissions.

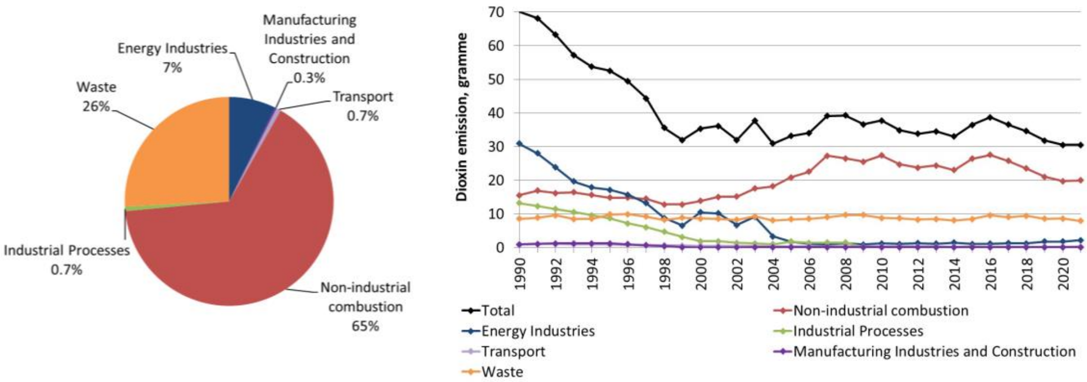


Figure 2.15 Emissions of dioxins and furans. Distribution according to the main sectors (2021) and time series for 1990 to 2021.

2.3.8 Hexachlorobenzene (HCB)

Stationary combustion accounts for 51 % of the estimated national hexachlorobenzene (HCB) emission in 2021. This owes mainly to combustion of municipal solid waste in heating and power plants. Transport is an important source, too, making up 31 % of the total emission in 2021. Emissions from transport have increased by 65 % since 1990 due to increasing diesel consumption. The HCB emission from stationary plants has decreased 80 % since 1990 mainly due to improved flue gas cleaning in MSW incineration plants. The emission from agriculture was very high in the early 1990'ties due to the use of pesticides containing impurities of HCB. The HCB emission from agriculture decreased by 90 % from 1990 to 2000 and by 94 % from 1990 to 2020, causing the share of HCB emission from agriculture to drop from 33 % in 1990 to 12 % in 2021. The emission from industrial processes has decreased due to the closure of steel production and secondary aluminium production in Denmark.

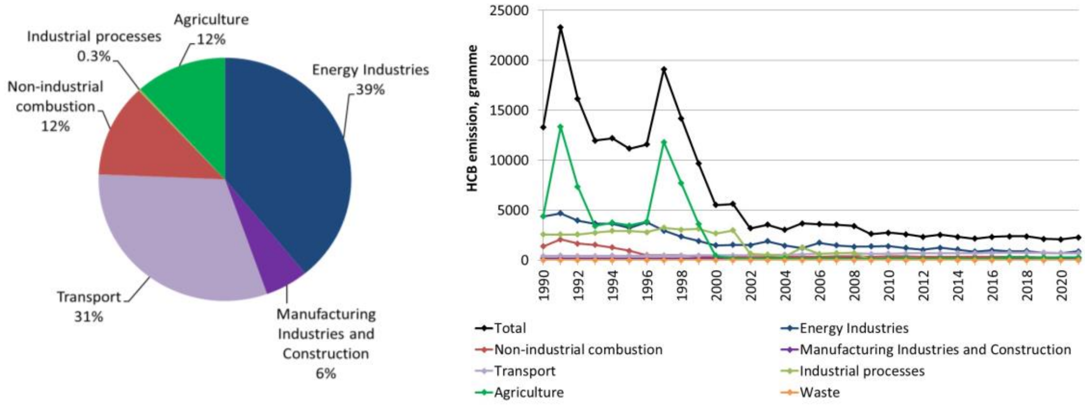


Figure 2.16 HCB emissions. Distribution according to the main sectors (2021) and time series for 1990 to 2021.

2.3.9 Polychlorinated biphenyls (PCBs)

Energy industries accounts for 55 % of the estimated national polychlorinated biphenyls (PCBs) emission in 2021. This owes mainly to combustion of biomass and coal. The emission from energy industries has decreased by 73 % since 1990 due to the lower fuel consumption, especially of coal. The emission from industrial processes was dominated by the steel production, which explains the trend as the plant closed down during 2001 and briefly reopened in 2005.

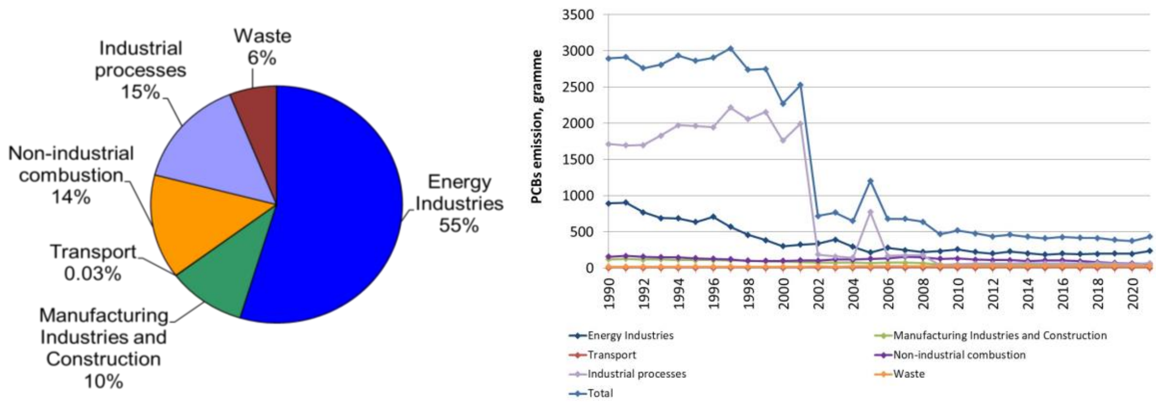


Figure 2.17 PCBs emissions. Distribution according to the main sectors (2021) and time series for 1990 to 2021.

3 Energy

3.1 Overview of the sector

The energy sector is reported in three main chapters:

3.2 Stationary combustion (NFR sector 1A1, 1A2 and 1A4)
3.3 Transport and other mobile sources (NFR sector 1A2, 1A3, 1A4 and 1A5)
3.4 Fugitive emissions (NFR sector 1B)

Summary tables for the emissions from the energy sector are shown below.

Table 3.1.1 SO_2, NO_x, NMVOC, CO, PM and BC emissions from the energy sector, 2021.

	NO_x	NMVOC	SO_x	NH_3	$PM_{2.5}$	PM_{10}	TSP	BC	CO
	kt NO_2	kt	kt SO_2	kt	kt	kt	kt	kt	kt
1A1 Energy Industries	15.23	1.23	2.46	0.01	0.53	0.62	0.79	0.03	16.5
1A2 Manufacturing industries and Construction	8.05	1.28	2.05	0.16	0.26	0.32	0.38	0.12	13.6
1A3 Transport	32.69	6.04	0.34	0.72	1.55	2.42	3.43	0.35	53.3
1A4 Other Sectors	13.64	11.12	1.35	1.28	7.46	7.57	7.84	1.21	99.6
1A5 Other	1.12	0.25	0.07	0.00	0.06	0.06	0.06	0.02	2.9
1B1 Fugitive Emissions from fuels, Solid fuels	-	-	-	-	0.00	0.01	0.01	0.01	-
1B2 Fugitive Emissions from fuels, Oil and Natural gas	0.06	6.72	0.47	-	0.00	0.00	0.00	0.00	0.1
Energy, Total	70.80	26.65	6.74	2.18	9.86	11.00	12.50	1.74	186.1

Table 3.1.2 HM emissions from the energy sector, 2021.

	Pb	Cd	Hg	As	Cr	Cu	Ni	Se	Zn
	t	t	t	t	t	t	t	t	t
1A1 Energy Industries	0.37	0.07	0.11	0.06	0.27	0.22	0.38	0.24	0.77
1A2 Manufacturing industries and Construction	0.40	0.03	0.05	0.07	0.08	0.10	0.64	0.08	1.16
1A3 Transport	8.65	0.05	0.03	0.04	0.22	61.20	1.69	0.08	31.66
1A4 Other Sectors	1.03	0.48	0.03	0.02	0.85	0.24	0.09	0.05	19.12
1A5 Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
1B1 Fugitive Emissions from fuels, Solid fuels	-	-	-	-	-	-	-	-	-
1B2 Fugitive Emissions from fuels, Oil and Natural gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy, Total	10.45	0.62	0.23	0.19	1.44	61.76	2.80	0.45	52.80

Table 3.1.3 PAH, dioxin, HCB and PCB emissions from the energy sector, 2021.

	PCDD/ PCDF	Benzo(a)- pyrene	Benzo(b)-fluoran-thene	Benzo(k)-fluoran-thene	Indeno-(1,2,3-cd)-py-rene	HCB	PCB
	g I-Teq	t	t	t	t	kg	kg
1A1 Energy Industries	2.22	0.01	0.05	0.03	0.01	0.89	0.24
1A2 Manufacturing industries and Construction	0.08	0.00	0.02	0.02	0.01	0.13	0.04
1A3 Transport	0.21	0.06	0.09	0.08	0.06	0.70	0.00
1A4 Other Sectors	19.94	1.12	1.14	0.65	0.65	0.27	0.06
1A5 Other	0.00	0.00	0.00	0.00	0.00	0.01	0.00
1B1 Fugitive Emissions from fuels, Solid fuels	-	-	-	-	-	-	-
1B2 Fugitive Emissions from fuels, Oil and Natural gas	0.00	0.00	0.00	0.00	0.00	-	-
Energy, Total	22.45	1.20	1.30	0.77	0.73	2.00	0.34

3.2 Stationary combustion (NFR sector 1A1, 1A2 and 1A4)

This chapter includes stationary combustion plants in the NFR sectors 1A1, 1A2 and 1A4. Emissions from stationary combustion in sector 1A5 are included elsewhere. Thus, emissions from stationary combustion plants in military buildings are included in sector 1A4a.

3.2.1 Source category description

Source category definition

In the Danish emission database, all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution) according to the CORINAIR system[1]. The emission inventories are prepared from a complete emission database based on the SNAP sectors. Aggregation to the NFR sector codes is based on a correspondence list between SNAP and NFR enclosed in Annex 3A-1. Stationary combustion is defined as combustion activities in the SNAP sectors 01-03, not including SNAP 0303.

Emissions from industrial processes are not included in stationary combustion. Fugitive emissions from fuels are not included in stationary combustion.

Stationary combustion plants are included in the emission source subcategories

- 1A1 Energy, Fuel consumption, Energy Industries
    - 1A1a Public electricity and heat production
    - 1A1b Petroleum refining
    - 1A1c Oil and gas extraction
- 1A2 Energy, Fuel consumption, 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 consumption, 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 NFR sector.

3.2.2 Emission share from stationary combustion compared to national total

Table 3.2.1 gives an overview of the emission share from stationary combustion compared to national total. Main emission sources are discussed in Chapter 3.2.4. A key category analysis is enclosed in Annex 1.

[1] Including some additional SNAP added for industrial combustion.

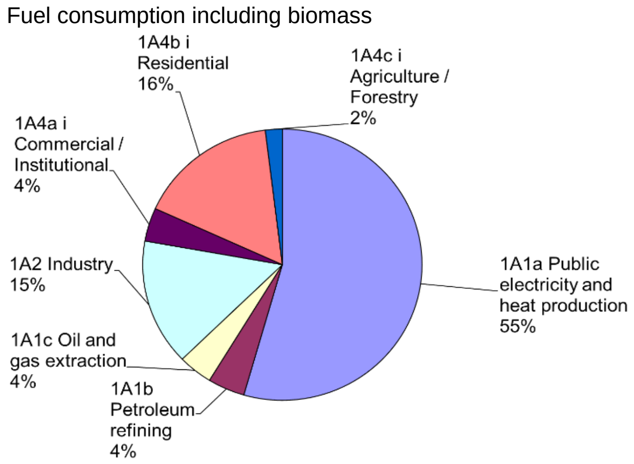
Table 3.2.1 Emission share from stationary combustion compared to national total, 2021.

Pollutant	Emission share, %
SO_2	65%
NO_x	29%
NMVOC	10%
CO	41%
NH_3	2%
TSP	10%
PM_{10}	36%
$PM_{2.5}$	65%
BC	63%
As	50%
Cd	85%
Cr	73%
Cu	0.8%
Hg	81%
Ni	36%
Pb	12%
Se	71%
Zn	32%
HCB	51%
PCDD/F	73%
Benzo(a)pyrene	88%
Benzo(b)fluoranthene	84%
Benzo(k)fluoranthene	80%
Indeno(123c,d)pyrene	78%
PCB	79%

3.2.3 Fuel consumption data

In 2021, the total fuel consumption for stationary combustion plants was 389 PJ of which 189 PJ was fossil fuels and 201 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 fuel consumption in Public electricity and heat production adds up to 55 % of the fuel consumption in stationary combustion plants. Other source categories with high fuel consumption are Residential and Industry.



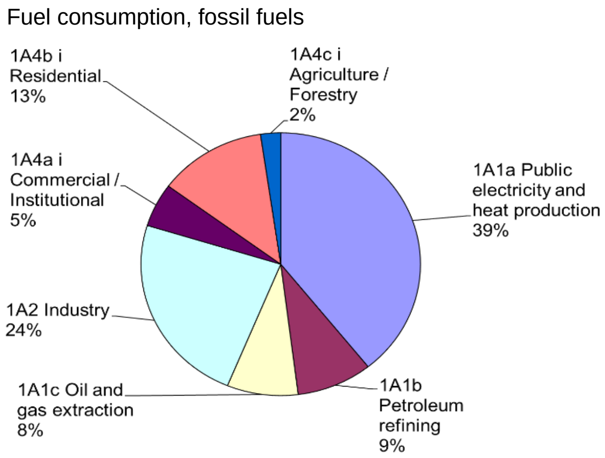


Figure 3.2.1 Fuel consumption of stationary combustion source categories, 2021. Based on DEA (2022a).

Natural gas, wood pellets, wood, coal, and waste are the most utilised fuels for stationary combustion plants. Natural gas is used in all plant (see Figure 3.2.2). Wood and wood pellets are mainly applied for public electricity and heat production and in residential plants. Coal is mainly used in power plants.

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

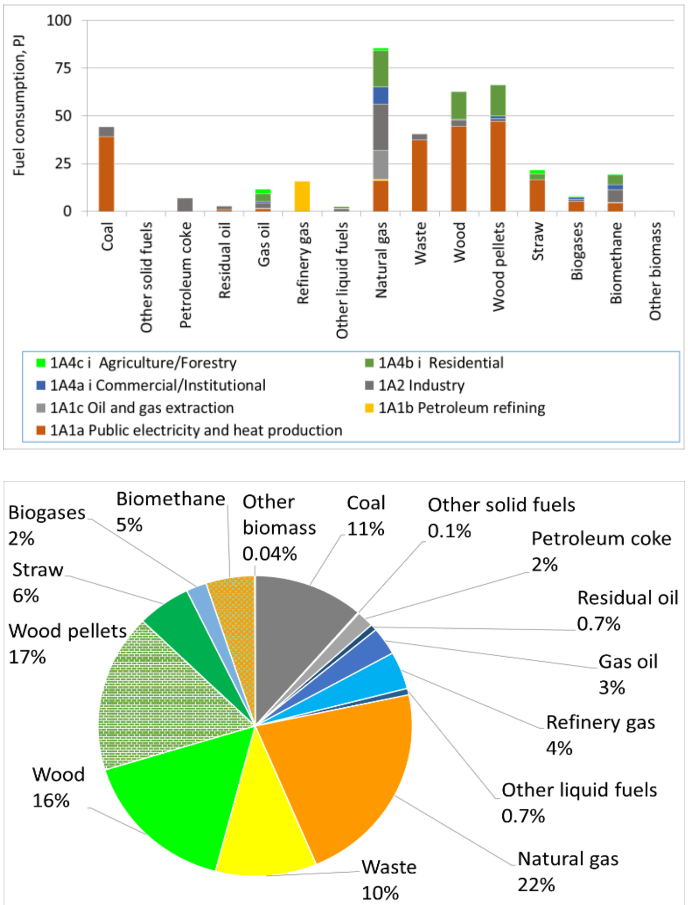
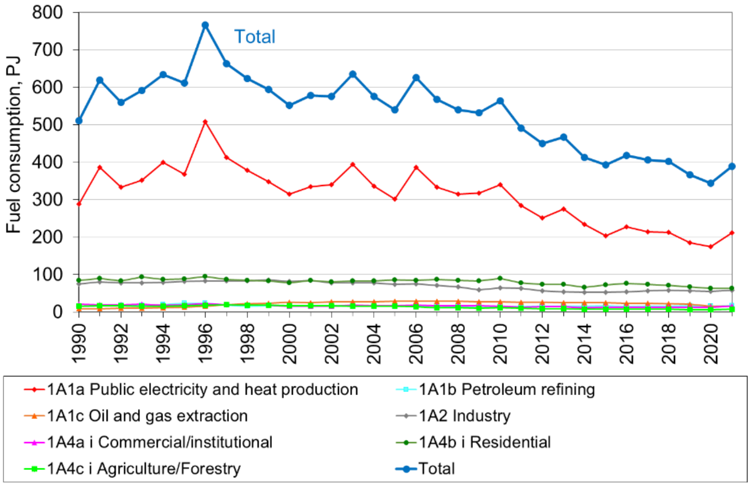


Figure 3.2.2 Fuel consumption of stationary combustion 2021, disaggregated to fuel type. Based on DEA (2022a).

Time series for fuel consumption for stationary combustion plants are presented in Figure 3.2.3. The fuel consumption for stationary combustion was 24 % lower in 2021 than in 1990, while the fossil fuel consumption was 60 % lower and the biomass fuel consumption 4.9 times the level in 1990.

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



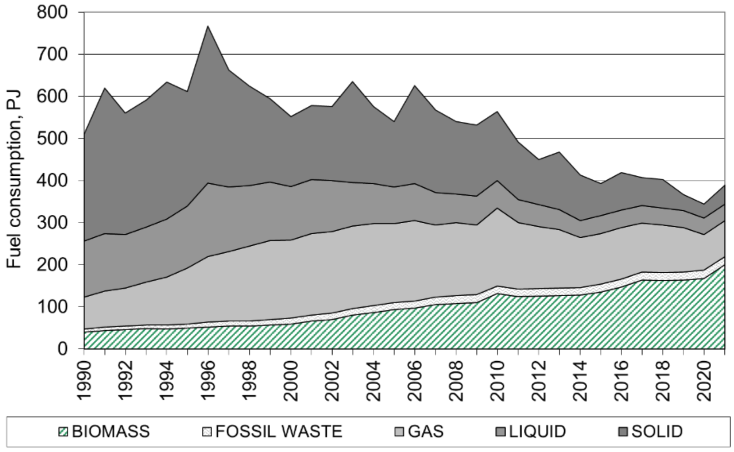


Figure 3.2.3 Fuel consumption time series, stationary combustion. Based on DEA (2022a).

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 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, 2003 and 2006 due to a large net electricity export In 2021, the net electricity import was 18 PJ, whereas there was a 25 PJ net electricity import in 2020. 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.

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. The estimates are based on DEA (2016d) and updated data (DEA, 2022d). The corrections are included here to explain the fluctuations in the time series for fuel rates and emissions.

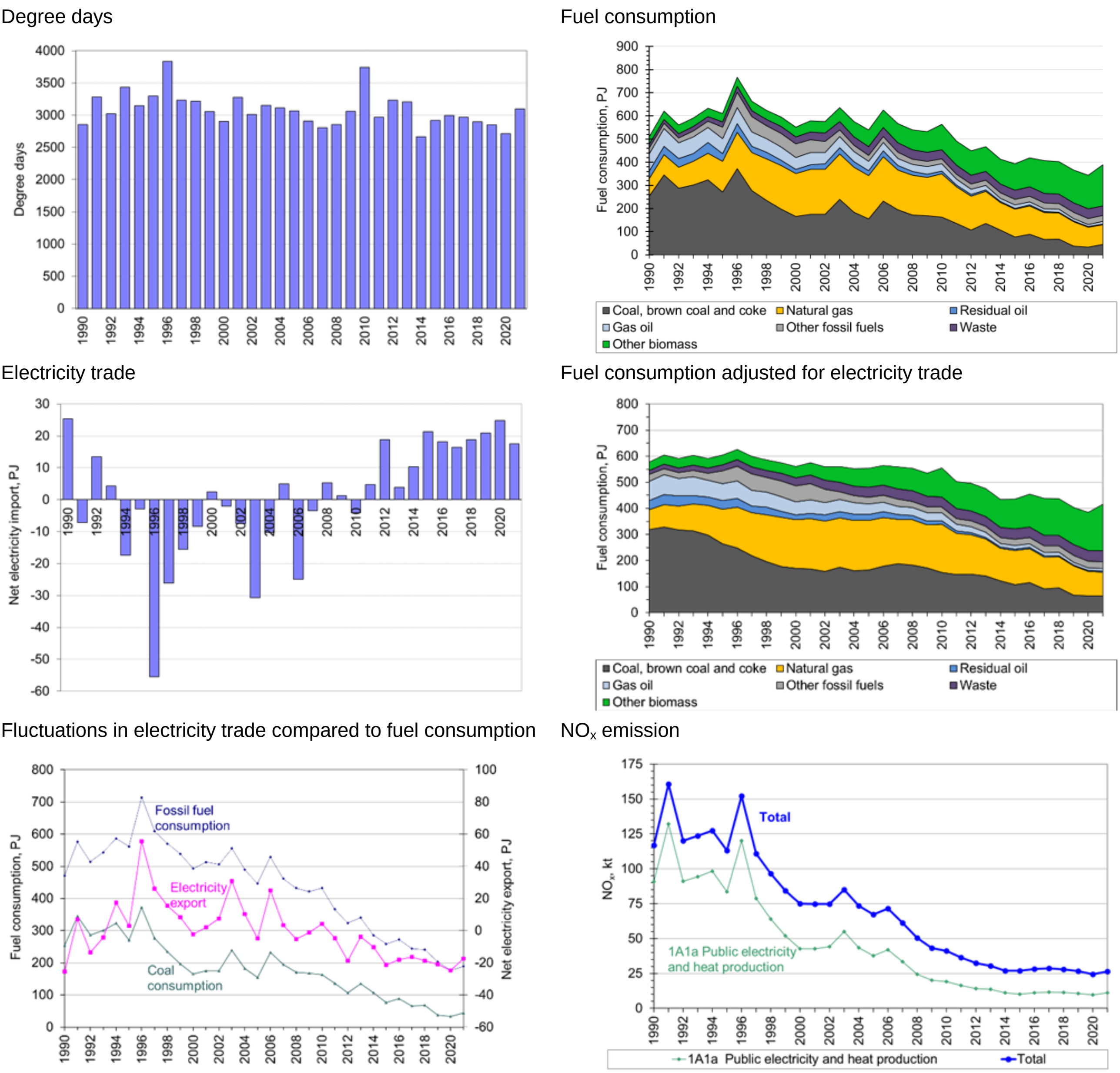


Figure 3.2.4 Comparison of time series fluctuations for electricity trade, fuel consumption and NO_x emission. Based on DEA (2022a).

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

Fuel consumption for Energy industries fluctuates due to electricity trade as discussed above. The fuel consumption in 2021 was 22 % lower than in 1990 and the fossil fuel consumption was 64 % 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 2021 added up to 138 PJ, which is 8.5 times the level in 1990 and 24 % higher than in 2020.

The fuel consumption in Industry was 22 % lower in 2021 than in 1990 (Figure 3.2.6) and the fossil fuel consumption was 36 % lower. The fuel consumption in industrial plants decreased considerably after 2006 as a result of the financial crisis. The biomass fuel consumption in Industry in 2021 added up to 14 PJ, which is 2.4 times the consumption in 1990.

The fuel consumption in Other Sectors decreased 29 % since 1990 (Figure 3.2.7) and increased 5 % since 2020. The fossil fuel consumption decreased 63 % since 1990. The biomass fuel consumption in Other sectors in 2021 added up to 48 PJ, which is 2.6 times the consumption in 1990. The consumption of wood and wood pellets in residential plants in 2021 was 3.6 times the consumption in year 2000 and 3.4 times the consumption in 1990.

Time series for subcategories are shown in Chapter 3.2.5.

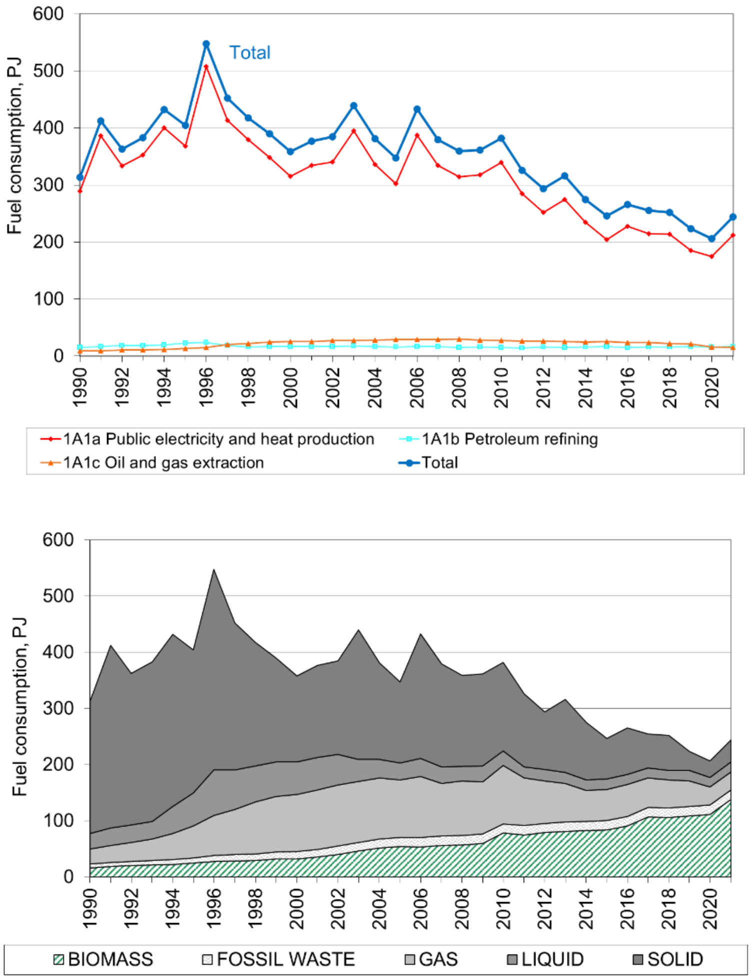


Figure 3.2.5 Fuel consumption time series for subcategories - 1A1 Energy Industries.

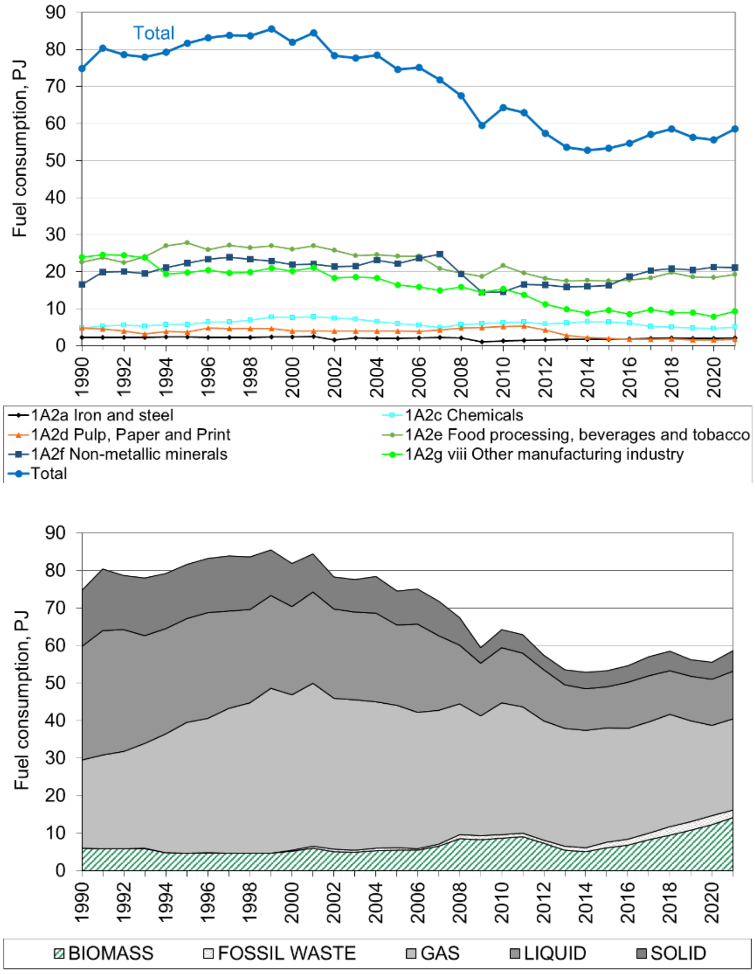
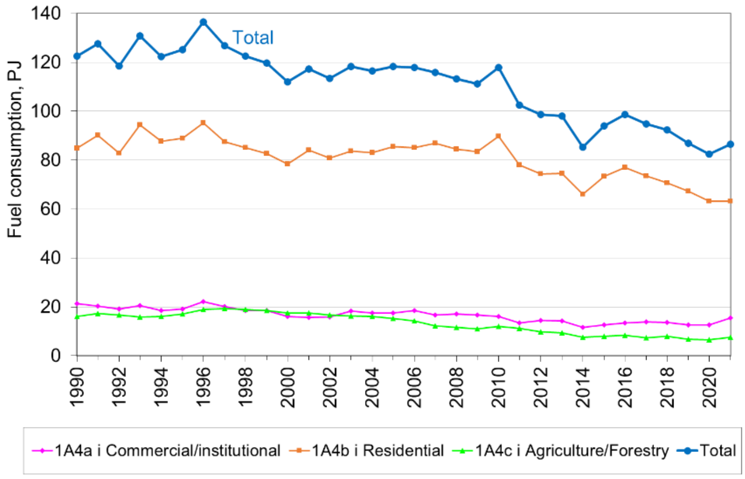


Figure 3.2.6 Fuel consumption time series for subcategories - 1A2 Industry.



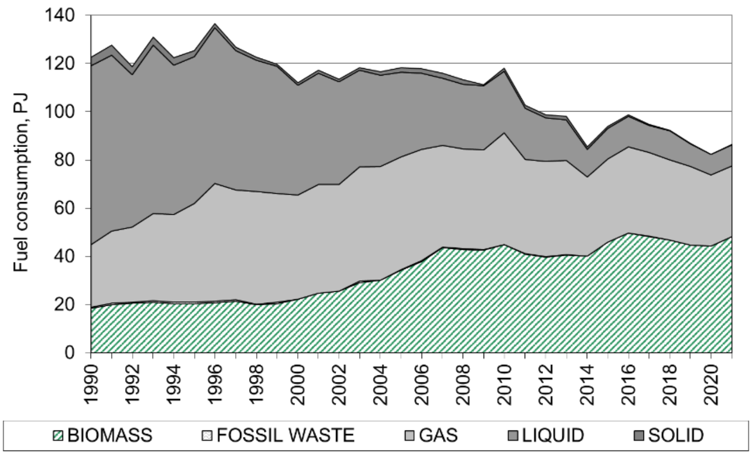


Figure 3.2.7 Fuel consumption time series for subcategories – 1A4 Other sectors

3.2.4 Emissions

SO_2

Stationary combustion is the most important emission source for SO_2 accounting for 65 % of the national emission in 2021. Table 3.2.2 presents the SO_2 emission inventory for the stationary combustion subcategories.

The largest emission sources are Industry accounting for 36 % of the emission and Public electricity and heat production accounting for 40 % of the emission from stationary combustion.

The main emission sources for industrial plants are cement industry, other non-metallic minerals (including mineral wool industry) and food and tobacco industry. Until year 2000, the SO_2 emission from the industrial category only accounted for a small part of the emission from stationary combustion, but due to reduced emissions from power plants, the share has now increased.

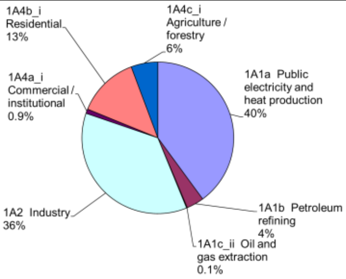
The main emission sources for Public electricity and heat production are combustion of straw and wood in district heating plants, and large power plants. The SO_2 emission share from Public electricity and heat production is lower than the fuel consumption share for this source category, which is 55 %. This is a result of effective flue gas desulphurisation equipment installed in power plants. In the Danish inventory, the source category Public electricity and heat production is further disaggregated. Figure 3.2.8 shows the SO_2 emission from Public electricity and heat production on a disaggregated level. District heating boilers < 50 MW and Power plants >300MW_{th} are the main emission sources, accounting for 46 % and 26 % of the emission.

The time series for SO_2 emission from stationary combustion is shown in Figure 3.2.9. The SO_2 emission from stationary combustion plants has decreased by 96 % since 1990 and 99 % since 1980. The large emission decrease is mainly a result of the reduced emission from Public electricity and heat production, made possible due to installation of desulphurisation plants and due to the use of fuels with lower sulphur content. The emission from other source categories also decreased considerably since 1990. Time series for subcategories are shown in Chapter 3.2.5.

The emission of SO_2 has decreased since 2005, but the emission level has steadied since 2014.

Table 3.2.2 SO_2 emission from stationary combustion plants, 2021[1].

		SO_2, t
1A1a	Public electricity and heat production	2245
1A1b	Petroleum refining	210
1A1c	Oil and gas extraction	8
1A2	Industry	2048
1A4a	Commercial/Institutional	53
1A4b	Residential	737
1A4c	Agriculture/Forestry	320
Total		5621



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

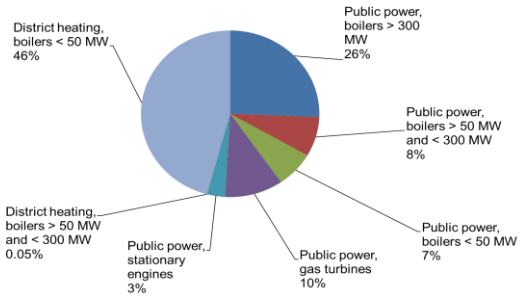


Figure 3.2.8 Disaggregated SO_2 emissions from 1A1a Public electricity and heat production.

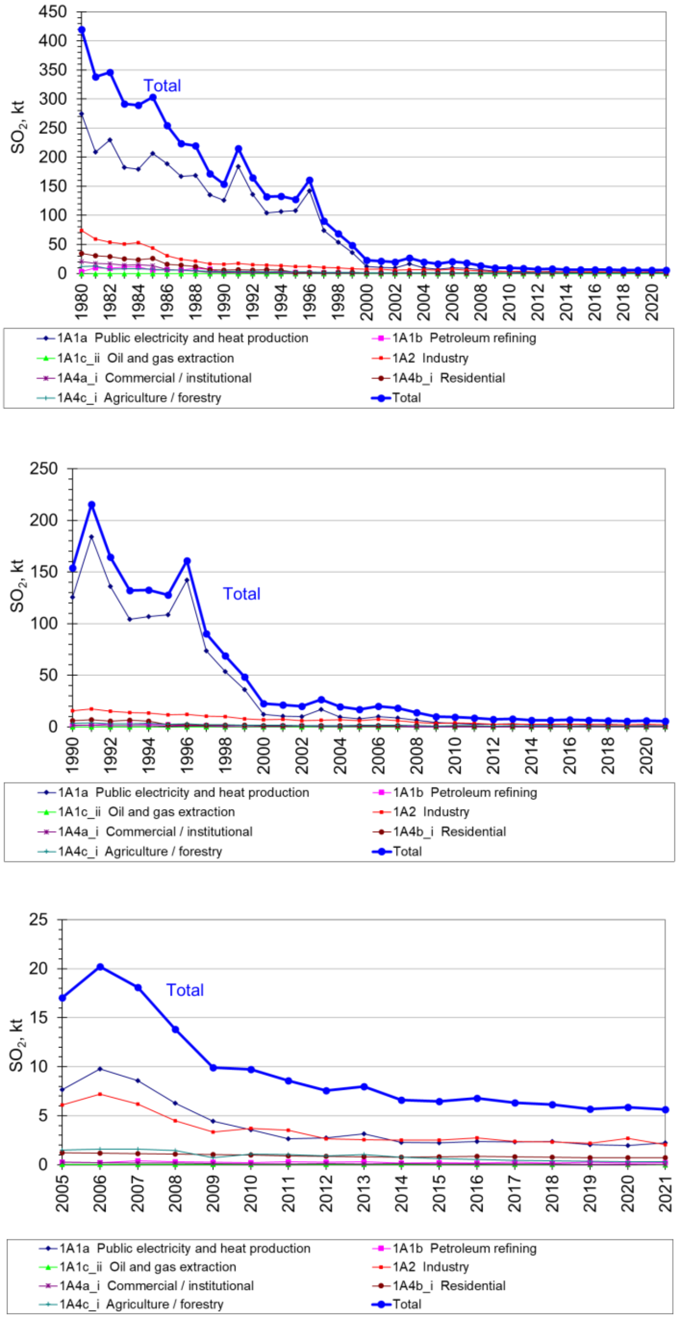


Figure 3.2.9 SO_2 emission time series for stationary combustion.

NO_x

Stationary combustion accounted for 29% of the national NO_x emission in 2021. Table 3.2.3 shows the NO_x emission inventory for stationary combustion subcategories.

Public electricity and heat production is the largest emission source accounting for 42 % of the emission from stationary combustion plants. The emission from Public power boilers > 50 MW_{th} accounts for 39 % of the emission in this subcategory, and District heating < 50MW for 23%.

Industrial combustion plants are also an important emission source accounting for 23 % of the emission. The main industrial emission source is cement production, which accounts for 44 % of the emission from industrial plants.

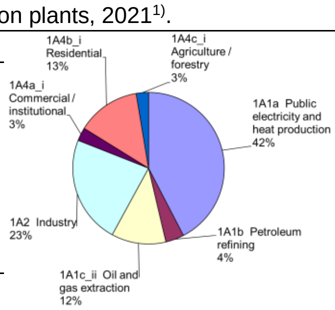
Residential plants account for 13 % of the NO_x emission. Oil and gas extraction, which is mainly offshore gas turbines accounts for 12 % of the NO_x emission.

Time series for NO_x emission from stationary combustion are shown in Figure 3.2.10. NO_x emission from stationary combustion plants has decreased by 78 % since 1990 and 82 % since 1985. The reduced emission is largely a result of the reduced emission from Public electricity and heat production due to installation of low NO_x burners, selective catalytic reduction (SCR) units and selective non-catalytic reduction (SNCR) units. The fluctuations in the time series follow the fluctuations in Public electricity and heat production, which, in turn, result from electricity trade fluctuations.

The emission has also decreased considerably since 2005, see Figure 3.2.10.

Table 3.2.3 NO_x emission from stationary combustion plants, 2021[1).]

	NO_x, t
1A1a Public electricity and heat production	11141
1A1b Petroleum refining	1034
1A1c Oil and gas extraction	3060
1A2 Industry	6053
1A4a Commercial/Institutional	746
1A4b Residential	3564
1A4c Agriculture/Forestry	689
Total	26287



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

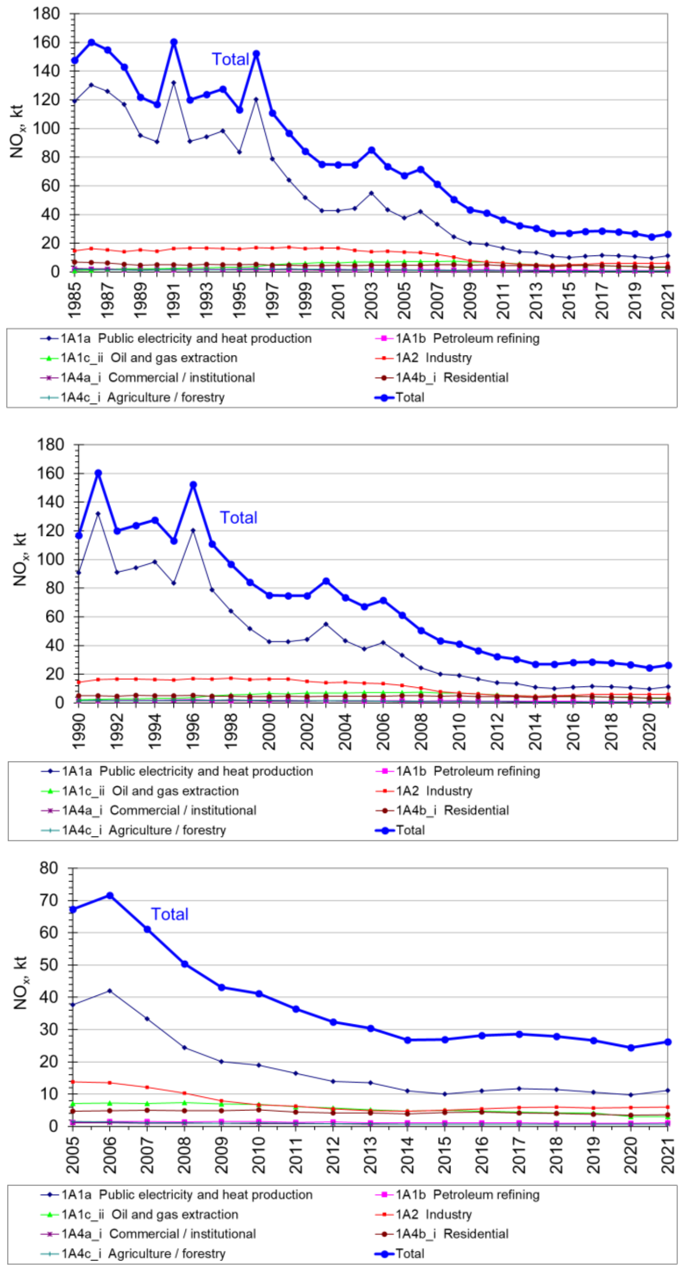


Figure 3.2.10 NO_x emission time series for stationary combustion.

NMVOC

Stationary combustion plants accounted for 10 % of the national NMVOC emission in 2020. Table 3.2.4 presents the NMVOC emission inventory for the stationary combustion subcategories.

Residential plants are the largest emission source accounting for 68 % of the emission from stationary combustion plants. For residential plants NMVOC is mainly emitted from wood and straw combustion, see Figure 3.2.11.

Public electricity and heat production is also a considerable emission source, accounting for 12 % of the emission. Lean-burn gas engines have a relatively high NMVOC emission factor and are the most important emission source in this subcategory (see Figure 3.2.11). The gas engines are fuelled by natural gas, biomethane or biogas fuelled.

Agricultural plants accounted for 13% of the emission in 2021. Combustion of straw was the main emission source in this category.

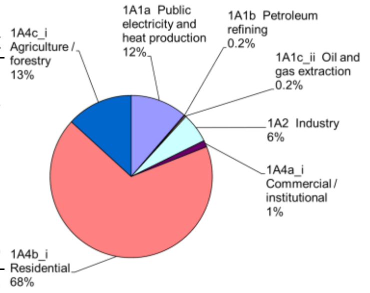
The time series for NMVOC emission from stationary combustion is shown in Figure 3.2.12. The emission has decreased by 39 % from 1990 and 45 % from 1985. The emission increased until 2007 and decreased after 2007. The increased emission is mainly a result of the increasing wood consumption in residential plants and of the increased use of lean-burn gas engines in CHP plants. The decrease after 2007 is a result of lower emission from residential wood combustion and the low number of operation hours for the lean burn gas engines.

The emission from residential plants has decreased 41 % since 1990. The NMVOC emission from residential wood combustion was 34 % lower in 2021 than in 1990. The consumption of wood in residential plants increased until 2007. However, the emission factor has decreased since 1990 due to installation of modern stoves and boilers with improved combustion technology. The use of wood in residential boilers and stoves was relatively low in 1998-99 resulting in a lower emission level.

The emission from straw combustion in farmhouse boilers has decreased over this period due to both a decreasing emission factor and decrease in straw consumption in this source category.

Table 3.2.4 NMVOC emission from stationary combustion plants, 2021[1].

	NMVOC, t
1A1a Public electricity and heat production	1182
1A1b Petroleum refining	24
1A1c Oil and gas extraction	25
1A2 Industry	618
1A4a Commercial/Institutional	137
1A4b Residential	7079
1A4c Agriculture/Forestry	1380
Total	10445



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

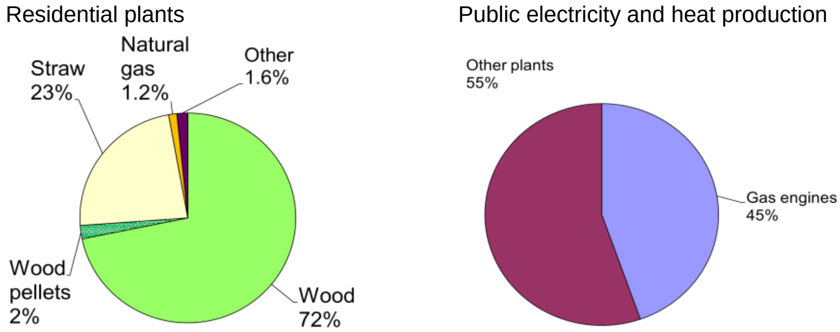


Figure 3.2.11 NMVOC emission from Residential plants and from Public electricity and heat production, 2021.

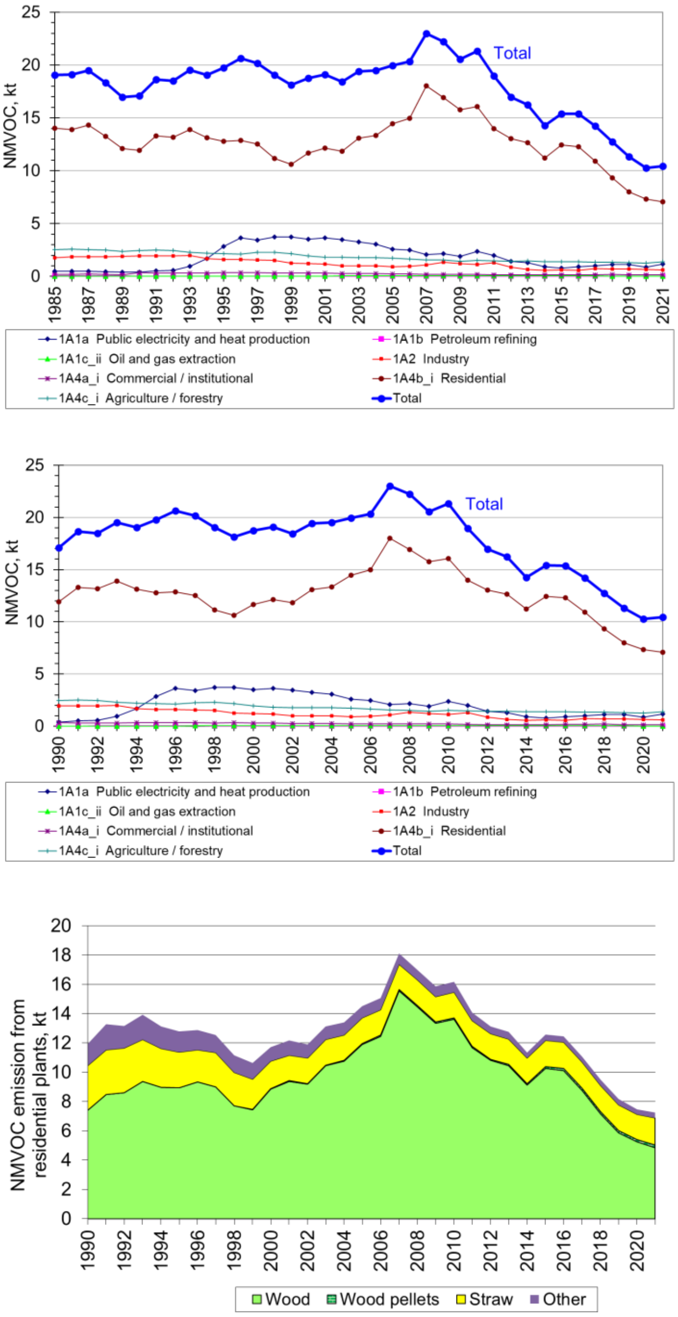


Figure 3.2.12 (a) NMVOC emission time series for stationary combustion and (b) Fuel specific emissions for residential plants.

CO

Stationary combustion accounts for 41 % of the national CO emission in 2021. Table 3.2.5 presents the CO emission inventory for stationary combustion subcategories.

Residential plants are the largest emission source, accounting for 62 % of the emission. Wood combustion accounted for 76 % of the emission from residential plants in 2021, see Figure 3.2.13. Combustion of straw and wood pellets are also a considerable emission sources, whereas the emission from other fuels used in residential plants is almost negligible.

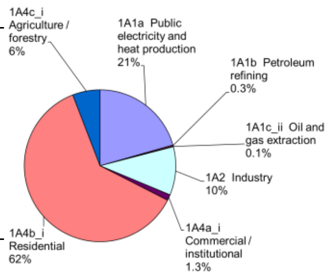
The time series for CO emission from stationary combustion is shown in Figure 3.2.14. The emission has decreased by 55 % from 1985 and 51 % from 1990. The time series for CO from stationary combustion plants follow the time series for CO emission from residential plants.

The increase of wood consumption in residential plants in 1999-2007 is reflected in the time series for CO emission. The consumption of wood in residential plants in 2007 was 3.1 times the 1990 level. In 2021, the consumption was 1.7 times the 1990 consumption level. The decreased emission in 2007-2021 is mainly a result of implementation of improved residential wood combustion technologies and the fact that the rapid increase of wood consumption until 2007 have stopped.

For residential straw combustion, both consumption and the CO emission factor have decreased since 1990.

Table 3.2.5 CO emission from stationary combustion plants, 2021[1)].

	CO, t
1A1a Public electricity and heat production	16243
1A1b Petroleum refining	215
1A1c Oil and gas extraction	77
1A2 Industry	8116
1A4a Commercial/Institutional	988
1A4b Residential	48604
1A4c Agriculture/Forestry	4631
Total	78873



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

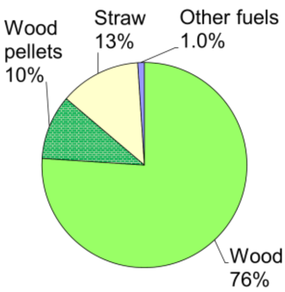
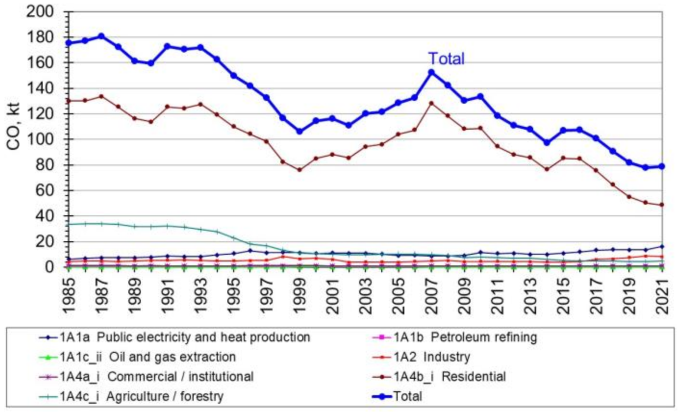
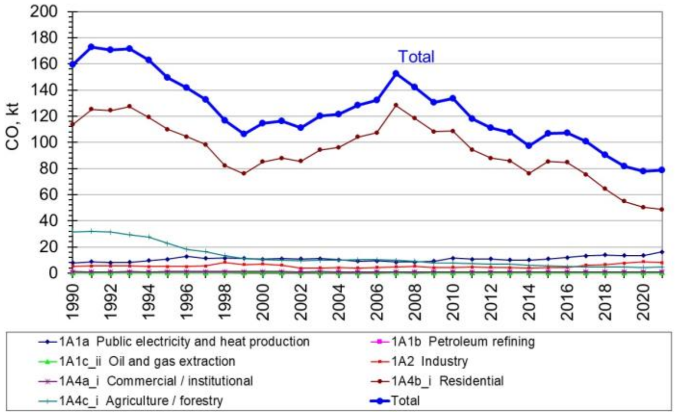


Figure 3.2.13 CO emission sources, Residential plants, 2021.

Stationary combustion, 1985-2021



Stationary combustion, 1990-2021



1A4b Residential plants, fuel origin

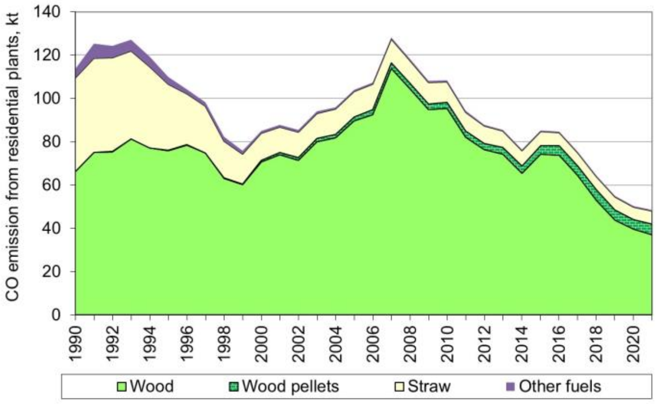


Figure 3.2.14 CO emission time series for stationary combustion.

NH_3

Stationary combustion plants accounted for 2.1 % of the national NH_3 emission in 2021.

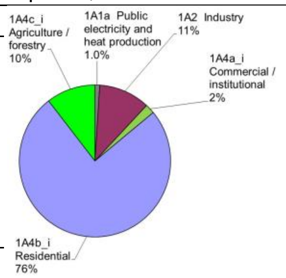
The NH_3 emission from non-residential plants is small and default emission factors are only available for biomass combustion in EEA Guidebook (EEA, 2019). However, based on national references, the NH_3 emission from waste incineration has been included in the Danish inventory.

Table 3.2.6 shows the NH_3 emission inventory for the stationary combustion subcategories. Residential plants account for 76 % of the emission. Wood combustion accounts for 62 % of the emission from residential plants, straw for 20 %, and wood pellets for 18%.

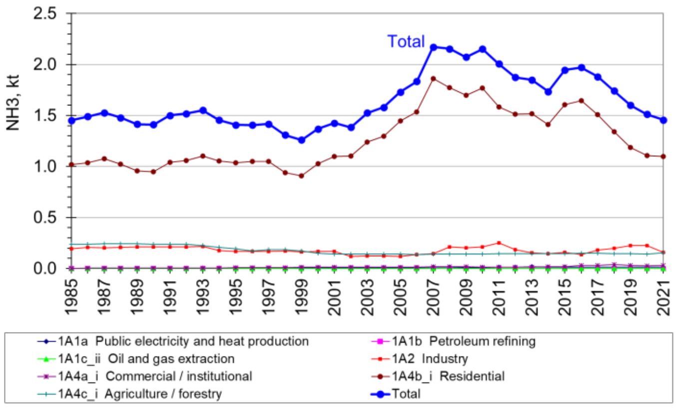
The time series for NH_3 emission is presented in Figure 3.2.15. The NH_3 emission has increased 3 % from 1990.

Table 3.2.6 NH_3 emission from stationary combustion plants, 2021[1].

	NH_3, t
1A1a Public electricity and heat production	15
1A1b Petroleum refining	-
1A1c Oil and gas extraction	-
1A2 Industry	159
1A4a Commercial/Institutional	30
1A4b Residential	1100
1A4c Agriculture/Forestry	153
Total	1456



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



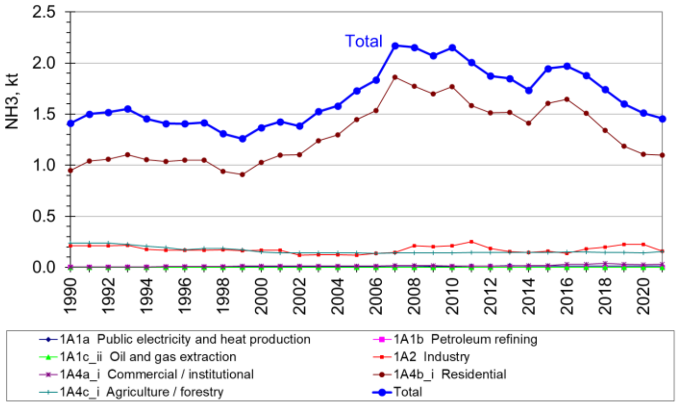


Figure 3.2.15 NH_3 emission time series, stationary combustion plants.

Particulate matter (PM)

TSP from stationary combustion accounted for 10 % of the national emission in 2020. The emission shares for PM_{10} and $PM_{2.5}$ are 36 % and 65 %, respectively.

PM emission data include condensable particles if data references including condensable are available.

Table 3.2.7 and Figure 3.2.16 show the PM emission inventory for the stationary combustion subcategories. Residential plants is the largest emission source accounting for 78 % of the $PM_{2.5}$ emission from stationary combustion plants.

The primary sources of PM emissions are

- Residential boilers, stoves and fireplaces combusting wood
- Farmhouse / residential boilers combusting straw
- Residential plants combusting wood pellets
- Wood combusted in non-residential plants

The PM emission from wood combusted in residential plants is the predominant source. Thus, 51 % of the $PM_{2.5}$ emission from stationary combustion is emitted from residential wood combustion. This corresponds to 33 % of the national emission.

Figure 3.2.17 shows the fuel consumption and the $PM_{2.5}$ emission of residential plants. Wood combustion accounts for 65 % of the $PM_{2.5}$ emission from residential plants, wood pellets for 13 %f and straw for 22 %.

Emission inventories for PM are reported for the years 1990-2021. The time series for PM emission from stationary combustion is shown in Figure 3.2.18. The time series for PM emission from stationary combustion plants follows the time series for PM emission from residential plants. The emissions of TSP, PM_{10} and $PM_{2.5}$ was 32 %, 35 % and 34 % lower in 2021 than in 1990.

The PM emissions increased until 2007 and decreased after 2007. The increase until 2007 was caused by the increased wood combustion in residential plants. However, the PM emission factors have decreased for this emission source category due to installation of modern stoves and boilers. The stabilisation of wood consumption after 2007 and decreased emission factor for residential wood combustion has resulted in a decrease of PM emission from stationary combustion after 2007.

Table 3.2.7 PM emission from stationary combustion plants, 2021[1)].

		TSP, t	PM_{10}, t	$PM_{2.5}$, t
1A1a	Public electricity and heat production	698	536	448
1A1b	Petroleum refining	86	84	84
1A1c	Oil and gas extraction	3	2	2
1A2	Industry	243	177	116
1A4a	Commercial/Institutional	100	94	91
1A4b	Residential	6438	6177	6077
1A4c	Agriculture/Forestry	943	941	938
Total		8510	8012	7756

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

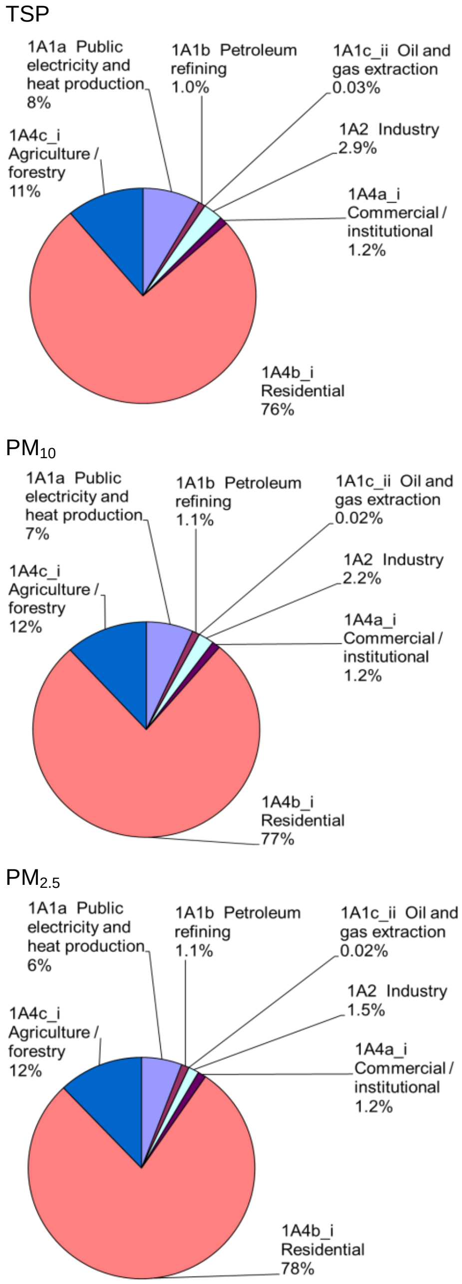
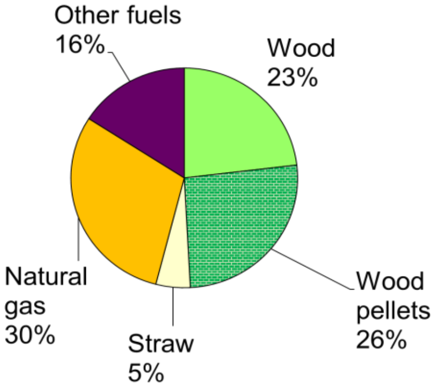


Figure 3.2.16 PM emission sources, stationary combustion plants, 2021.

Fuel consumption from residential plants



$PM_{2.5}$ emission from residential plants

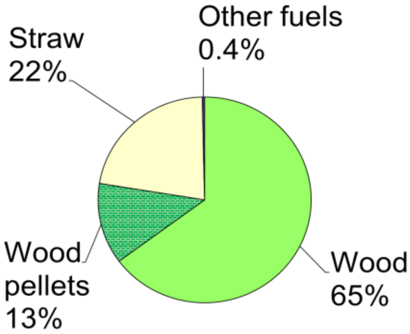
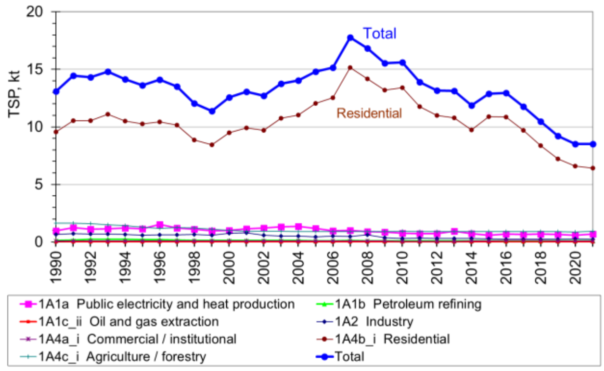
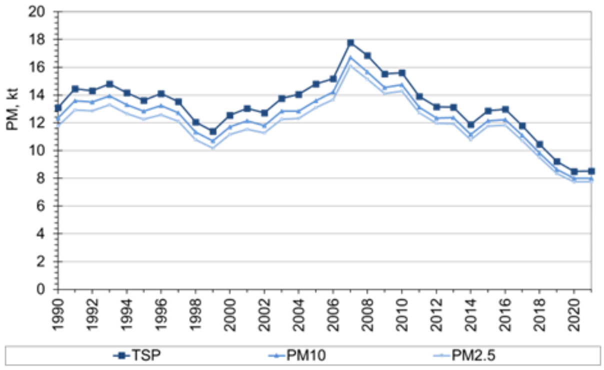


Figure 3.2.17 Fuel consumption and $PM_{2.5}$ emission from residential plants.

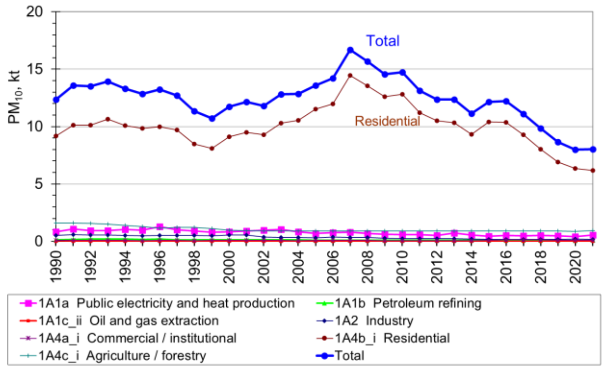
TSP time series



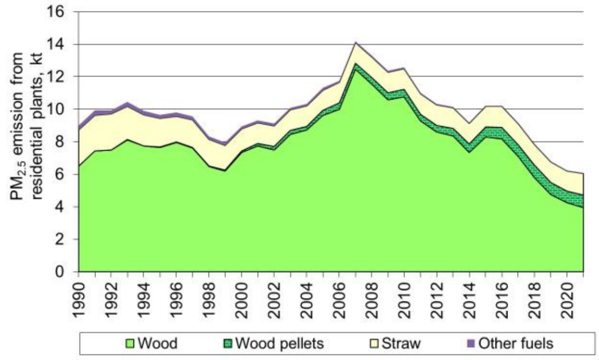
PM time series



PM_{10} time series



$PM_{2.5}$ emissions from residential plants, time series



$PM_{2.5}$ time series

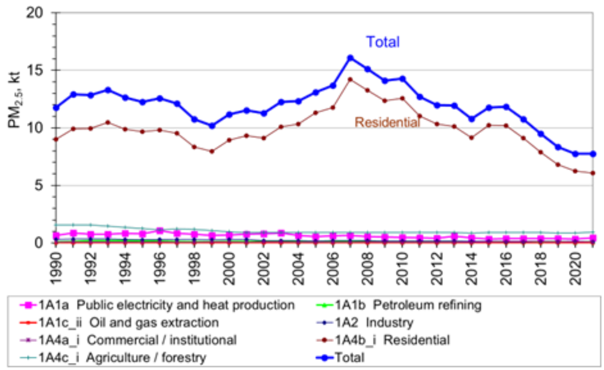


Figure 3.2.18 PM emission time series for stationary combustion.

Black carbon (BC)

Black carbon (BC) from stationary combustion accounted for 63 % of the national emission in 2021. Residential combustion is the main emission source accounting for 70 % of the emission from stationary combustion. Plants in Agriculture/forestry account for 24 % of the emission.

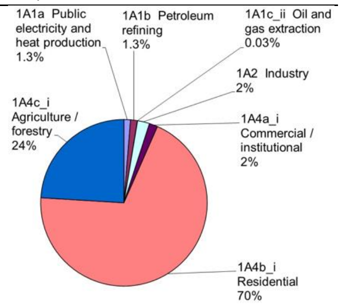
Combustion of straw, wood and wood pellets are the main emission sources for residential plants accounting for 49%, 36 %, and 15 % respectively.

Table 3.2.8 shows the BC emission inventory for the stationary combustion subcategories.

BC emissions are reported for year 1990 onwards. Figure 3.2.19 shows time series for BC emission. The emission in 2021 was 3 % lower than in 1990.

Table 3.2.8 BC emission from stationary combustion plants, 2021[1)].

	BC, t
1A1a Public electricity and heat production	14
1A1b Petroleum refining	15
1A1c Oil and gas extraction	0.37
1A2 Industry	26
1A4a Commercial/Institutional	18
1A4b Residential	767
1A4c Agriculture/Forestry	266
Total	1106



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

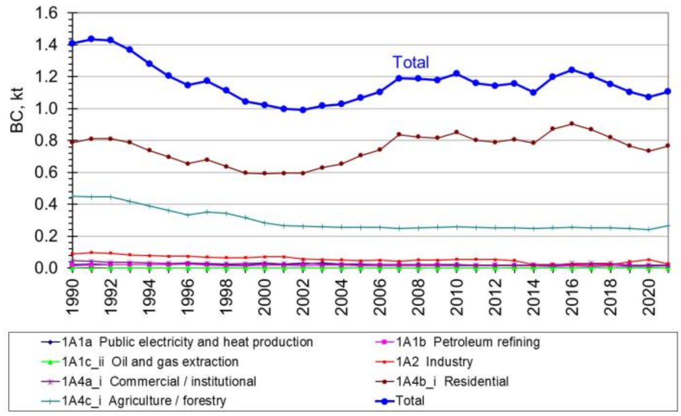


Figure 3.2.19 BC emission time series for stationary combustion.

Heavy metals

Stationary combustion plants are among the most important emission sources for heavy metals. The emission share for stationary combustion compared to national total is shown for each metal in Table 3.2.9.

Table 3.2.9 and Figure 3.2.20 present the heavy metal emission inventory for the stationary combustion subcategories. The source categories Public electricity and heat production, Residential and Industry are the main emission sources. The emission share for waste incineration plants has decreased considerably since the year 2000 due to installation of new improved flue gas cleaning technology that was initiated based on lower emission limit values in Danish legislation (DEPA, 2011).

Table 3.2.9 Heavy metal emission from stationary combustion plants, 2021[1].

	As, kg	Cd, kg	Cr, kg	Cu, kg	Hg, kg	Ni, kg	Pb, kg	Se, kg	Zn, kg
1A1a Public electricity and heat production	54	32	168	163	105	226	345	218	493
1A1b Petroleum refining	6	35	105	52	6	152	26	25	279
1A1c Oil and gas extraction	2	0	0	0	2	0	0	0	0
1A2 Industry	74	26	76	93	52	637	396	77	846
1A4a Commercial/Institutional	2	1	4	5	2	4	6	1	10
1A4b Residential	9	445	787	206	22	68	923	17	17511
1A4c Agriculture/Forestry	1	27	50	16	3	6	74	4	1088
Total	148	566	1192	535	192	1094	1769	343	20227
Emission share from stationary combustion	50%	85%	73%	0.8%	81%	36%	12%	71%	32%

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

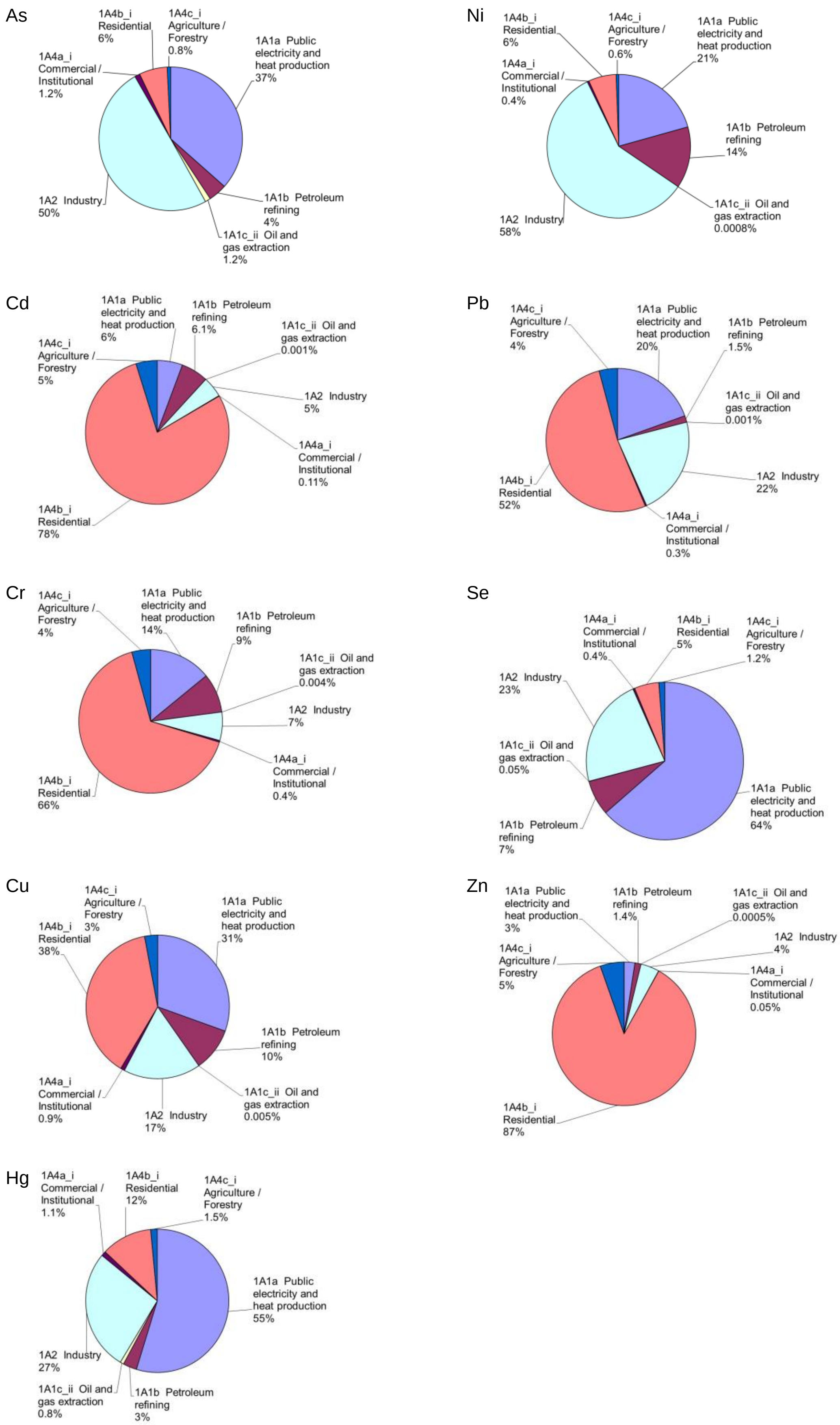


Figure 3.2.20 Heavy metal emission sources, stationary combustion plants, 2021.

The time series for heavy metal emissions are provided in Figure 3.2.21. Emissions of all heavy metals have decreased considerably (35 % - 93 %) since 1990, see Table 3.2.10. Emissions have decreased despite increased incineration of waste. This has been possible due to installation and improved performance of gas cleaning devices in waste incineration plants and also in large power plants, the latter being a further important emission source. The Zn and Cd emissions decrease only 35 % and 47 % respectively. The smaller decrease compared to other HMs is due to a relatively high emission share from residential wood combustion even in 1990.

For Cd, Cr, Pb and Zn the main emission source in recent years was residential plants, mainly from residential wood combustion. Thus, in recent years the time series for Cd, Cr, Pb and Zn follow the time series for residential wood combustion.

Table 3.2.10 Decrease in heavy metal emission 1990-2021.

Pollutant	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Decrease since 1990, %	87	47	79	85	93	92	88	91	35

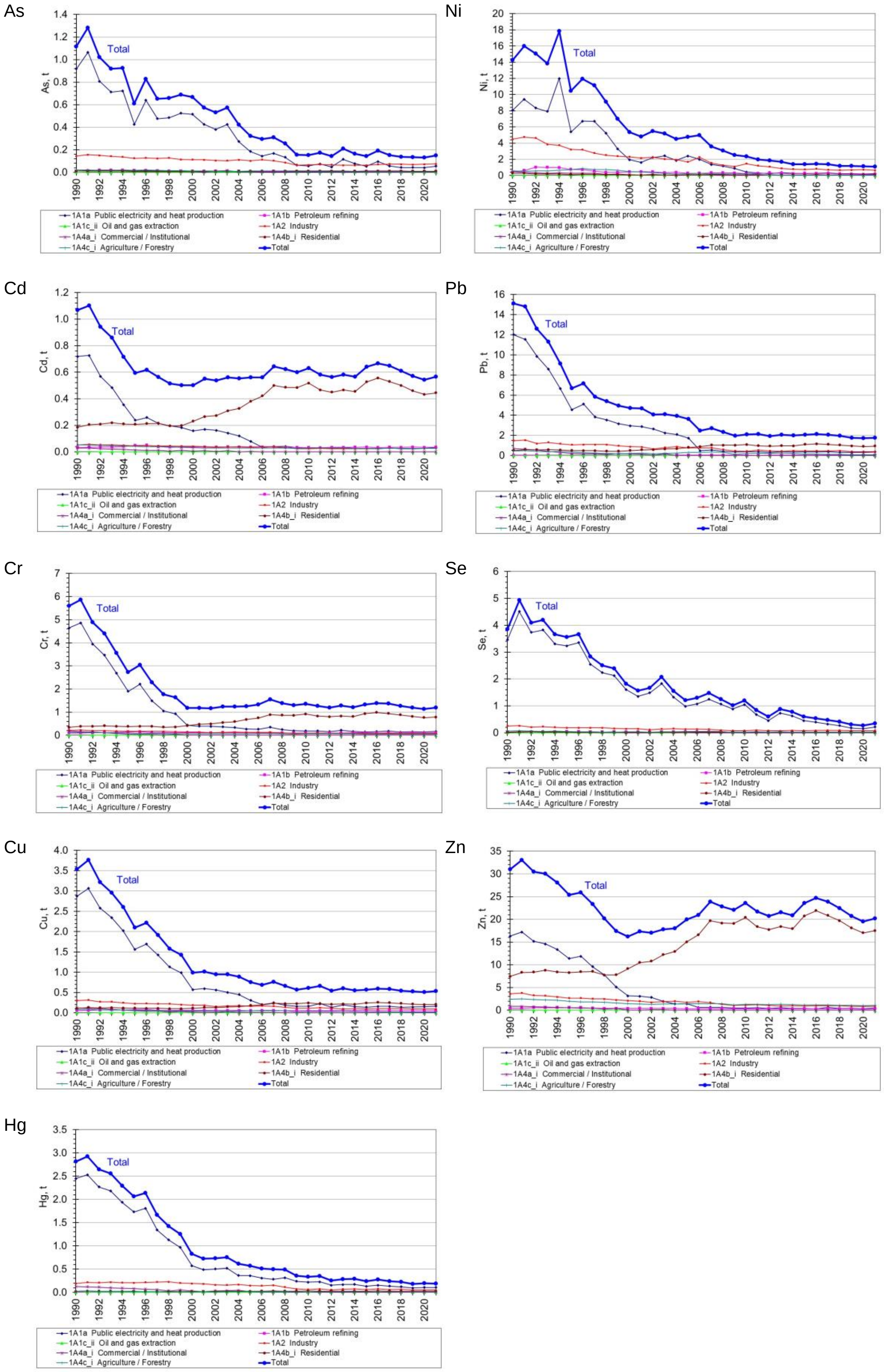


Figure 3.2.21 Heavy metal emission time series, stationary combustion plants.

Polycyclic aromatic hydrocarbons (PAH)

Stationary combustion plants accounted for more than 77 % of the PAH emission in 2021.

Table 3.2.11 and Figure 3.2.22 present the PAH emission inventories for the stationary combustion subcategories. Residential combustion is the largest emission source accounting for more than 80 % of the emission. Combustion of wood is the predominant source, accounting for more than 92 % of the PAH emission from residential plants, see Figure 3.2.23.

The time series for PAH emissions are presented in Figure 3.2.24. The time series for wood combustion in residential plants is also provided in Figure 3.2.24. The wood combustion in residential plants has increased whereas the emission factors have decreased due to installation of new residential wood combustion units. The consumption of wood applied in residential plants has decreased in 2016-2021.

Table 3.2.11 PAH emission from stationary combustion plants, 2021[1)].

	Benzo(a)-pyrene, kg	Benzo(b)-fluoran-thene, kg	Benzo(k)-fluoran-thene, kg	Indeno (1,2,3-c,d) pyrene, kg
1A1a Public electricity and heat production	12	47	31	8.6
1A1b Petroleum refining	0.02	0.07	0.01	0.03
1A1c Oil and gas extraction	0.04	0.11	0.05	0.08
1A2 Industry	1.1	12	12	6
1A4a Commercial/Institutional	62	82	28	45
1A4b Residential	985	969	581	545
1A4c Agriculture/Forestry	71	82	31	50
Total	1131	1193	682	655
Emission share from stationary combustion	88%	84%	80%	78%

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

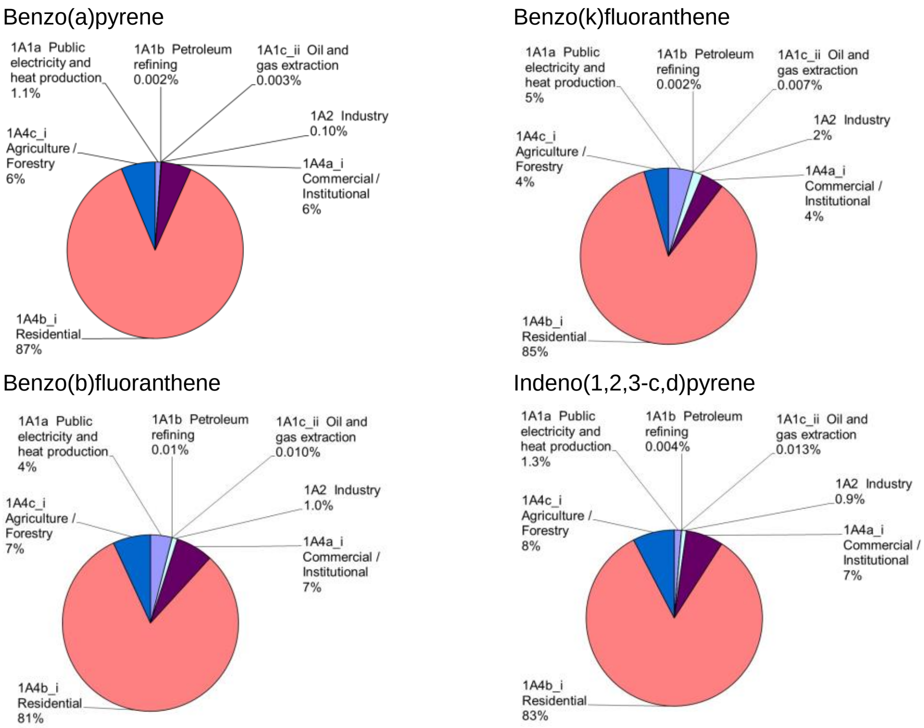


Figure 3.2.22 PAH emission sources, stationary combustion plants, 2021.

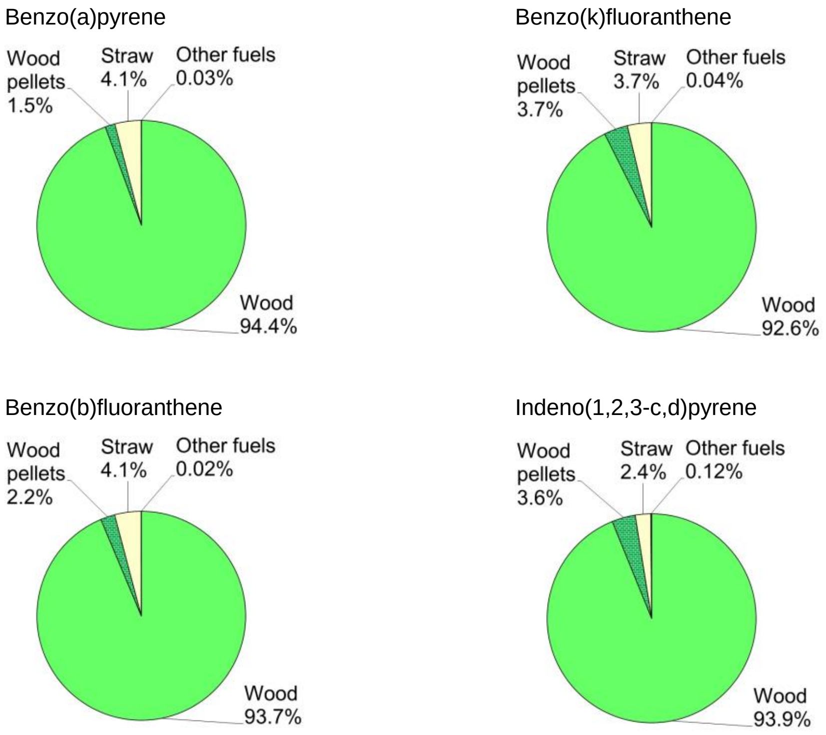
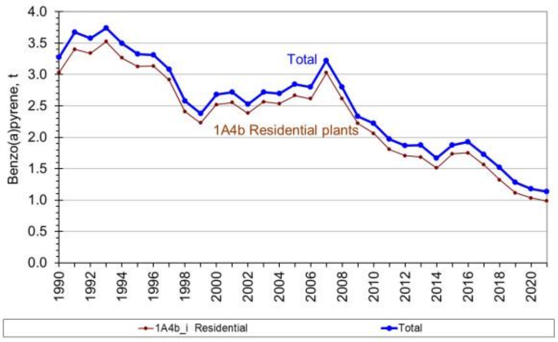
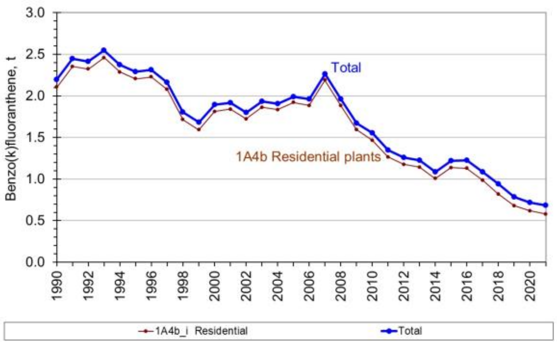


Figure 3.2.23 PAH emission from residential combustion plants (stationary), fuel origin.

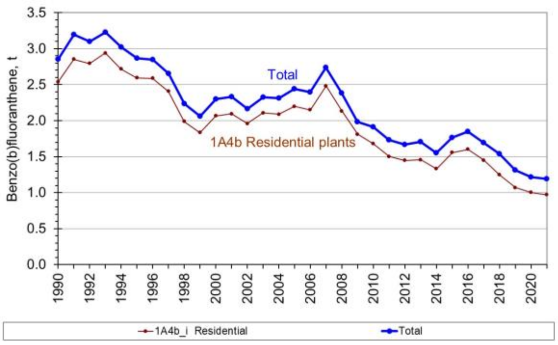
Benzo(a)pyrene



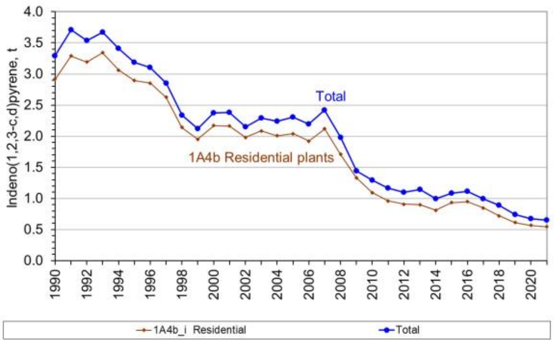
Benzo(k)fluoranthene



Benzo(b)fluoranthene



Indeno(1,2,3-c,d)pyrene



Combustion of wood in residential plants

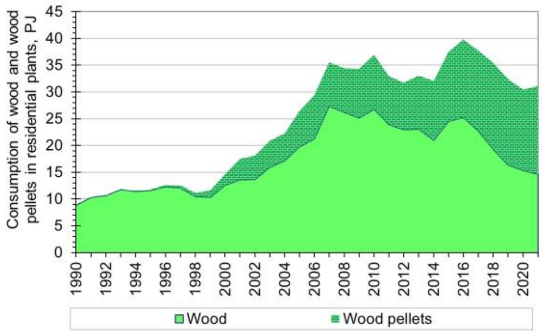


Figure 3.2.24 PAH emission time series, stationary combustion plants. Comparison with wood consumption in residential plants.

Polychlorinated dibenzodioxins and -furans (PCDD/F)

Stationary combustion plants accounted for 73 % of the national emission of polyclorinated dibenzodioxins and –furans (PCDD/F) in 2021.

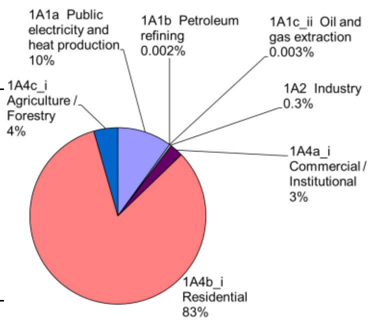
Table 3.2.12 presents the PCDD/F emission inventories for the stationary combustion subcategories. In 2021, the emission from residential plants accounted for 83 % of the emission. Combustion of wood and wood pellets are the predominant sources accounting for 61 % and 30 % of the emission from residential plants (Figure 3.2.25).

The time series for PCDD/F emission is presented in Figure 3.2.26. The PCDD/F emission has decreased 53 % since 1990 mainly due to installation of dioxin filters in waste incineration plants.

The emission from residential plants has increased due to increased wood consumption in this source category. The dioxin emission factors for residential wood combustion are dependent on the wood origin but independent of stove technology (Chapter 3.2.7). Thus, the dioxin emission from residential wood combustion has not decreased similar to e.g. the PM and PAH emissions due to implementation of new improved stoves and boilers.

Table 3.2.12 PCDD/F emission from stationary combustion plants, 2021[1)].

	PCDD/F, g I-teq
1A1a Public electricity and heat production	1.73
1A1b Petroleum refining	0.0005
1A1c Oil and gas extraction	0.0007
1A2 Industry	0.07
1A4a Commercial/Institutional	0.51
1A4b Residential	18.26
1A4c Agriculture/Forestry	0.89
Total	21.45



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

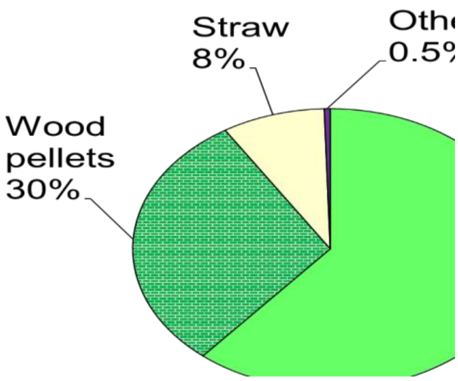
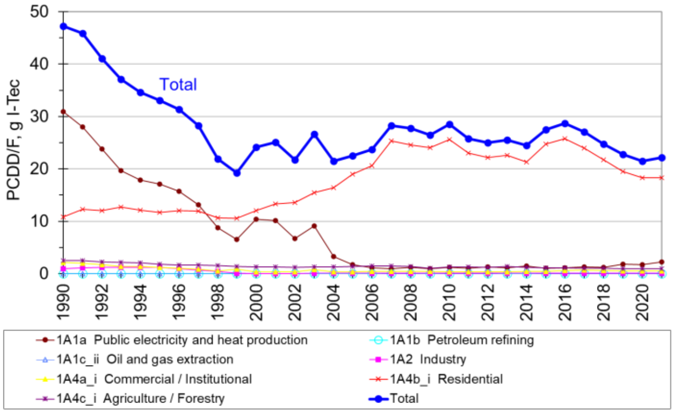
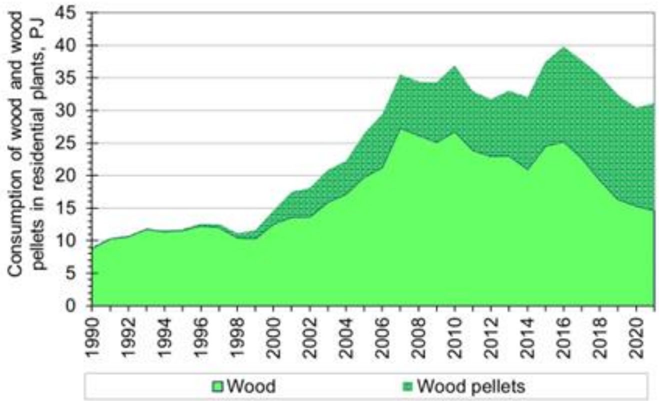


Figure 3.2.25 PCDD/F emission from residential plants, fuel origin.



Combustion of wood in residential plants



Time series for residential PCDD/F-emission

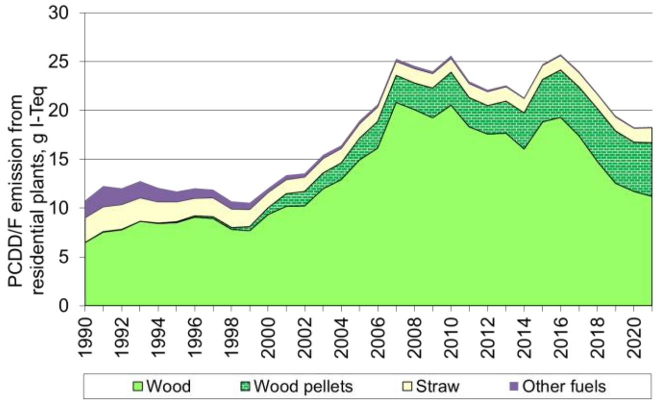


Figure 3.2.26 PCDD/F emission time series, stationary combustion plants.

Hexachlorobenzene (HCB)

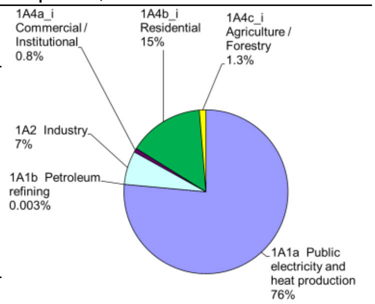
Stationary plants accounted for 51 % of the estimated national emission of hexachlorobenzene (HCB) in 2021.

Table 3.2.13 shows the HCB emission inventory for the stationary combustion subcategories. Public electricity and heat production account for 76 % of the emission. Residential plants account for 15 % of the emission.

The time series for HCB emission is presented in Figure 3.2.27. The HCB emission has decreased 80 % since 1990 mainly due to improved flue gas cleaning in waste incineration plants. The high emission from residential plants in 1990-1995 is related to combustion of coal in residential plants.

Table 3.2.13 HCB emission from stationary combustion plants, 2021[1)].

	HCB, kg
1A1a Public electricity and heat production	0.885
1A1b Petroleum refining	0.00003
1A1c Oil and gas extraction	0.00005
1A2 Industry	0.077
1A4a Commercial/Institutional	0.009
1A4b Residential	0.172
1A4c Agriculture/Forestry	0.015
Total	1.158



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

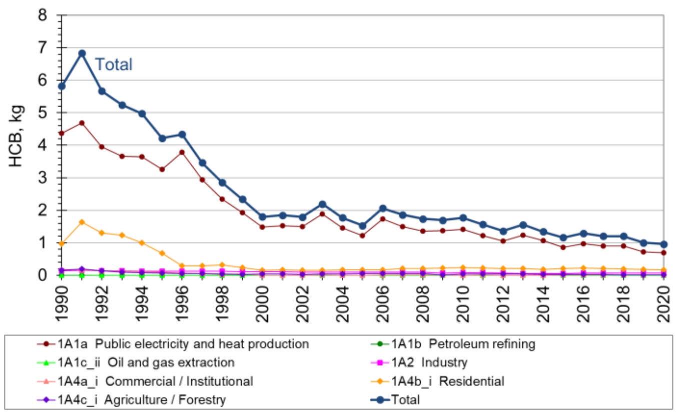


Figure 3.2.27 HCB emission time series, stationary combustion plants.

Polychlorinated biphenyls (PCB)

Polychlorinated biphenyls (PCBs) can be emitted in any chemical process involving chloride and organic carbon or emitted due to incomplete combustion of PCBs in fuel (waste incineration). In Denmark, waste with high levels of PCBs is only incinerated in plants with permission to incinerate this waste fraction, as it requires a high combustion temperature.

Different references for PCBs emissions are not directly comparable because some PCBs emission data are reported for individual PCB congeners, some as a sum of a specified list of PCB congeners and some PCBs emission data are reported as toxic equivalence (teq) based on toxicity equivalence factors (TEF) for 12 dioxin-like PCB congeners. The emission measurements reported by Thistlethwaite (2001a and 2001b) show that the emission of non-dioxin-like PCBs is high compared to the emission of dioxin-like PCBs.

Furthermore, teq values based on TEF are reported as WHO_{2005}-teq or WHO_{1998}-teq. This difference is however typically less than 50%[2].

For stationary combustion, the emission inventory is a sum of dioxin-like PCBs (dl-PCBs) emission, no teq values applied.

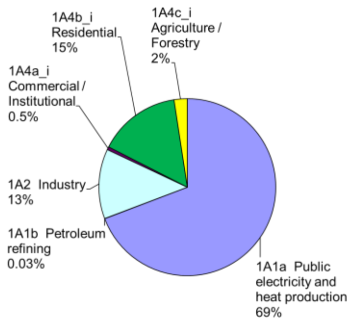
Stationary plants accounted for 79 % of the estimated national PCB emission in 2021.

Table 3.2.14 shows the dl-PCB emission inventory for the stationary combustion subcategories. Public electricity and heat production accounted for 69 % of the emission in 2021. Residential plants accounted for 15 % of the emission.

The time series for dl-PCB emission is presented in Figure 3.2.28. The dl-PCB emission has decreased 71 % since 1990. The decrease is mainly a result of the flue gas cleaning devices that have been installed in waste incineration plants for dioxin reduction.

Table 3.2.14 PCB emission from stationary combustion plants, 2021[1].

	PCB, kg
1A1a Public electricity and heat production	0.237
1A1b Petroleum refining	0.00012
1A1c Oil and gas extraction	0.00002
1A2 Industry	0.044
1A4a Commercial/Institutional	0.002
1A4b Residential	0.051
1A4c Agriculture/Forestry	0.008
Total	0.342



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

[2] Data have been compared for a few datasets in which each dioxin-like PCB congener was specified.

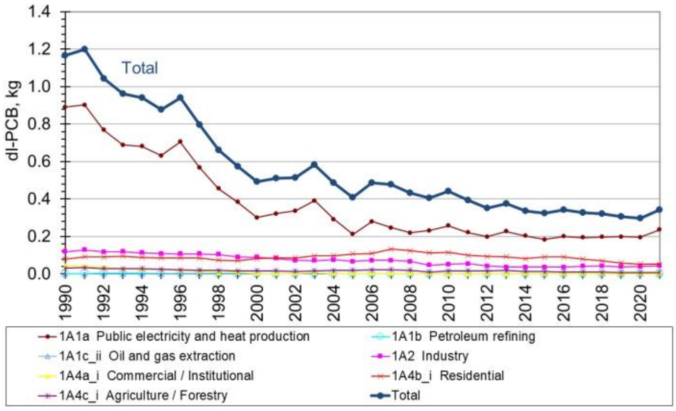


Figure 3.2.28 PCB emission time series, stationary combustion plants.

3.2.5 Trend for subsectors

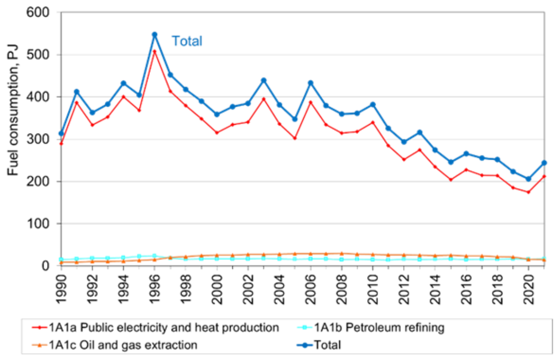
In addition to the data for stationary combustion, this chapter presents and discusses data for each of the subcategories in which stationary combustion is included. Time series are presented for fuel consumption and emissions.

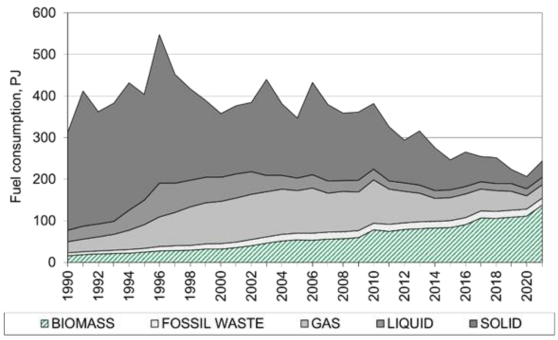
1A1 Energy industries

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

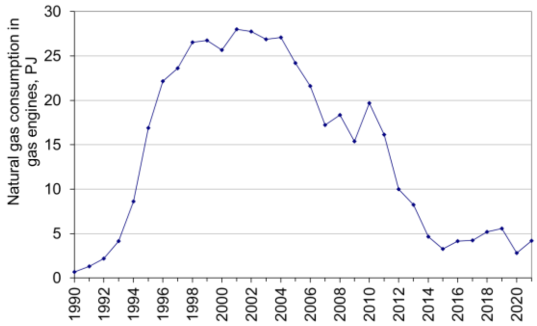
- 1A1a Public electricity and heat production
- 1A1b Petroleum refining
- 1A1c Oil and gas extraction

Figure 3.2.29 – 3.2.33 present time series for 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.

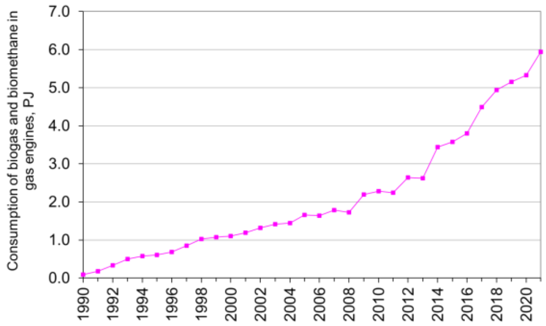




Natural gas fuelled engines



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



Residual oil in petroleum refining

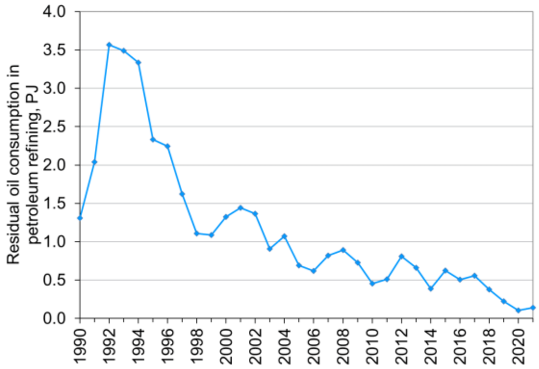


Figure 3.2.29 Time series for fuel consumption, 1A1 Energy industries.

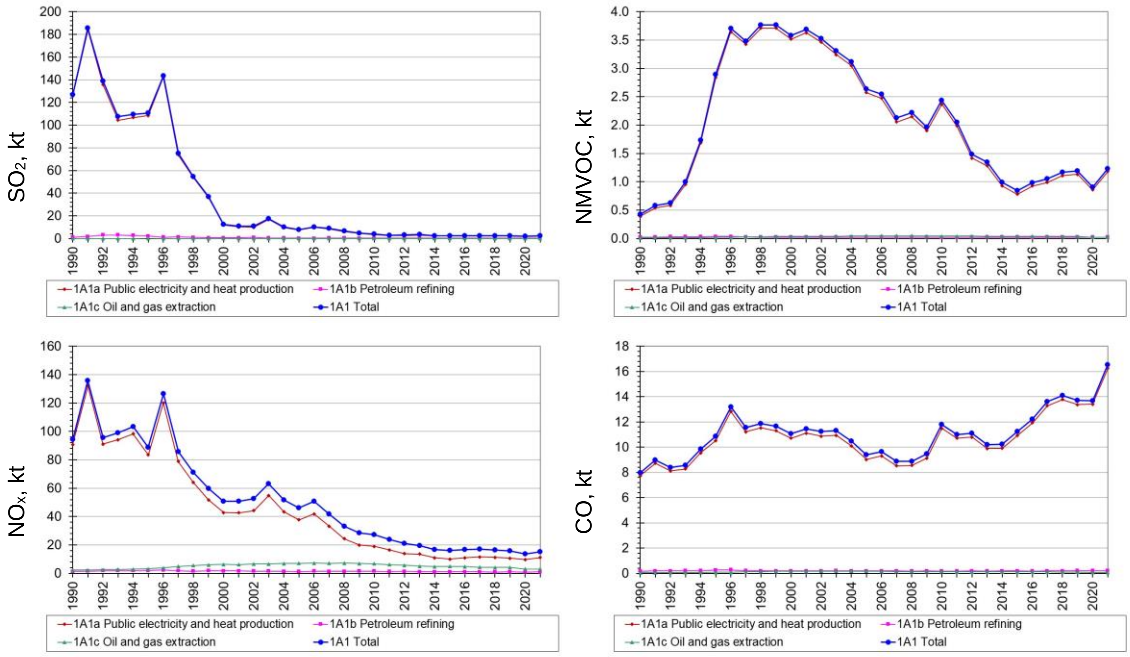


Figure 3.2.30 Time series for SO_2, NO_x, NMVOC and CO emission, 1A1 Energy industries.

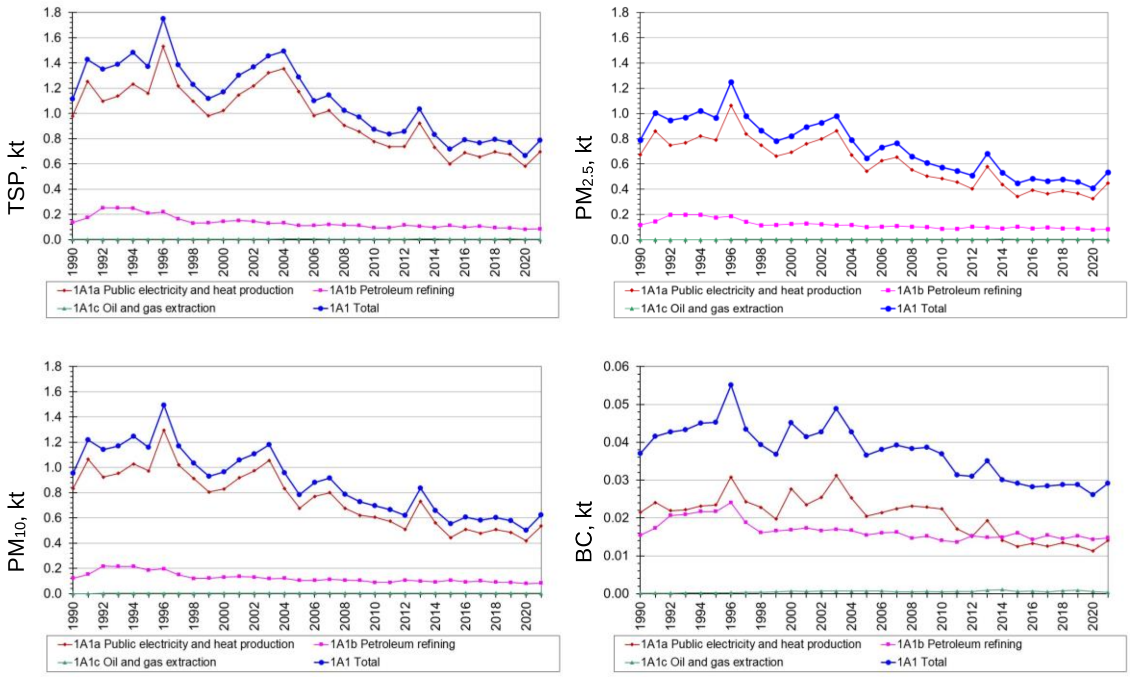


Figure 3.2.31 Time series for PM and BC emission, 1A1 Energy industries.

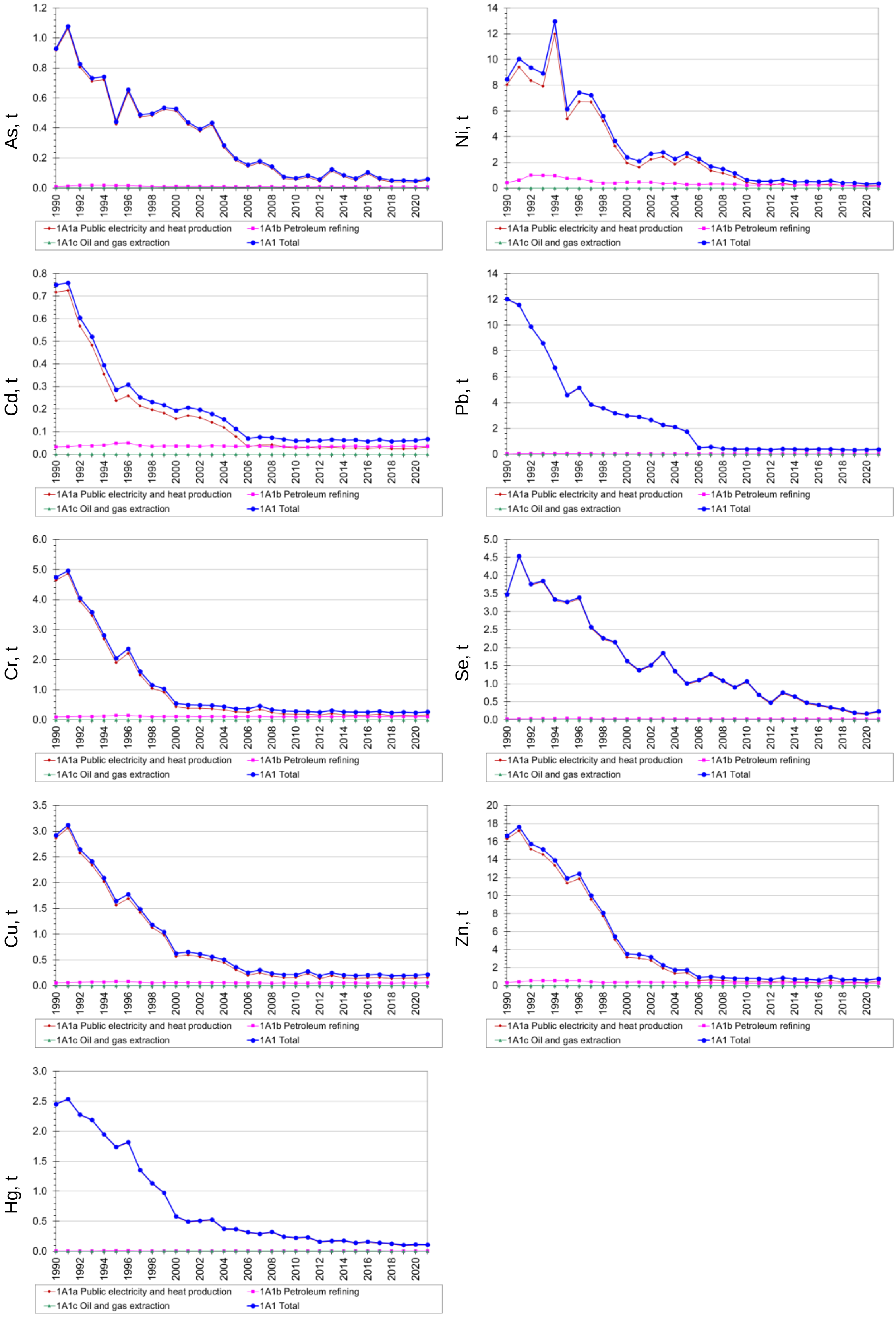


Figure 3.2.32 Time series for PM and BC emission, 1A1 Energy industries.

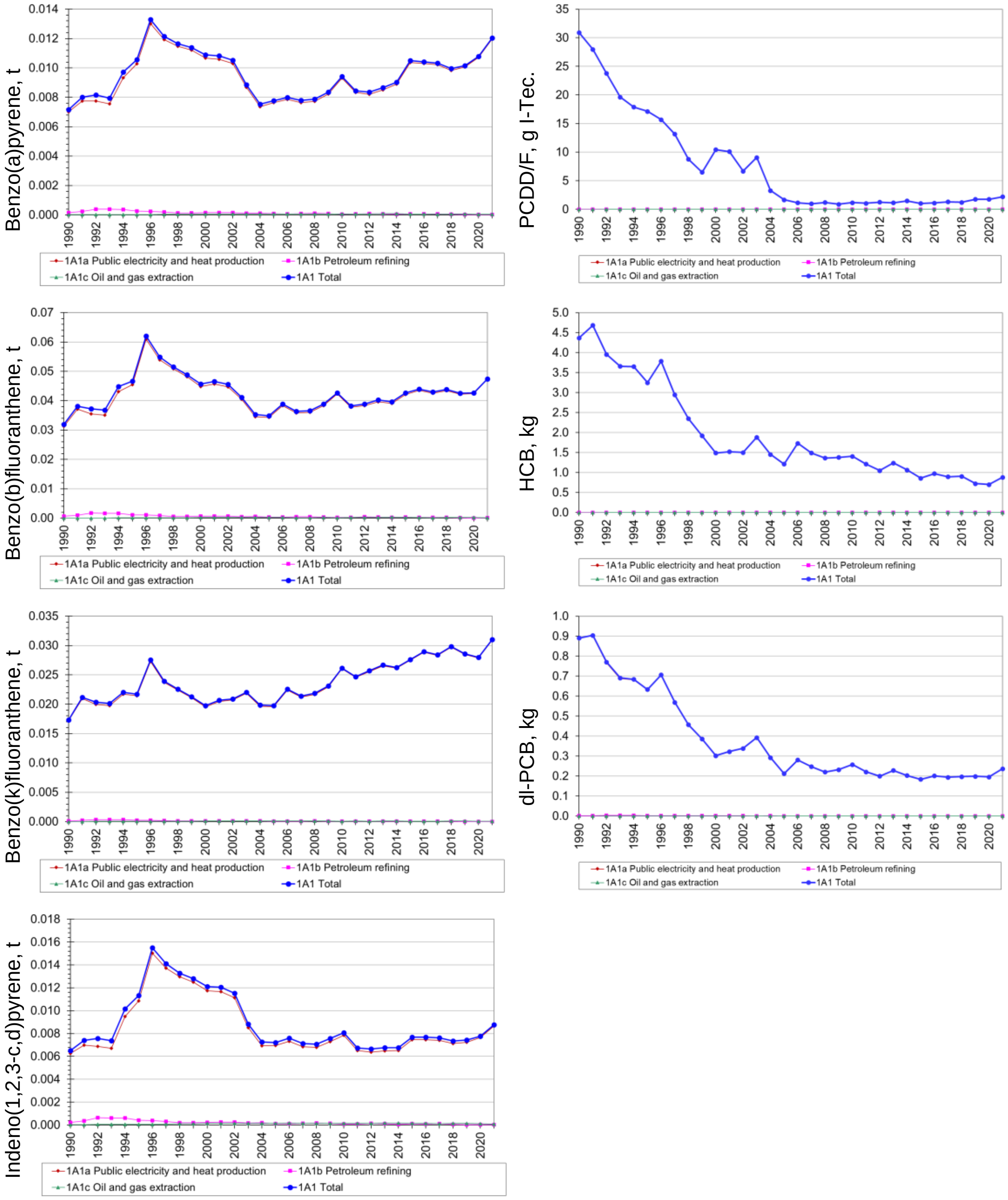


Figure 3.2.33 Time series for PAH, PCDD/F, HCB and dl-PCB emission, 1A1 Energy industries.

1A1a Public electricity and heat production

Public electricity and heat production is the largest source category regarding fuel consumption for stationary combustion. Figure 3.2.34 shows the time series for fuel consumption and emissions of SO_2, NO_x, NMVOC and CO.

As discussed in Chapter 3.2.3 the fuel consumption fluctuates mainly because of electricity trade. Coal is the fuel that is affected the most by the fluctuating electricity trade. In addition, the total fuel consumption is also influenced by the increased wind power production.

The total fuel consumption was 27 % lower in 2021 than in 1990, the fossil fuel consumption 73 % lower and the biomass consumption in 2021 was 8.5 times the 1990-level.

Coal was the main fuel in the source category in the 1990s, but the consumption has been decreasing in later years. The coal consumption in 2021 was only 17 % of the 1990 consumption in this sector. 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 3.2.29). The consumption of waste, biogas and biomass has increased.

The SO_2 emission has decreased 98 % from 1990 to 2021. This decrease is a result of both lower sulphur content in fuels and installation and improved performance of desulphurisation plants. The emission was 15 % higher in 2021 than in 2020.

The NO_x emission has decreased 88 % since 1990 due to installation of low NO_x burners, selective catalytic reduction (SCR) units and selective non-catalytic reduction (SNCR) units. The fluctuations in time series follow the fluctuations in fuel consumption and electricity trade. The NO_x emission was 15 % higher in 2021 than in 2020.

The emission of NMVOC in 2021 was 3.0 times the emission in 1990. The emission increased until 1996 and decreased after 2002. This is a result of the large number of gas engines installed in Danish CHP plants. The decreasing emission after 2004 is results of the decreasing fuel consumption for natural gas engines (Figure 3.2.29). In addition, the NMVOC emission factor for engines decreased in 1995-2007 due to introduction of an emission limits for unburned hydrocarbon[3] (DEPA, 2005).

The CO emission in 2021 was 2.1 times the emission in 1990. The fluctuations follow the fluctuations of the fuel consumption. In addition, the emission from gas engines is considerable.

[3] Including methane.

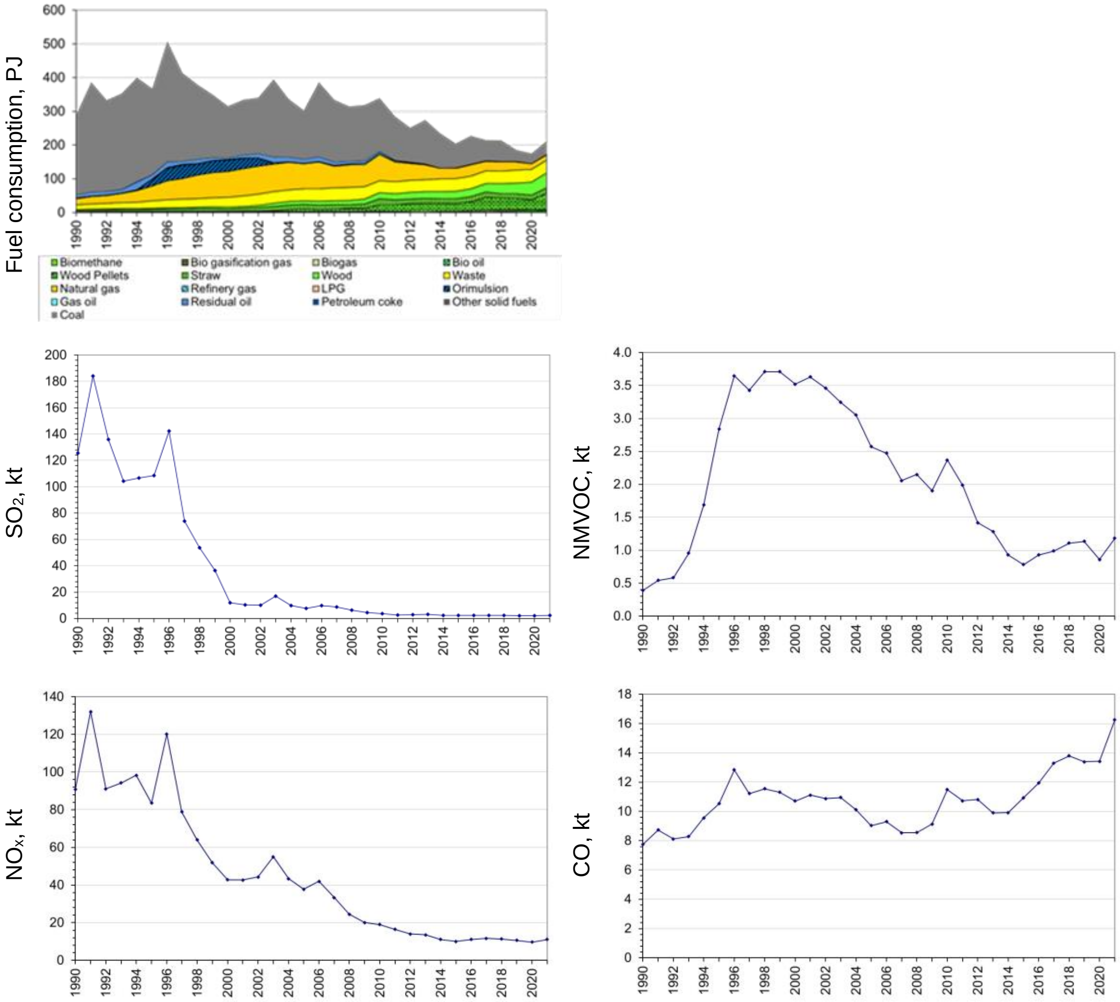


Figure 3.2.34 Time series for 1A1a Public electricity and heat production.

1A1b Petroleum refining

Petroleum refining is a small source category regarding both fuel consumption and emissions for stationary combustion. Presently two refineries are operating in Denmark. Figure 3.2.35 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 9 % since 1990.

The emission of SO_2 has shown a pronounced decrease (82 %) since 1990, mainly because decreased consumption of residual oil also shown in Figure 3.2.35. The increase in SO_2 emission in 1990-1992 also follows the residual oil consumption. The NO_x emission in 2021 was 25 % lower than in 1990. Since 2005, data for both SO_2 and NO_x are plant specific data stated by the refineries.

The NMVOC emission time series follows the time series for fuel consumption. A description of the Danish emission inventory for fugitive emissions from fuels is given in Plejdrup et al. (2021) and in Chapter 3.4.

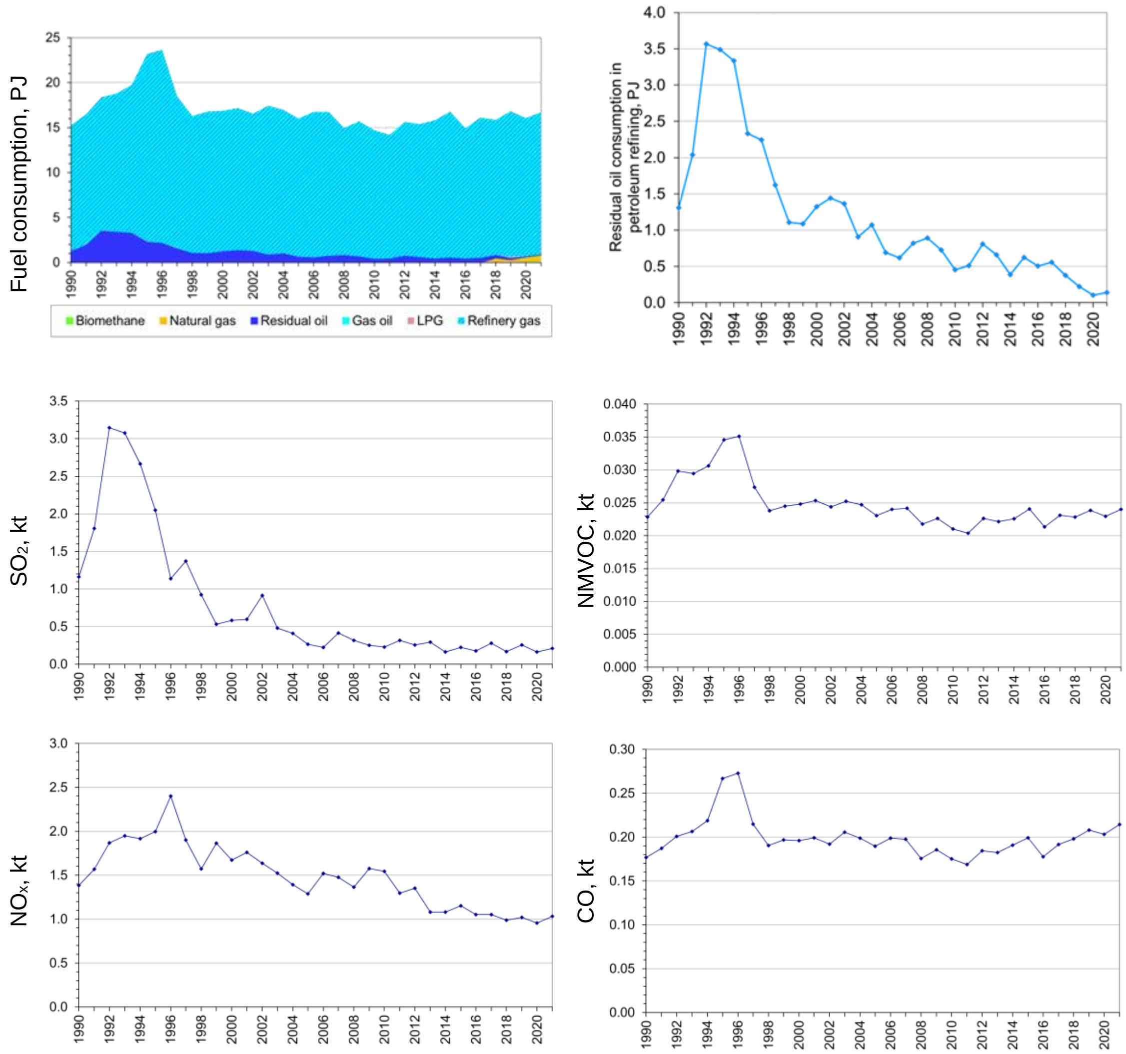


Figure 3.2.35 Time series for 1A1b Petroleum refining.

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. Fugitive emissions from fuels are not included in the sector. Venting and flaring are included in the sector 1B2c Venting and Flaring.

Figure 3.2.36 shows the time series for fuel consumption and emissions.

The fuel consumption in 2021 was 69% higher than in 1990. The fuel consumption has decreased since 2008. The large decrease between 2019 and 2020 is related to renovation of the largest gas field, Tyra.

The emissions follow the fuel consumption. The decrease of CO emission in 2005 – 2007 is a result of a lower emission factor. This decrease of emission factor is valid for gas turbines in cogeneration plants, but might not be valid for offshore gas turbines. However, the same emission factors have been assumed for CO emission due to the lack of data from offshore gas turbines.

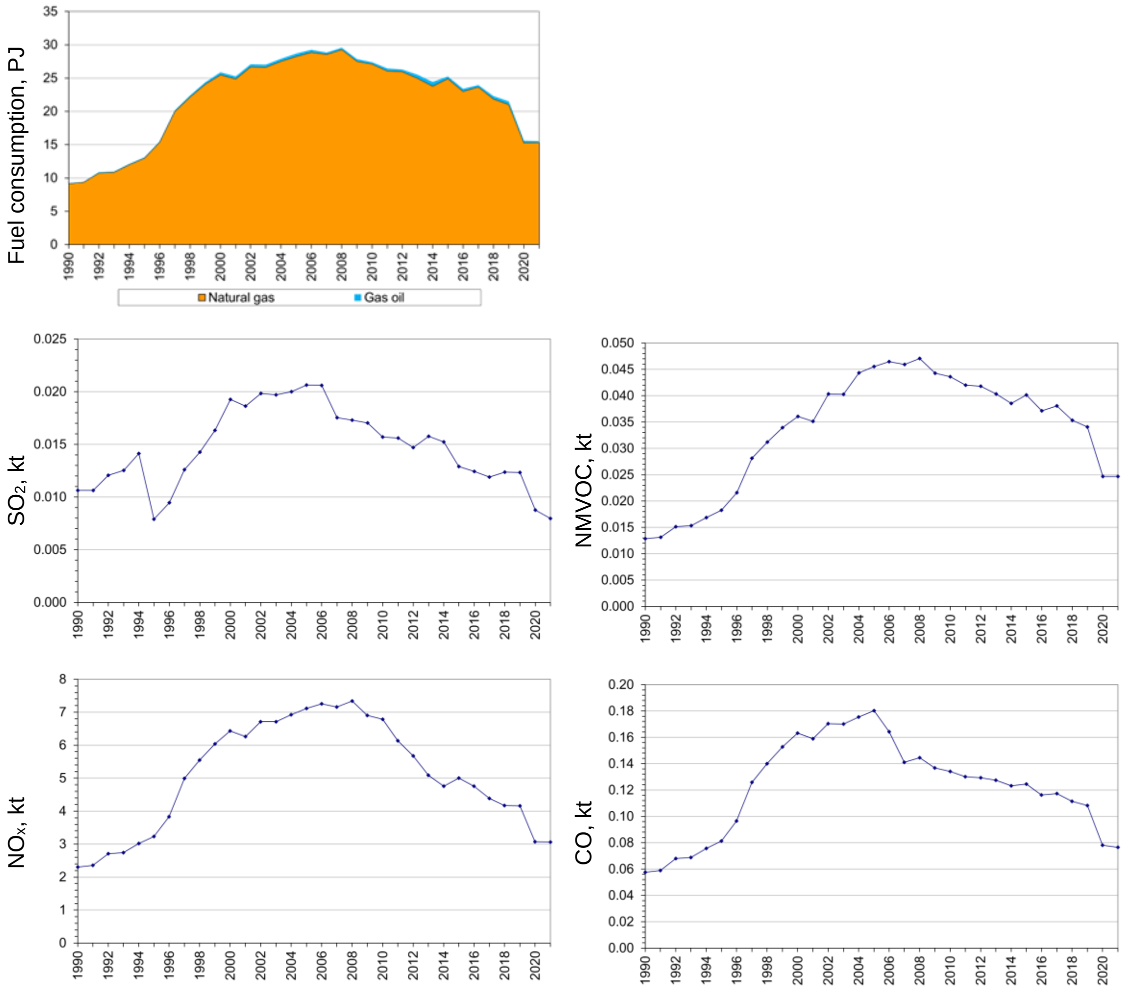


Figure 3.2.36 Time series for 1A1c Oil and gas extraction.

[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

Figure 3.2.37 - 3.2.41 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 22 % lower in 2021 than in 1990. The consumption of coal and liquid fossil fuels have decreased since 1990. The biomass consumption in 2021 was 2.4 times the consumption in 1990.

The SO_2 emission has decreased 87 % since 1990. This is mainly a result of lower consumption of residual oil in the industrial sector (Figure 3.2.37). Further, the sulphur content of residual oil and several other fuels has decreased since 1990 due to legislation and tax laws.

The NO_x emission has decreased 58 % since 1990 due to the reduced emission from industrial boilers in general. Cement production is the main emission source accounting for 44 % of the emission from industrial combustion in 2021 and more than 29 % of the emission in 1990-2021.

The NO_x emission from cement production was reduced considerably in 2009-2013. The emission increased in 2013-2021. The NO_x emission from cement industry was 44 % of the total emission from manufacturing industries and construction in 2021. The NO_x emission from cement production was reduced 59 % since 1990. The reduced emission is a result of installation of SCR on all production units at the cement production plant in 2004-2007[5] and improved performance of the SCR units in recent years. A NO_x tax was introduced in 2010 (DMT, 2008). The increase in 2015-2021 is related to a reduction of the NO_x-tax from 2015 (DMT, 2015) and an increased production.

The NMVOC emission has decreased 68 % since 1990. The decrease is mainly a result of decreased emission factor for combustion of wood in industrial boilers. The emission from gas engines has however increased considerably after 1995 due to the increased fuel consumption that is a result of the installation of a large number of industrial CHP plants (Figure 3.2.37). The NMVOC emission factor for gas engines is much higher than for boilers regardless of the fuel.

[5] To meet emission limit.

The CO emission in 2021 was 56 % higher than in 1990. The main sources of emission are combustion of wood and cement production. The CO emission from mineral wool production is included in the industry sector (2A6). The increased of emission in 1998 is related to the cement production plant in Denmark. The CO emission increased due to combustion of more paper pulp. In the following years, the combustion of this fuel was improved to decrease the CO emission (Annual environmental reports from Aalborg Portland, 1998-2002).

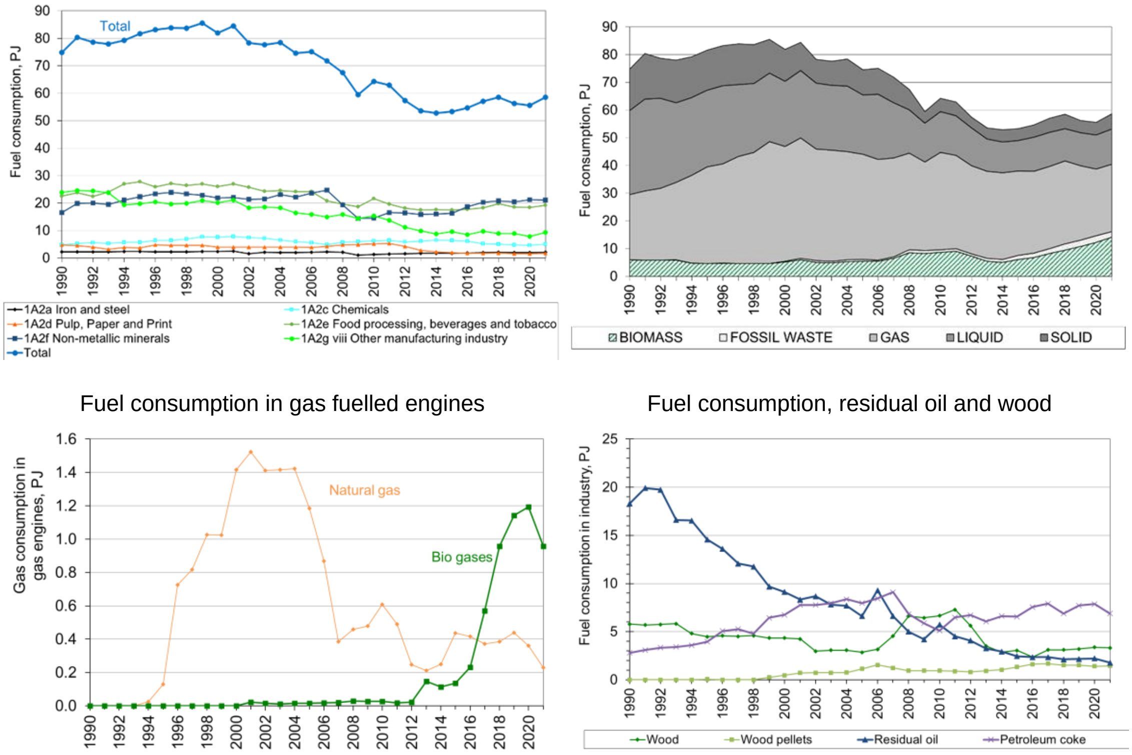


Figure 3.2.37 Time series for fuel consumption, 1A2 Industry.

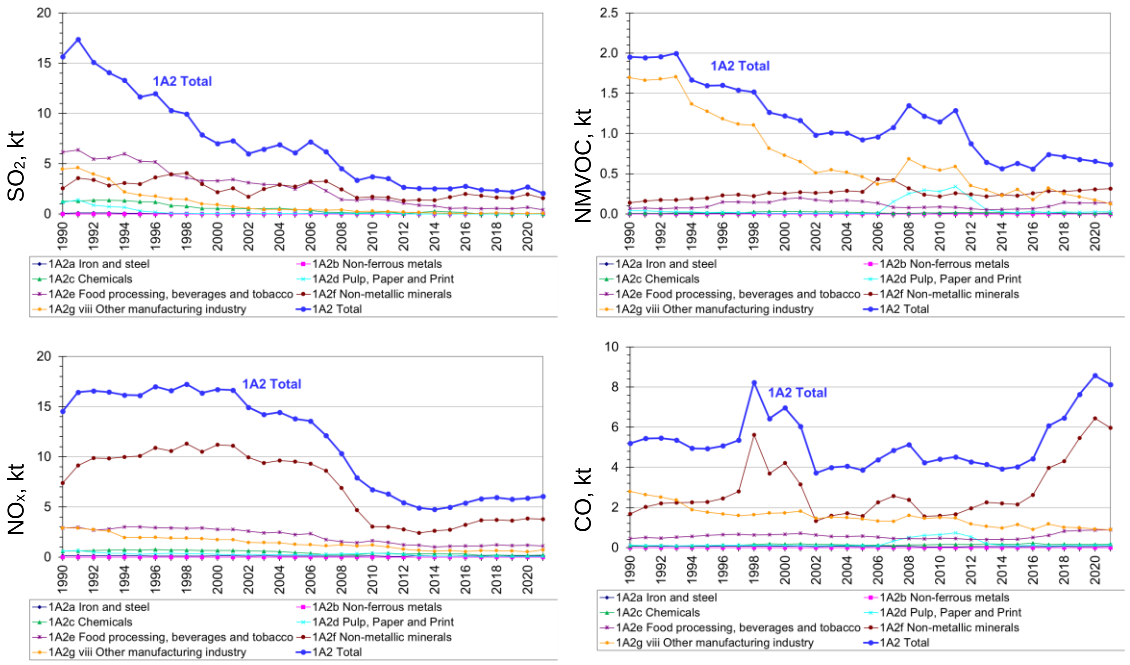


Figure 3.2.38 Time series for SO_2, NO_x, NMVOC and CO emission, 1A2 Industry.

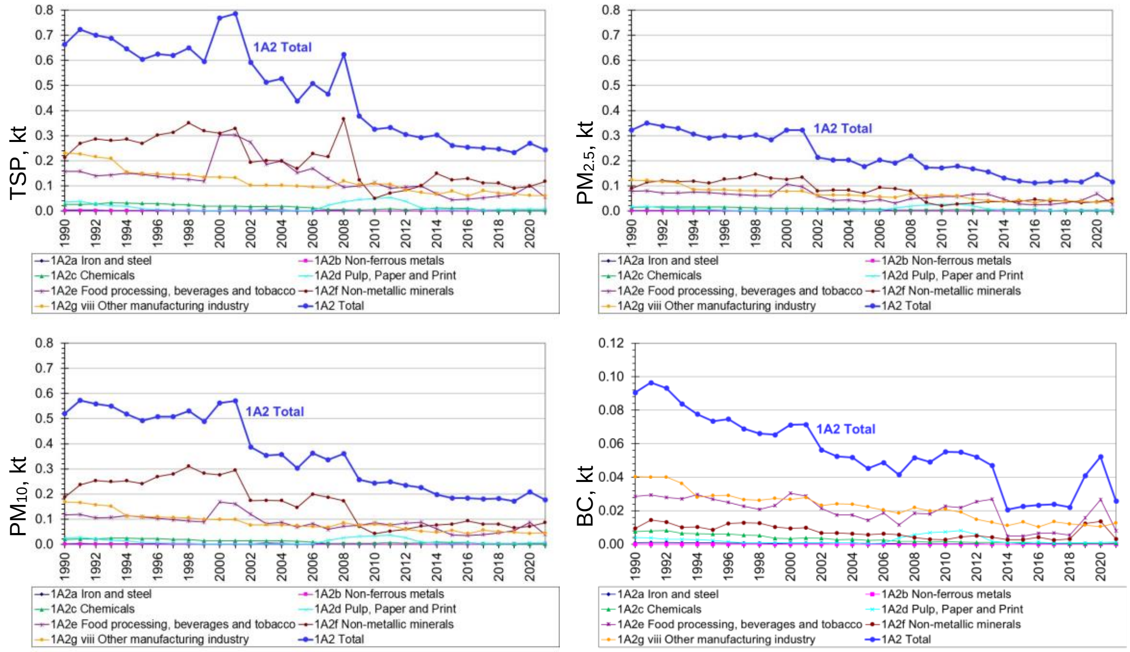


Figure 3.2.39 Time series for PM and BC emission, 1A2 Industry.

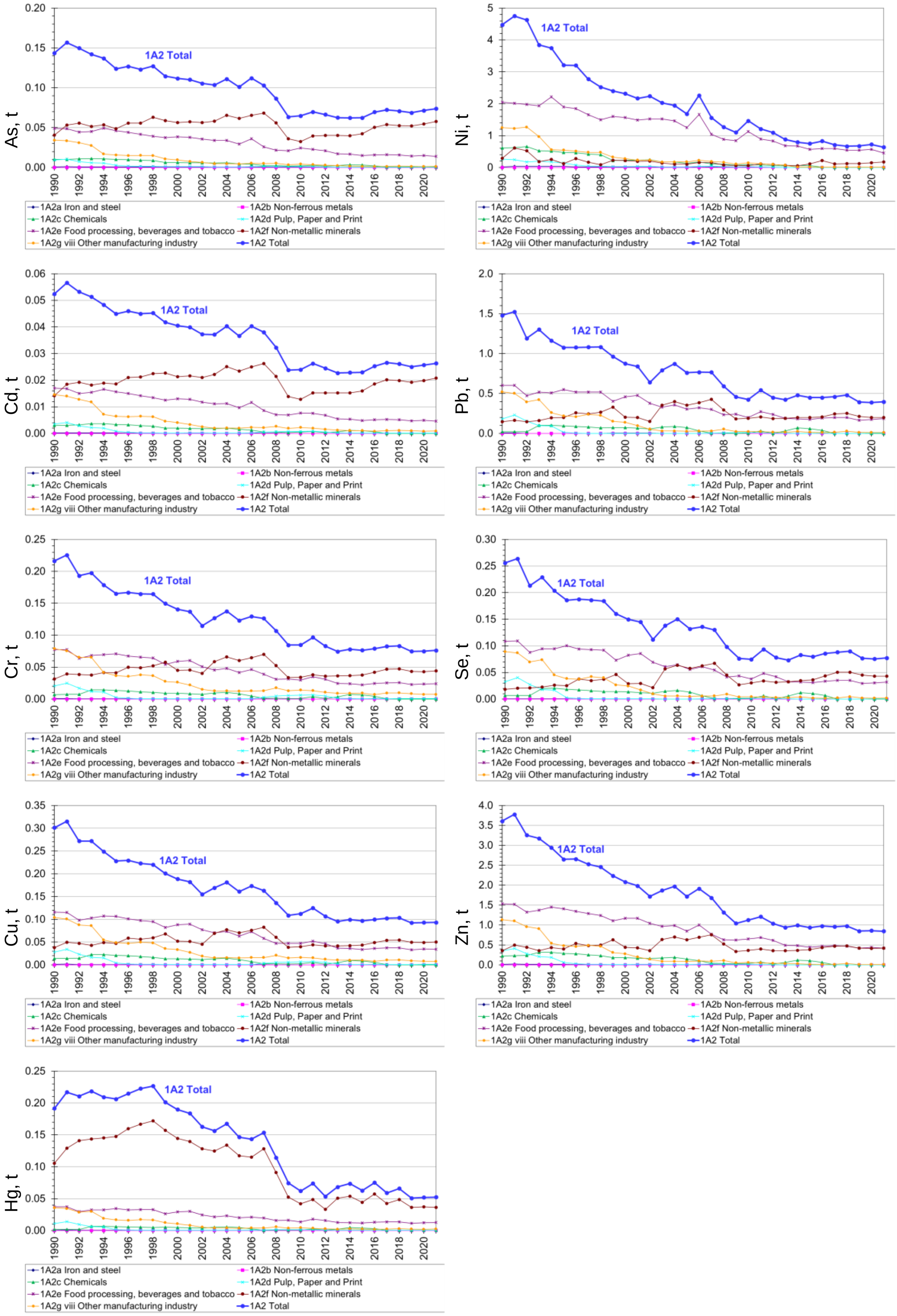


Figure 3.2.40 Time series for HM emission, 1A2 Industry.

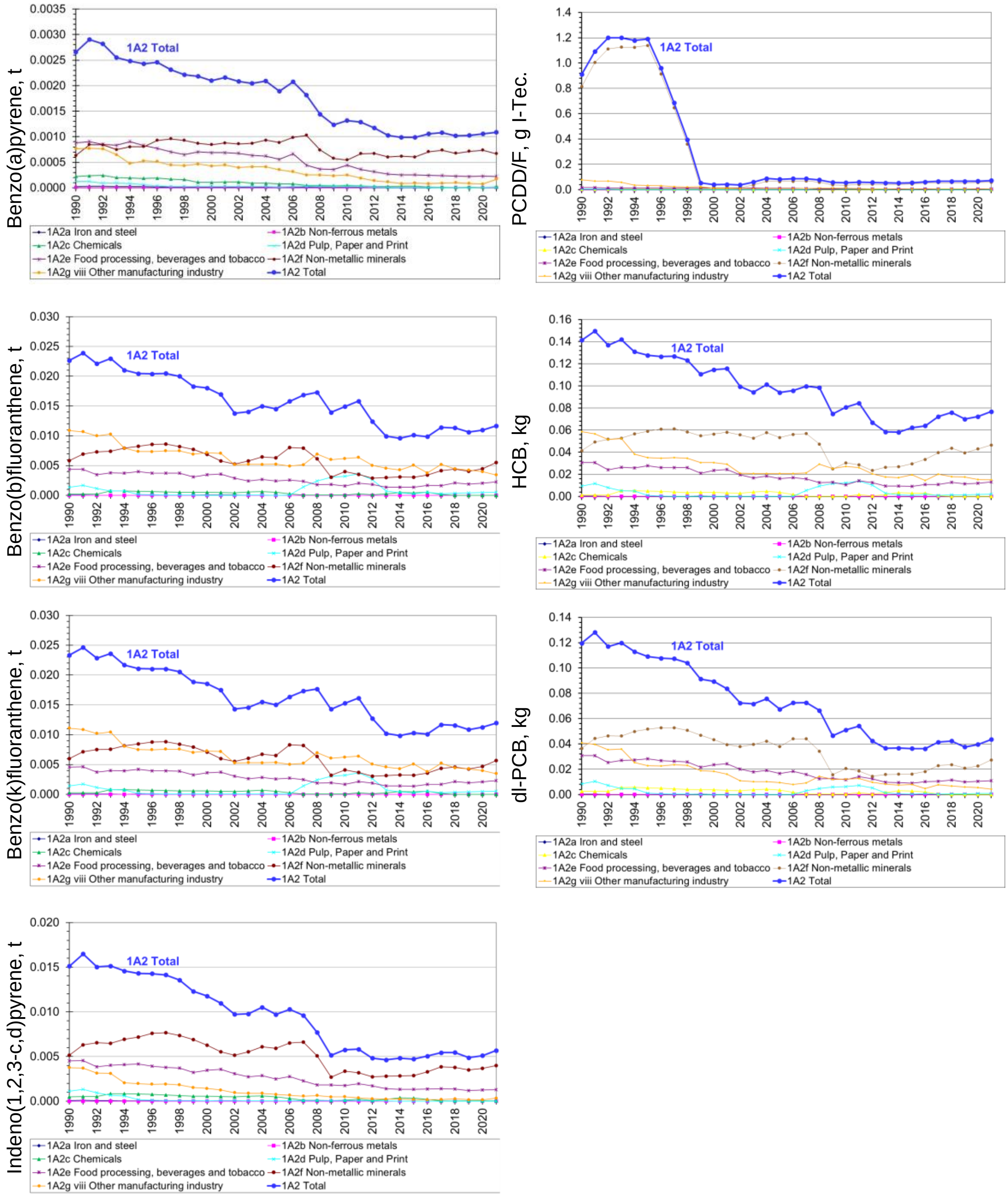


Figure 3.2.41 Time series for PAH, PCDD/F, HCB and dioxin-like PCB emission, 1A2 Industry

1A2a Iron and steel

Iron and steel is a very small emission source category. Figure 3.2.42 shows the time series for fuel consumption and emissions of SO_2, NO_x, NMVOC and CO.

Natural gas is the main fuel in the subsector.

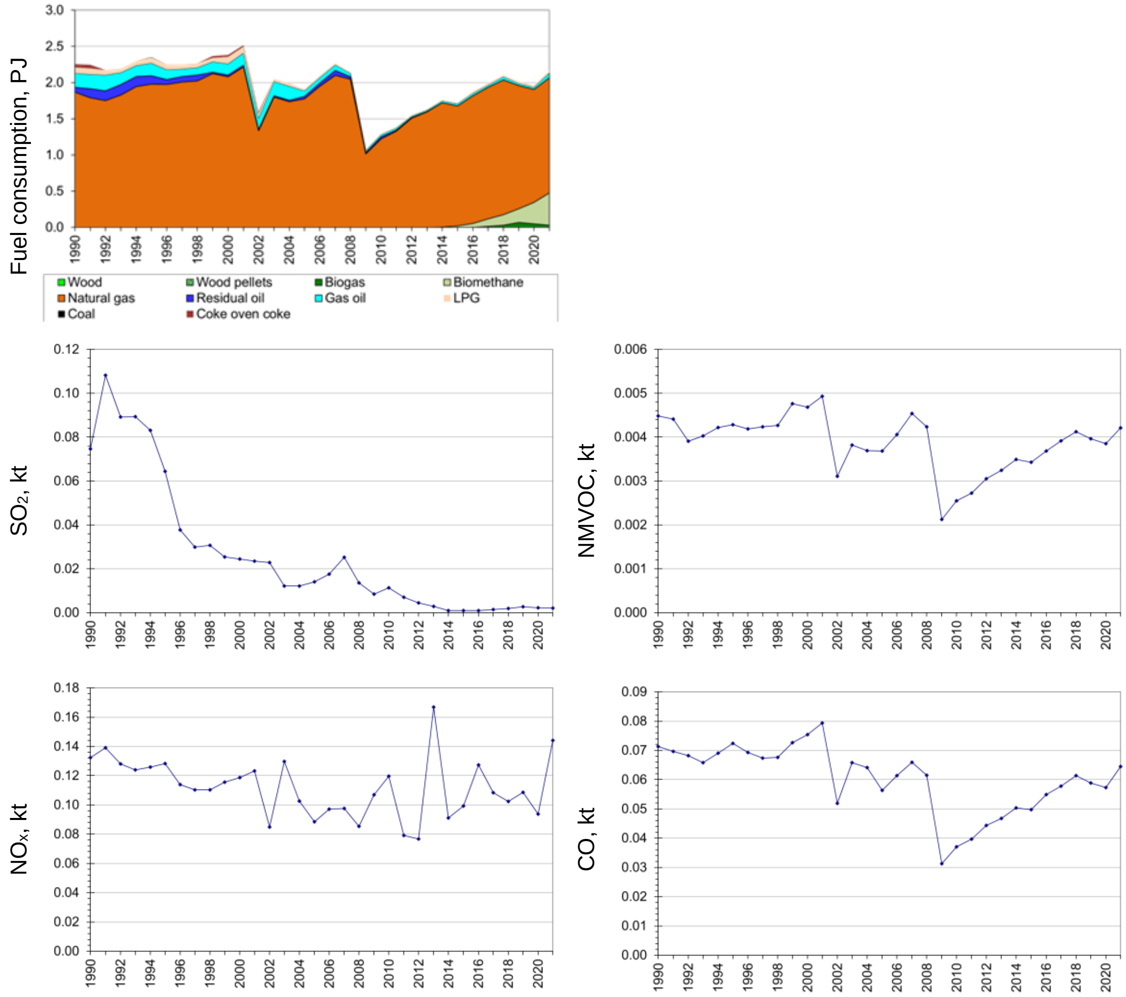


Figure 3.2.42 Time series for 1A2a Iron and steel.

1A2b Non-ferrous metals

According to the Danish energy statistics, no fuel is applied in the sector Non-ferrous metals.

1A2c Chemicals

Chemicals is a minor emission source category. Figure 3.2.43 shows the time series for fuel consumption and emissions of SO_2, NO_x, NMVOC and CO.

Natural gas is the main fuel in this subsector. The consumption of residual oil has decreased and the SO_2 emission follows this fuel consumption.

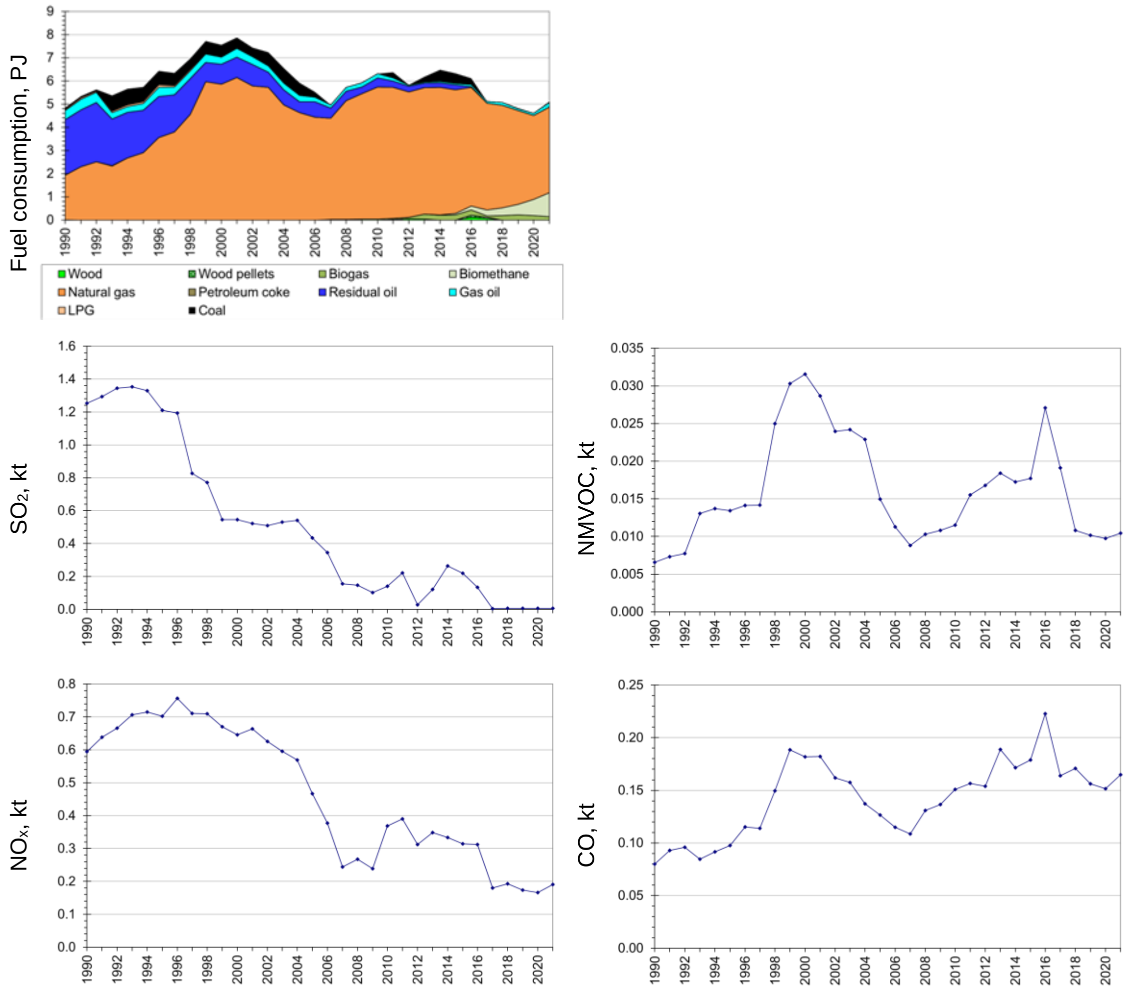


Figure 3.2.43 Time series for 1A2c Chemicals.

1A2d Pulp, paper and print

Pulp, paper and print is a minor emission source category. Figure 3.2.44 shows the time series for fuel consumption and emissions of SO_2, NO_x, NMVOC and CO.

Natural gas - and in 2007-2013, also wood - are the main fuels in the subsector. The consumption of coal and residual oil has decreased, and this is reflected in the SO_2 emission time series. The increased consumption of wood in 2007-2013 has resulted in a considerable increase and decrease in NMVOC and CO emission in 2007-2013.

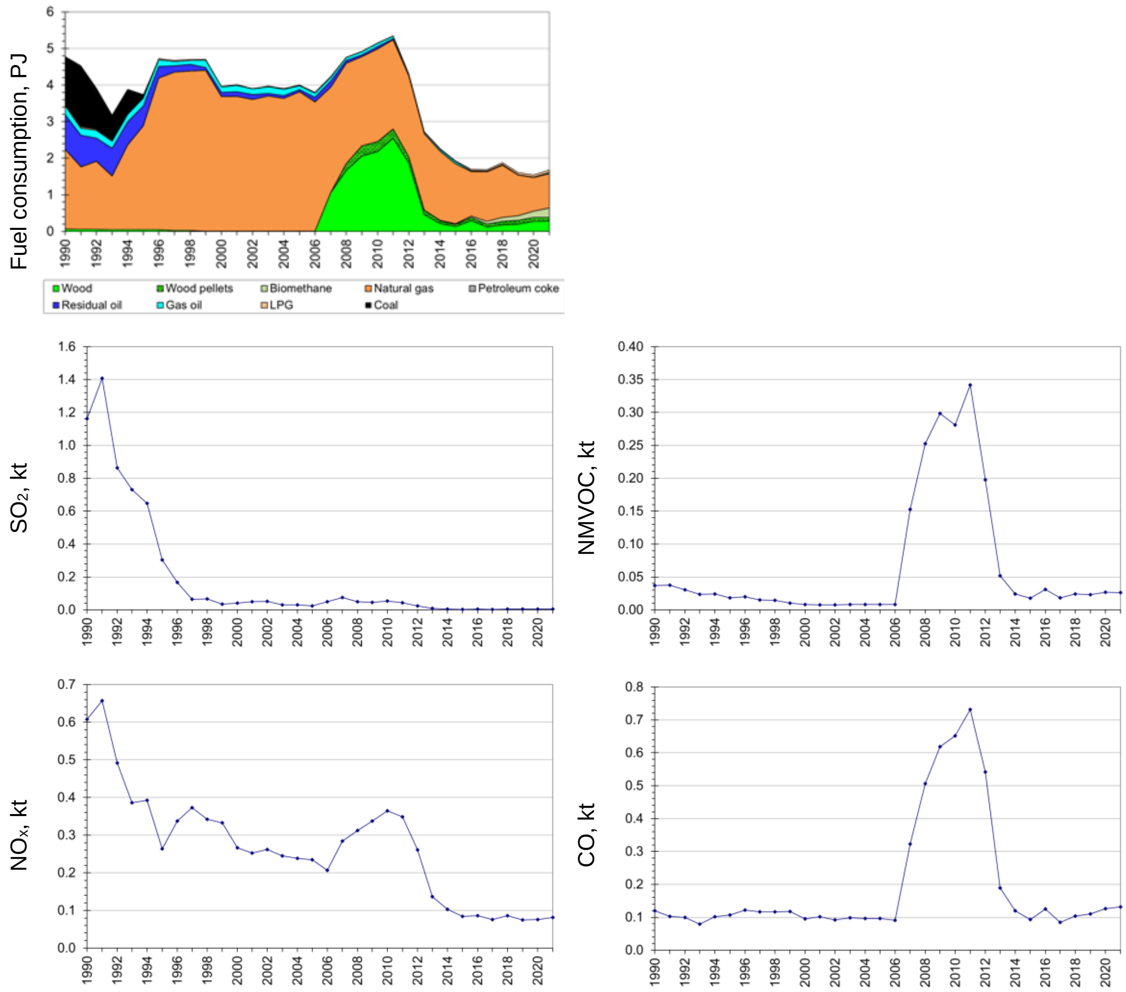


Figure 3.2.44 Time series for 1A2d Pulp, paper and print.

1A2e Food processing, beverages and tobacco

Food processing, beverages and tobacco is a considerable industrial subsector. Figure 3.2.45 shows the time series for fuel consumption and emissions of SO_2, NO_x, NMVOC and CO.

The fuel consumption decreased 15 % since 1990. 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 decreased consumption of residual oil and coal is reflected in the SO_2 emission time series.

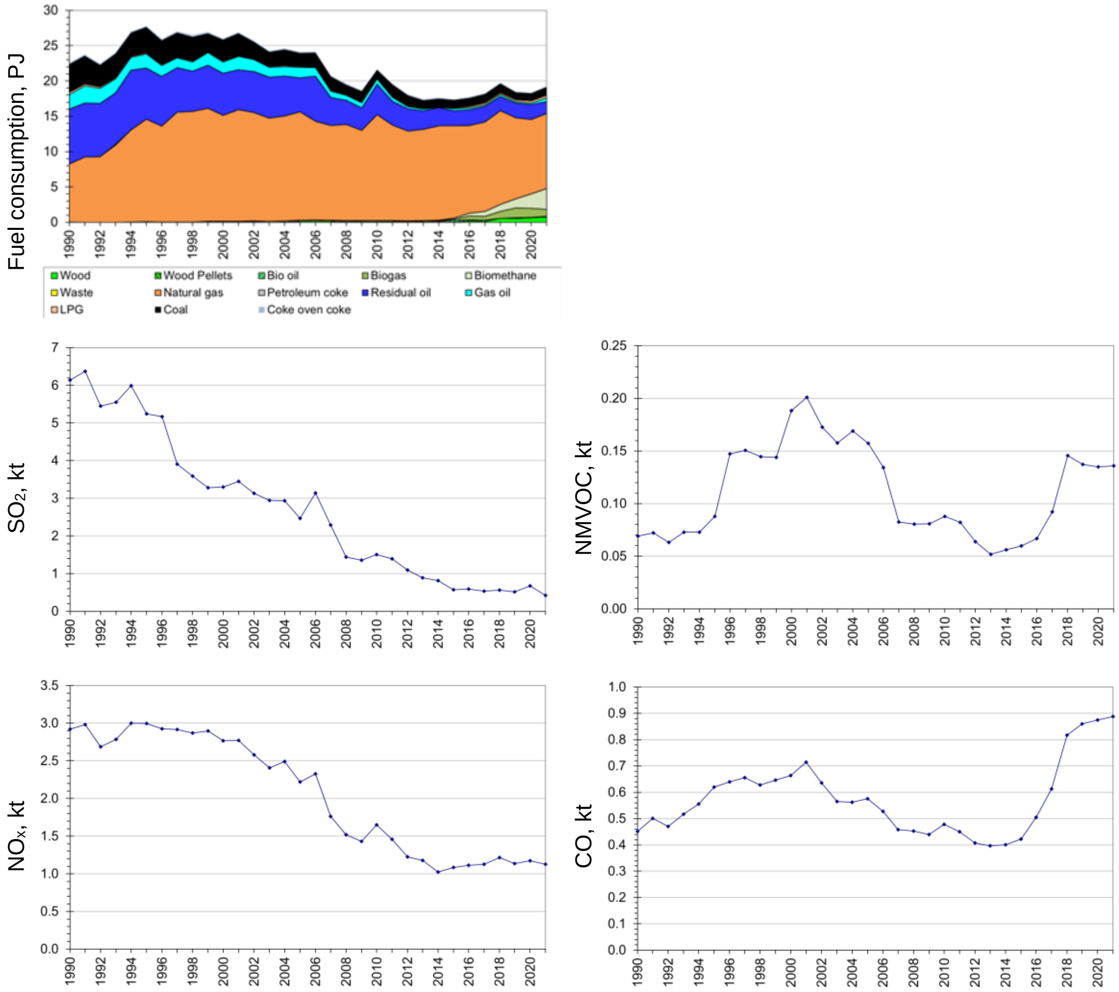


Figure 3.2.45 Time series for 1A2e Food processing, beverages and tobacco.

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. Production of mineral wool and glass is also included in the subsector. Figure 3.2.46 shows the time series for fuel consumption and emissions of SO_2, NO_x, NMVOC and CO.

The fuel consumption increased 27 % since 1990. 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 increased again. This is reflected in the time series.

The reduced NO_x emission is a result of installation of SCR on all production units at the cement production plant in 2004-2007[6] and improved performance of the SCR units in the following years. A NO_x tax was introduced in 2010 (DMT, 2008). The increased emission after 2015 is related to a reduction of the NO_x-tax (DMT, 2015) and an increased production rate.

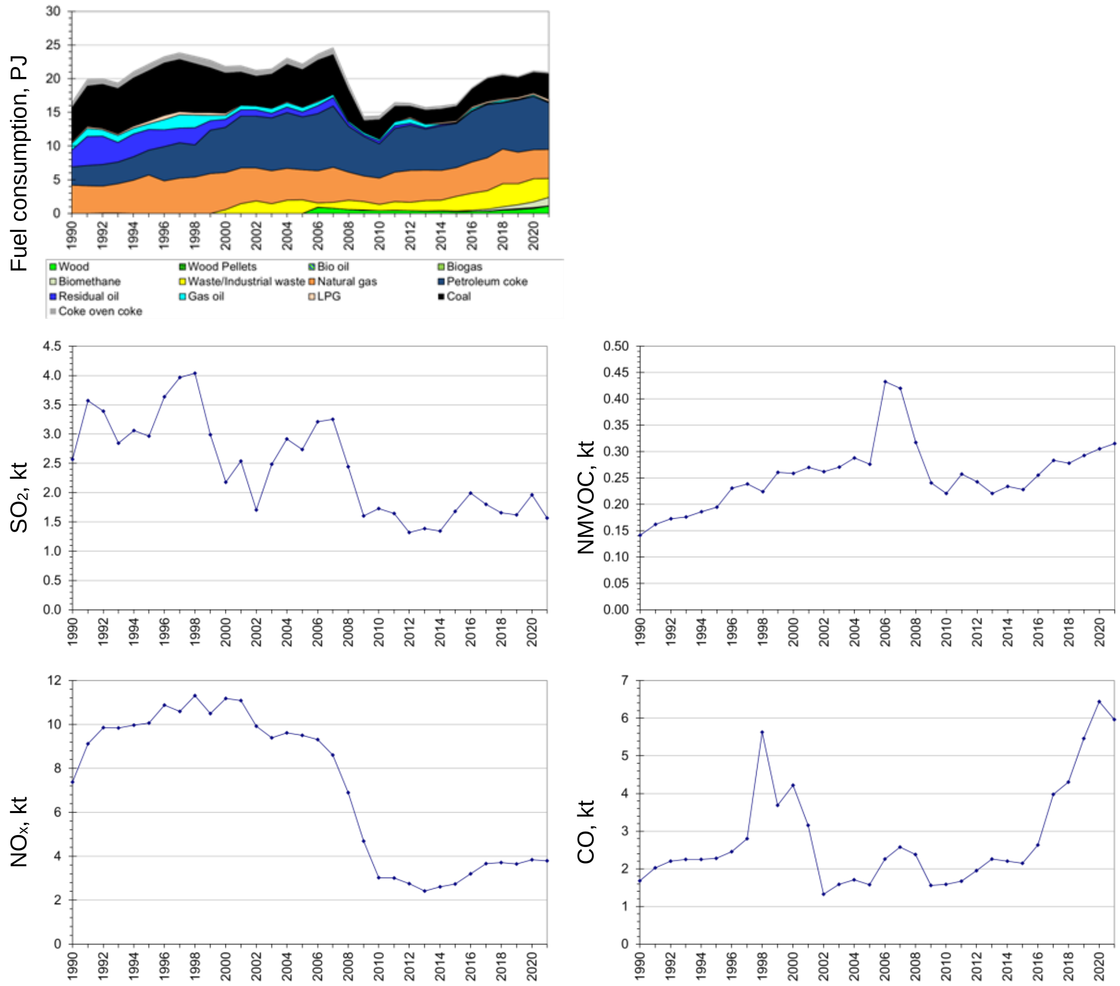


Figure 3.2.46 Time series for 1A2f Non-metallic minerals

[6] To meet emission limit.

1A2g Other manufacturing industry

Other manufacturing industry is a considerable industrial subsector. Figure 3.2.47 shows the time series for fuel consumption and emissions of SO_2, NO_x, NMVOC and CO.

The fuel consumption decreased 61 % since 1990. Natural gas, wood, wood pellets and gas oil are the main fuels in the subsector in recent years. The consumption of coal and oil has decreased.

The SO_2 emission decreased 99 % since 1990 as a result of both lower fuel consumption and a change of fuels towards fuels with lower sulphur content.

The NO_x emission decreased 75 % since 1990.

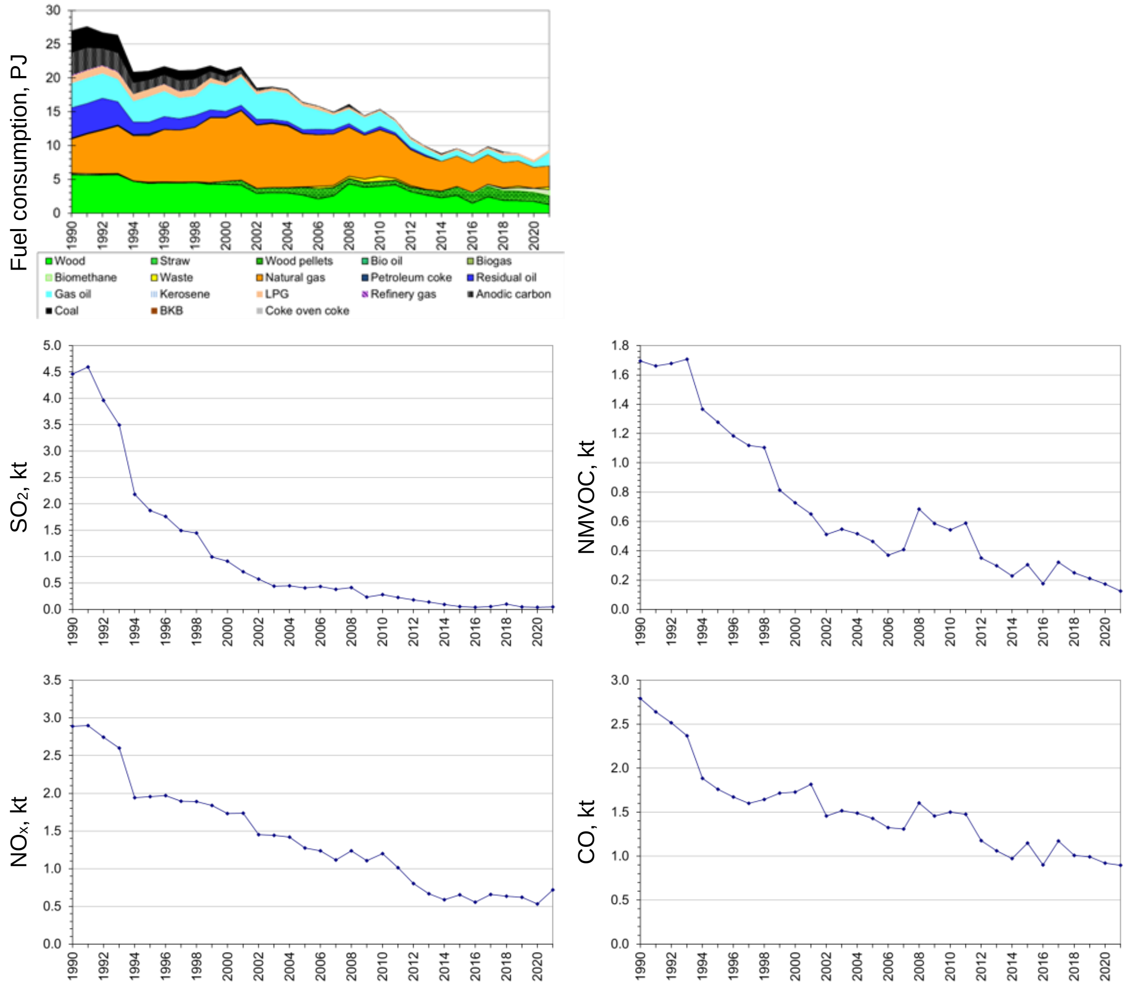


Figure 3.2.47 Time series for 1A2g Other manufacturing industry.

1A4 Other Sectors

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

- 1A4a Commercial/institutional plants.
- 1A4b Residential plants.
- 1A1c Agriculture/forestry.

Figure 3.2.48 – 3.2.52 present time series for this emission source category. Residential plants is the largest subcategory accounting for the largest part of all emissions. Time series for SO_2, NO_x, NMVOC and CO are discussed below each subcategory.

The PM emissions increased until 2007 and decreased after 2007. The increase until 2007 was caused by the increased wood combustion in residential plants. However, the PM emission factors have decreased for this emission source category due to installation of modern stoves and boilers (see Chapter 3.2.7). The stabilisation of wood consumption in residential plants in 2007-2021 has resulted in a decrease of PM emission from stationary combustion after 2007. The PM emission data for residential wood combustion include condensable particles.

The emission of BC was 18 % lower in 2021 than in 1990. The largest emission sources for BC is combustion of wood and straw in residential plants and in agricultural/forestry plants. The consumption of wood in residential plants has increased since 1990, but the emission factor has decreased due to implementation of new improved stoves and boilers, see Chapter 3.2.7.

The emission of some HMs has increased since 1990, whereas the emission of other HMs has decreased. The decreased emissions are related to lower consumption of solid and liquid fossil fuels and waste. The emissions of Zn and Cd have increased due to a considerable emission from residential wood combustion even in 1990. The emission factors for HMs from residential wood combustion are not considered dependent of combustion technology (Chapter 3.2.7), and thus the increasing consumption of wood until 2007 is reflected in the HM emissions.

Residential wood combustion is the predominant emission source for PAH emissions. The emission factors applied for residential wood combustion are technology dependent (Chapter 3.2.7) and thus the PAH emissions decrease in spite of the increasing consumption of wood.

The emission of PCDD/F has increased 29 % since 1990. The main emission source is residential combustion of wood, wood pellets, and straw. The dioxin emission factors for residential wood combustion are dependent on the wood origin but independent of stove technology (Chapter 3.2.7). Thus, the dioxin emission from residential wood combustion has not decreased similar to e.g. the PM and PAH emissions due to replacements of old stoves and boilers.

The emission of dl-PCBs has decreased 61 % since 1990.

The HCB emission time series follows the fuel consumption of coal in residential plants. The HCB emission factor for coal used in residential plants is high compared to other fuels.

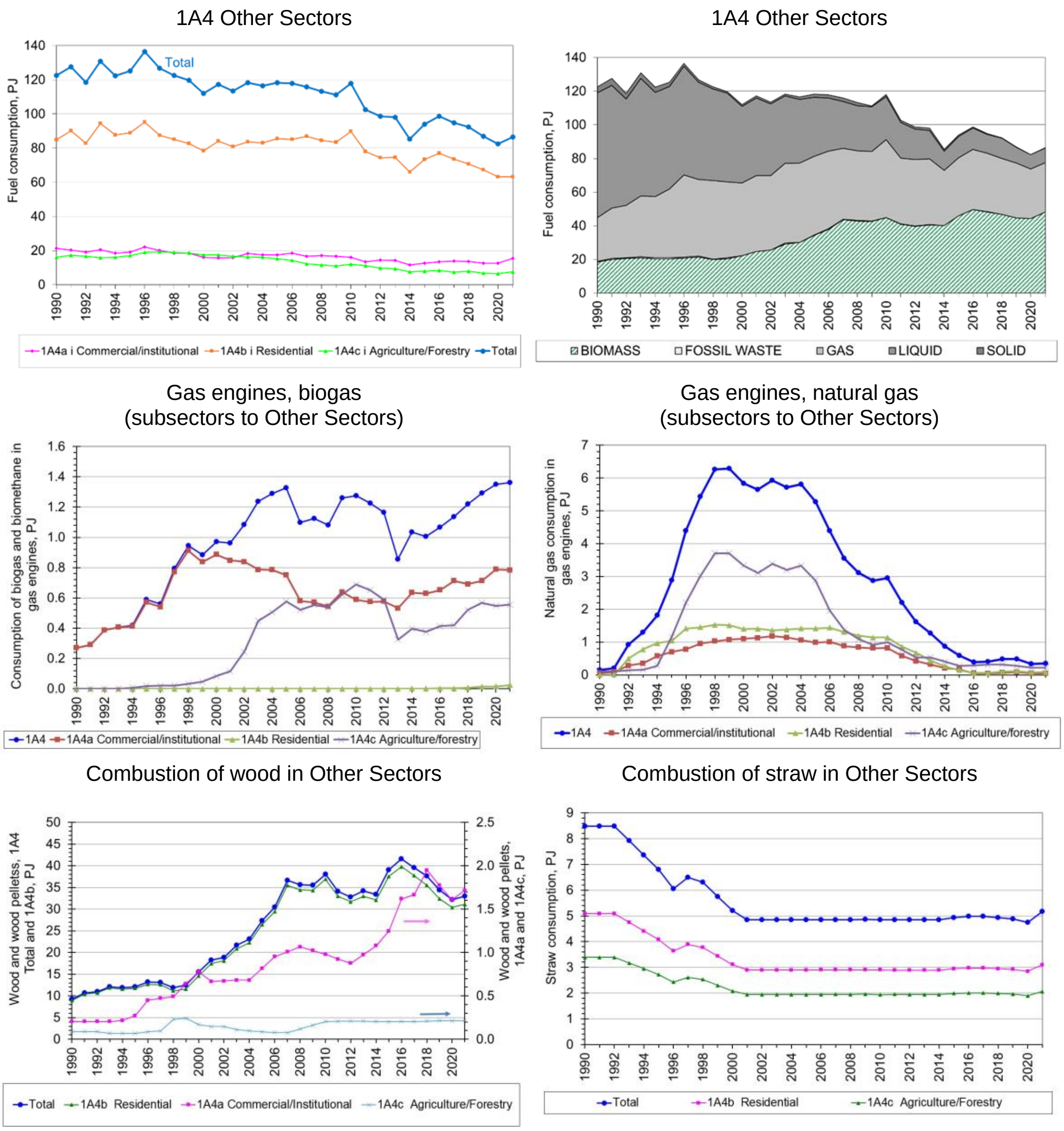


Figure 3.2.48 Time series for fuel consumption, 1A4 Other Sectors.

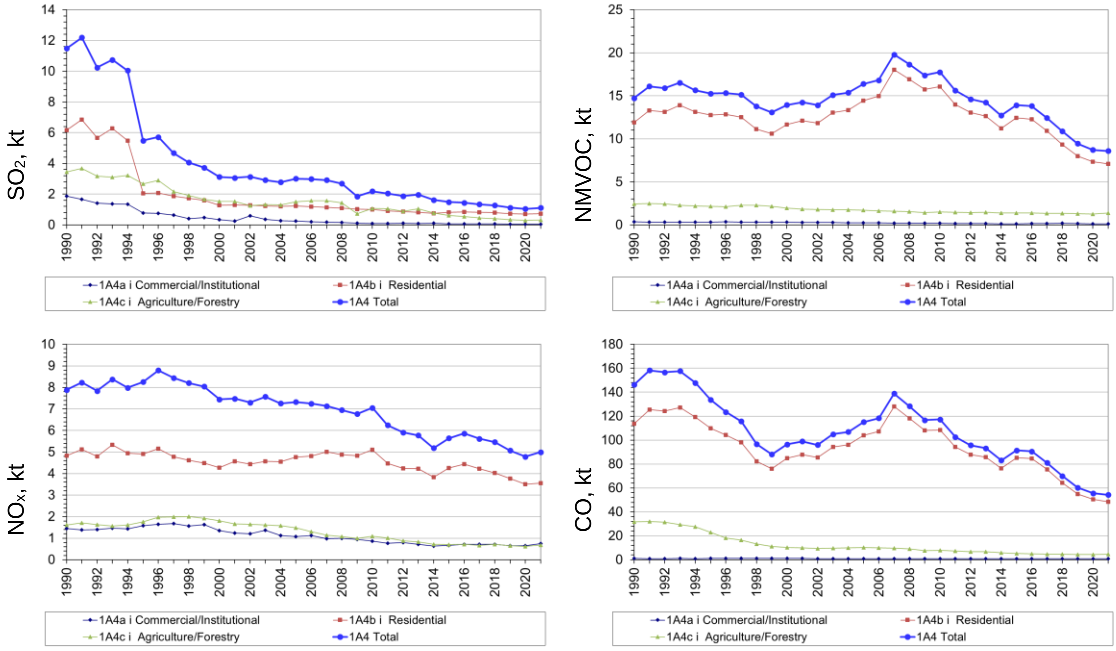


Figure 3.2.49 Time series for SO_2, NO_x, NMVOC and CO emission, 1A4 Other Sectors.

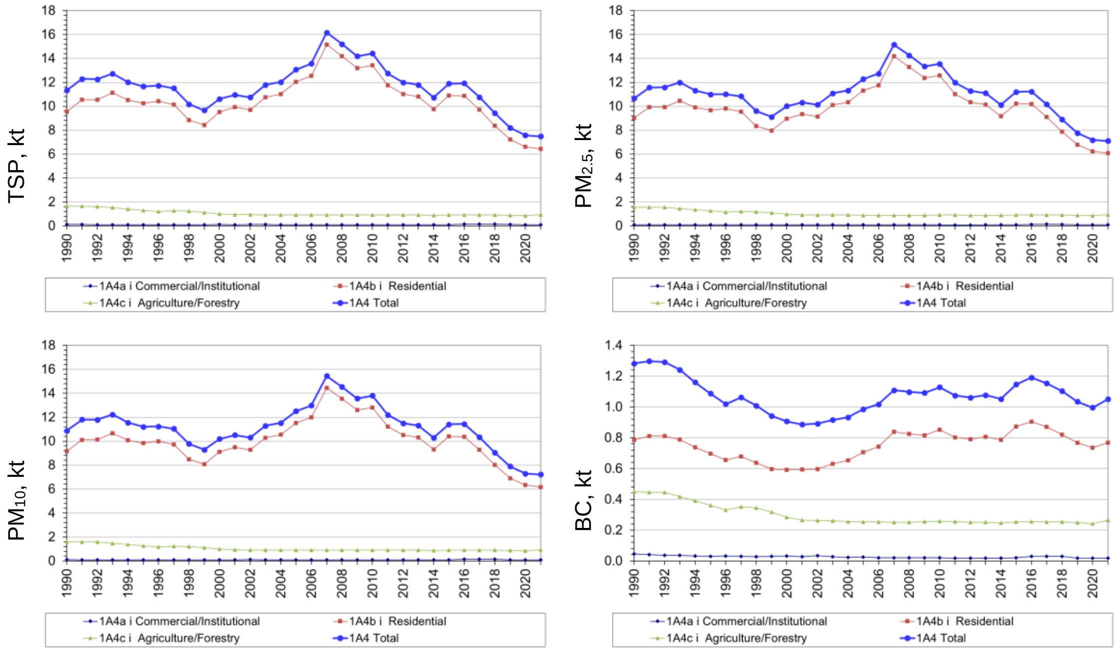


Figure 3.2.50 Time series for PM and BC emission, 1A4 Other Sectors.

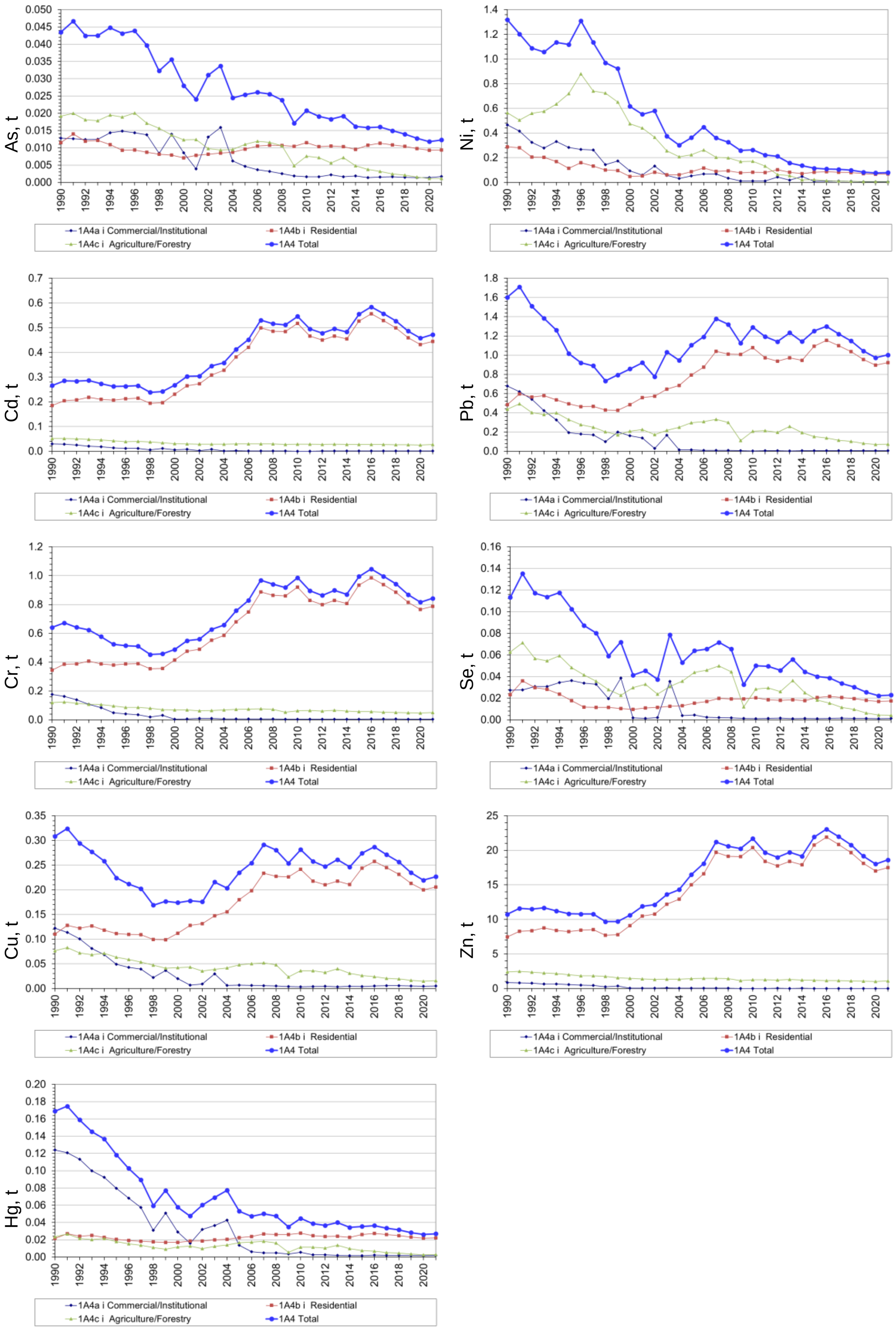


Figure 3.2.51 Time series for HM emission, 1A4 Other Sectors.

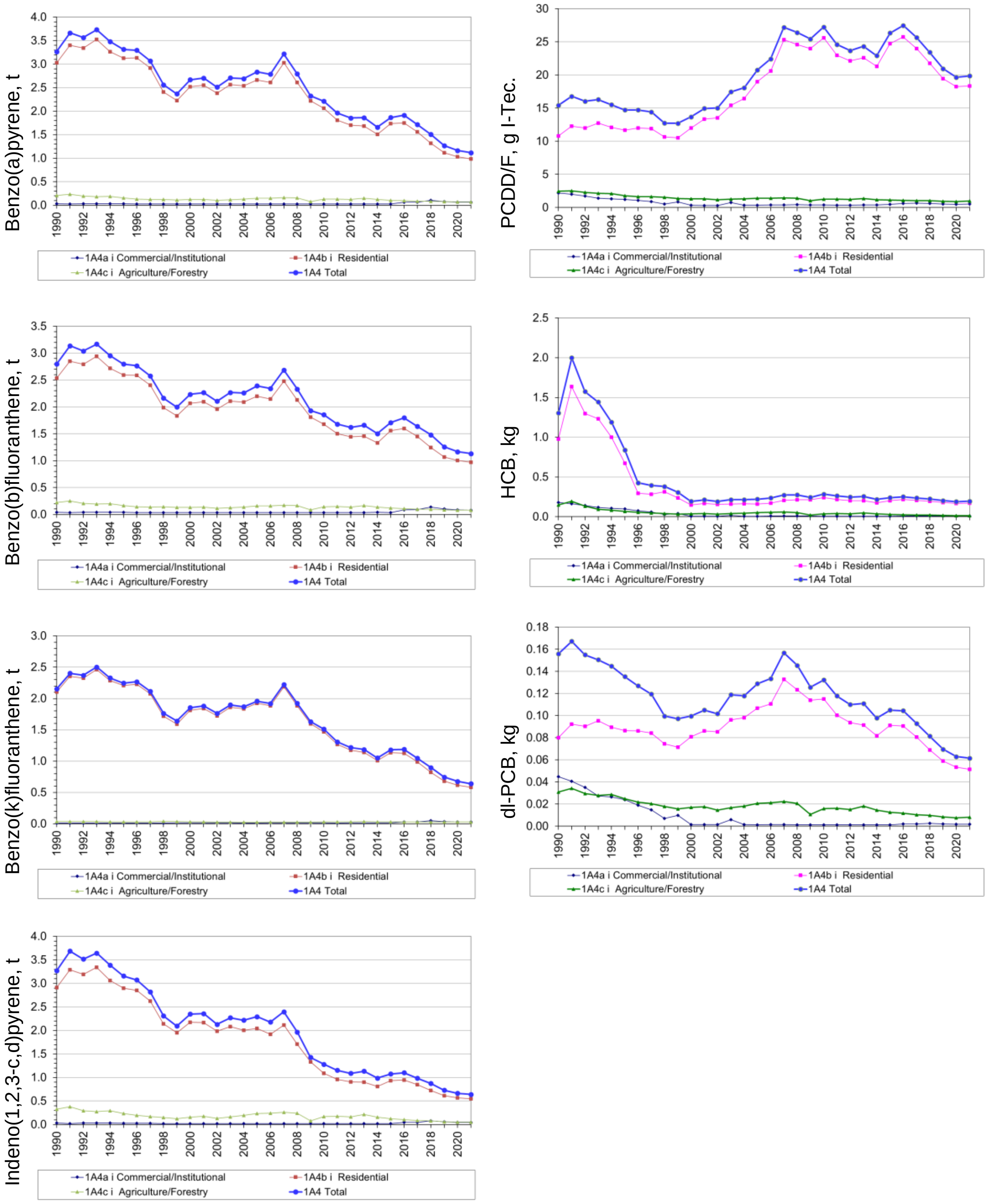


Figure 3.2.52 Time series for PAH, PCDD/F, HCB and dioxin-like PCB emission, 1A4 Other Sectors.

1A4a i Commercial and institutional plants

The emission source category Commercial and institutional plants consists of both stationary and mobile sources. In this chapter, only stationary sources are included (1A4a i).

The fuel consumption and the emissions from commercial and institutional plants are low compared to the other stationary combustion emission source categories. Figure 3.2.53 shows the time series for fuel consumption and emissions.

The fuel consumption in Commercial/institutional plants has decreased 28 % since 1990 and the fuels applied have changed. In later years, the main fuel is natural gas. The consumption of gas oil has decreased since 1990. The consumptions of wood, wood pellets, biogas, and biomethane have increased.

The SO_2 emission has decreased 97 % since 1990. The decrease is a result of both the change of fuel from gas oil to natural gas and of the lower sulphur content in gas oil and in residual oil. The lower sulphur content (0.05 % for gas oil since 1995 and 0.7 % for residual oil since 1997) is a result of Danish tax laws (DEPA, 1998).

The NO_x emission was 49 % lower in 2021 than in 1990. The decrease is mainly a result of the lower fuel consumption but also the change from gas oil to natural gas has contributed to the decrease. The emission from wood combustion has increased.

The NMVOC emission in 2021 was 61 % lower than the 1990 emission level. The combustion of wood has increased but the emission factor has decreased. The increase and decrease of natural gas consumption in gas engines (Figure 3.2.48) is also reflected in the time series for NMVOC emission.

The CO emission has decreased 5 % since 1990. This is a result of the change of fuels used in the sector. The emission from wood has increased whereas the emission from gas oil has decreased.

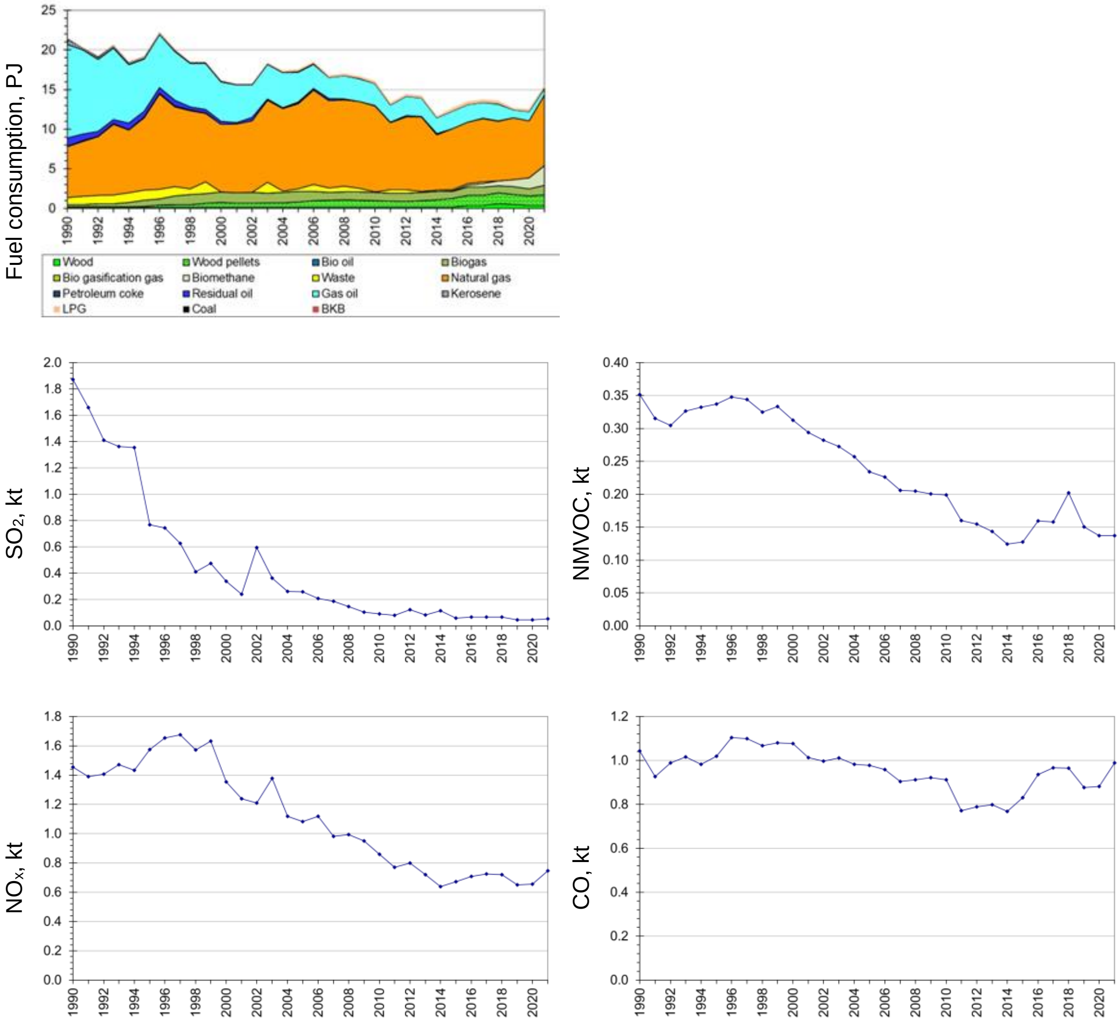


Figure 3.2.53 Time series for 1A4a Commercial /institutional.

1A4b i Residential plants

The emission source category Residential plants consists of both stationary and mobile sources. In this chapter, only stationary sources are included (1A4b i). Figure 3.2.54 shows the time series for fuel consumption and emissions. Time series for emissions of PM, PAHs, PCDD/F, HCB and dl-PCBs are also shown for this subsector because residential plants is a large emission source for these pollutants. The time series for residential combustion of wood and wood pellets is also shown in the figures.

For residential plants, the total fuel consumption was 26 % lower in 2021 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, wood pellets and biomethane has increased considerably.

Residential wood combustion is a large emission source for several pollutants. Replacement of older stoves and boilers with new improved stoves and boilers has been implemented in the emission inventory for residential wood combustion, see also Chapter 3.2.7.

The large decrease (88 %) of SO_2 emission from residential plants is mainly a result of a change of sulphur content in gas oil since 1995. The lower sulphur content (less than 0.05 %) is a result of Danish tax laws (DEPA, 1998). In addition, the consumption of gas oil has decreased and the consumption of natural gas that results in very low SO_2 emissions has increased. Finally, coal consumption in residential plants in the early 1990s was a considerable emission source for SO_2 emission until 1996.

The NO_x emission has decreased by 26 % since 1990. As mentioned above the fuel consumption has also decreased 26 %. The emission factor for wood is higher than for natural gas and gas oil and both consumption and the emission factor for wood have increased[7]. However, the NO_x emission factor for natural gas has decreased.

The emission of NMVOC has decreased 41 % since 1990. The consumption of wood has increased but the emission factor has decreased since 1990. The emission factors for wood and straw are higher than for liquid or gaseous fuels.

The CO emission has decreased 57 % since 1990. The use of wood that is the main source of emission has increased whereas the emission factor has decreased. The emission from combustion of straw has decreased whereas the consumption of wood pellets has increased since 1990.

Time series for emissions of PM, BC, HMs, PAHs, PCDD/F, PCB, HCB are shown in Figure 3.2.50 – 3.2.52.

[7] The NO_x emission factor for residential wood is technology dependent. The emission factor for new stoves is higher than for old stoves, see Chapter 3.2.7.

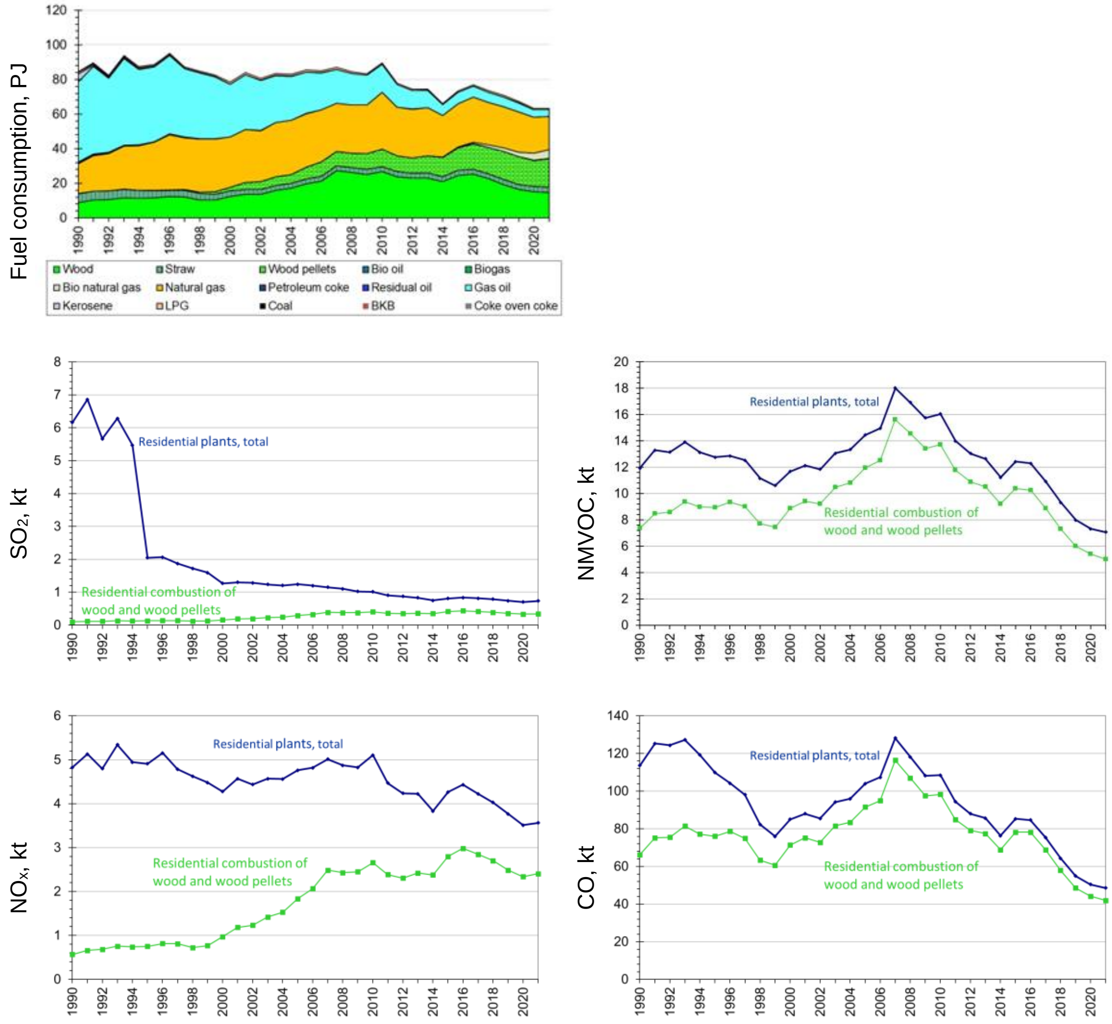


Figure 3.2.54 Time series for fuel consumption and emissions from 1A4b Residential plants.

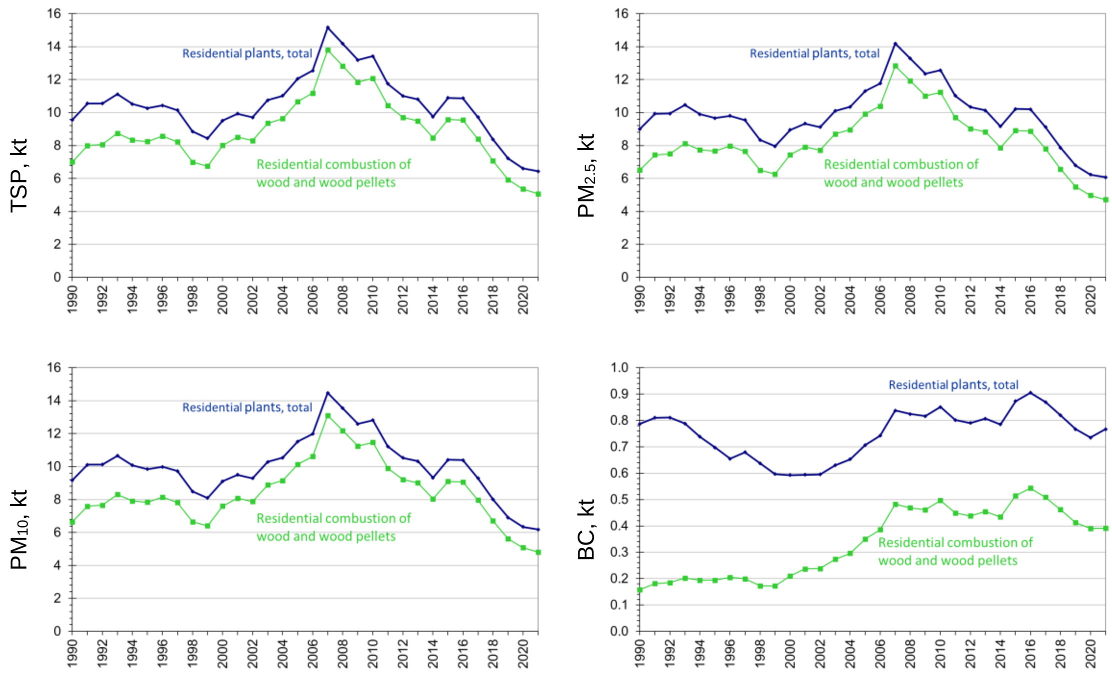


Figure 3.2.55 Time series for PM emissions from Residential plants.

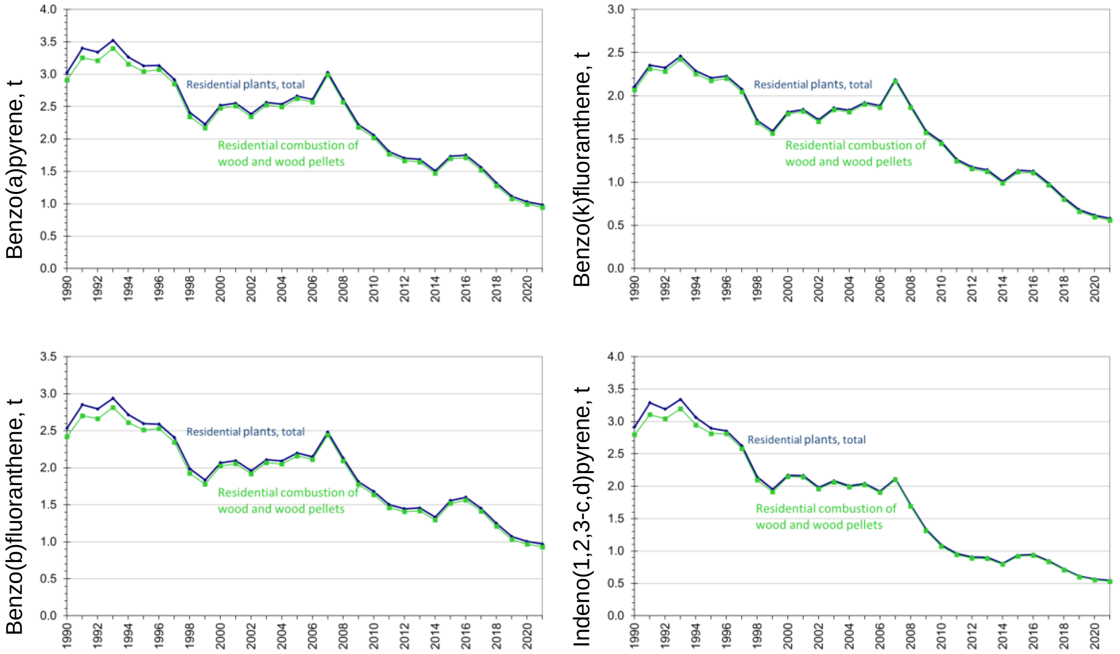


Figure 3.2.56 Time series for PAH emissions from Residential plants.

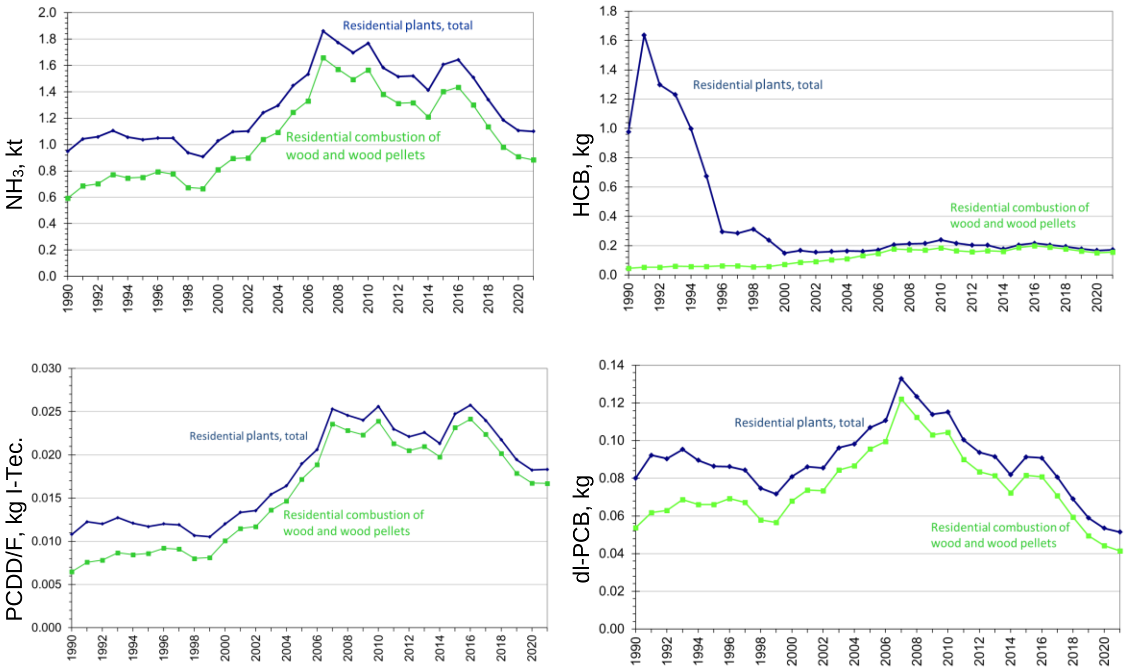


Figure 3.2.57 Time series for emissions of NH_3, PCDD/F, HCB and dl-PCBs from Residential plants.

1A4c i Agriculture/forestry

The emission source category Agriculture/forestry consists of both stationary and mobile sources. In this chapter, only stationary sources are included (1A4c i). Figure 3.2.58 shows the time series for fuel consumption and emissions.

For plants in Agriculture/forestry, the fuel consumption has decreased 53 % 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 3.2.48). 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, gas oil and straw has decreased since 1990. The consumption of biogas has increased.

The SO_2 emission was 91 % lower in 2021 than in 1990.

The emission of NO_x was 57 % lower in 2021 than in 1990.

The emission of NMVOC has decreased 44 % since 1990.

The CO emission has decreased 85 % since 1990. The major emission source is combustion of straw. In addition to the decrease of straw consumption, the emission factor for straw has also decreased since 1990.

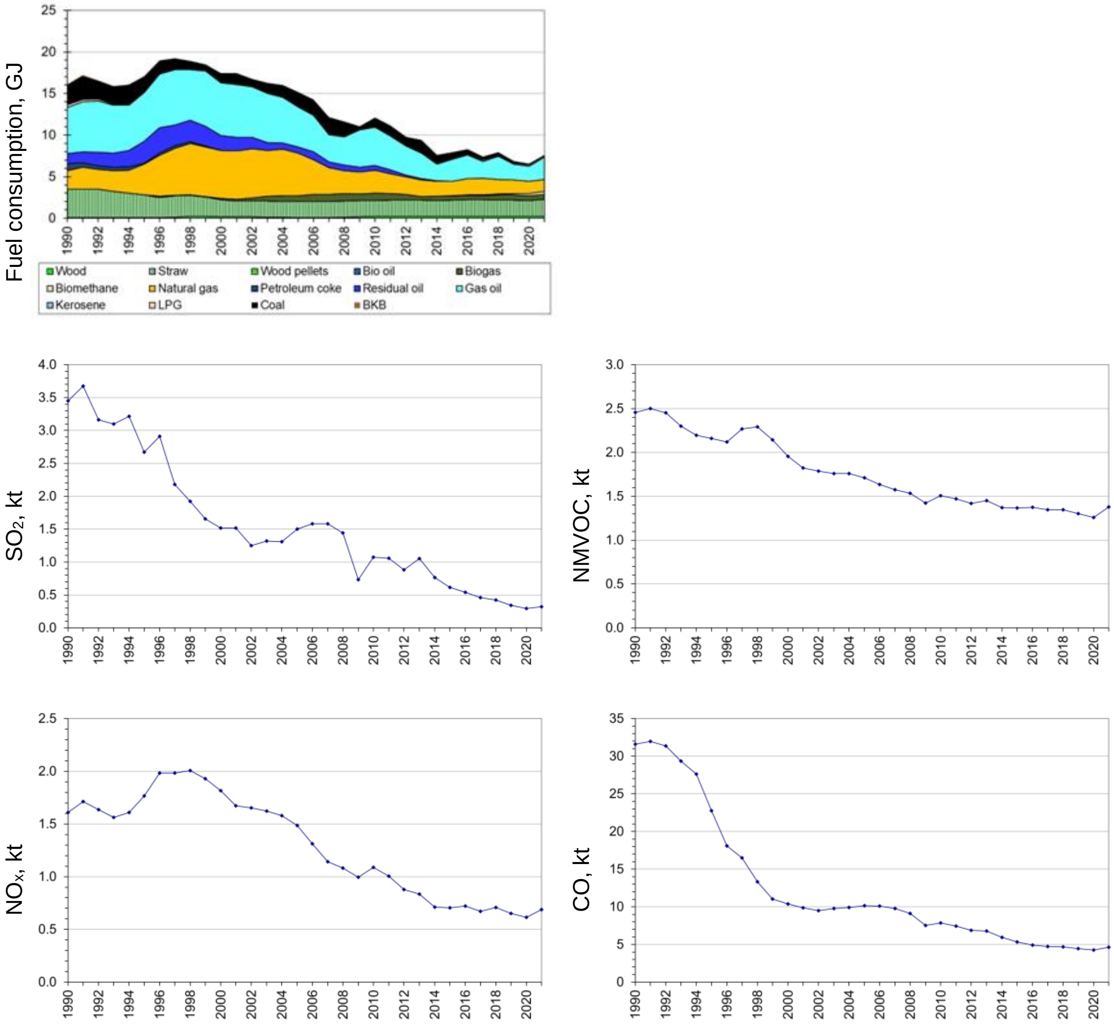


Figure 3.2.58 Time series for 1A4c Agriculture/Forestry.

3.2.6 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, 2019). 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.

Large part of the emissions is based on higher tier methods using either technology-specific, country-specific or plan-specific emission factors. For large point sources, the emissions of SO_2, NO_x, PM and heavy metals are generally plant specific and hence tier 3. The sources of emission factors are described in Chapter 3.2.7 and 3.2.8.

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 2021, 71 stationary combustion plants are specified as large point sources. Plant specific emission data are available from 65 of the plants[8]. 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, 2020b).
- Industrial plants,

[8] For CO_2 or other pollutants.

- 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 2021 inventory was 208 PJ. This corresponds to 53 % of the overall fuel consumption for stationary combustion.

A list of the large point sources for 2021 is provided in Annex 3A-6. The number of large point sources registered in the databases increased from 1990 to 2021. Aggregated fuel consumption rates for the large point sources are also shown in Annex 3A-6.

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. Which emission data are plant-specific is shown in Annex 3A-6.

The emission shares from point sources with plant specific data are shown in Table 3.2.15.

Table 3.2.15 Emission share, plant specific data.

Pollutant	Share from plant specific data, %
SO_2	46%
NO_x	45%
NMVOC	0.5%
CO	13%
NH_3	5.9%
TSP	4.0%
PM_{10}	3.7%
$PM_{2.5}$	3.1%
BC	0.9%
As	25%
Cd	2.6%
Cr	5%
Cu	10%
Hg	53%
Ni	6%
Pb	4%
Se	54%
Zn	1.4%
PCDD/F	3.5%

SO_2 and NO_x emissions from large point sources are often plant-specific based on continuous emission measurements. Emissions of CO, NMVOC, PM, heavy metals and PCDD/F are also plant-specific for some plants. Plant-specific emission data are obtained from:

- Annual environmental reports / environmental reporting available on the Danish EPA home page[9] (PRTR data), DEPA (2022b)
- Emission data reported by Ørsted[10], the major power plant operator in Denmark

[9] https://dma.mst.dk/prtr/offentlig/
[10] Former DONG Energy.

- Additional emission data reported to DCE

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

If plant-specific emission factors are not available, general area source emission factors 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 in Chapter 3.2.8.

Activity rates, fuel consumption

The fuel consumption rates are based on the Danish energy statistics prepared by DEA. DCE aggregates fuel consumption rates to SNAP categories. Some fuel types in the Danish energy statistics are added to obtain a less detailed fuel aggregation level. The fuel categories are shown in Annex 3A-3. The annex also includes default calorific values from the energy statistics. Plant specific data included in the energy statistics if available. The correspondence list between the energy statistics and SNAP categories is enclosed in Annex 3A-9.

Fuel consumption data are presented in Chapter 3.2.3.

The fuel consumption of the NFR 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, 2022c).

The data flow for fuel consumption is shown in Figure 3.2.59.

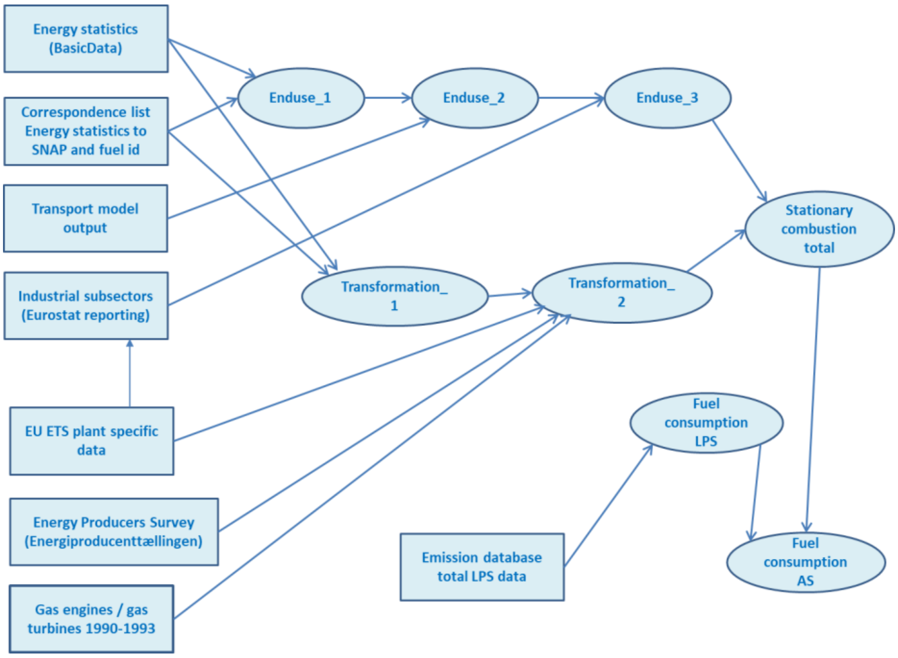


Figure 3.2.59 Fuel consumption data flow.

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 100-628 TJ in 1992-2018[11]) 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 Danish CO_2 emission inventory also refer to EU ETS.

For all other large point sources, the fuel consumption refers to an annually updated DEA database; the Energy Producers Survey (DEA, 2022b). 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 (DEA, 2022b) 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.

Fuel consumption for 1A1c Oil and gas extraction

The fuel consumption data for natural gas applied in 1A1c Oil and gas extraction reported in the EU ETS are not in agreement with the energy statistics for 1990-2020. This is because data in the energy statistics were based on the default net calorific value (NCV) for natural gas applied in Denmark, whereas the EU ETS data were based on fuel analysis of the natural gas applied offshore at each individual platform. DEA has improved the data collection for

[11] No border trade of petroleum coke in 2019-2021.

natural gas, and for 2021 the two data sets are in agreement. The fuel consumption data applied in the inventory for 1990-2020 for natural gas refer to the EU ETS data.

The gas oil consumption offshore included in EU ETS data have been implemented in the emission inventory. In the energy statistics this consumption is included in domestic sea transport (Rusbjerg, 2021).

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.

Biomethane

Biomethane is biogas upgraded for distribution in the natural gas grid. Biomethane has been included as a separate fuel in the energy statistics and in the emission inventory. In this report the fuel is referred to as biomethane, but others might refer to this fuel as bio natural gas or upgraded biogas.

Gas distributed in the Danish gas distribution system consists of (fossil) natural gas and biomethane. The gas composition has been assumed equal for all appliances in Denmark except for offshore consumption and the gas treatment plant. This assumption is in agreement with the Danish energy statistics (DEA, 2021a).

In the EU ETS data system, however, trading of biomethane certificates has been included in the fuel consumption data from the reporting year 2021. This agrees with the EU Guidance document for biomass issues in the EU ETS (EU 2017). In the chapter *5.2 Biogas in natural gas grids* it is specified that *Where an appropriate accounting system for biomass fractions is in place, it may be used under certain conditions. In particular a guarantee of origin system (in accordance with Articles 2(j) and 15 of the RES Directive) might be considered appropriate.* According to IPCC Guidelines (2006) the GHG emission inventories should be based on physical data and thus the trading of certificates will not be included in the inventories. Plant specific fuel consumption data for (fossil) natural gas and biomethane from EU ETS are implemented in the emission inventory by adding natural gas and biomethane and afterwards dividing into the two fuels according to the national split for pipeline gas.

The gas consumption offshore and in the Danish gas treatment plant have been assumed to be 100 % fossil natural gas. This is also in accordance with the Danish energy statistics.

Biogas and biomethane distributed in the town gas grid

The energy statistics includes a consumption of biogas for town gas production. In 2021, 119 TJ biogas and 114 TJ biomethane was distributed in the town gas grid.

In the energy statistics, biogas and biomethane distributed in the town gas grid is included in the fuel category town gas. In the emission inventory, biogas and biomethane distributed in the town gas grid have been included in the fuel categories biogas and biomethane.

Biogas

Biogas includes landfill gas, sludge gas and manure/organic waste gas[12]. In 2021, 75 % of the produced biogas was upgraded to biomethane. An increasing part of the biogas is upgraded to biomethane. Data from the Danish Energy Agency specifies production and consumption of each of the biogas types DEA, 2022e). In 2021, 75 % of the produced biogas was upgraded to biomethane.

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

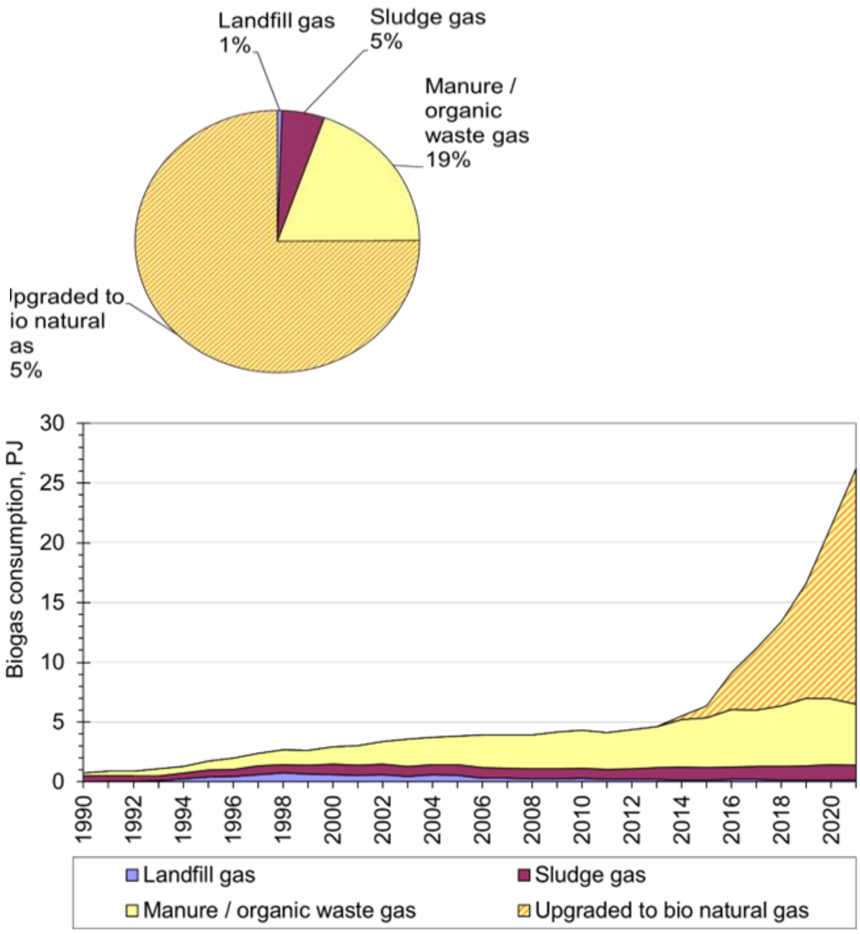


Figure 3.2.60 Biogas types (including biomethane) 2021 and the corresponding time series 1990-2021 (DEA, 2022e; DEA 2022a).

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 2021. 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.

[12] Based on manure with addition of other organic waste.

An indicative composition of town gas in 2015 according to the largest supplier of town gas in Denmark is shown in Table 3.2.16 (KE, 2015).

Table 3.2.16 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.

In earlier years, the composition of town gas was somewhat different. Table 3.2.17 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 3.2.17 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.

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.

Biogas and biomethane are applied for production of town gas, but in the emission inventory these fuels are included in the fuel categories biogas and biomethane, see the chapter *Biogas and biomethane distributed in the town gas grid*.

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 3.2.61. In 2019, 3 % of the incinerated waste was hazardous waste.

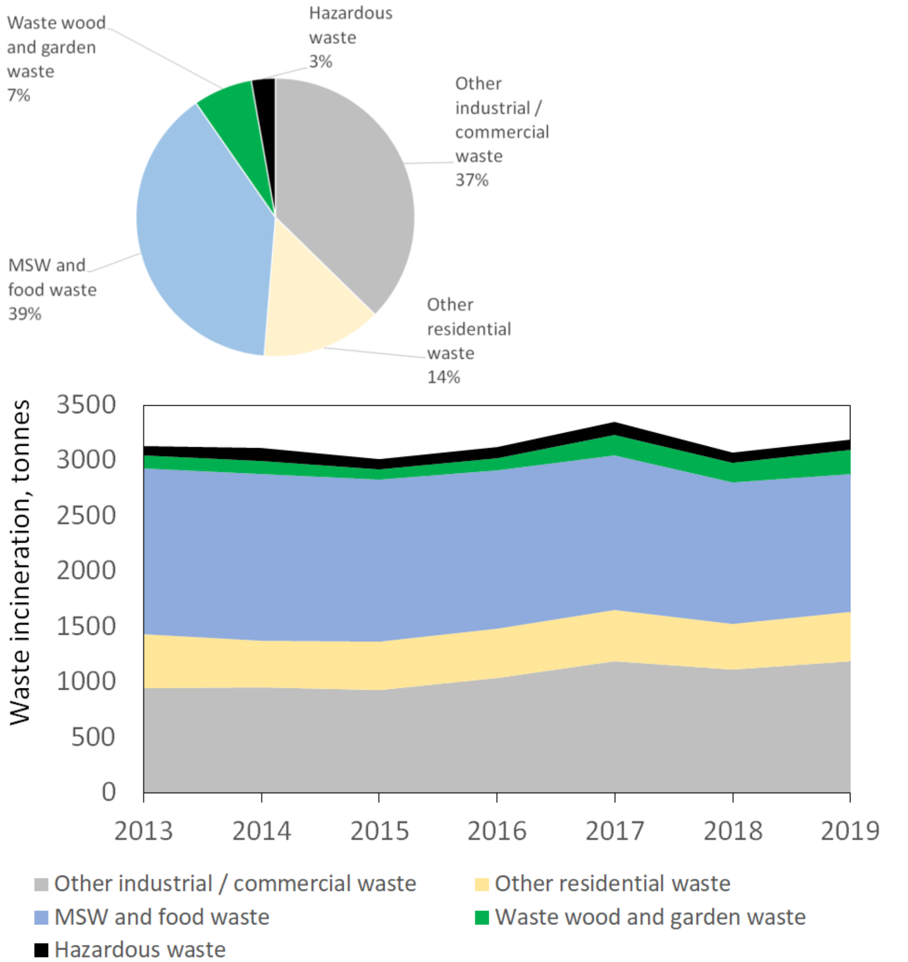


Figure 3.2.61 Waste fractions (weight) for incinerated waste in 2019 and the corresponding time series 2013-2019 (DEPA Waste statistics for 2019, 2021).

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.

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. 9.5 PJ in 2021. The use of fuels for non-energy purposes is included in the inventory in sector 2D Non-energy products from fuels and solvent use.

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 NIR Chapter 3.4 (Nielsen et al., 2023a).

3.2.7 Residential wood combustion

Residential wood combustion is the main emission source for some pollutants. The model applied for estimating emissions from residential wood combustion takes into account the replacement of old units, the different fuel consumption rates and emission factors of the applied technologies. The model for residential wood combustion emissions was revised in 2020 and reported in Nielsen and al. (2021b).

Residential wood combustion, fuel consumption

The total wood consumption is provided in the official energy statistics published by the DEA. However, for the purposes of calculating emissions from residential wood combustion, it is necessary to break down the wood consumption to different technologies, as different technologies have widely different emission factors.

In the Danish emission inventory, there is a differentiation between different types of stoves and boiler. In addition, there is a technology category for open fireplaces and similar and one for masonry stoves and similar. Wood pellets considered a separate fuel. The categories used in the inventory are provided in Table 3.2.18 below.

Table 3.2.18 Overview of the wood burning technologies.

Technology
Stoves (-1989)
Stoves (1990-2007)
Stoves (2008-2014)
Stoves (2015-2016)
Stoves (2017-)
Eco labelled stoves / new advanced stoves (-2014)
Eco labelled stoves / new advanced stoves (2015-2016)
Eco labelled stoves / new advanced stoves (2017-)
Open fireplaces and similar
Masonry heat accumulating stoves and similar
Boilers with accumulation tank (-1979)
Boilers without accumulation tank (-1979)
Boilers with accumulation tank (1980-)
Boilers without accumulation tank (1980-)
Pellet boilers / pellet stoves

The total number of wood-burning appliances has been estimated based on data from the Danish Chimneysweepers Association (SFL) supplemented with data from the Danish Building and Dwelling Register and data for replacement of older units. For further information, please see Nielsen et al. (2021b). The estimated wood consumption rates for each category are shown in Table 3.2.19 and Figure 3.2.62 below.

Table 3.2.19 Time series for fuel consumption in residential wood combustion, TJ.

Technology	1990	1995	2000	2005	2010	2015	2020	2021
Stoves (-1989)	5059	5505	4684	4829	4390	2069	430	299
Stoves (1990-2007)	189	1456	3004	6476	8545	7389	3971	3639
Stoves (2008-2014)	0	0	0	0	172	350	218	208
Stoves (2015-2016)	0	0	0	0	0	48	60	57
Stoves (2017-)	0	0	0	0	0	0	120	143
Eco labelled stoves / new advanced stoves (-2014)	0	0	0	1079	4003	5400	3347	3194
Eco labelled stoves / new advanced stoves (2015-2016)	0	0	0	0	0	432	538	515
Eco labelled stoves / new advanced stoves (2017-)	0	0	0	0	0	0	1076	1288
Open fireplaces and similar	215	276	289	439	581	533	331	317
Masonry heat accumulating stoves and similar	51	65	69	104	138	126	79	75
Boilers with accumulation tank (-1979)	1108	1064	745	566	1	0	0	0
Boilers without accumulation tank (-1979)	1108	1064	745	566	1	0	0	0
Boilers with accumulation tank (1980-)	681	1355	1965	3866	6307	6195	3905	3738
Boilers without accumulation tank (1980-)	426	773	1012	1786	2661	2029	1211	1159
Pellet boilers / pellet stoves	117	201	2112	6690	10105	12999	15101	16460

The time series for wood consumption in the 15 different technologies are illustrated in Figure 3.2.62. The consumption in new/ecolabelled stoves has increased. Details about disaggregation of the wood consumption between technologies are given in Nielsen et al. (2021b).

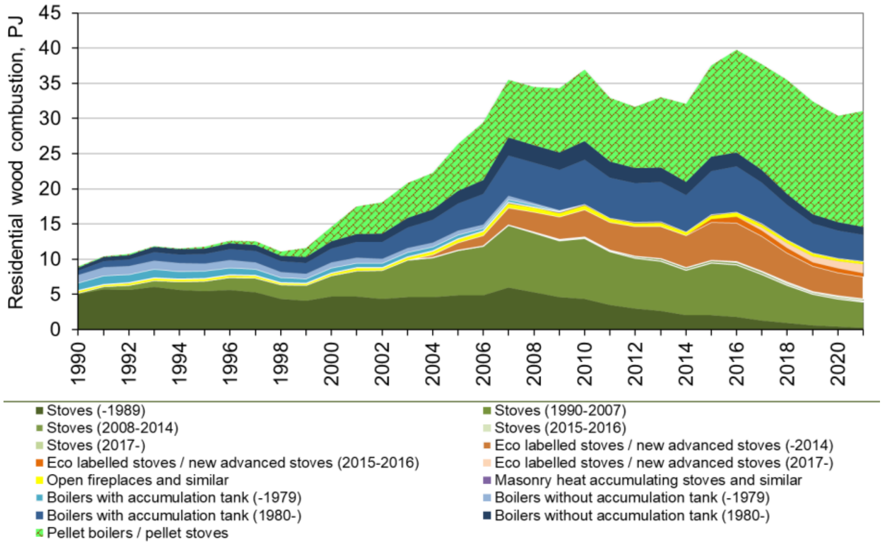


Figure 3.2.62 Technology specific wood consumption rates in residential plants.

Residential wood combustion, technology specific EMFs

For the pollutants NO_x, NMVOC, CO, NH_3, TSP, PM_{10}, $PM_{2.5}$, BC, PCB and PAH emission factors have been based on fuel consumption data and technology specific emission factors for 15 different technologies. Technology specific emission factors and implied emission factors for 2021 are shown in Table 3.2.20. References for the technology specific emission factors are shown in Table 3.2.21 and time series for IEFs are shown in Table 3.2.22.

Emission measurements performed in Denmark applying dilution tunnel have been prioritised. Thus, condensable particles are included in the emission factors.

The emission factors for dioxin are dependent on the applied wood but independent of stove technology. Four different emission factors are applied for: stoves, open fireplaces, boilers and pellet stoves/boilers.

For pollutants not included in Table 3.2.21, technology specific emission factors and time series have not been estimated and the emission factors are included in Chapter 3.2.8.

Table 3.2.20 Technology specific emission factors for residential wood combustion and IEF for log wood/wood chips, 2021.

Technology	NO_x, g/GJ	NMVOC, g/GJ	CO, g/GJ	NH_3, g/GJ	TSP, g/GJ	PM_{10}, g/GJ	$PM_{2.5}$, g/GJ	BC, g/GJ	PCDD/F, ng/GJ	dl-PCBs, ng/GJ	Benzo (a) pyrene, mg/GJ	Benzo (b) fluoran-thene, mg/GJ	Benzo (k) fluoran-thene, mg/GJ	Indeno (1.2.3-c,d) pyrene, mg/GJ
Stoves (-1989)	50	1200	8000	70	1000	950	930	17	1048	7049	116	55	119	62
Stoves (1990-2007)	50	600	4000	70	500	475	465	17	1048	7049	48	59	50	27
Stoves (2008-2014)	80	350	1900	37	389	370	362	31	1048	931	43	65	19	31
Stoves (2015-2016)	80	350	1900	37	317	301	295	31	1048	931	43	65	19	31
Stoves (2017-)	80	350	1900	37	253	240	235	31	1048	931	43	65	19	31
Eco labelled stoves / new advanced stoves (-2014)	75	175	1900	37	253	240	235	31	1048	466	43	65	19	31
Eco labelled stoves / new advanced stoves (2015-2016)	75	175	1900	37	190	181	177	31	1048	466	43	65	19	31
Eco labelled stoves / new advanced stoves (2017-)	75	175	1900	37	127	121	118	31	1048	466	43	65	19	31
Open fireplaces and similar	50	600	4000	74	882	838	820	34	55	60	35	25	29	21
Masonry heat accumulating stoves and sim-ilar	50	600	2402	70	63	60	59	18	282	7049	17	8	10	25
Boilers with accumulation tank (-1979)	80	350	9001	74	588	559	547	24	282	7049	991	926	632	1092
Boilers without accumulation tank (-1979)	80	350	10890	74	736	699	684	24	282	7049	991	926	632	1092
Boilers with accumulation tank (1980-)	95	175	1613	37	64	61	60	6	282	466	90	60	40	40
Boilers without accumulation tank (1980-)	95	350	1952	37	335	318	312	6	282	931	120	80	50	60
IEF residential log wood/wood chips, 2021	**74.4**	**332**	**2526**	**46.9**	**289**	**275**	**269**	**18.9**	**766**	**2312**	**63.5**	**62.1**	**36.7**	**35.0**
Pellet boilers / pellet stoves	**80**	**10**	**300**	**12**	**51**	**48**	**47**	**7**	**333**	**466**	**0.9**	**1.3**	**1.3**	**1.2**

Technology specific references and assumptions

The technology specific emission factor for each pollutant and technology are shown in Table 3.2.21. The reference and assumptions for each of the emission factor are also included in the table.

Table 3.2.21 Emission factors for residential wood combustion.

	Pollutant	Emission factor	Unit	Reference
Stoves (-1989)	NO_x	50	g/GJ	EEA (2019), Small combustion, Table 3.40, conventional stoves.
Stoves (1990-2007)	NO_x	50	g/GJ	EEA (2019), Small combustion, Table 3.40, conventional stoves.
Stoves (2008-2014)	NO_x	80	g/GJ	EEA (2019), Small combustion, Table 3.41, energy efficient stoves.
Stoves (2015-2016)	NO_x	80	g/GJ	Same as Stoves (2008-2014)
Stoves (2017-)	NO_x	80	g/GJ	Same as Stoves (2008-2014)
Eco labelled stoves / new advanced stoves (-2014)	NO_x	75	g/GJ	Andersen & Hvidbjerg (2017)
Eco labelled stoves / new advanced stoves (2015-2016)	NO_x	75	g/GJ	Andersen & Hvidbjerg (2017)
Eco labelled stoves / new advanced stoves (2017-)	NO_x	75	g/GJ	Andersen & Hvidbjerg (2017)
Open fireplaces and similar	NO_x	50	g/GJ	EEA (2019), Small Combustion, Open fireplaces, Table 3.39
Masonry heat accumulating stoves and similar	NO_x	50	g/GJ	EEA (2019), Small combustion, table 3.40, conventional stoves.
Boilers with accumulation tank (-1979)	NO_x	80	g/GJ	EEA (2019), Small combustion, table 3.43, conventional boilers.
Boilers without accumulation tank (-1979)	NO_x	80	g/GJ	EEA (2019), Small combustion, table 3.43, conventional boilers.
Boilers with accumulation tank (1980-)	NO_x	95	g/GJ	EEA (2019), Small combustion, table 3.42, advanced / eco-labelled stoves and boilers.
Boilers without accumulation tank (1980-)	NO_x	95	g/GJ	EEA (2019), Small combustion, table 3.42, advanced / eco-labelled stoves and boilers.
Pellet boilers / pellet stoves	NO_x	80	g/GJ	EEA (2019), Small combustion, table 3.44, pellet stoves and boilers.
Stoves (-1989)	NMVOC	1200	g/GJ	Assumed two times Stoves (1990-2007). EEA (2019), Small combustion, table 3.40, conventional stoves; 600 g/GJ (20 g/GJ - 3000 g/GJ).
Stoves (1990-2007)	NMVOC	600	g/GJ	EEA (2019), Small combustion, table 3.40, conventional stoves.
Stoves (2008-2014)	NMVOC	350	g/GJ	EEA (2019), Small combustion, table 3.41, energy efficient stoves.

	Pollutant	Emission factor	Unit	Reference
Stoves (2015-2016)	NMVOC	350	g/GJ	Same as Stove (2008-2014)
Stoves (2017-)	NMVOC	350	g/GJ	Same as Stove (2008-2014)
Eco labelled stoves / new advanced stoves (-2014)	NMVOC	175	g/GJ	Assumed ½ Stoves (2008-2014). The EEA (2019) emission factor for advanced / ecolabelled stoves and boilers is 250 g/GJ, but this emission factor has not been revised since the 2009 version of the Guidebook.
Eco labelled stoves / new advanced stoves (2015-2016)	NMVOC	175	g/GJ	Same as ecolabelled stoves (-2014).
Eco labelled stoves / new advanced stoves (2017-)	NMVOC	175	g/GJ	Same as ecolabelled stoves (-2014).
Open fireplaces and similar	NMVOC	600	g/GJ	EEA (2019), Open fireplaces, Table 3.39
Masonry heat accumulating stoves and similar	NMVOC	600	g/GJ	EEA (2019), Small combustion, table 3.40, conventional stoves.
Boilers with accumulation tank (-1979)	NMVOC	350	g/GJ	EEA (2019), Small combustion, table 3.43, conventional boilers.
Boilers without accumulation tank (-1979)	NMVOC	350	g/GJ	EEA (2019), Small combustion, table 3.43, conventional boilers.
Boilers with accumulation tank (1980-)	NMVOC	175	g/GJ	Assumed equal to ecolabelled stoves (-2014).
Boilers without accumulation tank (1980-)	NMVOC	350	g/GJ	Assumed 2 times the emission from boilers with accumulation tank (1980-)
Pellet boilers / pellet stoves	NMVOC	10	g/GJ	EEA (2019), Small combustion, table 3.44, pellet stoves and boilers.
Stoves (-1989)	CH_4	430	g/GJ	Methane emissions from residential biomass combustion, Paulrud et al. (2005) (SMED report, Sweden)
Stoves (1990-2007)	CH_4	215	g/GJ	Assumed ½ the emission factor for stoves (-1989).
Stoves (2008-2014)	CH_4	125	g/GJ	Estimated based on the emission factor for stoves (1990-2007) and the emission factors for NMVOC.
Stoves (2015-2016)	CH_4	125	g/GJ	Same as stoves (2008-2014)
Stoves (2017-)	CH_4	125	g/GJ	Same as stoves (2008-2014)
Eco labelled stoves / new advanced stoves (-2014)	CH_4	2	g/GJ	Low emissions from wood burning in an ecolabelled residential boiler. Olsson & Kjällstrand (2005).
Eco labelled stoves / new advanced stoves (2015-2016)	CH_4	2	g/GJ	Same as advanced / ecolabelled stoves
Eco labelled stoves / new advanced stoves (2017-)	CH_4	2	g/GJ	Same as advanced / ecolabelled stoves
Open fireplaces and similar	CH_4	430	g/GJ	Assumed equal to stoves (-1989).
Masonry heat accumulating stoves and similar	CH_4	215	g/GJ	Assumed equal to stoves (-1989).
Boilers with accumulation tank (-1979)	CH_4	211	g/GJ	Methane emissions from residential biomass combustion, Paulrud et al 2005 (SMED report, Sweden)
Boilers without accumulation tank (-1979)	CH_4	256	g/GJ	Methane emissions from residential biomass combustion, Paulrud et al 2005 (SMED report, Sweden)

	Pollutant	Emission factor	Unit	Reference
Boilers with accumulation tank (1980-)	CH_4	50	g/GJ	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-)	CH_4	50	g/GJ	Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004)
Pellet boilers / pellet stoves	CH_4	3	g/GJ	Methane emissions from residential biomass combustion, Paulrud et al 2005 (SMED report, Sweden)
Stoves (-1989)	CO	8000	g/GJ	Assumed two times Stoves (1990-2007). EEA (2019), Small combustion, table 3.40, conventional stoves; 4000 g/GJ (1000 g/GJ - 10,000 g/GJ).
Stoves (1990-2007)	CO	4000	g/GJ	EEA (2019), Small combustion, table 3.40, conventional stoves.
Stoves (2008-2014)	CO	1900	g/GJ	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Stoves (2015-2016)	CO	1900	g/GJ	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Stoves (2017-)	CO	1900	g/GJ	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Eco labelled stoves / new advanced stoves (-2014)	CO	1900	g/GJ	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Eco labelled stoves / new advanced stoves (2015-2016)	CO	1900	g/GJ	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Eco labelled stoves / new advanced stoves (2017-)	CO	1900	g/GJ	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Open fireplaces and similar	CO	4000	g/GJ	EEA (2019), Small Combustion, Table 3.39 Open fire-places
Masonry heat accumulating stoves and similar	CO	2402	g/GJ	Kindbom et al. (2017)
Boilers with accumulation tank (-1979)	CO	9001	g/GJ	Winther (2008)
Boilers without accumulation tank (-1979)	CO	10890	g/GJ	Winther (2008)
Boilers with accumulation tank (1980-)	CO	1613	g/GJ	Winther (2008)
Boilers without accumulation tank (1980-)	CO	1952	g/GJ	Winther (2008)
Pellet boilers / pellet stoves	CO	300	g/GJ	EEA (2019), Small Combustion, Table 3.44 Pellet stoves and boilers
Stoves (-1989)	NH_3	70	g/GJ	EEA (2019), Small combustion, table 3.40, conventional stoves.
Stoves (1990-2007)	NH_3	70	g/GJ	EEA (2019), Small combustion, table 3.40, conventional stoves.
Stoves (2008-2014)	NH_3	37	g/GJ	EEA (2019), Small combustion, table 3.41, energy efficient stoves.

	Pollutant	Emission factor	Unit	Reference
Stoves (2015-2016)	NH_3	37	g/GJ	Same as stoves (2008-2014).
Stoves (2017-)	NH_3	37	g/GJ	Same as stoves (2008-2014).
Eco labelled stoves / new advanced stoves (-2014)	NH_3	37	g/GJ	EEA (2019), Small combustion, table 3.42, advanced / eco-labelled stoves and boilers.
Eco labelled stoves / new advanced stoves (2015-2016)	NH_3	37	g/GJ	EEA (2019), Small combustion, table 3.42, advanced / eco-labelled stoves and boilers.
Eco labelled stoves / new advanced stoves (2017-)	NH_3	37	g/GJ	EEA (2019), Small combustion, table 3.42, advanced / eco-labelled stoves and boilers.
Open fireplaces and similar	NH_3	74	g/GJ	EEA (2019), Open fireplaces, Table 3.39
Masonry heat accumulating stoves and similar	NH_3	70	g/GJ	EEA (2019), Small combustion, table 3.40, conventional stoves.
Boilers with accumulation tank (-1979)	NH_3	74	g/GJ	EEA (2019), Small combustion, table 3.43, conventional boilers.
Boilers without accumulation tank (-1979)	NH_3	74	g/GJ	EEA (2019), Small combustion, table 3.43, conventional boilers.
Boilers with accumulation tank (1980-)	NH_3	37	g/GJ	EEA (2019), Small combustion, table 3.42, advanced / eco-labelled stoves and boilers.
Boilers without accumulation tank (1980-)	NH_3	37	g/GJ	EEA (2019), Small combustion, table 3.42, advanced / eco-labelled stoves and boilers.
Pellet boilers / pellet stoves	NH_3	12	g/GJ	EEA (2019), Small combustion, table 3.44, pellet stoves and boilers.
Stoves (-1989)	TSP	1000	g/GJ	Glasius et al. (2005)
Stoves (1990-2007)	TSP	500	g/GJ	Glasius et al. (2005), Glasius et al. (2007), Kindbom et al. (2017) and Schleicher (2018)
Stoves (2008-2014)	TSP	389	g/GJ	Kindbom et al. (2017)
Stoves (2015-2016)	TSP	317	g/GJ	MST (2015). Limit value 5 g/kg.
Stoves (2017-)	TSP	253	g/GJ	MST (2015). Limit value 4 g/kg.
Eco labelled stoves / new advanced stoves (-2014)	TSP	253	g/GJ	Nordic Ecolabelling limit 2012 update for hand fed stove for temporary firing or inset stove (4 g/kg).
Eco labelled stoves / new advanced stoves (2015-2016)	TSP	190	g/GJ	Nordic Ecolabelling limit update for hand fed stove for temporary firing or inset stove (3 g/kg).
Eco labelled stoves / new advanced stoves (2017-)	TSP	127	g/GJ	Nordic Ecolabelling limit update
Open fireplaces and similar	TSP	882	g/GJ	Alves et al. (2011)
Masonry heat accumulating stoves and similar	TSP	63	g/GJ	Tissari et al. (2009)
Boilers with accumulation tank (-1979)	TSP	588	g/GJ	Winther (2008)
Boilers without accumulation tank (-1979)	TSP	736	g/GJ	Winther (2008)
Boilers with accumulation tank (1980-)	TSP	64	g/GJ	Winther (2008)
Boilers without accumulation tank (1980-)	TSP	335	g/GJ	Winther (2008)

	Pollutant	Emission factor	Unit	Reference
Pellet boilers / pellet stoves	TSP	51	g/GJ	Kindbom et al. (2017)
Stoves (-1989)	PM_{10}	950	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (1990-2007)	PM_{10}	475	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (2008-2014)	PM_{10}	370	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (2015-2016)	PM_{10}	301	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (2017-)	PM_{10}	240	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Eco labelled stoves / new advanced stoves (-2014)	PM_{10}	240	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Eco labelled stoves / new advanced stoves (2015-2016)	PM_{10}	181	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Eco labelled stoves / new advanced stoves (2017-)	PM_{10}	121	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Open fireplaces and similar	PM_{10}	838	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Masonry heat accumulating stoves and similar	PM_{10}	60	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers with accumulation tank (-1979)	PM_{10}	559	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers without accumulation tank (-1979)	PM_{10}	699	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers with accumulation tank (1980-)	PM_{10}	61	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers without accumulation tank (1980-)	PM_{10}	318	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Pellet boilers / pellet stoves	PM_{10}	48	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (-1989)	$PM_{2.5}$	930	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (1990-2007)	$PM_{2.5}$	465	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (2008-2014)	$PM_{2.5}$	362	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (2015-2016)	$PM_{2.5}$	295	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP

	Pollutant	Emission factor	Unit	Reference
Stoves (2017-)	$PM_{2.5}$	235	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Eco labelled stoves / new advanced stoves (-2014)	$PM_{2.5}$	235	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Eco labelled stoves / new advanced stoves (2015-2016)	$PM_{2.5}$	177	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Eco labelled stoves / new advanced stoves (2017-)	$PM_{2.5}$	118	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Open fireplaces and similar	$PM_{2.5}$	820	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Masonry heat accumulating stoves and similar	$PM_{2.5}$	59	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers with accumulation tank (-1979)	$PM_{2.5}$	547	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers without accumulation tank (-1979)	$PM_{2.5}$	684	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers with accumulation tank (1980-)	$PM_{2.5}$	60	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers without accumulation tank (1980-)	$PM_{2.5}$	312	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Pellet boilers / pellet stoves	$PM_{2.5}$	47	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (-1989)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Stoves (1990-2007)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Stoves (2008-2014)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Stoves (2015-2016)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Stoves (2017-)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Eco labelled stoves / new advanced stoves (-2014)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Eco labelled stoves / new advanced stoves (2015-2016)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Eco labelled stoves / new advanced stoves (2017-)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Open fireplaces and similar	PCDD/F	55	ng/GJ	Gullet et al. (2005)
Masonry heat accumulating stoves and similar	PCDD/F	282	ng/GJ	Assumed equal to boilers

	Pollutant	Emission factor	Unit	Reference
Boilers with accumulation tank (-1979)	PCDD/F	282	ng/GJ	Glasius et al. (2005), Glasius et al. (2007), Hübner et al. (2005) and Hedman et al. (2006)
Boilers without accumulation tank (-1979)	PCDD/F	282	ng/GJ	Glasius et al. (2005), Glasius et al. (2007), Hübner et al. (2005) and Hedman et al. (2006)
Boilers with accumulation tank (1980-)	PCDD/F	282	ng/GJ	Glasius et al. (2005), Glasius et al. (2007), Hübner et al. (2005) and Hedman et al. (2006)
Boilers without accumulation tank (1980-)	PCDD/F	282	ng/GJ	Glasius et al. (2005), Glasius et al. (2007), Hübner et al. (2005) and Hedman et al. (2006)
Pellet boilers / pellet stoves	PCDD/F	333	ng/GJ	Hedman et al. (2006)
Stoves (-1989)	Benzo(a)	116	µg/GJ	Glasius et al. (2005)
Stoves (1990-2007)	Benzo(a)	48	µg/GJ	Glasius et al. (2005) except for Benzo(b)fluoranthene that refers to Schleicher (2018)
Stoves (2008-2014)	Benzo(a)	43	µg/GJ	Schleicher (2018)
Stoves (2015-2016)	Benzo(a)	43	µg/GJ	Schleicher (2018)
Stoves (2017-)	Benzo(a)	43	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (-2014)	Benzo(a)	43	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2015-2016)	Benzo(a)	43	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2017-)	Benzo(a)	43	µg/GJ	Schleicher (2018)
Open fireplaces and similar	Benzo(a)	35	µg/GJ	Gullet et al. (2003)
Masonry heat accumulating stoves and similar	Benzo(a)	17	µg/GJ	Tissari et al. (2007)
Boilers with accumulation tank (-1979)	Benzo(a)	991	µg/GJ	Winther (2008)
Boilers without accumulation tank (-1979)	Benzo(a)	991	µg/GJ	Winther (2008)
Boilers with accumulation tank (1980-)	Benzo(a)	90	µg/GJ	Johansson et al. (2006)
Boilers without accumulation tank (1980-)	Benzo(a)	120	µg/GJ	Johansson et al. (2006)
Pellet boilers / pellet stoves	Benzo(a)	0.9	µg/GJ	Orasche et al. (2012), distribution between Benzo(b)fluoranthene and Benzo(k)fluoranthene according to Lamberg et al. (2011).
Stoves (-1989)	Benzo(b)	55	µg/GJ	Glasius et al. (2005)
Stoves (1990-2007)	Benzo(b)	59	µg/GJ	Glasius et al. (2005) except for Benzo(b)fluoranthene that refers to Schleicher (2018)
Stoves (2008-2014)	Benzo(b)	65	µg/GJ	Schleicher (2018)
Stoves (2015-2016)	Benzo(b)	65	µg/GJ	Schleicher (2018)
Stoves (2017-)	Benzo(b)	65	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (-2014)	Benzo(b)	65	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2015-2016)	Benzo(b)	65	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2017-)	Benzo(b)	65	µg/GJ	Schleicher (2018)
Open fireplaces and similar	Benzo(b)	25	µg/GJ	Gullet et al. (2003)
Masonry heat accumulating stoves and similar	Benzo(b)	7.6	µg/GJ	Tissari et al. (2007)

	Pollutant	Emission factor	Unit	Reference
Boilers with accumulation tank (-1979)	Benzo(b)	926	µg/GJ	Winther (2008)
Boilers without accumulation tank (-1979)	Benzo(b)	926	µg/GJ	Winther (2008)
Boilers with accumulation tank (1980-)	Benzo(b)	60	µg/GJ	Johansson et al. (2006)
Boilers without accumulation tank (1980-)	Benzo(b)	80	µg/GJ	Johansson et al. (2006)
Pellet boilers / pellet stoves	Benzo(b)	1.3	µg/GJ	Orasche et al. (2012), distribution between Benzo(b)fluoranthene and Benzo(k)fluoranthene according to Lamberg et al. (2011).
Stoves (-1989)	Benzo(k)	119	µg/GJ	Glasius et al. (2005)
Stoves (1990-2007)	Benzo(k)	50	µg/GJ	Glasius et al. (2005) except for Benzo(b)fluoranthene that refers to Schleicher (2018)
Stoves (2008-2014)	Benzo(k)	19	µg/GJ	Schleicher (2018)
Stoves (2015-2016)	Benzo(k)	19	µg/GJ	Schleicher (2018)
Stoves (2017-)	Benzo(k)	19	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (-2014)	Benzo(k)	19	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2015-2016)	Benzo(k)	19	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2017-)	Benzo(k)	19	µg/GJ	Schleicher (2018)
Open fireplaces and similar	Benzo(k)	29	µg/GJ	Gullet et al. (2003)
Masonry heat accumulating stoves and similar	Benzo(k)	9.5	µg/GJ	Tissari et al. (2007)
Boilers with accumulation tank (-1979)	Benzo(k)	632	µg/GJ	Winther (2008)
Boilers without accumulation tank (-1979)	Benzo(k)	632	µg/GJ	Winther (2008)
Boilers with accumulation tank (1980-)	Benzo(k)	40	µg/GJ	Johansson et al. (2006)
Boilers without accumulation tank (1980-)	Benzo(k)	50	µg/GJ	Johansson et al. (2006)
Pellet boilers / pellet stoves	Benzo(k)	1.3	µg/GJ	Orasche et al. (2012), distribution between Benzo(b)fluoranthene and Benzo(k)fluoranthene according to Lamberg et al. (2011).
Stoves (-1989)	Indeno	62	µg/GJ	Glasius et al. (2005)
Stoves (1990-2007)	Indeno	27	µg/GJ	Glasius et al. (2005) except for Benzo(b)fluoranthene that refers to Schleicher (2018)
Stoves (2008-2014)	Indeno	31	µg/GJ	Schleicher (2018)
Stoves (2015-2016)	Indeno	31	µg/GJ	Schleicher (2018)
Stoves (2017-)	Indeno	31	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (-2014)	Indeno	31	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2015-2016)	Indeno	31	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2017-)	Indeno	31	µg/GJ	Schleicher (2018)
Open fireplaces and similar	Indeno	21	µg/GJ	Gullet et al. (2003)
Masonry heat accumulating stoves and similar	Indeno	25	µg/GJ	Tissari et al. (2007)
Boilers with accumulation tank (-1979)	Indeno	1092	µg/GJ	Winther (2008)
Boilers without accumulation tank (-1979)	Indeno	1092	µg/GJ	Winther (2008)

	Pollutant	Emission factor	Unit	Reference
Boilers with accumulation tank (1980-)	Indeno	40	µg/GJ	Johansson et al. (2006)
Boilers without accumulation tank (1980-)	Indeno	60	µg/GJ	Johansson et al. (2006)
Pellet boilers / pellet stoves	Indeno	1.2	µg/GJ	Orasche et al. (2012), distribution between Benzo(b)fluoranthene and Benzo(k)fluoranthene according to Lamberg et al. (2011).
Stoves (-1989)	dl-PCB	7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Stoves (1990-2007)	dl-PCB	7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Stoves (2008-2014)	dl-PCB	931	ng/GJ	Hedman (2006), modern boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Stoves (2015-2016)	dl-PCB	931	ng/GJ	Same as stoves (2008-2014).
Stoves (2017-)	dl-PCB	931	ng/GJ	Same as stoves (2008-2014).
Eco labelled stoves / new advanced stoves (-2014)	dl-PCB	466	ng/GJ	Hedman (2006), assumed ½ stoves (2017-)
Eco labelled stoves / new advanced stoves (2015-2016)	dl-PCB	466	ng/GJ	Same as Eco labelled stoves / new advanced stoves (-2014)
Eco labelled stoves / new advanced stoves (2017-)		466	ng/GJ	Same as Eco labelled stoves / new advanced stoves (-2014)
Open fireplaces and similar	dl-PCB	60	ng/GJ	EEA (2019), Open fireplaces, Table 3.39
Masonry heat accumulating stoves and similar		7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Boilers with accumulation tank (-1979)	dl-PCB	7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Boilers without accumulation tank (-1979)	dl-PCB	7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Boilers with accumulation tank (1980-)	dl-PCB	466	ng/GJ	Assumed equal to Eco labelled stoves / new advanced stoves (-2014)
Boilers without accumulation tank (1980-)	dl-PCB	931	ng/GJ	Hedman (2006), modern boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Pellet boilers / pellet stoves	dl-PCB	466	ng/GJ	Hedman (2006), assumed ½ modern boiler.
Stoves (-1989)	BC	17	g/GJ	Schleicher (2018)
Stoves (1990-2007)	BC	17	g/GJ	Schleicher (2018)
Stoves (2008-2014)	BC	31	g/GJ	Andersen & Hvidbjerg (2017)
Stoves (2015-2016)	BC	31	g/GJ	Andersen & Hvidbjerg (2017)
Stoves (2017-)	BC	31	g/GJ	Andersen & Hvidbjerg (2017)
Eco labelled stoves / new advanced stoves (-2014)	BC	31	g/GJ	Andersen & Hvidbjerg (2017)
Eco labelled stoves / new advanced stoves (2015-2016)	BC	31	g/GJ	Andersen & Hvidbjerg (2017)
Eco labelled stoves / new advanced stoves (2017-)		31	g/GJ	Andersen & Hvidbjerg (2017)
Open fireplaces and similar	BC	34	g/GJ	Alves et al. (2011)

	Pollutant	Emission factor	Unit	Reference
Masonry heat accumulating stoves and similar		18	g/GJ	Tissari et al. (2007)
Boilers with accumulation tank (-1979)	BC	24	g/GJ	Kindbom et al. (2017)
Boilers without accumulation tank (-1979)	BC	24	g/GJ	Kindbom et al. (2017)
Boilers with accumulation tank (1980-)	BC	6	g/GJ	Kindbom et al. (2017)
Boilers without accumulation tank (1980-)	BC	6	g/GJ	Kindbom et al. (2017)
Pellet boilers / pellet stoves	BC	7	g/GJ	Kindbom et al. (2017)

Implied emission factors for residential wood, time series

The time series for the residential wood combustion emission factors (not including wood pellets) have been estimated based on the time series for wood consumption in each technology. The time series are shown in Table 3.2.22.

Table 3.2.22 Implied emission factor time series for residential wood combustion (not including wood pellets).

Year	NO_x, g/GJ	NMVOC, g/GJ	CO, g/GJ	NH_3, g/GJ	TSP, g/GJ	PM_{10}, g/GJ	$PM_{2.5}$, g/GJ	BC, g/GJ	PCDD/F, ng/GJ	dl-PCB, ng/GJ	Benzo(a)-pyrene, mg/GJ	Benzo(b)-fluoran-thene, mg/GJ	Benzo(k)-fluoran-thene, mg/GJ	Indeno (1,2,3-c,d)-pyrene, mg/GJ
1990	63.2	836	7488	67.0	792	752	737	17.8	731	6076	330	274	234	316
1991	63.3	823	7302	66.5	776	737	722	17.6	733	6000	316	263	225	302
1992	63.4	810	7118	66.1	760	722	707	17.3	734	5924	303	251	215	287
1993	63.6	798	6934	65.6	744	707	692	17.1	735	5849	290	240	206	272
1994	63.7	785	6753	65.2	728	692	677	16.9	736	5774	276	228	197	258
1995	63.8	773	6574	64.8	712	677	663	16.7	738	5701	263	217	188	243
1996	63.9	761	6397	64.3	697	662	648	16.5	739	5629	250	206	179	229
1997	64.0	748	6208	63.9	680	646	633	16.2	741	5560	237	195	170	214
1998	64.1	734	6022	63.5	664	631	617	16.0	743	5492	224	183	161	200
1999	64.2	721	5838	63.1	647	615	602	15.8	746	5425	211	172	152	185
2000	64.3	708	5656	62.7	631	600	587	15.6	747	5359	198	161	143	171
2001	64.4	691	5448	62.3	611	581	569	15.4	749	5293	184	151	134	157
2002	64.5	673	5240	61.9	592	562	550	15.2	751	5226	171	140	124	143
2003	64.5	656	5037	61.6	572	544	533	15.0	753	5162	159	130	115	129
2004	65.3	629	4785	60.3	548	520	509	15.2	755	4921	146	119	106	116
2005	66.0	603	4544	59.1	524	498	487	15.4	758	4687	133	109	96	102
2006	66.5	587	4359	58.1	507	482	472	15.5	761	4509	121	99	87	89
2007	67.0	570	4176	57.2	491	466	456	15.6	764	4333	109	89	79	77
2008	67.6	553	3988	56.1	473	450	440	15.7	766	4142	98	79	71	64
2009	68.3	530	3771	55.0	452	430	421	15.8	766	3930	86	70	62	52
2010	69.0	508	3555	53.9	431	410	401	15.9	766	3718	75.0	60.6	53.5	39.6
2011	69.5	489	3443	53.3	417	396	388	16.1	766	3588	73.6	60.7	51.6	39.0
2012	70.0	471	3335	52.6	403	383	375	16.4	766	3459	72.3	60.8	49.8	38.4
2013	70.5	453	3228	52.0	390	370	363	16.7	766	3330	71.0	60.9	48.1	37.8
2014	71.0	435	3125	51.3	377	358	351	17.0	766	3200	69.7	61.1	46.4	37.3
2015	71.5	418	3025	50.7	363	345	338	17.2	766	3071	68.6	61.2	44.8	36.8
2016	72.0	401	2929	50.0	349	332	325	17.5	766	2941	67.4	61.3	43.2	36.4
2017	72.5	386	2838	49.4	336	319	313	17.8	766	2814	66.5	61.4	41.7	36.0
2018	73.0	371	2752	48.7	324	307	301	18.1	766	2686	65.6	61.6	40.3	35.7
2019	73.5	357	2672	48.1	312	296	290	18.3	766	2560	64.8	61.8	39.1	35.4
2020	74.0	344	2596	47.5	300	285	279	18.6	766	2435	64.2	61.9	37.9	35.2
2021	74.4	332	2526	46.9	289	275	269	18.9	766	2312	63.5	62.1	36.7	35.0

3.2.8 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 emission factors are either nationally referenced or based on the EEA Guidebook (EEA, 2019)[13].

Time series are provided in Annex 3A-4.

SO_2 emission factors

The SO_2 emission factors and references are shown in Table 3.2.23. Further details are included in Nielsen et al. (2018).

Time series are shown in Annex 3A-4. Time series have been estimated for:

- Combustion of coal in power plants
- Combustion of coal in other plants (including district heating and industrial plants)
- Combustion of coal in food industry
- Combustion of coal, petroleum coke and industrial waste in cement industry.
- Combustion of BKB in residential and industrial plants
- Combustion of coke oven coke in power plants
- Combustion of coke oven coke in residential and industrial plants
- Combustion of petroleum coke in other sectors than cement industry.
- Combustion of residual oil in power plants.
- Combustion of residual oil in refineries.
- Combustion of residual oil in other plants.
- Combustion of gas oil.
- Combustion of orimulsion.
- Waste incineration in CHP plants.
- Waste incineration in district heating and other plants.

[13] And former editions of the EEA Guidebook.

Table 3.2.23 SO_2 emission factors and references, 2021.

Fuel type	Fuel	NFR	NFR_name	SNAP	SO_2 emission factor, g/GJ	Reference
Solid	Anodic carbon	1A2g	Industry - other	032002	855	DCE estimate based on plant specific data.
	Coal	1A1a	Public electricity and heat production	0101	7	DCE estimate based on emission data reported by plant owners and fuel consumption data from EU ETS (2022).
				0102	389	DCE estimate based on country specific coal data from Dong Energy (Jensen, 2017) and coal import data from DEA (2022c).
		1A2a-g	Industry	03 except 0309, 0316, and 030701	389	DCE estimate based on country specific coal data from Dong Energy (Jensen, 2017) and coal import data from DEA (2022c).
		1A2e	Industry, food, beverages and tobacco	0309	231	DCE estimate based on plant specific data for 2010.
		1A2f	Cement industry	0316	67	DCE estimate based on plant specific data for 2011-2015.
		1A2g	Mineral wool production	Mineral wool 030701	861	DCE estimate based on plant specific data for 2010-2015.
		1A4b i	Residential	020200	389	DCE estimate based on country specific coal data from Dong Energy (Jensen, 2017) and coal import data from DEA (2022c).
		1A4c i	Agriculture/ Forestry	0203	389	DCE estimate based on country specific coal data from Dong Energy (Jensen, 2017) and coal import data from DEA (2022c).
	Fly ash fossil	1A1a	Public electricity and heat production	010101	7	Assumed equal to coal.
	BKB	1A4b	Residential	0202	389	Assumed equal to coal. DCE assumption.
	Coke oven coke	1A2a-g	Industry	03	389	Assumed equal to coal. DCE assumption.
		1A2e	Industry, food, beverages and tobacco	0309	231	DCE estimate based on plant specific data for 2010.
		1A2g	Mineral wool production	Mineral wool 030701	861	DCE estimate based on plant specific data for 2010-2015.
		1A4b	Residential	0202	389	Assumed equal to coal. DCE assumption.
Liquid	Petroleum coke	1A2a-g	Industry	03	605	DCE calculation based on DEPA (2001b), DEPA (2014), DEA (2016a) and EMEP (2006).
		1A2g	Cement industry	0316	67	DCE estimate based on plant specific data for 2011-2015.
		1A4a	Commercial/ Institutional	0201	605	DCE calculation based on DEPA (2001b), DEPA (2014), DEA (2016a) and EMEP (2006).
		1A4b	Residential	0202	605	DCE calculation based on DEPA (2001b), DEPA (2014), DEA (2016a) and EMEP (2006).
		1A4c	Agriculture/ Forestry	0203	605	DCE calculation based on DEPA (2001b), DEPA (2014), DEA (2016a) and EMEP (2006).
	Residual oil	1A1a	Public electricity and heat production	0101	100	DCE estimate based on plant specific data for 2008 and 2009.
				0102	344	DCE estimate based on EOF (2017) and DEA (2016a)
		1A1b	Petroleum refining	010306	339	DCE estimate based on plant specific data for year 2019.
		1A2a-g	Industry	03	344	DCE estimate based on EOF (2017) and DEA (2016a)

Fuel type	Fuel	NFR	NFR_name	SNAP	SO_2 emission factor, g/GJ	Reference
		1A4a	Commercial/ Institutional	0201	344	DCE estimate based on EOF (2017) and DEA (2016a)
		1A4b	Residential	0202	344	DCE estimate based on EOF (2017) and DEA (2016a)
		1A4c i	Agriculture/ Forestry	0203	344	DCE estimate based on EOF (2017) and DEA (2016a)
	Gas oil	1A1a	Public electricity and heat production	0101 0102	6.7	DCE estimate based on DEA (2018e)
		1A1b	Petroleum refining	010306	6.7	DCE estimate based on DEA (2018e)
		1A1c	Oil and gas extraction	0105	6.7	DCE estimate based on DEA (2018e)
		1A2a-g	Industry	03	6.7	DCE estimate based on DEA (2018e)
		1A4a	Commercial/ Institutional	0201	6.7	DCE estimate based on DEA (2018e)
		1A4b i	Residential	0202	6.7	DCE estimate based on DEA (2018e)
		1A4c	Agriculture/Forestry	0203	6.7	DCE estimate based on DEA (2018e)
	Kerosene	1A2g	Industry - other	03	5	DCE estimate based on Tønder (2004) and Shell (2013).
		1A4a	Commercial/ Institutional	0201	5	DCE estimate based on Tønder (2004) and Shell (2013).
		1A4b i	Residential	0202	5	DCE estimate based on Tønder (2004) and Shell (2013).
		1A4c i	Agriculture/ Forestry	0203	5	DCE estimate based on Tønder (2004) and Shell (2013).
	LPG	1A1a	Public electricity and heat production	All	0.13	DCE estimate based on Augustesen (2003), Krebs (2003) and DEA (2016a).
		1A2a-g	Industry	03	0.13	DCE estimate based on Augustesen (2003), Krebs (2003) and DEA (2016a).
		1A4a	Commercial/ Institutional	0201	0.13	DCE estimate based on Augustesen (2003), Krebs (2003) and DEA (2016a).
		1A4b i	Residential	0202	0.13	DCE estimate based on Augustesen (2003), Krebs (2003) and DEA (2016a).
		1A4c i	Agriculture/ Forestry	0203	0.13	DCE estimate based on Augustesen (2003), Krebs (2003) and DEA (2016a).
	Refinery gas	1A1b	Petroleum refining	0103	1	DCE estimate based on plant specific data for one plant, average value for 1995-2002.
Gas	Natural gas	1A1a	Public electricity and heat production	0101, 0102, except engines	0.43	DCE estimate based on data from Energinet.dk (2017) and Energinet.dk (2013)
				010105, engines	0.5	Kristensen (2003)
		1A1b	Petroleum refining	0103	0.43	DCE estimate based on data from Energinet.dk (2017) and Energinet.dk (2013)
		1A1c	Oil and gas extraction	0105	0.43	DCE estimate based on data from Energinet.dk (2017) and Energinet.dk (2013)
		1A2a-g	Industry	03 except engines	0.43	DCE estimate based on data from Energinet.dk (2017) and Energinet.dk (2013)
				Engines	0.5	Kristensen (2003)
		1A4a	Commercial/ Institutional	0201 except engines	0.43	DCE estimate based on data from Energinet.dk (2017) and Energinet.dk (2013)
				Engines	0.5	Kristensen (2003)

Fuel type	Fuel	NFR	NFR_name	SNAP	SO_2 emission factor, g/GJ	Reference
		1A4b i	Residential	0202 except engines	0.43	DCE estimate based on data from Energinet.dk (2017) and Energinet.dk (2013)
				Engines	0.5	Kristensen (2003)
		1A4c i	Agriculture/ Forestry	0203 except engines	0.43	DCE estimate based on data from Energinet.dk (2017) and Energinet.dk (2013)
				Engines	0.5	Kristensen (2003)
Waste	Waste	1A1a	Public electricity and heat production	0101	8.3	Nielsen et al. (2010a)
				0102	14	DCE estimate based on plant specific data for four plants, 2009 data.
		1A2a-g	Industry	03	14	Assumed equal to district heating plants (DCE assumption).
		1A4a	Commercial/ Institutional	0201	14	Assumed equal to district heating plants (DCE assumption).
	Industrial waste	1A2f	Industry – non-metallic minerals	031600	67	DCE estimate based on plant specific data for 2011-2015.
Biomass	Wood	1A1a	Public electricity and heat production	0101	1.9	Nielsen et al. (2010a)
				0102	11	EEA (2019), Energy Industries Table 3.13 Wood
		1A2a-g	Industry	03	11	EEA (2019), Manufacturing industries and construction (combustion)
		1A4a	Commercial/ Institutional	0201	11	EEA (2019), Small combustion Table 3.10 and Table 3.45 – Table 3.48
		1A4b i	Residential	0202	11	EEA (2019), Small combustion Table 3.6 Residential wood
		1A4c i	Agriculture/ Forestry	0203	11	EEA (2019), Small combustion Table 3.10 and Table 3.45 – Table 3.48
	Straw	1A1a	Public electricity and heat production	0101	49	Nielsen et al. (2010a)
				0102	115	Assumed equal to farmhouse boilers.
		1A4b i	Residential	0202	115	Jensen et al. (2017)
		1A4c i	Agriculture/ Forestry	0203	115	Jensen et al. (2017)
	Wood pellets	1A1a	Public electricity and heat production	0101	1.9	Nielsen et al. (2010a)
		1A2a-g	Industry	03	11	EEA (2019), Manufacturing industries and construction (combustion)
		1A4a	Commercial/ Institutional	0201	11	EEA (2019), Small combustion Table 3.10 and Table 3.45 – Table 3.48
		1A4b i	Residential	0202	11	EEA (2019), Small combustion Table 3.6 Residential wood
		1A4c i	Agriculture/ Forestry	0203	11	EEA (2019), Small combustion Table 3.10 and Table 3.45 – Table 3.48
	Bio oil	1A1a	Public electricity and heat production	0101	0.3	DCE estimate based on Folkecenter for Vedvarende Energi (2000) and DEA (2016a).
				0102	0.3	DCE estimate based on Folkecenter for Vedvarende Energi (2000) and DEA (2016a).
		1A2a-g	Industry	03	0.3	DCE estimate based on Folkecenter for Vedvarende Energi (2000) and DEA (2016a).

Fuel type	Fuel	NFR	NFR_name	SNAP	SO_2 emission factor, g/GJ	Reference
		1A4b i	Residential	0202	0.3	DCE estimate based on Folkecenter for Vedvarende Energi (2000) and DEA (2016a).
	Biogas	1A1a	Public electricity and heat production	0101, except engines	25	DCE estimate based on Christiansen (2003), Hjort-Gregersen (1999) and DEA (2016a).
				Engines	19.2	Nielsen & Illerup (2003)
				0102	25	DCE estimate based on Christiansen (2003), Hjort-Gregersen (1999) and DEA (2016a).
		1A2a-g	Industry	03, except engines	25	DCE estimate based on Christiansen (2003), Hjort-Gregersen (1999) and DEA (2016a).
				03, engines	19.2	Nielsen & Illerup (2003)
		1A4a	Commercial/ Institutional	0201, except engines	25	DCE estimate based on Christiansen (2003), Hjort-Gregersen (1999) and DEA (2016a).
				020105	19.2	Nielsen & Illerup (2003)
		1A4b	Residential	0202	25	DCE estimate based on Christiansen (2003), Hjort-Gregersen (1999) and DEA (2016a).
		1A4c i	Agriculture/ Forestry	0203, except engines	25	DCE estimate based on Christiansen (2003), Hjort-Gregersen (1999) and DEA (2016a).
				020304	19.2	Nielsen & Illerup (2003)
	Bio gasification gas	1A1a	Public electricity and heat production	010105	7	Kristensen (2017a) and Kristensen (2017b)
	Biomethane	1A1a	Public electricity and heat production	0101	0.43	Assumed equal to natural gas.
				010105	0.5	Assumed equal to natural gas.
		1A2a-g	Industry	03, except engines	0.43	Assumed equal to natural gas.
				03, Engines	0.5	Assumed equal to natural gas.
		1A4a	Commercial/ Institutional	0201, except engines	0.43	Assumed equal to natural gas.
				0201, engines	0.5	Assumed equal to natural gas.
		1A4b	Residential	0202, except engines	0.43	Assumed equal to natural gas.
				0202, engines	0.5	Assumed equal to natural gas.
		1A4c	Agriculture/ Forestry	0203, except engines	0.43	Assumed equal to natural gas.
				0203, engines	0.5	Assumed equal to natural gas.

NO_x emission factors

The NO_x emission factors and references are shown in Table 3.2.24. Further details are included in Nielsen et al. (2018).

Time series are included in Annex 3A-4. Time series have been estimated for

- Combustion of coal in power plants
- Combustion of coal in district heating and non-industrial plants
- Combustion of coal in industrial plants
- Combustion of coal, petroleum coke, residual oil and industrial waste in cement industry
- Combustion of BKB in industrial and residential plants
- Combustion of coke oven coke in industrial and residential plants
- Combustion of fossil fly ash
- Combustion of petroleum coke in public electricity and heat production
- Combustion of petroleum coke in industrial plants
- Combustion of residual oil in power plants
- Combustion of residual oil in industrial plants
- Combustion of gas oil in power plants
- Combustion of gas oil in offshore gas turbines
- Combustion of orimulsion in power plants
- Combustion of refinery gas
- Combustion of natural gas in power plants
- Combustion of natural gas in gas turbines
- Combustion of natural gas in gas engines
- Combustion of natural gas in district heating plants, large industrial boilers, large boilers in commercial/institutional plants and large boilers in agriculture/forestry
- Combustion of natural gas in offshore gas turbines
- Combustion of natural gas in residential boilers
- Combustion of natural gas in non-metallic minerals (bricks and tiles)
- Waste incineration in CHP plants
- Combustion of wood in power plants
- Combustion of wood in residential plants
- Combustion of bio oil in power plants
- Combustion of biogas in gas engines
- Combustion of biogas in power plants
- Combustion of biogas in large boilers
- Combustion of biogas in residential boilers
- Combustion of biomethane in power plants
- Combustion of biomethane in district heating plants and large boilers
- Combustion of biomethane in residential boilers

Table 3.2.24 NO_x emission factors and references, 2021.

Fuel type	Fuel	NFR	NFR_name	SNAP	NO_x emission factor, g/GJ	Reference
Solid	Anodic carbon	1A2g	Industry - other	032000	183	Assumed equal to coal. DCE assumption.
	Coal	1A1a	Public electricity and heat production	0101	14	DCE estimate based on plant specific emission data and EU ETS (2022)
				0102	95	DEPA (2001a)
		1A2a-g	Industry	03 except cement production	183	DCE estimate based on plant specific data for four plants in 2015.
		1A2f	Industry, cement production	0316	200	DCE estimate based on plant specific data for 2021.
		1A4b i	Residential	020200	95	DEPA (2001a)
		1A4c i	Agriculture/ Forestry	0203	95	DEPA (2001a)
	Fly ash fossil	1A1a	Public electricity and heat production	0101	14	Assumed equal to the emission factor for coal.
	BKB	1A4b	Residential	0202	95	Assumed equal to coal. DCE assumption.
	Coke oven coke	1A2a-g	Industry	03	183	Assumed equal to coal. DCE assumption.
		1A4b	Residential	0202	95	Assumed equal to coal. DCE assumption.
Liquid	Petroleum coke	1A2a-g	Industry	03	129	Assumed equal to residual oil. DCE assumption.
			Industry, non-metallic minerals, cement	0316	200	DCE estimate based on plant specific data for 2021.
		1A4a	Commercial/ Institutional	0201	51	EEA (2019). Tier 1, Small combustion, Table 3-5, liquid fuels applied in residential plants.
		1A4b	Residential	0202	51	EEA (2019). Tier 1, Small combustion, Table 3-5 liquid fuels applied in residential plants.
		1A4c	Agriculture/ Forestry	0203	51	EEA (2019). Tier 1, Small combustion, Table 3-5 liquid fuels applied in residential plants.
	Residual oil	1A1a	Public electricity and heat production	0101	138	DCE estimate based on plant specific data for 2008, 2009 and 2010. Plant specific data refer to: Energinet.dk (2009); Energinet.dk (2010); Energinet.dk (2011): EU ETS (2009-2011)
				0102	142	DEPA (2001a)
		1A1b	Petroleum refining	010306	142	EEA (2019), Energy Industries, Table 4-4 Tier 2 emission factors for source category 1.A.1.b, process furnaces using residual oil
		1A2a-g	Industry	03	129	DCE estimate based on plant specific data for 2015.
		1A2f	Industry, non-metallic minerals, cement	0316	200	DCE estimate based on plant specific data for 2021.
		1A4a	Commercial/ Institutional	0201	142	DEPA (2001a)
		1A4b	Residential	0202	142	DEPA (2001a)
		1A4c i	Agriculture/ Forestry	0203	142	DEPA (2001a)
	Gas oil	1A1a	Public electricity and heat production	010101, 010102, 010103	114	DCE estimate based on plant specific data for 2011.
				010104	230	DCE estimate based on plant specific data year 2015.
				010105	942	Nielsen et al. (2010a)
				0102	130	DEPA (2016b), DEPA (2012b), DEPA (2003b) and DEPA (1990)

Fuel type	Fuel	NFR	NFR_name	SNAP	NO_x emission factor, g/GJ	Reference
		1A1b	Petroleum refining	010306	65	EEA (2019), Energy Industries, Table 4-5 Tier 2 emission factors for source category 1.A.1.b, process furnaces, using gas oil
		1A1c	Oil and gas extraction	010500	198.1	Assumed equal to natural gas combustion applied in offshore gas turbines. DCE assumption.
		1A2a-g	Industry	03 except engines and turbines	130	DEPA (2016b), DEPA (2012b), DEPA (2003b) and DEPA (1990)
				Turbines	230	DCE estimate based on plant specific data year 2015.
				Engines	942	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201	52	DEPA (2001a)
				Engines	942	Nielsen et al. (2010a)
		1A4b i	Residential	0202	52	DEPA (2001a)
				Engines	942	Nielsen et al. (2010a)
		1A4c	Agriculture/Forestry	0203	52	DEPA (2001a)
				Engines	942	Nielsen et al. (2010a)
	Kerosene	1A2g	Industry - other	03	51	EEA (2019). Small Combustion Table 3-5. The emission factor is for liquid fuels combusted in residential plants.
		1A4a	Commercial/ Institutional	0201	51	EEA (2019). Small Combustion Table 3-5. The emission factor is for liquid fuels combusted in residential plants.
		1A4b i	Residential	0202	51	EEA (2019). Small Combustion Table 3-5. The emission factor is for liquid fuels combusted in residential plants.
		1A4c i	Agriculture/ Forestry	0203	51	EEA (2019). Small Combustion Table 3-5. The emission factor is for liquid fuels combusted in residential plants.
	LPG	1A1a	Public electricity and heat production	All	96	IPCC (1996).
		1A2a-g	Industry	03	96	IPCC (1996).
		1A4a	Commercial/ Institutional	0201	71	IPCC (1996).
		1A4b i	Residential	0202	47	IPCC (1996)
		1A4c i	Agriculture/ Forestry	0203	71	IPCC (1996)
	Refinery gas	1A1b	Petroleum refining	010304	170	DCE estimate based on plant specific data for a gas turbine in year 2000.
				010306	56	DCE estimate based on plant specific data for year 2015.
Gas	Natural gas	1A1a	Public electricity and heat production	010101, 010102	28	DEPA (2012b); DEPA (2015); DEPA (2016b)
				010103	31	Schweitzer & Kristensen (2015)
				010104	48	Nielsen et al. (2010a)
				010105	135	Nielsen et al. (2010a)
				0102	31	Schweitzer & Kristensen (2015)
		1A1b	Petroleum refining	0103	31	Schweitzer & Kristensen (2015)
		1A1c	Oil and gas extraction	010504	198.1	Estimate based on plant specific data. Bechmann Nielsen (2022)
		1A2a-g	Industry	03	31	Schweitzer & Kristensen (2015)
				Engines	135	Nielsen et al. (2010a)

Fuel type	Fuel	NFR	NFR_name	SNAP	NO_x emission factor, g/GJ	Reference
				Turbines	48	Nielsen et al. (2010a)
		1A2f		030700	87	DCE estimate based on plant specific data for 11 clay production plants, EU ETS (2011-2012); DEPA (2012b)
		1A4a	Commercial/ Institutional	0201	31	Schweitzer & Kristensen (2015)
				Engines	135	Nielsen et al. (2010a)
		1A4b i	Residential	0202	17.6	Schweitzer & Kristensen (2014)
				Engines	135	Nielsen et al. (2010a)
		1A4c i	Agriculture/ Forestry	0203	31	Schweitzer & Kristensen (2015)
				Engines	135	Nielsen et al. (2010a)
Waste	Waste	1A1a	Public electricity and heat production	0101	85	DCE estimate based on plant specific data for year 2021.
				0102	164	DCE estimate based on plant specific data for year 2000.
		1A2a-g	Industry	03	164	DCE estimate based on plant specific data for district heating plants in year 2000.
		1A4a	Commercial/ Institutional	0201	164	DCE estimate based on plant specific data for district heating plants in year 2000.
	Industrial waste	1A2f	Industry – non-metallic minerals, cement	031600	200	DCE estimate based on plant specific data for 2021.
Bio-mass	Wood	1A1a	Public electricity and heat production	010101 010102	33	Average emission factor for four power plants, 2018
				010103 010104	81	Nielsen et al. (2010a)
				0102	90	Serup et al. (1999)
		1A2a-g	Industry	03	90	Serup et al. (1999)
		1A4a	Commercial/ Institutional	0201	90	Serup et al. (1999)
		1A4b i	Residential	0202	74.4	Nielsen et al. (2021). The methodology for estimating this emission factor is also included in Chapter 3.2.7.
		1A4c i	Agriculture/ Forestry	0203	90	Serup et al. (1999)
	Straw	1A1a	Public electricity and heat production	0101	125	Nielsen et al. (2010a)
				0102	90	Nikolaisen et al. (1998)
		1A4b i	Residential	0202	154	Jensen et al. (2017)
		1A4c i	Agriculture/ Forestry	0203	154	Jensen et al. (2017)
	Wood pellets	1A1a	Public electricity and heat production	010101 010102	33	Average emission factor for four power plants, 2018
				010103 010104	81	Nielsen et al. (2010a)
				0102	90	Serup et al. (1999)
		1A2a-g	Industry	03	90	Serup et al. (1999)
		1A4a	Commercial/ Institutional	0201	90	Serup et al. (1999)
		1A4b i	Residential	0202	80	Nielsen et al. (2021).
		1A4c i	Agriculture/ Forestry	0203	90	Serup et al. (1999)
	Bio oil	1A1a	Public electricity and heat production	0101	114	Assumed equal to gas oil. DCE assumption.
				0102	130	Assumed equal to gas oil. DCE assumption.
		1A2a-g	Industry	03	130	Assumed equal to gas oil. DCE assumption.
				Engines	942	Assumed equal to gas oil. DCE assumption.
		1A4b i	Residential	0202	52	Assumed equal to gas oil. DCE assumption.

Fuel type	Fuel	NFR	NFR_name	SNAP	NO_x emission factor, g/GJ	Reference
	Biogas	1A1a	Public electricity and heat production	0101, not engines	28	Assumed equal to large natural gas fuelled boilers.
				Engines	202	Nielsen et al. (2010a)
				0102	28	DEPA (2001a)
		1A2a-g	Industry	03, not engines	28	Assumed equal to large natural gas fuelled boilers.
				03, engines	202	Nielsen et al. (2010a)
				030902	31	Assumed equal to large natural gas fuelled boilers.
		1A4a	Commercial/ Institutional	0201, not engines	28	DEPA (2001a)
				020105	202	Nielsen et al. (2010a)
		1A4b	Residential	0202	17.6	Assumed equal to natural gas (upgraded biogas)
		1A4c i	Agriculture/ Forestry	0203, not engines	28	DEPA (2001a)
				020304	202	Nielsen et al. (2010a)
	Bio gasification gas	1A1a	Public electricity and heat production	010105	173	Nielsen et al. (2010a)
	Biomethane	1A1a	Public electricity and heat production	010101 010102	28	Assumed equal to natural gas. DCE assumption.
				010103	31	Assumed equal to natural gas. DCE assumption.
				0102	31	Assumed equal to natural gas. DCE assumption.
		1A2a-g	Industry	03, except engines and turbines	31	Assumed equal to natural gas. DCE assumption.
				03, gas turbines	48	Assumed equal to natural gas. DCE assumption.
				03, engines	135	Assumed equal to natural gas. DCE assumption.
		1A4a	Commercial/ Institutional	0201	31	Assumed equal to natural gas. DCE assumption.
				0201, engines	135	Assumed equal to natural gas. DCE assumption.
		1A4b	Residential	0202	17.6	Assumed equal to natural gas. DCE assumption.
				0202, engines	135	Assumed equal to natural gas. DCE assumption.
		1A4c	Agriculture/ Forestry	0203	31	Assumed equal to natural gas. DCE assumption.
				0203, engines	135	Assumed equal to natural gas. DCE assumption.

NMVOC emission factors

The NMVOC emission factors for 2021 and references are shown in Table 3.2.25.

The emission factors for NMVOC refer to

- An emission measurement program for decentralised CHP plants (Nielsen et al., 2010a).
- The EEA Guidebook (EEA, 2019) and former editions.
- Aggregated emission factor based on the technology distribution for residential wood combustion (Nielsen et al., 2021b).
- DGC Danish Gas Technology Centre 2001, Naturgas – Energi og miljø (DGC, 2001).
- Gruijthuijsen & Jensen (2000). Energi- og miljøoversigt, Danish Gas Technology Centre, 2000 (In Danish).

The time series are included in Annex 3A-4. Time series have been estimated for

- Natural gas applied in gas engines
- Natural gas applied in gas turbines
- Natural gas applied in gas turbines offshore
- Waste incineration plants, CHP and district heating
- Industrial waste incineration
- Wood applied in the industrial sector
- Wood applied in residential plants
- Wood applied in institutional/commercial plants
- Wood applied in agricultural plants
- Biogas applied in gas engines

Table 3.2.25 NMVOC emission factors and references, 2021.

Fuel type	Fuel	NFR	NFR_name	SNAP	NMVOC, g/GJ	Reference
Solid	Anodic carbon	1A2g	Industry - other	0320	10	Assumed equal to coal. DCE assumption.
	Coal	1A1a	Public electricity and heat production	0101 0102	1.0	EEA (2019), Tier 1, Energy Industries Table 3-2
		1A2a-g	Industry	03	10	EEA (2019), Tier 1, Industry Table 3-2, assumed lower interval.
		1A4c i	Agriculture/ Forestry	0203	88.8	EEA (2019), Tier 1, Small combustion Table 3-7
	Fly ash fossil	1A1a	Public electricity and heat production	0101	1.0	Assumed equal to coal. DCE assumption.
	BKB	1A4b i	Residential	0202	484	EEA (2019), Tier 1, Small combustion Table 3-3
	Coke oven coke	1A2a-g	Industry	03	10	EEA (2019), Tier 1, Industry Table 3-2, assumed lower interval.
		1A4b	Residential	0202	484	EEA (2019), Tier 1, Small combustion Table 3-3
Liquid	Petroleum coke	1A2a-g	Industry	03	25	EEA (2019) Tier 1, Industry Table 3-4.
		1A4a	Commercial/ Institutional	0201	20	EEA (2019), Tier 1, Small combustion Table 3-9
		1A4b	Residential	0202	20	EEA (2019), Tier 1 for 1A4a/1A4c have been applied (DCE assumption). Small combustion Table 3-9.
		1A4c	Agriculture/ Forestry	0203	20	EEA (2019), Tier 1, Small combustion Table 3-9
	Residual oil	1A1a	Public electricity and heat production	010101 010102 010103	0.8	Nielsen et al. (2010a)
				010104	2.3	EEA (2019), Tier 1, Energy Industries Table 3-5
				010105	2.3	EEA (2019), Tier 1, Energy Industries Table 3-5
				010203	2.3	EEA (2019), Tier 1, Energy Industries Table 3-5
		1A1b	Petroleum refining	010306	2.3	EEA (2019), Tier 2, Energy Industries Table 4-4
		1A2a-g	Industry	03 except engines	0.8	Nielsen et al. (2010a)
				Engines	25	EEA (2019), Tier 1, Industry Table 3-4
		1A4a	Commercial/ Institutional	0201	20	EEA (2019), Tier 1, Small combustion Table 3-9
		1A4b	Residential	0202	20	EEA (2019), Tier 1, Small combustion Table 3-9, as-sumed equal to 1A4a/1A4c.
		1A4c i	Agriculture/ Forestry	0203	20	EEA (2019), Small combustion Tier 1, Table 3-9
	Gas oil	1A1a	Public electricity and heat production	010101 010102 010103	0.8	EEA (2019), Tier 1, Energy Industries Table 3-6
				010104	0.19	EEA (2019), Tier 2, Energy Industries Table 3-18
				010105	37.1	EEA (2019), Tier 2, Energy Industries Table 3-19
				0102	0.8	EEA (2019), Tier 1, Energy Industries Table 3-6
		1A1b	Petroleum refining	010306	0.8	EEA (2019), Tier 1, Energy Industries Table 3-6 (and Table 4.1)
		1A1c	Oil and gas extraction	010500	0.8	EEA (2019), Tier 1, Energy Industries Table 3-6

Fuel type	Fuel	NFR	NFR_name	SNAP	NMVOC, g/GJ	Reference
		1A2a-g	Industry	03 boilers	0.8	EEA (2019), Tier 1, Energy Industries Table 3-6
				Gas turbines	0.19	EEA (2019), Tier 2, Energy Industries Table 3-18
				Engines	37.1	EEA (2019), Tier 2, Energy Industries Table 3-19
		1A4a	Commercial/ Institutional	0201 except engines	20	EEA (2019), Tier 1, Small Combustion Table 3-9
				Engines	37.1	EEA (2019), Tier 2, Energy Industries Table 3-19
		1A4b i	Residential	0202	20	EEA (2019), Tier 1, Small Combustion Table 3-9
				Engines	37.1	EEA (2019), Tier 2, Energy Industries Table 3-19
		1A4c	Agriculture/Forestry	0203	20	EEA (2019), Tier 1, Small Combustion Table 3-9
	Kerosene	1A2a-g	Industry	03	0.8	EEA (2019), Tier 1, Energy Industries Table 3-6
		1A4a	Commercial/ Institutional	0201	20	EEA (2019), Tier 1, Small Combustion Table 3-9
		1A4b i	Residential	0202	20	EEA (2019), Tier 1, Small Combustion Table 3-9
		1A4c i	Agriculture/ Forestry	0203	20	EEA (2019), Tier 1, Small Combustion Table 3-9
	LPG	1A1a	Public electricity and heat production	0101 0102	0.8	EEA (2019), Tier 1, Energy Industries Table 3-6
		1A2a-g	Iron and steel	03	0.8	EEA (2019), Tier 1, Energy Industries Table 3-6
		1A4a	Commercial/ Institutional	0201	20	EEA (2019), Tier 1, Small Combustion Table 3-9
		1A4b i	Residential	0202	20	EEA (2019), Tier 1, Small Combustion Table 3-9
		1A4c i	Agriculture/ Forestry	0203	20	EEA (2019), Tier 1, Small Combustion Table 3-9
	Refinery gas	1A1b	Petroleum refining	0103	1.4	Assumed equal to natural gas fuelled gas turbines. DCE assumption.
Gas	Natural gas	1A1a	Public electricity and heat production	010101 010102 010103	2	Danish Gas Technology Centre (2001).
				010104	1.6	Nielsen et al. (2010a)
				010105	92	Nielsen et al. (2010a)
				0102	2	Danish Gas Technology Centre (2001).
		1A1b	Petroleum refining	0103	2	Danish Gas Technology Centre (2001).
		1A1c	Oil and gas extraction	0105	1.6	Nielsen et al. (2010a)
		1A2a-g	Industry	03 except engines and turbines	2	Danish Gas Technology Centre (2001).
				Turbines	1.6	Nielsen et al. (2010a)
				Engines	92	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201 except engines	2	Danish Gas Technology Centre (2001).
				Engines	92	Nielsen et al. (2010a)
		1A4b i	Residential	0202 except engines	4	Gruijthuijsen & Jensen (2000)
				Engines	92	Nielsen et al. (2010a)
		1A4c i	Agriculture/ Forestry	0203 except engines	2	Danish Gas Technology Centre (2001).
				Engines	92	Nielsen et al. (2010a)
Waste	Waste	1A1a	Public electricity and heat production	0101	0.56	Nielsen et al. (2010a)

Fuel type	Fuel	NFR	NFR_name	SNAP	NMVOC, g/GJ	Reference
				0102	0.56	Nielsen et al. (2010a). The CHP emission factor has been applied for other plant categories.
		1A2a-g	Industry	03	0.56	Nielsen et al. (2010a). The CHP emission factor has been applied for other plant categories.
		1A4a	Commercial/ Institutional	0201	0.56	Nielsen et al. (2010a). The CHP emission factor has been applied for other plant categories.
	Industrial waste	1A2f	Industry	0316	0.56	Nielsen et al. (2010a). The CHP emission factor has been applied for other plant categories.
Bio-mass	Wood	1A1a	Public electricity and heat production	0101	5.1	Nielsen et al. (2010a)
				0102	7.3	EEA (2019), Tier 1, Energy Industries Table 3-7
		1A2a-g	Industry	03	80	Estimate based on country specific data, see (1)
		1A4a	Commercial/ Institutional	0201	175	Estimate based on country specific data, see (1)
		1A4b i	Residential	0202	332	Nielsen et al. (2021) The methodology for estimating this emission factor is also included in Chapter 3.2.7.
		1A4c i	Agriculture/ Forestry	0203	175	Estimate based on country specific data, see (1)
	Straw	1A1a	Public electricity and heat production	0101	0.78	Nielsen et al. (2010a)
				0102	7.3	EEA (2019), Tier 1, Energy Industries Table 3-7
		1A4b i	Residential	0202	600	EEA (2019), Tier 1, Small Combustion Table 3-6
		1A4c i	Agriculture/ Forestry	0203	600	EEA (2019). Plants are assumed equal to residential plants.
				020302	12	EEA (2019), Tier 2, Small Combustion Table 3-45
	Wood pellets	1A1a	Public electricity and heat production	0101	5.1	Nielsen et al. (2010a)
				0102	7.3	EEA (2019), Tier 1, Energy Industries Table 3-7
		1A2a-g	Industry	03	10	Nielsen et al. (2021b)
		1A4a	Commercial/ Institutional	0201	10	Nielsen et al. (2021b)
		1A4b i	Residential	0202	10	Nielsen et al. (2021b)
		1A4c i	Agriculture/ Forestry	0203	10	Nielsen et al. (2021b)
	Bio oil	1A1a	Public electricity and heat production	010102	0.8	EEA (2019), Tier 1, Energy Industries Table 3-6 (gas oil)
				010105	37	EEA (2019), Tier 2, Energy Industries Table 3-19 (gas oil, large stationary CI reciprocating engines)
				0102	0.8	EEA (2019), Tier 1, Energy Industries Table 3-6 (gas oil)
		1A2a-g	Industry	03, not engines	0.8	EEA (2019), Tier 1, Energy Industries Table 3-6 (gas oil)
				010105	37	EEA (2019), Tier 2, Energy Industries Table 3-19 (gas oil, large stationary CI reciprocating engines)

Fuel type	Fuel	NFR	NFR_name	SNAP	NMVOC, g/GJ	Reference
		1A4b i	Residential	0202	20	EEA (2019), Tier 1, Small combustion Table 3-9 (liquid fuels)
	Biogas	1A1a	Public electricity and heat production	0101	2	Assumed equal to natural gas. DCE assumption.
				010105	10	Nielsen et al. (2010a)
				0102	2	Assumed equal to natural gas. DCE assumption.
		1A2a-g	Industry	03 except engines	2	Assumed equal to natural gas. DCE assumption.
				Engines	10	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201 except engines	2	Assumed equal to natural gas. DCE assumption.
				Engines	10	Nielsen et al. (2010a)
		1A4b	Residential	0202	4	Assumed equal to natural gas. DCE assumption.
		1A4c i	Agriculture/ Forestry	0203 except engines	2	Assumed equal to natural gas. DCE assumption.
				Engines	10	Nielsen et al. (2010a)
	Bio gasification gas	1A1a	Public electricity and heat production	010105	2	Nielsen et al. (2010a)
				0101 except engines	2	Assumed equal to natural gas. DCE assumption.
	Biomethane	1A1a	Public electricity and heat production	0101 except engines	2	Assumed equal to natural gas. DCE assumption.
				0101, gas turbines	1.6	Assumed equal to natural gas. DCE assumption.
				0101, engines	92	Assumed equal to natural gas. DCE assumption.
				0102	2	Assumed equal to natural gas. DCE assumption.
		1A1b	Petroleum refining	0103	2	Assumed equal to natural gas. DCE assumption.
		1A2a-g	Industry	03	2	Assumed equal to natural gas. DCE assumption.
				03, gas turbines	1.6	Assumed equal to natural gas. DCE assumption.
				03, gas engines	92	Assumed equal to natural gas. DCE assumption.
		1A4a	Commercial/ Institutional	0201	2	Assumed equal to natural gas. DCE assumption.
				0201, engines	92	Assumed equal to natural gas. DCE assumption.
		1A4b	Residential	0202	4	Assumed equal to natural gas. DCE assumption.
				0202, engines	92	Assumed equal to natural gas. DCE assumption.
		1A4c	Agriculture/ Forestry	0203	2	Assumed equal to natural gas. DCE assumption.
				0203, engines	92	Assumed equal to natural gas. DCE assumption.

1) The emission factor for combustion of wood in commercial/institutional plants, agricultural plants and industrial plants have been aggregated based on technology specific emission factors: industrial plants with production of electricity or district heating: 12 g/GJ (EEA, 2019) and other plants 350 g/GJ (EEA, 2019) in 1990-1995 and 175 g/GJ (EEA, 2019) since 2002. The aggregated emission factors for 2021 are 80 g/GJ for industrial plants and 175 g/GJ for commercial/institutional/agricultural plants. A time series has been applied in the inventory.

CO emission factors

The CO emission factors 2021 and references are shown in Table 3.2.26.

The emission factors for CO refer to

- The EEA Guidebook (EEA, 2019)[14].
- An emission measurement program for decentralised CHP plants (Nielsen et al., 2010a).
- Danish legislation (DEPA, 2001a)
- Nielsen et al. (2021). Aggregated emission factor based on the technology distribution for residential wood combustion and technology specific emission factors. See Chapter 3.2.7.
- DCE estimate based on annual environmental reports for Danish waste incineration plants without power production, year 2000.
- Nikolaisen et al. (1998)
- Jensen & Nielsen (1990)
- Bjerrum (2002)
- Sander (2002)
- Gruijthuijsen & Jensen (2000)
- Kristensen & Kristensen (2004)

The time series are included in Annex 3A-4. Time series have been estimated for

- Natural gas fuelled engines
- Natural gas fuelled gas turbines
- Waste incineration, CHP plants
- Waste incineration, other plants
- Wood combustion in district heating plants
- Wood combustion in industrial plants
- Wood combustion in commercial/institutional plants
- Wood combustion in agricultural plants
- Wood combustion in residential plants
- Straw combustion in district heating plants
- Straw combustion in residential / agricultural plants
- Biogas fuelled engines
- Wood pellet combustion in district heating plants
- Wood pellet combustion in industrial plants
- Wood pellet combustion in commercial/institutional plants

[14] And EEA (2007) for one emission factor.

Table 3.2.26 CO emission factors and references 2021.

Fuel type	Fuel	NFR	NFR_name	SNAP	CO emission factor, g/GJ	Reference
Solid	Anodic carbon	1A2a-g	Industry	03	10	Assumed the same emission factor as for coal. DCE assumption.
	Coal	1A1a	Public electricity and heat production	0101 and 0102	10	Sander (2002)
		1A2a-g	Industry	03	10	Assumed equal to boilers in public electricity and heat production. DCE assumption.
		1A4b i	Residential	0202	4787	EEA (2019), Tier 2, Small Combustion Table 3.15, residential boilers, solid fuels
		1A4c i	Agriculture/ Forestry	0203	931	EEA (2019), Tier 1, Small Combustion Table 3.7, 1A4a/c hard coal and brown coal
	Fly ash fossil	1A1a	Public electricity and heat production	0101	10	Assumed equal to coal. DCE assumption.
	BKB	1A4b i	Residential	0202	4787	EEA (2019), Tier 2, Small Combustion Table 3.15, residential boilers, solid fuels
	Coke oven coke	1A2a-g	Industry	03	10	Assumed the same emission factor as for coal. DCE assumption.
		1A4b	Residential	0202	4787	EEA (2019), Tier 2, Small Combustion Table 3.15, residential boilers, solid fuels
Liquid	Petroleum coke	1A1a	Public electricity and heat production	0101	66	EEA (2019), Tier 1, Manufacturing industries and construction Table 3.4 for liquid fuels.
		1A2a-g	Industry	03	66	EEA (2019), Tier 1, Manufacturing industries and construction Table 3.4 for liquid fuels.
		1A4a	Commercial/Institutional	0201	93	EEA (2019), Tier 1, Small Combustion Table 3.9
		1A4b	Residential	0202	93	EEA (2019), Tier 1, Small Combustion Table 3.9 (assumed equal to the emission factor for 1A4a/1A4c).
		1A4c	Agriculture/ Forestry	0203	93	EEA (2019), Tier 1, Small Combustion Table 3.9
	Residual oil	1A1a	Electricity and heat production	010101 010104 010105	15	Sander (2002)
				010102 010103	2.8	Nielsen et al. (2010a)
				0102	15.1	EEA (2019), Tier 1, Energy Industries Table 3.5.
		1A1b	Petroleum refining	010306	6	EEA (2019), Tier 2, Energy Industries Table 4.4.
		1A2a-g	Industry	03 except engines	2.8	Nielsen et al. (2010a)
				Engines	130	EEA (2019). Tier 2 emission factor for gas oil fuelled engines in Energy Industries, Table 3.19. Refers to Nielsen et al. (2010a).
		1A4a	Commercial/Institutional	0201	40	EEA (2019). Tier 2, Small Combustion Table 3.25.
		1A4b	Residential	0202	57	EEA (2019), Tier 1, Small Combustion Table 3.5
		1A4c i	Agriculture/ Forestry	0203	40	EEA (2019). Tier 2, Small Combustion Table 3.25.

Fuel type	Fuel	NFR	NFR_name	SNAP	CO emission factor, g/GJ	Reference
	Gas oil	1A1a	Public electricity and heat production	0101 except engines	15	Sander (2002)
				Engines	130	Nielsen et al. (2010a)
				0102	16.2	EEA (2019), Tier 1, Energy Industries Table 3.6, gas oil
		1A1b	Petroleum refining	010306	16.2	EEA (2019), Tier 1, Energy Industries Table 4.5, gas oil
		1A1c	Oil and gas extraction	0105	15	Sander (2002)
		1A2a-g	Industry	03 except gas turbines and engines	66	EEA (2019), Tier 1, Manufacturing industries and construction Table 3.4 for liquid fuels.
				Gas turbines	15	Sander (2002)
				Engines	130	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201 except engines	40	EEA (2019). Tier 2, Small Combustion Table 3.24.
				Engines	130	Nielsen et al. (2010a)
		1A4b i	Residential	0202 except engines	3.7	EEA (2019). Tier 2, Small Combustion Table 3.18. Gas oil applied in small residential boilers.
				Engines	130	Nielsen et al. (2010a)
		1A4c	Agriculture/Forestry	0203	40	EEA (2019). Tier 2, Small Combustion Table 3.24.
	Kerosene	1A2a-g	Industry	03	66	EEA (2019), Tier 1, Manufacturing industries and construction Table 3.4 for liquid fuels.
		1A4a	Commercial/ Institutional	0201	40	EEA (2019). Tier 2, Small Combustion Table 3.24.
		1A4b i	Residential	0202	3.7	EEA (2019). Tier 2, Small Combustion Table 3.18. Gas oil applied in small residential boilers.
		1A4c i	Agriculture/ Forestry	0203	40	EEA (2019). Tier 2, Small Combustion Table 3.24.
	LPG	1A1a	Public electricity and heat production	0101 and 0102	16.2	EEA (2019), Tier 1, Energy Industries Table 3.6
		1A2a-g	Industry	03	66	EEA (2019), Tier 1, Manufacturing industries and construction Table 3.4 for liquid fuels.
		1A4a	Commercial/ Institutional	0201	40	EEA (2019). Tier 2, Small Combustion Table 3.24.
		1A4b i	Residential	0202	3.7	EEA (2019). Tier 2, Small Combustion Table 3.18. Gas oil applied in small residential boilers.
		1A4c i	Agriculture/ Forestry	0203	40	EEA (2019). Tier 2, Small Combustion Table 3.24.
	Refinery gas	1A1b	Petroleum refining	0103	12.1	EEA (2019). Tier 1, Energy Industries Table 4.2 for refinery gas applied in petroleum refining.
Gas	Natural gas	1A1a	Public electricity and heat production	010101 and 010102	15	Sander (2002)
				010103	28	DEPA (2001a)
				010104	4.8	Nielsen et al. (2010a)
				010105	58	Nielsen et al. (2010a)
				0102	28	DEPA (2001a)
		1A1b	Petroleum refining	0103	28	Assumed equal to district heating plants.
		1A1c	Oil and gas extraction	0105	4.8	Nielsen et al. (2010a)

Fuel type	Fuel	NFR	NFR_name	SNAP	CO emission factor, g/GJ	Reference
		1A2a-g	Industry	03 except gas turbines and engines	28	DEPA (2001a)
				Gas turbines	4.8	Nielsen et al. (2010a)
				Engines	58	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201 except engines	28	DEPA (2001a)
				Engines	58	Nielsen et al. (2010a)
		1A4b i	Residential	0202 except engines	20	Gruijthuijsen & Jensen (2000)
				Engines	58	Nielsen et al. (2010a)
		1A4c i	Agriculture/ Forestry	0203 except engines	28	DEPA (2001a)
				Engines	58	Nielsen et al. (2010a)
Waste	Waste	1A1a	Public electricity and heat production	0101	3.9	Nielsen et al. (2010a)
				0102	10	DCE calculation based on annual environmental reports for Danish plants year 2000.
		1A2a-g	Industry	03	10	DCE calculation based on annual environmental reports for Danish plants year 2000.
		1A4a	Commercial/ Institutional	0201	10	DCE calculation based on annual environmental reports for Danish plants year 2000.
	Industrial waste	1A2f	Industry	0316	10	Assumed equal to waste, district heating plants. DCE assumption.
Biomass	Wood	1A1a	Public electricity and heat production	0101	90	Nielsen et al. (2010a)
				010203	240	DEPA (2001a)
		1A2a-g	Industry	03	240	DEPA (2001a)
		1A4a	Commercial/ Institutional	020100	240	DEPA (2001a)
		1A4b i	Residential	0202	2526	Nielsen et al. (2021). The methodology for estimating this emission factor is also included in Chapter 3.2.7.
		1A4c i	Agriculture/ Forestry	020300	240	DEPA (2001a)
	Straw	1A1a	Public electricity and heat production	0101	67	Nielsen et al. (2010a)
				0102	325	DEPA (2001a); Nikolaisen et al (1998)
		1A4b i	Residential	0202	2000	EEA (2007); Jensen & Nielsen (1990) and Bjerrum (2002), Kristensen & Kristensen (2004). Time series.
		1A4c i	Agriculture/ Forestry	0203	2000	EEA (2007); Jensen & Nielsen (1990) and Bjerrum (2002), Kristensen & Kristensen (2004). Time series.
				020302	325	DEPA (2001a); Nikolaisen et al (1998)
	Wood pellets	1A1a	Public electricity and heat production	0101	90	Nielsen et al. (2010a)
				010203	240	DEPA (2001a)
		1A2a-g	Industry	03	240	DEPA (2001a)
		1A4a	Commercial/ Institutional	020100	240	DEPA (2001a)
		1A4b i	Residential	0202	300	Nielsen et al. (2021b)
		1A4c i	Agriculture/ Forestry	020300	240	DEPA (2001a)

Fuel type	Fuel	NFR	NFR_name	SNAP	CO emission factor, g/GJ	Reference
	Bio oil	1A1a	Public electricity and heat production	0101	15	Assumed same emission factor as for gas oil. DCE assumption.
				0102	16.2	Assumed same emission factor as for gas oil. DCE assumption.
		1A2a-g	Industry	03	66	Assumed same emission factor as for gas oil. DCE assumption.
		1A4b i	Residential	0202	3.7	Assumed same emission factor as for gas oil. DCE assumption.
	Biogas	1A1a	Public electricity and heat production	0101 except engines	36	DEPA (2001a)
				Engines	310	Nielsen et al. (2010a)
				0102	36	DEPA (2001a)
		1A2a-g	Industry	03 except engines	36	DEPA (2001a)
				Engines	310	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201 except engines	36	DEPA (2001a)
				Engines	310	Nielsen et al. (2010a)
		1A4b	Residential	0202	20	Assumed equal to natural gas. DCE assumption.
		1A4c i	Agriculture/ Forestry	0203 except engines	36	DEPA (2001a)
				Engines	310	Nielsen et al. (2010a)
	Bio gasification gas	1A1a	Public electricity and heat production	010105	586	Nielsen et al. (2010a)
				010101	36	DEPA (2001a)
	Biomethane	1A1a	Public electricity and heat production	010101, 010102	15	Assumed equal to natural gas. DCE assumption.
				010103	28	Assumed equal to natural gas. DCE assumption.
				0101, gas turbines	4.8	Assumed equal to natural gas. DCE assumption.
				0101, engines	58	Assumed equal to natural gas. DCE assumption.
				0102	28	Assumed equal to natural gas. DCE assumption.
		1A1b	Petroleum refining	0103	28	Assumed equal to natural gas. DCE assumption.
		1A2a-g	Industry	03	28	Assumed equal to natural gas. DCE assumption.
				03, gas turbines	4.8	Assumed equal to natural gas. DCE assumption.
				03, engines	58	Assumed equal to natural gas. DCE assumption.
		1A4a	Commercial/ Institutional	0201	28	Assumed equal to natural gas. DCE assumption.
				0201, engines	58	Assumed equal to natural gas. DCE assumption.
		1A4b i	Residential	0202	20	Assumed equal to natural gas. DCE assumption.
				0202, engines	58	Assumed equal to natural gas. DCE assumption.
		1A4c i	Agriculture/ Forestry	0203	28	Assumed equal to natural gas. DCE assumption.
				0203, engines	58	Assumed equal to natural gas. DCE assumption.

NH_3 emission factors

NH_3 emissions have been estimated for

- Combustion of wood and wood pellets in residential plants
- Combustion of wood and wood pellets in commercial/institutional, agricultural and industrial plants
- Straw combustion in residential and agricultural plants
- Straw combustion in commercial/institutional and industrial plants
- Waste incineration in public power and heat production
- Residential combustion of coal
- Residential combustion of BKB
- Residential combustion of coke oven coke.

The NH_3 emission factors 2021 and references are shown in Table 3.2.27.

The emission factor for waste incineration plants refers to a Danish emission measurement programme (Nielsen et al., 2010a). The emission factor for residential wood combustion is based on Nielsen et al. (2021). All other emission factors refer to the EEA (2019).

Time series have been estimated for residential wood combustion, see Chapter 3.2.7 and Annex 3A-4.

Table 3.2.27 NH_3 emission factors and references, 2021.

Fuel	NFR (SNAP)	Emission factor, g/GJ	Reference
Coal	1A4b	0.3	EEA (2019), Tier 1, Small combustion Table 3-3
BKB	1A4b	0.3	EEA (2019), Tier 1, Small combustion Table 3-3
Coke oven coke	1A4b	0.3	EEA (2019), Tier 1, Small combustion Table 3-3
Wood	1A4b	46.85	Nielsen et al. (2021). The methodology for estimating this emission factor is included in Chapter 3.2.7.
Wood	1A4a, 1A4c, 1A2	37	EEA (2019), Tier 1, Small Combustion Table 3-10.
Wood pellets	1A4b, 1A4a, 1A4c, 1A2	12	Nielsen et al. (2021b).
Waste	1A1a	0.29	Nielsen et al. (2010a)
Straw	1A4b, 1A4c	70	EEA (2019), Tier 1, Small Combustion Table 3-6.
Straw	1A4a, 1A2	37	EEA (2019), Tier 1, Small Combustion Table 3-10.

Particulate matter (PM) emission factors

The PM emission factors and references are shown in Table 3.2.28. The emission factors for PM refer to

- The TNO/CEPMEIP emission factor database (TNO, 2001).
- Danish legislation:

    - DEPA (2001a), The Danish Environmental Protection Agency, Luftvejledningen (legislation from Danish Environmental Protection Agency).
    - DEPA (1990), The Danish Environmental Protection Agency, Bekendtgørelse 698 (legislation from Danish Environmental Protection Agency).
    - DEPA (1995), The Danish Environmental Protection Agency, Bekendtgørelse 518 (legislation from Danish Environmental Protection Agency).
- Calculations based on plant-specific emission data from a considerable number of waste incineration plants.
- Calculations based on plant-specific emission data from 7 power plants combusting wood and/or wood pellets
- Nielsen et al. (2021b). See also Chapter 3.2.7.
- Two emission measurement programs for decentralised CHP plants (Nielsen et al., 2010a; Nielsen & Illerup, 2003).
- An emission measurement program for large power plants (Livbjerg et al., 2001).
- Additional personal communication concerning straw combustion in residential plants (Kristensen, 2017c).

Emission factor time series have been estimated for residential wood combustion, combustion of wood and wood pellets in power plants, waste incineration in CHP plants, and waste incineration in other plants. All other emission factors have been considered constant in 1990-2021. The time series are included in Annex 3A-4.

Table 3.2.28 PM emission factors and references, 2021.

fuel_type	fuel	fuel	nfr	snap_id	TSP, g/GJ	Reference for TSP	PM_{10}, g/GJ	$PM_{2.5}$, g/GJ	Reference for PM_{10} and $PM_{2.5}$ emission factors or for the PM_{10} and the $PM_{2.5}$ fraction
Solid	101A	Anodic carbon	1A2g iii	0320	17	DEPA (1990), DEPA (1995)	12	7	TNO (2001)
	102A	Coal	1A1a	0101	3	Livbjerg et al. (2001)	2.6	2.1	Livbjerg et al. (2001)
				0102	6	TNO (2001)	6	5	TNO (2001)
			1A2 a-g	03	17	DEPA (1990), DEPA (1995)	12	7	TNO (2001)
			1A4c i	0203	17	DEPA (1990), DEPA (1995)	12	7	TNO (2001)
	103A	Fly ash fossil	1A1a	0101	3	Livbjerg et al. (2001)	2.6	2.1	Livbjerg et al. (2001)
	106A	BKB	1A4b i	0202	17	Same emission factor as for coal is assumed (DCE assumption)	12	7	Same emission factor as for coal is assumed (DCE assumption)
	107A	Coke oven coke	1A2 a-g	03	17	Same emission factor as for coal is assumed (DCE assumption)	12	7	Same emission factor as for coal is assumed (DCE assumption)
			1A4b	0202	17	Same emission factor as for coal is assumed (DCE assumption)	12	7	Same emission factor as for coal is assumed (DCE assumption)
Liquid	110A	Petroleum coke	1A2 a-g	03	10	TNO (2001)	7	3	TNO (2001)
			1A4a	0201	100	TNO (2001)	60	30	TNO (2001)
			1A4b	0202	100	TNO (2001)	60	30	TNO (2001)
			1A4c	0203	100	TNO (2001)	60	30	TNO (2001)
	203A	Residual oil	1A1a	010101	3	Nielsen & Illerup (2003)	3	2.5	Nielsen & Illerup (2003)
				010102	9.5	Nielsen et al. (2010a)	9.5	7.9	TNO (2001)
				010103	9.5	Nielsen et al. (2010a)	9.5	7.9	TNO (2001)
				010104	3	TNO (2001)	3	2.5	TNO (2001)
				010105	3	TNO (2001)	3	2.5	TNO (2001)
				0102	3	TNO (2001)	3	2.5	TNO (2001)
			1A1b	010306	50	TNO (2001)	40	35	TNO (2001)
			1A2 a-g	03	9.5	Nielsen et al. (2010a)	7.1	4.8	TNO (2001)
			1A4a	0201	14	DEPA (1990), DEPA (1995)	10.5	7	TNO (2001)
			1A4b	0202	14	DEPA (1990), DEPA (1995)	10.5	7	TNO (2001)
			1A4c i	0203	14	DEPA (1990), DEPA (1995)	10.5	7	TNO (2001)
	204A	Gas oil	1A1a	0101	5	TNO (2001)	5	5	TNO (2001)
				0102	5	TNO (2001)	5	5	TNO (2001)
			1A1b	010306	5	TNO (2001)	5	5	TNO (2001)
			1A1c	0105	5	TNO (2001)	5	5	TNO (2001)
			1A2a-g	03	5	TNO (2001)	5	5	TNO (2001)
			1A4a i	0201	5	TNO (2001)	5	5	TNO (2001)
			1A4b i	0202	5	TNO (2001)	5	5	TNO (2001)
			1A4c i	0203	5	TNO (2001)	5	5	TNO (2001)
	206A	Kerosene	1A2 a-g	all	5	TNO (2001)	5	5	TNO (2001)
			1A4a i	0201	5	TNO (2001)	5	5	TNO (2001)

fuel_type	fuel	fuel	nfr	snap_id	TSP, g/GJ	Reference for TSP	PM_{10}, g/GJ	$PM_{2.5}$, g/GJ	Reference for PM_{10} and $PM_{2.5}$ emission factors or for the PM_{10} and the $PM_{2.5}$ fraction
			1A4b i	0202	5	TNO (2001)	5	5	TNO (2001)
			1A4c i	0203	5	TNO (2001)	5	5	TNO (2001)
	303A	LPG	1A1a	0101, 0102	0.2	TNO (2001)	0.2	0.2	TNO (2001)
			1A2 a-g	03	0.2	TNO (2001)	0.2	0.2	TNO (2001)
			1A4a i	0201	0.2	TNO (2001)	0.2	0.2	TNO (2001)
			1A4b i	0202	0.2	TNO (2001)	0.2	0.2	TNO (2001)
			1A4c i	0203	0.2	TNO (2001)	0.2	0.2	TNO (2001)
	308A	Refinery gas	1A1b	0103	5	TNO (2001)	5	5	TNO (2001)
Gas	301A	Natural gas	1A1a	0101	0.1	TNO (2001)	0.1	0.1	TNO (2001)
				Gas turbines	0.1	Nielsen & Illerup (2003)	0.061	0.051	Nielsen & Illerup (2003)
				Engines	0.76	Nielsen & Illerup (2003)	0.189	0.161	Nielsen & Illerup (2003)
				0102	0.1	TNO (2001)	0.1	0.1	TNO (2001)
			1A1b	0103	0.1	TNO (2001)	0.1	0.1	TNO (2001)
			1A1c	0105	0.1	Nielsen & Illerup (2003)	0.061	0.051	Nielsen & Illerup (2003)
			1A2a-g	Engines	0.76	Nielsen & Illerup (2003)	0.189	0.161	Nielsen & Illerup (2003)
				Turbines	0.1	Nielsen & Illerup (2003)	0.061	0.051	Nielsen & Illerup (2003)
				Other	0.1	TNO (2001)	0.1	0.1	TNO (2001)
			1A4a i	0201	0.1	TNO (2001)	0.1	0.1	TNO (2001)
				Engines	0.76	Nielsen & Illerup (2003)	0.189	0.161	Nielsen & Illerup (2003)
			1A4b i	0202	0.1	TNO (2001)	0.1	0.1	TNO (2001)
				Engines	0.76	Nielsen & Illerup (2003)	0.189	0.161	Nielsen & Illerup (2003)
			1A4c i	0203	0.1	TNO (2001)	0.1	0.1	TNO (2001)
				Engines	0.76	Nielsen & Illerup (2003)	0.189	0.161	Nielsen & Illerup (2003)
Waste	114A	Waste	1A1a	0101	0.29	Nielsen et al. (2010a)	0.29	0.29	Nielsen & Illerup (2003)
				0102	4.2	The emission factor has been estimated by DCE based on plant specific data from MSW incineration plants, district heating, 2008	3.2	2.1	The emission factors have been estimated by DCE based on plant specific data from MSW incineration plants, district heating, 2008
			1A2 a-g	03	4.2	The emission factor has been estimated by DCE based on plant specific data from MSW incineration plants, district heating, 2008	3.2	2.1	The emission factors have been estimated by DCE based on plant specific data from MSW incineration plants, district heating, 2008
			1A4a i	0201	4.2	The emission factor has been estimated by DCE based on plant specific data from MSW incineration plants, district heating, 2008	3.2	2.1	The emission factors have been estimated by DCE based on plant specific data from MSW incineration plants, district heating, 2008

fuel_type	fuel	fuel	nfr	snap_id	TSP, g/GJ	Reference for TSP	PM_{10}, g/GJ	$PM_{2.5}$, g/GJ	Reference for PM_{10} and $PM_{2.5}$ emission factors or for the PM_{10} and the $PM_{2.5}$ fraction
	115A	Industrial waste	1A2f	0316	4.2	The emission factor has been estimated by DCE based on plant specific data from MSW incineration plants, district heating, 2008	3.2	2.1	The emission factors have been estimated by DCE based on plant specific data from MSW incineration plants, district heating, 2008
Biomass	111A	Wood	1A1a	0101	1.3	DCE estimate based on data from 7 plants, 2020	1.3	1.3	Assumed equal to TSP due to flue gas cleaning in power plants.
				0102	19	DEPA (2001a)	13	10	DEPA (2001a), TNO (2001)
			1A2 a-g	03	19	DEPA (2001a)	13	10	DEPA (2001a), TNO (2001)
			1A4a i	0201	143	DEPA (2001a)	143	135	TNO (2001)
			1A4b i	0202	289.4	Nielsen et al. (2021b). See also Chapter 3.2.7.	275.0	269.3	Nielsen et al. (2021b). See also Chapter 3.2.7.
			1A4c i	0203	143	DEPA (2001a)	143	135	TNO (2001)
	117A	Straw	1A1a i	0101	2.3	Nielsen et al. (2010a)	1.71	1.11	Nielsen & Illerup (2003)
				0102	21	DEPA (2001a)	15	12	TNO (2001)
			1A4b i	0202	433	Kristensen (2017c)	433	433	Zefeng (2011)
			1A4c i	0203	433	Kristensen (2017c)	433	433	Zefeng (2011)
				020302	21	DEPA (2001a)	15	12	TNO (2001)
	122A	Wood pellets	1A1a	0101	1.3	DCE estimate based on data from 7 plants, 2020	1.3	1.3	Assumed equal to TSP due to flue gas cleaning in power plants.
				0102	19	DEPA (2001a)	13	10	DEPA (2001a), TNO (2001)
			1A2 a-g	03	19	DEPA (2001a)	13	10	DEPA (2001a), TNO (2001)
			1A4a i	0201	51	Nielsen et al. (2021). See also Chapter 3.2.7.	48	47	Nielsen et al. (2021). See also Chapter 3.2.7.
			1A4b i	0202	51	Nielsen et al. (2021). See also Chapter 3.2.7.	48	47	Nielsen et al. (2021). See also Chapter 3.2.7.
			1A4c i	0203	51	Nielsen et al. (2021). See also Chapter 3.2.7.	48	47	Nielsen et al. (2021). See also Chapter 3.2.7.
	215A	Bio oil	1A1a	0101	5	Assuming same emission factors as for gas oil (DCE assumption)	5	5	Assuming same emission factors as for gas oil (DCE assumption)
				0102	5	Assuming same emission factors as for gas oil (DCE assumption)	5	5	Assuming same emission factors as for gas oil (DCE assumption)
			1A2a-g	03	5	Assuming same emission factors as for gas oil (DCE assumption)	5	5	Assuming same emission factors as for gas oil (DCE assumption)
			1A4b i	0202	5	Assuming same emission factors as for gas oil (DCE assumption)	5	5	Assuming same emission factors as for gas oil (DCE assumption)
	309A	Biogas	1A1a	0101, not engines	1.5	DEPA (1990), DEPA (1995)	1.5	1.5	All TSP emission is assumed to be <2,5µm (DCE assumption)
				010105	2.63	Nielsen & Illerup (2003)	0.451	0.206	Nielsen & Illerup (2003)

fuel_type	fuel	fuel	nfr	snap_id	TSP, g/GJ	Reference for TSP	PM_{10}, g/GJ	$PM_{2.5}$, g/GJ	Reference for PM_{10} and $PM_{2.5}$ emission factors or for the PM_{10} and the $PM_{2.5}$ fraction
				0102	1.5	DEPA (1990), DEPA (1995)	1.5	1.5	All TSP emission is assumed to be <2,5µm (DCE assumption)
			1A2a-g	Engines	2.63	Nielsen & Illerup (2003)	0.451	0.206	Nielsen & Illerup (2003)
				Other	1.5	DEPA (1990), DEPA (1995)	1.5	1.5	All TSP emission is assumed to be <2,5µm (DCE assumption)
			1A4a i	0201	1.5	DEPA (1990), DEPA (1995)	1.5	1.5	All TSP emission is assumed to be <2,5µm (DCE assumption)
				Engines	2.63	Nielsen & Illerup (2003)	0.451	0.206	Nielsen & Illerup (2003)
			1A4b	0202	0.1	Biogas upgraded for the town gas grid. Assumed equal to natural gas	0.1	0.1	Biogas upgraded for the town gas grid. Assumed equal to natural gas
			1A4c i	0203	1.5	DEPA (1990), DEPA (1995)	1.5	1.5	All TSP emission is assumed to be <2,5µm (DCE assumption)
				Engines	2.63	Nielsen & Illerup (2003)	0.451	0.206	Nielsen & Illerup (2003)
	310A	Bio gasification gas	1A1a	010105	2.63	Same emission factor as for biogas assumed (DCE assumption)	0.451	0.206	Same emission factor as for biogas assumed (DCE assumption)
				010101	0.2	Assumed equal to LPG	0.2	0.2	Assumed equal to LPG
	315A	Biomethane	1A1a	0101	0.1	Assumed equal to natural gas	0.1	0.1	Assumed equal to natural gas
				Gas turbines	0.1	Assumed equal to natural gas	0.061	0.051	Assumed equal to natural gas
				Engines	0.76	Assumed equal to natural gas	0.189	0.161	Assumed equal to natural gas
				0102	0.1	Assumed equal to natural gas	0.1	0.1	Assumed equal to natural gas
			1A2a-g	03	0.1	Assumed equal to natural gas	0.1	0.1	Assumed equal to natural gas
				Gas turbines	0.1	Assumed equal to natural gas	0.061	0.051	Assumed equal to natural gas
				Engines	0.76	Assumed equal to natural gas	0.189	0.161	Assumed equal to natural gas
			1A4a	0201	0.1	Assumed equal to natural gas	0.1	0.1	Assumed equal to natural gas
				Engines	0.76	Assumed equal to natural gas	0.189	0.161	Assumed equal to natural gas
			1A4b	0202	0.1	Assumed equal to natural gas	0.1	0.1	Assumed equal to natural gas
				Engines	0.76	Assumed equal to natural gas	0.189	0.161	Assumed equal to natural gas
			1A4c	0203	0.1	Assumed equal to natural gas	0.1	0.1	Assumed equal to natural gas
				Engines	0.76	Assumed equal to natural gas	0.189	0.161	Assumed equal to natural gas

Black carbon (BC) emission factors

The BC fractions of $PM_{2.5}$ and the references for the fractions are shown in Table 3.2.29. The BC fractions depend on fuel and sector.

Emission factor fractions for BC all refer to EEA (2019). All emission factors are shown as percentage of $PM_{2.5}$ and in g per GJ.

The time series are included in Annex 3A-4. Time series have been estimated for residential wood combustion and for waste incineration. The BC fraction of $PM_{2.5}$ is considered constant for each fuel/technology.

Table 3.2.29 BC fraction of $PM_{2.5}$, 2021.

Fuel	Fuel	NFR	SNAP	BC share of $PM_{2.5}$	BC emission factor, g/GJ	Reference for BC share
101A	Anodic carbon	1A2	03	2.2%	0.154	EEA (2019), Energy Industries, Table 3-2
102A	Coal	1A1a	0101	2.2%	0.0462	EEA (2019), Energy Industries, Table 3-2
102A	Coal	1A1a	0102	2.2%	0.11	EEA (2019), Energy Industries, Table 3-2
102A	Coal	1A2	03	6.4%	0.448	EEA (2019), Manufacturing Industries, Table 3-2
102A	Coal	1A4a	0201	6.4%	0.448	EEA (2019), Small Combustion, Table 3-7
102A	Coal	1A4b	0202	6.4%	0.448	EEA (2019), Small Combustion, Table 3-3
102A	Coal	1A4c	0203	6.4%	0.448	EEA (2019), Small Combustion, Table 3-7
103A	Fly ash fossil	1A1a	010104	2.2%	0.0462	Assumed equal to coal. DCE assumption.
106A	BKB	1A2	03	6.4%	0.448	EEA (2019), Manufacturing Industries, Table 3-2
106A	BKB	1A4a	0201	6.4%	0.448	EEA (2019), Small Combustion, Table 3-7
106A	BKB	1A4b	0202	6.4%	0.448	EEA (2019), Small Combustion, Table 3-3
106A	BKB	1A4c	0203	6.4%	0.448	EEA (2019), Small Combustion, Table 3-7
107A	Coke oven coke	1A4b	0202	6.4%	0.448	EEA (2019), Small Combustion, Table 3-3
107A	Coke oven coke	1A2	0301	6.4%	0.448	EEA (2019), Manufacturing Industries, Table 3-2
110A	Petroleum coke	1A1a	0101	5.6%	0.168	EEA (2019), Energy Industries, table 3-5
110A	Petroleum coke	1A2	03	56.0%	1.68	EEA (2019), Manufacturing Industries, Table 3-4
110A	Petroleum coke	1A4a	0201	56.0%	16.8	EEA (2019), Small Combustion, Table 3-9
110A	Petroleum coke	1A4b	0202	8.5%	2.55	EEA (2019), Small Combustion, Table 3-5
110A	Petroleum coke	1A4c	0203	56.0%	16.8	EEA (2019), Small Combustion, Table 3-9
203A	Residual oil	1A1a	010101	5.6%	0.14	EEA (2019), Energy Industries, Table 3-5
203A	Residual oil	1A1a	010102, 010103	5.6%	0.4424	EEA (2019), Energy Industries, Table 3-5
203A	Residual oil	1A1a	0102	5.6%	0.14	EEA (2019), Energy Industries, Table 3-5
203A	Residual oil	1A1b	010306	5.6%	1.96	EEA (2019), Energy Industries, Table 4-4
203A	Residual oil	1A2	03	56.0%	2.688	EEA (2019), Manufacturing Industries, Table 3-4
203A	Residual oil	1A4a	0201	56.0%	3.92	EEA (2019), Small Combustion, Table 3-9
203A	Residual oil	1A4b	0202	8.5%	0.595	EEA (2019), Small Combustion, Table 3-5
203A	Residual oil	1A4c	0203	56.0%	3.92	EEA (2019), Small Combustion, Table 3-9
204A	Gas oil	1A1a	0101, 0102	33.5%	1.675	EEA (2019), Energy Industries, Table 3-6
204A	Gas oil	1A1a	010104	33.5%	1.675	EEA (2019), Energy Industries, Table 3-18
204A	Gas oil	1A1a	010105	78.0%	3.9	EEA (2019), Energy Industries, Table 3-19
204A	Gas oil	1A1b	010306	33.5%	1.675	EEA (2019), Energy Industries, Table 4-5
204A	Gas oil	1A1c	010500	33.5%	1.675	EEA (2019), Energy Industries, Table 3-18
204A	Gas oil	1A2	03	56.0%	2.8	EEA (2019), Manufacturing Industries, Table 3-4
204A	Gas oil	1A2	03 turbines	33.5%	1.675	EEA (2019), Energy Industries, Table 3-18
204A	Gas oil	1A2	03 engines	78.0%	3.9	EEA (2019), Energy Industries, Table 3-19
204A	Gas oil	1A4a	0201	56.0%	2.8	EEA (2019), Small Combustion, Table 3-9
204A	Gas oil	1A4a	020105	78.0%	3.9	EEA (2019), Energy Industries, Table 3-19
204A	Gas oil	1A4b	0202	3.9%	0.195	EEA (2019), Small Combustion, Table 3-18

Fuel	Fuel	NFR	SNAP	BC share of $PM_{2.5}$	BC emission factor, g/GJ	Reference for BC share
204A	Gas oil	1A4b	020204	78.0%	3.9	EEA (2019), Energy Industries, Table 3-19
204A	Gas oil	1A4c	0203	56.0%	2.8	EEA (2019), Small Combustion, Table 3-9
204A	Gas oil	1A4c	020304	78.0%	3.9	EEA (2019), Energy Industries, Table 3-19
206A	Kerosene	1A2	03	56.0%	2.8	EEA (2019), Manufacturing Industries, Table 3-4
206A	Kerosene	1A4a	0201	56.0%	2.8	EEA (2019), Small Combustion, Table 3-9
206A	Kerosene	1A4b	0202	8.5%	0.425	EEA (2019), Small Combustion, Table 3-5
206A	Kerosene	1A4c	0203	56.0%	2.8	EEA (2019), Small Combustion, Table 3-9
225A	Orimulsion	1A1a	010101	2.2%	0.0352	Assumed equal to coal. DCE assumption.
303A	LPG	1A1a	0101	2.5%	0.005	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A1a	010104	2.5%	0.005	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A1a	0102	2.5%	0.005	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A2b	010306	2.5%	0.005	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A2	03	4.0%	0.008	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A4a	020100	4.0%	0.008	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A4a	020105	4.0%	0.008	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A4b	0202	5.4%	0.0108	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A4c	0203	4.0%	0.008	Assumed equal to natural gas. DCE assumption.
308A	Refinery gas	1A2	03	18.4%	0.92	EEA (2019), Energy Industries, Table 4-2
308A	Refinery gas	1A1a	010101	18.4%	0.92	EEA (2019), Energy Industries, Table 4-2
308A	Refinery gas	1A1a	010203	18.4%	0.92	EEA (2019), Energy Industries, Table 4-2
308A	Refinery gas	1A1b	0103	18.4%	0.92	EEA (2019), Energy Industries, Table 4-2
301A	Natural gas	1A1a	0101	2.5%	0.0025	EEA (2019), Energy Industries, Table 3-4
301A	Natural gas	1A1a	010104	2.5%	0.001275	EEA (2019), Energy Industries, Table 3-17
301A	Natural gas	1A1a	010105	2.5%	0.004025	EEA (2019), Energy Industries, Table 3-20
301A	Natural gas	1A1a	010200	2.5%	0.0025	EEA (2019), Energy Industries, Table 3-4
301A	Natural gas	1A1c	0105	2.5%	0.001275	EEA (2019), Energy Industries, Table 3-4
301A	Natural gas	1A1c	010504	2.5%	0.001275	EEA (2019), Energy Industries, Table 3-17
301A	Natural gas	1A2	03	4.0%	0.004	EEA (2019), Manufacturing Industries, Table 3-3
301A	Natural gas	1A2	03 turbines	2.5%	0.001275	EEA (2019), Energy Industries, Table 3-17
301A	Natural gas	1A2	03 engines	2.5%	0.004025	EEA (2019), Energy Industries, Table 3-20
301A	Natural gas	1A4a	0201	4.0%	0.004	EEA (2019), Small Combustion, Table 3-8
301A	Natural gas	1A4a	020104	2.5%	0.001275	EEA (2019), Small Combustion, Table 3-17
301A	Natural gas	1A4a	020105	2.5%	0.004025	EEA (2019), Energy Industries, Table 3-20
301A	Natural gas	1A4b	0202	5.4%	0.0054	EEA (2019), Small Combustion, Table 3-16
301A	Natural gas	1A4b	020204	2.5%	0.004025	EEA (2019), Energy Industries, Table 3-20
301A	Natural gas	1A4c	020300	4.0%	0.004	EEA (2019), Small Combustion, Table 3-8
301A	Natural gas	1A4c	020303	2.5%	0.001275	EEA (2019), Energy Industries, Table 3-17
301A	Natural gas	1A4c	020304	2.5%	0.004025	EEA (2019), Energy Industries, Table 3-20
114A	Waste	1A1a	0101	3.5%	0.01015	EEA (2019), Municipal waste Incineration, Table 3-1
114A	Waste	1A1a	0102	3.5%	0.0735	EEA (2019), Municipal waste Incineration, Table 3-1
114A	Waste	1A2	03	3.5%	0.0735	EEA (2019), Municipal waste Incineration, Table 3-1
114A	Waste	1A4a	0201	3.5%	0.0735	EEA (2019), Municipal waste Incineration, Table 3-1
115A	Industrial waste	1A2	03	3.5%	0.0735	EEA (2019), Municipal waste Incineration, Table 3-1

Fuel	Fuel	NFR	SNAP	BC share of $PM_{2.5}$	BC emission factor, g/GJ	Reference for BC share
111A	Wood	1A1a	0101	3.3%	0.0429	EEA (2019), Energy Industries, Table 3-7
111A	Wood	1A1a	0102	3.3%	0.33	EEA (2019), Energy Industries, Table 3-7
111A	Wood	1A2	03	28.0%	2.8	EEA (2019), Manufacturing Industries, Table 3-5
111A	Wood	1A4a	0201	28.0%	37.8	EEA (2019), Small Combustion, Table 3-10
111A	Wood	1A4b	0202	-	18.9	See residential wood combustion, Chapter 3.2.7
111A	Wood	1A4c	0203	28.0%	37.8	EEA (2019), Small Combustion, Table 3-10
117A	Straw	1A1a	0101	3.3%	0.03663	EEA (2019), Energy Industries, Table 3-7
117A	Straw	1A1a	0102	3.3%	0.396	EEA (2019), Energy Industries, Table 3-7
117A	Straw	1A2	03	28.0%	3.36	EEA (2019), Manufacturing Industries, Table 3-5
117A	Straw	1A4a	020103	28.0%	121	EEA (2019), Small Combustion, Table 3-10
117A	Straw	1A4b	0202	28.0%	121	EEA (2019), Small Combustion, Table 3-10 (Assumed equal to agricultural plants)
117A	Straw	1A4c	020300	28.0%	121	EEA (2019), Small Combustion, Table 3-10
122A	Wood pellets	1A1a	0101	3.3%	0.0429	EEA (2019), Energy Industries, Table 3-7
122A	Wood pellets	1A1a	0102	3.3%	0.33	EEA (2019), Energy Industries, Table 3-7
122A	Wood pellets	1A2	0301	28.0%	2.8	EEA (2019), Manufacturing Industries, Table 3-5
122A	Wood pellets	1A4a	0201	-	7	See residential wood combustion, Chapter 3.2.7
122A	Wood pellets	1A4b	0202	-	7	See residential wood combustion, Chapter 3.2.7
122A	Wood pellets	1A4c	0203	-	7	See residential wood combustion, Chapter 3.2.7
215A	Bio oil	1A1a	0101	33.5%	1.675	Assumed equal to gas oil. DCE assumption.
215A	Bio oil	1A1a	010105	78.0%	3.9	Assumed equal to gas oil. DCE assumption.
215A	Bio oil	1A1a	0102	33.5%	1.675	Assumed equal to gas oil. DCE assumption.
215A	Bio oil	1A2	03	56.0%	2.8	EEA (2019), Manufacturing Industries, Table 3-4
215A	Bio oil	1A2	03 engines	78.0%	3.9	Assumed equal to gas oil. DCE assumption.
215A	Bio oil	1A4a	020105	78.0%	3.9	Assumed equal to gas oil. DCE assumption.
215A	Bio oil	1A4b	020200	3.9%	0.295	Assumed equal to gas oil. DCE assumption.
215A	Bio oil	1A4b	020304	78.0%	3.9	Assumed equal to gas oil. DCE assumption.
309A	Biogas	1A1a	0101	3.3%	0.0495	Assumed % equal to wood. DCE assumption
309A	Biogas	1A1a	010105	3.3%	0.006798	Assumed % equal to wood. DCE assumption
309A	Biogas	1A1a	0102	3.3%	0.0495	Assumed % equal to wood. DCE assumption
309A	Biogas	1A2	03	28.0%	0.42	Assumed % equal to wood. DCE assumption
309A	Biogas	1A1c	010505	3.3%	0.006798	Assumed % equal to wood. DCE assumption
309A	Biogas	1A4a	0201	28.0%	0.42	Assumed % equal to wood. DCE assumption
309A	Biogas	1A4c	0203	28.0%	0.0054	Assumed % equal to wood. DCE assumption
310A	Bio gasification gas	1A1a	010105	3.3%	0.006798	Assumed % equal to wood. DCE assumption
310A	Bio gasification gas	1A2	03 engines	28.0%	0.05768	Assumed % equal to wood. DCE assumption
310A	Bio gasification gas	1A4a	020105	3.3%	0.006798	Assumed % equal to wood. DCE assumption
310A	Bio gasification gas	1A4c	020304	28.0%	0.05768	Assumed % equal to wood. DCE assumption

Fuel	Fuel	NFR	SNAP	BC share of $PM_{2.5}$	BC emission factor, g/GJ	Reference for BC share
315A	Biomethane	1A1a	0101, except engines	2.5%	0.0025	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A1a	010105 Engines	2.5%	0.004025	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A1a	0102	2.5%	0.0025	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A1b	0103	2.5%	0.0025	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A2	03	4.0%	0.004	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A2	03, Engines	2.5%	0.004025	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A4a	0201	4.0%	0.004	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A4a	0201, engines	2.5%	0.004025	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A4b	0202	5.4%	0.0054	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A4b	0202, engines	2.5%	0.004025	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A4c	0203	4.0%	0.004	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A4c	0203, engines	2.5%	0.004025	Assumed equal to natural gas. DCE assumption.

Heavy metals emission factors

The heavy metal emission inventory has been documented in detail in Nielsen et al. (2013c).

The HM emission factors 2021 and references are shown in Table 3.2.30.

The emission factors for HM refer to

- Two emission measurement programmes carried out on Danish decentralised CHP plants (Nielsen et al., 2010a; Nielsen & Illerup, 2003).
- Implied Emission Factors for power plants based on plant specific data reported by the power plant owners.
- A CONCAWE study (Gon & Kuenen, 2009)
- Data for Danish natural gas (Gruijthuijsen, 2001; Energinet.dk, 2010)
- The EEA Guidebook (EEA, 2019).
- Struschka et al. (2008)
- Hedberg et al. (2002)

The time series are included in Annex 3A-4. Time series have been estimated for

- Coal combustion in electricity and district heat production plants
- Waste incineration plants in public electricity and heat production
- Waste incineration in other combustion plants.

Table 3.2.30 HM emission factors and references, 2021.

fuel_type	fuel_gr_abbr	nfr	nfr_name	snap	As mg/GJ	Cd mg/GJ	Cr mg/GJ	Cu mg/GJ	Hg mg/GJ	Ni mg/GJ	Pb mg/GJ	Se mg/GJ	Zn mg/GJ	Reference
Solid	Anodic carbon	1A2g	Industry	All	4	1.8	13.5	17.5	7.9	13	134	1.8	200	EEA (2019), Tier 1, Industry Table 3-2.
	Coal	1A1a	Public electricity and heat production	All	0.51	0.07	0.86	0.48	1.3	0.97	0.62	5.9	1.9	Implied emission factor 2008 estimated by DCE based on plant specific emission data for power plants.
		All other	All other	All	4	1.8	13.5	17.5	7.9	13	134	23	200	EEA (2019), Tier 1, Industry Table 3-2. For Se: Tier 1, Energy Industries Table 3-2. See also Nielsen et al. (2013c)
	Fly ash fossil	1A1a	Public electricity and heat production	0101	0.51	0.07	0.86	0.48	1.3	0.97	0.62	5.9	1.9	Implied emission factor 2008 estimated by DCE based on plant specific emission data for power plants.
	BKB	1A4b i	Residential	0202	2.5	1.5	11.2	22.3	5.1	12.7	130	1.8	220	EEA (2019), Tier 1, Small Combustion Table 3-3. For Se Tier 1, Small Combustion Table 3-7 (for 1A4a/c).
	Coke oven coke	1A2 a-g	Industry	All	4	1.8	13.5	17.5	7.9	13	134	1.8	200	EEA (2019), Tier 1, Industry Table 3-2.
		1A4b	Residential	0202	2.5	1.5	11.2	22.3	5.1	12.7	130	1.8	220	EEA (2019), Tier 1, Small Combustion Table 3-3. For Se Tier 1, Small Combustion Table 3-7 (for 1A4a/c).
Liquid	Petroleum coke	all	All	All	3.98	1.2	2.55	5.31	0.341	255	4.56	2.06	87.8	EEA (2019), Tier 1, Energy Industries Table 3-5 (for heavy fuel oil)
	Residual oil	1A1a	Public electricity and heat production	All	2.1	0.53	2.6	2.4	0.21	362	2.6	1.2	7.4	Implied emission factor 2008 estimated by DCE based on plant specific emission data for power plants.
		All other	All other	All	3.98	1.2	2.55	5.31	0.341	255	4.56	2.06	87.8	EEA (2019), Tier 1, Energy Industries Table 3-5 (for heavy fuel oil)
	Gas oil	-	Engines	all	0.055	0.011	0.2	0.3	0.11	0.013	0.15	0.22	58	Nielsen et al. (2010a)
		-	All other	All	0.002	0.001	0.2	0.13	0.12	0.005	0.012	0.002	0.42	Gon & Kuenen (2009)
	Kerosene	All	All	All	0.002	0.001	0.2	0.13	0.12	0.005	0.012	0.002	0.42	Assumed equal to gas oil. DCE assumption.

fuel_type	fuel_gr_abbr	nfr	nfr_name	snap	As mg/GJ	Cd mg/GJ	Cr mg/GJ	Cu mg/GJ	Hg mg/GJ	Ni mg/GJ	Pb mg/GJ	Se mg/GJ	Zn mg/GJ	Reference
	LPG	All	All	All	0.002	0.001	0.2	0.13	0.12	0.005	0.012	0.002	0.42	EEA (2019), Tier 1, Small Combustion Table 3-5 (for 1A4b, other liquid fuels)
	Refinery gas	1A1b	Petroleum refining	All	0.352	2.19	6.69	3.29	0.372	7.37	1.61	1.56	17.0	EEA (2019), Tier 1, Energy Industries Table 4-2 (for refinery gas, 1A1b).
Gas	Natural gas	-	Engines	All	0.05	0.003	0.05	0.01	0.1	0.05	0.04	0.01	2.9	Nielsen et al. (2010a)
		-	All other	All	0.119	0.00025	0.00076	0.000076	0.1	0.00051	0.0015	0.0112	0.0015	Gruijthuijsen (2001). For Hg: Nielsen et al. (2010a), also applied in EEA (2019), Tier 1, Energy Industries Table 3-4. For Se: EEA (2019), Tier 1, Energy Industries Table 3-4.
Waste	Waste	-	All	All	0.59	0.44	1.56	1.3	1.79	2.06	5.52	1.11	2.33	Nielsen et al. (2010a).
	Industrial waste	1A2f	Industry - Other	All	0.59	0.44	1.56	1.3	1.79	2.06	5.52	1.11	2.33	Nielsen et al. (2010a).
Biomass	Wood and wood pellets	-	All non-residential	All	0.19	0.27	2.34	2.6	0.4	2.34	3.62	0.5	2.3	For Cd, Hg and Zn: Nielsen et al. (2010a) For Cr, Cu, Ni and Pb: Nielsen & Illerup (2003). For As and Se: EEA (2019), Tier 1, Small Combustion Table 3-10 (for solid biomass applied in 1A4a/c). Reference for As: Struschka et al. (2008). Reference for Se: Hedberg et al. (2002).
		1A4b i	Residential	All	0.19	13	23	6	0.56	2	27	0.5	512	EEA (2019), Tier 1, Small Combustion, Table 3.6 for residential biomass combustion
	Straw	1A1a	Public electricity and heat production	All	0.19	0.32	1.6	1.7	0.31	1.7	6.2	0.5	0.41	For Cd, Hg and Zn: Nielsen et al. (2010a). For Cr, Cu, Ni and Pb: Nielsen & Illerup (2003). For As and Se: EEA (2019), Tier 1, Small Combustion Table 3-10.
		1A4b i	Residential	0202	0.19	13	23	6	0.56	2	27	0.5	512	EEA (2019), Tier 1, Small Combustion Table 3-6.
		1A4c i	Agriculture/ Forestry	0203	0.19	13	23	6	0.56	2	27	0.5	512	EEA (2019), Tier 1, Small Combustion Table 3-6 (for 1A4b).

fuel_type	fuel_gr_abbr	nfr	nfr_name	snap	As mg/GJ	Cd mg/GJ	Cr mg/GJ	Cu mg/GJ	Hg mg/GJ	Ni mg/GJ	Pb mg/GJ	Se mg/GJ	Zn mg/GJ	Reference
	Bio oil	-	Engines	en-gines	0.055	0.011	0.2	0.3	0.11	0.013	0.15	0.22	58	Assumed equal to gas oil. DCE assumption.
		-	All other	-	0.002	0.001	0.2	0.13	0.12	0.005	0.012	0.002	0.42	Assumed equal to gas oil. DCE assumption.
	Biogas	-	All non-residential	All	0.04	0.002	0.18	0.31	0.12	0.23	0.005	0.21	3.95	Nielsen et al. (2010a)
		1A4b	Residential	All	0.119	0.00025	0.00076	0.000076	0.1	0.00051	0.0015	0.0112	0.0015	Assumed equal to natural gas (biogas upgraded for distribution in the town gas grid).
	Bio gasification gas	1A1a	Public electricity and heat production	010105	0.12	0.009	0.029	0.045	0.54	0.014	0.022	0.18	0.058	Nielsen et al. (2010a)
				010101	0.002	0.001	0.2	0.13	0.12	0.005	0.012	0.002	0.42	Assumed equal to gas oil. DCE assumption.
	Biomethane	-	All except engines	All	0.119	0.00025	0.00076	0.000076	0.1	0.00051	0.0015	0.0112	0.0015	Assumed equal to natural gas.
			Engines	en-gines	0.05	0.003	0.05	0.01	0.1	0.05	0.04	0.01	2.9	Assumed equal to natural gas.

PAH emission factors

The PAH emission factors 2020 and references are shown in Table 3.2.31.

The emission factors for PAH refer to

- Research carried out by TNO (Berdowski et al., 1995).
- Research carried out by Statistics Norway (Finstad et al., 2001).
- An emission measurement program performed on biomass-fuelled plants. The project was carried out for the Danish Environmental Protection Agency (Jensen & Nielsen, 1996).
- Finstad et al. (2001)
- Two emission measurement programs carried out on Danish decentralised CHP plants (Nielsen et al., 2010a; Nielsen & Illerup, 2003).
- Additional information from the gas sector (Jensen, 2001).
- EEA (2019)
- Nielsen et al. (2021b)

In general, emission factors for PAH are uncertain.

The time series are included in Annex 3A-4. Time series have been estimated for

- Residential wood combustion
- Natural gas fuelled engines
- Biogas-fuelled engines

Table 3.2.31 PAH emission factors and references, 2021.

fuel_type	fuel_id	fuel_gr_abbr	nfr_id	snap_id	Benzo(a)-pyrene µg per GJ	Benzo(b)-fluoranthene µg per GJ	Benzo(k)-fluoranthene µg per GJ	Indeno-(1,2,3-c,d)-pyrene µg per GJ	Reference
Solid	102A	Anodic carbon	1A2g	0320	23	929	929	698	Finstad et al. (2001)
		Coal	1A1a	All	0.7	37	29	1.1	EEA (2019). Tier 1, Energy Industries Table 3-2
			1A2 a-g	All	23	929	929	698	Finstad et al. (2001)
			1A4c i	0203	59524	63492	1984	119048	Finstad et al. (2001)
	103A	Fly ash fossil	1A1a	0101	0.7	37	29	1.1	EEA (2019). Tier 1, Energy Industries Table 3-2
	106A	BKB	1A4b i	0202	59524	63492	1984	119048	Finstad et al. (2001) (Same emission factor as for coal is assumed. DCE assumption)
	107A	Coke oven coke	1A2 a-g	All	23	929	929	698	Finstad et al. (2001)
			1A4b	0202	59524	63492	1984	119048	Finstad et al. (2001)
Liquid	110A	Petroleum coke	1A2 a-g	All	80	42	66	160	Finstad et al. (2001). Assumed equal to residual oil.
			1A4a i	All	80	42	66	160	Finstad et al. (2001). Assumed equal to residual oil.
			1A4b i	All	80	42	66	160	Finstad et al. (2001). Assumed equal to residual oil.
			1A4c i	All	80	42	66	160	Finstad et al. (2001). Assumed equal to residual oil.
	203A	Residual oil	1A1a	All	109.6	475.41	93.21	177.28	Finstad et al. (2001)
			1A1b	010306	109.6	475.41	93.21	177.28	Finstad et al. (2001)
			1A2 a-g	All	80	42	66	160	Finstad et al. (2001)
			1A4a i	All	80	42	66	160	Finstad et al. (2001)
			1A4b i	All	80	42	66	160	Finstad et al. (2001)
			1A4c i	All	80	42	66	160	Finstad et al. (2001)
	204A	Gas oil	1A1a	Not engines	109.6	475.41	93.21	177.28	Finstad et al. (2001)
				Engines	1.9	15	1.7	1.5	Nielsen et al. (2010a)
			1A1b	010306	109.6	475.41	93.21	177.28	Finstad et al. (2001)
			1A1c	010500	109.6	475.41	93.21	177.28	Finstad et al. (2001)
			1A2 a-g	Not engines	80	42	66	160	Finstad et al. (2001)
				Engines	1.9	15	1.7	1.5	Nielsen et al. (2010a)
			1A4a i	Not engines	80	42	66	160	Finstad et al. (2001)
				Engines	1.9	15	1.7	1.5	Nielsen et al. (2010a)
			1A4b i	0202	80	42	66	160	Finstad et al. (2001)
			1A4c i	0203	80	42	66	160	Finstad et al. (2001)
Gas	301A	Natural gas	1A1a	010104	1	1	2	3	Nielsen & Illerup (2003)
				010105	1.2	9	1.7	1.8	Nielsen et al. (2010a)
			1A1c	010504	1	1	2	3	Nielsen & Illerup (2003)
			1A2 a-g	Turbines	1	1	2	3	Nielsen & Illerup (2003)
				Engines	1.2	9	1.7	1.8	Nielsen et al. (2010a)
			1A4a i	020105	1.2	9	1.7	1.8	Nielsen et al. (2010a)
			1A4b i	020202	0.133	0.663	0.265	2.653	Jensen (2001)

fuel_type	fuel_id	fuel_gr_abbr	nfr_id	snap_id	Benzo(a)-pyrene	Benzo(b)-fluoranthene	Benzo(k)-fluoranthene	Indeno-(1,2,3-c,d)-pyrene	Reference
				020204	1.2	9	1.7	1.8	Nielsen et al. (2010a)
			1A4c i	020304	1.2	9	1.7	1.8	Nielsen et al. (2010a)
Waste	114A	Waste	1A1a	All	0.8	1.7	0.9	1.1	Nielsen et al. (2010a)
			1A4a i	0201	0.8	1.7	0.9	1.1	Nielsen et al. (2010a)
	115A	Industrial waste	1A2f	0316	0.8	1.7	0.9	1.1	Nielsen et al. (2010a)
Biomass	111A	Wood	1A1a	0101	11	15	5	10	Nielsen et al. (2010a)
				0102	6.46	1292.52	1292.52	11.56	Finstad et al. (2001)
			1A2 a-g	all	6.46	1292.52	1292.52	11.56	Finstad et al. (2001)
			1A4a i	0201	168707	221769	73469	119728	Finstad et al. (2001)
			1A4b i	All	64151	61908	37856	35181	Nielsen et al. (2021b)
			1A4c i	all	168707	221769	73469	119728	Finstad et al. (2001)
	117A	Straw	1A1a	0101	0.5	0.5	0.5	0.5	Nielsen et al. (2010a)
				0102	1529	3452	1400	1029	Berdowski et al. (1995)
			1A4b i	0202	12956	12828	6912	4222	Berdowski et al. (1995)
			1A4c i	0203	12956	12828	6912	4222	Berdowski et al. (1995)
	122A	Wood pellets	1A1a	0101	11	15	5	10	Nielsen et al. (2010a)
				0102	6.46	1292.52	1292.52	11.56	Finstad et al. (2001)
			1A2 a-g	03	6.46	1292.52	1292.52	11.56	Finstad et al. (2001)
			1A4a i	0201	900	1300	1300	1200	Nielsen et al. (2020)
			1A4b i	0202	900	1300	1300	1200	Nielsen et al. (2020)
	215A	Bio oil	1A1a	All	109.6	475.41	93.21	177.28	Same emission factors as for gas oil is assumed (DCE assumption).
			1A2 a-g	All	80	42	66	160	Same emission factors as for gas oil is assumed (DCE assumption).
			1A4b i	0202	80	42	66	160	Same emission factors as for gas oil is assumed (DCE assumption).
	309A	Biogas	Engines	All	1.3	1.2	1.2	0.6	Nielsen et al. (2010a)
	310A	Bio gasification gas	Engines	010105	2	2	2	2	Nielsen et al. (2010a)
	315A	Biomethane	1A4b i	0202	0.133	0.663	0.265	2.653	Jensen (2001)
			Gas turbines	-	1	1	2	3	Assumed equal to natural gas
			Engines	-	1.2	9	1.7	1.8	Assumed equal to natural gas

PCDD/F emission factors

The PCDD/F emission factors 2021 and references are shown in Table 3.2.32.

The emission factor for residential wood combustion refers to Nielsen et al. (2021). The emission factor is based on technology specific emission factors, see chapter 3.2.7.

The emission factors for decentralised CHP plants[15] refer to an emission measurement program for these plants (Nielsen et al. 2010a).

All other emission factors refer to research regarding PCDD/F emission carried out by NERI (now DCE) to prepare a new PCDD/F emission inventory (Henriksen et al., 2006).

In general, emission factors for PCDD/F are uncertain.

The time series are included in Annex 3A-4. Time series have been estimated for

- Residential wood combustion
- Waste incineration plants.

[15] Natural gas fueled engines, biogas fueled engines, gas oil fueled engines, engines fueled by biomass gasification gas, CHP plants combusting straw or wood and waste incineration plants.

Table 3.2.32 Emission factors for PCDD/F, 2021.

fuel_type	fuel_id	fuel_gr_abbr	nfr_id	snap_id	PCDD/F, ng per GJ	Reference
Solid	102A	Anodic carbon	1A2g	0320	1.32	Henriksen et al., 2006
		Coal	1A1a	0101 and 0102	1.32	Henriksen et al., 2006
			1A2 a-g	03	1.32	Henriksen et al., 2006
			1A4c i	0203	300	Henriksen et al., 2006
	103A	Fly ash fossil	1A1a	0101	1.32	Henriksen et al., 2006
	106A	BKB	1A4b i	0202	800	Henriksen et al., 2006
	107A	Coke oven coke	1A2 a-g	03	1.32	Henriksen et al., 2006
			1A4c	0203	800	Henriksen et al., 2006
Liquid	110A	Petroleum coke	1A2 a-g	03	1.32	Henriksen et al., 2006
			1A4a i	0201	300	Henriksen et al., 2006
			1A4b i	0202	800	Henriksen et al., 2006
			1A4c i	0203	300	Henriksen et al., 2006
	203A	Residual oil	1A1a	All	0.882	Henriksen et al., 2006
			1A1b	010306	0.882	Henriksen et al., 2006
			1A2 a-g	03	0.882	Henriksen et al., 2006
			1A4a i	0201	10	Henriksen et al., 2006
			1A4b i	0202	10	Henriksen et al., 2006
			1A4c i	0203	10	Henriksen et al., 2006
	204A	Gas oil	1A1a	Not engines	0.882	Henriksen et al., 2006
				Engines	0.99	Nielsen et al., 2010a
			1A1b	010306	0.882	Henriksen et al., 2006
			1A1c	0105	0.882	Henriksen et al., 2006
			1A2 a-g	Not engines	0.882	Henriksen et al., 2006
				Engines	0.99	Nielsen et al., 2010a
			1A4a i	Not engines	10	Henriksen et al., 2006
				Engines	0.99	Nielsen et al., 2010a
			1A4b i	Not engines	10	Henriksen et al., 2006
				Engines	0.99	Nielsen et al., 2010a
			1A4c i	0203	10	Henriksen et al., 2006
	206A	Kerosene	1A2a-g	03	0.882	Henriksen et al., 2006
			1A4a i	0201	10	Henriksen et al., 2006
			1A4b i	0202	10	Henriksen et al., 2006
			1A4c i	0203	10	Henriksen et al., 2006
	303A	LPG	1A1a	0101 and 0102	0.025	Henriksen et al., 2006
			1A2a-g	03	0.025	Henriksen et al., 2006
			1A4a i	0201	2	Henriksen et al., 2006
			1A4b i	0202	2	Henriksen et al., 2006
			1A4c i	0203	2	Henriksen et al., 2006
	308A	Refinery gas	1A1b	0103	0.025	Henriksen et al., 2006
Gas	301A	Natural gas	1A1a	Not engines	0.025	Henriksen et al., 2006
				Engines	0.57	Nielsen et al., 2010a
			1A1b	0103	0.025	Henriksen et al., 2006
			1A1c	010504	0.025	Henriksen et al., 2006
			1A2 a-g	03, Not engines	0.025	Henriksen et al., 2006
				Engines	0.57	Nielsen et al., 2010a
			1A4a i	0201	2	Henriksen et al., 2006
				020105	0.57	Nielsen et al., 2010a
			1A4b i	0202	2	Henriksen et al., 2006
				020204	0.57	Nielsen et al., 2010a
			1A4c i	0203	2	Henriksen et al., 2006
				020304	0.57	Nielsen et al., 2010a
Waste	114A	Waste	1A1a	0101 and 0102	5	Nielsen et al., 2010a
			1A4a i	0201	5	Nielsen et al., 2010a
	115A	Industrial waste	1A2f	0316	5	Nielsen et al., 2010a

fuel_type	fuel_id	fuel_gr_abbr	nfr_id	snap_id	PCDD/F, ng per GJ	Reference
Biomass	111A	Wood	1A1a	0101	14	Nielsen et al., 2010a
				0102	1	Henriksen et al., 2006
			1A2 a-g	03	1	Henriksen et al., 2006
			1A4a i	0201	400	Henriksen et al., 2006
			1A4b i	0202	766	Nielsen et al. (2021)
			1A4c i	0203	400	Henriksen et al., 2006
	117A	Straw	1A1a	0101	19	Nielsen et al., 2010a
				0102	22	Henriksen et al., 2006
			1A4b i	0202	500	Henriksen et al., 2006
			1A4c i	0203	400	Henriksen et al., 2006
	122A	Wood pellets	1A1a	0101	14	Nielsen et al., 2010a
				0102	1	Henriksen et al., 2006
			1A2 a-g	03	1	Henriksen et al., 2006
			1A4a i	0201	333	Nielsen et al. (2021)
			1A4b i	0202	333	Nielsen et al. (2021)
			1A4c i	0203	333	Nielsen et al. (2021)
	215A	Bio oil	1A1a	0101 and 0102	0.882	Henriksen et al., 2006
			1A2 a-g	03	0.882	Henriksen et al., 2006
			1A4b i	0202	10	Henriksen et al., 2006
	309A	Biogas	1A1a	Engines	0.96	Nielsen et al., 2010a
				Not engines	0.025	Henriksen et al., 2006
			1A2a-g	Not engines	0.025	Henriksen et al., 2006
				Engines	0.96	Nielsen et al., 2010a
			1A4a i	Not engines	2	Henriksen et al., 2006
				Engines	0.96	Nielsen et al., 2010a
			1A4b	Not engines	2	Henriksen et al., 2006
			1A4c i	Not engines	2	Henriksen et al., 2006
				Engines	0.96	Nielsen et al., 2010a
	310A	Bio gasification gas	1A1a	010105	1.7	Nielsen et al., 2010a
	315A	Biomethane	1A1a	0101 and 0102	0.025	Assumed equal to natural gas
			1A2a-g	03	0.025	Assumed equal to natural gas
			1A4a	0201	2	Assumed equal to natural gas
			1A4b	0202	2	Assumed equal to natural gas
			1A4c	0203	2	Assumed equal to natural gas
			All engines	Engines	0.57	Assumed equal to natural gas

HCB emission factors

The HCB emission inventory has been documented in Nielsen et al. (2014b).

Table 3.2.33 shows the emission factors and references for the Danish emission factors.

Table 3.2.33 Emission factors for HCB, 2021.

Fuel	NFR (SNAP)	Emission factor, ng/GJ	Reference
Coal	1A1, 1A2	6,700	Grochowalski & Konieczyński (2008); EEA (2019) Energy Industries Table 3-2
Coal	1A4b	1,200,000	Syc et al. (2011)
Coal	1A4a and 1A4c	23,000	Syc et al. (2011)
Other solid fuels	1A1, 1A2	6,700	Assumed equal to coal.
Other solid fuels	1A4	1,200,000	Assumed equal to coal.
Liquid fuels1)	1A1, 1A2, 1A4	220	Nielsen et al. (2010a)
Gaseous fuels	1A1, 1A2, 1A4	-	Negligible
Waste	1A1, 1A2, 1A4	4300	Nielsen et al. (2010a). A time series have been estimated. The emission factor for 1990 (190,000 ng/GJ) refer to Pacyna et al. (2003).
Wood and wood pellets	1A1, 1A2	5,000	EEA (2019) Energy Industries Table 3-7
Wood and wood pellets	1A4	5,000	EEA (2019) Small Combustion Table 3-6
Straw	1A1, 1A2	113	Nielsen et al. (2010a)
Straw	1A4	5,000	EEA (2019) Energy Industries Table 3-7
Biogas	1A1, 1A2, 1A4	190	Nielsen et al. (2010a)
Bio gasification gas	1A1, 1A2, 1A4	800	Nielsen et al. (2010a)
Biomethane	1A1, 1A2, 1A4	-	Negligible

1) The emission factor for LPG and refinery gas is negligible.

For coal, the emission factor from Grochowalski & Konieczyński (2008) is applied for Energy Industries and for industrial plants. This emission factor is also applied in the EEA Guidebook (EEA, 2019).

For residential plants, the emission factor 1,200,000 ng/GJ is applied referring to Syc et al. (2011). For commercial/institutional plants and for plants in agriculture / forestry the lower end of the value in Syc et al. (2011) (23,000 ng/GJ) is applied.

The emission factor for gas oil fuelled CHP engines (220 ng/GJ) referring to Nielsen et al. (2010a) is applied for all liquid fuels except for LPG and refinery gas.

For gaseous fuels, LPG and refinery gas no data are available, and the emission is negligible.

For waste combustion, emission data from Danish plants are available and these data are applied (Nielsen et al., 2010a). The emission factor 4,300 ng/GJ is applied for 2005 onwards. The HCB emission factor for 1990 refers to Pacyna et al. (2003). The emission of HCB is related to emission of PCDD/F and the decline rate between 1990 and 2005 is based on the decline rate for PCDD/F.

Recent emission measurements from Polish industrial waste incineration plants confirms the emission factor level for waste incineration considering that the PCDD/F emission level is 15 times the PCDD/F emission level for Danish plants.

For wood combustion, the emission factors from EEA (2019) are applied for both Energy industries, industrial plants and for non-industrial plants. For residential wood combustion, it would be relevant to estimate a time series. However, the currently available data are considered insufficient for this estimate.

The Cl content in straw is higher than in wood (Villeneuve et al., 2013) and thus the emission from straw combustion might potentially be higher. However, the emission factor for CHP plants combusting straw reported in Nielsen et al. (2010a) is lower than the emission factor applied for wood.

The emission factor for Energy Industries and industrial combustion refer to Nielsen et al. (2010a). For non-industrial plants, the EEA (2019) emission factor is applied.

The emission factors for biogas and biomass gasification gas both refer to Nielsen et al. (2010a).

PCB emission factors

The PCB emission inventory has been documented in Nielsen et al. (2014b).

PCB emission is strongly related to the Cl content of the fuel (Syc et al., 2011) and to the emission level for PCDD/F (Hedman et al., 2006; Syc et al., 2011; Pandelova et al., 2009).

The Cl content of straw, bark and manure is higher than for wood (Villeneuve et al., 2012). Villeneuve et al. (2012) states the Cl contents 50-60 mg/kg wood, 100-370 mg/kg bark, 1000-7000 mg/kg straw.

Different references for PCB emissions are not directly comparable because some PCB emission data are reported for individual PCB congeners, some as a sum of a specified list of PCB congeners and some PCB emission data are reported as toxic equivalence (teq) based on toxicity equivalence factors (TEF) for 12 dioxin-like PCB congeners. The emission measurements reported by Thistlethwaite (2001a and 2001b) show that the emission of non-dioxin-like PCBs is high compared to the emission of dioxin-like PCBs.

Furthermore, teq values based on TEF are reported as WHO_{2005}-teq or WHO_{1998}-teq. This difference is however typically less than 50%[16].

Table 3.2.34 shows the emission factors that have been selected for the Danish PCB emission inventory and reference for each emission factor. All emission factors are dioxin-like PCBs (but not teq values). PCB emission factors have been added for all fuels except LPG, refinery gas and natural gas. The emission from these three fuels is considered negligible.

[16] Data have been compared for a few datasets in which each dioxin-like PCB congener was specified.

Table 3.2.34 Emission factors for ∑dl-PCB, stationary combustion, 2021

Fuel	NFR (SNAP)	Emission factor, ∑ dl-PCB, ng/GJ	Emission factor, PCB, ng WHO_{1998}-teq/GJ	Reference
Coal	1A1	839	3.16	Grochowalski & Konieczyński (2008)
Coal	1A2	5,700	53	Thistlethwaite (2001a)
Coal	1A4	7,403	66	Syc et al. (2011)
Other solid fuels	1A1	839	3.16	Assumed equal to coal.
Other solid fuels	1A2	5,700	53	Assumed equal to coal.
Other solid fuels	1A4	7,403	66	Assumed equal to coal.
Residual oil and orimulsion	1A1, 1A2, 1A4	839	3.2	The teq value refers to Dyke et al. (2003). The TEQ value is equal to the emission factor for coal combustion in power plants and the sum of dioxin-like PCB congeners has been assumed equal to the corresponding factor for coal.
Gas oil	1A1, 1A2, 1A4	93	0.11	Nielsen et al. (2010a)
Other liquid fuels[1)]	1A1, 1A2, 1A4	93	0.11	Assumed equal to gas oil.
Gaseous fuels	1A1, 1A2, 1A4	-	-	Negligible
Waste	1A1, 1A2, 1A4	109 (time series)	0.28 (time series)	Nielsen et al. (2010a). A time series have been estimated. The emission factor for 1990 (46,000 ng/GJ or 117 ng WHO1998teq/GJ) have been estimated based on the assumption that the PCB emission factor time series follow the PCDD/F time series.
Wood	1A1, 1A2, 1A4a/c	2,800	21	Thistlethwaite (2001a)
Wood	1A4b	2,312 (time series)	-	Hedman et al. (2006). A time series have been estimated based on time series for technologies applied in Denmark.
Straw	1A1, 1A2	3,110	31.2	Assumed equal to residential plants.
Straw	1A4	3,110	31.2	Syc et al. (2011)
Wood pellets	1A1, 1A2, 1A4a/c, 1A4b	465.5	-	Hedman et al. (2006).
Biogas	1A1, 1A2, 1A4	90	0.13	Nielsen et al. (2010a)
Bio gasification gas	1A1, 1A2, 1A4	144	0.17	Nielsen et al. (2010a)
Biomethane	1A1, 1A2, 1A4	-	-	Negligible

1) Except LPG and refinery gas.

The emission factor for waste incineration refers to recent Danish field measurements. Historical data are not available, but a time series have been estimated based on the assumption that the dl-PCB emission factor follows the PCDD/-F emission factor. The estimated emission factor for 1990 is 45,671 ng/GJ or 117 ng WHO-teq/GJ. This emission level is confirmed by other references (Kakareka & Kukharchyk, 2005; Andrijewski et al., 2004). The emission factor time series is shown in Table 3.2.35.

For residential wood combustion, technology specific emission factors in toxicological equivalence are available from Hedman et al. (2006). However, sums of dioxin-like PCBs are not included in the reference. The emission factors for dioxin-like PCBs have been estimated based on the data for toxicological equivalence and the sum of dioxin-like PCBs in Thistlethwaite (2001a). Thus, the teq factors referring to Hedman (2006) have been multiplied by 2800/21. This assumption is highly uncertain, but the resulting emission factors seem to be in agreement with other references for residential wood combustion. A technology distribution time series for residential wood combustion in Denmark is available and have been applied for estimating the time series for the aggregated emission factor shown in Table 3.2.35.

For wood pellets the emission factor for residential plants from Hedman et al. (2006) have been applied for all combustion of wood pellets.

Emission factor time series for waste incineration and for residential wood combustion are shown in Table 3.2.35.

Table 3.2.35 Emission factor time series for waste incineration and for residential wood combustion.

Year	Waste incineration ∑dl-PCB, ng/GJ	Residential wood combustion[1)] ∑dl-PCB, ng/GJ
1990	45671	6076
1991	38063	6000
1992	30433	5924
1993	22825	5849
1994	19773	5774
1995	16721	5701
1996	13690	5629
1997	10638	5560
1998	7586	5492
1999	5515	5425
2000	3423	5359
2001	3423	5293
2002	3423	5226
2003	3423	5162
2004	1766	4921
2005	109	4687
2006	109	4509
2007	109	4333
2008	109	4142
2009	109	3930
2010	109	3718
2011	109	3588
2012	109	3459
2013	109	3330
2014	109	3200
2015	109	3071
2016	109	2941
2017	109	2814
2018	109	2686
2019	109	2560
2020	109	2435
2021	109	2312

1. Wood pellets not included.

Implied emission factors

A considerable part of the emission data for waste incineration plants and large power plants are plant-specific. Thus, the area source emission factors do not necessarily represent average values for these plant categories. To attain a set of emission factors that expresses the average emission for power plants combusting coal and for waste incineration plants, implied emission factors have been calculated for these two plant categories. The implied emission factors are presented in Annex 3A-5. The implied emission factors are calculated as total emission divided by total fuel consumption.

3.2.9 Uncertainty

According to the EEA Guidelines (EEA, 2019), uncertainty estimates should be estimated. Uncertainty estimates include uncertainty with regard to the total emission inventory as well as uncertainty with regard to trends.

Methodology
The Danish uncertainty estimates are based on the simple Tier 1 approach.

The uncertainty estimates are based on emission data for the base year and year 2021 as well as on uncertainties for fuel consumption and emission factors for each of the NFR source categories. Residential plants have however been split in two parts: Residential wood combustion and other residential plants.

The base year for all pollutants is 1990.

The uncertainty for fuel consumption in stationary combustion plants is based on EEA (2013). The uncertainties are shown in Table 3.2.36.

The applied uncertainties for emission factors are based on EEA (2013). The uncertainty for emission factors that are based on recent Danish emission measurements are however estimated lower than suggested in the Guidebook. The applied uncertainties for emission factors are listed in Table 3.2.37.

Table 3.2.36 Uncertainty rates for fuel consumption, %.

Sector	%
1A1a Public electricity and heat production	1
1A1b Petroleum refining	1
1A1c_ii Oil and gas extraction	1
1A2 Manufacturing industries and construction	2
1A4a_i Commercial / institutional	3
1A4b_i Residential (excluding wood)	3
1A4b_i Residential wood	10
1A4c_i Agriculture / forestry / fishing	3

Table 3.2.37 Uncertainty rates for emission factors, %.

Sector	SO_2	NO_x	NMVOC	CO	PM	HM	PAH	HCB	Dioxin	NH_3	PCB	BC
1A1a Public electricity and heat production	10	15	50	20	20	50	100	1000	200	1000	1000	1000
1A1b Petroleum refining	10	20	50	20	50	100	100	1000	1000	1000	1000	1000
1A1c_ii Oil and gas extraction	10	20	50	20	50	100	100	1000	1000	1000	1000	1000
1A2 Manufacturing industries and construction	10	20	50	20	30	100	100	1000	1000	1000	1000	1000
1A4a_i Commercial/institutional	20	50	50	50	50	300	1000	1000	1000	1000	1000	1000
1A4b_i Residential (excluding wood)	20	30	50	50	50	300	1000	1000	1000	1000	1000	1000
1A4b_i Residential wood	20	50	100	100	200	1000	1000	500	600	100	1000	1000
1A4c_i Agriculture / forestry/fishing	20	50	50	50	50	300	1000	1000	1000	1000	1000	1000

Results
The uncertainty estimates for stationary combustion emission inventories are shown in Table 3.2.38. Detailed calculation sheets are provided in Annex 3A-7.

The total emission uncertainty is 5.9 % for SO_2 and 10 % for NO_x.

Table 3.2.38 Uncertainty estimates, tier 1 approach, 2021.

Pollutant	Uncertainty Total emission, %	Trend 1990-2020, %	Uncertainty Trend, %-age points
SO_2	±5.9	-96	±0.2
NO_x	±10	-78	±2
NMVOC	±50	-39	±6
CO	±54	-51	±9
NH_3	±222	3	±137
TSP	±120	-35	±10
PM_{10}	±121	-35	±10
$PM_{2.5}$	±122	-34	±9
BC	±547	-5	±218
As	±67	-87	±8
Cd	±430	-47	±193
Cr	±241	-79	±49
Cu	±350	-85	±51
Hg	±44	-93	±2
Ni	±73	-92	±4
Pb	±192	-88	±22
Se	±41	-91	±2
Zn	±160	-35	±86
HCB	±771	-80	±33
PCDD/F	±462	-53	±181
Benzo(a)pyrene	±840	-65	±25
Benzo(b)fluoranthene	±786	-58	±38
Benzo(k)fluoranthene	±822	-69	±41
Indeno(1,2,3-c,d)pyrene	±819	-80	±15
PCB	±715	-71	±33

3.2.10 Source specific QA/QC and verification

An updated quality manual for the Danish GHG emission inventories was published in 2020 (Nielsen et al., 2020a). 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). Details about the source specific QA/QC is included in Annex 3A-10.

Documentation concerning verification of the Danish emission inventories was published by Fauser et al. (2013).

The latest update of the sector report for stationary combustion was reviewed by Jytte Boll Illerup from the Danish Environmental Protection Agency (Nielsen, 2021). Former editions of the sector report for stationary combustion have been reviewed by other external experts in 2004, 2006, 2009, 2014 and 2018.

3.2.11 Source specific improvements and recalculations

Recalculations for stationary combustion are shown in Table 3.2.39.

For SO_2 the recalculation is below 0.7 % for 1990-2019. The recalculation for 2020 is +1.1 %, mainly caused by an increase in the sector 1A2e. This increase is related to the revised energy statistics that states a higher consumption of coal in industrial plants.

For NO_x, the recalculation is below 1% except for 2020 where the recalculation is 1.3 %. The increase in industrial sectors and in sector 1A4c is related to recalculations of the consumption of diesel oil in mobile sources. This cause changes the split of gas-/diesel oil between mobile sources and stationary combustion. For 2020, the higher consumption of coal applied in industrial plants in the latest energy statistics also contribute to the increased estimate for NO_x-emission.

For NMVOC, the recalculation is between 0.0 % and + 0.8% for 1990-2020. The increased consumption of gas oil in the sectors 1A2 and 1A4c cause increased NMVOC estimates. The increase is mainly in sector 1A4c due to the higher NMVOC emission factor for gas oil applied in this sector. A considerable increase of the estimated emission in 2016 onwards is related to an improved disaggregation of biomethane to different plant technologies. This has caused a higher estimate for gas applied in reciprocating gas engines that have a higher emission factor for NMVOC than other plant technologies.

For CO, the recalculation is below 0.2% for 1990-2020.

For NH_3, the recalculations are below 1 % for 1990-2020.

The recalculations for PMs and BC are below 0.4 % for 1990-2019 and below 1% for 2020. The decreased estimate for PM emissions in 2020 is related to revised PM emission factors for power plants/CHP-plants combusting wood or wood pellets. These revised emission factors are applied from 2020 onwards and are based on plant specific emission data for power plants 2020.

For HMs, the reported emissions 1990-2020 are in the interval -0.1 % to +2.1 % of the emissions reported last year. The recalculations are below 0.2 % for all years except 2020, and the recalculations are related to the updated energy statistics from 2022.

For PCDD/F, the recalculation for 1990-2020 are in the interval 0.0% to +0.4%. The increase is mainly in sector 1A4c and related to the increased consumption of gas oil in the sector.

For PAHs, the recalculations are in the interval -0.4 % to +3.0 %. The recalculations are low for 1990-2017 and the recalculations in 2018-2020 are related to the changes in the updated energy statistics from 2022.

For HCB, the recalculation is below 0.3 % and for PCB the recalculations are below 0.5 %.

Table 3.2.39 Recalculations for stationary combustion. Emissions reported in 2023 compared to emissions reported in 2022.

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
						Per cent					
SO_2	100.2	100.1	100.4	100.5	100.5	100.3	100.2	100.2	100.3	100.2	101.1
NO_x	100.3	100.3	100.5	100.5	100.7	100.7	100.8	100.8	100.9	101.0	101.3
NMVOC	100.2	100.2	100.2	100.2	100.2	100.3	100.3	100.4	100.8	100.8	100.8
CO	100.1	100.1	100.2	100.2	100.1	100.1	100.1	100.1	100.2	100.0	99.8
TSP	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.4	100.1	99.0
PM_{10}	100.2	100.1	100.2	100.1	100.1	100.1	100.1	100.1	100.4	100.1	99.3
$PM_{2.5}$	100.2	100.2	100.2	100.1	100.1	100.1	100.1	100.1	100.4	100.1	99.6
BC	100.8	100.9	101.0	101.0	100.8	100.6	100.5	100.5	101.2	100.5	100.3
NH_3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.4	100.0	100.0
As	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.7
Cd	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.1
Cr	100.0	100.0	100.1	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.3
Cu	100.0	100.0	100.0	100.1	100.1	100.1	100.1	100.1	100.1	100.0	100.9
Hg	100.0	100.0	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	101.1
Ni	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.3
Pb	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	102.0
Se	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	102.1
Zn	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.3
HCB	100.0	100.0	100.0	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.2
PCDD/F	100.0	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.4	100.1	100.2
Benzo(a)pyrene	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	103.0	99.8	99.7
Benzo(b)fluoranthene	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	101.6	99.8	99.6
Benzo(k)fluoranthene	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	102.3	99.9	99.9
Indeno(123cd)pyrene	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	102.8	99.9	100.0
PCB	100.0	100.0	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.0	100.5

Energy statistics

For stationary combustion plants, the emission estimates for the years 1990-2020 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 2018, 2019 and 2020. The revisions are shown in the energy statistics. A large number of fuels have been revised including coal, natural gas, biomethane, wood, wood pellets, biogas, agricultural waste (straw), fossil waste and biomass waste.

A revision of the energy statistics for consumption of coal in industrial plants in 2020 cause an increase of the emission reported for the industrial sector. The consumption of coal applied in industrial plants in 2020 is 242 TJ higher in the latest energy statistics than in the energy statistics from 2021.

The consumption of natural gas in the Danish gas treatment plant Nybro is reported as part of the sector 1A1c. The gas consumption was earlier subtracted from sector 1A1c whereas it is now subtracted from sector 1A1a. In later years, there has been no fuel consumption in the gas turbine installed in the gas treatment plant.

Revised estimates for combustion of gas-/diesel oil in mobile sources have resulted in revised split between stationary combustion and mobile sources. Further details about the background for the recalculation is included in the mobile combustion chapter. The gas oil reallocated from mobile sources to stationary combustion is +3752 TJ for 1990. For 2020, the recalculation is +

1926 TJ. The recalculation is split between industrial plants and agricultural plants.

An improved disaggregation of biomethane to plant types has been implemented. As a result, a higher consumption of gas applied in reciprocating gas engines has been estimated for 2014 onwards.

Emission factors

For large plants, some additional plant specific emission data for 2020 became available during 2022. These data have been implemented.

As mentioned above, revised PM emission factors for wood and wood pellets applied in power plants have been implemented for 2020 onwards.

3.2.12 Source specific planned improvements

Plant specific emission data for 2021 available after December 2022 will be implemented.

Recent emission measurements for BC from residential wood combustion will be implemented.

3.2.13 References for Chapter 3.2

Andersen, J.S. & Hvidbjerg, R.L. 2017: Laboratoriemålinger af emissioner fra brændeovne ved forskellige fyringsteknikker, Teknologisk Institut, Redaktion: Miljøstyrelsen. Available at: https://www2.mst.dk/Udgiv/publikationer/2017/11/978-87-93614-42-0.pdf (2023-02-22).

Augustesen. J.N. 2003: Personal communication e-mail 11-08-2003 from Jane Nørgaard Augustesen. Statoil refinery to Per G. Kristensen, Danish Gas Technology Centre. The mail was forwarded 30-09-2003.

Bechmann Nielsen, 2022: email from Henrik Bechmann Nielsen, Miljøstyrelsen, 2022-08-18.

Berdowski, J.J.M., Veldt, C., Baas, J., Bloos, J.P.J. & Klein, A.E. 1995: Technical Paper to the OSPARCOM-HELCOM-UNECE Emission Inventory of heavy Metals and Persistent Organic Pollutants, TNO-report, TNO-MEP – R 95/247.

Christiansen, 2003: Personal communication, Jørgen Christiansen, Energigruppen Jylland, 2003.

Danish Energy Agency (DEA), 2016a: The Danish energy statistics from 2016.

Danish Energy Agency (DEA), 2016d: The Danish energy statistics from 2016, Tables.

Danish Energy Agency (DEA), 2018e: Personal communication, Jane Rusbjerg, 2018-12-18.

Danish Energy Agency (DEA), 2022a: The Danish energy statistics, Available at: https://ens.dk/service/statistik-data-noegletal-og-kort/maanedlig-og-aarlig-energistatistik (2023-02-22).

Danish Energy Agency (DEA), 2022b: The Danish energy statistics, Energy Producers Survey, Energiproducenttællingen 1990-2020. Unpublished.

Danish Energy Agency (DEA), 2022c: The Danish energy statistics, International reporting. The data will be available at: https://ens.dk/service/statistik-data-noegletal-og-kort/noegletal-og-internationale-indberetninger (2023-02-22).

Danish Energy Agency (DEA), 2022d: The Danish energy statistics, Tables. Available at: https://ens.dk/service/statistik-data-noegletal-og-kort/maanedlig-og-aarlig-energistatistik (2023-02-22).

Danish Environmental Protection Agency (DEPA) 1990: Bekendtgørelse om begrænsning af emissioner af svovldioxid, kvælstofoxider og støv fra store fyringsanlæg, Bekendtgørelse 689 af 15/10/1990, (Danish legislation). Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=48656 (2023-02-22).

Danish Environmental Protection Agency (DEPA) 1995: Bekendtgørelse om ændring af Bekendtgørelse om begrænsning af emissioner af svovldioxid, kvælstofoxider og støv fra store fyringsanlæg, Bekendtgørelse 518 af 20/06/1995, (Danish legislation). Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=48479 (2023-02-22).

Danish Environmental Protection Agency (DEPA) 1998: Bekendtgørelse af lov om afgift af svovl, Bekendtgørelse 688 af 17/09/1998 (Danish legislation). Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=13266 (2023-02-22).

Danish Environmental Protection Agency (DEPA) 2001a: Luftvejledningen, Begrænsning af luftforurening fra virksomheder, Vejledning fra Miljøstyrelsen nr. 2 2001 (Danish legislation). Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=12728 (2023-02-22).

Danish Environmental Protection Agency (DEPA), 2001b: Bekendtgørelse om begrænsning af svovlindholdet i visse flydende og faste brændstoffer. Bekendtgørelse 532 af 25/05/2001. Danish legislation. Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=12458 (2023-02-22).

Danish Environmental Protection Agency (DEPA) 2003b: Bekendtgørelse om begrænsning af visse luftforurenende emissioner fra store fyringsanlæg, Bekendtgørelse 808 af 25/09/2003, (Danish legislation). Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=12697 (2023-02-22).

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 (2023-02-22).

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 (2023-02-22).

Danish Environmental Protection Agency (DEPA) 2011: Bekendtgørelse om anlæg, der forbrænder affald. Bekendtgørelse 1356 af 21/12/2011. Danish legislation. Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=139530 (2023-02-22).

Danish Environmental Protection Agency (DEPA) 2012b: Bekendtgørelse om begrænsning af visse luftforurenende emissioner fra store fyringsanlæg, Bekendtgørelse 1453 af 20/12/2012, (Danish legislation). Available at: https://www.retsinformation.dk/eli/lta/2012/1453 (2023-02-22).

Danish Environmental Protection Agency (DEPA), 2014: Bekendtgørelse om svovlindholdet i faste og flydende brændstoffer. Bekendtgørelse 640 af 12/06/2014. Danish legislation. Available at: https://www.retsinformation.dk/eli/lta/2014/640 (2023-02-22).

Danish Environmental Protection Agency (DEPA) 2015: Bekendtgørelse om begrænsning af visse luftforurenende emissioner fra store fyringsanlæg, Bekendtgørelse 162 af 16/02/2015, (Danish legislation). Available at: https://www.retsinformation.dk/eli/lta/2015/162 (2023-02-22).

Danish Environmental Protection Agency (DEPA) 2016b: Bekendtgørelse om begrænsning af visse luftforurenende emissioner fra store fyringsanlæg, Bekendtgørelse 513 af 22/05/2016, (Danish legislation). Available at: https://www.retsinformation.dk/eli/lta/2016/513 (2023-02-22).

Danish Environmental Protection Agency (DEPA) 2022b: Annual environmental reports / environmental reporting available on the Danish EPA home page at: https://dma.mst.dk/prtr/offentlig/ (2023-02-22).

Danish Gas Technology Centre (DGC) 2001: Naturgas – Energi og miljø (In Danish).

Danish Ministry of Taxation (DMT) 2008: Lov om afgift af kvælstofoxider. Lov nr 472 af 17/06/2008. Danish legislation. Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=120340 (2023-02-22).

Danish Ministry of Taxation (DMT), 2015: Lov om ændring af lov om afgift af kvælstofoxider og forskellige andre love. Danish legislation. Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=176801 (2023-02-22).

Energinet.dk, 2013: Personal communication, e-mail from Jesper Bruun, Energinet.dk, 2013-03-26.

Energinet.dk, 2017: Personal communication, email from Signe Sonne, Energinet.dk. 2017-09-12.

EOF, 2017: Energi- og Olieforum (EOF), 2017: Energi- og Olieforum at: http://www.eof.dk/Priser-og-Forbrug/Fuelolie.aspx (2018-09-08).

EU ETS, 2022: Data for 2021 reported to EU ETS. Confidential.

European Environment Agency (EEA), 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/EMEP-CORINAIR5 (2023-02-22).

European Environment Agency (EEA), 2013: EMEP/EEA air pollutant emission inventory guidebook 2013. Available at:
http://www.eea.europa.eu//publications/emep-eea-guidebook-2013 (2023-02-22).

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 (2023-02-22).

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 (2023-02-22).

Finstad, A., Haakonsen, G., Kvingedal, E. & Rypdal, K. 2001: Utslipp til luft av noen miljøgifter i Norge, Dokumentasjon av metode og resultater, Statistics Norway Report 2001/17 (In Norwegian). Available at:
http://www.ssb.no/a/publikasjoner/pdf/rapp_200117/rapp_200117.pdf (2023-02-22).

Folkecenter for Vedvarende Energi, 2000: Notat vedrørende emissioner fra forbrændingsmotorer. planteolie sammenlignet med diesel. 28-03-2000. (In Danish) Available at: http://www.folkecenter.dk/dk/folkecenter/publikationer/ (2018-03-01).

Glasius, M., Vikelsøe, J., Bossi, R., Andersen, H.V., Holst, J., Johansen, E. & Schleicher, O. 2005: Dioxin, PAH og partikler fra brændeovne. Danmarks Miljøundersøgelser. 27s – Arbejdsrapport fra DMU nr. 212. Available at:
http://www2.dmu.dk/1_viden/2_Publikationer/3_arbrapporter/rapporter/AR212.pdf (2023-02-22).

Glasius, M., Konggaard, P., Stubkjær, J., Bossi, R., Hertel, O., Ketzel, M., Wåhlin, P., Schleicher, O. & Palmgren, F. 2007: Danmarks Miljøundersøgelser. Partikler og organiske forbindelser fra træfyring - nye undersøgelser af udslip og koncentrationer - Arbejdsrapport fra DMU, nr. 235. Available at:
https://www2.dmu.dk/Pub/AR235.pdf (2023-02-22).

Gon & Kuenen, J. 2009: Improvements to metal emission estimates, 10th Joint TFEIP/EIONET meeting, 11-12 May 2009, Vienna, Austria.

Gruijthuijsen, L.v. & Jensen, J.K. 2000: Energi- og miljøoversigt, Danish Gas Technology Centre 2000 (In Danish).

Gruijthuijsen, L. v. 2001: Metaller i naturgas, Målerapport, April 2001, Dansk Gasteknisk Center (in Danish).

Henriksen, T.C., Illerup, J.B. & Nielsen, O.-K. 2006: Dioxin Air Emission Inventory 1990-2004. National Environmental Research Institute, Denmark. 90 pp. – NERI Technical report no 602. Available at: http://www2.dmu.dk/Pub/FR602.pdf (2023-02-22).

Hjort-Gregersen. K. 1999: Centralised Biogas Plants. Danish Institute of Agricultural and Fisheries Economics. 1999.

IPCC, 1996: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual (Volume 3). Available at: http://www.ipcc-nggip.iges.or.jp/public/gl/invs6.html (2023-02-22).

IPCC, 2006: Revised 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (2023-02-22).

Jensen, L. & Nielsen, P.A. 1990: Emissioner fra halm- og flisfyr, dk-Teknik & Levnedsmiddelstyrelsen 1990 (In Danish).

Jensen, L. & Nielsen, P.A. 1996: Emissioner fra halm- og flisfyr, Arbejdsrapport fra Miljøstyrelsen nr. 5 1996, Bilagsrapport (In Danish).

Jensen, J. 2001: Danish Gas Technology Centre, Personal communication e-mail 11-10-2001.

Jensen, T.N., Brønnum, A. S. & Andreasen, M.B. 2017: Primær reduktion af emissioner fra 400 kW portionsfyret halmkedel. Teknologisk Institut og Maskinfabrikken Faust. Udgivet af Miljøstyrelsen. Available at: https://www2.mst.dk/Udgiv/publikationer/2017/04/978-87-93529-88-5.pdf (2023-02-22).

Jensen, J.N. 2017: Dong Energy. Personal communication, email 2017-08-16.

Jeppesen, J.S. 2007: København energi (Copenhagen Energy), Jørgen Steen Jeppesen, personal communication.

Krebs, 2003: Personal communication, email from Peter Krebs, BP Gas, 2003-09-30.

KE, 2015: Københavns Energi (KE), 2015 (Copenhagen Energy) fact sheet on town gas.

Kristensen, P.G. 2003: Kortlægning af emissioner fra decentrale kraftvarmeværker, Eltra PSO projekt 3141, Delrapport 4, Måleprogram og analyse af emissioner fra gasfyrede decentrale kraftvarmeanlæg < 25 MW_e, April 2003. Dansk Gasteknisk Center.

Kristensen, E.F. & Kristensen, J.K. 2004: Development and test of small-scale batch-fired straw boilers in Denmark. Biomass and Bioenergy 26 (2004).

Kristensen, P.G. 2007: Danish Gas Technology Centre, Per Gravers Kristensen, personal communication, town gas, email 19-04-2007.

Kristensen, P.G. 2017a: Danish Gas Technology Centre. Forgasningsgasanlæg og svovlkrav i MCP-direktivet. Rådgivning, notat. Not published. Forwarded by email 2017-08-07.

Kristensen, P.G. 2017b: Danish Gas Technology Centre. SO_2 emission factor estimate. Not published. Forwarded by email 2017-08-24.

Kristensen, E.F. 2017c: Personal communication, email from Erik Fløjgaard Kristensen, Institut for Ingeniørvidenskab, Aarhus Universitet, 2017-08-24 and 2017-08-28.

Livbjerg, H. Thellefsen, M. Sander, B. Simonsen, P., Lund, C., Poulsen, K. & Fogh, C.L. 2001: Feltstudier af Forbrændingsaerosoler, EFP -98 Projekt, Aerosollaboratoriet DTU, FLS Miljø, Forskningscenter Risø, Elsam, Energi E2 (in Danish).

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: http://www2.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR442.pdf (2023-02-22).

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 (2023-02-22).

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 (2023-02-22).

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 (2023-02-22).

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 (2023-02-22).

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: https://www2.dmu.dk/Pub/FR786.pdf (2023-02-22).

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://www2.dmu.dk/Pub/FR795.pdf. (2023-02-22).

Nielsen, M., Nielsen, O.-K. & Hoffmann, L. 2013c: Improved inventory for heavy metal emissions from stationary combustion plants. 1990-2009. Aarhus University, DCE – Danish Centre for Environment and Energy, 111 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 68. http://dce2.au.dk/pub/SR68.pdf (2023-02-22).

Nielsen, M., Nielsen, O.-K. & Plejdrup, M. 2014a: Danish emission inventories for stationary combustion plants. Inventories until 2011. Aarhus University, DCE – Danish Centre for Environment and Energy, 188 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 102 http://dce2.au.dk/pub/SR102.pdf (2023-02-22).

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Nielsen, M., Fauser, P., Mikkelsen, M.H., Albrektsen, R., Hjelgaard, K., Hoffmann, L., Thomsen, M., Bruun, H.G. 2014b: Danish emission inventory for hexachlorobenzene and polychlorinated biphenyls. Aarhus University, DCE – Danish Centre for Environment and Energy, 65 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 103 https://dce2.au.dk/pub/SR103.pdf (2023-02-22).

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 (2023-02-22).

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, 44 pp. Scientific Report No. 406 http://dce2.au.dk/pub/SR406.pdf (2023-02-22).

Nielsen, O.-K., Nielsen, M. & Plejdrup, M.S. 2021b: Updating the emission model for residential wood combustion. Aarhus University, DCE – Danish Centre for Environment and Energy, 85 pp. Scientific Report No. 442. http://dce2.au.dk/pub/SR442.pdf (2023-02-22).

Nielsen, M. 2021: Danish emission inventories for stationary combustion plants. Inventories until 2018. Aarhus University, DCE – Danish Centre for Environment and Energy, 280 pp. Scientific Report No. 424. Available at: http://dce2.au.dk/pub/SR424.pdf (2023-02-22).

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. 2023: Denmark's National Inventory Report 2023. Emission Inventories 1990-2021 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Aarhus University, DCE – Danish Centre for Environment and Energy.

Nikolaisen, L., Nielsen, C., Larsen, M.G., Nielsen, V. Zielke, U., Kristensen, J.K. & Holm-Christensen, B. 1998: Halm til energiformål, Teknik – Miljø – Økonomi, 2. udgave, 1998, Videncenter for halm og flisfyring (In Danish).

Nordic Ecolabelling of stoves, 2015: Nordic Ecolabelling of Stoves, Version 4.1, 11 June 2014 - 30 June 2019.

Plejdrup, M.S., Nielsen, O.-K. & Nielsen, M. 2021: The Danish emission inventory for fugitive emissions from fuels. Aarhus University, DCE – Danish Centre for Environment and Energy, 61 pp. Scientific Report No. 463 http://dce2.au.dk/pub/SR463.pdf (2023-02-22).

Schweitzer, J. & Kristensen, P., 2014: Evaluation of the NOx emissions of the Danish population of gas boilers below 120 kW, Project report October 2014. Danish Gas Technology Centre, Jean Schweitzer, Per G. Kristensen.

Schweitzer, J. & Kristensen, P., 2015: Evaluation of the NOx emissions of the Danish population of gas boilers above 120 kW, Project report, October 2015. Danish Gas Technology Centre, Jean Schweitzer, Per G. Kristensen.

Serup, H., Falster, H., Gamborg, C., Gundersen, P., Hansen, L. Heding, N., Jacobsen, H.H., Kofman, P., Nikolaisen, L. & Thomsen, I.M. 1999: Træ til energiformål, Teknik – Miljø – Økonomi, 2. udgave, 1999, Videncenter for halm og flisfyring (In Danish).

Shell, 2013: Shell product sheets. Available at: http://www.epc.shell.com/Docs/GPCDOC_X_cbe_26724_key_140003766633_201012210739.pdf (2022-02-14).

Thistlethwaite, G. 2001a: Determination of Atmospheric Pollutant Emission Factors at a Small Coal-fired heating boiler, 2001. A report produced for the Department of the Environment, Transport and the Regions, the National Assembly for Wales, the Scottish Executive and the Department of the Environment for Northern Ireland by AEA Technology Environment.

Thistlethwaite, G. 2001b: Determination of Atmospheric Pollutant Emission Factors at a Small Industrial Wood-Burning Furnace, 2001. A report produced for the Department of the Environment, Transport and the Regions, the National Assembly for Wales, the Scottish Executive and the Department of the Environment for Northern Ireland by AEA Technology Environment.

TNO, 2001: The TNO CEPMEIP emission factor database 2001. Available at: http://www.air.sk/tno/cepmeip/ (2023-02-22).

Tønder, Søren Hvid, 2004: Shell refinery. Personal communication telephone, 2004.

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), fisheries (vessel technical data, hours at sea), railways (e.g. train technical data, number of train km's) 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/NFR correspondence table for transport.

SNAP classification	CRF/NFR classification
0701 Road traffic: Passenger cars	1A3bi Road transport: Passenger cars
0702 Road traffic: Light duty vehicles	1A3bii Road transport: Light duty vehicles
0703 Road traffic: Heavy duty vehicles	1A3biii Road transport: Heavy duty vehicles
0704/0705 Road traffic: Mopeds and motor cycles	1A3biv Road transport: Mopeds & motorcycles
0706 Road traffic: Evaporation	1A3bv Road transport: Evaporation
0707 Road traffic: Brake and tire wear	1A3bvi Road transport: Brake and tire wear
0708 Road traffic: Road abrasion	1A3bvii Road transport: Road abrasion
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, Landing and Take Off ((LTO)[1] refers to the part of flying, which is below 1000 m. This part of the aviation emissions (SNAP codes 080501 and

[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.

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 for aviation explained in the following are based on UNFCCC categorization, in order to be consistent with the Danish NIR report.

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) regardless of vessel flag is reported under 1A4ciii.

For mobile sources, the DEMOS (Danish Emission model system for Mobile Sources) model developed at DCE, Aarhus University, is used to calculate the emission inventories. The DEMOS model system comprise database models for road transport (DEMOS-Road), aviation (DEMOS-Aviation), navigation (DEMOS-Navigation), railways (DEMOS-Rail) and non-road mobile machinery (DEMOS-NRMM).

For emission reporting purposes the output results from DEMOS 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 DEMOS model is used also as a calculation tool in research projects, environmental impact assessment studies, and to produce basic emission information, which requires various aggregation levels.

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.

Total fuel consumption for mobile sources

Table 3.3.2 Fuel consumption (PJ) for mobile sources in 2021 in NFR sectors.

NFR ID	Fuel consumption (PJ)
Manufacturing industries/Construction (mobile)	8.5
Civil aviation (Domestic)	1.2
Road transport: Passenger cars	87.3
Road transport:Light duty vehicles	21.8
Road transport:Heavy duty vehicles	52.9
Road transport: Mopeds & motorcycles	1.0
Railways	2.5
National navigation (Shipping)	7.2
Commercial/Institutional: Mobile	2.4
Residential: Household and gardening (mobile)	0.4
Agriculture/Forestry/Fishing: Off-road agriculture/forestry	9.2
Agriculture/Forestry/Fishing: National fishing	5.0
Other, Mobile	3.1
Road transport total	163.0
Other mobile total	39.6
Domestic total	202.6
Civil aviation (International)	17.5
Navigation (international)	18.2

Table 3.3.2 shows the fuel consumption for mobile sources based on DEA statistics for 2021 in NFR sectors. The fuel consumption figures in time series 1985-2021 are given in Annex 3.B.16 (NFR format) and are shown for 2021 in Annex 3.B.15 (CollectER format). Road transport has a major share of the fuel consumption for domestic mobile sources. In 2021, 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 5 %, 4 % and 4 %, respectively. For the remaining sectors, the total fuel consumption share is 7 %.

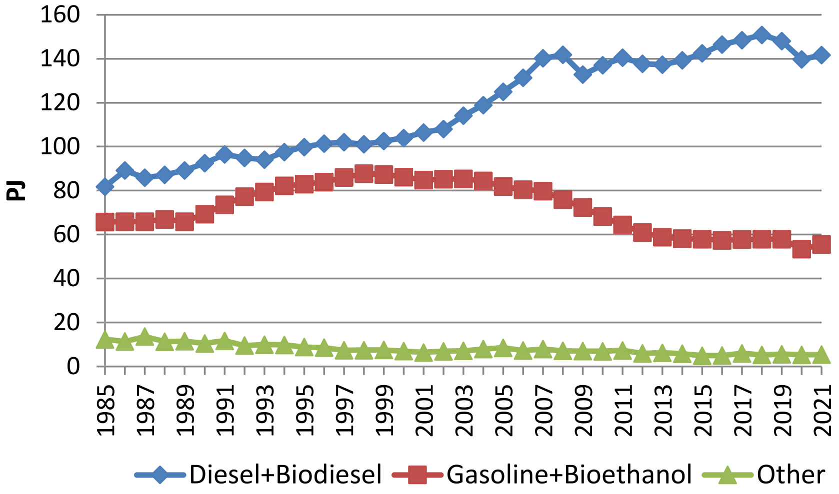


Figure 3.3.1 Fuel consumption per fuel type for domestic mobile sources 1985-2021.

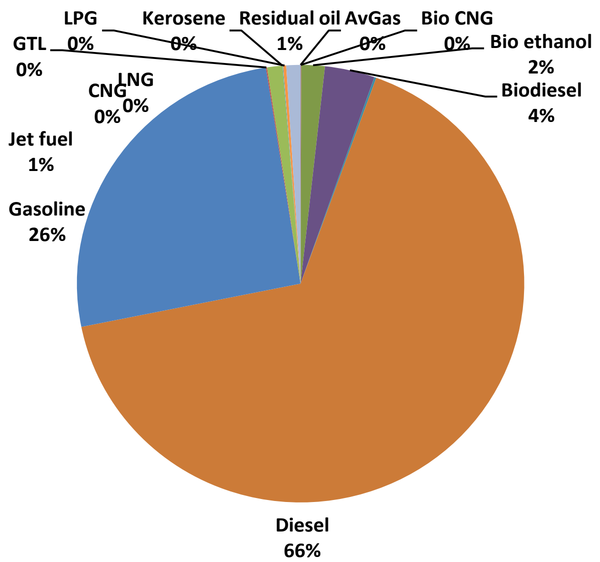


Figure 3.3.2 Fuel consumption share per fuel type for domestic mobile sources in 2021.

From 1985 to 2021, diesel (sum of diesel and biodiesel) and gasoline (sum of neat gasoline and bio ethanol) fuel consumption has changed by 73 % and -16 %, respectively (Figure 3.3.1), and in 2021 the fuel consumption shares for diesel and gasoline were 70 % and 27 %, respectively (not shown). Other fuels only have a 3 % share of the domestic mobile sources total (Figure 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 mobile sources 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[2].

Fuel consumption for road transport

As shown in Figure 3.3.3, the fuel consumption for road transport[3] has generally increased until 2007, except from a small fuel consumption decline noted in 2000. Reduced traffic causes significant fuel consumption declines in 2008-2009 during the global financial crisis, and in 2020 during the periods with COVID-19 lock down and social restrictions in the Danish society. 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 to 2018. 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). The largest fuel consumption impact related to COVID-19 is noted for passenger cars.

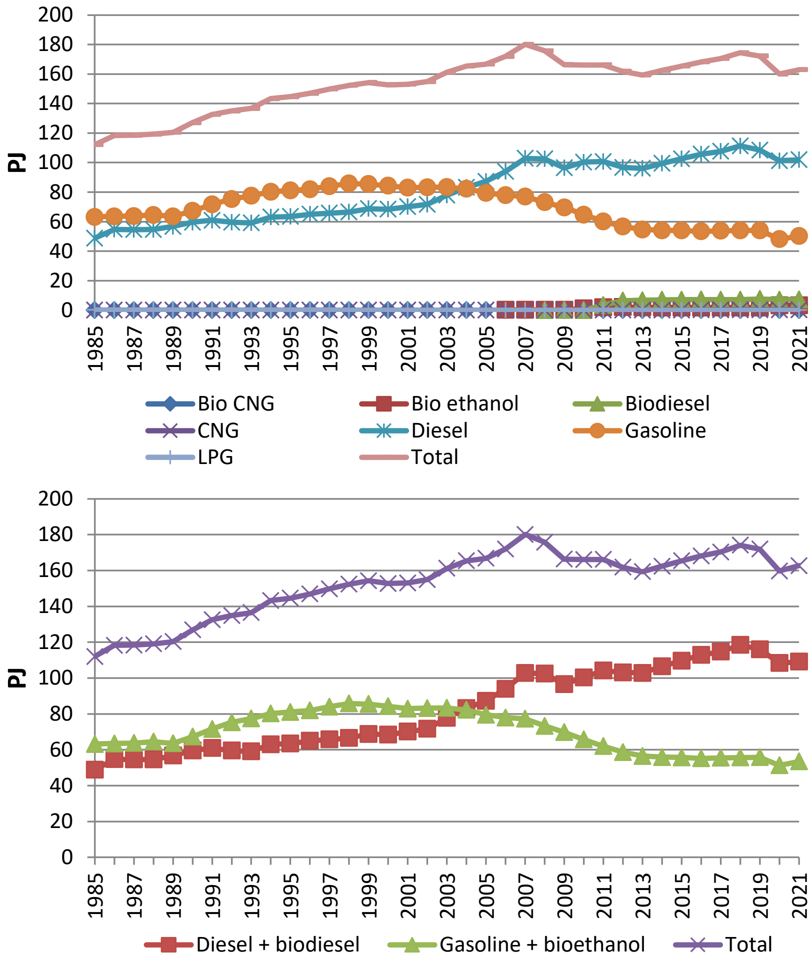


Figure 3.3.3 Fuel consumption per fuel type and as totals for road transport 1985-2021.

[2] The gasoline and diesel fuel sold at the conventional gas filling stations contain bio ethanol and biodiesel. Small amounts of gasoline and diesel are bought by individuals at the gas stations, filled into fuel cans and subsequently used to propel gasoline working machines (gasoline) and recreational craft (gasoline and diesel).
[3] The sum share of bioethanol and biodiesel in the gasoline and diesel fuel blends for road transport is 5.4 %, in 2021.

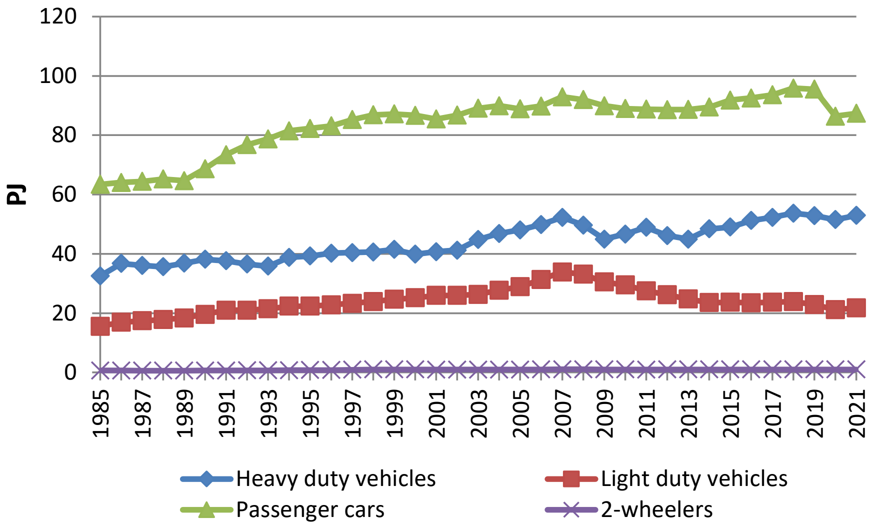


Figure 3.3.4 Total fuel consumption per vehicle type for road transport 1985-2021.

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 characterised by increasing fuel consumption for diesel passenger cars until 2018, while declines in the fuel consumption for trucks and buses (heavy-duty vehicles) are noted for 2008- 2009, 2012-2013 and 2019-2020, and fuel consumption reductions for light duty vehicles are noted for 2008-2014 and 2019-2020.

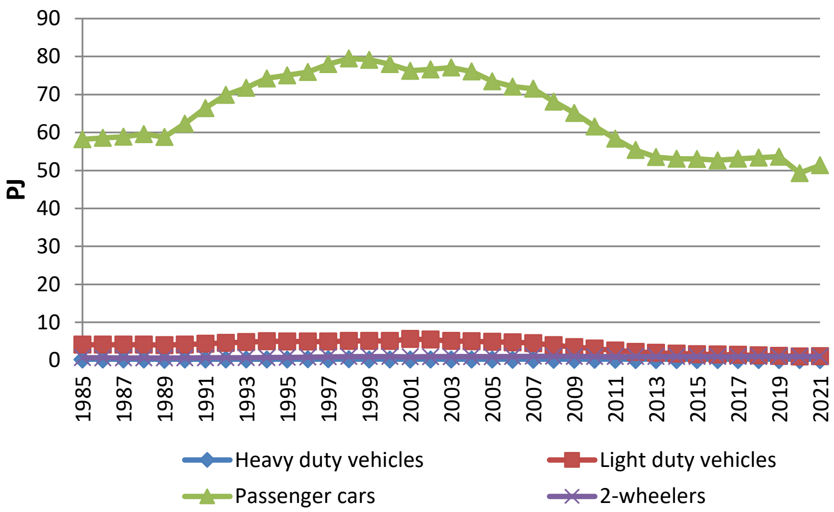


Figure 3.3.5 Gasoline fuel consumption per vehicle type for road transport 1985-2021.

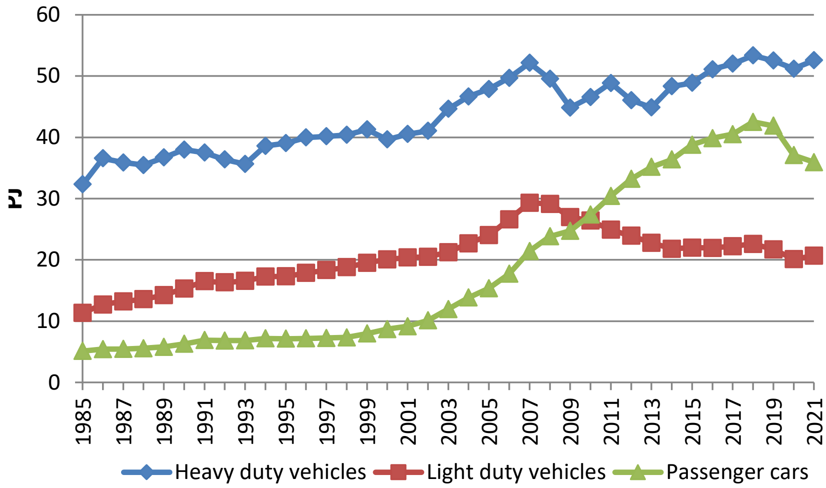


Figure 3.3.6 Diesel fuel consumption per vehicle type for road transport 1985-2021.

In 2021, fuel consumption shares for gasoline passenger cars, diesel heavy-duty vehicles, diesel passenger cars and diesel light duty vehicles were 31, 32, 22 and 13 %, respectively (Figure 3.3.7).

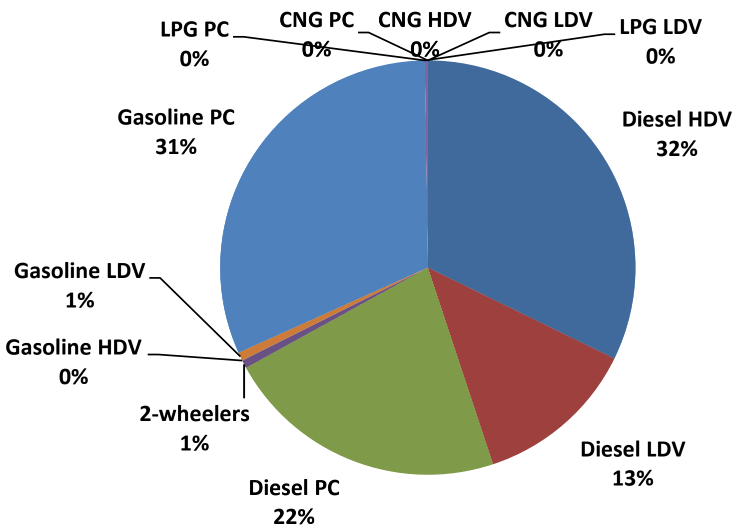


Figure 3.3.7 Fuel consumption share (PJ) per vehicle type for road transport in 2021.

Fuel consumption for 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 1985-2021 time series are shown per fuel type in Figures 3.3.9-3.3.12 for diesel, gasoline, residual oil and jet fuel, and liquefied natural gas (LNG) and gas-to-liquid (GTL) manufactured from natural gas, respectively.

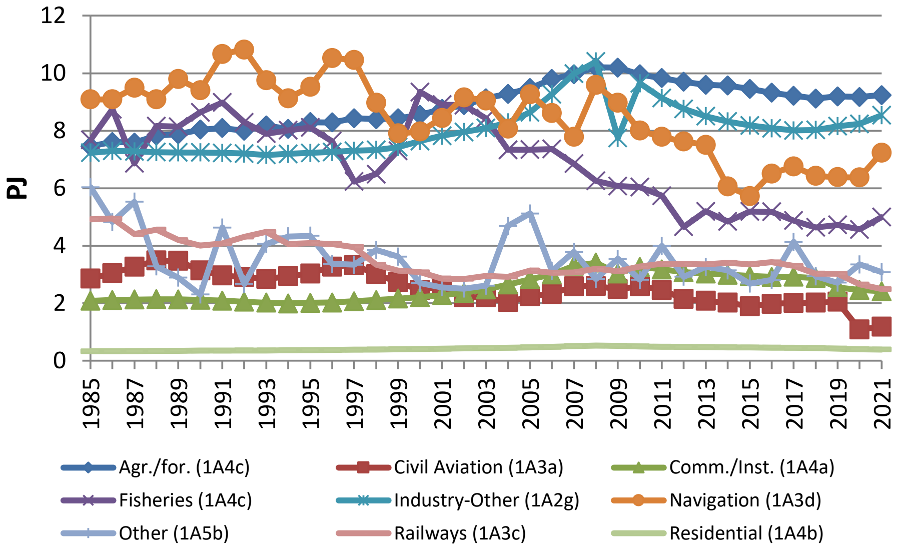


Figure 3.3.8 Total fuel consumption in CRF sectors for other mobile sources 1985-2021.

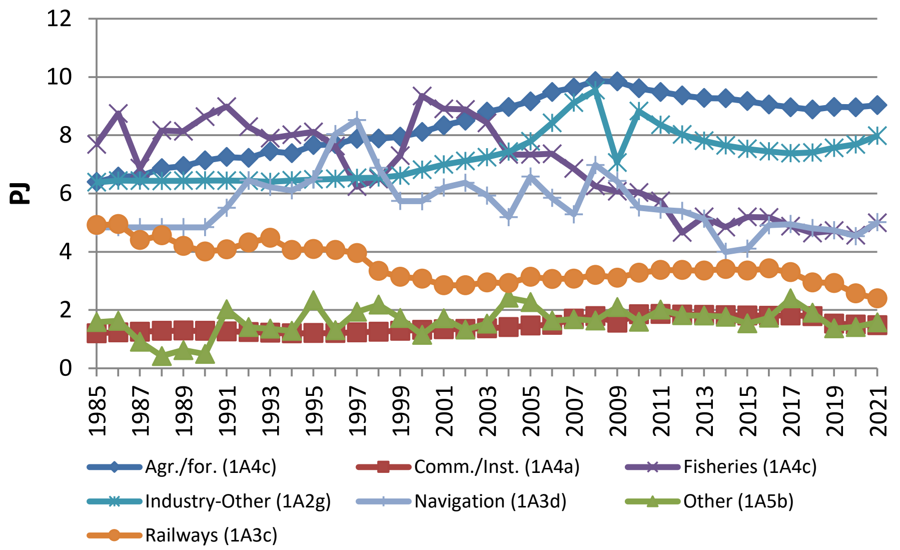


Figure 3.3.9 Diesel fuel consumption in CRF sectors for other mobile sources 1985-2021.

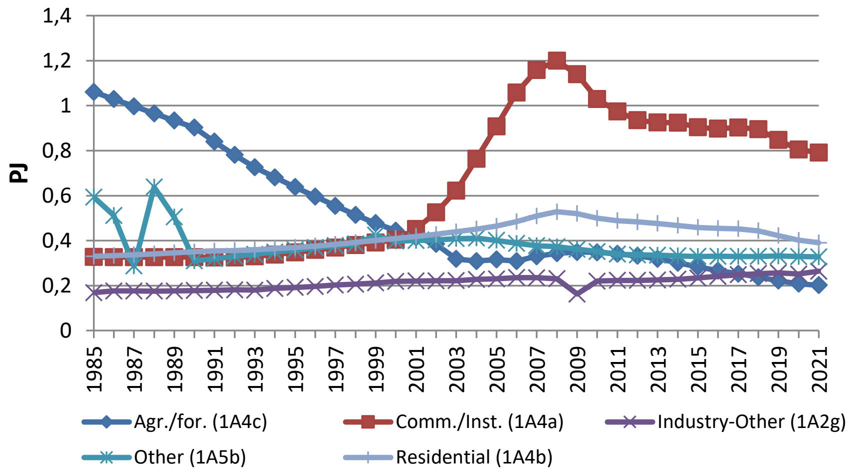


Figure 3.3.10 Gasoline fuel consumption in CRF sectors for other mobile source 1985-2021.

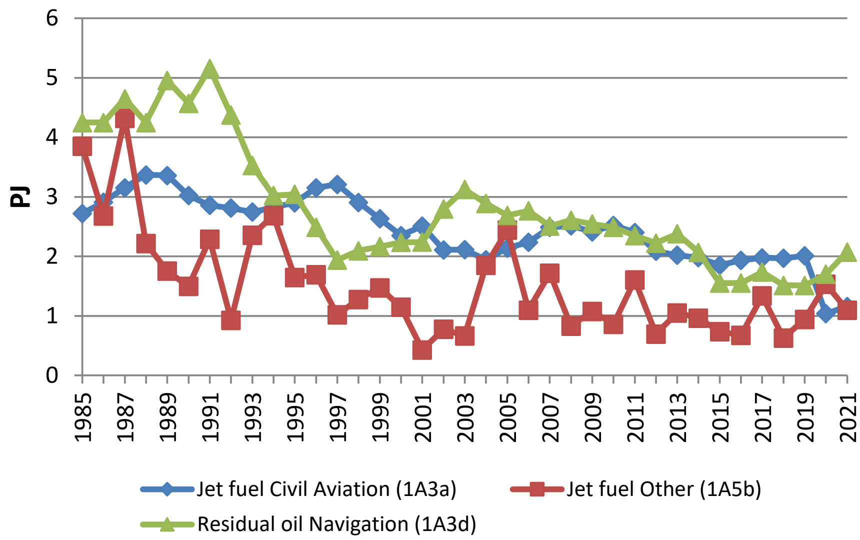


Figure 3.3.11 Residual oil and jet fuel consumption in CRF sectors for other mobile sources 1985-2021.

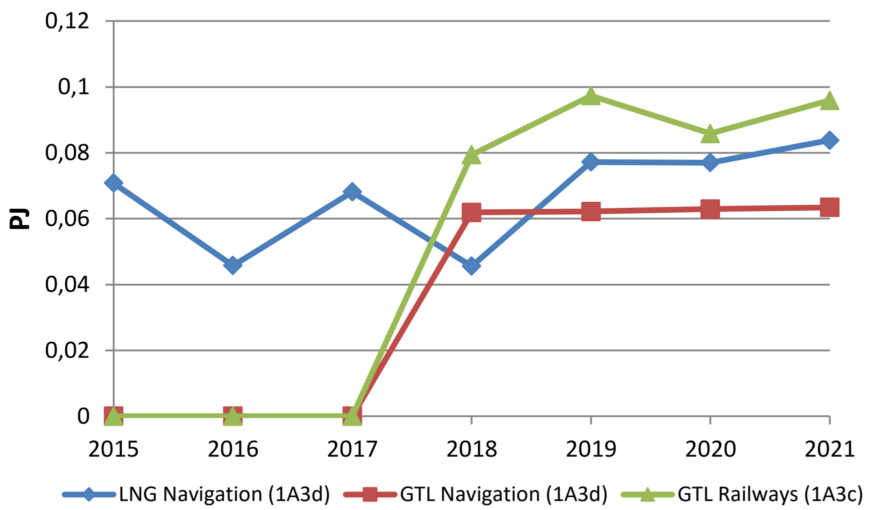


Figure 3.3.12 LNG and GTL fuel consumption in CRF sectors for other mobile sources 1985-2021.

For diesel, although the number of tractors and harvesters decrease in the entire period 1985-2020, the contemporary increase in the engine sizes of new sold machines makes the total fuel consumption grow until 2008. The turnover of old less fuel efficient machinery and the decline in the number of tractors and harvesters explain the total fuel consumption decrease from 2008 onwards. 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. The fuel efficiency improvements for new sold vehicles is the main reason for total fuel consumption decline from 2010-2018. 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 new sales of ATV's from the mid 2000's until 2011, followed by a decrease in new sales of ATV's from 2011 forward.

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, and in 2020 a huge decline in jet fuel consumption is noted due to the impact of COVID-19 on flight travel demand.

From 2015 onwards small amounts of LNG has been used by domestic ferries, and from 2018 onwards GTL has been used by a few domestic ferries and private railway lines.

Fuel consumption for international transport

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, transport to Greenland and the Faroe Islands, tank vessels and foreign fishing boats. For jet petrol, the sudden fuel consumption drop in 2002 is explained by the recession in the aviation 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, and in 2020 a huge decline in jet fuel consumption is noted due to the impact of COVID-19 on flight travel demand.

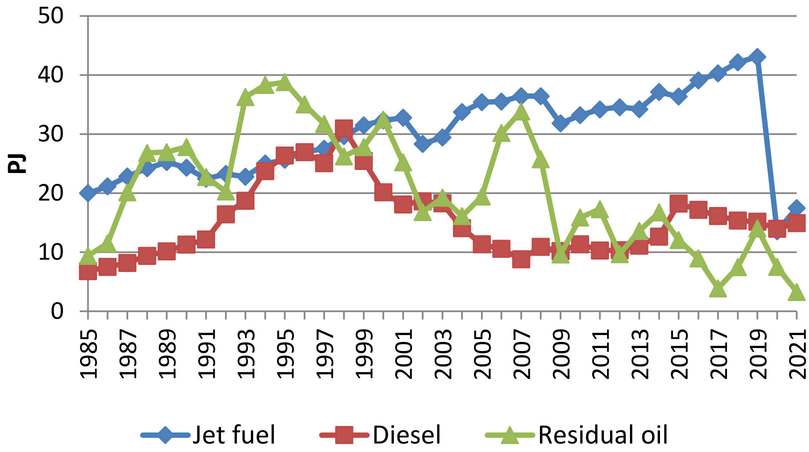


Figure 3.3.13 Bunker fuel consumption 1985-2021.

Total emissions of SO_2, NO_X, NMVOC, CO, NH_3, TSP, PM_{10}, $PM_{2.5}$ and BC

In Table 3.3.3 the SO_2, NO_X, NMVOC, CO NH_3, TSP, PM_{10}, $PM_{2.5}$ and BC emissions for road transport and other mobile sources are shown for 2021 in NFR sectors. The emission figures in the time series 1985-2021 are given in Annex 3.B.16 (NFR format) and are shown for 2021 in Annex 3.B.15 (CollectER format).

From 1985 to 2021, the road transport emissions of SO_2, NO_X, NMVOC, CO, PM (exhaust emissions; all size fractions) and BC have decreased by 99, 79, 92, 91, 93 and 92 %, respectively (Figures 3.3.14-3.3.19), whereas the NH_3 emissions have increased by 1052 % during the same time period (Figure 3.3.20).

For other mobile sources, the emission changes for SO_2, NO_X, NMVOC, CO, PM (all size fractions) and BC are -96, -42, -64, -37, -78 and -81 %, respectively (Figures 3.3.21-3.3.25). The NH_3 emissions have increased by 28 % during the same time period (Figure 3.3.26).

Table 3.3.3 Emissions of SO_2, NO_X, NMVOC, CO NH_3, TSP, PM_{10}, $PM_{2.5}$ and BC in 2021 for road transport and other mobile sources.

	SO_2	NO_x	NMVOC	CO	NH_3	TSP	PM_{10}	$PM_{2.5}$	BC
	tonnes	tonnes	tonnes	tonnes	tonnes	tonnes	tonnes	tonnes	tonnes
Manufacturing industries/Construction (mobile)	4	1997	662	5506	2	139	139	139	95
Civil aviation (Domestic)	27	356	19	610	0	3	3	3	1
Road transport: Passenger cars	38	10007	2988	41400	628	90	90	90	57
Road transport:Light duty vehicles	9	6635	159	1799	46	62	62	62	48
Road transport:Heavy duty vehicles	23	3770	156	1836	45	60	60	60	35
Road transport: Mopeds & motorcycles	0	124	830	6126	1	13	13	13	2
Road transport: Gasoline evaporation	0	0	1348	0	0	0	0	0	0
Road transport: Brake wear	0	0	0	0	0	720	706	281	19
Road transport: Tyre wear	0	0	0	0	0	979	588	411	150
Road transport: Road abrasion	0	0	0	0	0	1188	594	321	0
Railways	1	1201	60	181	0	14	14	14	9
National navigation (Shipping)	219	10278	451	1046	0	295	292	291	27
Commercial/Institutional: Mobile	1	473	731	27029	0	39	39	39	19
Residential: Household and gardening (mobile)	0	34	871	11638	0	16	16	16	1
Agriculture/Forestry/Fishing: Off-road agriculture/forestry	4	2326	650	5887	2	202	202	202	117
Agriculture/Forestry/Fishing: National fishing	234	5805	272	777	0	103	102	101	22
Other, Mobile	69	1123	255	2924	1	55	55	55	21
Road transport exhaust total	71	20536	5482	51161	721	225	225	225	142
Road transport non exhaust total	0	0	0	0	0	2888	1887	1013	169
Other mobile sources total	559	23595	3971	55598	6	866	862	860	311
Domestic total	630	44131	9453	106760	727	3979	2975	2098	622
Civil aviation (International)	402	6163	87	1060	0	56	56	56	20
Navigation (International)	860	29592	1144	3269	0	672	665	662	50

Emissions of SO_2, NO_X, NMVOC, CO, NH_3, TSP, PM_{10}, $PM_{2.5}$ and BC for road transport

The step-wise lowering of the sulphur content in diesel fuel has given rise to a substantial decrease in the road transport emissions of SO_2 (Figure 3.3.14). In 1999, the sulphur content was reduced from 500 ppm to 50 ppm (reaching gasoline levels), and for both gasoline and diesel the sulphur content was reduced to 10 ppm in 2005. Since Danish diesel and gasoline fuels have the same sulphur percentages, at present, the 2021 shares for SO_2 emissions and fuel consumption for passenger cars, heavy-duty vehicles, light-duty vehicles and 2-wheelers are the same in each case: 53, 33, 13 and 1 %, respectively (Figure 3.3.21).

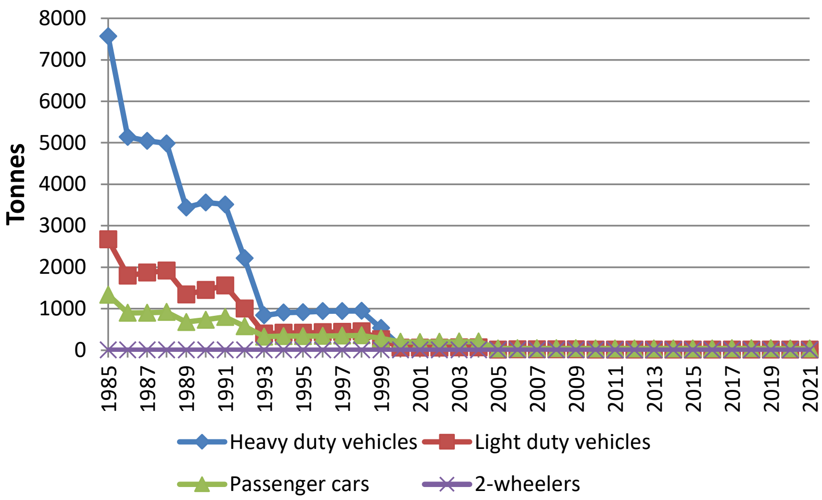


Figure 3.3.14 SO_2 emissions (tonnes) per vehicle type for road transport 1985-2021.

Historically, the emission totals of NMVOC and CO have been very dominated by the contributions coming from private cars, as shown in Figures 3.3.16- 3.3.17. However, the NMVOC and CO (and NO_x) emissions from this vehicle type have shown a steady decreasing tendency since the introduction of private catalyst cars in 1990 (EURO I) and the introduction of even more emission-efficient EURO II, III, IV and V private cars (introduced in 1997, 2001, 2006 and 2011, respectively).

For NO_x the emission decrease for passenger cars is composed of a significant drop in emissions from gasoline cars driven by technology improvements, and an increase in emissions from diesel cars due to the dieselization of the Danish vehicle fleet, and almost unchanged emission factors for diesel passenger cars until Euro 6, regardless of EU emission legislation demands. For light duty vehicles, the NO_x emission trend is also the result of a technology driven emission reduction for gasoline vehicles, and a traffic induced emission increase for diesel vehicles; the emission factors for the latter vehicle category have been relatively constant until Euro 6 just as for diesel cars.

The most modern Euro 6d-TEMP and 6d diesel passenger cars and Euro 6d-TEMP light duty vehicles which entered into the fleet in 2018 and 2021 and 2019, respectively, however, have significantly lower NO_x emission factors compared to earlier Euro standards. Hence the gradual growth in the numbers of Euro 6d-TEMP and 6d vehicles is going to reduce the emissions for diesel passenger cars and light duty vehicles in the years to come. Relatively large NO_x emission reductions is noted for passenger cars in 2020 related to COVID-19.

For heavy duty vehicles until Euro III, the real traffic NO_x emissions are not reduced in the order as intended by the EU emission legislation. Most markedly for Euro II engines, the emission factors are even higher than for Euro I due to the so-called engine cycle-beating effect. Outside the legislative test cycle stationary measurement points, the electronic engine control for heavy duty Euro II and III engines switches to a fuel efficient engine running mode, thus leading to increasing NO_x emissions (Figure 3.3.15). However, the reduction in transport activities due to the global financial crisis in 2008 and 2009 and improved emission factors for Euro IV onwards causes the NO_x emissions for heavy duty vehicles to decrease significantly from 2008.

Exhaust particulate emissions from road transportation vehicles are well below $PM_{2.5}$. The emissions from light- and heavy-duty vehicles have significantly decreased since the mid-1990s due to gradually stricter EURO emission standards. In recent years until 2008 the environmental benefit of introducing gradually cleaner diesel private cars has been somewhat outbalanced by an increase in sales of new vehicles. After 2008, the PM emissions gradually become lower due to the increasing number of Euro V cars equipped with particulate filter sold in Denmark from 2006 onwards (Figure 3.3.18).

BC - commonly understood as the solid part of the particulate emissions - is calculated as shares of TSP for each Euro engine technology class (Figure 3.3.19). In broad terms, the development in BC emissions follows the TSP emission trend, but deviates in some cases, most markedly for diesel cars and vans. For these vehicle types the BC share of TSP increases in moderate steps from conventional engine technologies to Euro IV. As a result, the BC emission development becomes environmentally less positive than for TSP, until the introduction of Euro V vehicles, for which the installed particulate filters have very high removal rates of BC.

An undesirable environmental side effect of the introduction of catalyst cars is the increase in the emissions of NH_3 from the first two generations of catalyst cars (Euro I and II) compared to conventional cars. The emission factors for later catalytic converter technologies are considerably lower than the ones for Euro I and II, thus causing the emissions to decrease from 2001 onwards (Figure 3.3.20).

The 2021 emission shares for passenger cars, heavy-duty vehicles, light-duty vehicles and 2-wheelers for NO_x (49, 18, 32 and 1 %), NMVOC (exhaust: 54, 3, 3 and 15 %), CO (81, 4, 3 and 12 %), PM (40, 27, 27 and 6 %), BC (33, 48, 19 and 0 %), and NH_3 (87, 6, 7 and 0 %), are also shown in Figure 3.3.21.

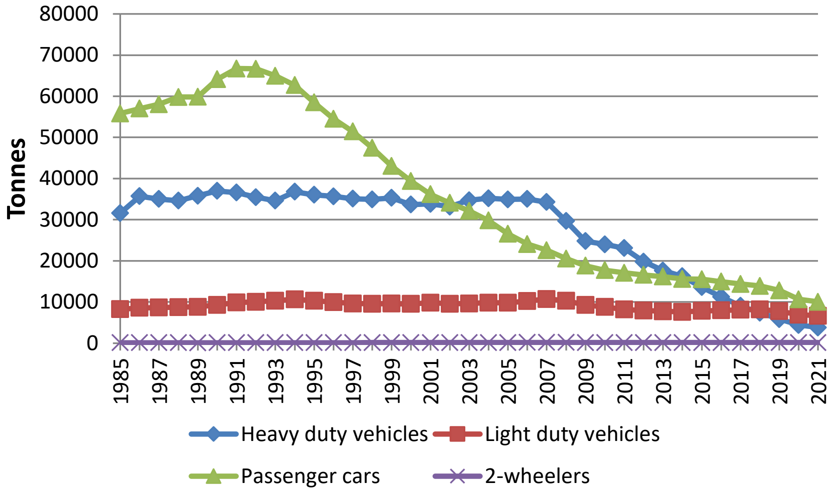


Figure 3.3.15 NO_X emissions (tonnes) per vehicle type for road transport 1985-2021.

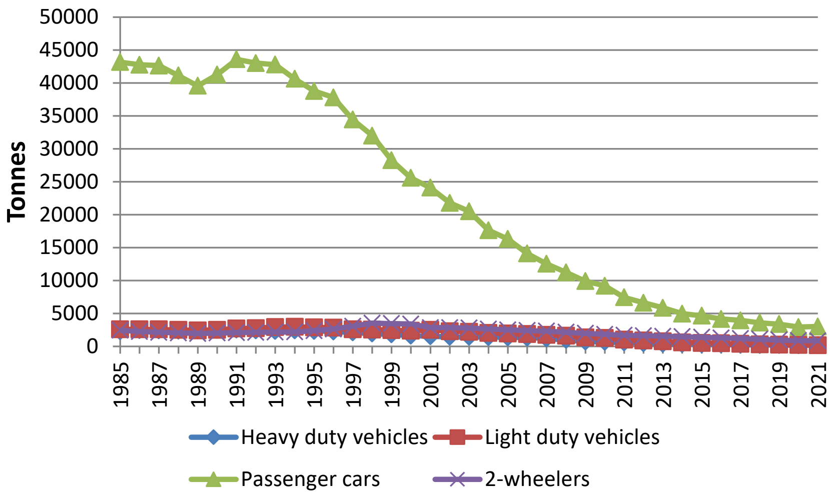


Figure 3.3.16 NMVOC emissions (tonnes) per vehicle type for road transport 1985-2021.

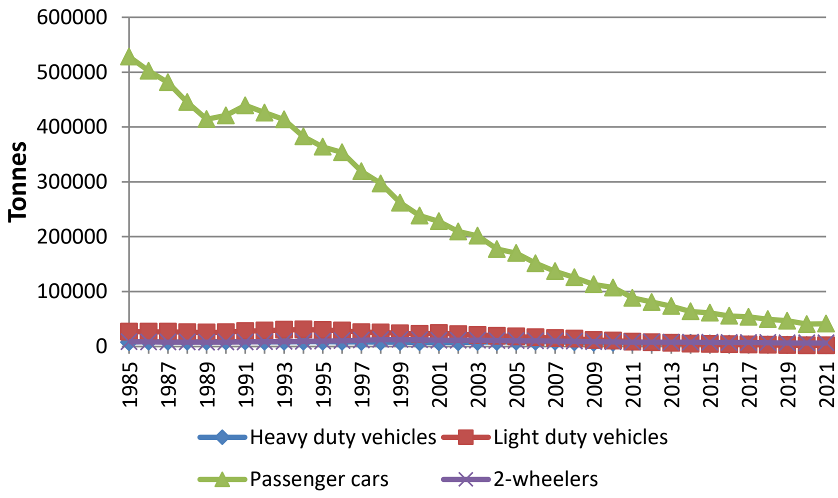


Figure 3.3.17 CO emissions (tonnes) per vehicle type for road transport 1985-2021.

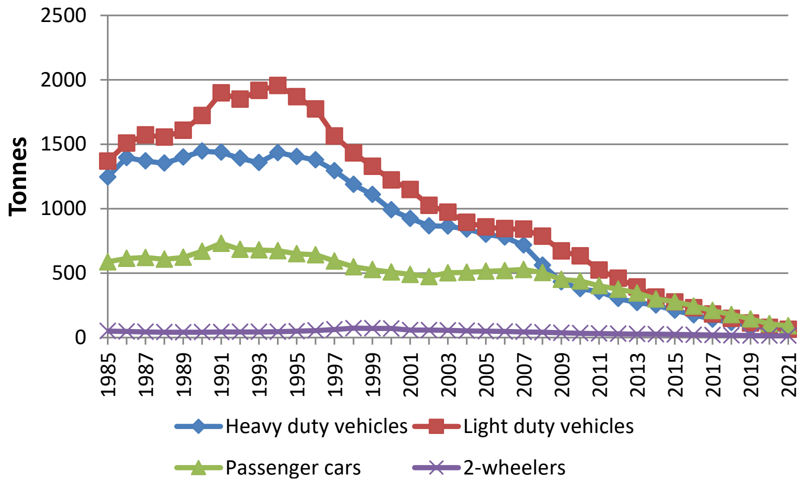


Figure 3.3.18 PM emissions (tonnes) per vehicle type for road transport 1985-2021.

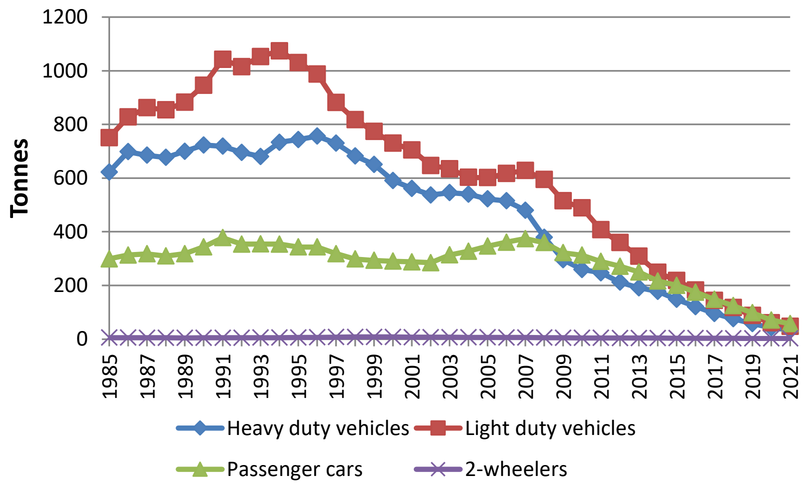


Figure 3.3.19 BC emissions (tonnes) per vehicle type for road transport 1985-2021.

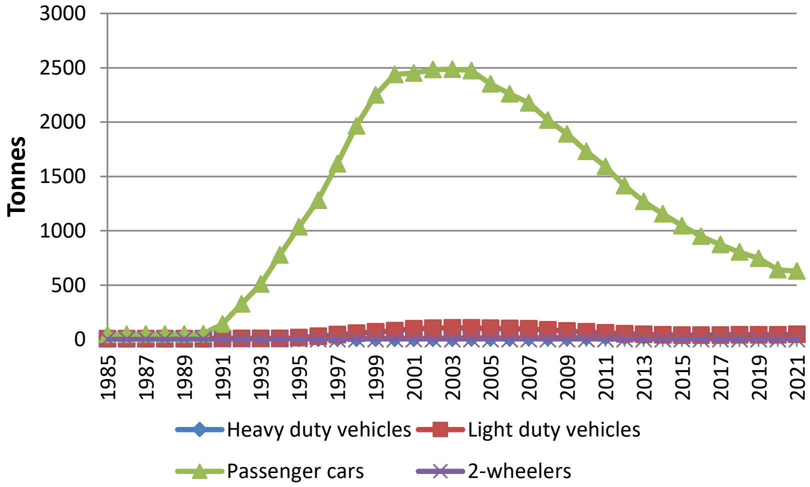


Figure 3.3.20 NH_3 emissions (tonnes) per vehicle type for road transport 1985-2021.

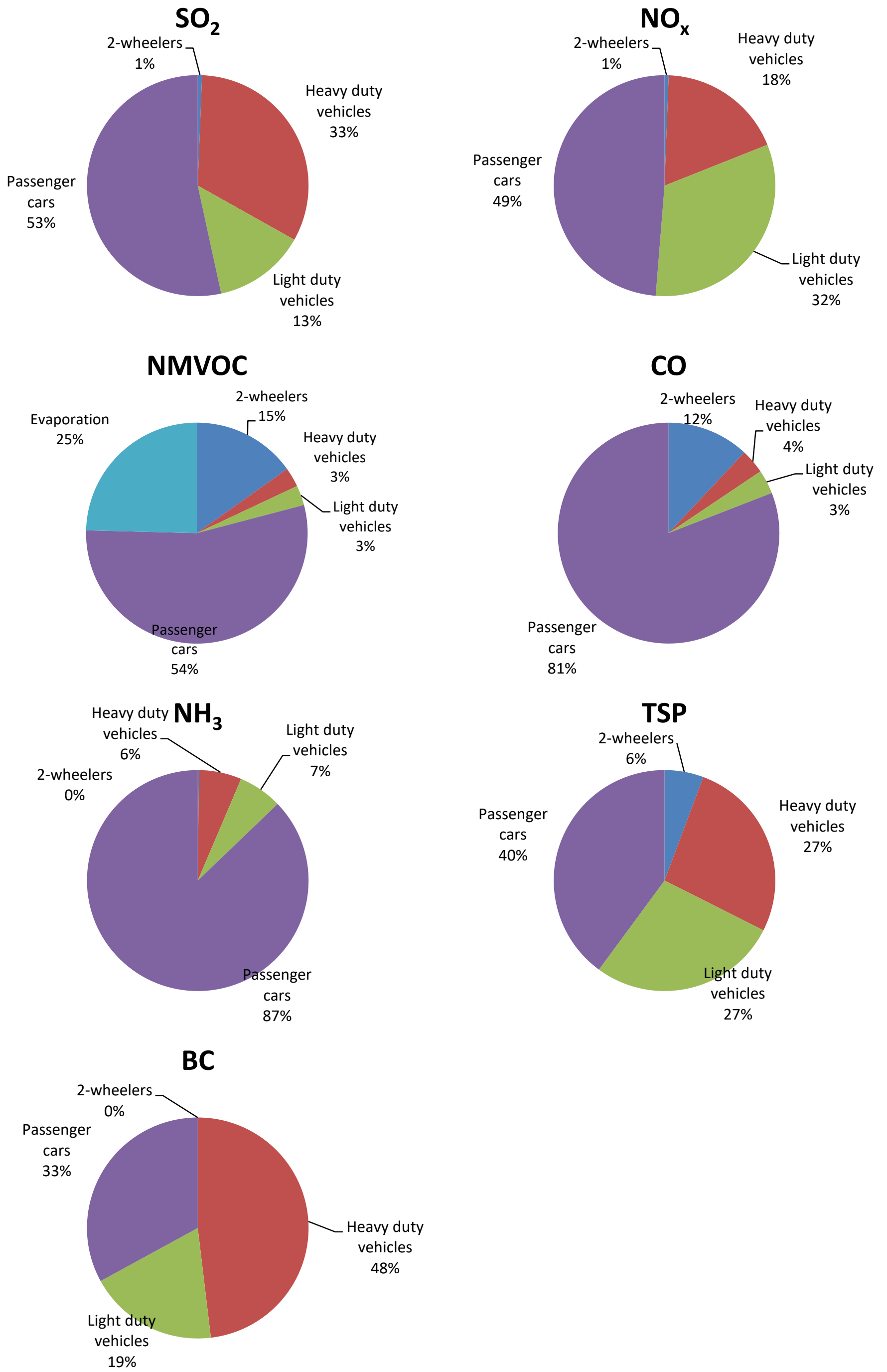


Figure 3.3.21 SO_2, NO_X, NMVOC, CO, NH_3, PM and BC emission shares pr vehicle type for road transport in 2021.

Non-exhaust emissions of TSP, PM_{10}, $PM_{2.5}$ and BC

Apart from the exhaust emission estimates of particulate matter (PM), the Danish emission inventories also comprise the non-exhaust PM emissions coming from road transport brake and tyre wear, and road abrasion.

In Table 3.3.3, the non-exhaust TSP, PM_{10}, $PM_{2.5}$ and BC emissions for road transport are shown for 2021 in NFR sectors. The activity data and emission factors are also shown in Annex 3.B.15.

The respective source category distributions for TSP, PM_{10} and $PM_{2.5}$ emissions are identical for each of the non-exhaust emission types brake wear, tyre wear and road abrasion, and, hence, only the PM_{10} distributions are shown in Figure 3.3.22. For Brake wear, passenger cars caused the highest emissions in 2021, followed by trucks, light-duty vehicles, buses and 2-wheelers. In the case of tyre wear and road abrasion, passenger cars caused the highest emissions in 2021, followed by light-duty vehicles, trucks, buses and 2-wheelers.

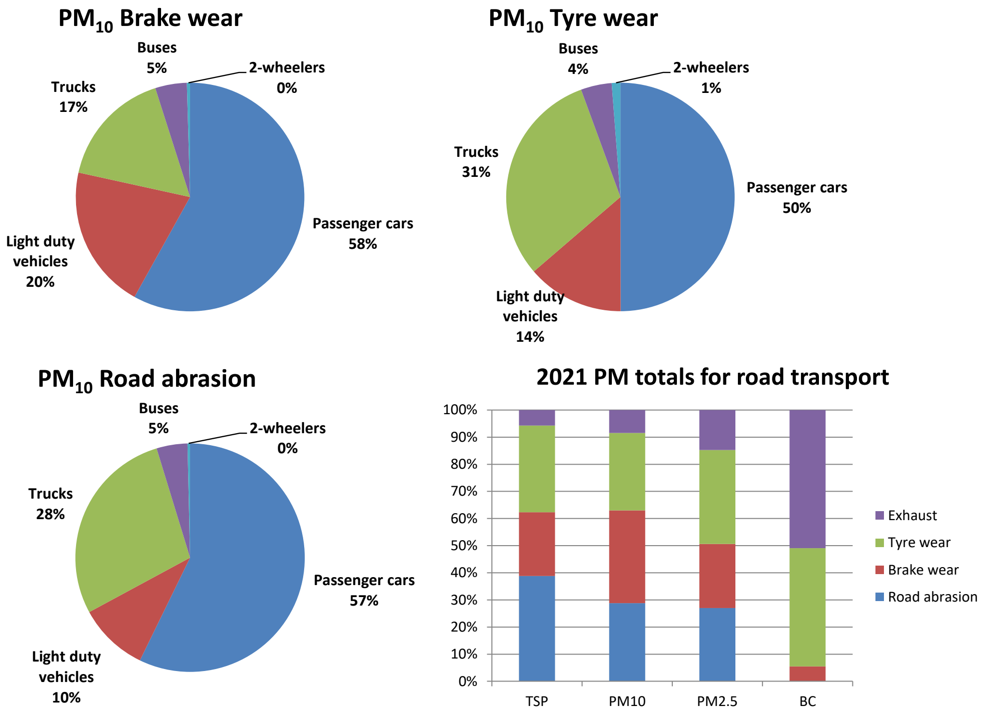


Figure 3.3.22 Brake and tyre wear and road abrasion PM_{10} emission shares and PM and BC exhaust/non-exhaust distributions for road traffic in 2021.

Figure 3.3.22 also shows the exhaust/non-exhaust distribution of the total particulate emissions from road transport, for each of the size classes TSP, PM_{10} and $PM_{2.5}$ and for BC. The exhaust emission shares of total road transport TSP, PM_{10}, $PM_{2.5}$ and BC are 6, 8, 15 and 51 %, respectively, in 2021. For brake and tyre wear and road abrasion the TSP shares are 24, 32 and 39 %, respectively. The same three sources have PM_{10} shares of 34, 28 and 29 %, respectively, $PM_{2.5}$ shares of 24, 35, 27 %, and BC shares of 5, 44 and 0 %, respectively. In general, the non-exhaust shares of total particulate emissions are expected to increase in the future as total exhaust emissions decline. The latter emission trend is due to the stepwise strengthening of exhaust emission standards for all vehicle types.

Emissions of SO_2, NO_X, NMVOC, CO, NH_3, TSP, PM_{10}, $PM_{2.5}$ and BC for other mobile sources

For SO_2 the trends in the Navigation (1A3d) emissions shown in Figure 3.3.23 mainly follow the development of the heavy fuel oil consumption (Figure 3.3.11). The SO_2 emissions for Fisheries (1A4c) correspond with the development in the consumption of marine gas oil. The main explanation for the development of the SO_2 emission curves for Railways (1A3c) and non-road machinery in Agriculture/forestry (1A4c) and Industry (1A2f), are the stepwise sulphur content reductions for diesel used by machinery in these sectors.

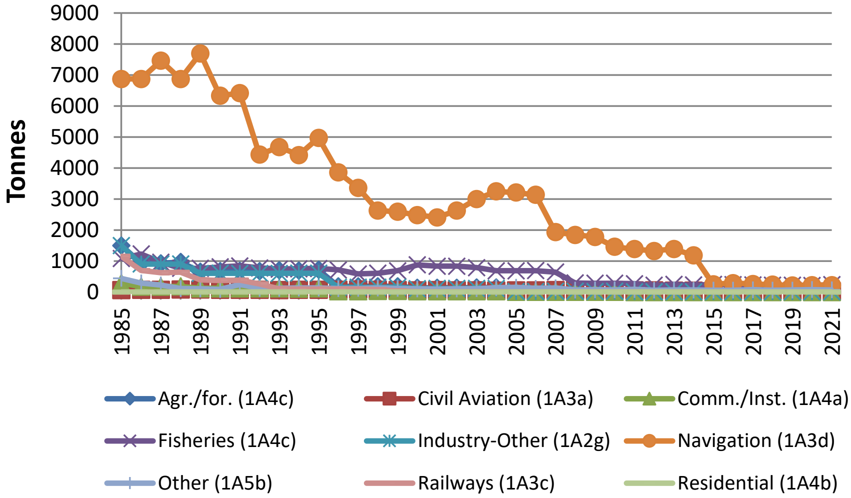


Figure 3.3.23 SO_2 emissions (ktonnes) in NFR sectors for other mobile sources 1985-2021.

NO_X emissions mainly come from diesel machinery, and the most important sources are Navigation (1A3d), Agriculture/forestry/fisheries (1A4c), Industry (1A2f) and Railways (1A3c), as shown in Figure 3.3.24. The 2021 emission shares are 44, 35, 8 and 5 %, respectively (Figure 3.3.30). Minor emissions come from the sectors Other (1A5), Civil Aviation (1A3a), Commercial/Institutional (1A4a) and Residential (1A4b).

The NO_X emission trend for Navigation, Fisheries and Agriculture/Forestry is determined by fuel consumption fluctuations for these sectors, and the development of emission factors.

For ship engines, the emission factors tend to increase for new engines until mid-1990s. After that, the emission factors gradually reduce until 2000, bringing them to a level comparable with the emission limits for new engines in this year. From 2012, the high-speed ferry "Catexpress" entered into service on the two important Danish domestic ferry routes "Sjællands Odde-Ebeltoft" and "Sjællands Odde-Aarhus". The ferry "Catexpress" has relatively high NO_x emission factors and relatively low specific fuel consumption factors, this causes the implied NO_x emission factor to change.

For agricultural and forestry machines the diesel fuel consumption increases from 1985 to 2008 and is then followed by a decrease from 2009 onwards (Figure 3.3.9). The NO_x emission performance for non road diesel machinery are characterized by somewhat higher NO_x emission factors for 1991-stage I machinery, and gradually improved emission performance for stage I and onwards emission technology levels entering the stock since the late 1990s. Consequently, the total NO_x emissions for agriculture/forestry increase up to 2001, and then reduces from 2003 onwards.

The NO_x emissions for industrial non-road machinery decline from 1985-2021. The emission reductions are, however, mostly pronounced from 2009 onwards. The emission development from 1985 to 2021 for industry NO_x is the product of a rather constant fuel consumption from 1985-1999, a fuel consumption increase from 2000 to 2008, and a fuel consumption decrease from 2009 onwards (Figure 3.3.9), in combination with a development in emission factors as explained for agricultural machinery. For industry, the NO_x emission impact from the global financial crisis becomes very visible for 2009.

For railways, the gradual shift towards electrification explains the declining trend in diesel fuel consumption and NO_X emissions for this transport sector until 2001.

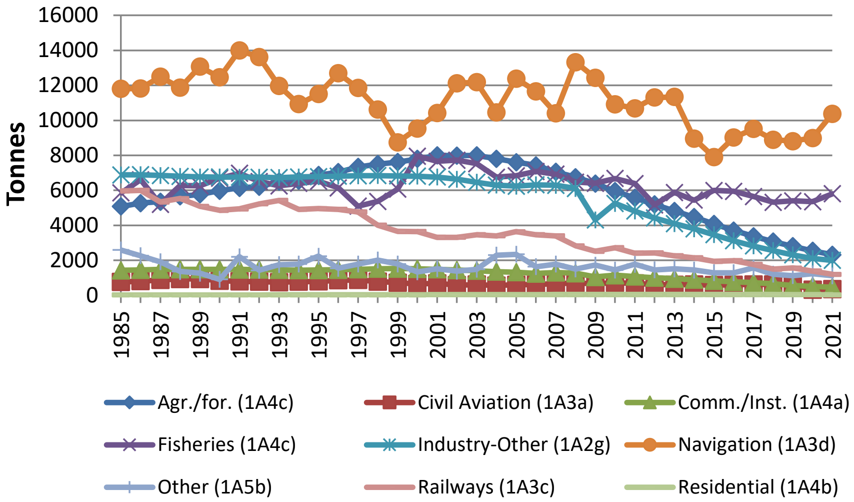


Figure 3.3.24 NO_X emissions (tonnes) in NFR sectors for other mobile sources 1985-2021.

The 1985-2021 time series of NMVOC and CO emissions are shown in Figures 3.3.25 and 3.3.26 for other mobile sources. The 2021 sector emission shares are shown in Figure 3.3.30. For NMVOC, the most important sectors are Agriculture/forestry/fisheries (1A4c), Residential (1A4b), Commercial/Institutional (1A4a) and Industry (1A2g), with 2021 emission shares of 23, 22, 18 and 17 %, respectively.

The same four sectors also contribute with most of the CO emissions. For Commercial/Institutional (1A4a), Residential (1A4b), Agriculture/forestry/fisheries (1A4c) and Industry (1A2g) the emission shares are 49, 21, 12 and 10 %, respectively. Minor NMVOC and CO emissions come from Navigation (1A3d), Railways (1A3c), Civil Aviation (1A3a) and Other (1A5).

For NMVOC and CO, the significant emission increases for the commercial/institutional and residential sectors after 2000 are due to the increased number of gasoline working machines. Improved NMVOC emission factors for diesel machinery in agriculture and gasoline equipment in forestry (chain saws) are the most important explanations for the NMVOC emission decline in the Agriculture/forestry/fisheries sector. This explanation also applies for the industrial sector, which is dominated by diesel-fuelled machinery. From 1997 onwards, the NMVOC emissions from Other (1A5) decrease due to the gradually phase-out of the 2-stroke engine technology for recreational craft. The main reason for the significant 1985-2006 CO emission decrease for Agriculture/forestry-/fisheries is the phasing out of gasoline tractors.

As shown in Figure 3.3.30, for other mobile sources the largest TSP contributors in 2021 are Agriculture/forestry/fisheries (1A4c), Navigation (1A3d) and Industry (1A2f) with emission shares of 35 %, 34 % and 16 %, respectively. The remaining sectors: Railways (1A3c), Civil aviation (1A3a), Other (1A5), Commercial/Institutional (1A4a) and Residential (1A4b) represent only minor emission sources.

The 1985-2021 TSP emissions for navigation and fisheries are determined by the fuel consumption fluctuations in these years, and the development of the emission factors, which to a major extent is a function of the fuel type and fuel sulphur content.

For agriculture/forestry non road machinery the TSP emissions development from 1985-2020 are also determined by the development of fuel consumption and emission factors. The diesel consumption increases from 1985 to 2008 followed by a decrease from 2009 onwards (Figure 3.3.9), whereas the emission factors are gradually reduced during the whole time period. Consequently, the total TSP emissions for agriculture/forestry are quite constant until 1990, and then reduced from 1991 onwards.

The TSP emissions for industrial non-road machinery decline from 1985-2021. The latter emission development is the product of gradually reduced emission factors throughout the period, in combination with a rather constant fuel consumption from 1985-1999, which later on increases from 2000 to 2008 followed by a fuel consumption decrease from 2009 onwards (Figure 3.3.9). For industry, the TSP emission impact from the global financial crisis becomes very visible for 2009.

The TSP emission explanations for railways are the same as for NO_x (Figure 3.3.24).

Apart from marine engines, BC is calculated as shares of TSP for each engine emission technology class and in broad terms the development in BC emissions follows the TSP emission trend. For marine engines (used in navigation and fisheries) fuel type and engine type specific BC emission factors are used in the emission calculations, and hence the BC emissions rely on the fuel consumption development per fuel type and engine type in the inventory period.

The amounts of NH_3 emissions calculated for other mobile sources are very small. The largest emission sources are Agriculture-/forestry/fisheries (1A4c), Industry (1A2f), Other (1A5b) and Railways (1A3c), with emission shares of 43 %, 24 %, 15 % and 9 %, respectively.

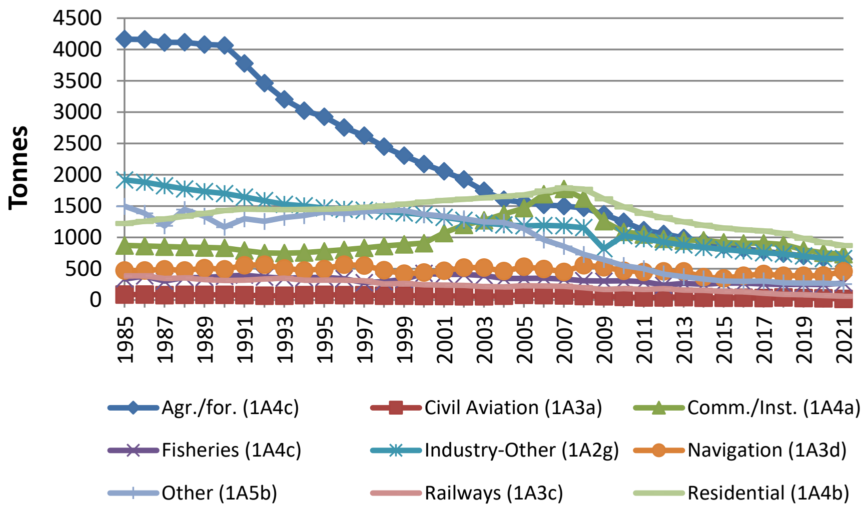


Figure 3.3.25 NMVOC emissions (tonnes) in NFR sectors for other mobile sources 1985-2021.

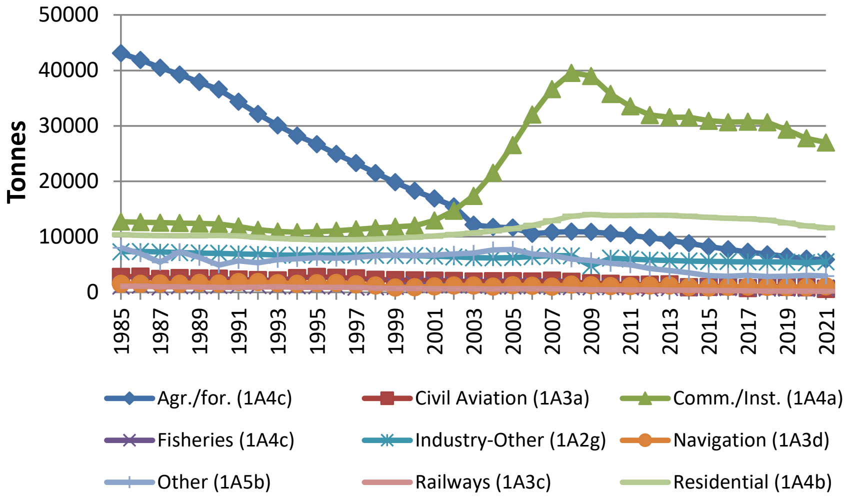


Figure 3.3.26 CO emissions (tonnes) in NFR sectors for other mobile sources 1985-2021.

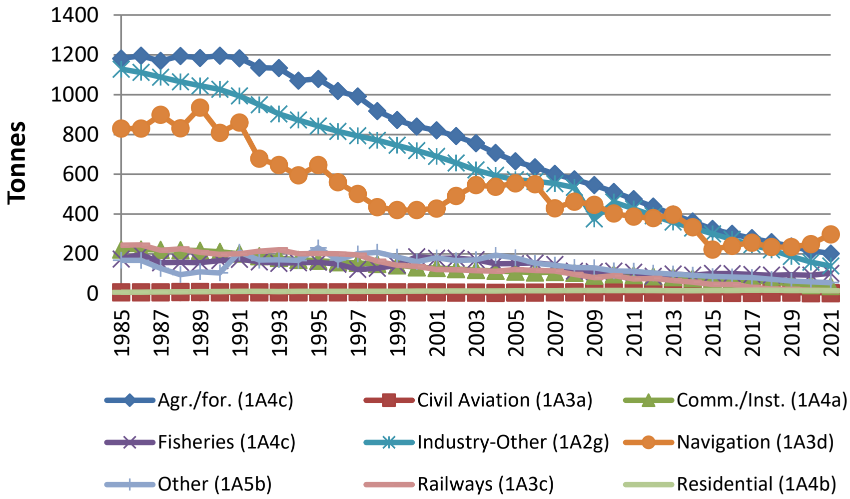


Figure 3.3.27 TSP emissions (tonnes) in NFR sectors for other mobile sources 1985-2021.

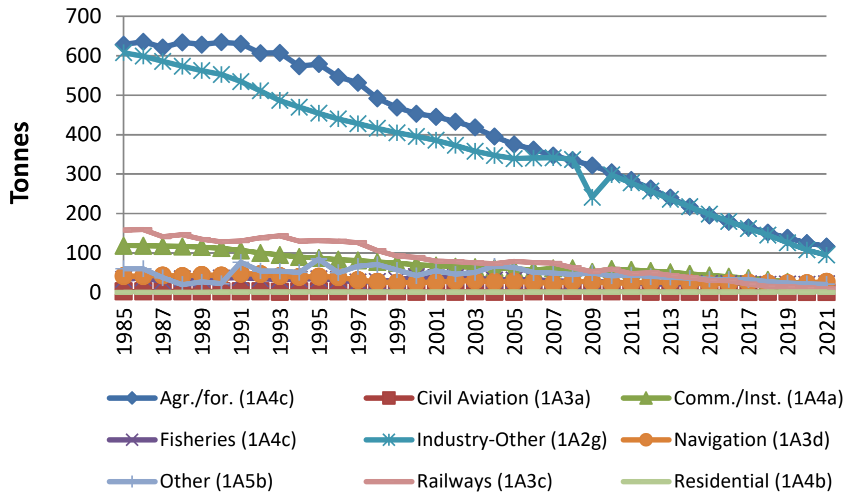


Figure 3.3.28 BC emissions (tonnes) in NFR sectors for other mobile sources 1985-2021.

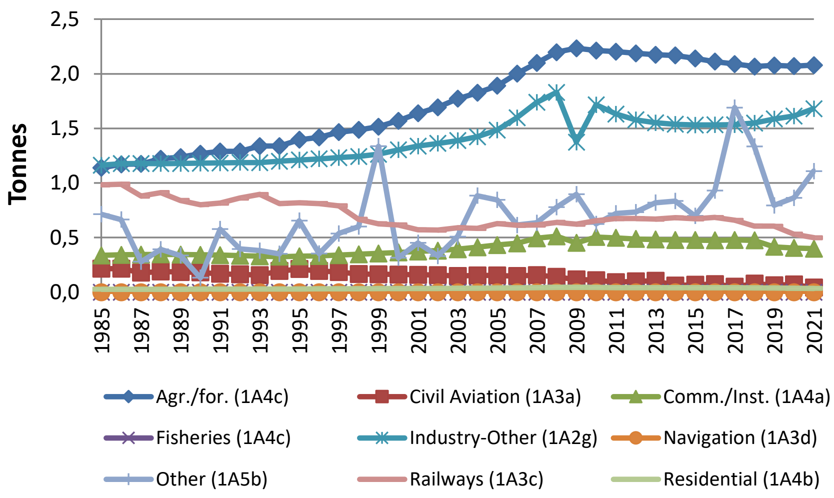


Figure 3.3.29 NH$_3$ emissions (tonnes) in NFR sectors for other mobile sources 1985-2021.

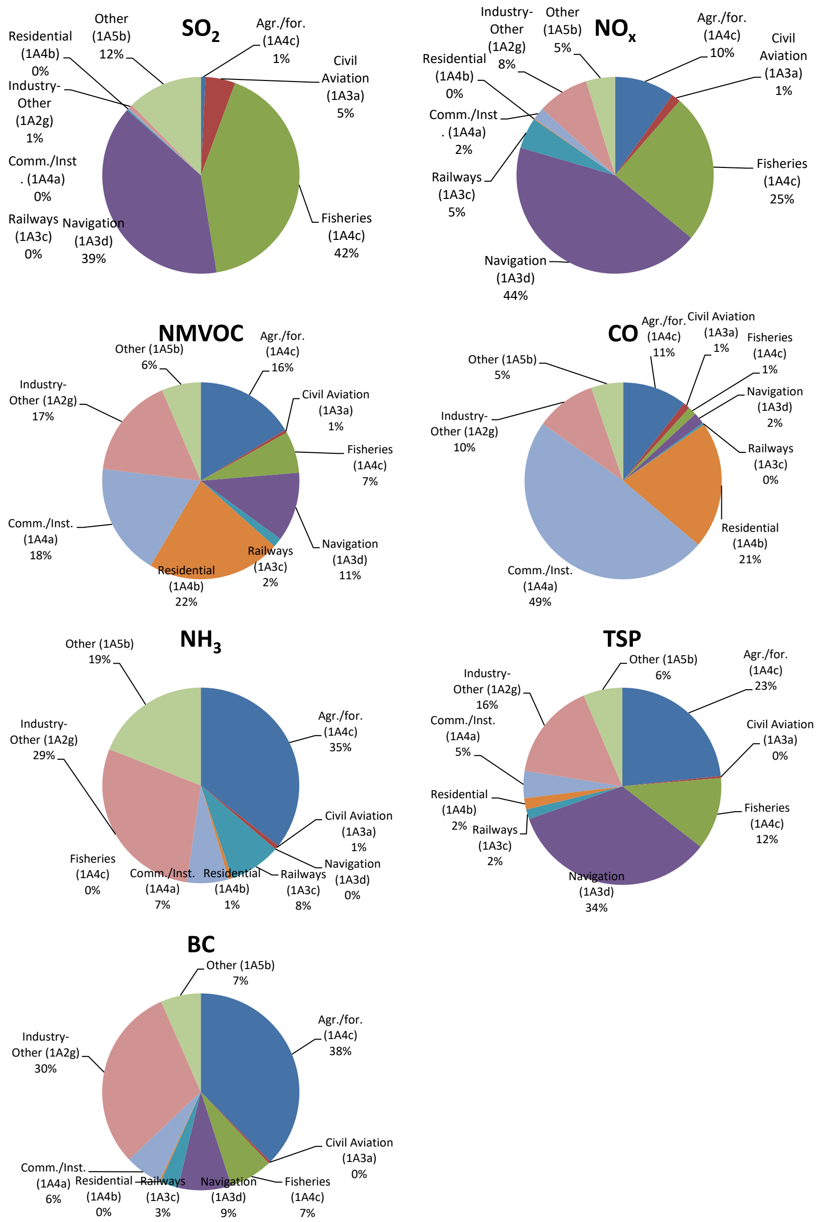


Figure 3.3.30 SO$_2$, NO$_X$, NMVOC, CO, NH$_3$, PM and BC emission shares pr vehicle type for other mobile sources in 2021.

Emissions of heavy metals

In Table 3.3.4, the heavy metal emissions for road transport and other mobile sources are shown for 2021 in NFR sectors. The emission figures in the time series 1990-2021 are given in Annex 3.B.16 (NFR format) and are shown for 1990 and 2021 in Annex 3.B.15 (CollectER format).

Table 3.3.4 Heavy metal emissions in 2021 for road transport and other mobile sources.

	Arsenic	Cadmium	Chromium	Copper	Mercury	Nickel	Lead	Selenium	Zinc
	kg	kg	kg	kg	kg	kg	kg	kg	kg
Manufacturing industries/Construction (mobile)	0	2	5	4	1	2	9	0	318
Civil aviation (Domestic)	0	0	0	0	0	0	357	0	1
Road transport: Passenger cars	0	28	56	88	14	30	118	0	5600
Road transport:Light duty vehicles	0	5	15	12	3	5	27	0	946
Road transport:Heavy duty vehicles	0	7	27	19	6	7	43	0	1432
Road transport: Mopeds & motorcycles	0	0	0	0	0	0	0	0	23
Road transport: Gasoline evaporation	0	0	0	0	0	0	0	0	0
Road transport: Brake wear	0	6	81	61024	0	79	7941	14	12654
Road transport: Tyre wear	0	3	4	15	0	25	79	20	10711
Road transport: Road abrasion	0	0	24	12	0	19	56	0	90
Railways	0	0	2	1	0	0	3	0	93
National navigation (Shipping)	31	3	15	31	5	1529	22	44	105
Commercial/Institutional: Mobile	0	0	1	1	0	1	2	0	92
Residential: Household and gardening (mobile)	0	0	0	0	0	0	0	0	18
Agriculture/Forestry/Fishing: Off-road agriculture/forestry	0	2	6	4	1	2	10	0	346
Agriculture/Forestry/Fishing: National fishing	6	1	5	6	3	8	12	23	58
Other, Mobile	0	0	1	1	0	0	2	0	80
Road transport exhaust total	1	40	99	119	23	43	188	0	8001
Road transport non exhaust total	0	9	109	61051	0	122	8076	34	23455
Other mobile sources total	37	9	35	50	11	1542	418	67	1113
Domestic total	38	57	243	61220	34	1707	8682	102	32569
Civil aviation (International)	0	0	0	0	0	0	0	0	0
Navigation (International)	57	6	30	57	12	2425	51	102	247

The heavy metal emission estimates for road transport are to a large extent based on a national research study made by Winther and Slentø (2010). The latter study calculate the exhaust related emissions from fuel and engine oil as well as the wear related emissions from tyre, brake and road wear. New supplementary emission factors from COPERT 5 for brake wear and road abrasion is included for fossil fueled and electric passenger cars, and based on these data proportional adjustments are made to calculate new brake wear and road abrasion emission factors for fossil fueled and electric light commercial vehicles also.

Apart from Pb, the emission factors only deviate to a less extent due to changes in fleet and mileage composition over the years; this brought relative changes in fuel consumption per fuel type, engine oil use and aggregated emission factors for brake, tyre and road wear.

The most important exhaust related emissions for road transport are Zn, Pb, Cu and Cr. the most important wear related emissions are Cu and Pb almost solely coming from tyre wear, and Zn from brake and tyre wear. For other mobile sources, the most important emission contributions are calculated for

Ni, Se and As, coming from the use of marine diesel oil in fisheries and navigation and residual oil in navigation.

The Figures 3.3.31 and 3.3.32 show the heavy metal emission distributions for all road transport sources split into vehicle categories, and for other mobile sectors, respectively.

For non-road mobile machinery in agriculture, forestry, industry, commercial/institutional and recreational, as well as military and railways, fuel related emission factors from road transport are used derived for the year 2009.

For civil aviation jet fuel no emissions are estimated due to lack of emission data, whereas for aviation gasoline fuel related emission factors for road transport gasoline is used derived for the year 2009, except for Pb where national data exist.

For navigation and fisheries, the heavy metal emission factors are fuel related, and are taken from the EMEP/EEA guidebook.

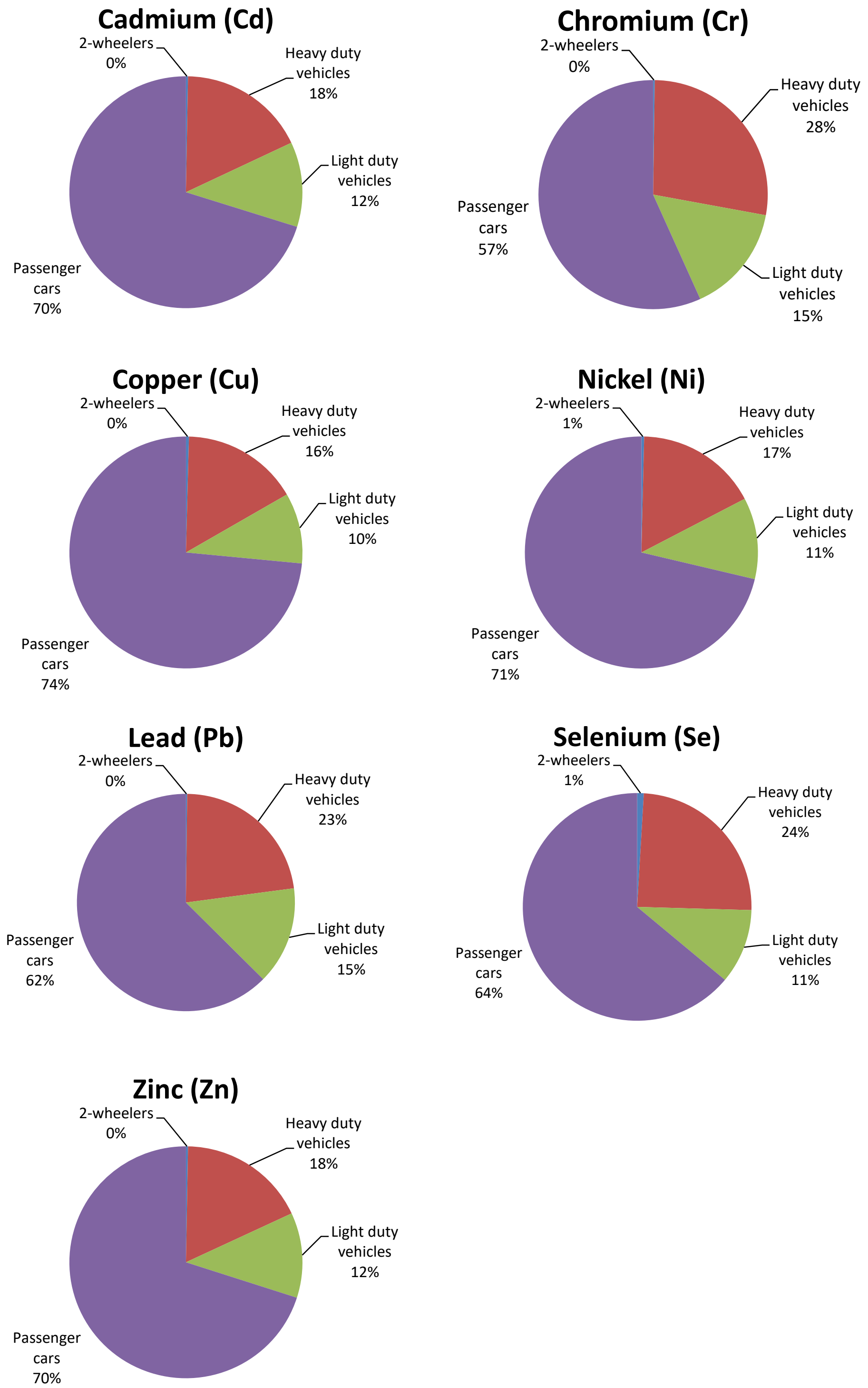


Figure 3.3.31 Heavy metal emission shares for road transport in 2021.

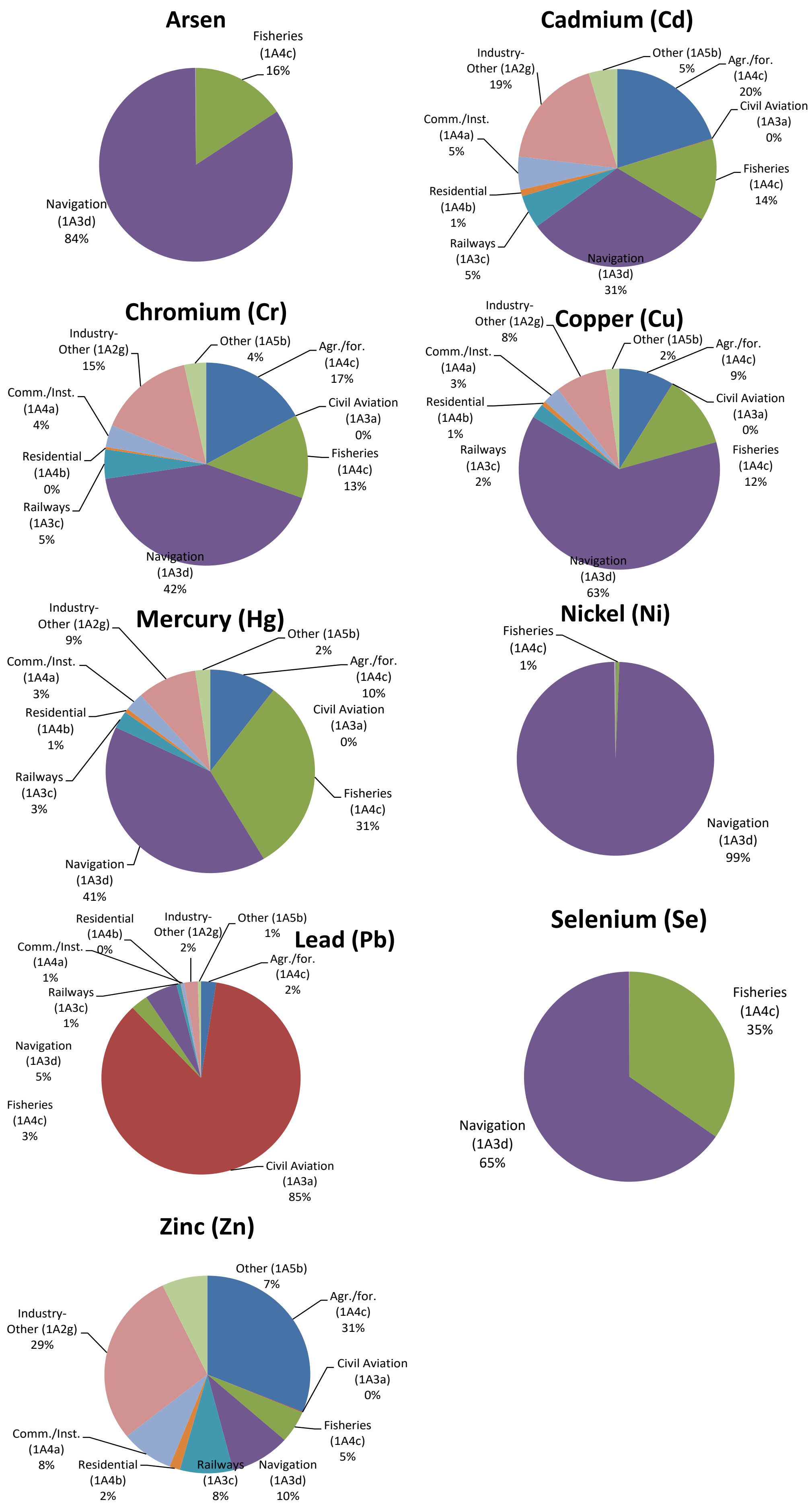


Figure 3.3.32 Heavy metal emission shares for other mobile sources in 2021.

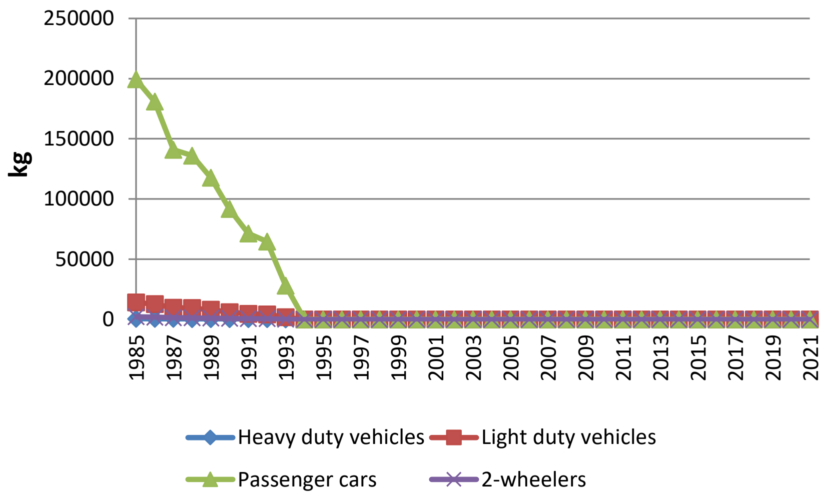


Figure 3.3.33 Pb emissions (kg) pr vehicle type for road transport 1985-2021.

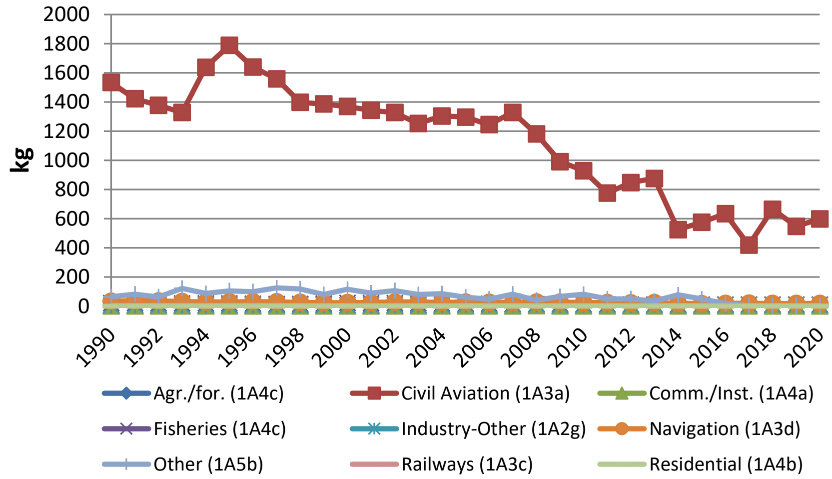


Figure 3.3.34 Pb emissions (kg) in NFR sectors for other mobile sources 1990-2021.

Emissions of dioxin and PAH

In Table 3.3.5, the dioxin, PAH, HCB and PCB emissions for road transport and other mobile sources are shown for 2021 in NFR sectors. The emission figures in the time series 1990-2021 are given in Annex 3.B.16 (NFR format) and are shown for 1990 and 2021 in Annex 3.B.15 (CollectER format).

Table 3.3.5 Dioxin, PAH, HCB and PCB emissions in 2021 for road transport and other mobile sources.

	HCB	Dioxins/Furans	Benzo(b) flouranthene	Benzo(k) flouranthene	Benzo(a) pyrene	Indeno (1,2,3-c,d) pyrene	PCB
	g	g	kg	kg	kg	kg	g
Manufacturing industries/Construction (mobile)	0.049	0.007	4.1	4.0	2.1	2.2	0.005
Civil aviation (Domestic)	0.000	0.000	0.0	0.0	0.0	0.0	0.000
Road transport: Passenger cars	0.222	0.038	43.6	33.5	38.8	38.7	0.090
Road transport:Light duty vehicles	0.127	0.012	14.5	11.3	12.9	12.1	0.018
Road transport:Heavy duty vehicles	0.323	0.055	27.4	30.6	4.5	7.0	0.004
Road transport: Mopeds & motorcycles	0.000	0.017	0.5	0.2	0.3	0.5	0.003
Road transport: Gasoline evaporation	0.000	0.000	0.0	0.0	0.0	0.0	0.000
Road transport: Brake wear	0.000	0.000	0.3	0.4	0.5	0.0	0.000
Road transport: Tyre wear	0.000	0.000	0.0	0.0	3.8	0.0	0.000
Road transport: Road abrasion	0.000	0.000	0.0	0.0	0.0	0.0	0.000
Railways	0.015	0.002	0.9	1.0	0.1	0.2	0.002
National navigation (Shipping)	0.017	0.089	3.8	1.6	0.8	6.1	0.006
Commercial/Institutional: Mobile	0.009	0.005	0.9	0.8	0.5	0.6	0.002
Residential: Household and gardening (mobile)	0.000	0.002	0.1	0.0	0.0	0.1	0.001
Agriculture/Forestry/Fishing: Off-road agriculture/forestry	0.056	0.007	4.7	4.5	2.3	2.4	0.005
Agriculture/Forestry/Fishing: National fishing	0.010	0.060	3.2	1.5	0.7	5.9	0.004
Other, Mobile	0.010	0.003	0.9	0.8	0.5	0.5	0.002
Road transport exhaust total	0.672	0.121	86.0	75.6	56.5	58.3	0.116
Road transport non exhaust total	0.000	0.000	4.4	0.0	0.0	0.0	0.000
Other mobile sources total	0.166	0.175	14.5	14.7	11.4	18.0	0.028
Domestic total	0.838	0.296	104.9	90.3	67.9	76.3	0.143
Civil aviation (International)	0.000	0.000	0.0	0.0	0.0	0.0	0.000
Navigation (International)	0.041	0.223	10.2	4.8	2.5	18.3	0.015

For mobile sources, road transport displays the largest emission of dioxins and PAH. The dioxin emission share for road transport is 41 % of all mobile emissions in 2021, whereas Navigation and Agriculture/forestry-/fisheries have smaller shares of 30 and 23 %. For the different PAH components, road transport shares are around 80 % of total emissions for mobile sources. The remaining emissions almost solely come from Agriculture/forestry-/fisheries, Navigation and Industry with Agriculture/forestry/fisheries as the largest source.

Figures 3.3.35 and 3.3.36 show the dioxin and PAH emission distributions into vehicle categories and other mobile sectors, respectively.

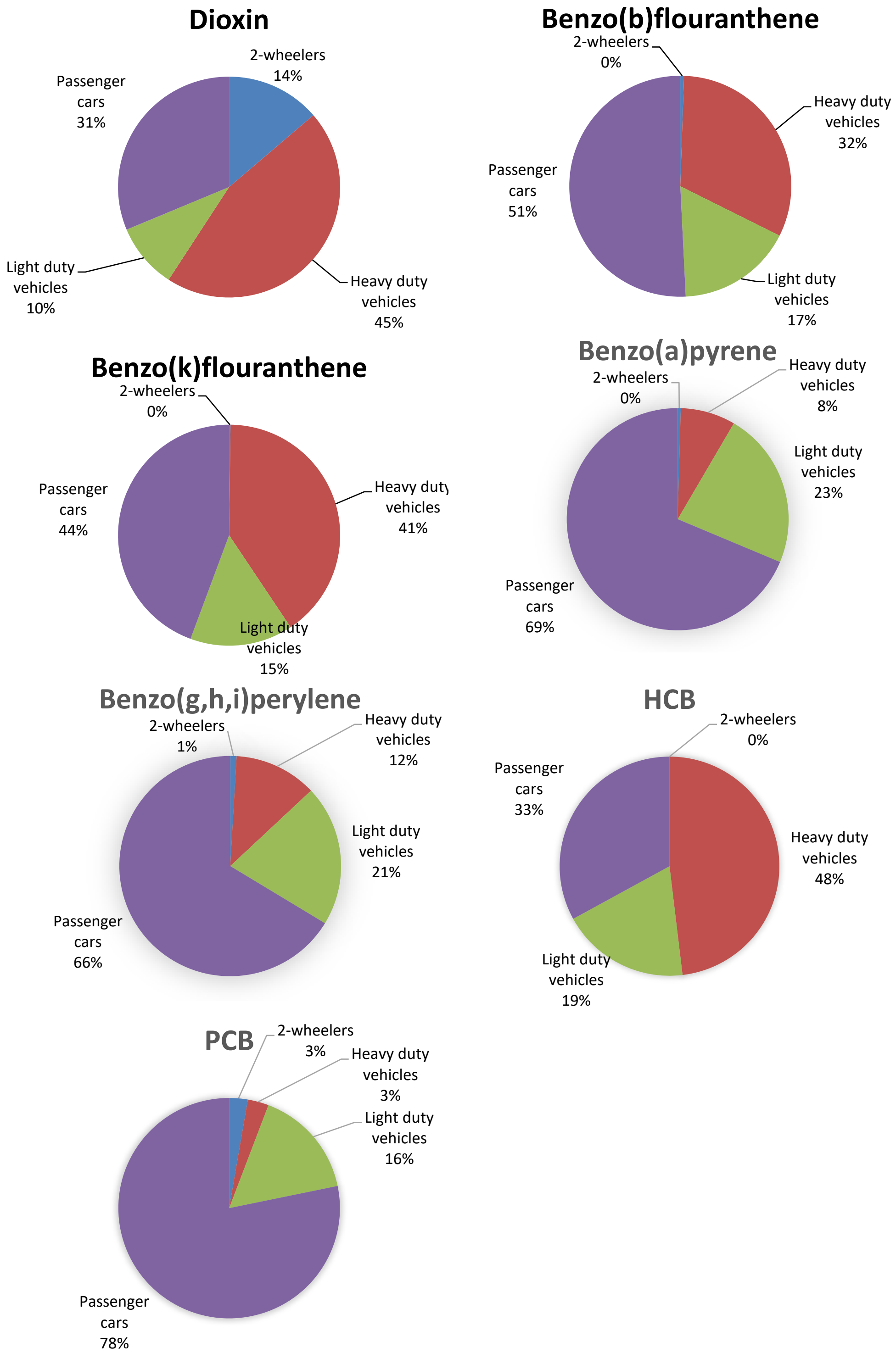


Figure 3.3.35 Dioxin, PAH, HCB and PCB emission shares for road transport in 2021.

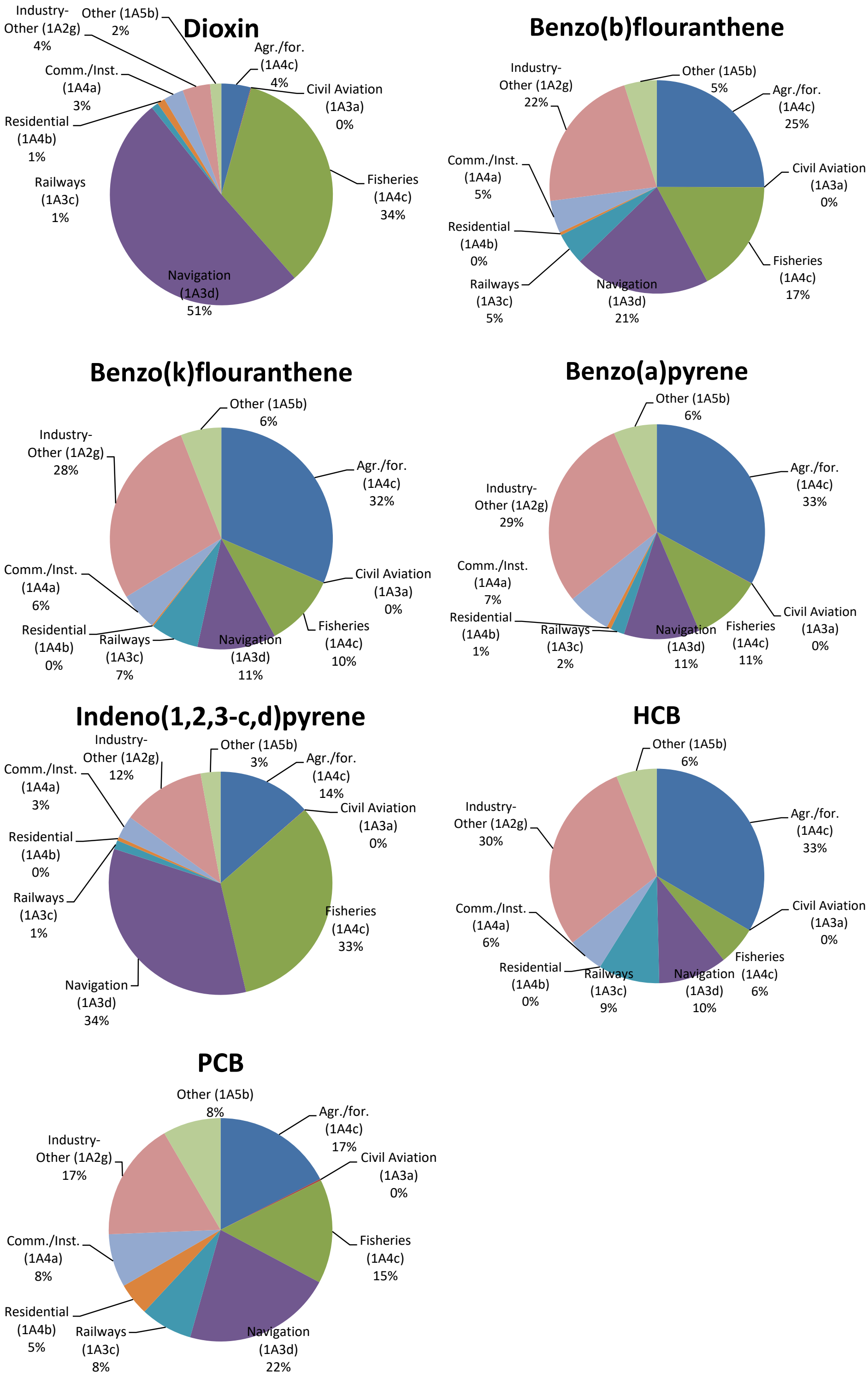


Figure 3.3.36 Dioxin, PAH, HCB and PCB emission shares for other mobile sources in 2021.

Emissions from international transport

The most important emissions from bunker fuel consumption (fuel consumption for international transport) are SO_2 and NO_x. The bunker emission totals are shown in Table 3.3.3 for 2021, split into sea transport and civil aviation. All emission figures in the 1985-2021 time series are given in Annex 3.B.16 (NFR format). In Annex 3.B.15, the emissions are also given in CollectER format for 2021.

The differences in emissions between navigation and civil aviation are much larger than the differences in fuel consumption and display a poor emission performance for international sea transport. In broad terms, the emission trends shown in Figure 3.3.37 are similar to the fuel consumption development.

However, for navigation, minor differences occur for the emissions of SO_2 and NO_X due to varying amounts of marine gas oil and residual oil, and for SO_2 and NO_X the development in the emission factors also have an impact on the emission trends. For civil aviation, apart from the annual consumption of jet fuel, the development of the NO_X emissions is also due to yearly variations in LTO/aircraft type (earlier than 2001) and city-pair statistics (2001 onwards).

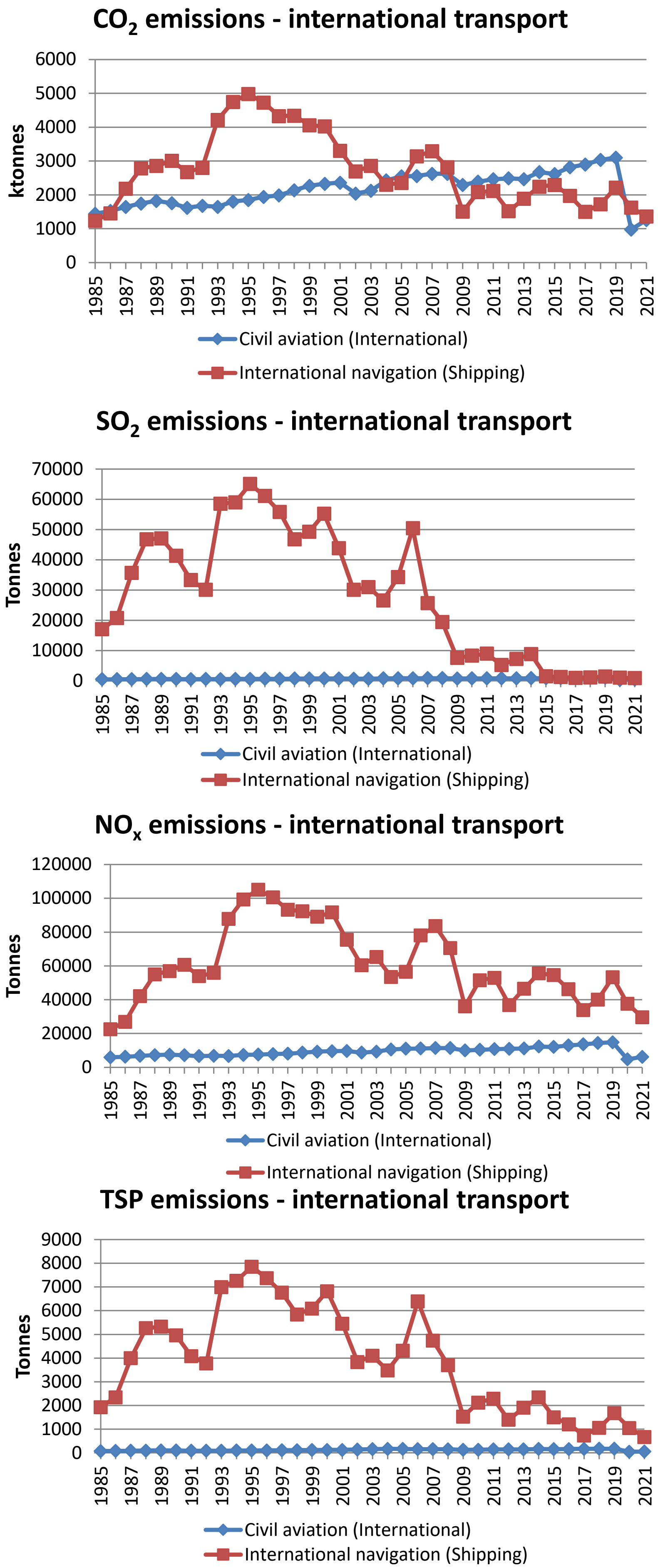


Figure 3.3.37 CO_2, SO_2, NO_X and TSP emissions for international transport 1985-2021.

3.3.2 Activity data, emission factors and calculation methodologies 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 calculations are made with DEMOS-Road (Danish Emission model system for Mobile Sources) model developed at DCE, Aarhus University, 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, DEMOS-Road groups all present and future vehicles in the Danish fleet into vehicle classes, subclasses and layers. The layer classification is a further division of vehicle subclasses into groups of vehicles with the same average fuel consumption and emission behaviour, according to EU emission legislation levels. Table 3.3.6 gives an overview of the different model classes and sub-classes, and all model layers are shown in Annex 3.B.1.

Fleet and annual mileage data are provided by DTU Transport for the vehicle categories present in COPERT 5 (Jensen, 2022a). 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 3.3.7.

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 1985-2021, 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, 2022a) 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) and Prince (2021).

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 truck-trailers and articulated trucks in two gross vehicle weight categories, < 40 tonnes and > 40 tonnes. The data has been further processed by DTU Transport; by using appropriate assumptions, the mileage have been backcasted to 1985 and forecasted to 2021.

Table 3.3.6 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

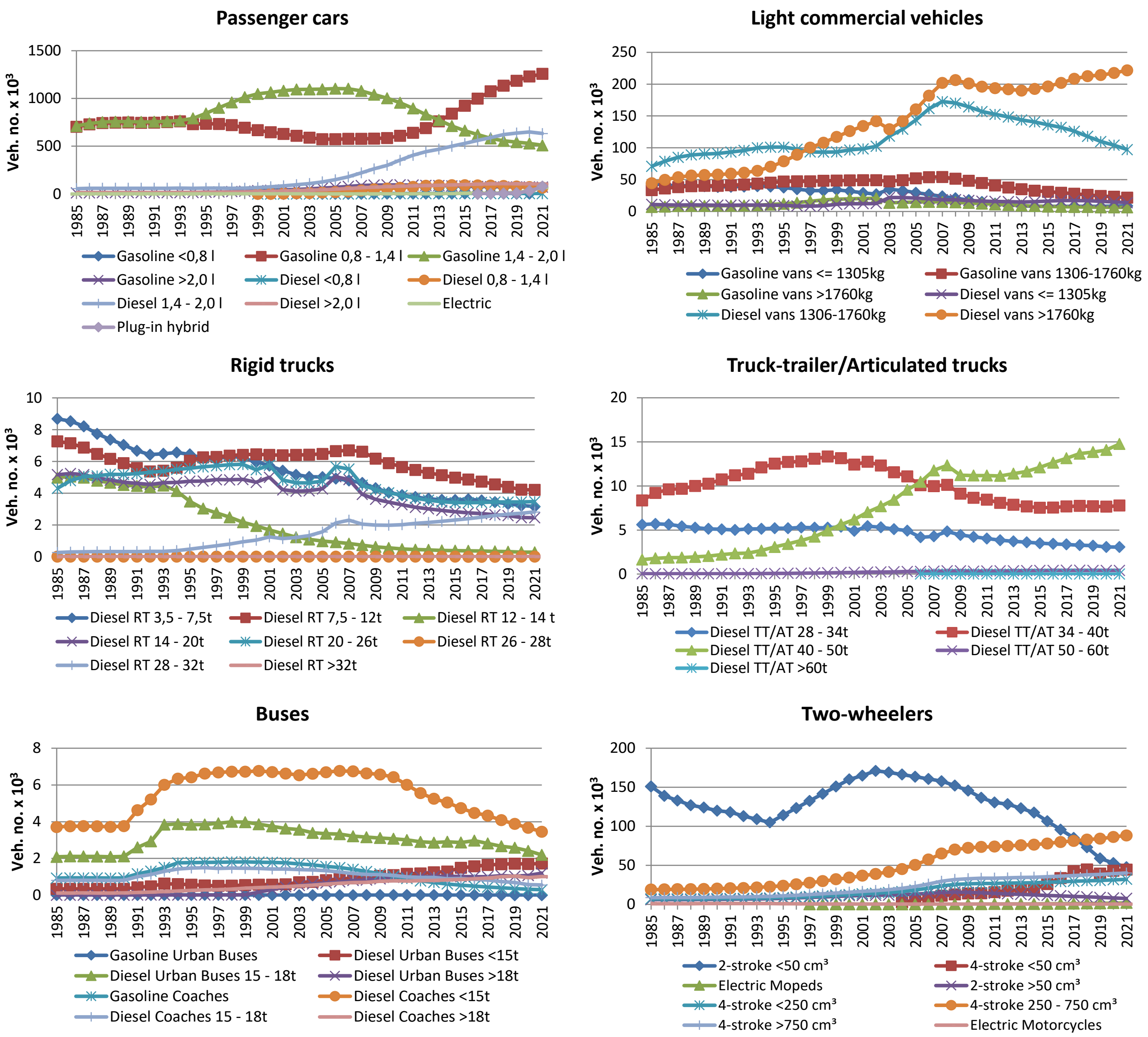


Figure 3.3.38 Number of vehicles in sub-classes in 1985-2021.

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 throughout the 1985-2010 period, and from 2012-2021.The vehicle numbers are summed up in layers for each year (Figure 3.3.39:

$$N_{j,y} = \sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \qquad (1)$$

Where N = number of vehicles, j = layer, y = year, i = first year of registration.

Weighted annual mileages pr layer are calculated as the sum of all mileage driven pr 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 pr layer are shown in Annex 3.B.1 and 2.B.2 for 1985-2021. The trends in vehicle numbers per layer are also shown in Figure 3.3.39. 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.

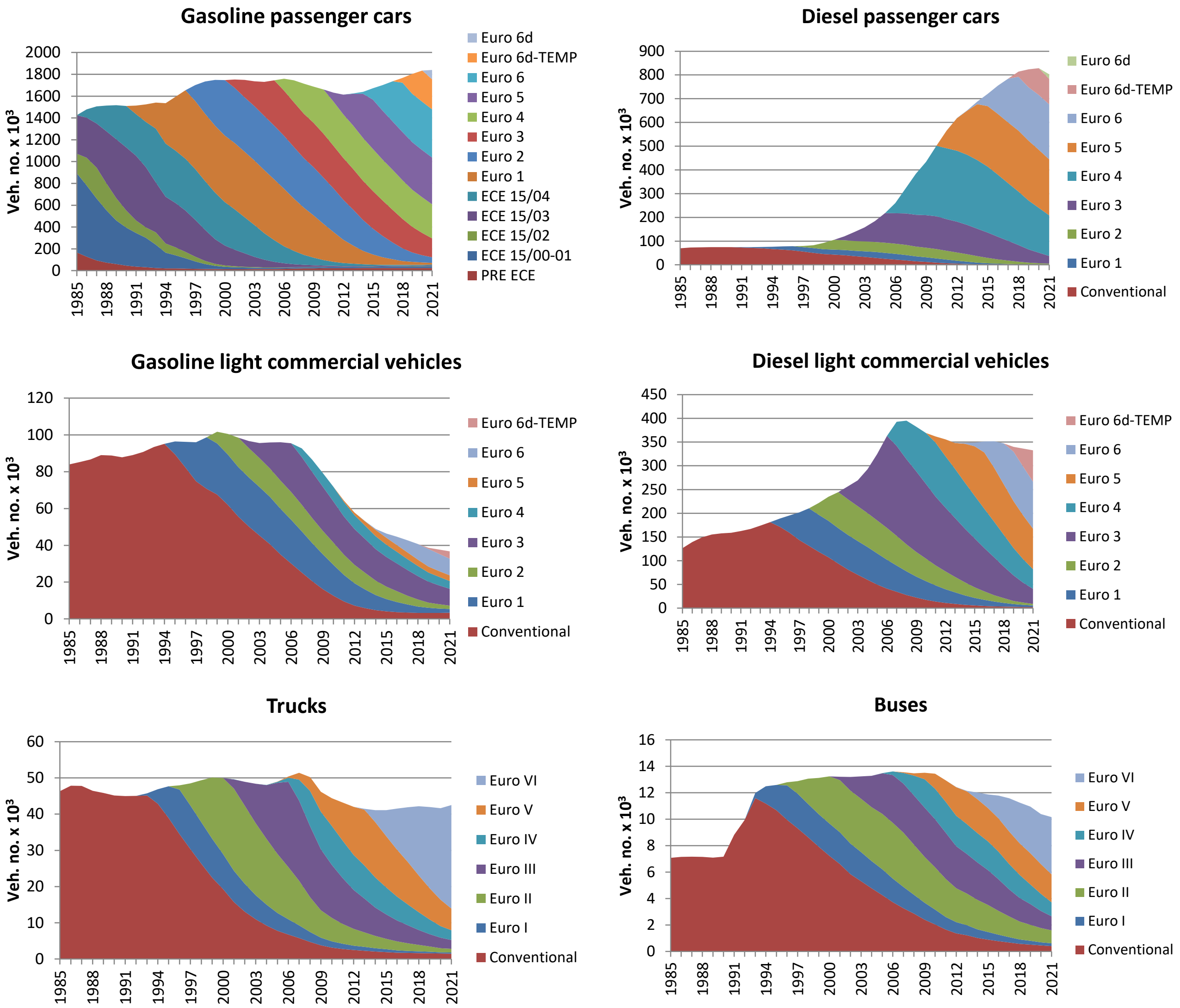


Figure 3.3.39 Layer distribution of vehicle numbers pr vehicle type in 1985-2021.

Emission legislation

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[4] (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 pr 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 behavior, and as an effect, 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 for future Euro 6 vehi-

[4] 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.

cles, the so-called Euro 6c vehicles, the "World-Harmonized Light-Duty Vehicles Test Procedure" (WLTP), has been developed which simulates much more closely real world driving behavior.

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 September 2017 for all new car models and by 1 September 2019 for all new cars (Euro 6d-TEMP). From 1 January 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 January 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 September 2018 and 1 September 2019, for diesel cars and vans, respectively. For Euro 6d, the enter into service dates are set to 1 January 2021 and 1 January 2022 for cars and vans, respectively. (pers. comm. Katja Asmussen, Danish EPA, 2018).

Table 3.3.7 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[5]: Passenger cars and light duty trucks (<1305 kg) have the same emission limits 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.

[5] Reference mass: net vehicle weight + mass of fuel and other liquids + 100 kg.

Table 3.3.7 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 DEMOS-Road come from the COPERT 5 model[6]. 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 3.3.6. The factors are listed in Annex 3.B.4.

It should be noted that for PHEV (plug-in hybrid electric vehicles) cars and vans, the utility factor is set to 0.5, i.e. 50 % of total mileage is assumed to be battery driven, according to assumptions made by DEA (2021)[7]. The fuel consumption and emission factors for plug-in vehicles used in the Danish national emission inventories for road transport, and shown in the present NIR, only contain the part of fuel consumption and emissions related to the combustion of fossil fuel (gasoline) in the vehicles. The emissions related to the generation of the electricity used by battery electric vehicles and plug-in vehicles are included under stationary sources in the Danish emission inventories as prescribed by the UNFCCC reporting guidelines.

Adjustment for vehicle fuel efficiency

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

[6] For vans, the COPERT model do not fully stratify fuel consumption factors into vehicle weight classe. Instead fuel consumption factor data for vans are obtained from the HBEFA (Handbook of Emission Factors) model version 4.1 (e.g. Matzer et al., 2019).
[7] The electric driven mileage shares for Danish urban, rural and highway driving conditions are derived by weighing in electric driven mileage shares for urban, rural and highway driving conditions obtained from HBEFA.

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 $\overline{TA_{NEDC}}(i,f,k)$ 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 2015-2010, the $\overline{FC_{inuse}}(i,f,k)$ values for 2014 are adjusted for the years 2015-2020[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 2014-2020.

For new cars registered in 2021, no valid type approval fuel efficiency values can be obtained from the Danish fleet and mileage database kept by DTU Transport. Instead the type approval fuel efficiency values for new cars in 2020 is used for 2021 also. For 2021 the aggregated value of 104.1 g CO_2/km is used. This value is well above the EU 95 g CO_2/km target, but this exceedance can very well be justified due to increases in new sales of electric cars and plug-in hybrids in Denmark in 2021.

For years beyond 2021 annual fuel efficiency, improvement rates are used for new cars depending on fuel type as suggested by DEA (2022b).

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 (2022b).

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,

[8] The ICCT monitoring report include new cars up to 2017. For new cars from 2018-2020, fuel gap figures are used for cars from 2017.

which have been retrofitted with filters during the 2000's (Winther, 2011). It is assumed that the particulate emissions from these retrofitted vehicles are the same as the particulate emissions from Euro V.

From the Danish vehicle register, information exist of the number of pre-Euro 5 diesel passenger cars and vans which have been retrofitted with open particle filters from 2006 onwards. These retrofit data are included in the Danish inventory by assuming that particulate emissions are lowered by 30 % compared with the emissions from the same Euro technology with no filter installed.

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.

Adjustment for Euro 5 diesel passenger cars

In COPERT 5 new emission factors are available for those Euro 5 diesel passenger cars for which engine control software has been installed in order to reduce the emissions, as a result of the diesel scandal.

The Euro 5 vehicles in question were brought to vehicle workshops during the vehicle recall program from 2016-2018. A short description of the recall program and the cars included is given below:

- Engine software was updated in 70,946 cars, evenly shared by 1/3 in each of the years 2016-2018
- Vehicle first registration years of the updated cars were between 2009-2016
- Engine sizes of the updated cars were < 1.4 l (9 %) and 1.4-2 l (91 %)

In DEMOS-Road, each year's updates were distributed into first registration year-engine size categories, according to their fleet shares in the respective first registration year-engine size categories.

The number of included cars in the software update program was provided by the Danish Safety Technology Authority (Bonde, 2021) and engine size and model year information was provided by Volkswagen (Hjortshøj, 2021).

Adjustment for biofuel usage

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.

Adjustment for deterioration

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 stabilise 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 from COPERT V, 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 pr hour, respectively.

Firstly, the deterioration factors are calculated for the corresponding trip speeds of 19 and 63 km pr hour 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″:

$$UDF = U_A \cdot MTC + U_B \text{, MTC} < \text{U}_{\text{MAX}} \qquad (3)$$

$$UDF = U_A \cdot U_{MAX} + U_B \text{, MTC} >= \text{U}_{\text{MAX}} \qquad (4)$$

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 3.3.6). For trip speeds between 19 and 63 km per hour (Danish urban trip speed; c.f. Table 3.3.6) 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 2021.

Calculation of emissions and fuel consumption for hot engines

Emissions and fuel consumption results for operationally hot engines are calculated in DEMOS-Road for each year, layer and road type. DEMOS-Road use the COPERT V detailed calculation methodology. The calculation 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 3.3.6. For non-catalyst vehicles this yields:

$$E_{j,k,y} = EF_{j,k,y} \cdot S_k \cdot N_{j,y} \cdot M_{j,y} \tag{6}$$

Here E = fuel consumption/emission, EF = fuel consumption/emission factor, S = road type share and k = road type.

For catalyst vehicles the calculation becomes:

$$E_{j,k,y} = DF_{j,k,y} \cdot EF_{j,k,y} \cdot S_k \cdot N_{j,y} \cdot M_{j,y} \tag{7}$$

Calculation of 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 calculated separately in DEMOS-Road, using the detailed calculation methodology and cold start emission factors from COPERT 5. 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 2021 are given in Rubek et al. (2022). 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:

$$CE_{j,y} = \beta \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr - 1) \tag{8}$$

Where CE is the cold extra emissions, β = 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 future 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 future EURO standards. Correspondingly, the β-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:

$$CE_{j,y} = \beta_{red} \cdot \beta_{EUROI} \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr_{EUROI} - 1) \qquad (9)$$

where β_{red} = the β reduction factor.

For CH_4, specific emission factors for cold driven vehicles are included in COPERT 5. The β and β_{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.

Calculation of evaporative emissions from gasoline vehicles

For each year, evaporative emissions of hydrocarbons are calculated for hot and warm running loss, hot and warm soak and diurnal evaporation. The calculations in DEMOS-Road 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.

$$E^R_{j,y} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot ((1-\beta) \cdot HR + \beta \cdot WR) \qquad (10)$$

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:

$$E^S_{j,y} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot ((1-\beta) \cdot HS + \beta \cdot WS) \qquad (11)$$

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:

$$E_{j,y}^{D} = 365 \cdot N_{j,y} \cdot e^{D} \quad (12)$$

Each year's total is the sum of each layer's running loss, soak loss and diurnal emissions.

Energy balance between inventory and sales

The calculated fuel consumption in DEMOS-Road 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, 2022).

For gasoline, the DEA sales 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 bottom-up gasoline fuel consumption on Danish roads and total gasoline fuel sold.

For diesel, the DEA sales data for road transport are adjusted at first, in order to account for recreational craft fuel consumption, which are not directly stated in the statistics.

The DEA data for diesel consist of fuel sold in Denmark and used on Danish roads and fuel sold in Denmark and used abroad (diesel border sales). 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 diesel border sales (diesel used abroad) is allocated to truck-trailer and articulated trucks (TT/AT trucks) in two total vehicle weight categories, < 40 tonnes and > 40 tonnes, and coaches.

The distribution of the diesel used abroad is split into the three vehicle categories by using the relative fuel consumption used in Denmark by foreign TT/AT trucks (< 40 tonnes and > 40 tonnes) and coaches (calculated based on mileage driven in Denmark by foreign trucks (paragraph 3.3.2) and corresponding fuel consumption factors).

The calculated "border" scaling factors of the TT/AT trucks and coaches in the model, i.e. the ratio between the total model fuel consumption (model fuel consumption in Denmark and model fuel consumption abroad) and the model fuel consumption in Denmark for these vehicle categories are shown in (Figure 3.3.25).

The total model fuel consumption for all vehicle categories is subsequently calculated in a first step, as the product of fuel consumption factors and corresponding total mileage, the latter being adjusted for mileage driven outside Denmark, as described above in the case of TT/AT trucks and coaches (adjusted bottom up diesel fuel consumption).

Next, the percentage difference between the first step model diesel fuel consumption (adjusted bottom up diesel fuel consumption) and the total diesel fuel sold in Denmark 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.

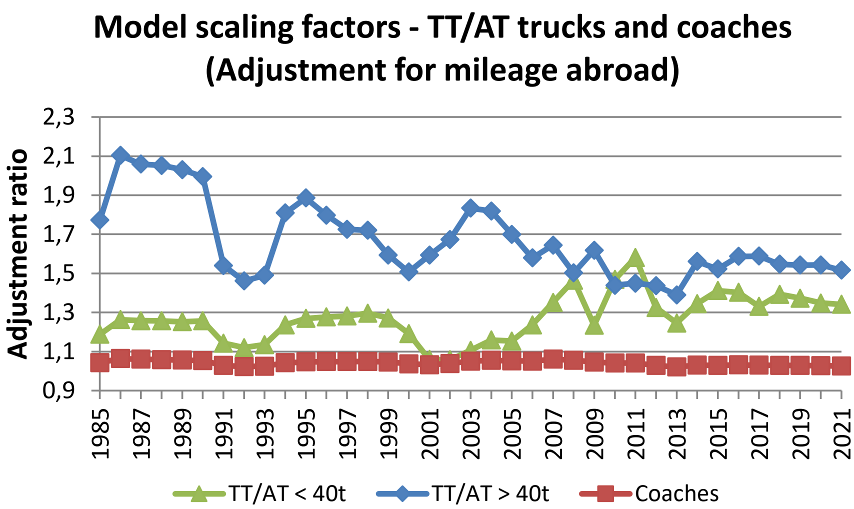


Figure 3.3.40 Fuel and emission adjustment ratios for TT/AT trucks and coaches: Bottom-up fuel consumption plus diesel used abroad vs bottom-up fuel consumption.

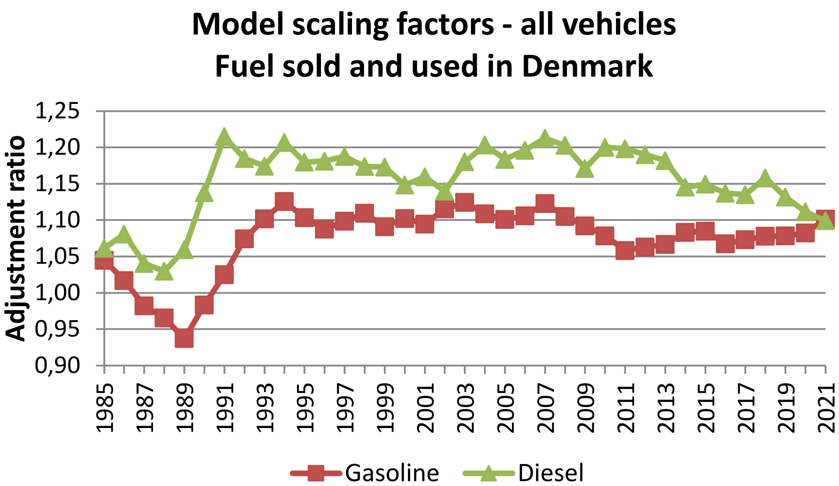


Figure 3.3.41 Gasoline and diesel fuel ratios (fuel and emission adjustment factors) regardless of vehicle category: Fuel sold and used in Denmark vs bottom-up fuel consumption used in Denmark

The reasons for the differences between DEA sales figures and bottom-up fuel estimates shown in Figure 3.3.41 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 1985-2021. The total fuel consumption and emissions are shown in Annex 3.B.8, pr vehicle category and as grand totals, for 1985-2021 (and NFR 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 2021.

In Table 3.3.8, the aggregated emission factors for SO_2, NO_X, NMVOC, CO, NH_3, TSP and BC are shown in CollectER format for Danish road transport.

Table 3.3.8 Fuel-based emission factors for SO_2, NO_X, NMVOC, CO, NH_3, TSP & BC for road transport in Denmark (2021).

SNAP ID	Category	Mode	Fuel type	Emission factors[1] [g pr GJ]						
				SO_2	NO_X	NMVOC	CO	NH_3	TSP	BC
070101	Passenger cars	Highway	Bio CNG	0.00	6.00	10.89	219.21	9.08	0.49	0.07
070101	Passenger cars	Highway	Bio ethanol	0.00	42.22	11.26	375.87	17.74	0.35	0.05
070101	Passenger cars	Highway	Biodiesel	0.00	218.78	1.06	6.23	2.15	1.82	1.48
070101	Passenger cars	Highway	CNG	0.00	6.00	10.89	219.21	9.08	0.49	0.07
070101	Passenger cars	Highway	Diesel	0.47	218.78	1.06	6.23	2.15	1.82	1.48
070101	Passenger cars	Highway	Gasoline	0.46	42.22	11.26	375.87	17.74	0.35	0.05
070101	Passenger cars	Highway	LPG	0.00	358.22	60.34	1660.36	8.84	0.68	0.11
070102	Passenger cars	Rural	Bio CNG	0.00	9.92	12.10	124.37	3.78	0.36	0.05
070102	Passenger cars	Rural	Bio ethanol	0.00	42.11	13.87	298.64	9.96	0.33	0.05
070102	Passenger cars	Rural	Biodiesel	0.00	197.79	1.31	12.66	2.28	1.57	1.28
070102	Passenger cars	Rural	CNG	0.00	9.92	12.10	124.37	3.78	0.36	0.05
070102	Passenger cars	Rural	Diesel	0.47	197.79	1.31	12.66	2.28	1.57	1.28
070102	Passenger cars	Rural	Gasoline	0.46	42.11	13.87	298.64	9.96	0.33	0.05
070102	Passenger cars	Rural	LPG	0.00	391.28	91.63	605.57	3.95	0.74	0.12
070103	Passenger cars	Urban	Bio CNG	0.00	15.96	34.85	181.46	2.16	0.35	0.05
070103	Passenger cars	Urban	Bio ethanol	0.00	75.86	186.17	2144.70	2.88	0.27	0.04
070103	Passenger cars	Urban	Biodiesel	0.00	202.00	3.72	31.77	1.52	3.10	1.95
070103	Passenger cars	Urban	CNG	0.00	15.96	34.85	181.46	2.16	0.35	0.05
070103	Passenger cars	Urban	Diesel	0.47	202.00	3.72	31.77	1.52	3.10	1.95
070103	Passenger cars	Urban	Gasoline	0.46	75.86	186.17	2144.70	2.88	0.27	0.04
070103	Passenger cars	Urban	LPG	0.00	210.24	137.33	951.83	2.75	0.76	0.13
070201	Light duty vehicles	Highway	Bio CNG	0.00	11.73	18.92	209.32	9.02	0.73	0.11
070201	Light duty vehicles	Highway	Bio ethanol	0.00	88.04	9.57	389.86	18.64	0.38	0.06
070201	Light duty vehicles	Highway	Biodiesel	0.00	338.15	3.19	23.09	1.72	2.94	2.35
070201	Light duty vehicles	Highway	CNG	0.00	11.73	18.92	209.32	9.02	0.73	0.11
070201	Light duty vehicles	Highway	Diesel	0.47	338.15	3.19	23.09	1.72	2.94	2.35
070201	Light duty vehicles	Highway	Gasoline	0.46	88.04	9.57	389.86	18.64	0.38	0.06
070201	Light duty vehicles	Highway	LPG	0.00	436.65	94.72	859.14	0.00	0.64	0.07
070202	Light duty vehicles	Rural	Bio CNG	0.00	15.85	22.27	167.27	3.68	0.53	0.08
070202	Light duty vehicles	Rural	Bio ethanol	0.00	83.72	16.09	322.65	12.02	0.32	0.05
070202	Light duty vehicles	Rural	Biodiesel	0.00	319.35	3.41	18.63	1.77	2.28	1.80
070202	Light duty vehicles	Rural	CNG	0.00	15.85	22.27	167.27	3.68	0.53	0.08
070202	Light duty vehicles	Rural	Diesel	0.47	319.35	3.41	18.63	1.77	2.28	1.80
070202	Light duty vehicles	Rural	Gasoline	0.46	83.72	16.09	322.65	12.02	0.32	0.05
070202	Light duty vehicles	Rural	LPG	0.00	454.67	122.25	517.47	0.00	0.58	0.05
070203	Light duty vehicles	Urban	Bio CNG	0.00	23.78	52.98	259.23	2.16	0.54	0.08
070203	Light duty vehicles	Urban	Bio ethanol	0.00	111.73	191.77	3517.92	3.25	0.31	0.05
070203	Light duty vehicles	Urban	Biodiesel	0.00	283.10	7.50	27.18	1.24	4.11	2.99
070203	Light duty vehicles	Urban	CNG	0.00	23.78	52.98	259.23	2.16	0.54	0.08
070203	Light duty vehicles	Urban	Diesel	0.47	283.10	7.50	27.18	1.24	4.11	2.99
070203	Light duty vehicles	Urban	Gasoline	0.46	111.73	191.77	3517.92	3.25	0.31	0.05
070203	Light duty vehicles	Urban	LPG	0.00	248.80	217.40	891.41	0.00	0.59	0.05
070301	Heavy duty vehicles	Highway	Bio CNG	0.00	15.58	7.02	179.28	0.76	0.36	0.08
070301	Heavy duty vehicles	Highway	Bio ethanol	0.00	723.61	291.35	434.92	0.31	0.00	0.00
070301	Heavy duty vehicles	Highway	Biodiesel	0.00	44.49	2.48	26.29	0.91	0.86	0.46
070301	Heavy duty vehicles	Highway	CNG	0.00	15.58	7.02	179.28	0.76	0.36	0.08
070301	Heavy duty vehicles	Highway	Diesel	0.47	44.49	2.48	26.29	0.91	0.86	0.46
070301	Heavy duty vehicles	Highway	Gasoline	0.46	723.61	291.35	434.92	0.31	0.00	0.00
070302	Heavy duty vehicles	Rural	Bio CNG	0.00	32.67	5.45	139.11	0.41	0.45	0.14
070302	Heavy duty vehicles	Rural	Bio ethanol	0.00	672.33	414.16	500.36	0.31	0.00	0.00
070302	Heavy duty vehicles	Rural	Biodiesel	0.00	78.19	2.94	35.50	0.83	1.13	0.66
070302	Heavy duty vehicles	Rural	CNG	0.00	32.67	5.45	139.11	0.41	0.45	0.14
070302	Heavy duty vehicles	Rural	Diesel	0.47	78.19	2.94	35.50	0.83	1.13	0.66
070302	Heavy duty vehicles	Rural	Gasoline	0.46	672.33	414.16	500.36	0.31	0.00	0.00
070303	Heavy duty vehicles	Urban	Bio CNG	0.00	42.71	4.28	109.31	0.22	0.52	0.17
070303	Heavy duty vehicles	Urban	Bio ethanol	0.00	612.00	606.03	605.55	0.28	0.00	0.00
070303	Heavy duty vehicles	Urban	Biodiesel	0.00	171.75	4.09	63.24	0.68	2.49	1.56
070303	Heavy duty vehicles	Urban	CNG	0.00	42.71	4.28	109.31	0.22	0.52	0.17
070303	Heavy duty vehicles	Urban	Diesel	0.47	171.75	4.09	63.24	0.68	2.49	1.56
070303	Heavy duty vehicles	Urban	Gasoline	0.46	612.00	606.03	605.55	0.28	0.00	0.00

Continued										
070400	Mopeds	Urban	Bio ethanol	0.00	199.24	2404.09	4329.01	1.21	28.59	4.65
070400	Mopeds	Urban	Gasoline	0.46	199.24	2404.09	4329.01	1.21	28.59	4.65
070501	Motorcycles	Highway	Bio ethanol	0.00	174.21	462.45	7110.46	1.12	9.40	1.67
070501	Motorcycles	Highway	Gasoline	0.46	174.21	462.45	7110.46	1.12	9.40	1.67
070502	Motorcycles	Rural	Bio ethanol	0.00	120.83	511.85	6291.10	1.31	10.98	1.96
070502	Motorcycles	Rural	Gasoline	0.46	120.83	511.85	6291.10	1.31	10.98	1.96
070503	Motorcycles	Urban	Bio ethanol	0.00	77.15	700.15	5846.21	1.20	10.11	1.80
070503	Motorcycles	Urban	Gasoline	0.46	77.15	700.15	5846.21	1.20	10.11	1.80

[1] References. SO_2: Country specific; NO_X, NMVOC, CO, NH_3, PM and BC: COPERT 5.

Calculation of non-exhaust particulate emissions from road transport

The TSP, PM_{10} and $PM_{2.5}$ emissions arising from tyre and brake wear (SNAP 0707) and road abrasion (SNAP 0708) are estimated for the years 2000-2021 as prescribed by the UNECE convention reporting format. The emissions are calculated in DEMOS-Road by multiplying the total annual mileage per vehicle category with the correspondent average emission factors for each source type. The calculation procedure is consistent with the COPERT 5 model approach used in DEMOS-Road to estimate the Danish national emissions coming from exhaust. A more thorough explanation of the calculations is given by Winther and Slentø (2010).

Specific Danish tyre wear rates (mg/vkm) for different vehicle categories are found from data provided by the Danish Tyre Trade Environmental Foundation, as explained by Slentø and Winther (2010). These wear rates are further differentiated according to urban, rural and highway driving using relative trip speed correction functions from EMP/EEA (2019).

Based on the literature Winther and Slentø (2010) assume that 5 % of tyre wear is within the airborne PM_{10} fraction. From EMEP/EEA (2019) one gets that 60 % and 42 % of tyre wear TSP is emitted as PM_{10} and $PM_{2.5}$, respectively, thus enabling the calculation of TSP and $PM_{2.5}$ emission factors (mg/vkm).

For brake wear and road abrasion the emission factors (mg/vkm) are taken from EMEP/EEA (2019). The emission factors and total emissions for 2021 are shown in Annex 3.B.15.

3.3.3 Activity data and emission factors for other mobile sources

The emission inventories for other mobile sources are divided into several sub-sectors: Civil aviation, national navigation, national fishing, railways, military, and non road mobile machinery in agriculture, forestry, industry, commercial/institutional and residential.

The emission calculations are made for each sub-sector in the DEMOS model using the detailed method as described in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2019)[9].

Civil aviation

The activity data used in DEMOS-Aviation consists of air traffic statistics provided by the Danish Civil Aviation and Railway Authority and Copenhagen Airport. Fuel statistics for jet fuel consumption and aviation gasoline are obtained from the Danish energy statistics (DEA, 2022a).

[9] For military and other sea vessels than ferries, the simple fuel based method is used.

For 2001 onwards, the Danish Civil Aviation and Railway Authority provides data records per flight (city-pairs). Each flight record consists of e.g. ICAO codes for aircraft type, origin and destination airport, maximum take-off mass (MTOM), flight call sign and aircraft registration number.

In DEMOS-Aviation, 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 DEMOS-Aviation (e.g. Winther, 2022a).

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 criterias 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 2001-2021. 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 origin-destination airport pairs and associated flight distances. 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. The actual distance flown are in reality longer than great circle distance between two airports, and this is adjusted for in the DCE emission model, as explained in section 3.3.4.

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 Transport, Construction and Housing Authority. The assignment of representative aircraft types for Copenhagen Airport is done as described above. For the remaining Danish airports, representative aircraft types are not di-

[10] Excluding flights for Greenland and the Faroe Islands. These flights are separately listed in Annex 3.B.10.

rectly assigned. Instead, appropriate average assumptions are made relating to the fuel consumption and emission data part.

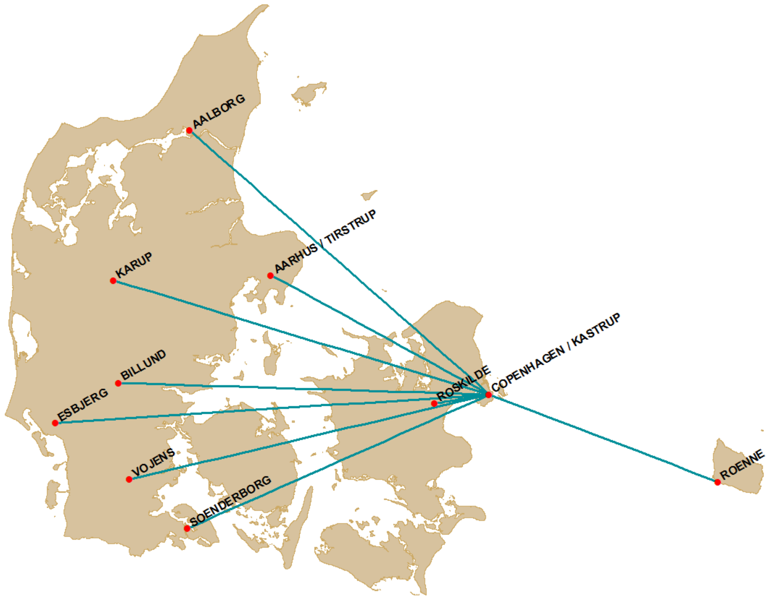


Figure 3.3.42 Most frequent domestic flying routes for large aircraft in Denmark.

Copenhagen Airport is the starting or end point for most of the domestic aviation made by large aircraft in Denmark (Figure 3.3.42; 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 Civil Aviation and Railway Authority, 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 Airport is merely marginal.

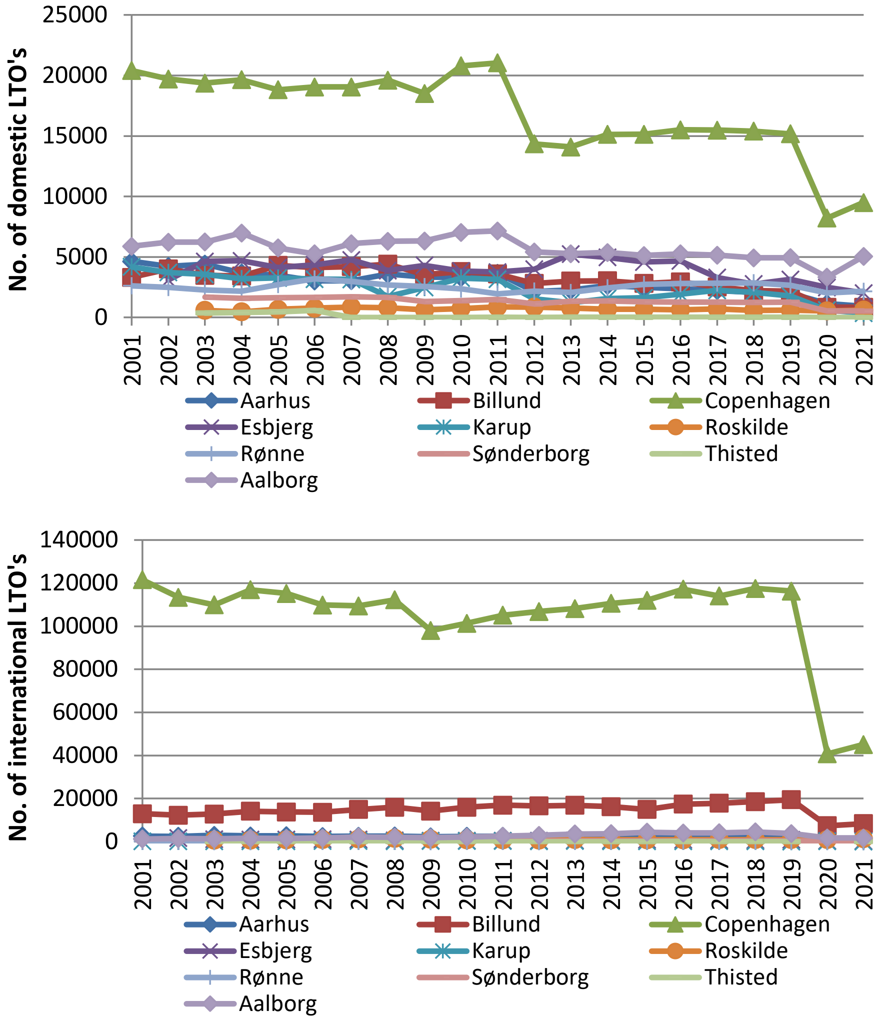


Figure 3.3.43 No. of LTO's for the most important airports in Denmark 2001-2021.

Figure 3.3.43 shows the number of domestic and international LTO's for Danish airports[11], in a time series from 2001-2021.

Non-road mobile machinery and recreational craft

Non-road mobile machinery are used in the agricultural, forestry, industrial, commercial/institutional and residential sectors, and the activity data are gathered from numerous sources. The activity data for non road mobile machinery are described in the following together with activity data for recreational craft.

Detailed tractor fleet data for 2003-2020 and total numbers 1950-2002 for tractors in the Danish motor register are provided by Statistics Denmark (2021a, 2021b).

Total numbers for tractors (tractors in motor register and other tractors) for 1982-2005 are provided by Statistics Denmark (2021c). Total numbers for tractors (tractors in motor register and other tractors) for 1974-1981 are found in consecutive statistical publications e.g. Agricultural statistics 1974 (Statistics Denmark, 1975), as well as supplementary stock numbers per fuel type (diesel and gasoline).

[11] Flights for Greenland and the Faroe Islands are included under domestic in the figure.

Supplementary new sales data in kW classes are provided by the Association of Danish Agricultural Machinery Dealers for 1982-2018. Engine load factors and annual working hours for tractors come from Bak et al. (2003).

Number of forestry machines, engine size, annual working hours and average life times are provided by the Danish Forest Association (Clemmensen, 2022).

For the most important types of building and construction machinery used in industry, annual new sales data for 1996 onwards has been provided by the Association of Danish Agricultural Machinery Dealers (Fasting, 2022).

Fork lift sales data has been provided by the Association of Producers and Distributors of Fork Lifts in Denmark for 1976-2019. Further, WITS (World Industrial Truck Sales) and FEM (Federation European Material) fork lift sales figures for Denmark in 2000-2021 as well as branch distribution information has been provided by Toyota Material Handling (Christensen, 2021).

For telescopic loaders branch distribution information has been provided by Scantruck (Faurby, 2021).

The share of Stage IIIB and IV diesel engines used in the building and construction sector with preinstalled diesel particle filters, has been estimated in different engine size classes, based on questionnaire answers from the most important mobile machinery manufacturers and Danish machinery importers (Winther, 2022c).

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).

For the most important types of household and gardening machinery used in commercial/institutional and residential, annual new sales data for 2006 onwards is provided by the Association for Industrial Technics, Tools and Automation (BITVA: Brancheforeningen for industriel teknik, værktøj og automation). Until 2018 new sales data was 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).

The total number of refrigerating units for long distance transport trucks has been estimated for 1990 and 2021 by Teknologisk Institut (1992, 2022). Based on these data, a linear development in the number of refrigerating units from 1990 to 2021 has been assumed. For distribution lorries, the total number of refrigerating units for distribution lorries has been estimated for 1990 by the Teknologisk Institut (1992), and a proportional increase in the number of units has been assumed based on the development in the number of Danish inhabitants from 1990 to 2021.

For a remaining group of non road mobile machinery types with low emission contributions (e.g. pumps, generators, compressors), total stock numbers from 1990 to 2021 has been estimated based on 1990 stock numbers from Teknologisk Institut (1992, 1993) and a proportional development of the stock numbers with GDP. For these machinery types, load factors, engine sizes and annual working hours has been gathered by Winther et al. (2006).

The stock development from 1985-2021 for the most important types of machinery are shown in Figures 3.3.44-3.3.51 below. The stock data are also listed in Annex 3.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 in 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 activities in general (pers. comm. Per Stjernqvist, Volvo Construction Equipment 2010). For fork lifts 5 % and 20 % activity 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 3.3.44-3.3.45, respectively.

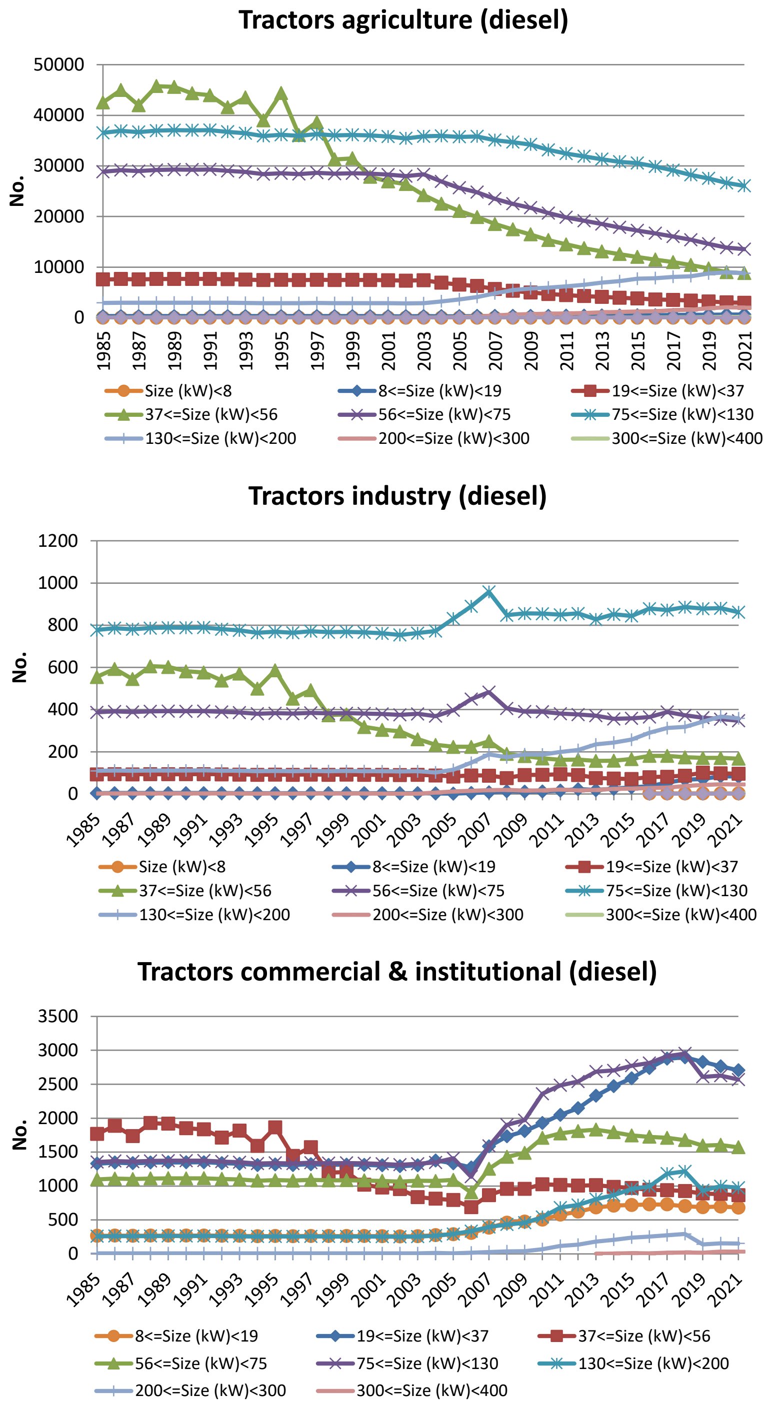


Figure 3.3.44 Total numbers in kW classes for tractors from 1985 to 2021.

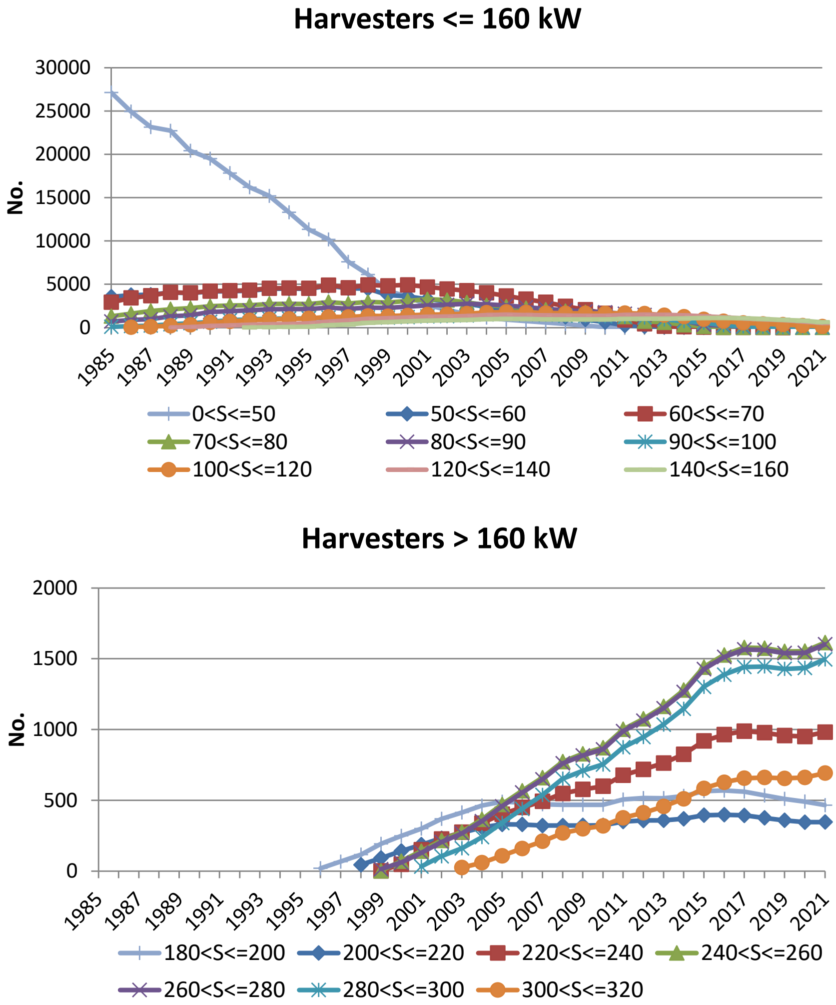
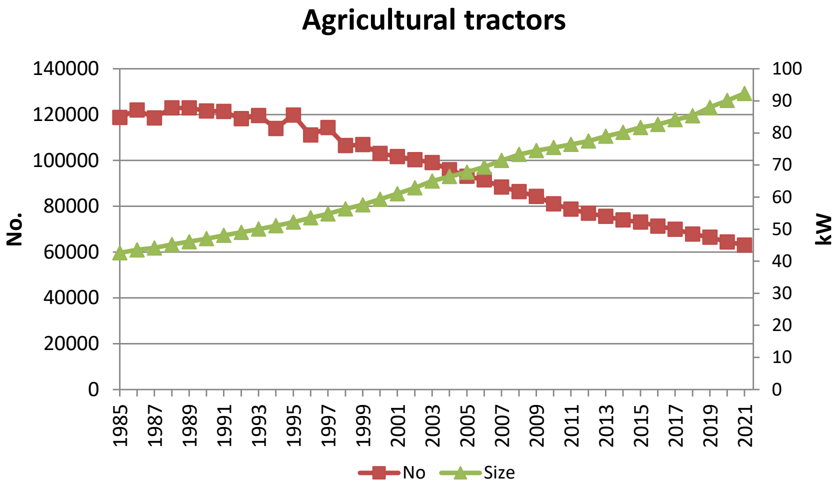


Figure 3.3.45 Total numbers in kW classes for harvesters from 1985 to 2021.

The tractor and harvester developments towards fewer vehicles and larger engines, shown in Figure 3.3.46, are very clear. From 1985 to 2021, tractor and harvester numbers decrease by around 47 % and 74 %, respectively, whereas the average increase in engine size for tractors is 117 %, and 378 % for harvesters, in the same time period.



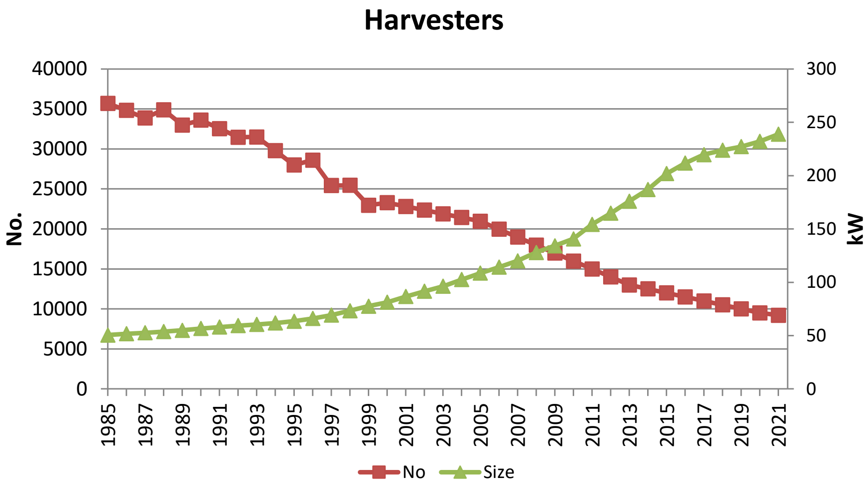


Figure 3.3.46 Total numbers and average engine size for tractors and harvesters from 1985 to 2021.

The most important non road machinery types for industry are different types of construction machinery and fork lifts. The Figures 3.3.47 and 3.3.48 show the 1985-2021 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. It is, however, 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.

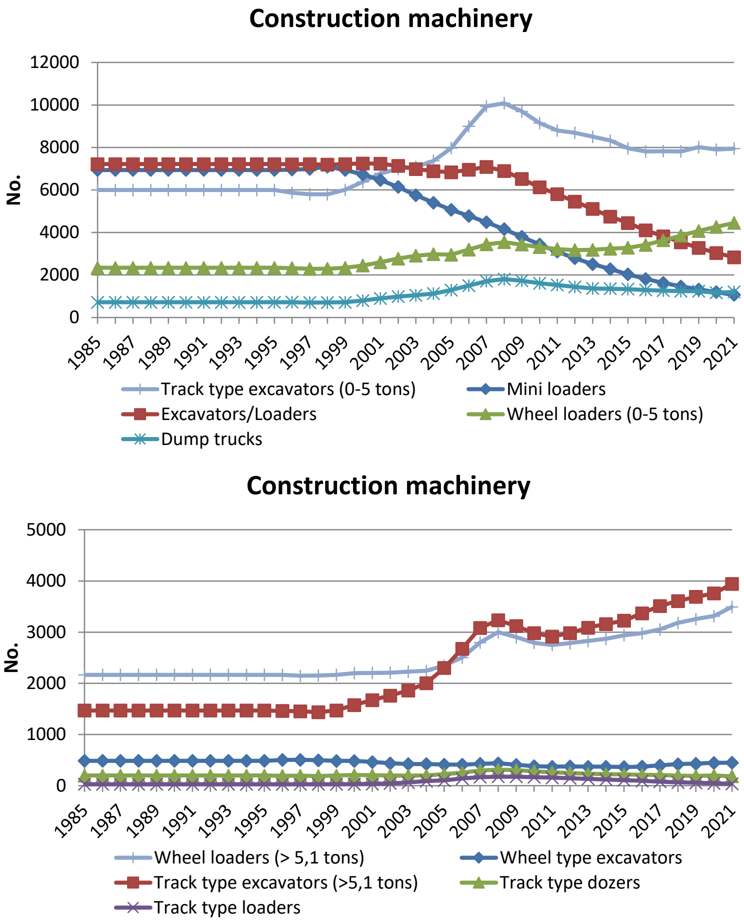
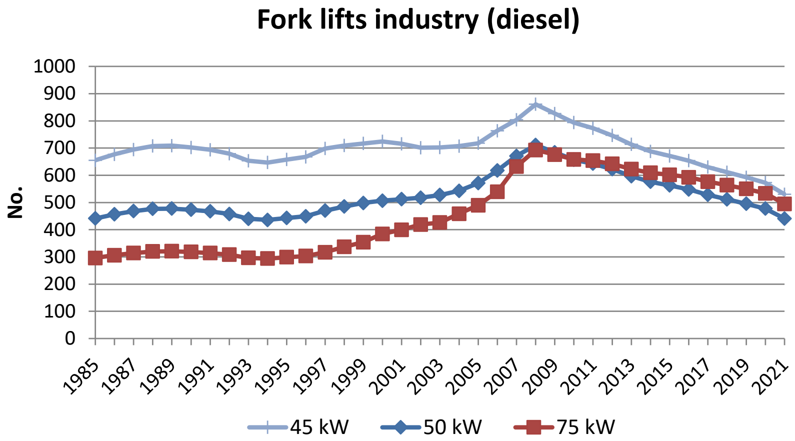


Figure 3.3.47 1985-2021 stock development for specific types of construction machinery.



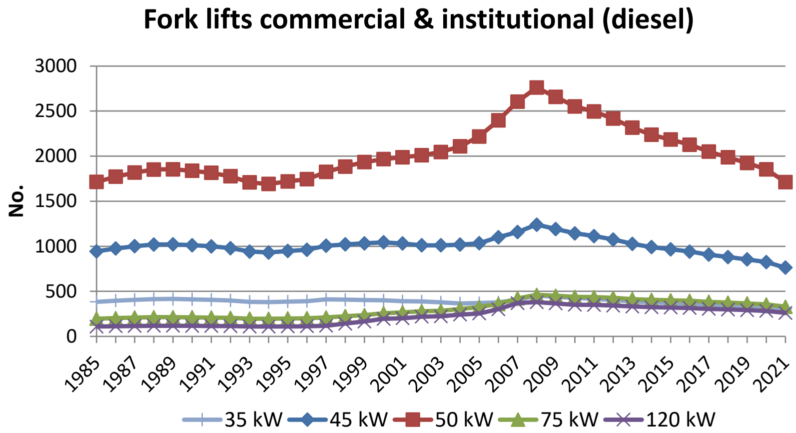
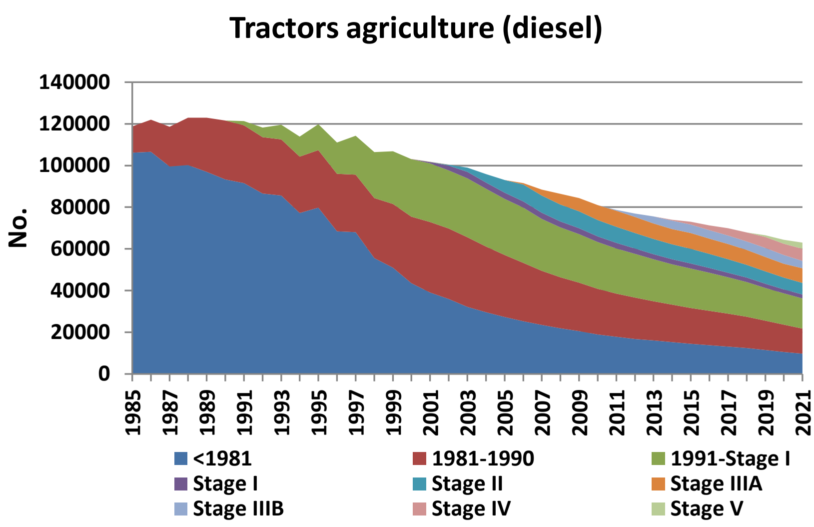


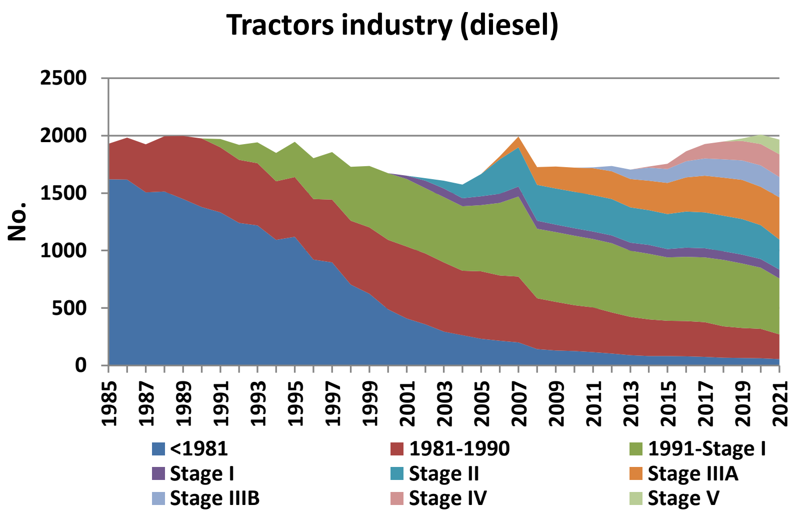
Figure 3.3.48 Total numbers of diesel fork lifts in kW classes from 1985 to 2021.

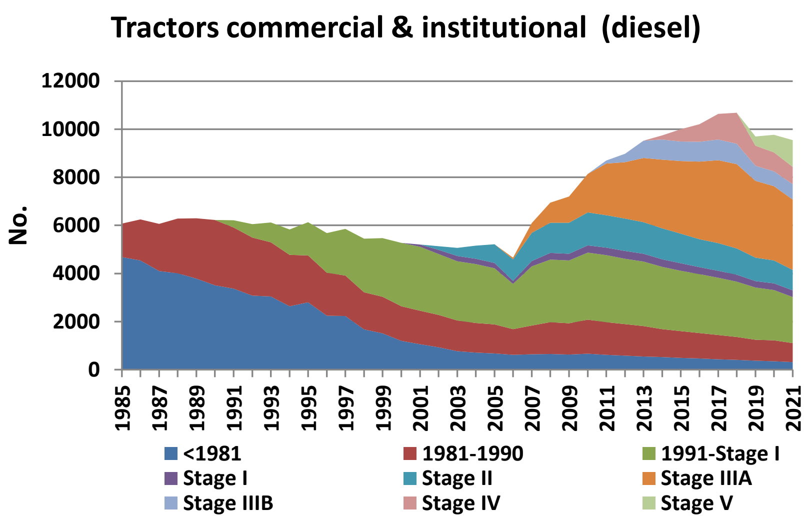
Figure 3.3.49 shows the emission layer distribution for the total stock of tractors, harvesters, construction machinery (most important types, Figure 3.3.47) and diesel fork lifts from 1990-2021.

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 3.3.49.

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 3.3.49.

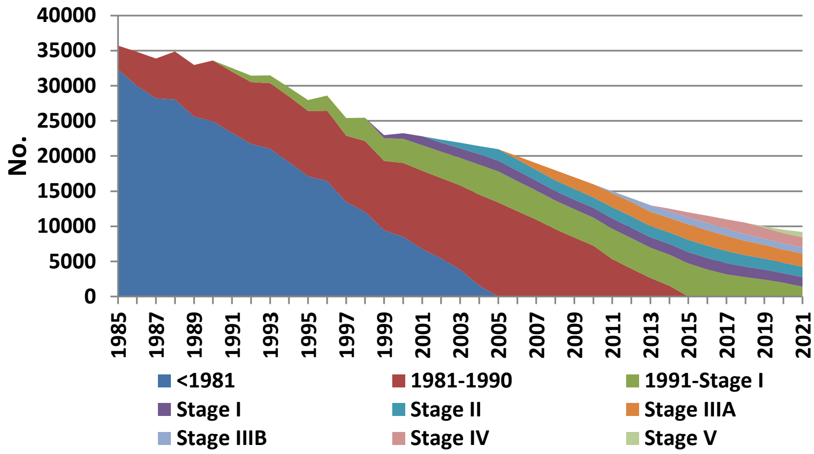

Tractors agriculture (diesel)
No.
140000
120000
100000
80000
60000
40000
20000
0
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
<1981
1981-1990
1991-Stage I
Stage I
Stage II
Stage IIIA
Stage IIIB
Stage IV
Stage V


Tractors industry (diesel)
No.
2500
2000
1500
1000
500
0
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
<1981
1981-1990
1991-Stage I
Stage I
Stage II
Stage IIIA
Stage IIIB
Stage IV
Stage V

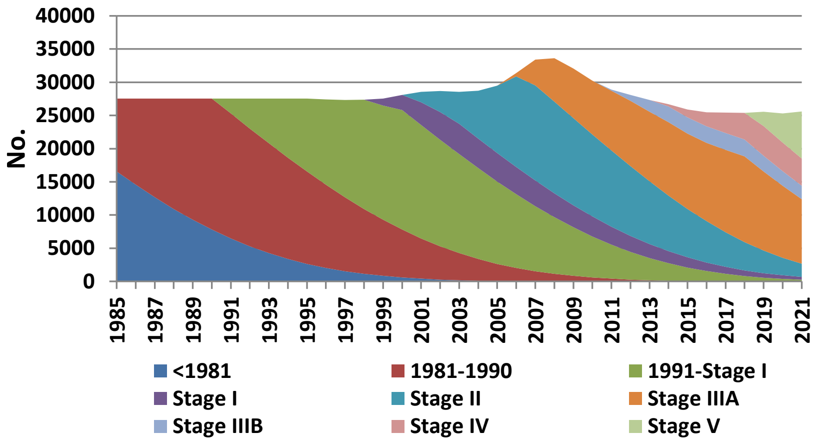

Tractors commercial & institutional (diesel)
No.
12000
10000
8000
6000
4000
2000
0
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
<1981
1981-1990
1991-Stage I
Stage I
Stage II
Stage IIIA
Stage IIIB
Stage IV
Stage V

Continued

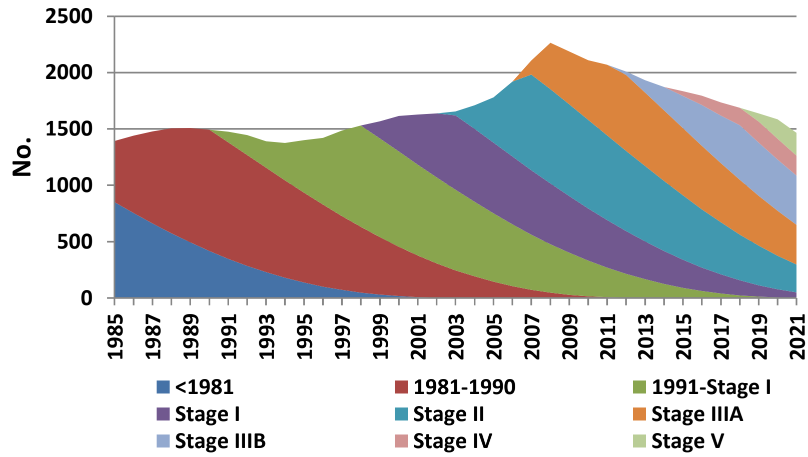
Harvesters



Construction machinery



Fork lifts industry (diesel)



Continued

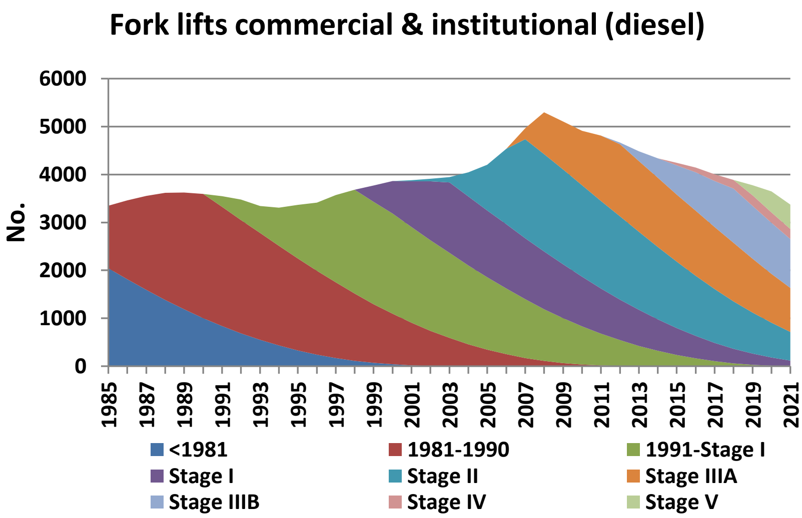


Figure 3.3.49 Layer distribution for tractors, harvesters, construction machinery and diesel fork lifts (1985 to 2021).

The 1990-2021 stock development for the most important household and gardening machinery used in commercial/institutional and residential is shown in Figure 3.3.50.

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.

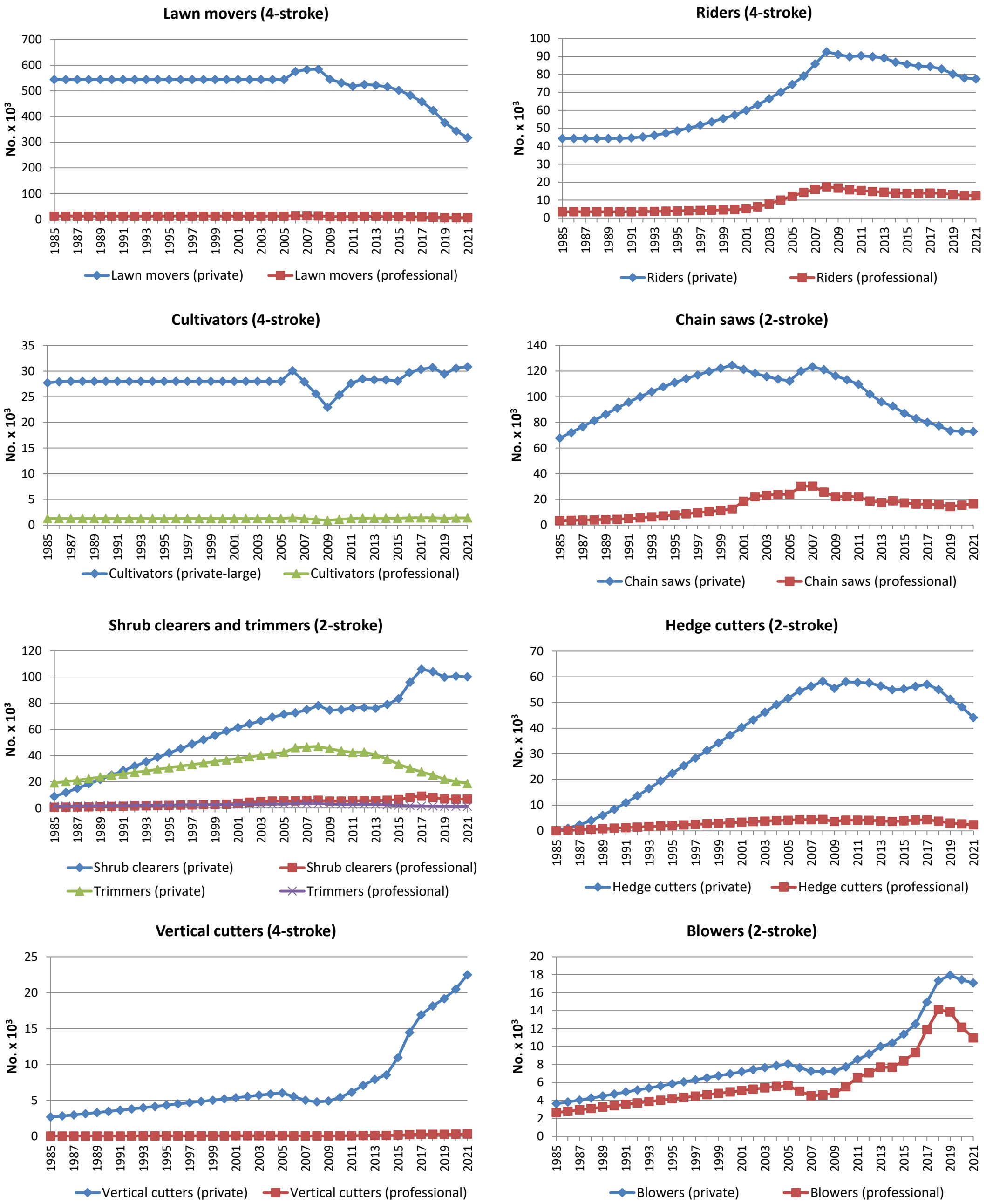


Figure 3.3.50 Stock developments 1985-2021 for the most important household and gardening machinery types.

The total stock development for the most important household and gardening machinery types is shown in Figure 3.3.51 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 3.3.51. 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.

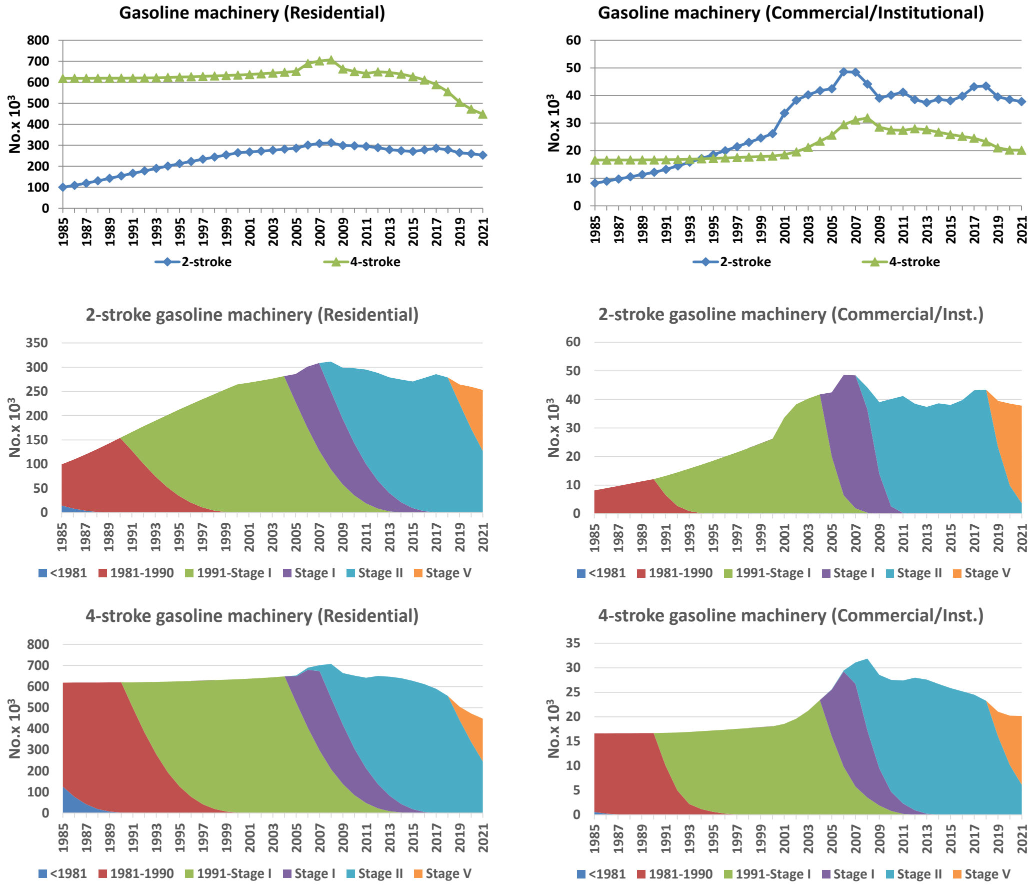


Figure 3.3.51 Layer distribution for the most important household and gardening machinery types split into residential and commercial/institutional (1985-2021).

Figure 3.3.52 shows the development in numbers of different recreational craft from 1985-2021. 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).

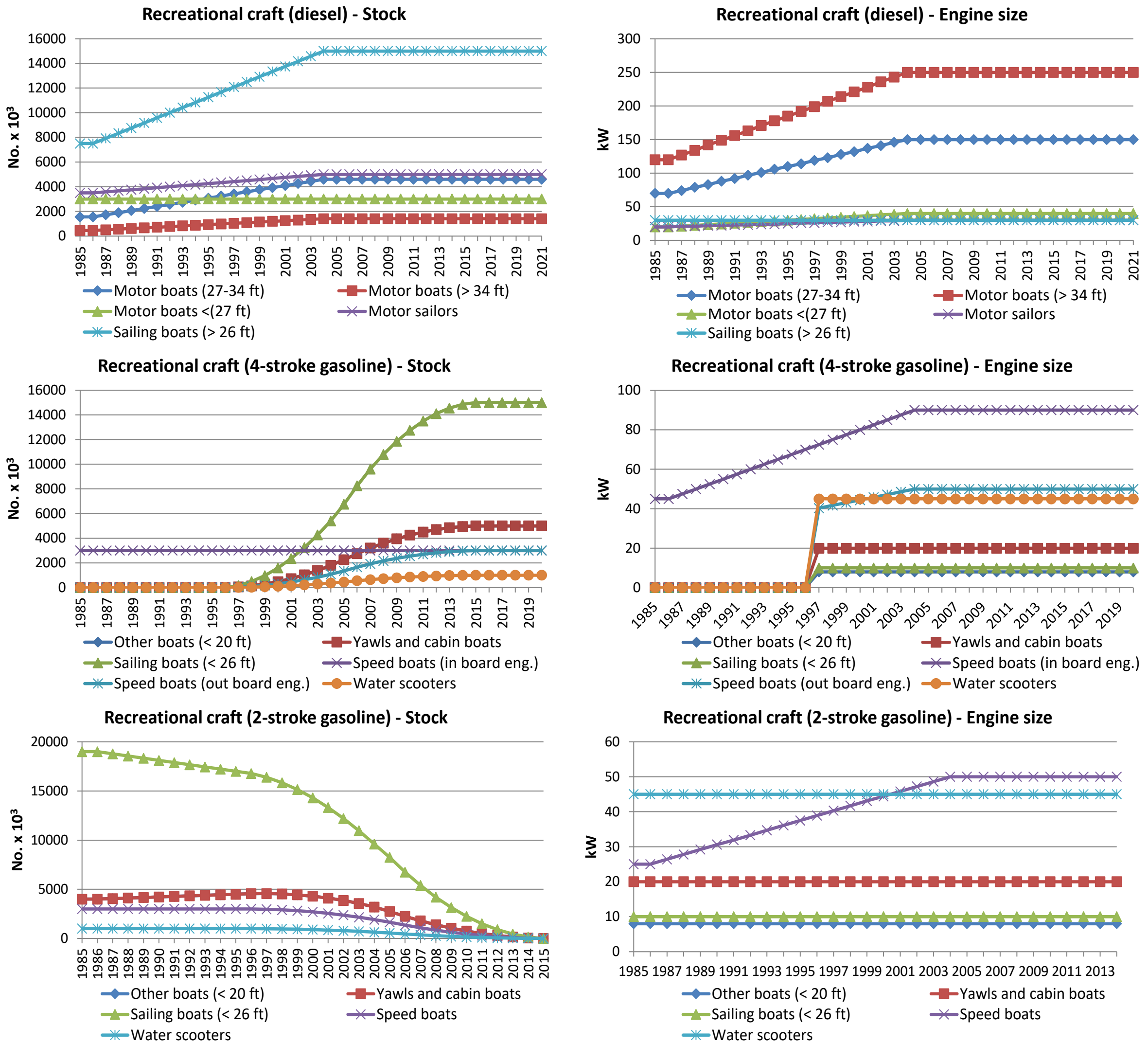


Figure 3.3.52 1985-2021 Stock and engine size development for recreational craft.

National navigation

National navigation include the activities made by domestic ferries, fuel sold in Denmark and used for freight transport between Denmark and Greenland or the Faroe Island, and fuel used for the remaining part of the traffic between two Danish ports.

Table 3.3.9 lists the most important domestic ferry routes (regional ferries) in Denmark in the period 1990-2021. For these ferry routes and the years 1990-2005, the following detailed traffic and technical data have been gathered by Winther (2008): Ferry name, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size, share of annual trips and sailing time (single trip).

For 2006-2021, the above mentioned traffic and technical data for specific ferries have been provided by Nielsen (2021) in the case of Mols-Linien (Sjællands Odde-Ebeltoft, Sjællands Odde-Århus, Kalundborg-Århus, Køge-Rønne, Tårs-Spodsbjerg), 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 3.3.9 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+

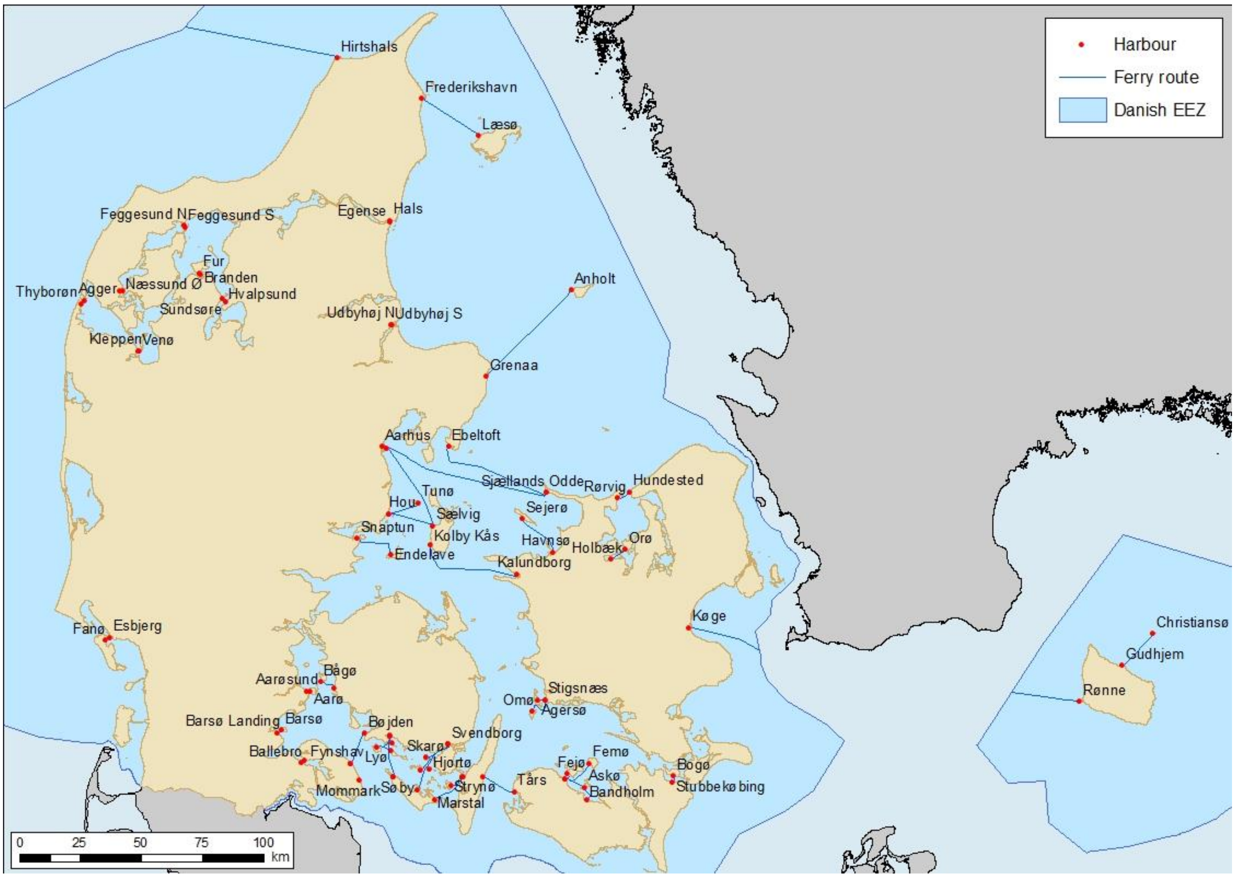


Figure 3.3.53 Domestic ferry routes in Denmark (2021).

Table 3.3.10 lists the small ferry routes (island and short cut ferries) included in the Danish inventory for the period 1990-2021. For these ferry routes and the years 1990-2021, the following detailed traffic and technical data have been gathered by Rasmussen (2017) and Andersen (2019): Ferry name, engine size (MCR), engine year, share of annual trips and sailing time (single trip). Supplementary data for engine type, fuel type and average load factor is provided by Kristensen (2017).

Table 3.3.10 Small ferry routes comprised in the Danish inventory.

Ferry service	Service period
Assens-Baagø	1990+
Ballebro-Hardeshøj	1990+
Bandholm-Askø	1990+
Barsø Landing-Barsø	2018+
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+
Kragenæs-Askø	2020+
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+
Sælvig-Aarhus	2021+
Søby-Fynshav	2009+
Søby-Mommark	-2009
Thyborøn-Agger	1990+
Udbyhøj Nord - Udbyhøj Syd	2017+
Aarø-Aarøsund	1990+

The number of round trips per ferry route from 1990 to 2021 is provided by Statistics Denmark (2022). Figure 3.3.53 show all ferry routes in use in 2021 (Esbjerg/Hanstholm/Hirtshals-Torshavn not shown).

For all ferry routes, detailed data in terms of ferry name, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size, number of trips and sailing time (single trip) is shown in Annex 3.B.12 for the years 1985-2021. There is a lack of historical traffic data for 1985-1989, and hence, data for 1990 is used for these years, to support the fuel consumption and emission calculations.

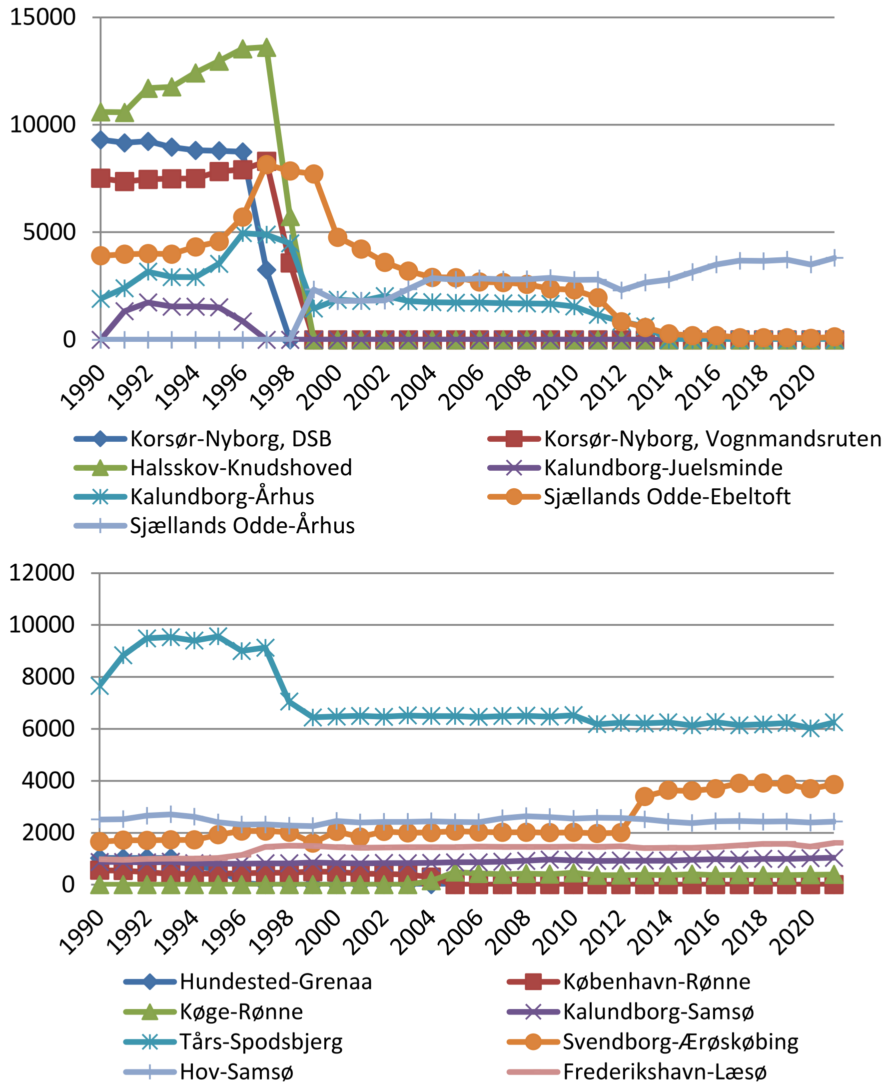


Figure 3.3.54 No. of round trips for the most important ferry routes in Denmark 1990-2021.

It is seen from Table 3.3.9 (and Figure 3.3.54) that several ferry routes were closed in the 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, 2022). The fuel used by freight transport between Denmark and the Faroe Islands (Eimskip) is bought outside Denmark (Helgason, 2022). 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 1) DEA national fuel sales for national sea transport minus fuel consumption at Danish off shore installations (off shore reduced fuel sales[12]) and 2) 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 the "off shore reduced" 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).

The LNG fuel calculated for Danish ferries is slightly higher than the LNG fuel sales for national navigation reported in the DEA fuel statistics. Subsequently, an inventory fuel balance is made to account for the total LNG fuel sold reported in the DEA fuel statistics.

National Fishing

For fishing vessels, electronic log data for 1985-2020 are provided by the Danish Fisheries Agency (Hernov, 2021) and for 2021 by Aarhus University (Andersen, 2022) for each fishing trip made by Danish registered fishing vessels.

The log data register the following: Vessel registration number, build year, type, overall length (OAL), brutto tonnes (BT), total installed engine power (kW) and hours at sea.

Average engine load factors (%) are taken from Winther and Martinsen (2020) based on data provided by Hanstholm Fisheries Association (Amdissen, 2020).

Figure 3.3.55 show hours at sea for the Danish fishing vessels split into OAL classes for the years 1990-2021.

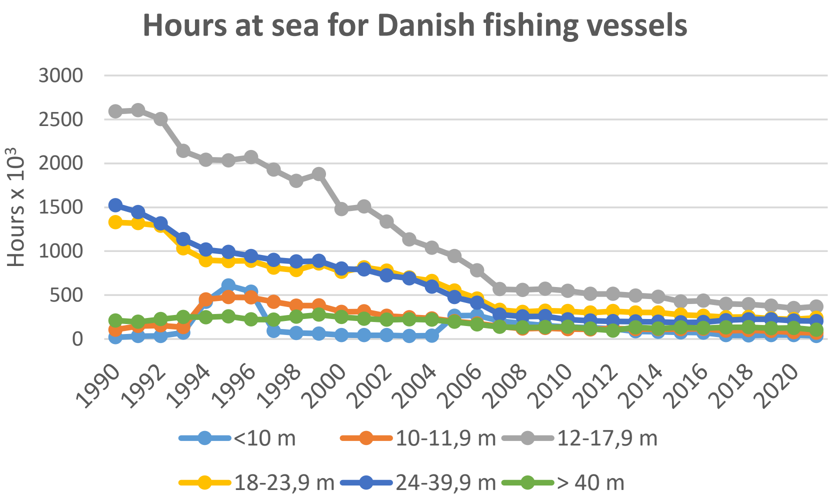


Figure 3.3.55 Total hours at sea for Danish fishing vessels 1990-2021.

Railways

The activity data for railways used in the DEMOS-Rail model consists of the total energy use for Danish railways activities from 1985-2021 provided by DEA (2022a), train km statistics for private railway lines provided by Danish

[12] According to the Danish Energy Authority, the latter diesel fuel sales are reported as sold for national navigation by the fuel sales reporting oil companies.

Civil Aviation and Railway Authority (Schelde, 2022), and detailed train specific data provided by the private railway companies.

For several private railway companies the following data has been collected for each railway line operated by the companies: Litra type, Litra new sales year, Euro emission level, fuel type, fuel consumption factors, number of seats/standing rooms, and percentage distribution of annual Litra km driven per Litra type (Hjortsø, 2022; Hansen, 2022; Jensen, 2022b). For railway lines not able to provide data, and for the earliest years in the time series in general, supplementary data has been gathered from relevant web pages (e.g. www.jernbanen.dk).

The railway activities by other companies than private railway companies is predominantly made by Danish State Railways. The fuel consumption for these latter railway activities are calculated in DEMOS-Rail as the difference between DEA national fuel sales for railways and the bottom-up calculated fuel consumption for private railway companies.

Military

The activity data for military activities consists of fuel consumption information from DEA (2022a).

International navigation

The activity data for military, railways and international sea transport consists of fuel consumption information from DEA (2021a).

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 fuel estimated for the ferry routes Esbjerg/Hanstholm/Hirtshals-Torshavn, and fuel bought by Royal Arctic Line is transferred from international sea transport to national sea transport in fuel sales, prior to inventory fuel input.

For all sectors, fuel consumption figures are given in Annex 3.B.15 for the years 1990 and 2021 in CollectER format, and fuel consumption time series are given in Annex 3.B.16 in NFR format.

Emission legislation

For other mobile sources, 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, have legislative limits for specific fuel consumption been internationally agreed in order to reduce the emissions of CO_2.

For non-road mobile machinery, recreational craft and railway locomotives/motor cars, the emission directives list specific emission limit values (g pr 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 3.3.11) relate to Stage I-IV non-road mobile 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 3.3.15). For Stage I-IV tractors the relevant directives are 2000/25 and 2005/13 (Table 3.3.11).

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 non road mobile machinery, the directive 2002/88 distinguishes between Stage I and II hand-held (SH) and not hand-held (NS) types of machinery (Table 3.3.12). 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 non road mobile machinery, EU directive 2016/1628 relate to diesel non road mobile machinery other than agricultural tractors and railways machinery (Table 3.3.11) and non road gasoline machinery (Table 3.3.12). EU directive 167/2013 relate to Stage V agricultural and forestry tractors (Table 3.3.11). The Stage V emission limits are also shown in Annex 3.B.11.

Table 3.3.11 Overview of EU emission directives relevant for diesel fuelled non-road mobile machinery.

Stage	Engine size	CO	VOC	NO_x	VOC+NO_x	PM	Diesel machinery			Diesel 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 3.3.12 Overview of the EU Emission Directives relevant for gasoline fueled non-road mobile 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 $(HC+NOx) \times CO^{0.784} \leq 8.57$ and the conditions CO ≤ 20.6 g/kWh and (HC+NOx) ≤ 2.7 g/kWh.

For recreational craft, Directive 2003/44 comprises the Stage I 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 3.3.13. 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 3.3.14 the Stage II emission limits are shown for recreational craft. CO and HC+NOx limits are provided for gasoline engines depending on the rated engine power and the engine type (stern-drive vs. outboard) while CO, HC+NOx, and particulate emission limits are defined for compression ignition (CI) engines depending on the rated engine power and the swept volume.

Table 3.3.13 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 3.3.14 Overview of the EU Emission Directive 2013/53 for recreational craft.

Diesel engines					
Swept Volume, SV	Rated Engine Power, P_N	Implement date	CO	HC + NO_x	PM
l/cyl.	kW		g/kWh	g/kWh	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		CO	HC + NO_x	PM
	kW		g/kWh	g/kWh	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 3.3.15 Overview of the EU Emission Directives relevant for railway locomotives and motorcars.

				CO	HC	NO_x	HC+NO_x	PM	
	EU directive	Engine size [kW]		g/kWh					Imp. date
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 — Aircraft Engine Emissions 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:

1) 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.
2) 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.
3) 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.
4) 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.
5) 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 3.3.16.

Table 3.3.16 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 1.1.2008 & 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 %).

π_{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 "www.easa.europa.eu/domains/environment/icao-aircraft-engine-emissions-databank" hosted by the European Aviation Safety Agency (EASA).

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 ≤ n < 2000 RPM
- 9.8 g pr kWh, n ≥ 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[13]: 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 Carribean 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 NOx emission limit functions are shown in Table 3.3.17.

Table 3.3.17 Tier I-III NOx 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 3.3.18 shows the EU and IMO (Regulation 14 plus amendments) legislation in force for SECA (Sulfur Emission Control Area) areas and outside SECA's.

[13] For ships operating in a designated Emission Control Area. Outside a designated Emission Control Area, Tier II limits apply.

Table 3.3.18 Current legislation in relation to marine fuel quality.

Legislation	Marine area	Heavy fuel oil		Gas oil	
		S- %	Implement. date	S- %	Implement. date
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.

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 SO_2 emission factors are fuel related, and rely on the sulphur contents given in the relevant EU fuel directives or in the Danish legal announcements. However, for jet fuel the default factor from IPCC (2006) is used. For ferries operated by Mols Linjen fuel sulphur data from fuel suppliers are used from 2017 onwards, and for small ferries fuel sulphur data from fuel suppliers are used in all inventory years.

Road transport diesel is assumed to be used by engines in military, railways (apart from railway lines using GTL) and recreational craft. Road transport gasoline is assumed to be used by non-road working machinery and recreational craft. Hence, these types of machinery have the same SO_2 emission factors, as for road transport. For GTL a fuel sulphur content of 5 ppm is used based on fuel supplier's information.

Time series of fuel sulphur contents for the relevant fuel types and their references are listed in Annex 14.

Annex 14 also 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 mobile sources, the emission factor source for NH_3, PAH and PCB is the EMEP/EEA guidebook (EMEP/EEA, 2019).

For BC the emission factor source is Comer et al. (2017) for national sea transport and fisheries, apart for ferries using GTL. In this case BC emission factors for marine diesel is used due to lack of data. The BC emission factors for the remaining inventory categories come from (EMEP/EEA, 2019).

The heavy metal emission factors for road transport and other mobile sources originate from Winther and Slentø (2010). For national sea transport and fisheries, the heavy metal emission factor source is the EMEP/EEA guidebook (EMEP/EEA, 2019). For HCB the emission factors come from Nielsen et al. (2014). For civil aviation jet fuel, no heavy metal emission factors are proposed due to lack of data.

In the case of military ground equipment, due to lack of fleet/activity and emission data, aggregated emission factors for gasoline and diesel are derived from total road traffic emission results. For piston engine aircraft using aviation gasoline, emission factors from (EMEP/EEA, 2019) are used.

For railways NO_x, VOC, CO and TSP emission factors are derived from specific Danish emission measurements from the Danish State Railways (Mølgård, 2022). For private railway lines, NO_x, VOC, CO, TSP and BC emission factors are estimated for the different train type technologies using diesel or GTL. The NMVOC emission factors for railways are derived from the VOC emission factors using a NMVOC/CH_4 split, based on expert judgement.

For non road machinery in agriculture, forestry, industry, commercial/institutional and residential, and for recreational craft, the NO_x, VOC, CO and TSP emission factors are derived from various European measurement programmes; see IFEU (2004, 2009), Notter and Schmied (2015) and Winther et al. (2006). For non road machinery equipped with particle filters, TSP emission factors comes from ICCT (2016). The NMVOC/CH_4 split is taken from IFEU (2009).

For national sea transport and fisheries, the NO_x emission factors predominantly come from the engine manufacturer MAN Energy Solutions, as a function of engine production year. The CO and VOC emission factors come from the Danish TEMA2015 emission model (Ministry of Transport, 2015). TSP emission factors are provided by IMO (2015), whereas the PM_{10} and $PM_{2.5}$ size fractions are obtained from MAN Energy Solutions.

Specifically for the ferries used by Mols Linjen, NO_x, VOC and CO emission factors are provided by Kristensen (2008), originating from engine measurements (Hansen et al., 2004; Wismann, 1999; PHP, 1996). Complimentary emission factor data for new ferries is provided by Kristensen (2013) and engine load specific emission data is provided by Nielsen (2019).

For island and short-cut ferries using GTL, NO_x, VOC, CO and TSP emission factors are taken from Winther (2022a).

For the LNG fueled ferry in service on the Hou-Sælvig route NO_x, NMVOC, CO and TSP emission factors are taken from Bengtsson et al. (2011).

For marine engines using diesel or residual oil VOC/CH_4 splits are taken from EMEP/EEA (2019), and all emission factors are shown in Annex 3.B.13.

For national sea transport, international sea transport and fisheries, total fuel consumption and aggregated emission factors per fuel type are shown Annex 3.B.13 for the years 1985-2020. For ferries, total fuel consumption and emission factors per ferry per route are shown Annex 3.B.13 for 2021. For fisheries total engine MWh's produced, total fuel consumption, fuel balance factors and emission factors are shown Annex 3.B.13 for 1985-2021.

The source for aviation (jet fuel) 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).

For all sectors, emission factors are given in CollectER format in Annex 3.B.15 for 2021. Table 3.3.19 shows the emission factors for SO_2, NO_X, NMVOC, CO, NH_3, TSP and BC in CollectER format used to calculate the emissions from other mobile sources in Denmark.

Factors for deterioration, transient loads and gasoline evaporation for non-road mobile 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, 2009, 2014), and are shown in Annex 3.B.10. For more details regarding the use of these factors, please refer to paragraph 3.1.4 or Winther et al. (2006).

Engine load adjustment factors for marine engines

For marine 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 and fishing vessels 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). Only sfc is adjusted in the calculations, due to the actual engine load levels for ferries and fishing vessels 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.

Table 3.3.19 Fuel based emission factors for SO_2, NO_X, NMVOC, CO, NH_3, TSP and BC for other mobile sources in Denmark (2021).

					Emission factors[1] [g pr GJ]						
SNAP ID	Category	Fuel type	Tier level	CH_4 % of VOC	SO_2	NO_X	NMVOC	CO	NH_3	TSP	BC
080100	Military	Diesel	Tier 1	9.8	0.44	162.02	2.80	25.59	1.39	1.79	1.25
080100	Military	Gasoline	Tier 1	5.0	0.43	53.08	96.71	903.16	10.63	0.56	0.09
080100	Military	Jet fuel	Tier 1	9.6	22.99	250.57	24.94	229.89	0.00	1.16	0.56
080200	Railways	Diesel	Tier 3	3.7	0.47	489.78	23.76	68.48	0.20	5.74	3.73
080200	Railways	GTL	Tier 3	3.7	0.23	281.57	36.66	179.96	0.20	2.83	1.84
080300	Recreational craft	Bio ethanol	Tier 3	2.8	0.00	528.75	394.86	7060.69	0.11	4.29	0.21
080300	Recreational craft	Biodiesel	Tier 3	2.4	0.00	568.84	96.01	339.27	0.17	51.35	19.00
080300	Recreational craft	Diesel	Tier 3	2.4	46.84	568.84	96.01	339.27	0.17	51.35	19.00
080300	Recreational craft	Gasoline	Tier 3	2.8	0.46	528.75	394.86	7060.69	0.11	4.29	0.21
080402	National sea traffic	Diesel	Tier 3	2.0	23.38	1250.85	60.27	120.89	0.00	20.14	3.39
080402	National sea traffic	GTL	Tier 3	2.0	0.23	952.99	50.68	141.58	0.00	10.54	5.51
080402	National sea traffic	LNG	Tier 3	74.0	0.00	161.63	92.45	269.39	0.00	8.51	0.22
080402	National sea traffic	Residual oil	Tier 3	2.0	48.90	1896.39	66.66	196.73	0.00	93.09	4.74
080403	Fishing	Diesel	Tier 3	2.0	46.84	1162.59	54.46	155.59	0.00	20.54	4.43
080404	International sea traffic	Diesel	Tier 1	2.0	46.84	1538.68	61.66	176.16	0.00	23.78	2.36
080404	International sea traffic	Residual oil	Tier 1	2.0	48.90	2016.04	68.02	194.33	0.00	96.63	4.52
080501	Air traffic. Dom. < 3000 ft.	AvGas	Tier 1	2.0	22.83	71.70	422.10	18219.00	1.60	10.00	1.50
080501	Air traffic. Dom. < 3000 ft.	Jet fuel	Tier 3	10.0	22.99	275.61	15.07	202.67	0.00	1.79	0.85
080502	Air traffic. Int. < 3000 ft.	Jet fuel	Tier 3	10.0	22.99	296.24	22.11	205.47	0.00	3.07	1.65
080503	Air traffic. Dom. > 3000 ft.	Jet fuel	Tier 3	0.0	22.99	301.20	6.38	106.21	0.00	2.20	1.32
080504	Air traffic. Int. > 3000 ft.	Jet fuel	Tier 3	0.0	22.99	292.48	5.80	62.97	0.00	4.66	2.50
080600	Agriculture	Bio ethanol	Tier 3	12.2	0.00	108.07	1095.07	18632.00	1.51	30.59	1.53
080600	Agriculture	Diesel	Tier 3	2.4	0.47	268.15	32.98	243.78	0.20	22.58	13.60
080600	Agriculture	Gasoline	Tier 3	12.2	0.46	108.07	1095.07	18632.00	1.51	30.59	1.53
080700	Forestry	Bio ethanol	Tier 3	6.0	0.00	54.79	3754.76	17915.98	0.09	82.19	4.11
080700	Forestry	Diesel	Tier 3	2.4	0.47	54.27	14.74	174.86	0.21	2.53	1.75
080700	Forestry	Gasoline	Tier 3	6.0	0.46	54.79	3754.76	17915.98	0.09	82.19	4.11
080800	Industry	Bio ethanol	Tier 3	3.6	0.00	211.09	1508.19	14359.20	0.10	23.93	1.20
080800	Industry	Diesel	Tier 3	2.4	0.47	238.18	31.82	214.81	0.20	16.64	11.84
080800	Industry	Gasoline	Tier 3	3.6	0.46	211.09	1508.19	14359.20	0.10	23.93	1.20
080800	Industry	LPG	Tier 3	5.0	0.00	139.87	33.20	13.98	0.21	0.70	0.03
080900	Household and gardening	Bio ethanol	Tier 3	2.3	0.00	88.22	2230.92	29809.57	0.09	40.76	2.04
080900	Household and gardening	Gasoline	Tier 3	2.3	0.46	88.22	2230.92	29809.57	0.09	40.76	2.04
081100	Commercial and institutional	Bio ethanol	Tier 3	4.0	0.00	68.40	858.90	33713.45	0.09	15.96	0.80
081100	Commercial and institutional	Diesel	Tier 3	2.4	0.47	269.73	31.60	238.15	0.20	17.70	12.36
081100	Commercial and institutional	Gasoline	Tier 3	4.0	0.46	68.40	858.90	33713.45	0.09	15.96	0.80
081100	Commercial and institutional	LPG	Tier 3	5.0	0.00	139.89	33.20	13.98	0.21	0.70	0.03
080501	Air traffic. Dom. < 3000 ft., CPH	AvGas	Tier 1	2.0	22.83	71.70	422.10	18219.00	1.60	10.00	1.50
080501	Air traffic. Dom. < 3000 ft., CPH	Jet fuel	Tier 3	10.0	22.99	273.86	12.68	232.24	0.00	1.52	0.55
080502	Air traffic. Int. < 3000 ft., CPH	Jet fuel	Tier 3	10.0	22.99	330.00	18.68	214.27	0.00	2.01	0.66
080503	Air traffic. Dom. > 3000 ft., CPH	Jet fuel	Tier 3	0.0	22.99	323.82	3.26	60.29	0.00	2.55	0.81
080504	Air traffic. Int. > 3000 ft., CPH	Jet fuel	Tier 3	0.0	22.99	364.56	2.97	39.91	0.00	3.18	1.01

[1] SO_2: Country-specific; Military: Aggregated emission factors for road transport; Railways (NO_x, CO, NMVOC and TSP): Danish State Railways; Agriculture, forestry, industry, household gardening and recreational craft (NO_x, CO, VOC and TSP): IFEU (2004, 2009, 2014), Notter and Schmied (2015), ICCT (2016); National navigation/National fishing/International navigation: MAN B&W (NO_x), Ministry of Transport (2015) (CO, NMVOC), IMO (TSP), specific data from Mols Linjen (NO_x, CO, NMVOC, TSP) & LNG emission factors (NO_x, CO, NMVOC, TSP) from Bengtsson et al. (2011) & GTL emission factors (NO_x, CO, NMVOC, TSP) from Winther (2022a); Aviation (NO_X, CO, NMVOC, TSP): EMEP/EEA.

3.3.4 Calculation methods for other mobile sources

Civil aviation

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:

$$FC^{a}_{LTO} = \sum_{m=1}^{5} t_m \cdot ff_{a,m} \tag{13}$$

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:

$$E^{a}_{LTO} = \sum_{m=1}^{5} FC_{a,m} \cdot EI_{a,m} \tag{14}$$

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 2001-2021.

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 13 and 14). 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 2021. 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 actual flown distance between the origin and the destination airports.

The actual flown distance between two airports can be derived as a function of the ideal great circle distance (GCD) between the airports in question. The relation between actual distance and GCD flown is taken from the German TREMOD AV model (Knörr et al., 2012). For GCD <= 100 NM (<= 185.2 km), 60 km must be added to the great circle distance (GCD) in order to find actual distance flown. For GCD > 100 NM (>185.2 km), 4 % additional flown distance is added for the part of GCD > 100 NM (>185.2 km):

- Actual flown distance (GCD <= 185.2 km) = GCD + 60 km
- Actual flown distance (GCD > 185.2 km) = (GCD – 185.2 km) x 1,04 + 185.2 km + 60 km

If the actual flown 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:

$$E(y) = E_{x_i} + \frac{(y - x_i)}{x_{i+1} - x_i} \cdot (E_{x_{i+1}} - E_{x_i}) \quad y<x_{max}, \; i = 0,1,2\ldots max\text{-}1 \qquad (15)$$

In (15) x_i and x_{max} denominate the separate distances and the maximum distance, respectively, with known fuel consumption and emissions. If the actual flown distance, y, exceeds x_{max} the maximum figures for fuel consumption and emissions must be extrapolated and the equation then becomes:

$$E(y) = E_{x_{max}} + \frac{(y - x_{max})}{x_{max} - x_{max-1}} \cdot (E_{x_{max}} - E_{x_{max-1}}) \quad y>x_{max} \qquad (16)$$

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 2021[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 15 and 16.

The overall fuel precision (fuel balance) in the model is 1.00 in 2021, 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

[14] Excluding flights for Greenland and the Faroe Islands.

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:

$$E_{Basis}(X)_{i,j,k} = N_{i,j,k} \cdot HRS_{i,j,k} \cdot P \cdot LF_i \cdot EF_{y,z} \qquad (17)$$

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 emission level, z. The deterioration factors for diesel and gasoline 2-stroke engines are found from:

$$DF_{i,j,k}(X) = \frac{K_{i,j,k}}{LT_i} \cdot DF_{y,z} \qquad (18)$$

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:

$$DF_{i,j,k}(X) = \sqrt{\frac{K_{i,j,k}}{LT_i}} \cdot DF_{y,z} \qquad (19)$$

The deterioration factors inserted in (18) and (19) 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:

$$TF_{i,j,k}(X) = TF_z \qquad (20)$$

Where i = machinery type, j = engine size, k = engine age and z = emission level.

The transient factors inserted in (20) 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.

As a part of some engine manufacturer's emission reduction strategy, a part of the Stage IIIB and IV machines used in building and construction are equipped with preinstalled particle filters, and hence have low particle emissions. This particle filter effect on particle emissions needs to be taken into account in the calculations, since the baseline emission factors for TSP more aligns with EU emission legislation limits, and these emission limits do not necessarily require particulate filters in order to be met.

The particle reduction factor, F_{dpf}, for any given machinery type, engine size and engine age in year X, depends on the share of engines with preinstalled particle filters, in the different size classes and emission levels:

$$F_{dpf,i,j,k}(X) = \frac{(1 - S_{y,z}) \cdot EF_{y,z} + S_{y,z} \cdot EF_{dpf,y,z}}{EF_{y,z}} \quad (21)$$

Where F_{dpf}, = particle reduction factor, S = Share of engines with preinstalled filters, i = machinery type, j = engine size, and k = engine age. This emission reduction factor only relates to particle emissions from Stage IIIB and IV diesel engines with preinstalled filters[15]. The emissions from all other non road machines are not affected by this adjustment.

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 17-21:

$$E(X)_{i,j,k} = E_{Basis}(X)_{i,j,k} \cdot TF(X)_{i,j,k} \cdot (1 + DF(X)_{i,j,k}) \cdot F_{dpf,i,j,k}(X)) \quad (22)$$

The evaporative hydrocarbon emissions from fuelling are calculated as:

$$E_{Evap,fueling,i} = FC_i \cdot EF_{Evap,fueling} \quad (23)$$

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:

$$E_{Evap,\tan k,i} = N_i \cdot EF_{Evap,\tan k,i} \quad (24)$$

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.

National navigation and international navigation

The fuel consumption and emissions in year X, for domestic ferries are calculated as:

$$E(X) = \sum_i N_i \cdot T_i \cdot S_{i,j} \cdot P_i \cdot LF_j \cdot LAF_j \cdot EF_{k,l,y} \quad (25)$$

[15] The particle emission adjustment relating to Stage IIIB and IV engines equipped with particle filters also significantly affects BC emissions, since particle filters very efficiently reduce BC from the exhaust.

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, other national sea transport and international navigation, the emissions are calculated using a simplified approach:

$$E(X) = \sum_i EC_{i,k} EF_{k,l,y} \tag{26}$$

Where E = fuel consumption/emissions, EC = energy consumption, EF = fuel consumption/emission factor in g per kg fuel, i = category (other national sea transport, international navigation), k = fuel type, l = engine type, y = average engine year.

The emission factor inserted in (28) 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:

$$EF_{k,l,y} = \frac{\sum_{year=X}^{year=X-LT} EF_{k,l}}{LT_{k,l}} \tag{27}$$

National fishing

For fishing vessels, the fuel consumption and emissions in year X, are calculated as:

$$E(X) = \sum_i T_i \cdot P_j \cdot LF_j \cdot LAF_j \cdot EF_{k,l,y} \tag{28}$$

Where E = fuel consumption/emissions, T = sailing time pr fishing trip in hours, P = engine size in kW, LF = engine load factor, LAF = engine load adjustment factor, EF = fuel consumption/emission factor in g pr kWh, i = fishing trip no., j = fishing vessel registration no., k = fuel type, l = engine type, y = engine year.

Railways

The fuel consumption and emissions in year X, for private railway lines are calculated as:

$$E(X) = \sum_i EF_{i,j,k} \times S_{i,j} \times M_i \tag{29}$$

Here E = fuel consumption/emission, EF = fuel consumption/emission factor in g per km, S = Litra type share of total train set km, M = total train set km, i = railway line, j = Litra type and k = fuel type.

The fuel consumption for Danish State Railways are found as the difference between total fuel consumption from DEA (2022) and the fuel consumption for private railway lines calculated in (x).

The emissions in year X, for Danish State Railways are calculated as:

$$E(X) = FC(X) \times EF(X) \qquad (30)$$

Where E = fuel consumption/emissions, FC = fuel consumption, EF = emission factor in g per kg fuel.

Military

For military, the emissions are estimated with the simple method using fuel-related emission factors and fuel consumption from the DEA:

$$E(X) = FC(X) \times EF(X) \qquad (31)$$

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.15 for the years 1990 and 2021 and as time series 1985-2021 in Annex 3.B.16 (NFR format).

Energy balance between inventory and sales

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 navigation and national fishing, non-road mobile 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 navigation

Fuel used for the remaining part of the traffic between two Danish ports, other national sea transport, is taken as the difference between 1) DEA national fuel sales for national sea transport minus fuel consumption at Danish off shore installations (off shore reduced fuel sales[16]) and 2) the bottom-up calculated fuel consumption for Danish ferries in DEMOS-Navigation.

For years when the fuel estimates for ferries (not including the ferry to the Faroe Islands) are higher than the "off shore reduced" 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).

National fishing

For fisheries, the calculation methodology is activity based with a fuel balance, and input fuel data is in principle the diesel fuel sold for fisheries reported by DEA.

For years when diesel fuel calculated for national navigation are higher than the "Off shore reduced" fuel sold for national navigation, diesel is transferred from fisheries to national navigation in the inventories.

[16] According to the Danish Energy Authority, the latter diesel fuel sales are reported as sold for national navigation by the fuel sales reporting oil companies.

Incorrectly reported gasoline and heavy fuel oil for fisheries is transferred to recreational craft (reported under "Other") and national navigation, 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 navigation and fisheries for diesel oil and between national navigation 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 mobile machinery and recreational craft

For diesel and LPG, the non-road fuel consumption estimated DEMOS-NRMM is partly covered by the fuel consumption amounts in the following DEA sectors: agriculture and forestry, market gardening, and building and construction. The remaining quantity of non-road diesel and LPG is taken from the DEA industry sector.

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 is transferred from DEA road transport in order to outbalance the bottom up fuel consumption calculated in DEMOS-NRMM.

The amount of diesel and LPG in DEA industry not being used by non-road mobile 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 in DEMOS-NRMM are subsequently subtracted from the DEA fishery sector. For gasoline, the DEA reported fuel consumption for fisheries is far too small to outbalance the bottom up fuel consumption for recreational craft, and hence the missing fuel amount is taken from the DEA road transport sector in order to fill the fuel gap.

Road transport

The bottom up diesel estimate for recreational craft is subtracted from road transport and grouped in the "Other" inventory category together with military activities.

For 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.

Classification of domestic and international aviation and navigation for Denmark

The distinction between domestic and international fuel consumption and emissions from aviation and navigation for Denmark are 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

For the emission components reported to the UNECE LRTAP convention, emission uncertainty estimates are made for road transport and other mobile sources using the guidelines for estimating uncertainties in the EMP/EEA guidebook (EMEP/EEA, 2019). However, for TSP, PM_{10}, $PM_{2.5}$ and BC the latter source indicates no uncertainty factor and, instead, this factor is based on expert judgement.

The activity data uncertainty factor is assumed to be 2 and 10 % for road transport and other mobile sources, respectively, based on expert judgement.

The uncertainty estimates should be regarded as preliminary only and may be subject to changes in future inventory documentation. The calculations are shown in Annex 3.B.17 for all emission components.

Table 3.3.20 Uncertainties for activity data, emission factors and total emissions in 2021 and as a trend.

Pollutant	Emission factor uncertainties [%] Road	Other	Emission uncertainties [%] Overall 2021	Trend
SO_2	50	50	46	1
NO_x	50	100	57	9
NMVOC	50	100	51	4
CO	50	100	58	8
NH_3	1000	1000	992	633
TSP	50	100	45	7
PM_{10}	50	100	46	4
$PM_{2.5}$	50	100	51	2
BC	50	100	54	1
Arsenic	1000	1000	868	48
Cadmium	1000	1000	856	153
Chromium	1000	1000	853	160
Copper	1000	1000	999	2
Mercury	1000	1000	745	102
Nickel	1000	1000	921	34
Lead	1000	1000	928	4
Selenium	1000	1000	760	128
Zinc	1000	1000	960	15
Dioxins	1000	1000	720	138
Benzo(b) flouranthene	1000	1000	842	173
Benzo(k) flouranthene	1000	1000	857	255
Benzo(a) pyrene	1000	1000	902	199
indeno(1,2,3-c,d) pyrene	1000	1000	801	154
HCB	1000	1000	826	224
PCB	1000	1000	813	30

As regards time series consistency, background flight data cannot be made available on a city-pair level from 2000 or earlier. However, aided by LTO/aircraft statistics for these years and the use of proper assumptions, a good level of consistency is still obtained in 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)

It is the intention to publish every second year a sector report for road transport and other mobile sources. The last sector report concerned the 2020 inventory (Winther, 2022a).

The QA/QC descriptions of the Danish emission inventories for transport are given in Nielsen et al. (2022).

3.3.7 Recalculations

The following recalculations and improvements of the emission inventories have been made since the previous emission reporting in 2021. The absolute and percentage emission changes in 2005 and 2020 since the previous emission reporting are shown in the table in the end of this section.

Road transport

For road transport the following changes have been made.

- More precise fleet information on the number of diesel passenger cars and vans retrofitted with particulate filters, and reclassifications of some of the diesel passenger cars and vans from Euro 5 to Euro 4 in fleet data.
- Diesel fuel consumption for road transport has slightly decreased due to a subtraction of the diesel fuel used by recreational craft. In the previous inventory submissions this fuel was subtracted from the fishery sector in the energy statistics. However, according to the Ministry of Taxation the diesel fuel for recreational craft is purchased at road transport fuel stations, and must therefore be subtracted from road transport instead in the energy statistics.
- Gasoline fuel consumption for road transport has slightly decreased due to more annual working hours for residential gasoline machinery, and hence larger calculated amounts of gasoline for these machinery types in the inventories. This gasoline fuel consumption change has an impact on the gasoline fuel balance made across sectors to account for total gasoline fuel sales.

Navigation

For navigation the following changes have been made.

- An error in diesel fuel input data has been corrected for the years 2015-2018.
- A few changes in sailing time, main engine size and engine load factors has been made for some of the small island ferries.
- The fuel type Gas-to-liquid (GTL) has been used by some small ferries since 2018, and is introduced in the inventories for the years 2018-2021.

Fisheries

For fisheries the following changes have been made.

- Diesel fuel consumption for fisheries has slightly increased. In the previous inventory submissions the diesel fuel used by recreational craft was subtracted from the fishery sector. However, according to the Ministry of Taxation the diesel fuel for recreational craft is purchased at road transport fuel stations, and this fuel must therefore be subtracted from road transport instead of fisheries in the overall energy input data.

Agriculture/forestry

For agriculture/forestry the following changes have been made.

- Engine load factors for agricultural tractors and harvesters are substantially reduced based on telemetri data gathered in the emission inventory for the UK.
- Updated stock and utility data for small gasoline machinery types (e.g. sweepers, bedding machines, fodder trucks) are provided by agricultural key experts, and used as input for updated inventory calculations for the years 1990-2020.
- Small adjustments are made in the total stock for forestry machinery due to errors discovered for the years 2005-2020.

Industry

For industry the following changes have been made.

- Engine load factors for tractors used in industry (building and construction, manufacturing industries) and commercial/institutional non road sectors has been substantially lowered based on telemetri data gathered in the emission inventory for the UK.
- Updated stock information of diesel fueled Stage IIIB and IV non road machinery for building and construction machinery equipped with diesel particulate filters.
- Updated PM emission factors for Stage IIIB, IV and V diesel machinery based on new emission measurement data gathered by ICCT (2016).
- Proxy data development in the 1985-2021 periods are used to adjust stock numbers for small sources machinery types, e.g. pumps, compressors and personal lifts.
- Updated number of refrigeration units on board Danish long distance and local distribution trucks based on data from Danish Technological Institute.

Commercial and institutional

For commercial and institutional the following changes have been made.

- Engine load factors for tractors used in industry (building and construction, manufacturing industries) and commercial/institutional non road sectors has been substantially reduced based on telemetri data gathered in the emission inventory for the UK.

Residential

For residential the following changes have been made.

- The calculated gasoline fuel consumption for residential gasoline machinery has slightly increased due to more annual working hours expected for these machinery types.

Railways

A major inventory revision has been made for railways. A new model has been developed which include Tier 3 estimates for fuel consumption and emissions for train traffic carried out by private railways.

- The fuel type Gas-to-liquid (GTL) has been used by some private railway companies since 2018, and is introduced in the railways emission inventories for the years 2018-2021.

Civil aviation
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 for all years have caused small emission changes from 1985-2020.

3.3.8 Improvements

Fuel consumption and emission factors for road transport vehicles will be updated by the time when new data becomes available from COPERT model updates.

Table 3.3.21 The absolute and percentage emission changes in 2005 and 2020 since the previous emission reporting.

Year	Pollutant	Difference	Agr./for. (1A4c)	Civil Aviation (1A3a)	Comm./Inst. (1A4a)	Fisheries (1A4c)	Industry-Other (1A2g)	Navigation (1A3d)	Other (1A5b)	Railways (1A3c)	Residential (1A4b)	Road (1A3b)
2005	BC	Tonnes	-180	0	-9	4	29	0	0	-2	0	-47
	CH4	Tonnes	-11	0	0	-2	6	-5	0	0	15	-14
	CO	Tonnes	-2145	0	10	154	1037	0	-2	-5	3068	-1381
	CO2	kTonnes	-292	0	-14	74	41	0	0	0	9	-88
	N2O	Tonnes	-12	0	-1	2	2	0	0	0	0	-2
	NH3	Tonnes	-1	0	0	0	0	0	0	0	0	-6
	NMVOC	Tonnes	-435	0	-7	50	169	5	0	-8	286	-187
	NOx	Tonnes	-3538	0	-164	933	511	0	-3	-80	9	-933
	PM10	Tonnes	-319	0	-15	20	54	0	-1	-3	4	-78
	PM2.5	Tonnes	-319	0	-15	20	54	0	-1	-3	4	-78
	SO2	Tonnes	-9	0	0	94	1	0	0	0	0	-1
	TSP	Tonnes	-319	0	-15	21	54	0	-1	-3	4	-78
2020	BC	Tonnes	-68	0	-9	5	14	0	0	0	0	-30
	CH4	Tonnes	-9	0	0	-1	7	-4	0	0	6	-1
	CO	Tonnes	-3676	0	-59	158	1555	-6	1	33	3612	-48
	CO2	kTonnes	-182	0	-23	74	64	0	-5	0	8	-78
	N2O	Tonnes	-8	0	-1	2	3	0	0	0	0	-3
	NH3	Tonnes	0	0	0	0	0	0	0	0	0	-5
	NMVOC	Tonnes	-244	0	-9	56	185	3	0	-1	154	14
	NOx	Tonnes	-1015	0	-128	1175	378	-37	-1	-71	10	-425
	PM10	Tonnes	-118	0	-13	20	22	-1	0	0	4	-70
	PM2.5	Tonnes	-118	0	-13	20	22	-1	0	0	4	-70
	SO2	Tonnes	-1	0	0	47	0	2	-3	0	0	0
	TSP	Tonnes	-118	0	-13	20	22	-1	0	0	4	-70
2005	BC	%	-32,4	0,0	-12,8	15,8	9,5	0,1	-0,7	-2,2	32,5	-3,1
	CH4	%	-12,4	0,0	0,2	-22,8	19,1	-33,3	0,0	-3,3	34,6	-1,0
	CO	%	-15,5	0,0	0,0	15,8	19,8	0,0	0,0	-0,8	36,6	-0,7
	CO2	%	-29,4	0,0	-6,3	15,8	6,8	0,0	0,0	0,0	33,8	-0,7
	N2O	%	-29,7	0,0	-7,6	15,8	6,6	0,0	0,0	0,0	33,9	-0,6
	NH3	%	-27,1	0,0	-7,2	#DIV/0!	6,7	#DIV/0!	-0,2	0,0	33,6	-0,3
	NMVOC	%	-21,8	0,0	-0,5	17,0	16,7	1,0	0,0	-3,3	20,5	-0,7
	NOx	%	-31,7	0,0	-11,0	15,8	8,9	0,0	-0,1	-2,2	30,2	-1,3
	PM10	%	-32,4	0,0	-12,1	15,8	10,5	0,0	-0,4	-2,2	32,5	-3,4
	PM2.5	%	-32,4	0,0	-12,1	15,8	10,5	0,0	-0,4	-2,2	32,5	-3,4
	SO2	%	-29,9	0,0	-10,4	15,8	6,8	0,0	0,0	0,0	33,8	-0,7
	TSP	%	-32,4	0,0	-12,1	15,8	10,5	0,0	-0,4	-2,2	32,5	-3,4
2020	BC	%	-35,3	0,0	-28,7	28,1	15,0	-0,3	-0,5	-1,7	36,0	-14,5
	CH4	%	-16,5	0,0	-0,4	-14,6	42,9	-12,3	0,0	-0,9	41,3	-0,2
	CO	%	-37,9	0,0	-0,2	28,1	41,3	-0,7	0,0	18,0	43,2	-0,1
	CO2	%	-21,2	0,0	-11,6	28,1	11,7	0,0	-2,1	0,0	38,1	-0,7
	N2O	%	-20,4	0,0	-13,6	28,1	10,5	0,0	0,0	0,0	38,4	-0,8
	NH3	%	-18,7	0,0	-13,1	#DIV/0!	10,5	#DIV/0!	-1,2	0,0	37,9	-0,7
	NMVOC	%	-26,7	0,0	-1,2	29,4	38,9	0,8	0,0	-0,9	20,1	0,3
	NOx	%	-28,5	0,0	-19,9	28,1	21,8	-0,4	-0,1	-4,9	37,7	-1,9
	PM10	%	-35,2	0,0	-23,7	28,1	16,1	-0,6	-0,4	-1,7	36,0	-20,7
	PM2.5	%	-35,2	0,0	-23,7	28,1	16,1	-0,6	-0,4	-1,7	36,0	-20,7
	SO2	%	-21,2	0,0	-12,3	28,1	12,1	0,7	-4,2	-1,7	38,1	-0,7
	TSP	%	-35,2	0,0	-23,7	28,1	16,1	-0,6	-0,4	-1,7	36,0	-20,7

3.3.9 References

Amdissen, H. 2020: Unpublished data material for fishing vessels provided by Hanstholm Fisheries Association.

Andersen, C. 2019: Unpublished data material for small ferries.

Andersen, N. R. 2022: Unpublished trip-level activity data for Danish fishing vessels provided by Department of Ecoscience, Aarhus University.

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).

Bonde, R. 2021: Information of the Euro 5 vehicle recall program provided the Danish Safety Technology Authority.

Brun, I. 2018: Data for fork lifts provided by Toyota Material Handling Danmark A/S.

Christensen, A. 2018: Personal communication, Allan Christensen, N.C. Nielsen A/S.

Christensen, T. 2022: Data for fork lifts provided by Toyota Material Handling Danmark A/S.

Clemmensen, C. 2022: Data for forestry machines provided by the Danish Forest Association).

Comer, B., Olmer, N., Mao, X., Roy, B. & Rutherford, D. 2017: Black Carbon emissions and fuel use in global shipping 2015. ICCT report, pp. 103, International Council on Clean Transportation, 2017.

Cowi, 2008: Model til beregning af vej og banetransportens CO_2-ævivalent emissioner, Technical note, pp. 42, Ministry of Transport (in Danish).

Dalsø, S.H. 2022: Unpublished train technical data provided by Nordjyske Jernbaner.

Dávastovu, J. 2010: Unpublished data material from Smyril Line.

DEA, 2022a: The Danish energy statistics, Available at: https://ens.dk/sites/ens.dk/files/Statistik/energistatistik2019_dk-webtilg.pdf (13-01-2020).

DEA, 2022b: 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 Air-

port in Relation to Working Environment (Danish with English summary). DCE - 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.

Faurby, D. 2021: Unpublished data material from Scantruck A/S.

Fasting, P. 2022: New sales data for building and construction machinery provided by the Association of Danish Agricultural Machinery Dealers.

Hansen, C.O. 2010: Estimation af udenlandske bilers trafikarbejde i Danmark i 2009, Notatnr. 12032-005, 12 pp. Danish Road Directorate, 2010.

Hansen, E. 2022: Unpublished train technical data provided by Aarhus Letbane I/S.

Hansen, K.F. & Jensen, M.G. 2004: MÅLING AF EMISSIONER FRA FREMDRIVNINGSANLÆG PÅ MADS MOLS. Ruston 20RK270, Sagsnr.: 1076868, Documentation note, 5 pages (in Danish).

Helgason, S.H. 2022: Fuel purchase data provided by Eim Skip.

Hernov, F. 2021: Unpublished trip-level activity data for Danish fishing vessels provided by the Danish Fisheries Agency.

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 p. (in Danish).

Hjortshøj, T. 2021. Engine size and model year information provided by Thomas Hjortshøj, Volkswagen, 2021.

ICAO, 2008: Annex 16 "International standards and recommended practices, Environmental protection", Volume II "Aircraft engine emissions", 3rd ed. (2008) plus amendments, 108 pp., ISBN 978-92-9231-123-0.

ICAO, 2011: Airport Air Quality Manual (doc. 9889), first ed. International Civil Aviation Organization. ISBN 978-92-9231-862-8.

ICCT, 2016: Technology pathways for diesel engines used in non-road vehicles and equipment, ICCT White paper, 47 pp., International Council on Clean Transportation, 2016.

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 Verbrennungs-motoren 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 Greenhouse Gas Study/GHG3 Executive Summary and Report.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, E. 2016: Unpublished data material from Scantruck A/S.

Jensen, T.C. 2022a: Dokumentation af konvertering af trafiktal til emissionsopgørelser, arbejdsnotat 81834, 38 pp. DTU Transport, 2021.

Jensen, T.B. 2022b: Unpublished train technical data provided by Midtjyske Jernbaner.

Johnsen, T. 2018: Personal communication, Thomas Johnsen, The Danish Bicycle Traders Association.

Jørgensen, H. 2017: Unpublished data material from Færgen A/S.

Knörr, W., Schacht, A. & Göres, S. 2012: Entwicklung eines Modells zur Berechnung der Energieeinsätze und Emissionen des zivilen Flugverkehrs – TREMOD AV, Texte 48/2012, ISSN 1862-4804, 66 pp., Umweltbundesamt.

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. Available at:
http://www.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/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. 2022: Unpublished data material from the Danish State Railways.

Møller, K. 2015: Unpublished data material from Ærøfærgerne A/S.

Nielsen, D. 2019: Unpublished emission data material provided by Mols-Linjen.

Nielsen, D. 2022: 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., Nielsen, M., Fauser, P., Mikkelsen, M.H., Albrektsen, R., Hjelgaard, K., Hoffmann, L., Thomsen, M. & Bruun, H.G. 2014: Danish emission inventory for hexachlorobenzene and polychlorinated biphenyls. Aarhus University, DCE – Danish Centre for Environment and Energy, 65 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 103. Available at:
https://dce2.au.dk/pub/SR103.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., Stupak, I., Scott-Bentsen, N., Rasmussen, E., Petersen, S.B., Baunbæk, L., & Hansen, M.G. 2022: Denmark's National Inventory Report 2022. Emission Inventories 1990-2020 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Aarhus University, DCE – Danish Centre for Environment and Energy, 969 pp. Scientific Report No. 494 http://dce2.au.dk/pub/SR494.pdf.

Notter, B. & Schmied, M. 2015: Non-road energy consumption and pollutant emissions. Study for the period from 1980 to 2050. Federal Office for the Environment, Bern, 237 pp. Environmental studies no. 1519. Available at: Non-road energy consumption and pollutant emissions (admin.ch).

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 pages.

Prince, M. 2021: Unpublished data material for unregistered mopeds, Prince legal advisers.

Rasmussen, T. 2017: Unpublished data material for small ferries.

Rasmussen, H. 2021: Fuel purchase data from Royal Arctic Line.

Rubek, F., Scharling, M. & Cappelen, J. 2022: The Climate of Denmark 2021 - with English summary, Technical report No 22-01, pp. 76, Danish Meteorological Institute.

Schelde, T., 2022: Traffic data for private railway lines 2010-2021 provided by Danish Civil Aviation and Railway Authority.

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, 1974: Agricultural statistics 1974, Statistiske meddelelser 1975:13, Statistics Denmark. Available at: Publikation: Landbrugsstatistik 1974 - Danmarks Statistik (dst.dk).

Statistics Denmark, 2021a: Tractor stock data for 2003-2020 provided by Marie Louise Bak, Statistics Denmark.

Statistics Denmark, 2021b: Tractor stock data for 1950-2009 provided by Henriette Moric Ingemann, Statistics Denmark.

Statistics Denmark, 2021c: Number of tractors and harvesters 1982-2005 from Statbank Denmark (Table MASK). Available at:
http://www.statistikbanken.dk/statbank5a/default.asp?w=1364

Statistics Denmark, 2022: Ferry traffic data from Statbank Denmark (Table SKIB31). Available at:
http://www.statistikbanken.dk/statbank5a/default.asp?w=1364

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, A., Dornoff, J. & 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. & 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. Available at:
http://www.dmu.dk/Udgivelser/Ar-bejdsrapporter/Nr.+200-249/

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. Transport and Air Pollution Symposium - 3rd Environment and Transport Symposium, nr. 17, Toulouse, France, 2-4 June 2009.

Winther, M. & Slentø, E. 2010: Heavy Metal Emissions for Danish Road Transport. National Environmental Research Institute, Aarhus University, Denmark. 99 pp. – NERI Technical Report no. 780. Available at:
http://www.dmu.dk/Pub/FR780.pdf.

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., 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.

Winther, M. & Martinsen, L. 2020: Analyse af CO2-emissioner og økonomi ved grøn omstilling af fiskefartøjer. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 36 s. - Videnskabelig rapport nr. 431 Analyse af CO2 emissioner og økonomi ved grøn omstilling af fiskefartøjer (au.dk).

Winther, M. 2022a: Danish emission inventories for road transport and other mobile sources. Inventories until 2020. Aarhus University, DCE – Danish Centre for Environment and Energy, 138pp. Scientific Report No. 504. http://dce2.au.dk/pub/SR504.pdf

Winther, M. 2022b: Brændstofforbrug og emissioner for ø- og genvejsfærger. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 19 s.– Fagligt notat nr. 2022|66. Available at: https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notater_2022/N2022_66.pdf

Winther, M. 2022c: The share of Stage IIIB and IV diesel engines used in the building and construction sector with preinstalled diesel particle filters. Unpublished questionnaire data from the most important mobile machinery manufacturers and Danish machinery importers.

Wismann, T. 1999: MOLS-LINIEN, Mai Mols - Måling af emissioner fra hovedturbiner, dk-RAPPORT 14.901, 9 pages (in Danish).

3.4 Fugitive emissions

This chapter covers fugitive emissions from fuels in the NFR sector 1B. 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 only emissions from storage in coal piles are included in the emission inventory. The fugitive sector consists of the following NFR categories:

1B1 Solid fuels
1B2a Oil
1B2b Natural gas
1B2c Venting and flaring
1B2d Other*
** not occurring in the Danish emission inventory*

Most fugitive emission sources are of minor importance compared to the total Danish emissions. Fugitive and national total emissions for selected pollutants are given in Table 3.4.1.

Table 3.4.1 National and fugitive emissions of SO_2, NO_x, CO, NMVOC, $PM_{2.5}$ and BC in 2021, and the fugitive emissions share of national total emissions.

	National emission, ktonnes	Fugitive emission, ktonnes	Fugitive/national emission, %
SO_2	9	0.47	5.4
NO_x	89	0.06	0.1
CO	192	0.10	0.0
NMVOC	107	6.72	6.3
$PM_{2.5}$	12	0.00	0.0
BC	2	0.01	0.4

3.4.1 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 *(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 is not occurring in Denmark. Accordingly, only emissions from storage in coal piles are included in the emission inventory.

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 negligible in oil and gas production and in refineries, as controlled venting enters the gas flare system.

Table 3.4.2 summarizes the Danish fugitive emissions in 2021 for selected pollutants.

Table 3.4.2 Summary of the Danish fugitive emissions in 2021.

NFR category	snap category	Pollutant	Emission	Unit	Share of total fugitive
1B1a	Storage of solid fuel	TSP	11.600	tonnes	86.9%
1B1a	Storage of solid fuel	PM_{10}	10.208	tonnes	85.4%
1B1a	Storage of solid fuel	$PM_{2.5}$	2.784	tonnes	61.5%
1B1a	Storage of solid fuel	BC	7.734	tonnes	98.9%
1B2ai	Production of oil	NMVOC	2.826	tonnes	<0.1%
1B2ai	Offshore loading of oil	NMVOC	361.280	tonnes	5.4%
1B2ai	Onshore loading of oil	NMVOC	9.700	tonnes	0.1%
1B2ai	Storage of crude oil	NMVOC	269.001	tonnes	4.0%
1B2aiv	Petroleum products processing	NMVOC	5173.200	tonnes	77.0%
1B2aiv	Sulphur recovery plants	SO_2	359.908	tonnes	77.0%
1B2av	Service stations (including refuelling of cars)	NMVOC	653.160	tonnes	9.7%
1B2b	Production of gas	NMVOC	120.302	tonnes	1.8%
1B2b	Natural gas transmission	NMVOC	17.692	tonnes	0.3%
1B2b	Natural gas distribution	NMVOC	10.105	tonnes	0.2%
1B2b	Town gas distribution	NMVOC	20.822	tonnes	0.3%
1B2c	Venting in gas storage	NMVOC	2.116	tonnes	<0.1%
1B2c	Flaring in oil refinery	SO_2	107.195	tonnes	22.9%
1B2c	Flaring in oil refinery	NO_x	7.539	tonnes	13.4%
1B2c	Flaring in oil refinery	NMVOC	16.548	tonnes	0.2%
1B2c	Flaring in oil refinery	CO	28.790	tonnes	29.8%
1B2c	Flaring in oil refinery	TSP	0.193	tonnes	1.4%
1B2c	Flaring in oil refinery	PM_{10}	0.193	tonnes	1.6%
1B2c	Flaring in oil refinery	$PM_{2.5}$	0.193	tonnes	4.3%
1B2c	Flaring in oil refinery	BC	0.047	tonnes	0.6%
1B2c	Flaring in gas and oil extraction	SO_2	0.470	tonnes	0.1%
1B2c	Flaring in gas and oil extraction	NO_x	48.199	tonnes	85.4%
1B2c	Flaring in gas and oil extraction	NMVOC	59.955	tonnes	0.9%
1B2c	Flaring in gas and oil extraction	CO	67.008	tonnes	69.3%
1B2c	Flaring in gas and oil extraction	TSP	1.528	tonnes	11.5%
1B2c	Flaring in gas and oil extraction	PM_{10}	1.528	tonnes	12.8%
1B2c	Flaring in gas and oil extraction	$PM_{2.5}$	1.528	tonnes	33.8%
1B2c	Flaring in gas and oil extraction	BC	0.035	tonnes	0.5%
1B2c	Flaring in gas storage	SO_2	0.006	tonnes	<0.1%
1B2c	Flaring in gas storage	NO_x	0.695	tonnes	1.2%
1B2c	Flaring in gas storage	NMVOC	0.336	tonnes	<0.1%
1B2c	Flaring in gas storage	CO	0.863	tonnes	0.9%
1B2c	Flaring in gas storage	TSP	0.020	tonnes	0.1%
1B2c	Flaring in gas storage	PM_{10}	0.020	tonnes	0.2%
1B2c	Flaring in gas storage	$PM_{2.5}$	0.020	tonnes	0.4%
1B2c	Flaring in gas storage	BC	<0.001	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	SO_2	<0.001	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	NO_x	0.031	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	NMV	0.035	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	CO	0.039	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	TSP	<0.001	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	PM_{10}	<0.001	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	$PM_{2.5}$	<0.001	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	BC	<0.001	tonnes	<0.1%

3.4.2 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 (1B1 Solid fuels, 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 solid fuels (1B1)

Coal mining is not occurring in Denmark, and emissions from solid fuels only include particulate matter and black carbon from storage of coal in piles.

Activity data

Coal production is not occurring in Denmark. The annual total amount of coal used are included in the import statistics provided by DEA (DEA, 2022b). Coal is primarily used in power plants, and the annual fluctuations in the import rates mainly owe to variations in electricity import/export and temperature variations. The time series show a decreasing trend due to a shift of fuels in power and heat production from coal and oil to natural gas, waste and biomass (Figure 3.4.1).

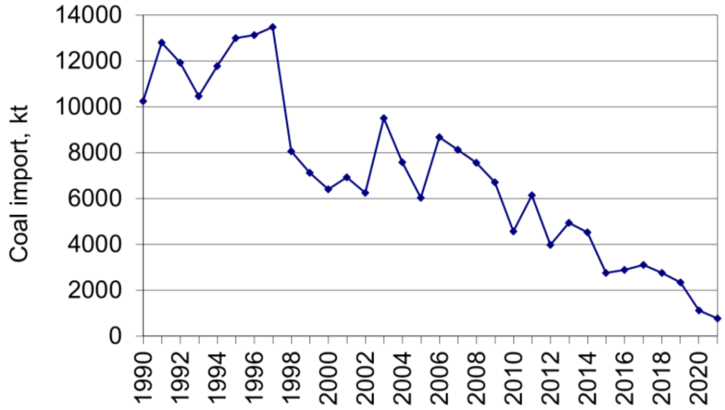


Figure 3.4.1 Import of coal.

Emission factors

The emission factors are listed in Table 3.4.3. Emissions of particulate matter (PM) from coal storage are estimated using emission factors from the Coordinated European Particulate Matter Emission Inventory Program, CEPMEIP (Visschedijk et al., 2004). Abatement technologies are used to rduce the dust from coal storage, e.g. wind protection and spraying of water with or without additives. According to the Integrated Pollution Prevention and Control Reference Document on Best Available Techniques on Emissions from Storage July 2006 (European Commission, 2006) the abatement efficiency is 80-95 % for spraying with water without additives and 90-99 % for spraying with water with additives. The US-EPA (1996) include efficiency of using water sprays and chemical stabilizer or wetting agents, respectively, both given as 40 % for $PM_{2.5}$. The abatement efficiencies of 90 % for TSP and 40 % for $PM_{2.5}$ are used in the Danish emission inventory and 78% is applied for PM_{10} (average of the efficiencies for TSP and $PM_{2.5}$).

Denmark has a long tradition for environmental avaerness and regulation. There has been focus on dust from coal storage as early as in the 1980s, as the medium sized coalfired plants typically are located in urban areas. In 1980 the Danish Environmental Protection Agency appointed a steering committee for a project assessing the issues associated with change to coal for the medium sized combustion plants. Due to the fact that most of the large coal piles are located in or near urban areas, where the large harbours and a number of large coalfired plants are located, and because of the early awareness and regulation, the emission reducing due to use of abatement technologies are applied for the years 1990 forward.

The BC emission factor is estimated as a fraction of the TSP emission factor, based on characteristics for other bituminous coal included in the 2006 IPCC Guidelines Volume 2 (Equation 3.4.1).

$$EF_{BC} = EF_{TSP} \cdot C \cdot H \cdot 0.001 \qquad \text{(Equation 3.4.1)}$$

where EF_{BC} is the emission factor for BC [g/Mg], EF_{TSP} is the emission factor for TSP [g/Mg], C is the carbon content [kg C/GJ], and H is the heating value [GJ/Mg]. The EF_{BC} estimation is based on C = 25.8 kg C/GJ and H = 25.8 GJ/Mg, as given for other bituminous coal in IPCC (2006).

The estimated BC emission factor exceed the $PM_{2.5}$ and the PM_{10} emission factors as coal dust for the major part consist of larger particles. For combustion sources, the BC emission factor does not exceed the $PM_{2.5}$ emission factor. While coal dust is not BC in the traditional sense (from incomplete combustion), it is carbon that is primarily dark black in color and absorbs across the visible spectrum (Khan et al., 2017). According to the Reporting Guidelines (UNECE, 2015), BC is defined as follow: ""Black carbon" (BC), which means carbonaceous particulate matter that absorbs light".

The same abatement efficiency is applied for BC as for TSP, as the BC emission factor is based on the TSP emission factor.

Table 3.4.3 Emission factors used to estimate particulate emissions from coal storage.

	TSP	PM_{10}	$PM_{2.5}$	BC
Emission factor, unabated [g/tonnes]	150	60	6	100
Abatement efficiency [%]	90	78	40	90
Emission factor, abated [g/tonnes]	15	13,2	3,6	10

Emissions

Emissions from coal storage (Figure 3.4.2) are proportional to the import rates, and the causes of the variations are described above.

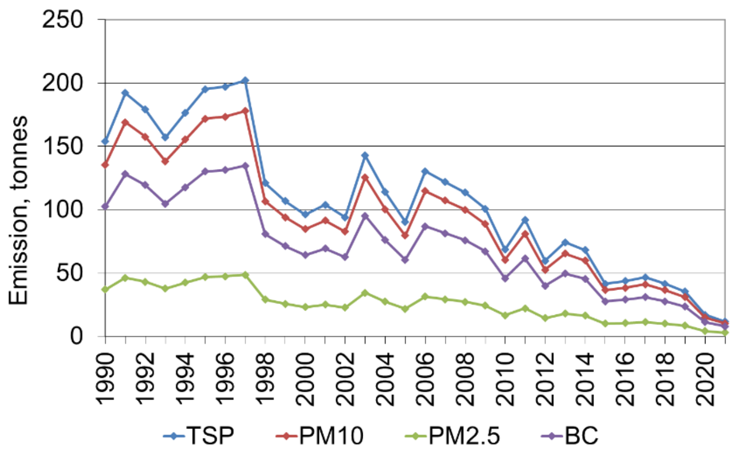


Figure 3.4.2 Emissions from coal storage.

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, 2022). Exploration of oil and gas is 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. Explored rates are shown in Figure 3.4.3.

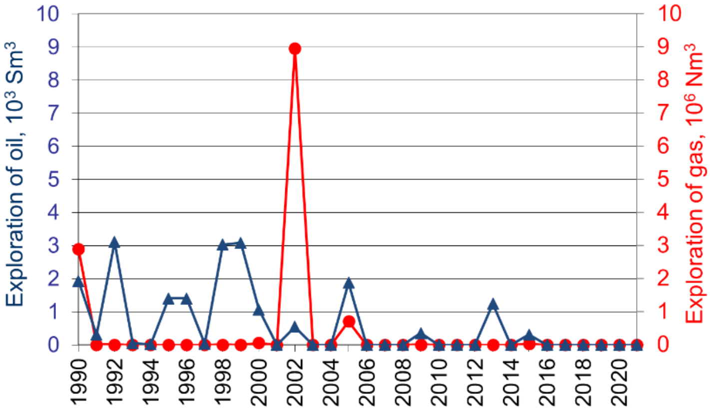


Figure 3.4.3 Exploration of oil and gas.

Emission factors

Emissions from exploration are calculated from the same emissions that are used for flaring in upstream oil and gas production. Further description on the emission factors, which are based on DEPA (2008) and EMEP/EEA (2019), is included in the Section *Fugitive emissions from venting and flaring (1B2c)* below and the emission factors are listed in Table 3.4.10.

Emissions

Calculated NMVOC emissions from exploration of oil and gas are shown in Figure 3.4.4. There is no correlation between emissions from oil and gas, as the individual exploration drillings have different ratios between oil and gas rates.

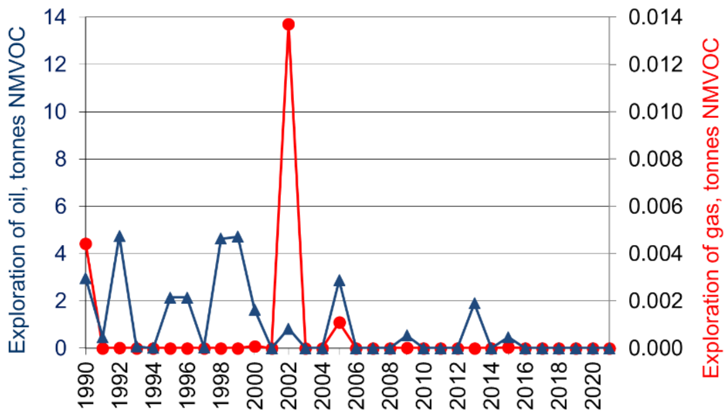


Figure 3.4.4 NMVOC emissions from exploration of oil and gas.

Production (1B2a2, 1B2b2)

Activity data

Activity data used for oil and gas production are provided by the Danish Energy Agency (DEA, 2022a). As seen in Figure 3.4.5 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.

The Tyra platforms are closed in the period between September 2019 and the winter season 2023/2024 due to redevelopment. The Tyra platforms have for 30 years been processing the majority of the Danish natural gas production, and the redevelopment ensures continued production from Denmark's largest producing gas field.

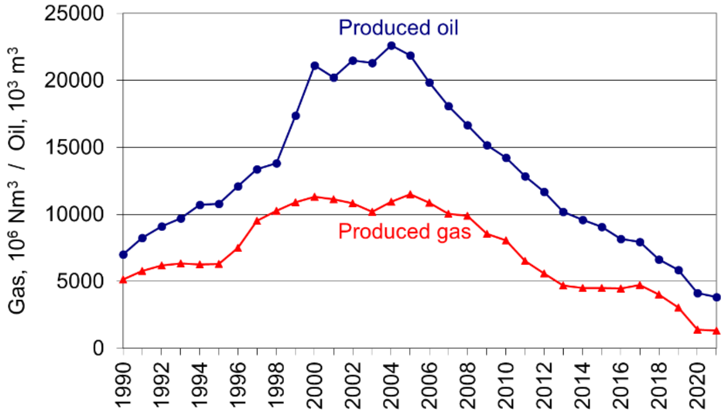


Figure 3.4.5 Production of oil and gas.

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 3.4.4).

Table 3.4.4 Emission factors for exploration of oil and gas.

	EF(NMVOC)	Reference
Production of oil, Gg/1000m^3	7.40E-07	IPCC, 2006
Production of gas, Gg/Mm3	9.10E-05	IPCC, 2006

Emissions

Calculated NMVOC emissions from oil and gas production are shown in Figure 3.4.6 for selected years. The annual variations follow the production rates.

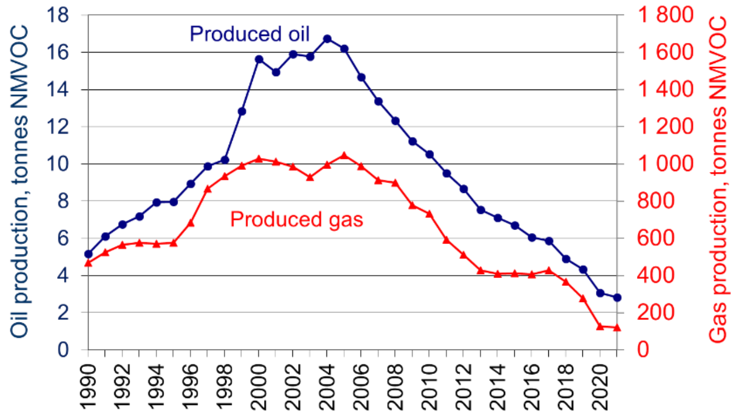


Figure 3.4.6 NMVOC emissions from production of oil and gas.

Transport (1B2a3)

Activity data

Fugitive emissions of oil transport include loading of ships from storage tanks or directly from the wells, and storage and handling at the oil terminal. Activity data for loading offshore and onshore are provided by the Danish Energy

Agency (DEA, 2022a) and from the annual self-regulating reports and supporting information from Danish Oil Pipe A/S (Boesen, 2022), respectively. The latter also provide annual emissions from storage and handling at the oil terminal.

The rates of oil loaded on ships roughly follow the trend of the oil production (see Figure 3.4.7). Offshore loading of ships was introduced in 1999. In earlier years, the produced oil was transported to land via pipeline.

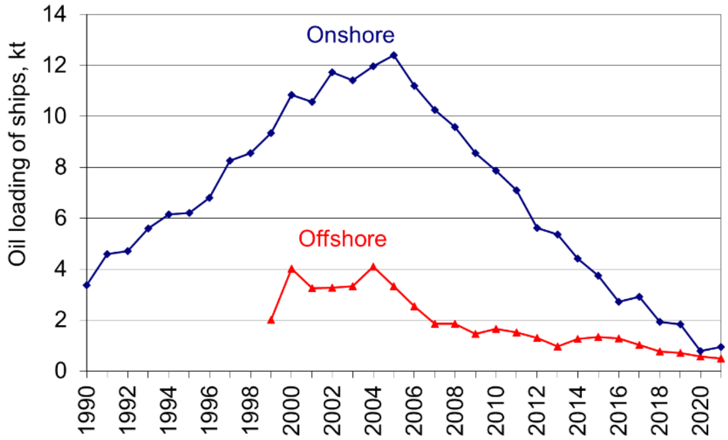


Figure 3.4.7 Onshore and offshore loading of ships.

Emission factors

Emissions from storage tanks at the Oil terminal are provided annually by Danish Oil Pipe A/S. During 2009 new emission reducing technologies (degassing unit) were installed at the crude oil terminal, leading to a significant decrease of the emissions as shown in Figure 3.4.8.

Emissions from offshore loading are based on the default emission factors for offshore loading of ships from the 2019 IPCC Refinement (IPCC, 2019). A 50/50 split between loading with/without VRU is assumed in the emission calculations.

Emission factors for onshore loading is based on annual reports from the Harbour Terminal for the years 2012-2019 (A/S Dansk Shell - Havneterminalen, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021; Crossbridge – Havneterminalen, 2022), which include loaded amounts, standard NMVOC emission factors and emissions of NMVOC (2013-2017) or VOC (2019-). The emission factor for 2012 is applied for the earlier years in the time series. The NMVOC emission factor show a significant decrease from 2016-2019 due to installation of a new vapour recovery unit (VRU2) during 2017. No emissions were reported for 2018, but has been estimated according to the environmental approval for VRU2 (Danish EPA, 2017) which include a requirement of 85 % emission reduction of the VRU2. For years with only VOC emission data, NMVOC is assumed to make up 80% of VOC, in accordance with the annual reports for the harbour terminal. Emission factors for loading of ships offshore and on-shore are listed in Table 3.4.5.

Table 3.4.5 NMVOC emission factors for loading of ships onshore and offshore.

Source	NMVOC EF	Unit	Reference
Ships off-shore	0.63	Mg/1000m^3	IPCC, 2019
Ships on-shore, 1985-2012	584	g/tonne	A/S Dansk Shell - Havneterminalen, 2013
Ships on-shore, 2013	587	g/tonne	A/S Dansk Shell - Havneterminalen, 2014
Ships on-shore, 2014-2016	584	g/tonne	A/S Dansk Shell - Havneterminalen, 2015, 2016, 2017
Ships on-shore, 2017	334	g/tonne	A/S Dansk Shell - Havneterminalen, 2018
Ships on-shore, 2018	88	g/tonne	A/S Dansk Shell - Havneterminalen, 2019 Danish EPA, 2017
Ships on-shore, 2019	7	g/tonne	A/S Dansk Shell - Havneterminalen, 2020
Ships on-shore, 2020	8	g/tonne	A/S Dansk Shell - Havneterminalen, 2021
Ships on-shore, 2021	10	g/tonne	Crossbridge - Havneterminalen, 2022

Emissions

NMVOC emissions from transport of oil are shown in Figure 3.4.8.

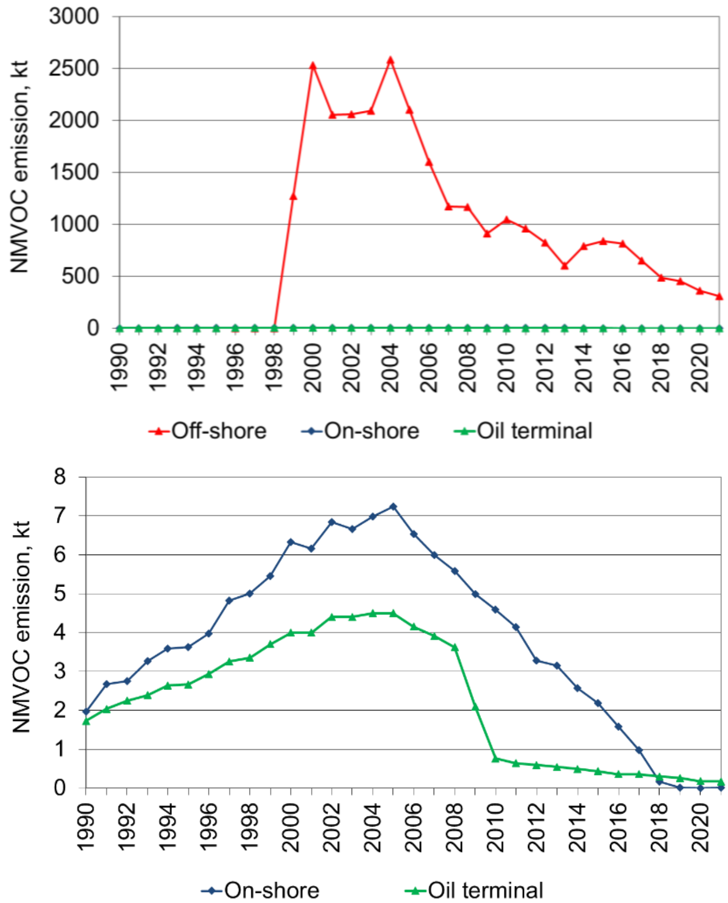


Figure 3.4.8 a) NMVOC emissions from storage at the raw oil terminal and from onshore and offshore loading of ships. b) Emissions from offshore loading are excluded from figure b.

Refining (1B2a4)

Activity data

Emissions from oil refinery processes include 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.

The EMEP/EEA Guidebook lists potential emissions from catalytic cracking unit regenerators with partial burn and without a CO boiler and from fluid coking units. In Denmark, these processes are not used. In Denmark, visbreaking (a thermal cracking process) is used at refineries instead of the aforementioned processes. No information on emissions from this process is available from the emissions reported by the Danish refineries, and as no method is included in the 2019 EMEP/EEA Guidebook, this source is not included in the emission inventory.

Rates of crude oil processed in the two Danish refineries are given in their annual environmental report (Crossbridge, 2022; Kalundborg Refinery, 2022). Until 1996 a third refinery was in operation, leading to a decrease in the crude oil rate from 1996 to 1997. Activity date is shown in Figure 3.4.9.

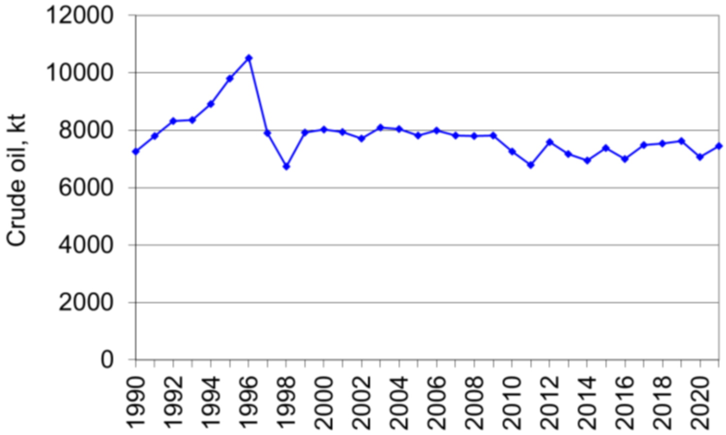


Figure 3.4.9 Crude oil processed in Danish refineries.

Emission factors

Emissions of SO_2 and VOC are given 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 and the remaining 90 % is NMVOC (Hjerrild & Rasmussen, 2014).

Emissions

Refineries are a significant source to fugitive emissions of SO_2, the most important activity being flaring. In 1990-1993, emissions from petroleum product processing were included in emissions from flaring in refineries (NFR category 1B2c). From 1994 the data delivery format was changed, which made it possible to split the emissions into contributions from flaring and processing, respectively. Emissions from processing are included in NFR category 1B2aiv from 1994 and forward.

SO_2 and NMVOC emissions are shown in Figure 3.4.10. One refinery was shut down in 1996 leading to lower emissions in 1997. Technical improvements of the sulphur recovery system at one of the two Danish refineries lead to a decrease of SO_2 emissions from 1996-1998. The large emissions from 2005 and onwards owe to shutdowns due to maintenance and accidents. Further, construction and initialisation of new facilities and problems related to the ammonium thiosulphate (ATS) plant at the one refinery has led to increased emissions. In 2007, the capacity of the ATS plant was increased followed by commissioning difficulties.

The increase of NMVOC emissions 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 does not correlate 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.

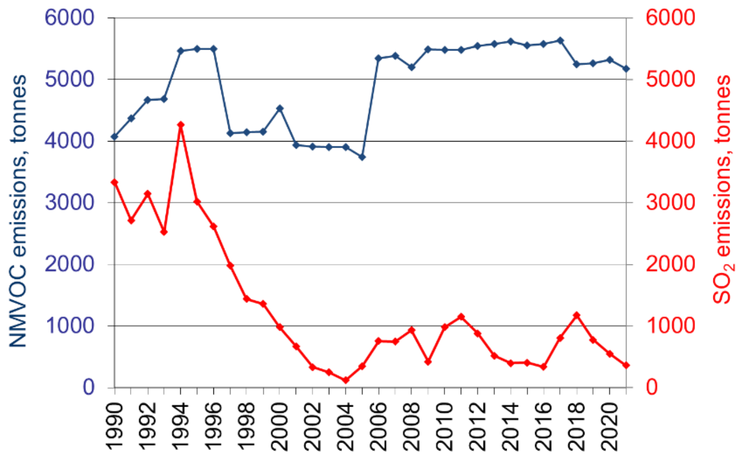


Figure 3.4.10 SO_2 and NMVOC emissions from crude oil processing including sulphur recovery in Danish refineries.

Service stations (1B2a5)

Activity data

Calculations of emissions from service stations are based on gasoline sales figures from the Danish Energy statistics (DEA, 2022b). The gasoline sales show an increase from 1990-1998 and a decreasing trend since 1999 as shown in Figure 3.4.11.

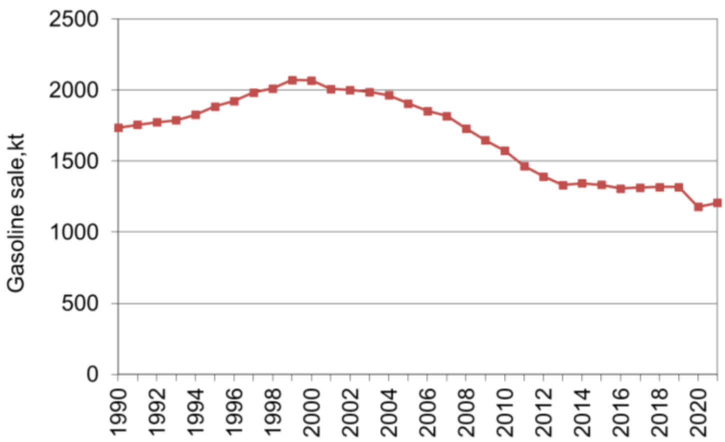


Figure 3.4.11 Gasoline sales in Denmark.

Emission factors

The NMVOC emission from service stations is calculated by use of different emission factors for the time series as shown in Table 3.4.6.

In 1994, the emission factors for NMVOC from service stations were investigated by Fenhann and Kilde (1994) for 1990 and 1991, individually. The emission factors reported for reloading for 1990 are used for the years 1985-1990, while the emission factor for 1991 is used for 1991 only. In 1995, Stage I was made obligatory, and the emission factor from the 2019 EMEP/EEA Guidebook (EMEP/EEA, 2019) is applied from 1997 and onwards. Linear interpolation is applied for the years 1995-1996.

Fenhann & Kilde (1994) also include NMVOC emission factors for refuelling for the years 1990, 1991, 1992, and 1993. The same value is given for these years. From 1994, the refuelling emission factor is based on the EMEP/EEA Guidebook (EMEP/EEA, 2019). An abatement rate of 85 % is given in the 2019 EMEP/EEA Guidebook, while 60 % were given in the 2006 EMEP/EEA Guidebook (EMEP/EEA, 2006). The Danish requirement is 85 % abatement under optimal conditions, but 70 % in practice (Danish Ministry of the Environment, 1994). Based on this, 70 % abatement is applied in the emission calculations.

Table 3.4.6 Emission factors used for estimating NMVOC from service stations.

Year	Reloading of tankers [kg NMVOC per tonnes gasoline]	Source	Refuelling of vehicles [kg NMVOC per tonnes gasoline]	Source	Sum of reloading and refuelling [kg NMVOC per tonnes gasoline]
1985-1990	1.28	Fennhann & Kilde, 1994	1.52	Fennhann & Kilde, 1994	2.8
1991	0.64	Fennhann & Kilde, 1994	1.52	Fennhann & Kilde, 1994	2.16
1992	0.519	Interpolation	1.52	Fennhann & Kilde, 1994	2.039
1993	0.397	Interpolation	1.004	Fennhann & Kilde, 1994	1.401
1994	0.276	MST, 1994	0.488	EMEP/EEA 2019 with 70 % efficiency (national regulation)	0.764
1995	0.202	interpolation	0.488	EMEP/EEA 2019 with 70 % efficiency (national regulation)	0.69
1996	0.127	interpolation	0.488	EMEP/EEA 2019 with 70 % efficiency (national regulation)	0.615
1997 onwards	0.053	EMEP/EEA 2019	0.488	EMEP/EEA 2019 with 70 % efficiency (national regulation)	0.541

Emissions

Emissions from service stations are shown in Figure 3.4.12. The decrease from 1990 to 1999 owes to decreasing emission factors due to technological improvements. From 1999 to 2005, the decrease owe to a combination of decreasing gasoline sales and decreasing emission factors. Since 2005, the decreasing trend is less pronounced and only variates with the gasoline sales, which show a slight decreasing trend.

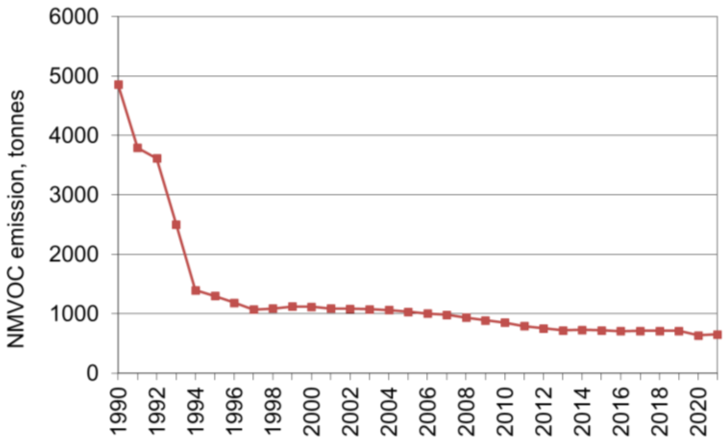


Figure 3.4.12 NMVOC emissions from service stations.

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 transmission rates, 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 3.4.13. Transmission rates for 1990-1998 refer to annual environmental reports of DONG Energy. For 1999-2006, the transmission rates refer to the Danish Gas Technology Centre (Karll 2002, 2003, 2004, 2005; Oertenblad 2006, 2007). From 2008 onwards, transmission rates refer to Energinet.dk (2022b). 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 production, in the winter temperature and to the variation in import/export. The transmission rate is less than the production rate, as part of the produced natural gas is exported through the NOGAT pipeline system.

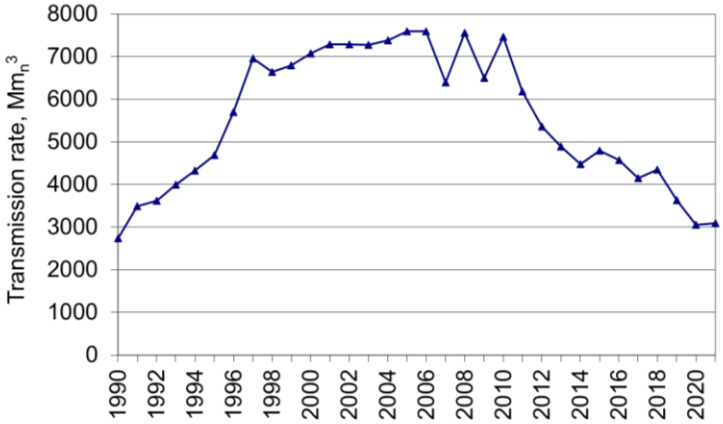


Figure 3.4.13 Rates for transmission of natural gas.

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 (2022c) (Table 3.4.7).

Table 3.4.7 Annual gas composition, lower heating value and density for Danish natural gas.

		Unit	1990	2000	2005	2010	2015	2019	2020	2021
Methane	CH_4	molar-%	90.92	86.97	88.97	89.95	88.80	91.2	95.9	96.16
Ethane	C_2H_6	molar-%	5.08	6.88	6.14	5.71	6.08	5.01	3.05	2.9
Propane	C_3H_8	molar-%	1.89	3.17	2.50	2.19	2.47	1.75	0.18	0.12
i-Butane	i-C_4H_{10}	molar-%	0.36	0.43	0.40	0.37	0.39	0.31	0.05	0.04
n-Butane	n-C_4H_{10}	molar-%	0.50	0.61	0.55	0.54	0.59	0.46	0.03	0.02
i-Petane	i-C_5H_{12}	molar-%	0.14	0.11	0.11	0.13	0.13	0.11	0.01	0.01
n-Petane	n-C_5H_{12}	molar-%	0.10	0.08	0.08	0.08	0.10	0.07	0.01	0
n-Hexane and heavier hydrocarbons	C^{6+}	molar-%	0.09	0.06	0.05	0.06	0.05	0.05	0.02	0.02
Nitrogen	N_2	molar-%	0.31	0.34	0.29	0.31	0.32	0.29	0.31	0.3
Carbon dioxide	CO_2	molar-%	0.60	1.35	0.90	0.66	1.07	0.76	0.44	0.41
Lower heating value	H_n	MJ/m^3_n	39.176	40.154	39.671	39.461	39.635	38.812	36.700	36.620
Density	ρ	kg/m^3_n	0.808	0.846	0.825	0.816	0.828	0.803	0.749	0.746

Emissions

Emissions of NMVOC from transmission of natural gas are shown in Figure 3.4.14. 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.

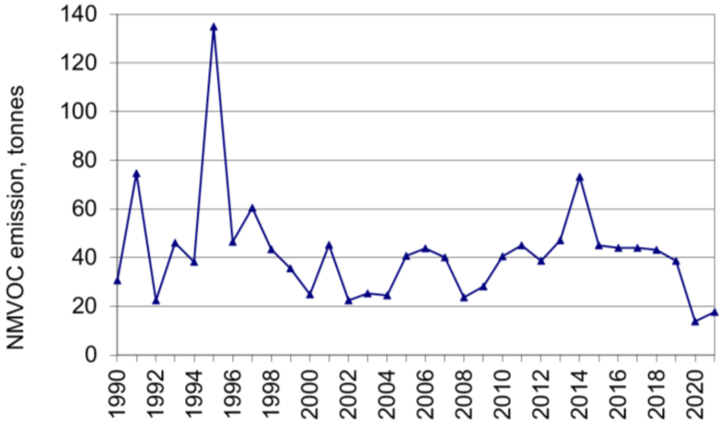


Figure 3.4.14 NMVOC emissions from transmission of natural gas.

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. Distribution rates for 1999-2006 refer to DONG Energy/Danish Gas Technology Centre/Danish gas distribution companies (Karll 2002, 2003, 2004, 2005; Oertenblad 2006, 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.

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 has 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 are 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 3.4.15.

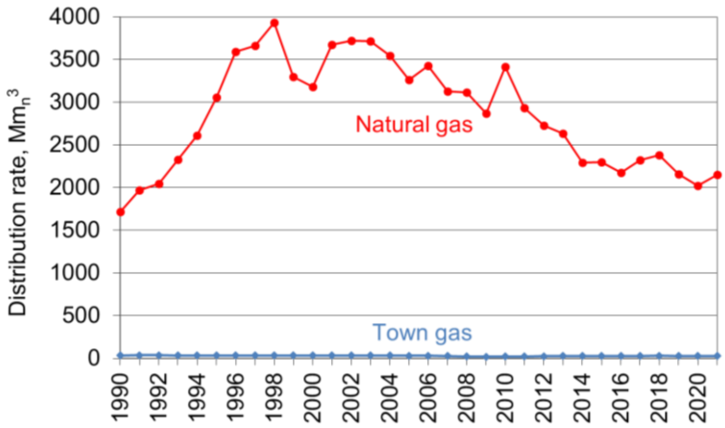


Figure 3.4.15 Distribution rates of natural gas and town gas.

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 3.4.7). 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 2015, the share of biogas is 17.5 %, 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 % un-upgraded biogas can be added to the town gas without causing problems with the appliances' combustion. The gas composition of biogas is given in Table 3.4.8.

Table 3.4.8 Composition of biogas admixed to town gas (Jeppesen, 2014; Ea Energianalyse, 2014).

Methane	molar-%	60.98
Nitrogen	molar-%	0.001
Carbon dioxide	molar-%	39.02
Lower heating value	MJ/m^3_n	21.53
Density	kg/m^3_n	0.808

The distribution companies provide emissions of CH_4 for 1997 and onwards. For 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 NMVOC from distribution of natural gas and town gas are shown in Figure 3.4.16. The decreasing trend for town gas owe to phase-out of town gas distribution in two areas. Further relining of old pipelines has reduced the gas loss from town gas distribution.

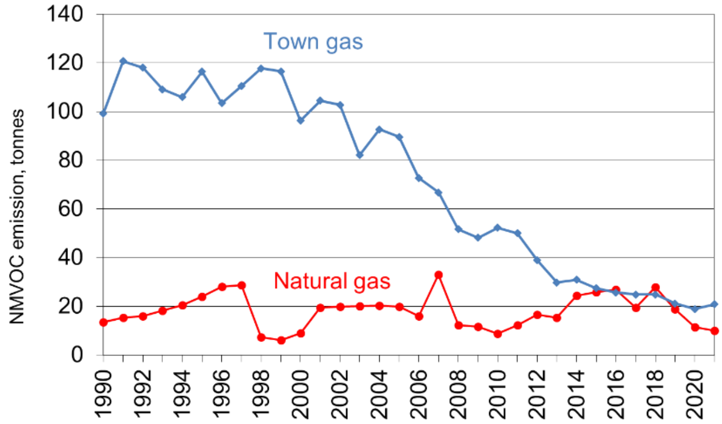


Figure 3.4.16 NMVOC emissions from transmission of natural gas.

Fugitive emissions from venting and flaring (1B2c)

Venting occur in the two Danish natural gas storage facilities. Flaring occurs in refineries, in oil and gas production, in gas treatment and storage facilities, and in gas transmission and distribution.

Venting

Activity data

The natural gas storage facilities are obligated to make environmental reports on 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 3.4.17. 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.

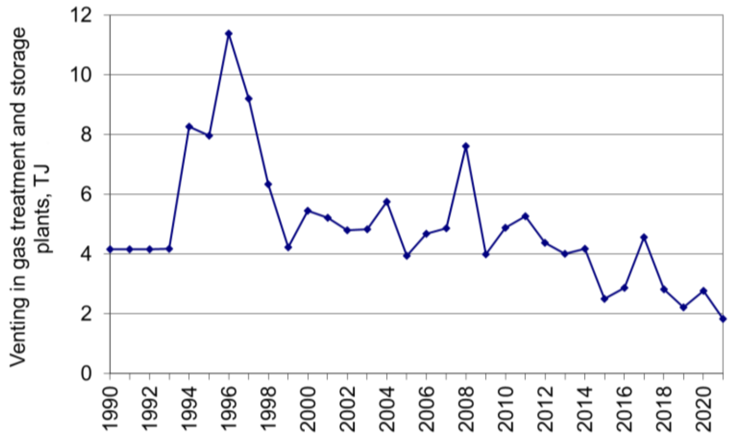


Figure 3.4.17 Venting rates in gas storage facilities.

Emission factors

Emissions of NMVOC from venting are given in the environmental reports for the gas storage facilities (Energinet.dk, 2022a).

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 3.4.18.

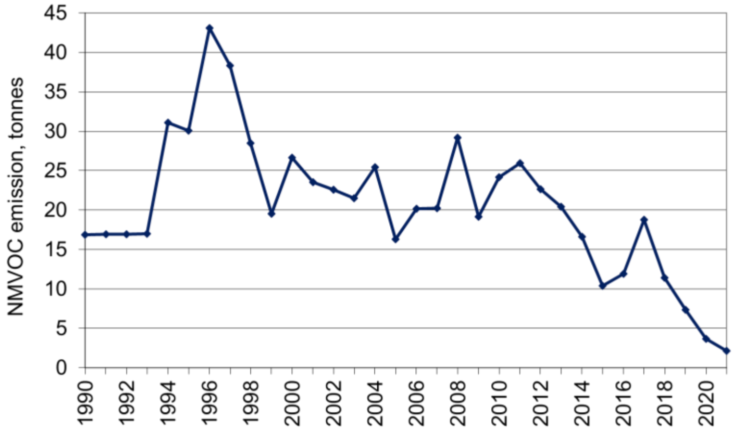


Figure 3.4.18 NMVOC emissions from venting rates in gas storage facilities.

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 3.4.19.

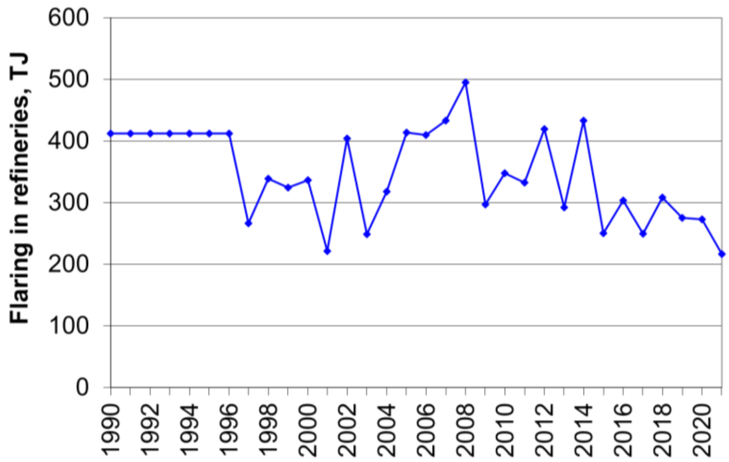


Figure 3.4.19 Flaring rates in refineries.

Emission factors

SO_2 emissions are provided annually by the refineries, while NO_x emissions are provided annually by only one refinery. 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 NMVOC emission factor based on the 2008 refinery gas composition are applied for both refineries for the entire time series. Emissions of the remaining pollutants are based on standard emission factors from the 2019 EMEP/EEA Guidebook. Emission factors for selected pollutants are listed in Table 3.4.9.

Table 3.4.9 Emission factors for flaring in refineries.

Pollutant	Emission factor, g/GJ
NO_x	29.2
NMVOC	76.45
CO	133
TSP	0.89
PM_{10}	0.89
$PM_{2.5}$	0.89
BC	0.21

Emissions

Emissions of NMVOC and SO_2 are shown in figure 3.4.20. The variation over the time series mainly reflects the annual variation in the activity rate for flaring. SO_2 in the early years of the time series are very uncertain as one refinery is closed and as only very scarce amounts of information are available. It has not been possible to get further verification the data for 1990-1994.

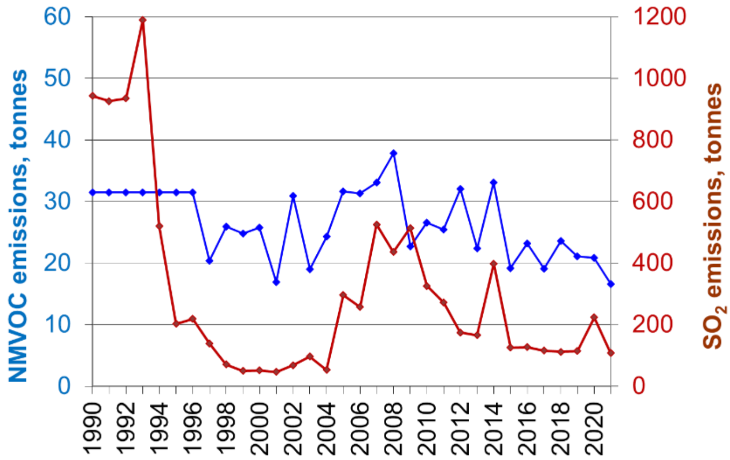


Figure 3.4.20 NMVOC and SO_2 emissions from flaring in refineries.

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 for 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, 2022a). Flaring rates are shown in Figure 3.4.21. 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 3.4.5. Further, there is focus on reduction of the amount being flared for environmental reasons.

The Tyra platforms are closed in the period between September 2019 and the winter season 2023/2024 due to redevelopment. The Tyra platforms have for 30 years been processing the majority of the Danish natural gas production, and the redevelopment ensures continued production from Denmark's largest producing gas field.

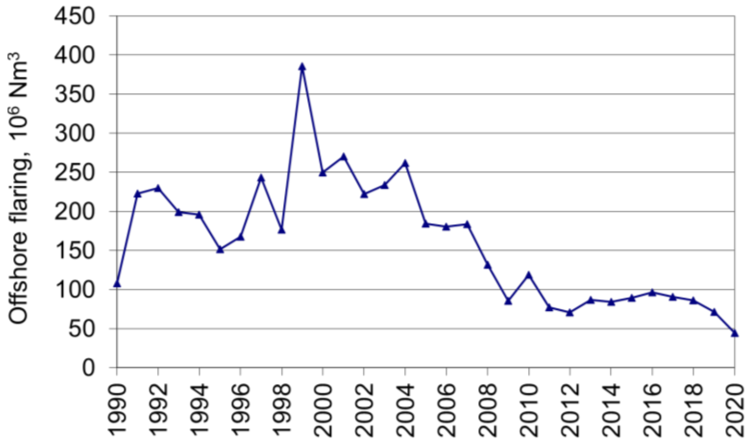


Figure 3.4.21 Flaring rates in upstream oil and gas production.

Emission factors

The emission factors for flaring in upstream oil and gas production are shown in Table 3.4.10. The NO_x emission factor is based on the conclusion in a Danish study of NO_x emissions from offshore flaring carried out by the Danish Environmental Protection Agency (DEPA, 2008). The recommended NO_x emission factor (31 008 g per GJ or 0.0015 tonnes NO_x per tonnes gas) corresponds well with the emission factors used to estimate NO_x emission in other countries with oil production in the North Sea (Netherlands: approximately 0.0014 tonnes NO_x per tonnes gas and United Kingdom: approximately 0.0013 tonnes NO_x per tonnes gas). Emission factors for all other pollutants are based on standard Tier 1 emission factors for stationary combustion of gaseous fuels in energy industries from the 2019 EMEP/EEA Guidebook.

Table 3.4.10 Emission factors for flaring in upstream oil and gas production.

Pollutant	Emission factor, g/Nm^3
SO_2	0.012
NO_x	1.23
NMVOC	1.53
CO	1.71
TSP	0.039
PM_{10}	0.039
$PM_{2.5}$	0.039
BC	0.0009

Emissions

Emissions from flaring in upstream oil and gas production are estimated from the same emission factors for all years in the time series, and the variations reflect only the variations in the flared amounts. As shown in Figure 3.4.22, 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.

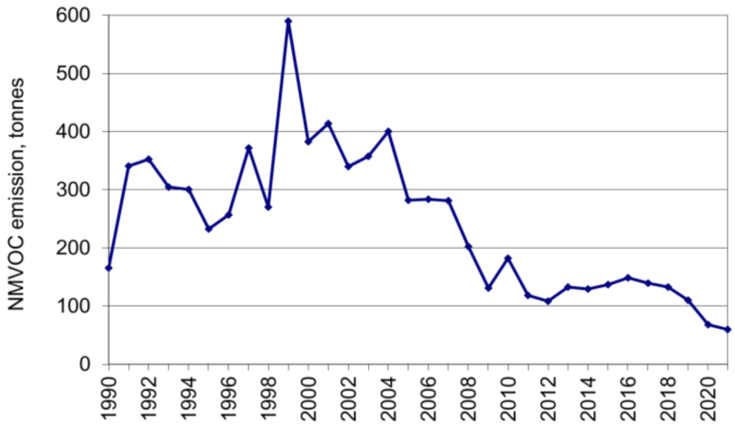


Figure 3.4.22 NMVOC emissions from flaring in upstream oil and gas production.

Flaring in gas treatment and storage facilities

Activity data

Activity data for flaring at the gas treatment facility are given in environmental reports (1994-2005) and in the EU-ETS reports (2006 onwards) and for gas storage facilities in environmental reports (Energinet.dk, 2022a). 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 (Figure 3.4.23). 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. The increase in 2017 owe to increased flaring amount at the gas treatment plant.

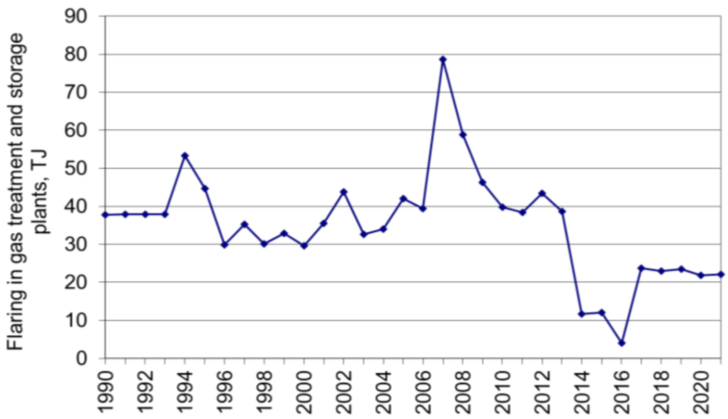


Figure 3.4.23 Flaring in gas treatment and storage facilities.

Emission factors

NMVOC emissions are provided for the relevant treatment and storage facilities. Emissions of other pollutants 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 (Table 3.4.10).

Emissions

Emissions from flaring in gas treatment and storage facilities are of minor importance to the total fugitive emissions. NMVOC emissions are included in Figure 3.4.24.

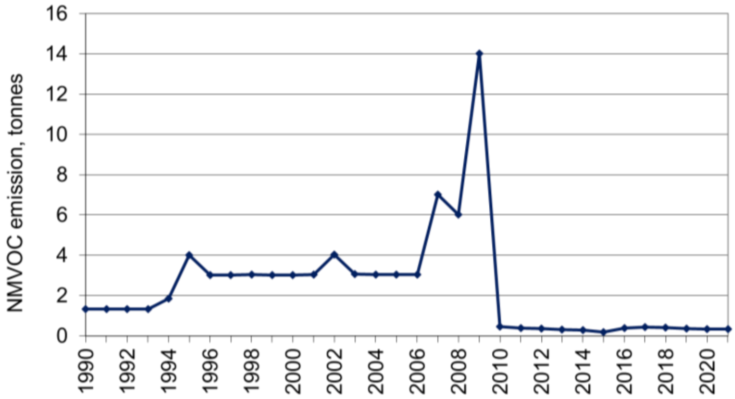


Figure 3.4.24 NMVOC emissions from flaring in gas treatment and storage facilities.

Flaring in gas transmission and distribution

Activity data

The Danish gas transmission company acquired a mobile flare, which have been used during large maintenance work since 2013. Also, flaring have occurred in gas distribution. Flaring rates are provided by the relevant companies. Total flaring amounts in gas transmission and distribution are shown i Figure 3.4.25.

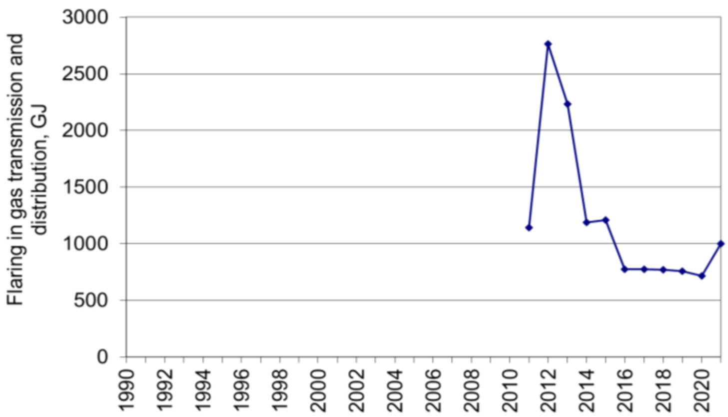


Figure 3.4.25 NMVOC emissions from flaring in gas treatment and storage facilities.

Emission factors

Emissions from flaring in gas transmission and distribution are calculated from the same emission factors, which are used for flaring in upstream oil and gas production (Table 3.4.10).

Emissions

Emissions from flaring in gas transmission and distribution are of minor importance to the total fugitive emissions. NMVOC emissions are included in Figure 3.4.26.

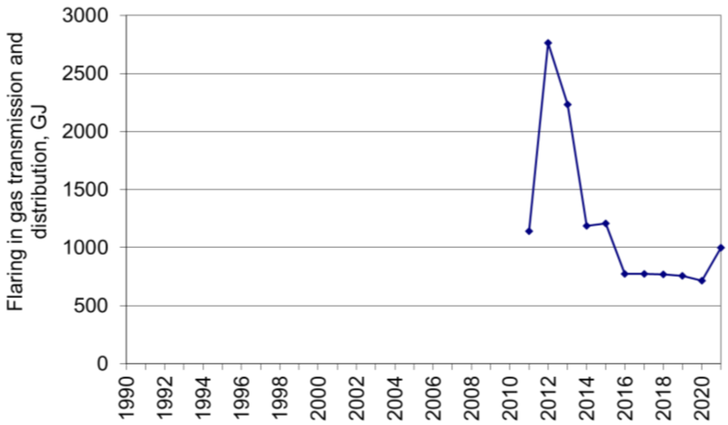


Figure 3.4.26 NMVOC emissions from flaring in gas transmission and distribution.

3.4.3 Uncertainties and time series consistency

The applied methodology for uncertainty estimates refers to Pulles & Aardenne (2004). The Danish uncertainty estimates are based on the simple approach 1 described in the 2006 IPCC Guidelines (IPCC, 2006).

Input data

The uncertainty estimates are based on the calculated emissions for the base year and for the latest inventory year, and on the uncertainty rates for both activity data and emission factors. Data are aggregated for the NFR category 1B - Fugitive Emissions from Fuels. Base year refers to 1990 for all pollutants. Emission data, activity data and emission factors are described in Section *3.4.2 Activity data, emission factors and emissions for fugitive sources*.

For each pollutant the primary emission source/sources is the determinant for the overall uncertainty level. Uncertainty levels are based on the IPCC Guidelines, the EMEP/EEA Guidebook, reports under the EU ETS and DCE assumptions. Uncertainty levels for activity data and emission factors are listed in Table 3.4.11.

Table 3.4.11 Uncertainty levels for activity rates and emission factors for NFR category 1B - Fugitive Emissions from Fuels.

Pollutant	Activity data uncertainty level, %	Emission factor uncertainty level, %
SO_2	10	25
NO_x	7.5	125
NMVOC	2	125
CO	7.5	125
TSP	2	50
PM_{10}	2	50
$PM_{2.5}$	2	50
BC	2	100
As	7.5	500
Cd	7.5	500
Cr	7.5	500
Cu	7.5	500
Hg	7.5	500
Ni	7.5	500
Pb	7.5	500
Se	7.5	500
Zn	7.5	500
PCDD/F	7.5	500
Benzo(b)fluoranthene	7.5	500
Benzo(k)fluoranthene	7.5	500
Benzo(a)pyrene	7.5	500
Indeno(1,2,3-cd)pyrene	7.5	500

Results

The uncertainty model estimates uncertainties for both the emission level and the trend. The uncertainty on the emission level for SO_2, NO_x, NMVOC and CO is 27 %, 125 %, 125 % and 125 %, respectively. For PM the uncertainty is 50 %, for BC the uncertainty is 100 % and for HM and PAHs the uncertainty is 500 %.

The individual uncertainty estimates for the fugitive emission inventory are shown in Table 3.4.12. The trend refers to the years 1990 onwards for all pollutants, and show a decresing trend for all pollutants between -47% and -92%.

Table 3.4.12 Estimated uncertainty levels for emissions and trends for fugitive emissions.

Pollutant	Emission level uncertainty [%]	Trend [%]	Trend uncertainty [%]
SO_2	27	-89	2
NO_x	125	-62	4
NMVOC	125	-50	1
CO	125	-61	4
TSP	50	-92	0.2
PM_{10}	50	-91	0.2
$PM_{2.5}$	50	-89	0.3
BC	100	-92	0.2
As	500	-61	4
Cd	500	-47	6
Cr	500	-47	6
Cu	500	-47	6
Hg	500	-60	4
Ni	500	-47	6
Pb	500	-48	6
Se	500	-49	5
Zn	500	-47	6
PCDD/F	500	-63	4
Benzo(b) fluoranthene	500	-63	4
Benzo(k) fluoranthene	500	-64	4
Benzo(a)pyrene	500	-63	4
Indeno (1,2,3-cd) pyrene	500	-64	4

3.4.4 Source specific QA/QC and verification

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 plants) 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 (offshore fuel and flaring rates).
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 NFR and SNAP source categories. Significant dips and jumps are controlled and explained.

Data deliveries

Table 3.4.13 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 3.4.13 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	Frederikke Byrial Zilstorff	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	Søren Boesen	No formal data agreement.
Gas distribution	Natural gas and town gas distribution rates from the distribution company, sales and losses (meter differences)	Activity data	Evida	Susanne Kirkegaard	No formal data agreement.
Emissions from refinery	Fuel consumption and emission data.	Activity data and emission data	Kalundborg Refinery, Crossbridge	Anette Holst, Trine Bjerre Kristiansen	No formal data agreement.
Treatment and storage of gas	Environmental reports and supplemental data from plants defined as large point sources (Lille Torup, Stenlille, Nybro)	Activity data and emission data	Energinet.dk Ørsted	Christian Guldager Corydon Per Korshøj	No formal data agreement.
Onshore loading	Annual report for the harbour terminal.	Activity data and emission data	Crossbridge	Trine Bjerre Kristiansen	No formal data agreement.
Emission factors	Emission factors origin from a large number of sources	Emission factors	See Section *3.4.2 Activity data, emission factors and emissions for fugitive sources* regarding emission factors		

National external review

A documentation report for the sector "The Danish emission inventory for fugitive emissions from fuels" was published in 2021. The report includes detailed information on the methodology used in the emission inventories for greenhouse gases and air pollution (Plejdrup et al., 2021). The report was reviewed by Jesper Werner Løhndorf Christensen from the Danish Energy Agency.

The previous versions of the documentation report from 2015 and 2009 was reviewed by Glen Thistlethwaite from Ricardo Energy & Environment, Oxfordshire, UK and by Anette Holst, Statoil A/S, The Refinery, Kalundborg, Denmark, respectively.

3.4.5 Recalculations

The most significant recalculations are made for NMVOC.

For "1B2ai - Fugitive emissions oil: Exploration, production, transport" the largest change is a decrease of 1.1 kt NMVOC in 2004, corresponding 0.7 % of the national total NMVOC emission.

For “1B2b - Fugitive emissions from natural gas” the recalculation is -0.05 kt – 0.02 kt, corresponding -0.03 % and 0.01 % of the national total NMVOC emission in 2004 and 1997, respectively.

For “1B2c - Venting and flaring” the recalculation is -0.01 kt – 0.02 kt, corresponding less than 0.01% of the national total NMVOC emission.

For all other pollutants, the recalculations are ≤ 0.01 % of the national total emission, and the largest recalculations are for $PM_{2.5}$, CO and Hg from “1B2c - Venting and flaring”.

The recalculations are described by source in the following section.

Coal storage

Activity data is updated for 2020 according to energy statistics by the DEA. The recalculation increase the TSP emission by 0.38 t, which is of minor importance to the national total TSP emission.

Exploration of oil and gas & flaring in offshore oil and gas production

The NCV for natural gas used in calculations of implied emission factors have been updated. Further, minor updates for offshore flaring have been made in accordance with the statistics from the Danish Energy Agency. This recalculation influence emissions from exploration of oil and gas, and offshore flaring in oil and gas production. The recalculation leads to minor changes in emissions. The recalculation is of minor importance, corresponding <0.01% of the national total NMVOC emission for all years.

Offshore loading

The NMVOC EF has been updated according to the IPCC 2019 Refinement. The recalculation decrease the NMVOC emissions for offshore loading by 27%. The recalculation is between -1122 t and -155, corresponding 0.7 % and 0.1 % of the national total NMVOC emission in 2004 and 2020, respectively.

Onshore loading

Update of the activity data for 2018-2019 according to data provided by the Crossbridge harbour terminal. The recalculation is minor, increasing the NMVOC emission in 2019 by 0.8 t.

Oil storage

Minor updates of the NMVOC EF for oil storage at the crude oil terminal have been made due to new information from the company. The recalculation is of minor importance, changing the annual NMVOC emissions between -0.4 t and 0.4 t.

Flaring in refineries

The NMVOC EF has been updated for the years 1984-1989 according to the EF used for the following years. The recalculation is of minor importance, decreasing the annual NMVOC emission by 2.5 t.

Gas transmission

The NMVOC EF has been updated for the years 1999-2006 in accordance with Marcogaz data for these years. The recalculation decrease the NMVOC emission by 3.3t to 30.8 t, the latter corresponding 0.02% of the national total NMVOC emission in 2002.

Gas distribution

The NMVOC EF has been updated for all years due to a revision of gap filling before 2006 and updated data and information from the distribution company for the years 2018-2020. The largest recalculation is for 2020, increasing the NMVOC emission by 5.6 t, which is of minor importance to the national total emission.

Venting

Emissions from gas chromatographs at the Danish gas treatment plant has been included as a new source in the inventory. The annual amount of natural gas loss from measurement equipment of 14 000 Nm3 has been estimated by the gas treatment plant and is included in the inventory of methane losses from the Danish distribution and transmission network. The recalculation increase the NMVOC emission by 2 t per year for 1990-2019 and 1 t for the years 2020 and 2021, which is of minor importance to the national total emission.

Flaring in gas transmission and distribution

The NOx and NMVOC EFs have been corrected due to an error in the calculation. The recalculation is of minor importance, largest for the years 1985-1989 with increase of 0.1 t per year.

3.4.6 Response to NECD Review recommendation

The 2022 NECD review did not include any findings for the fugitive sector.

3.4.7 Source specific planned improvements

Gas transmission and distribution

A review of the inventory for fugitive emissions from gas transmission and distribution is planned within the next year. Depending on the findings during the review, potential changes are assumed included in the 2024 submission.

Offshore oil and gas production

A review of the inventory for fugitive emissions from offshore oil and gas production is ongoing and will continue in the coming years. It is expected that a new national methodology can be implemented in the 2024 or 2025 submission. The work is made in close cooperation with the Danish operators on the North Sea and the trade association for the Danish North Sea oil- and gas producers (Dansk Offshore). The aim is to develop a new methodology, which is to the extent possible based on company emission estimations and results from measurement campaigns for a number of offshore platforms. Only few measurements have been carried out to date, but the operators are planning on further measurement campaigns in 2023.

The first draft estimates based on few input data indicate that the emissions are significantly lower than estimates based on the default emission factors included in the 2019 IPCC Refinement. The Danish oil and gas production is subject to environmental and safety regulations which contribute to reduction of fugitive emissions. The new EU regulation on methane emissions reduction in the energy sector (EU, 2021) will entail focus on and initiatives regarding emissions reduction and quantification, and results and knowledge will be used in the development of a national methodology.

Changes in practise and equipment over the time series will be taken into account in cooperation with the operators. The methodology will be validated against methods and emission factors used by other countries or regions to the extent possible.

3.4.8 References

A/S Dansk Shell - Havneterminalen, 2013: Annual Report for the Harbour Terminal (in Danish).

A/S Dansk Shell - Havneterminalen, 2014: Annual Report for the Harbour Terminal (in Danish).

A/S Dansk Shell - Havneterminalen, 2015: Annual Report for the Harbour Terminal (in Danish).

A/S Dansk Shell - Havneterminalen, 2016: Annual Report for the Harbour Terminal (in Danish).

A/S Dansk Shell - Havneterminalen, 2017: Annual Report for the Harbour Terminal (in Danish).

A/S Dansk Shell - Havneterminalen, 2018: Annual Report for the Harbour Terminal (in Danish).

A/S Dansk Shell - Havneterminalen, 2019: Annual Report for the Harbour Terminal (in Danish).

A/S Dansk Shell - Havneterminalen, 2020: Annual Report for the Harbour Terminal (in Danish).

A/S Dansk Shell - Havneterminalen, 2021: Annual Report for the Harbour Terminal (in Danish).

Boesen, S. 2022: Personal communication, e-mail correspondence 28/6 2022, Orsted.

Crossbridge - Havneterminalen, 2022: Annual Report for the Harbour Terminal 2021 (in Danish).

Crossbridge, 2022: Annual environmental report for the refinery 2021.

Danish Energy Agency, 2022a: Data for oil and gas production in Denmark. Available at: https://ens.dk/en/our-services/oil-and-gas-related-data/monthly-and-yearly-production (10-01-2023). Reports for earlier years. Available at: https://ens.dk/en/our-responsibilities/oil-gas/reports-oil-and-gas-activities (10-01-2023).

Danish Energy Agency, 2022b: 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 (10-01-2023).

DEPA, 2008: Emissionsfaktorer for NO_x-emissioner fra flaring fra platforme i Nordsøen (in Danish). Not published.

Ea Energianalyse, 2014: Anvendelse af biogas i naturgas i København (in Danish).

EMEP/EEA, 2006: EMEP/CORINAIR Emission Inventory Guidebook – 2006. Available at: https://www.eea.europa.eu/publications/EMEPCORINAIR4 (10-01-2023).

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 (10-01-2023).

Energinet.dk, 2022a: Environmental reports and supplementary data for Lille Torup and Stenlille gas storage facilities. Personal communication, e-mail correspondence 15/8 2022, Christian Guldager Corydon.

Energinet.dk, 2022b: Data for gas loss and flaring in gas transmission. Personal communication, e-mail correspondence 20/9 2022, Frederikke Byrial Zilstorff.

Energinet.dk, 2022c: Annual gas quality. Available at: https://www.energidataservice.dk/tso-gas/gascompositionyearly (10-01-2023).

Kalundborg Refinery, 2022: Sustainability report 2021 (in Danish). Available at: https://www.kalundborgrefinery.com/sustainability (10-01-2023).

Erichsen, K.L. 2022: Personal communication, e-mail correspondence 17/8 2022, Danish Energy Agency.

European Commission, 2006: Integrated Pollution Prevention and Control Reference Document on Best Available Techniques on Emissions from Storage. July 2006. Available at: https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/esb_bref_0706.pdf (10-01-2023).

Fenhann, J. & Kilde, N.A. 1994: Inventory of Emissions to the Air from Danish Sources 1972-1992. Risø National Laboratory, Roskilde, Denmark.

Hjerrild & Rasmussen, 2014: Fugitive VOC from refineries. Documentation for expert judgement.

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (10-01-2023).

IPCC, 2019: 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html (10-01-2023).

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.

Khan, A.L., Dierssen, H., Schwarz, J.P., Schmitt, C., Chlus, A., Hermanson, M., Painter, T.H. & McKnight D.M., 2017: Impacts of coal dust from an active mine on the spectral reflectance of Arctic surface snow in Svalbard, Norway. Journal of Geophysical Research—Atmospheres 122(3): 1,767-1,778. doi:10.1002/2016JD025757.

Oertenblad, M. 2006: Personal communication, e-mail 2006, Danish Gas Technology Centre.

Oertenblad, M. 2007: Personal communication, e-mail 2007, Danish Gas Technology Centre.

Plejdrup, M.S., Nielsen, O.-K. & Nielsen, M. 2021. The Danish emission inventory for fugitive emissions from fuels. Aarhus University, DCE – Danish Centre for Environment and Energy, 61 pp. Scientific Report No. 463 http://dce2.au.dk/pub/SR463.pdf (10-01-2023).

Pulles, T. & Aardenne, J.v., 2004: Good Practice Guidance for LRTAP Emission Inventories, 24. June 2004.

UNECE (2015): Guidelines for Estimating and Reporting Emission Data under the Convention on Long-Range Transboundary Air Pollution / prepared by the Convention's Task Force on Emission Inventories and Projec-tions and the Secretariat. Available at: https://www.unece.org/fileadmin/DAM/env/documents/2015/AIR/EB/English.pdf (10-01-2023).

US-EPA, 1996: AP-42, APPENDIX B.2 GENERALIZED PARTICLE SIZE DISTRIBUTIONS. Available at: https://www3.epa.gov/ttn/chief/ap42/appendix/appb-2.pdf (10-01-2023).

Visschedijk, A., Pacynab, J., Pullesa, T., Zandvelda, P. & van der Gon, H.D., 2004: Coordinated European particulate matter emission inventory. Conference: P. Dilara et al. (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC 2004, pp 163-174.

4 Industrial processes and product use

4.1 Overview of the sector

The chapter on *Industrial processes and product use* (IPPU) (NFR sector 2) is outlined as follows:

- Mineral products (NFR 2A)
- Chemical industry (NFR 2B)
- Metal production (NFR 2C)
- Non-energy products from fuels and solvent use (NFR 2D)
- Other product use (NFR 2G)
- Other industry production (NFR 2H)
- Wood processing (NFR 2I)
- Other production, consumption, storage, transportation or handling of bulk products (NFR 2L)

The industrial processes included in the Danish inventory are those in large companies, e.g. cement factories, as well as a number of smaller companies e.g. iron foundries.

Table 4.1.1 presents an overview of sources and groups of pollutants included in the present reporting. Explanations to the abbreviations are given below the table. In addition to the indicated groups of pollutants some groups do not include all relevant pollutants. For some processes, it is not possible to separate emissions from the fuels and the emissions stemming from the raw materials. This is especially the case for processes with contact, e.g. cement and lime production. Detailed information on this subject can be found in the following table.

Table 4.1.1 Survey of IPPU sector with NFR-code included in the Danish inventory.

Industrial sector	NFR	SO_2/NO_X/ NH_3	NMVOC/ CO	PMs	HMs	POPs
Cement production	2A1	IE	IE	IE	IE	IE
Lime production	2A2	IE	IE	x	-	x
Container glass production	2A3	-	-	x	x	-
Glass wool production	2A3	x	x	x	-	-
Quarrying and mining of minerals other than coal	2A5a	-	-	x	-	-
Construction and demolition	2A5b	-	-	x	-	-
Storage, handling and transport of mineral products	2A5c	-	-	x	-	-
Production of bricks and tiles	2A6	x	-	-	-	x
Production of expanded clay products	2A6	x	-	-	-	x
Stone wool production	2A6	x	x	x	x	x
Sulphuric acid production	2B10a	x	-	-	-	-
Nitric acid production	2B2	x	-	x	-	-
Catalyst production	2B10a	x	-	x	-	-
Production of chemical ingredients	2B10a	-	x	-	-	-
Pesticide production	2B10a	x	x	-	-	-
Production of tar products	2B10a	x	x	-	x	x
Electric arc furnace steel production	2C1	x	x	x	x	x
Rolling mills steel production	2C1	IE	x	x	x	-
Grey iron foundries	2C1	IE	IE	x	x	x
Secondary aluminium production	2C3	IE	IE	x	x	x
Secondary lead production	2C5	x	IE	x	x	x
Allied metal manufacturing	2C7c	IE	IE	-	x	-
Domestic solvent use incl. fungicides	2D3a	-	x	-	-	-
Road paving with asphalt	2D3b	-	x	x	-	-
Asphalt roofing	2D3c	-	x	x	-	-
Coating applications	2D3d	-	x	-	-	-
Degreasing	2D3e	-	IE	-	-	-
Dry cleaning	2D3f	-	x	-	-	-
Chemical products	2D3g	-	x	-	-	-
Printing	2D3h	-	x	-	-	-
Other solvent use	2D3i	-	x	-	-	-
Use of fireworks	2G4	x	x	x	x	-
Use of tobacco	2G4	x	x	x	x	x
Use of shoes	2G4	-	-	x	-	-
Use of charcoal for barbeques	2G4	x	x	x	x	x
Paraffin wax use	2G4	-	x	x	-	x
Bread production	2H2	-	x	-	-	-
Wine production	2H2	-	x	-	-	-
Beer production	2H2	-	x	-	-	-
Spirits production	2H2	-	x	-	-	-
Sugar production	2H2	-	x	-	-	-
Meat curing	2H2	-	x	-	-	-
Use of margarine and solid cooking fats	2H2	-	x	-	-	-
Coffee roasting	2H2	-	x	-	-	-
Flour production	2H2	-	-	x	-	-
Wood processing	2I	-	-	x	-	-
Slaughterhouse waste	2L	x	-	-	-	-

x Included in the present inventory.

\- Not included/not relevant.

IE Included elsewhere.

Table 4.1.2 presents an overview of the most significant source categories for 1990 and 2021. Many changes have occurred over the time series; some factories have closed and others have opened, Table 4.1.2 is therefore only representable for the years 1990 and 2021.

Table 4.1.2 Overview of 1990 and 2021 emissions from Industrial processes and product use (IPPU).

	Total emission from IPPU	Fraction of national total, %	Largest contributor in IPPU	Emission from largest contributor	Fraction of IPPU, %
			1990		
SO_2	4.10 kt	2.3	2A6 Other mineral products	2.96 kt	72.1
NO_x	0.96 kt	0.3	2B2 Nitric acid production	0.81 kt	84.0
NMVOC	42.47 kt	20.0	2D3i Other solvent use	21.08 kt	49.6
CO	13.74 kt	1.9	2A6 Other mineral products	11.15 kt	81.1
NH_3	0.67 kt	0.5	2A6 Other mineral products	0.27 kt	41.1
TSP	10.73 kt	9.8	2A5b Construction and demolition	7.92 kt	73.8
HMs	23.73 t	8.1	Zn from 2C1 Iron and steel production	12.02 t	50.6
POPs	0.35 t	2.8	PAHs from 2C1 Iron and steel production	0.29 t	83.6
			2021		
SO_2	0.95 kt	11.1	2A6 Other mineral products	0.61 kt	63.9
NO_x	0.07 kt	0.1	2G Other product use	0.05 kt	70.0
NMVOC	33.09 kt	31.0	2D3i Other solvent use	17.76 kt	53.7
CO	3.67 kt	1.9	2G Other product use	3.23 kt	87.8
NH_3	0.41 kt	0.6	2A6 Other mineral products	0.27 kt	66.2
TSP	7.11 kt	8.4	2A5b Construction and demolition	4.43 kt	62.3
HMs	7.14 t	4.8	Cu from 2G Other product use	2.22 t	31.1
POPs	0.09 t	2.1	PAHs from 2G Other product use	0.09 t	99.7

4.2 Mineral products

4.2.1 Source category description

The sub-sector *Mineral products* (NFR 2A) covers the following processes relevant for the Danish inventories:

- 2A1 Cement production
- 2A2 Lime production
- 2A3 Glass production
- 2A5a Quarrying and mining of minerals other than coal
- 2A5b Construction and demolition
- 2A5c Storage, handling and transport of mineral products
- 2A6 Other mineral products

The time series for emission of acidifying substances, NMVOC, particulate matter, heavy metals, and POPs from *Mineral products* (NFR 2A) is available in the NFR tables. Table 4.2.1 presents an overview of emissions from 2021.

Table 4.2.1 Overview of 2021 emissions from *Mineral products*.

	Total emission from mineral industries	Fraction of IPPU, %	Largest contributor in Mineral industries	Emission from largest contributor	Fraction of Mineral industries, %
SO_2	0.61 kt	63.9	2A6 Other mineral products	0.61 kt	100.0
NMVOC	0.09 kt	0.3	2A3 Glass production	0.06 kt	62.6
CO	0.01 kt	0.3	2A6 Other mineral products	0.01 kt	76.6
NH_3	0.34 kt	83.5	2A6 Other mineral products	0.27 kt	79.3
TSP	5.89 kt	82.9	2A5b Construction and demolition	4.43 kt	75.1
HMs	0.14 t	1.9	Pb from 2A3 Glass production	0.05 t	32.8
POPs	0.01 kg	0.01	PCBs from 2A2 Lime production	0.01 kg	94.2

4.2.2 Cement production

There is only one plant for cement production in Denmark; and this is a large point source with plant-specific emission data. It has not been possible to separate emissions from fuel consumption and emissions from process activities. Process emissions from the production of cement are therefore included in the energy section. See Chapter 3.2 and Annex 3A-6.

4.2.3 Lime production

The production of limestone and lime/burned lime/quicklime 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. The following category is covered:

- Lime production

The following pollutants are relevant for the lime production process:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Persistent organic pollutants: HCB, PCDD/F, PCB

Emissions associated with the fuel use are estimated and reported in the energy sector.

Methodology

Data on the amount of lime produced are available from Statistics Denmark on a national level and emission factors are available from EMEP/EEA and national literature.

Activity data

The activity data regarding production of lime are obtained from Statistics Denmark (2022). The data are presented in Table 4.2.2 and the full time series in Annex 3C-1.

Table 4.2.2 Production of burnt lime, t (Statistics Denmark, 2022).

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Burnt lime	133796	105898	97846	75928	52380	64226	46379	42770	55358	62921

Slaking of lime does not emit any pollutants. All burnt lime that is later slaked, is included in the data presented in the table above. Adding the production of slaked lime to the activity data, would therefore result in a double counting.

Emission factors

The emission factors used to calculate the emissions from lime production are shown in Table 4.2.3 along with their respective sources. Emission factors from EMEP/EEA (2019) are valid for a controlled process (Tier 2[1]). For verification of the TSP emission factor, please refer to Hjelgaard & Nielsen (2018).

[1] EMEP/EEA (2019) Guidebook, chapter 2.A.2 Lime production, page 11, Table 3.3.

Table 4.2.3 Emission factors for production of lime.

Pollutant	Unit	Value	Source
TSP	kg/t	0.40	EMEP/EEA (2019)
PM_{10}	kg/t	0.20	EMEP/EEA (2019)
$PM_{2.5}$	kg/t	0.03	EMEP/EEA (2019)
BC	g/t	0.14	EMEP/EEA (2019)
HCB	mg/t	0.01	Nielsen et al. (2013)
PCDD/F	µg/t	0.02	Henriksen et al. (2006)
PCB	mg/t	0.15	Nielsen et al. (2013)

Emission trends

The emission trends for particles and POPs for lime production are shown in Table 4.2.4 and in Figure 4.2.1. Emission data for the entire time series are available in Annex 3C-2.

Table 4.2.4 Emission of particles and POPs.

	Unit	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
TSP	t	53.5	42.4	39.1	30.4	21.0	25.7	18.6	17.1	22.1	22.1
PM_{10}	t	26.8	21.2	19.6	15.2	10.5	12.8	9.3	8.6	11.1	11.1
$PM_{2.5}$	t	4.0	3.2	2.9	2.3	1.6	1.9	1.4	1.3	1.7	1.7
BC	kg	18.5	14.6	13.5	10.5	7.2	8.9	6.4	5.9	7.6	7.6
HCB	g	1.1	0.8	0.8	0.6	0.4	0.5	0.4	0.3	0.4	0.4
PCDD/F	mg	2.4	1.9	1.8	1.4	0.9	1.2	0.8	0.8	1.0	1.0
PCB	g	20.1	15.9	14.7	11.4	7.9	9.6	7.0	6.4	8.3	8.3

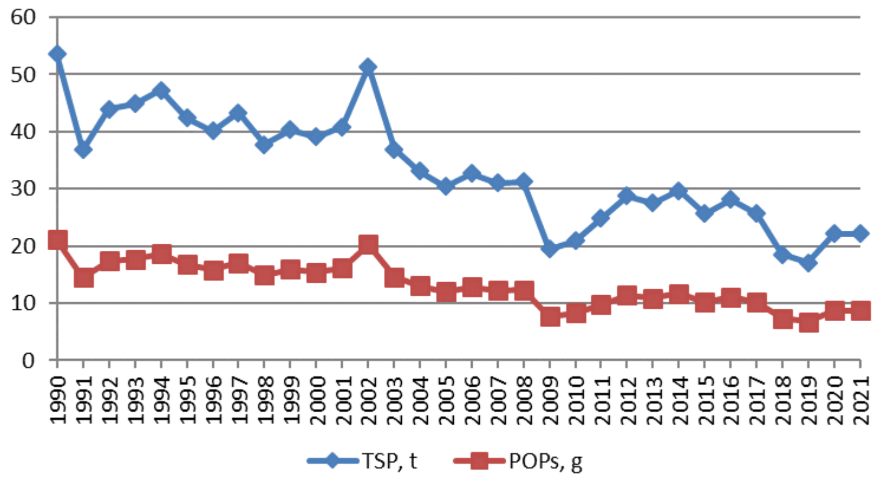


Figure 4.2.1 Emission trends for particles and POPs from lime production.

There is a peak in emissions in 2002 due to a corresponding peak for the activity data. The activity data are based on the official statistics from Statistics Denmark and there is no immediate explanation for this peak. There are very few producers in Denmark and therefore it will not be possible to obtain more detailed data from Statistics Denmark.

4.2.4 Glass production

Glass production covers production of:

- Flat glass
- Container glass
- Glass wool

The production of flat glass is concentrated at few European producers and none of these have plants in Denmark. The processes in Denmark are limited to mounting of sealed glazing units. The mounting process is not considered to contribute to emission of pollutants to air in Denmark.

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 industrial art glass products: Holmegaard A/S both situated in Fensmark, Næstved. Saint-Gobain Isover situated in Vamdrup is the only Danish producer of glass wool. The following categories are covered:

- Container glass
- Glass wool

The following pollutants are relevant for the glass production process:

- NMVOC
- CO
- NH_3
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: As, Cd, Cr, Ni, Pb, Se, Zn

Emissions associated with the fuel use are estimated and reported in the energy sector.

Methodology

The annual produced amount of container glass is estimated based on the consumption of raw materials. Data on raw materials are gathered from environmental reports (1997-2013) (Ardagh, 2014) and EU-ETS data (2006-2021) (Ardagh 2022). 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 are included in the data on container glass.

The produced amount of glass wool is available in the company's environmental reports for 1996-2014 (Saint-Gobain Isover, 2015), and from EU-ETS and PRTR data (Saint-Gobain Isover, 2022a and 2022b). Production data back to 1990 are estimated as the constant average of 1997-1999.

Emission factors for container glass are available from EMEP/EEA (2019) and for glass wool from company measurements.

Activity data

Activity data for the production of container glass and glass wool are presented in Table 4.2.5 and Figure 4.2.2. The full time series is available in Annex 3C-3.

Table 4.2.5 Production of container glass and glass wool, kt product.

	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Container glass	-	164.0	140.0	183.3	168.2	172.9	155.7	156.2	158.1	140.4	157.2
Glass wool	35.6	35.6	35.6	39.7	37.3	24.9	33.0	43.5	44.6	42.1	49.4

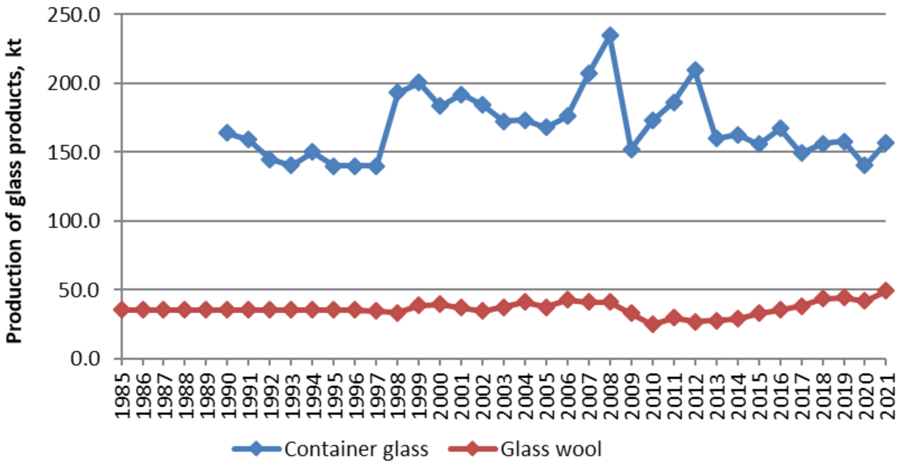


Figure 4.2.2 Activity data for container glass and glass wool production.

Both the container glass and glass wool production display a significant decrease from 2008 to 2010 that can be explained by the financial crises.

Emission factors

Yearly measurements of the emissions from production of container glass provide emissions of TSP (1997-2014), Pb (1997-2014), Se (1997-2009; 2012-2013) and Zn (1997-2001) (Ardagh, 2014 and 2015). Emissions of As, Cd, Cr and Ni are estimated from standard emission factors, the same is the case where direct emissions are not available for TSP, Pb, Se and Zn. PM_{10} and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1/0.9/0.8) and BC is estimated as 0.062 % of $PM_{2.5}$, all available from EMEP/EEA (2019), Tier 2 container glass. All used emission factors are shown in Table 4.2.6. From 2006, measured particle emissions from the singular Danish container glass producer decrease 90 % due to installation of abatement equipment; all calculated particle and heavy metal emissions are therefore also lowered with 90 % from 2006.

Table 4.2.6 Emission factors for production of container glass.

Pollutant	Applied for the years	Unit	Value	Source
TSP	1990-1996	g/t	280	EMEP/EEA (2019)
	2015-2021	g/t	13.7	EMEP/EEA (2019) with CS abatement[1]
PM_{10}	All	% of TSP	90	EMEP/EEA (2019)
$PM_{2.5}$	All	% of TSP	80	EMEP/EEA (2019)
BC	All	% of $PM_{2.5}$	0.06	EMEP/EEA (2019)
As	1990-2005	g/t	0.29	EMEP/EEA (2019)
	2006-2021	g/t	0.03	EMEP/EEA (2019) with CS abatement[1]
Cd	1990-2005	g/t	0.12	EMEP/EEA (2019)
	2006-2021	g/t	0.01	EMEP/EEA (2019) with CS abatement[1]
Cr	1990-2005	g/t	0.37	EMEP/EEA (2019)
	2006-2021	g/t	0.04	EMEP/EEA (2019) with CS abatement[1]
Ni	1990-2005	g/t	0.24	EMEP/EEA (2019)
	2006-2021	g/t	0.02	EMEP/EEA (2019) with CS abatement[1]
Pb	1990-1996	g/t	2.9	EMEP/EEA (2019)
	2015-2021	g/t	0.29	EMEP/EEA (2019) with CS abatement[1]
Se	1990-1996	g/t	1.5	EMEP/EEA (2019)
	2010-2011; 2014-2021	g/t	0.19	Average IEF (2008-09;2012-13)
Zn	1990-1996; 2002-2005	g/t	0.23	Average IEF (2007-2001)
	2006-2021	g/t	0.02	Average IEF (2007-2001) with CS abatement[1]

[1] Country specific abatement is measured by the producer to 90 %.

The emission of NH_3 and TSP from the production of glass wool has been measured yearly for 1996-2021 and are available in the company's environmental reports (Saint-Gobain Isover, 2015 and 2022b) supplemented with personal contact to the company (Saint-Gobain Isover 2022c). NMVOC and CO have also been measured for 2007-2014 and 1996-1997 respectively. For the years where no measured emission data are available, emissions are calculated using implied emission factors (IEFs) based on the available measurements. PM_{10} and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1/0.9/0.8) from EMEP/EEA (2019). All used emission factors are shown in Table 4.2.7. Since it has not been possible to separate process emissions from the emissions from fuel combustion, the measured/calculated emissions from glass wool production presented here account for the entire production.

Table 4.2.7 Emission factors for production of glass wool.

Pollutant	Applied for the years	Unit	Value	Source
NMVOC	1985-2006	kg/t	1.35	Average IEF (2007-2009)
	2015-2021	kg/t	1.17	Average IEF (2012-2014)
CO	1985-1995; 1998-2021	kg/t	0.06	IEF (1997)
NH_3	1985-1995	kg/t	7.6	Average IEF (1996-1998)
	2015	kg/t	4.4	Average IEF (2012-2014)
TSP	1990-1995	kg/t	2.9	Average IEF (1996-2000)
PM_{10}	All	% of TSP	90	EMEP/EEA (2019)
$PM_{2.5}$	All	% of TSP	80	EMEP/EEA (2019)
BC	All	% of $PM_{2.5}$	2.0	EMEP/EEA (2019)

Emission trends

The only pollutants to which both container glass and glass wool productions contribute are particles. Table 4.2.8 and Annex 3C-4 shows the individual emissions from the two sources.

Table 4.2.8 Emission from glass production.

	Pollutant	Unit	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Container glass	TSP	t	-	46	39	26	7.0	1.7	2.1	2.1	2.2	1.9	2.2
	PM_{10}	t	-	41	35	23	6.3	1.5	1.9	1.9	1.9	1.7	1.9
	$PM_{2.5}$	t	-	36	31	20	5.5	1.3	1.7	1.7	1.7	1.5	1.7
	BC	kg	-	22	19	13	3.4	0.8	1.0	1.0	1.1	0.9	1.0
	As	kg	-	48	41	53	49	5.0	4.5	4.5	4.6	4.1	4.6
	Cd	kg	-	20	17	22	20	1.7	1.6	1.6	1.6	1.4	1.6
	Cr	kg	-	61	52	68	62	6.4	5.8	5.8	5.8	5.2	5.8
	Ni	kg	-	39	34	44	40	4.2	3.7	3.7	3.8	3.4	3.8
	Pb	kg	-	476	406	330	148	24	45	45	46	41	46
	Se	kg	-	246	210	340	107	33	30	30	30	27	30
	Zn	kg	-	38	32	57	39	4.0	3.6	3.6	3.6	3.2	3.6
Glass wool	NMVOC	t	48	48	48	54	50	32	39	51	52	49	58
	CO	t	2.0	2.0	2.0	2.3	2.1	1.4	1.9	2.5	2.5	2.4	2.8
	NH3	t	271	271	271	225	116	108	145	76	99	65	71
	TSP	t	-	102	102	111	85	26	38	40	38	34	19
	PM_{10}	t	-	92	92	100	77	23	34	36	34	30	17
	$PM_{2.5}$	t	-	82	82	89	68	21	30	32	30	27	15
	BC	t	-	1.6	1.6	1.8	1.4	0.4	0.6	0.6	0.6	0.5	0.3

4.2.5 Quarrying and mining of minerals other than coal

Quarrying and mining of minerals other than coal covers several different types of minerals and occurs all over Denmark. The following category is covered:

- Quarrying and mining of minerals other than coal

The following pollutants are relevant for quarrying and mining:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$

Methodology

The annual amount of extracted minerals is available from national statistics. These resource extraction data cover "sand and gravel", "chalk and dolomite", "marble, granite, sandstone, porphyry, basalt and building stone, etc." and "other".

Emission factors are calculated using the Tier 2 methodology spreadsheet available from EMEP/EEA (2019).

Activity data

Activity data for quarrying and mining of minerals other than coal are presented in Table 4.2.9; the full time series is available in Annex 3C-5.

The activity data from Statistics Denmark (2022) called "marble, granite, sandstone, porphyry, basalt and building stone, etc." is believed to be mostly granite chippings, this category is entered in the Tier 2 model as "crushed rock". The categories "sand and gravel" and "chalk and dolomite" are entered as "sand and gravel". And the category "other" is entered as "Recycled aggregates" due to the lack of information on this category.

Statistical data on quarrying for the latest reporting year, is not made available in time for the reporting deadline. Therefore, the two latest reported years are the same. Activity data for the latest reporting year in this year's submission, will be updated with the correct statistical data in next year's submission.

Table 4.2.9 Extracted minerals other than coal, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Crushed rock	945	1103	332	315	240	234	537	233	175	175
Sand and gravel	43534	51581	63184	73805	44147	57456	63991	65553	64174	64174
Recycled aggregates	908	908	947	813	1052	1090	1306	1100	1315	1315

Emission factors

The applied emission factors are shown in Table 4.2.11. Emission factors are calculated based on the Tier 2 methodology calculation model spreadsheet (EMEP/EEA, 2019). All Danish quarries are small quarries (<100,000 kt annual production), in fact, all sites in the three categories are assumed to produce between 9-775 kt mineral in annual average in any year of the time series. Being a small country, Danish emission factors are calculated as one region. The average wind speed is 4.72 m per second (2011-2019 average), number of days per year with at least 1 mm natural precipitation is 155 (2016) and number of days with a wind speed > 19.3 km per hour is 105 (2016). All weather related data are collected from DMI (2020). All additional country specific data entered into the model, are presented in Table 4.2.10.

Table 4.2.10 Country specific data used in the Tier 2 methodology calculation model.

	Crushed rock	Sand and gravel	Recycled aggregates
General data			
Number of quarries	2	100	35[a]
Material processing			
Percentage of wet processing	0%	42%[b]	42%[b]
Internal transport			
Distance travelled on unpaved road	2400 km[c]	2400 km	0 km

[a] Auto-calculated from the production (i.e. activity data), [b] It rains a minimum of 1mm per day in Denmark 42% of the year, [c] Denmark is a small country with small distances and the default value is considered far too high

Table 4.2.11 Emission factors for quarrying and mining of minerals other than coal

	Unit	TSP	PM_{10}	$PM_{2.5}$
Crushed rock	g/t	77	29	6.4
Sand and gravel	g/t	18	7.4	2.0
Recycled aggregates	g/t	33	15	4.1

Emission trends

Emissions of $PM_{2.5}$ are presented in Figure 4.2.3. Emissions of TSP. PM_{10} and $PM_{2.5}$ are available in Annex 3C-6.

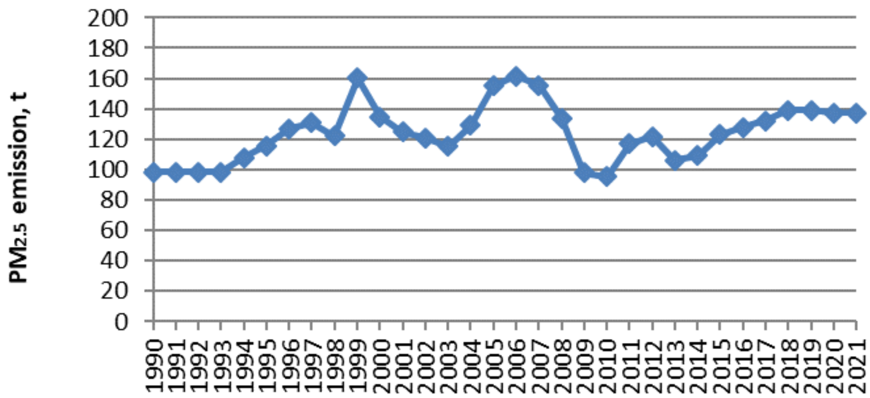


Figure 4.2.3 Emission of fine particles ($PM_{2.5}$) from quarrying and mining of other minerals than coal.

4.2.6 Construction and demolition

Construction and demolition covers the following category:

- Construction and demolition

The following pollutants are relevant for construction and demolition:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$

Methodology

Emissions from construction and demolition are calculated using the Tier 1 methodology from EMEP/EEA (2019) expressed in the following equation:

$$EM_{PM10} = EF_{PM10} \cdot A_{affected} \cdot d \cdot (1 - CE) \cdot \left(\frac{24}{PE}\right) \cdot \left(\frac{s}{9\%}\right)$$

Where: EM_{PM10} is the PM_{10} emission, EF_{PM10} is the emission factors, $A_{affected}$ is the area affected by construction activity, d is the duration of construction, CE

is the efficiency of emission control measures, *PE* is the Thornthwaite precipitation-evaporation index (correction for soil moisture) and *s* is the soil silt content.

The activity data for construction ($A_{affected}$) are calculated based on national statistics on completed buildings (m^2) (detached houses, undetached houses, apartment buildings and non-residential buildings) and roads (m).

Emission factors (EF_{PM10}) are available from EMEP/EEA (2019).

Activity data
Activity data for construction and demolition are presented in Table 4.2.12. The full time series is available in Annex 3C-7.

Table 4.2.12 Activity of construction and demolition, mill. m^2.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Construction of houses	2.3	1.3	2.5	3.6	2.2	2.2	3.0	3.3	3.4	3.5
Construction of apartment	0.7	0.5	0.4	0.9	0.3	0.4	1.4	1.6	2.0	1.6
Construction of non-residential	5.3	4.0	6.1	4.6	3.7	2.9	2.9	2.6	2.1	2.2
Construction of road	1.8	1.7	1.6	2.2	2.9	0.8	2.0	0.4	1.0	0.9

Emission factors
The default emission factors are shown in Table 4.2.13.

Table 4.2.13 Default emission factors for different building type constructions.

Pollutant	Unit	Houses	Apartment buildings	Non-residential buildings	Road	Source
TSP	$kg/m^2/year$	0.29	1.0	3.3	7.7	EMEP/EEA (2019)
PM_{10}	$kg/m^2/year$	0.086	0.30	1.0	2.3	EMEP/EEA (2019)
$PM_{2.5}$	$kg/m^2/year$	0.0086	0.030	0.1	0.23	EMEP/EEA (2019)

The default duration (*d*) of the different construction types and the default control efficiency (*CE*) are available in EMEP/EEA (2019). The Thornthwaite precipitation-evaporation index was calculated for the years 2015-2017. The average obtained *PE* index is 75.9 which corresponds to a humid climate. Denmark is a very sandy country, and the silt content (*s*) is therefore assumed to be 15 % (DCE judgement). Danish roads span from 3 to 20 meters, an average road width of 12 m is assumed (DCE judgement).

Table 4.2.14 below presents the applied emission factors for the different types of construction. These emission factors corresponds to:

$$EF_{PM10} \cdot d \cdot (1 - CE) \cdot \left(\frac{24}{PE}\right) \cdot \left(\frac{s}{9\%}\right)$$

Table 4.2.14 Applied emission factors for different building type constructions.

Pollutant	Unit	Houses	Apartment buildings	Non-residential buildings	Road
TSP	kg/m^2	0.076	0.395	0.722	2.030
PM_{10}	kg/m^2	0.023	0.119	0.219	0.606
$PM_{2.5}$	kg/m^2	0.002	0.012	0.022	0.061

Emission trends
Emissions of $PM_{2.5}$ are presented in Figure 4.2.4. Emissions of TSP, PM_{10} and $PM_{2.5}$ are available in Annex 3C-8.

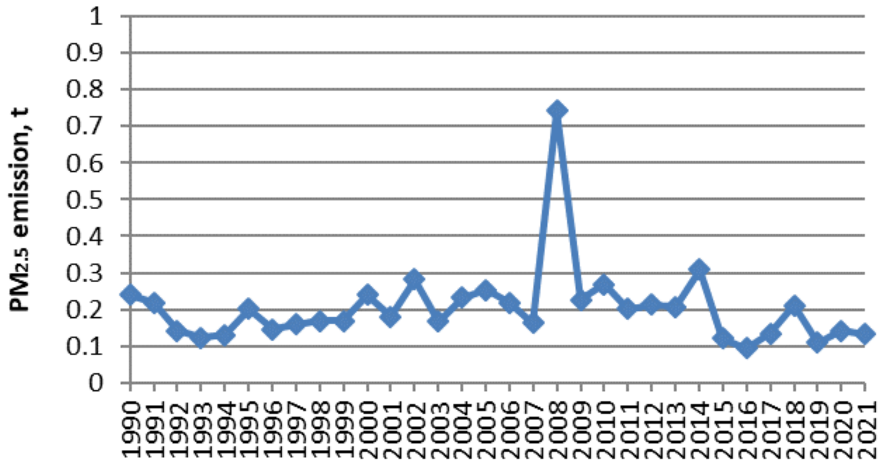


Figure 4.2.4 Emission of particulate matter ($PM_{2.5}$) from construction and demolition.

The peak in 2008 is caused by a large increase in construction of road.

4.2.7 Storage, handling and transport of mineral products

Storage, handling and transport of mineral products covers the following category:

- Storage, handling and transport of mineral products

The following pollutants are relevant for storage, handling and transport of mineral products:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$

Methodology

The activity data for storage, handling and transport of mineral products covers minerals used in cement production, ceramics production, other uses of soda ash, flue gas desulphurisation and stone wool. The particle emissions from storage, handling and transport of mineral products in lime production, glass production quarrying/mining and construction/demolition are already included in the respective categories.

The activity data for storage, handling and transport of mineral products are gathered from the five included sources (mass mineral).

The emission factor for TSP is assumed to be 0.1 % of activity data, PM_{10} and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1/0.5/0.05).

Activity data

Activity data for storage, handling and transport of mineral products are presented in Table 4.2.15. The entire time series is available in Annex 3C-9.

Table 4.2.15 Activity of storage, handling and transport of mineral products, kt mineral.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Storage, handling and transport of mineral product	1328	1567	1769	1680	966	905	1149	1134	1226	1314

Emission factors

The applied emission factors are shown in Table 4.2.16.

Table 4.2.16 Emission factors for storage, handling and transport of mineral products.

Pollutant	Value	Unit	Source
TSP	0.1	t/kt	Expert judgement
PM_{10}	0.05	t/kt	Particle distribution from EMEP/EEA (2019)
$PM_{2.5}$	0.005	t/kt	Particle distribution from EMEP/EEA (2019)

Emission trends

Emissions are presented in Figure 4.2.5 and Annex 3C-10.

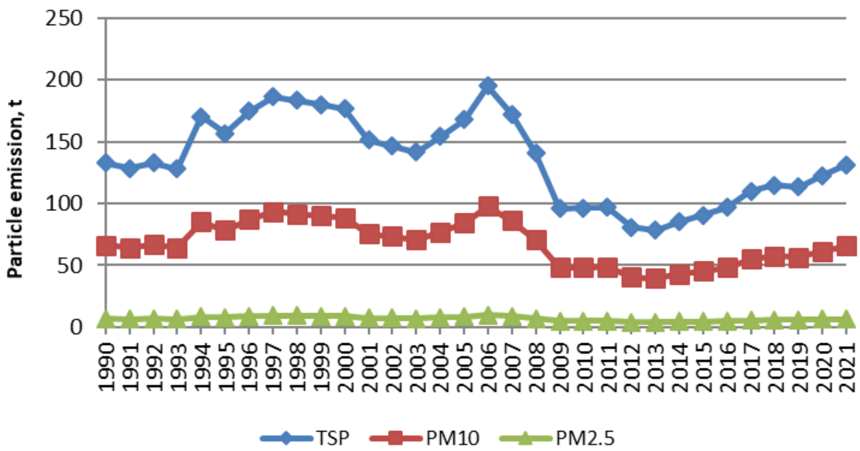


Figure 4.2.5 Emission of particulate matter from storage, handling and transport of mineral products.

4.2.8 Other mineral products

The sub-sector "Other" in the mineral industry section covers production of bricks and tiles (aggregates or bricks/blocks for construction), expanded clay products for different purposes (aggregates as absorbent for chemicals, cat litter, and for other miscellaneous purposes) and stone wool from the company Rockwool. The following categories are covered:

- Production of bricks and tiles
- Expanded clay products
- Stone wool

The following pollutants are covered:

- SO_2
- CO
- NMVOC
- NH_3
- Heavy metals: As
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Persistent organic pollutants: PCDD/F

NO_x from stone wool production is included in the energy sector (NFR 1A2f Stationary Combustion in Manufacturing Industries and Construction: Non-Metallic Minerals).

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. Rockwool produces stone wool at three localities in Denmark: Hedehusene[2], Vamdrup and Øster Doense.

Methodology

The SO_2 emission from the production of bricks/tiles and expanded clay products is related to the sulphur content in the raw material. The SO_2 emission and fuel consumption are known for nine different producers of ceramics for 2007-2014 (and also 2015-2021 for expanded clay production at LECA). The SO_2 emission from the fuel consumption is calculated using Danish standard emission factors, and this is subtracted from the total SO_2 emission. The remaining emission is used to calculate two SO_2 emission factors for brickworks and expanded clay production respectively for 1980-2006 based on IEF (2007-2010) and two based on IEF (2012-2014) for 2015 onward. These factors are used for all producers of bricks/tiles and for all expanded clay producers. However, from 2006 onward the expanded clay producer LECA is reported as a large point source with its own (implied) emission factors for SO_2. These emission factors are calculated using the same method as described above; i.e. the difference between total emission and fuel emission. The PCDD/F emission factor is known from national literature.

Stone wool is produced from mineral fibres and a binder. The raw materials are melted in a cupola fired by coke and natural gas. Information on emissions from some years are used as implied emission factors to calculate emissions for years where measurements are not available. Production data are used as activity data and raw material consumption is used as surrogate data to complete the time series. The data have been extracted from the environmental reports (Rockwool, 2014), reporting to PRTR (Rockwool, 2022b), EU-ETS (Rockwool, 2022a) and Statistics Denmark (2022). Measured emissions of CO and NH_3 are available for the years 2001, 2004 and 2007-2014, for NH_3 also 2015-2021 and for CO also 2021 (Rockwool, 2022c). Emissions of particulate matter are available for 1995-2014 and 2016-2021 (for Doense), and for NMVOC, As and PCDD/F, the inventory is based on measured emissions for 2012-2014, 2007-2015 and 2004 respectively. Process emissions of SO_2 are included in the energy sector for 1980-2020 as Rockwool has been using SO_2 heavy fuels and measured emissions are difficult to separate between energy and process. But since 2021, Rockwool in Vamdrup only uses natural gas and gasoil as fuel, and SO_2 emissions are therefore reported in this sector. SO_2 emissions from the Rockwool production site in Doense is still included under Energy.

Activity data

National statistics on bricks, tiles and expanded clay (together called ceramics) contain a broad range of different products, most of them in units of numbers (no.). The consumption of limestone is therefore used as alternative activity data for these source categories; available for 2006-2021 (EU-ETS data). The national statistics are used as surrogate data; available for 1985-2021. Prior to 1985 activity data are estimated as the 1985-1989 average.

Data on the produced amount of stone wool is known for 1995-2004 (Statistics Denmark, 2022) and 2014-2021 (Rockwool, 2022a, confidential). Data on the consumption of raw materials are used as surrogate data to complete the time series. Raw material consumption is available from the annual environmental

[2] The melting of minerals (cupola) has been closed down in 2002.

reports (Rockwool, 2014). Activity data for 1985-1994 is kept constant as the average value of 1995-1999.

The chosen activity data for "Other mineral products" are not presented in the NFR tables, they are however, shown in Table 4.2.17, Figure 4.2.6 and Annex 3C-11. The large point sources LECA (expanded clay products producer) and Rockwool (2006-) are not presented separately, as EU-ETS data are confidential. LECA is included in expanded clay, but stone wool is in Denmark only produced by the single producer; Rockwool.

Table 4.2.17 Production of "Other mineral products".

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Brickworks	kt $CaCO_3$-eq	75.7	82.1	58.6	71.7	81.1	79.2	35.1	46.2	64.3	61.1	60.6
Expanded clay	kt $CaCO_3$-eq	51.5	50.6	46.2	47.5	44.0	43.3	19.1	19.5	41.7	37.5	60.9
Stone wool	kt produced	-	153.5	153.5	123.3	152.6	143.6	c	c	c	c	c

c: confidential

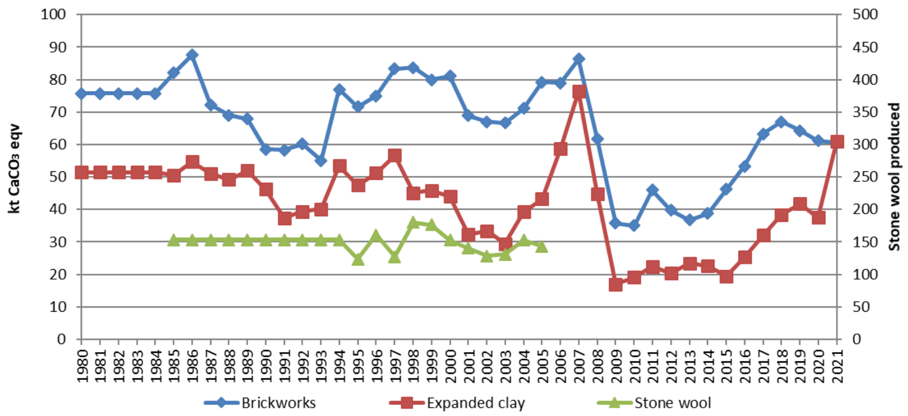


Figure 4.2.6 Consumption of $CaCO_3$ equivalents in the production of ceramics and the production of stone wool.

Both the brickworks, expanded clay productions and stone wool production displays a significant decrease from 2007 to 2009 that can be explained by the global financial crises.

Emission factors

For production of ceramics the emission factors for SO_2 are determined from the individual companies reporting of SO_2 emission (environmental reports) for the years 2007-2014 and activity for the corresponding years. The years 2015-2021 are also included for the large point source LECA. The SO_2 emissions have been adjusted for fuel related emissions to derive the process emissions. The PCDD/F emission factors shown in Table 4.2.18 are calculated from 0.018 µg per tonne product (Henriksen et al., 2006), using the total carbonate consumption (environmental reports), national production statistics (Statistics Denmark) and assumption of 2.5 kg per brick/tile.

Stone wool emission factors are calculated from measured emission data; i.e. implied emission factors (see Table 4.2.19 below). Stone wool emission factors for CO and NH_3 are average values measured and reported in the annual environmental reports for each Rockwool factory for the years 2001, 2004 and 2007-2014, CO is also known for 2021 and NH_3 is also known for 2015-2021 (Rockwool, 2022b and 2022c). TSP emission data are available in the environmental reports for 1995-2014 and PRTR/personal communication for 2016-

2021. PM_{10} and $PM_{2.5}$ emission factors are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1/0.9/0.7). The applied emission factor for BC is actually that of glass wool from EMEP/EEA (2019). NMVOC emissions are known for Doense for 2012-2014, arsenic is measured for 2007-2015, SO_2 is measured for Vamdrup in 2021 and PCDD/F emissions are known from Henriksen et al. (2006).

Table 4.2.18 Emission factors for Other mineral products, units are per t $CaCO_3$ equivalent.

Pollutant	Applied for the years	Brickworks Value Unit	Expanded clay Value Unit	Source
SO_2	1980-2006	9.9 kg	51.5 kg	Average IEF[1] (2007-2010)
	2015-2021	4.4 kg	39.3[2] kg	Average IEF[1] (2012-2014)
PCDD/F	All	0.25 µg	0.13 µg	Henriksen et al. (2006)[3]

1 Calculated using data from the companies' environmental reports.

2 Average value for expanded clay production, the actual applied EFs are one for LECA only and one for the remaining producers.

3 Some calculations were necessary to derive the desired units.

Table 4.2.19 Emission factors for stone wool production, units are per t produced.

Pollutant	Applied for the years	Value Unit	Source
NMVOC	All	0.22 kg	Average IEF[1] (2012-2014)
CO	1985-2000; 2002-2003; 2005-2006	40 - 128 kg	IEFs[1] (2001; 2004; 2007-2008)
	2015-2020	0.02 - 0.26 kg	IEFs[1] (2010-2014)
NH_3	1985-2000; 2002-2003; 2005-2006	1.3 - 2.3 kg	IEFs[1] (2001; 2004; 2007)
TSP	1990-1994	0.38 - 0.89 kg	IEFs[1] (1995-2002)
	2015-2019[4]	0.54 kg	Average IEF[1] (2010-2014)
PM_{10}	All	90 % of TSP	DCE judgement
$PM_{2.5}$	All	70 % of TSP	DCE judgement
BC	All	2 % of $PM_{2.5}$	EMEP/EEA (2019)[2]
As	1990-2006	0.33-0.51 g	IEFs (2007; 2008-2014)
	2016-2021	0.12 - 0.33 g	IEFs (2008-2014)
PCDD/F	All	0.37 µg	Henriksen et al. (2006)[3]

1 Calculated using data from the companies' environmental reports.

2 Valid for glass wool.

3 Some calculations were necessary to derive the desired units.

4 Only applied for Vamdrup.

Emission trends

The only pollutants to which more than one source category contributes are SO_2 and PCDD/F, these two emissions are presented in the figures below. Figure 4.2.7 and Figure 4.2.8 show the emissions of SO_2 and PCDD/F respectively, emissions are presented individual for the three sources.

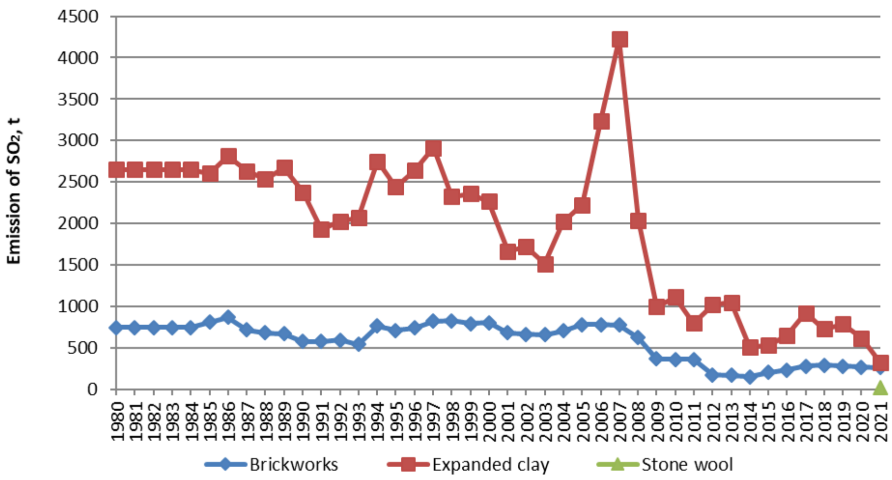


Figure 4.2.7 Emissions of SO_2 from ceramics.

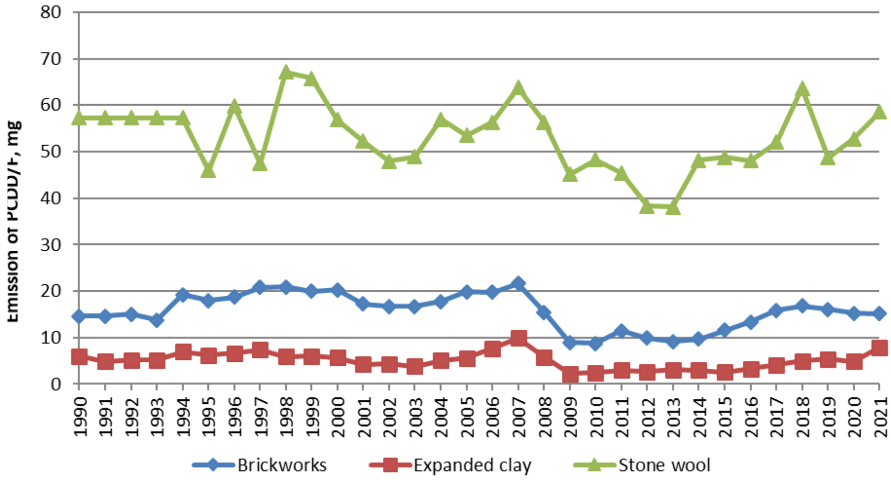


Figure 4.2.8 Emissions of PCDD/F from ceramics and stone wool.

Emissions of the remaining pollutants can be found in Annex 3C-12, where NMVOC, CO, NH_3, particle and As emissions stem only from stone wool production.

The measurements of CO emissions show a strong decrease from the two stone wool factories in 2009 and 2010, respectively, due to installation of abatement equipment.

4.3 Chemical industry

4.3.1 Source category description

The sub-sector *Chemical industry* (NFR 2B) covers the following processes:

- 2B2 Nitric acid/fertiliser production
- 2B10a Other chemical industry
    - Sulphuric acid production
    - Catalyst/fertiliser production
    - Production of chemical ingredients
    - Pesticide production
    - Production of tar products

The time series for emission of acidifying substances, NMVOC, particulate matter, heavy metals, and POPs from *Chemical industry* (NFR 2B) is available in the NFR tables. Table 4.3.1 presents an overview of emissions from 2021.

Table 4.3.1 Overview of 2021 emissions from *Chemical industry*.

	Total emission from Chemical industries		Fraction of IPPU, %	Largest contributor in Chemical industries	Emission from largest contributor		Fraction of Chemical industries, %
SO_2	0.29	kt	30.6	2B10a Other chemical industry	0.29	kt	100.0
NO_x	0.02	kt	30.0	2B10a Other chemical industry	0.02	kt	100.0
NMVOC	0.02	kt	0.05	2B10a Other chemical industry	0.02	kt	100.0
NH_3	0.01	kt	2.6	2B10a Other chemical industry	0.01	kt	100.0
TSP	0.01	kt	0.10	2B10a Other chemical industry	0.01	kt	100.0
HM	1.08	kg	0.015	Hg from 2B10a Other chemical industry	1.08	kg	100.0
POPs	0.18	g	0.3	PAH from 2B10a Other chemical industry	0.18	g	100.0

4.3.2 Nitric and sulphuric acid production

The production of sulphuric acid, nitric acid as well as NPK fertilisers has been concentrated at one company; Kemira GrowHow A/S (Kemira GrowHow, 2004). The production of sulphuric acid and nitric acid/fertiliser ceased in 1996/7 and in the middle of 2004, respectively. The following categories are covered:

- Sulphuric acid
- Nitric acid

The following pollutants are relevant for the nitric and sulphuric acid production processes:

- SO_2
- NO_x
- NH_3
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC

Methodology

In the NFR tables, SO_2 emissions from sulphuric acid production are reported under 2B10a Other chemical industry. In this report however, these emissions are reported alongside with emissions from nitric acid production since they are produced by the same company.

Information on emissions is obtained from environmental reports, contact to the company as well as information from the county. Information on emissions of SO_2, NO_x and NH_3 is available for 1990, 1994-1997; 1990, 1994-2002 and 1989-2004 respectively, TSP is available for 1996-2004. Implied emission factors (IEF) are calculated for the years where measurements are available; these implied emission factors are then used to calculate emissions for the remaining years.

Activity data

The activity data regarding production of nitric- and sulphuric acid are obtained through environmental reports and personal communication with Kemira (Kemira GrowHow, 2004 and 2005). The data are presented in Table 4.3.2 and Annex 3C-13.

Table 4.3.2 Production of nitric and sulphuric acid, t.

	1980	1985	1990	1995	2000	2001	2002	2003	2004
Nitric acid	350	350	450	390	433	382	334	386	229
Sulphuric acid	188	188	148	102	NO	NO	NO	NO	NO

NO: Not occurring.

Emission factors

The calculated implied emission factors for SO_2, NO_x, NH_3 and TSP are presented in Table 4.3.3.

Table 4.3.3 IEFs for production of nitric- and sulphuric acid.

Process	Pollutant	IEF	Unit
Nitric acid	NO_x	0.95-1.79	kg/t
Nitric acid	NH_3	0.03-0.26	kg/t
Nitric acid	TSP	0.56-0.98	kg/t
Sulphuric acid	SO_2	1.40-2.69	kg/t

Due to the lack of information on the particle distributions PM_{10} and $PM_{2.5}$, these are put equal to TSP for nitric acid production. BC is estimated as 1.8 % of $PM_{2.5}$ according to EMEP/EEA (2019) (chemical industry, average).

Emission trends

The time series for SO_2 follows the amount of sulphuric acid produced, i.e. the fluctuation follows the activity until the activity ceased in 1997. The same is the case for NO_X from production of nitric acid. Emission data are presented in Figure 4.3.1 and Annex 3C-14.

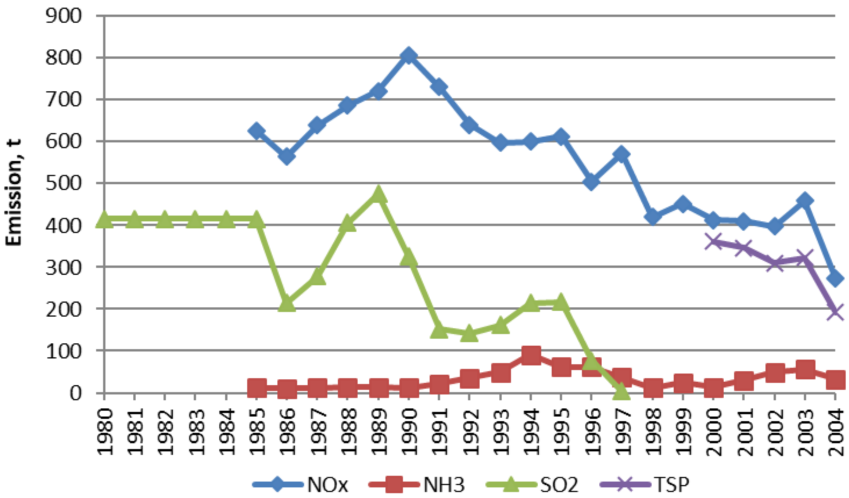


Figure 4.3.1 Emissions from nitric and sulphuric acid production.

4.3.3 Catalyst production

Production of a wide range of catalysts and potassium nitrate is concentrated at one company: Haldor Topsøe A/S situated in Frederikssund. The products are catalysts for many purposes (for hydro-processing, ammonia, $DeNO_x$, methanol, hydrogen and synthesis gas, sulphuric acid, formaldehyde, and combustion catalysts) and potassium nitrate (fertiliser). The following category is covered:

- Other: catalysts

The following pollutants are relevant for the catalyst production processes:

- NO_x
- NH_3
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC

Methodology

The emissions of NO_X, NH_3 and PM_{10} from production of catalysts and fertilisers are measured annually from 1996 to 2021 (Haldor Topsøe, 2013 and 2022). The emissions from 1985-1995 were extrapolated.

The process related NO_X emission has been estimated as 80 % of the measured total NO_X emission; Haldor Topsøe reports this assumption in their environmental report (Haldor Topsøe, 2013). The plant is equipped with a $DeNO_x$ flue gas cleaning system and depending on the efficiency of the cleaning system emissions of NH_3 will occur.

Activity data

The activity data regarding production of catalysts and fertiliser are obtained through environmental reports from Haldor Topsøe (2013) where these are available. For years where environmental reports are unavailable, production data are estimated using the drivers mentioned in Table 4.3.4. Production data are presented in Table 4.3.5 and Annex 3C-15, the annex also includes the applied surrogate data.

Table 4.3.4 Source of activity data.

Years	Determined by
1985-1995	Extrapolation
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 (Haldor Topsøe, 2013)
2013-2014	Estimated using the consumption of raw materials as surrogate data
2015-2021	Catalyst production is known from Statistics Denmark, and fertiliser production is estimated using the fuel consumption as surrogate data and the average production for 2003-2012

Table 4.3.5 Production of catalysts and potassium nitrate, kt.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Catalysts produced	-	-	-	17.2	23.2	20.5	-	-	-	-
Potassium nitrate produced	-	-	-	19.2	23.3	25.9	-	-	-	-
Total produced	16.8	23.7	30.5	36.4	46.5	46.4	62.4	61.9	59.5	51.2

Emission factors

The calculated implied emission factors for NO_x, NH_3 and particles are presented in Table 4.3.6.

Table 4.3.6 Implied emission factors for production of catalysts and potassium nitrate.

	NO_x	NH_3	TSP	PM_{10}	$PM_{2.5}$	BC
Unit	t/kt	t/kt	t/kt	t/kt	t/kt	kg/kt
Range	0.32-1.76	0.11-3.70	0.08-0.70	0.06-0.56	0.05-0.42	0.8-7.5

TSP and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1/0.8/0.6) from CEPMEIP (Values for 'Production of nitrogen fertiliser'). BC is estimated as 1.8 % of $PM_{2.5}$ according to EMEP/EEA (2019) (chemical industry, average).

Emission trends

The particle emissions fluctuate, which is typically caused by variations in the performance of the filters. This is quite common for particle abatement. As such the particle emission is not directly correlated to the production, but more influenced by the efficiency of the abatement.

The NO_x emission has been reduced in spite of increasing production due to installation of $DeNO_x$ technology on the stacks. The installation of this abatement occurred in 1999 and 2000. The minor fluctuations in NO_x emission in the years since are caused by variations in the abatement efficiency, e.g. when the system is failing, problems with the dosage of NH_3, etc.

The emission of NH_3 shows an increasing trend throughout the 00's; from 14 tonnes in 2000 to 165 tonnes in 2009; in the same period the implied emission factor fluctuates around the average 1.77 tonnes per kt product but shows no trend. For the remaining time series, the NH_3 emission only varies between 16-20 tonnes with the exception of 2010 where 123 tonnes were emitted.

Emissions of NO_x, NH_3 and TSP are shown in Figure 4.3.2 and Annex 3C-16.

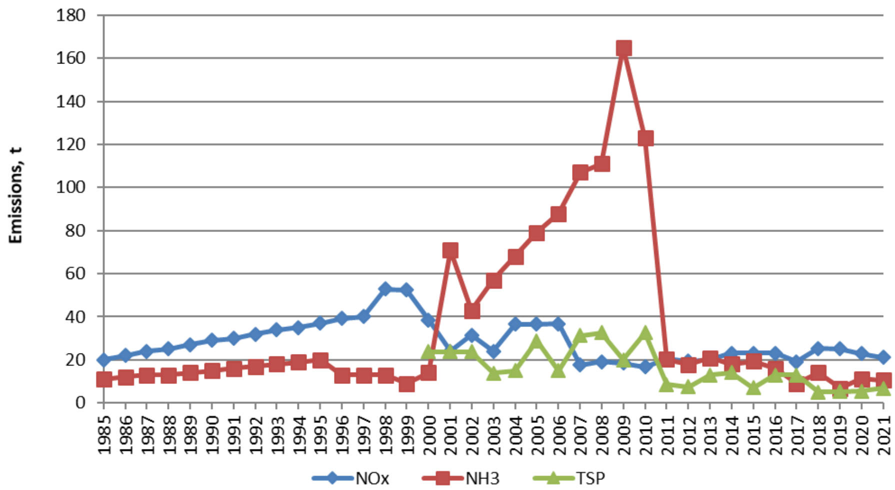


Figure 4.3.2 Emissions from catalyst and fertiliser production.

4.3.4 Production of chemical ingredients

The production of chemical ingredients takes place in a number of different companies. One of the major companies is Danisco Grindsted located in Grindsted (Danisco Grindsted, 2014). The following category is covered:

- Processes in organic chemical industry

The following pollutant is relevant for the production process of chemical ingredients:

- NMVOC

Methodology

The following description of the production of chemical ingredients is based on the historical environmental reports from the company (Danisco Grindsted, 2014).

The raw materials are primarily natural or nature identical raw materials/substances: vegetable oils, animal fatty acids, glycerine, other organic substances, mineral acidic and alkaline compounds, solvents etc. The products are emulsifiers, stabilisers, flavours, enzymes, antioxidants, pharmaceuticals, and preservatives.

Activity data

Due to confidentiality no activity data are available.

Emission factors

Due to confidentiality no emission factors are available.

Emission trends

The emission of NMVOC from production of chemical ingredients has been measured from 1997 to 2016 (Danisco Grindsted, 2014 and DuPont, 2017). The emission has in this period decreased from 85 tonnes to 9 tonnes. However, no explanation can be given on these conditions, as information on activity is not available. From 2017, emissions are estimated using implied emission factors. The NMVOC emissions are presented in Table 4.3.7 and Annex 3C-17.

Table 4.3.7 Emissions from the production of chemical ingredients, t.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
NMVOC	44	75	87	62	16	12	10	9	9	8

4.3.5 Pesticide production

The production of pesticides in Denmark is concentrated at one company: Cheminova A/S situated in Harboøre. The following category is covered:

- Pesticide production

The following pollutants are relevant for the pesticide production process:

- SO_2
- NMVOC

Because it is not possible to separate process and fuel emissions reported in the company’s environmental reports, SO_2 emissions for this source category includes emissions from fuel consumption.

Methodology

The air emissions from Cheminova are measured from a number of sources; e.g. exhaust from process plant, sulphur recovery plant and biological sewage treatment plant. Only some of the emissions are available and they are only presented as aggregated data.

The produced amount of pesticides is known for 1996-2009 (Cheminova, 2010). Emissions of SO_2 and NMVOC are measured annually and are available for 1990-2021 and 1990-2000+2013-2021 respectively (Cheminova 2010, 2015 and 2022). For the years where data are not available, activity data are extrapolated and emissions are calculated using implied emission factors.

Activity data

Activity data for 1980-1995 are calculated using the national statistics on value of pesticides produced (million DKK) as surrogate data. For 2010-2021, no information on the production is available and activity data are estimated using DCE judgement. Activity data on the production of pesticides are presented in Table 4.3.8 and Annex 3C-18.

Table 4.3.8 Production of pesticides, t.

	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Pesticide production	20796	42010	37671	45320	60284	53504	40000	60000	60000	60000	60000

Emission factors

The calculated implied emission factors for pesticide production are presented in Table 4.3.9.

Table 4.3.9 Implied emission factors for pesticide production, Claus process.

	Substance	Interval[1], kg/t	Average, kg/t
Pesticides	SO_2	0.1-26.1	6.2[2]
	NMVOC	0.2-10.4	1.4[3]

[1] of 1980/1985-2021, [2] of 1990-2021, [3] of 1990-2000 and 2013-2021.

Emission trends

The emission of NMVOC from production of pesticides is reduced significantly from 1989 to 1992. The decrease can be explained by introduction of flue gas cleaning equipment rather than any decrease in activity.

The emission of SO_2 is from the sulphur regeneration plant (Claus plant) decreased drastically from 2006-2007 due to installation of a scrubber in the beginning of 2007 (Cheminova, 2008).

Emissions are presented in Figure 4.3.3 and Annex 3C-19.

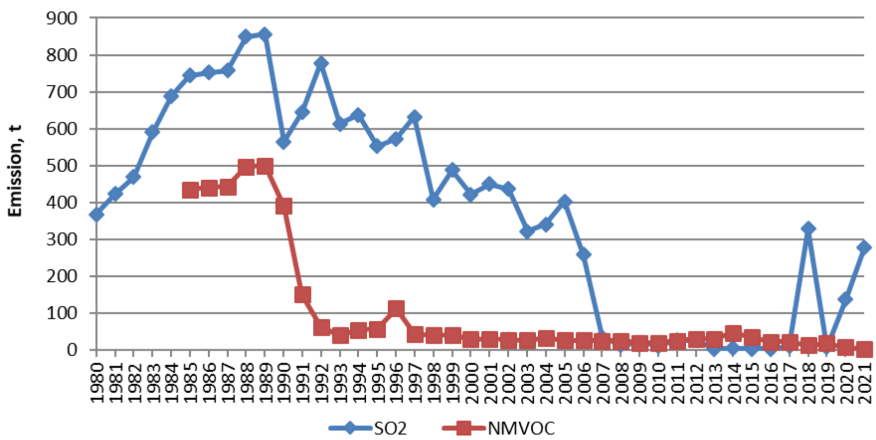


Figure 4.3.3 Emissions of SO_2 and NMVOC from pesticide production.

4.3.6 Production of tar products

One Danish factory (Koppers) situated in Nyborg produces tar products. The following category is covered:

- Production of tar products

The following pollutants are relevant for the production process of tar products:

- SO_2
- NMVOC
- Hg
- PAH: Benzo(a)pyrene

Methodology

Koppers is a chemical plant that refines coal tar. The main products of the company are coal tar pitch, carbon black feedstock, creosote oil and naphthalene.

The production takes place in closed system and the storage tanks is run at vacuum to keep releases to the surroundings to a minimum. (Koppers, 2014).

Activity data are known for 2002-2019 (Koppers, 2017a and 2022) and estimated using surrogate data (Statistics Denmark, 2022) for previous years. The emissions are based on measured emissions reported in the environmental reports from the company (Koppers, 2017a, 2017b and 2022). Where no emissions are reported, these are calculated using implied emission factors.

Activity data

Activity data for production of tar products are presented in Table 4.3.10 and Annex 3C-20 (also presents the surrogate data).

Table 4.3.10 Activity data for production of tar products, kt.

	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Tar products	108	108	181	235	199	164	133	236	274	260	263

Emission factors

Calculated implied emission factors are presented in Table 4.3.11.

Table 4.3.11 Implied emission factors for production of tar products.

Pollutant	Unit	Value	Average of	Applied for
SO_2	t/kt	1.0	2002-2006	1980-2000
NMVOC	kg/kt	4.3	2002-2006	1985-2000
Hg	g/kt	67.8	2008	1990-2007
Benzo(a)pyrene	g/kt	0.7	2005	1990-2021

Emission trends

The SO_2 emission varies depending on the sulphur content in the raw tar. The NMVOC emission is fugitive, i.e. the emission is mainly associated with leakages, maintenance work and accidental releases. As such, there is no correlation between the SO_2 and NMVOC emission as the two pollutants are emitted through different processes from different sources. The Hg emission for the later years is based on measured emissions by the plant. The fluctuations are caused by differences in the raw material, differences in production conditions and differences in abatement efficiency.

Emissions are presented in Table 4.3.12 and Annex 3C-21.

Table 4.3.12 Emissions from production of tar products.

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
SO_2	Mg	108	108	181	235	199	212	105	153	14	14	13
NMVOC	Mg	-	0.5	0.8	1.0	0.9	0.9	1.2	0.9	2.6	2.2	4.8
Hg	kg	-	-	12.3	15.9	13.5	11.1	1.5	1.0	0.2	0.1	1.1
Benzo(a)pyrene	kg	-	-	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2

4.4 Metal production

4.4.1 Source category description

The processes within the sub-sector *Metal industry* (NFR 2C) in Denmark in relation to emission of other pollutants are:

- 2C1 Steel production
- 2C1 Iron production
- 2C3 Secondary aluminium production
- 2C5 Secondary lead production
- 2C7c Red bronze production

The time series for emission of SO_2, NMVOC, particulate matter, heavy metals, and POPs from *Metal production* is available in the NFR tables. Table 4.4.1 presents an overview of emissions from 2021.

Table 4.4.1 Overview of emissions from 2021

	Total emission from Metal industries	Fraction of IPPU, %	Largest contributor in Metal industries	Emission from largest contributor	Fraction of Metal industries, %
SO_2	0.6 t	0.07	2C5 Lead production	0.6 t	100.0
NMVOC	4.8 t	0.01	2C1 Iron and steel production	4.8 t	100.0
TSP	221.5 t	3.1	2C1 Iron and steel production	217.8 t	98.3
HMs	3.1 t	43.9	Pb from 2C5 Lead production	1.5 t	46.2
POPs	0.06 kg	0.1	PCBs from 2C1 Iron and steel production	0.05 kg	92.3

In the NFR tables, steel production and iron production are summed into one category called "Iron and steel production". This NFR sector 2C1 comprises three activities: An electric arc furnace (EAF) (until 2001/2002 and in 2005), rolling mills (from 2003) and grey iron foundries (whole time series). The most interesting activity from an emission perspective is the EAF. After the closing of the EAF, the site has since 2003 been used for rolling steel slabs imported from steelworks in other countries. This change in production results in large changes in activity data and emissions. In 2005, the EAF was shortly reopened, which explains the higher activity level this year.

Regarding the steelworks that use iron and steel scrap as raw material, the emissions to a large degree depend on the quality of the scrap. This fact may result in large annual variations for one or more of the heavy metals. This may also be the case for iron foundries, as they also use scrap as raw material, but they have not been subject to the same requirements to analyse emissions of heavy metals to air.

4.4.2 Steel production

The production of semi-manufactured steel products (e.g. steel sheets/plates and bars) is concentrated at one company: Det Danske Stålvalseværk A/S situated in Frederiksværk. After the closure of the primary production in 2002, the two rolling mills were divided in two companies called DanSteel and Duferco. The following categories are covered:

- Electric furnace steel plant
- Rolling mill

The following pollutants are relevant for the steel production processes:

- SO_2
- NO_x
- NMVOC
- CO
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn
- POPs: HCB, PCDD/F, PAHs, PCB

Methodology

The steelwork was closed down in January 2002 and then partly re-opened again 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 4.4.1.

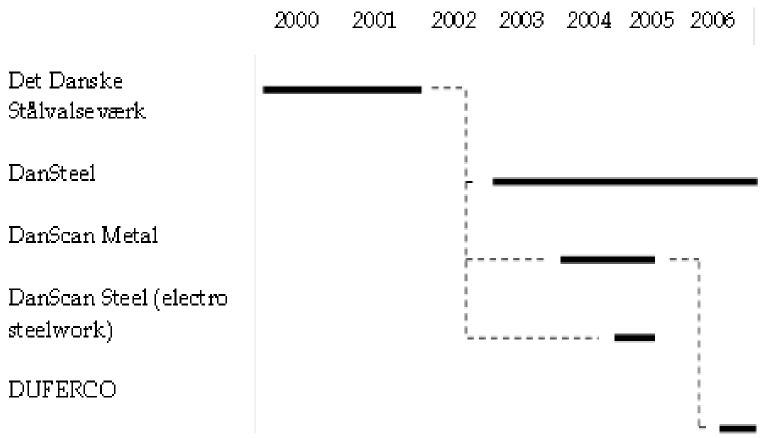


Figure 4.4.1 Timeline for production at the Danish steelwork.

Activity data

Statistical data on steel production activities are available in environmental reports from the single Danish plant (Stålvalseværket, 2002) and the rolling mills factories (DanSteel, 2016 and Duferco, 2014, 2016) supplemented with other literature and personal contact with the plants (DanSteel, 2022 and Duferco, 2021); see Table 4.4.2 and Annex 3C-22.

Table 4.4.2 Overall mass flow for Danish steel production, kt.

		1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Det danske stålvalseværk												
Raw material	Iron and steel scrap	-	-	-	657	680	-	-	-	-	-	-
Intermediate product	Steel slabs etc.	-	-	-	654	803	-	-	-	-	-	-
Product	Steel sheets	444	444	444	478	380	-	-	-	-	-	-
	Steel bars	170	170	170	239	251	-	-	-	-	-	-
	Products, total	614[1]	614[1]	614[1]	717	631	250[2]	-	-	-	-	-
Dansteel												
Raw material	Steel slabs	-	-	-	-	-	515	457	525	637	582	673
Product	Steel sheets	-	-	-	-	-	433	381	441	538	494	561
Duferco												
Raw material	Steel billets	-	-	-	-	-	-	141	137	164	137	126
Product	Steel bars	-	-	-	-	-	-	129	129	156	130	120

[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 applied emission factors are presented in Table 4.4.3. Regarding the electric arc furnace the emissions for all other pollutants than TSP have been estimated by use of emission factor from literature.

Table 4.4.3 Emission factors for steel production.

	Unit	Electric Arc Furnace	Rolling Mill
SO_2	g/t	60[6]	-
NO_x	g/t	130[6]	-
NMVOC	g/t	46[6]	7[6]
CO	kg/t	1.7[6]	-
TSP	g/t	61-68[4]	2.5-11.1[4]
PM_{10}	g/t	80 % of TSP[6]	2.4-10.5[4]
$PM_{2.5}$	g/t	70 % of TSP[6]	1.5-6.6[4]
BC	g/t	0.36 % of $PM_{2.5}$[6]	0.36 % of $PM_{2.5}$[6]
As	mg/t	15[6]	-
Cd	mg/t	10-80[2]	0.1-0.4[4]
Cr	mg/t	100[6]	-
Cu	mg/t	20[6]	-
Hg	mg/t	50-400[2,6]	-
Ni	g/t	0.4-1.4[2]	0.004-0.010[4]
Pb	g/t	1.0-5.0[2]	0.005[5]
Se	g/t	0.02[6]	-
Zn	g/t	3.6-19.0[2,6]	0.005[5]
HCB	mg/t	3.2[3]	-
PCDD/F	mg/t	0.8[6]	-
Total 4 PAHs	g/t	0.48[1,6]	-
PCB	mg/t	2.5[3]	-

[1] Divided by four for an estimate of the individual pollutants, [2] Illerup et al. (1999), [3] Nielsen et al. (2013), [4] Implied emission factor, [5] DCE judgement, [6] EMEP/EEA (2019)

Emission trends

Emissions from the electro steelwork and rolling mills are presented in Table 4.4.4 and Annex 3C-23.

Table 4.4.4 Emissions from the electro steelwork and rolling mills.

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
SO_2	t	37	37	37	43	38	15	-	-	-	-	-
NO_x	t	-	80	80	93	82	33	-	-	-	-	-
NMVOC	t	-	28	32	37	33	19	6.1	6.9	7.7	6.8	8.2
CO	t	-	1.0	1.0	1.2	1.1	0.4	-	-	-	-	-
TSP	t	-	-	141	153	95	72	45.4	52.9	53.6	44.3	56.8
PM_{10}	t	-	-	71	82	33	15	3.0	5.4	4.8	3.4	4.2
$PM_{2.5}$	t	-	-	62	72	29	12	2.5	4.0	3.8	2.7	3.2
BC	t	-	-	0.22	0.26	0.10	0.05	1.11	1.11	1.35	1.13	1.04
As	kg	-	-	9.2	10.8	9.5	3.8	-	-	-	-	-
Cd	kg	-	-	39	22	16	7.1	0.8	0.8	1.0	0.9	0.8
Cr	kg	-	-	61	72	63	25	-	-	-	-	-
Cu	kg	-	-	12	14	13	5.0	-	-	-	-	-
Hg	kg	-	-	246	143	63	13	-	-	-	-	-
Ni	kg	-	-	757	430	252	104	2.8	1.7	2.4	2.1	1.8
Pb	kg	-	-	2967	1720	669	268	1.9	2.2	2.7	2.5	2.8
Se	kg	-	-	12	14	13	5.0	-	-	-	-	-
Zn	kg	-	-	11492	6547	3085	902	3.0	3.3	4.0	3.6	3.8
HCB	kg	-	-	2.0	2.3	2.0	0.8	-	-	-	-	-
PCDD/F	g	-	-	12.0	7.5	0.5	0.8	-	-	-	-	-
Benzo(b)flouranthene	kg	-	-	74	86	76	30	-	-	-	-	-
Benzo(k)flouranthene	kg	-	-	74	86	76	30	-	-	-	-	-
Benzo(a)pyrene	kg	-	-	74	86	76	30	-	-	-	-	-
Indeno(1,2,3-c,d)pyrene	kg	-	-	74	86	76	30	-	-	-	-	-
PCB	kg	-	-	1.5	1.8	1.6	0.6	-	-	-	-	-

Due to the change in production process in the beginning of the 00's, the emissions (and even more so the implied emission factors) change drastically from 2001 to 2002 and from 2002 to 2003. Please refer to Figure 4.4.1 and Table 4.4.2 (Annex 3C-22).

4.4.3 Iron production

Multiple grey iron foundries exist in Denmark, producing a wide range of products like e.g. cast iron pipes, central heating boilers and flywheels. The following category is covered:

- Grey iron foundries

The following pollutants are relevant for the iron production process:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn
- POPs: HCB, PCB

Methodology

There are about 15 grey iron producers in Denmark, most of these are small producing only 10-1000 tonnes per year. The emissions from iron foundries are based on yearly production statistics from Statistics Denmark (2022), emission measurements (implied emission factors) and standard emission factors.

Activity data

Statistical data on production in grey iron foundries are available from Statistics Denmark (2022) for the entire time series. The activity data are presented in Table 4.4.5 and Annex 3C-24.

Table 4.4.5 Activity data, iron foundries, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Grey iron foundries	104.9	100.5	108.0	107.2	86.5	96.2	112.8	99.2	83.5	106.6

Emission factors

The applied emission factors are presented in Table 4.4.6.

Table 4.4.6 Emission factors for grey iron foundries.

	Unit	Grey iron foundries	Reference
TSP	g/t	2000	CEPMEIP[1]
PM_{10}	g/t	600	CEPMEIP[1]
$PM_{2.5}$	g/t	90	CEPMEIP[1]
BC	% of $PM_{2.5}$	10	EMEP/EEA (2019)[2]
As	g/t	0.3	EMEP/Corinair (2007)[3]
Cd	g/t	0.1	EMEP/Corinair (2007)[3]
Cr	g/t	1.0	EMEP/Corinair (2007)[3]
Cu	g/t	1.0	EMEP/Corinair (2007)[3]
Hg	g/t	0.04	EMEP/Corinair (2007)[3]
Ni	g/t	0.3	EMEP/Corinair (2007)[3]
Pb	g/t	3.0	EMEP/Corinair (2007)[3]
Se	g/t	0.01	EMEP/Corinair (2007)[3]
Zn	g/t	5.0	EMEP/Corinair (2007)[3]
HCB	mg/t	0.04	Nielsen et al. (2013).
PCB	mg/t	0.5	Nielsen et al. (2013).

[1] CEPMEIP & EMEP/Corinair 2007, SNAP 030303, Table 8.1, [2] SNAP 040302 Ferroalloys, [3] SNAP 030303, Table 8.1.

Emission trends

Emissions from grey iron foundries are presented in Table 4.4.7 and Annex 3C-25.

Table 4.4.7 Emissions from grey iron foundries.

	Unit	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
TSP	t	210	201	216	214	173	192	226	198	167	213
PM_{10}	t	63	60	65	64	52	58	68	60	50	64
$PM_{2.5}$	t	9	9	10	10	8	9	10	9	8	10
BC	t	0.9	0.9	1.0	1.0	0.8	0.9	1.0	0.9	0.8	1.0
As	kg	31	30	32	32	26	29	34	30	25	32
Cd	kg	10	10	11	11	9	10	11	10	8	11
Cr	kg	105	100	108	107	86	96	113	99	83	107
Cu	kg	105	100	108	107	86	96	113	99	83	107
Hg	kg	4.2	4.0	4.3	4.3	3.5	3.8	4.5	4.0	3.3	4.3
Ni	kg	31	30	32	32	26	29	34	30	25	32
Pb	kg	315	301	324	322	259	289	338	298	250	320
Se	kg	1.0	1.0	1.1	1.1	0.9	1.0	1.1	1.0	0.8	1.1
Zn	kg	524	502	540	536	432	481	564	496	417	533
HCB	g	4.2	4.0	4.3	4.3	3.5	3.8	4.5	4.0	3.3	4.3
PCB	g	52	50	54	54	43	48	56	50	42	53

4.4.4 Secondary aluminium production

Only one Danish producer of secondary aluminium exists; "Stena Aluminium". The following category is covered:

- Secondary aluminium production

The following pollutants are relevant for the secondary aluminium production:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: Cd, Pb
- POPs: HCB, PCDD/F, PCB

Methodology

Secondary aluminium industries were identified from a list of companies with the relevant environmental approvals acquired from the Danish Environmental Agency. All producers were contacted when necessary to determine if they use scrap aluminium in their production. The only secondary aluminium producer (called Stena Aluminium) closed in the end of 2008.

Activity data

The activity data are known from the company's environmental reports (Stena Aluminium, 2008) for 1996-2008 and are presented in Table 4.4.8 and Annex 3C-26.

Table 4.4.8 Activity data for secondary aluminium production, kt.

	1990[1]	1995[1]	2000	2005	2006	2007	2008
Stena Aluminium	30.2	30.2	32.9	23.4	31.3	35.1	36.2

1990-1995: Calculated average of 1996-2000.

Emission factors

Emission factors for the production of secondary aluminium are presented in Table 4.4.9.

Table 4.4.9 Emission factors for secondary aluminium production.

Pollutant	Unit	Value	Source
TSP	kg/t	0.12	Average IEF (1998-2000)
PM_{10}	% of TSP	70.0	EMEP/EEA (2019)
$PM_{2.5}$	% of TSP	27.5	EMEP/EEA (2019)
BC	% of $PM_{2.5}$	2.3	EMEP/EEA (2019)
Cd	g/t	0.03	Average IEF (1998-2000)
Pb	g/t	0.15	Average IEF (1998-2000)
HCB	mg/t	20.0	Nielsen et al. (2013)
PCDD/F	mg/t	0.035	EMEP/EEA (2019)
PCB	mg/t	3.4	Nielsen et al. (2013)

Emission trends

Emissions from secondary aluminium production are available in Table 4.4.10 and Annex 3C-27.

Table 4.4.10 Emissions from secondary aluminium production.

	Unit	1990	1995	2000	2005	2006	2007	2008
TSP	t	3.6	3.6	3.9	2.8	3.8	4.2	4.3
PM_{10}	t	2.5	2.5	2.8	2.0	2.6	2.9	3.0
$PM_{2.5}$	t	1.0	1.0	1.1	0.8	1.0	1.2	1.2
BC	kg	23.0	23.0	25.0	17.8	23.8	26.7	27.5
Cd	kg	0.91	0.9	1.0	0.7	0.9	1.1	1.1
Pb	kg	4.5	4.5	4.9	3.5	4.7	5.3	5.4
HCB	kg	0.60	0.60	0.66	0.47	0.63	0.70	0.72
PCDD/F	g	1.1	1.1	1.2	0.8	1.1	1.2	1.3
PCB	kg	0.10	0.10	0.11	0.08	0.11	0.12	0.12

4.4.5 Secondary lead production

One Danish company producing secondary lead has been identified; Hals Metal. The following category is covered:

- Secondary lead production

The following pollutants are relevant for the secondary lead production:

- SO_2
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$
- Heavy metals: As, Cd, Hg, Pb, Zn
- POPs: HCB, PCDD/F, PCB

Methodology

Only one Danish company, called Hals Metal A/S, 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.

Hals Metal A/S has closed down in 2021. This year's reporting of 2021 data will therefore be the last production year from the plant.

Activity data

Activity data from Hals Metal is provided by the company (Hals Metal, 2021). 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 melting. 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) stated that 200-300 tonnes lead tiles were recast in 2000. Since the building stock worthy of preservation is constant, it is considered reasonable to also let the activity of recasting of lead tiles be constant.

Activity data for secondary lead is shown in Table 4.4.11 and Annex 3C-28.

Table 4.4.11 Activity data for secondary lead production, t.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Hals Metal	540	750	540	691	635	745	348	322	194	97
Lead tiles	250	250	250	250	250	250	250	250	250	250
Total	790	1000	790	941	885	995	598	572	444	347

Emission factors

Emission factors are presented in Table 4.4.12. Measurements of SO_2, Hg, PCDD/F and PCB are available for Hals Metal for 2008-2010, these measurements are used to calculate plant specific emission factors. For Hg, the calculated implied emission factor (IEF) is also applied to the unabated production as a country specific emission factor. Hals Metal is a modern secondary lead production facility, and emission factors for "current technology" are therefore chosen for emission factors found in literature.

Table 4.4.12 Emission factors for secondary lead production.

Pollutant	Unit	Current technology	Reference	Unabated	Reference
SO_2	kg/t	6.4	Average IEF (2008-2010)	NA	
TSP	kg/t	0.012	BREF, Table 5.13	14.8	EMEP/EEA (2019)[1]
PM_{10}	kg/t	0.010	Visschedijk et al. (2004)	11.8	EMEP/EEA (2019)[1]
$PM_{2.5}$	kg/t	0.005	Visschedijk et al. (2004)	8.8	EMEP/EEA (2019)[1]
As	g/t	0.09	BREF, Table 5.13	47	EMEP/EEA (2019)[1]
Cd	g/t	0.03	BREF, Table 5.13	15	EMEP/EEA (2019)[1]
Hg	g/t	0.46	Average IEF (2008-2010)	0.46	Average IEF (2008-2010)
Pb	g/t	2.3	BREF, Table 5.13	5800	EMEP/EEA (2019)[1]
Zn	g/t	0.04	BREF, Table 5.13[2]	35	EMEP/EEA (2019)[1]
HCB	µg/t	300	Nielsen et al. (2013)	300	Nielsen et al. (2013)
PCDD/F	µg/t	2.0	Average IEF (2008-2010)	8.0	EMEP/EEA (2019)[1]
PCB	µg/t	981	Average IEF (2008-2010)	3.2	EMEP/EEA (2019)[1]

[1] Chapter 2.C.5, Table 3.4, [2] Value for Ausmelt/ISASMELT

Emission trends

Emissions from secondary lead production are available in Table 4.4.13 and Annex 3C-29.

Table 4.4.13 Emissions from secondary lead production.

	Unit	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
SO_2	t	3.5	4.8	3.5	4.4	4.1	4.8	2.2	2.1	1.2	0.6
TSP	t	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
PM_{10}	t	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
$PM_{2.5}$	t	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
As	kg	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
Cd	kg	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Hg	kg	0.4	0.5	0.4	0.4	0.4	0.5	0.3	0.3	0.2	0.2
Pb	kg	1451	1452	1451	1452	1451	1452	1451	1451	1450	1450
Zn	kg	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
HCB	g	0.2	0.3	0.2	0.3	0.3	0.3	0.2	0.2	0.1	0.1
PCDD/F	mg	3.1	3.5	3.1	3.4	3.3	3.5	2.7	2.6	2.4	2.2
PCB	g	0.5	0.7	0.5	0.7	0.6	0.7	0.3	0.3	0.2	0.1

4.4.6 Red bronze production

The following category is covered:

- Allied metal manufacturing (Red bronze production)

The following pollutants are relevant for the red bronze production process:

- Heavy metals: Cd, Cu, Pb, Zn

Methodology

In Denmark casting of brass and bronze primarily occurs in clay bonded sand or chemically bonded sand with or without core. These production processes are usually used in small production and are suitable for series of 1-100 pcs, e.g. for prototypes, test series and small production series.

In addition, lost-wax precisions casting is used for e.g. sculptures and shell molding (aka. Croning casting) for large or medium-sized batches.

Products vary from valves and propellers to headstone ornaments and sculptures. The weight of these product are known to vary from 5 grams up to 2.5 tonnes.

Activity data

Activity data are estimated based on Statistics Denmark (2022), Illerup et al. (1999). Activity data are presented in Table 4.4.14 and Annex 3C-30.

Table 4.4.14 Activity data for red bronze production, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Red bronze production	3.9	4.5	4.3	5.5	4.6	3.8	4.0	3.7	3.1	3.1

Emission factors

The applied emission factors are presented in Table 4.4.15 and are all referenced to Illerup et al. (1999).

Table 4.4.15 Emission factors for red bronze production.

Pollutant	Unit	Value
Cd	g/t	1
Cu	g/t	10
Pb	g/t	15
Zn	g/t	140

Emission trends

Emissions trends for Cd, Cu, Pb, and Zn from red bronze production are presented in Table 4.4.16 and Annex 3C-31.

Table 4.4.16 Emissions from red bronze production, kg.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Cd	3.9	4.5	4.3	5.5	4.6	3.8	4.0	3.7	3.1	3.1
Cu	39	45	43	55	46	38	40	37	31	31
Pb	58	67	65	82	69	58	60	56	47	46
Zn	545	630	603	769	648	538	557	521	437	428

4.5 Non-energy products from fuels and solvent use

4.5.1 Source category description

The processes within the sub-sector *Non-energy products from fuels and solvent use* (NFR 2D) in Denmark in relation to emission of other pollutants are:

- 2D3a, d, e, f, g, h, i NMVOCs used as solvents
- 2D3b Road paving with asphalt
- 2D3c Asphalt roofing

The creosote treatment of wood is not occurring in Denmark. It would require a special permission in order to use creosote for wood treatment in Denmark, no such permission has been granted.

It is unknown to what extent asphalt blowing is occurring in Denmark. There is no Tier 1 methodology and emission factor available in the EMEP/EEA Guidebook. The emission factors presented in the Guidebook (Table 3-8) refers to the 2007 version of the EMEP/Corinair Guidebook. When examining EMEP/Corinair (2007), the emission factor stated for PAH is 3.75 kg per tonne, which for some reason has ended up in EMEP/EEA (2019) as 4.00 kg per tonne benzo(a)pyrene. As the original (non-referenced) emission factor is total PAH, it would be incorrect to accept this as the emission factor for benzo(a)pyrene.

4.5.2 NMVOC from solvents use

NMVOC emissions from solvent use are allocated in the following categories according to EMEP/EEA (2019):

- 2D3a Domestic solvent use including fungicides
- 2D3d Coating applications
- 2D3f Dry cleaning incl. 2D3e Degreasing
- 2D3g Chemical products
- 2D3h Printing
- 2D3i Other solvent use

Only NMVOCs used as solvents are relevant for these categories. 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 (UNFCCC, 2008; Pärt, 2005; Karjalainen, 2005). 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 solvent ends up in waste or as emissions to water and may finally also contribute to air pollution by evaporation from these compartments. Emission inventories for solvents are based on model estimates, as direct and continuous emissions are only measured from a limited number of sources.

Methodology

The amount of solvent use attributing emissions in the industrial sectors and households are calculated using a model that is readily updated on a yearly basis.

The method is mainly based on the detailed approach and methodology described in EMEP/EEA (2019) and IPCC (2006), and emissions are calculated for industrial sectors, households for the stated NFR sectors, as well as for individual pollutants.

The emission modelling of solvents is done by estimating the amount of (pure) solvents consumed. All relevant solvents must be estimated, or at least those together representing more than 90 % of the total pollutant emission. (EMEP/EEA, 2019; IPCC, 2006).

The detailed method used in the Danish emission inventory for solvent use, represents a chemicals approach, where each pollutant is estimated separately. The sum of emissions of all estimated pollutants used as solvents equals the pollutant emission from solvent use.

Pollutant list

The definitions of solvents and (NM)VOC that are used in the Danish emission inventory 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".

This implies that some NMVOCs, e.g. ethylene glycol, that have vapour pressures just around 0.01 kPa at 20 °C, may only be defined as VOCs at use conditions with higher temperature. However, use conditions at elevated temperatures are typically found in industrial processes. Here the capture of solvent fumes is often efficient, thus resulting in small emissions (communication with industries).

The Danish list of NMVOCs comprises approx. 30 pollutants or pollutant groups representing more than 95 % of the total emission from solvent use, cf. Table 4.5.4.

Activity data

For each pollutant or product a mass balance is formulated:

Consumption = (production + import) – (export + destruction/disposal + hold-up)

Data on production, import and export amounts of solvents and solvent containing products are collected from Statistics Denmark (2022), which contains detailed statistical information on the Danish society. Manufacturing and trading industries are committed to reporting production and trade figures to the Danish Customs & Tax Authorities in accordance with the Combined Nomenclature. Import and export figures are available on a monthly basis from 1988 to present. Production figures are reported quarterly as "industrial commodity statistics by commodity group and unit" from 1990 to present.

Destruction and disposal of solvents lower the pollutant emissions. In principle this amount must be estimated for each pollutant in all industrial activities and for all uses of pollutant containing products. At present the solvent inventory only considers destruction and disposal for a limited number of pollutants. For some pollutants it is inherent in the emission factor, and for others the reduction is specifically calculated from information obtained from the industry or literature.

Hold-up is the difference in the amount in stock in the beginning and at the end of the year of the inventory. No information on solvents in stock has been obtained from industries. Furthermore, the inventory spans over several years so there will be an offset in the use and production, import and export balance over time.

In some industries the solvents are consumed in the process, e.g. in the graphics and plastic industry, whereas in the production of paints and lacquers the solvents are still present in the final product. These products can either be exported or used in the country. In order not to double count consumption amounts of pollutants it is important to keep track of total solvent use, solvents not used in products and use of solvent containing products. Furthermore some pollutants may be represented as individual pollutants and also in chemical groups, e.g. "o-xylene", "mixture of xylenes" and "xylene". Some pollutants are better inventoried as a group rather than individual pollutants, due to missing information on use or emission for the individual pollutants. The Danish inventory considers single pollutants, with a few exceptions.

Activity data for pollutants are thus primarily calculated from the mass balance equation with input from Statistics Denmark. When Statistics Denmark holds no information on production, import and export or when more reliable information is available from industries, scientific reports or expert judgements the data can be adjusted or even replaced. The used amounts of products (activity data) in Table 4.5.1 are derived from used amounts of pollutants by assessing the amount of pollutants that is comprised within products belonging to each of the categories. The complete time series is presented in Annex 3C-32.

Table 4.5.1 Activity data for NMVOCs used as solvents, kt.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Coating applications	94.1	83.5	91.0	104.2	74.6	45.1	43.1	38.4	37.5	43.6
Degreasing, dry cleaning and electronics	1.7	1.4	1.5	0.6	0.4	0.2	0.2	0.2	0.3	0.2
Chemical products manufacturing or processing	415	407	575	585	751	629	513	521	511	523
Other use of solvents and related activities	198	176	212	197	182	143	146	132	129	139
Printing industry	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Domestic solvent use	35.2	29.1	43.9	41.0	35.5	25.6	38.8	28.6	40.9	21.3

Emission factors

For each pollutant the emission is calculated by multiplying the consumption with the fraction emitted (emission factor), according to:

*Emission = consumption * emission factor*

The present Danish method uses emission factors that represent specific industrial activities, such as processing of polystyrene, dry cleaning etc. or that represent use categories, such as paints and detergents. Some pollutants have been assigned emission factors according to their water solubility. Higher hydrophobicity yields higher emission factors, since a lower amount ends in waste water, e.g. ethanol (hydrophilic) and turpentine (hydrophobic).

Emission factors for solvents are categorised in four groups in ascending order: (1) Lowest emission factors in the chemical industry, e.g. lacquer and paint manufacturing, due to emission reducing abatement techniques and destruction of solvent containing waste, (2) Other processes in industry, e.g. graphic industry, have higher emission factors, (3) Non-industrial use, e.g. auto repair and construction, have even higher emission factors, (4) Diffuse use of solvent containing products, e.g. painting, where practically all the pollutant present in the products will be released during or after use.

For a given pollutant the consumed amount can thus be attributed with two or more emission factors; one emission factor representing the emissions occurring at a production or processing plant and one emission factor representing the emissions during use of a solvent containing product. If the chemical is used in more processes and/or is present in several products more emission factors are assigned to the respective chemical amounts.

Emission factors can be defined from surveys of specific industrial activities or as aggregated factors from industrial branches or sectors. Furthermore, emission factors may be characteristic for the use pattern of certain products. The emission factors used in the Danish inventory also rely on the work done in a joint Nordic project (Fauser et al., 2009).

The emission factors are listed in Table 4.5.2 and Annex 3C-33. They are based on the values in the Guidebook (EMEP/EEA, 2019) and adjusted on a country specific basis according to the assessment described above. For more details, please refer to the sector report Hjelgaard & Nielsen (2018).

Table 4.5.2 NMVOC emission factors for solvent use.

	Unit	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Coating applications	t/kt	59	60	63	60	56	59	60	60	60	62
Degreasing, dry cleaning and electronics	t/kt	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Chemical products manufacturing or processing	t/kt	21	20	17	12	8	8	10	10	10	10
Other use of solvents and related activities	t/kt	117	120	112	111	90	109	99	103	103	110
Printing industry	t/kt	40	40	42	40	34	39	39	39	40	39
Domestic solvent use	t/kt	151	145	157	155	145	137	149	121	125	143

Source allocation

The Danish Working Environment Authority (WEA) is administrating the registrations of chemicals and products to the Danish product register. All manufacturers and importers of products for occupational and commercial use are obliged to register. The following products are comprised in the registration agreement:

- Chemicals and materials that are classified as dangerous according to the regulations set up by the Danish Environmental Protection Agency (EPA).
- Chemicals and materials that are listed with a limit value on the WEA "limit value list".
- Materials, containing 1 % or more of a chemical, which is listed on the WEA "limit value list".
- Materials, containing 1 % or more of a chemical, which are classified as hazardous to humans or the environment according to the EPA rules on classification.

There are the following important exceptions for products, which do not need to be registered:

- Products exclusively for private use.
- Pharmaceuticals ready for use.
- Cosmetic products.

The Danish product register does therefore not comprise a complete account of used pollutants. Source allocations of exceptions from the duty of declaration are done based on information from trade organisations, industries and scientific reports.

The database Substances in Preparations in the Nordic Countries (SPIN) holds information on use of various pollutants in product and activities, i.e. Use Categories Nordic (UCN), and on use in industrial categories, i.e. according to the standard nomenclature for economic activities (NACE) system. The use amount from Statistics Denmark is first distributed in SNAP categories according to UCN data, and second according to NACE industrial use in NFR categories.

Use of spray cans

Emissions from use of spray cans (CRF 3D3i Other solvent use) include the propellant (propane and butane) and solvents. Propellants comprise, according to communication with "Aerosol Industriens Brancheforening" and FORCE (2009), approx. 33 vol-% (24 weight-%) of a can. According to Rambøll (2004) the remaining amount is solvents (VOCs), 71 weight-% for spray paint and 51 weight-% for cosmetics, and non-VOCs, 5 weight-% for spray paints and 25 weight-% for cosmetics. 3% of the Danish marked is spray paints. The rest is cosmetics, which comprises deodorants, hairspray and foam products. 90% of the use in Denmark is imported. It is assumed that approx. 5% remains in the can and is destroyed in waste handling. Based on these assumptions the total VOC emissions from use of spray cans in Denmark is 1.79 kt per year. This amount is assigned to all years as no detailed consumption trend is available. The specific compounds are propane and butane as propellants and ethanol, tert-butanol, acetone, butanone, butylacetate, ethylacetate, propanol, toluene and xylene as solvents.

Emission trends

Table 4.5.3, Figure 4.5.1 and Annex 3C-34 show the emissions of NMVOC, where the used amounts of single pollutants have been assigned to specific products and NFR sectors. The general decrease from 1996 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.

Table 4.5.3 NMVOC emissions from solvent use.

	Unit	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Coating applications	kt	5.5	5.0	5.8	6.2	4.2	2.7	2.6	2.6	2.9	3.1
Degreasing and dry cleaning	t	0.09	0.07	0.08	0.03	0.02	0.01	0.01	0.01	0.01	0.01
Chemical products	kt	8.6	8.1	9.7	7.1	6.3	4.9	4.9	5.2	6.6	5.8
Other use of solvents	kt	23.2	21.1	23.7	21.9	16.4	15.5	14.4	14.3	18.1	17.8
Printing industry	t	9.1	8.0	9.7	7.1	6.3	9.1	9.5	9.5	14.2	12.9
Domestic solvent use	kt	5.3	4.2	6.9	6.3	5.1	3.5	5.8	2.6	3.0	4.0
Total NMVOC	kt	42.6	38.4	46.1	41.6	32.1	26.7	27.7	24.7	30.6	30.6

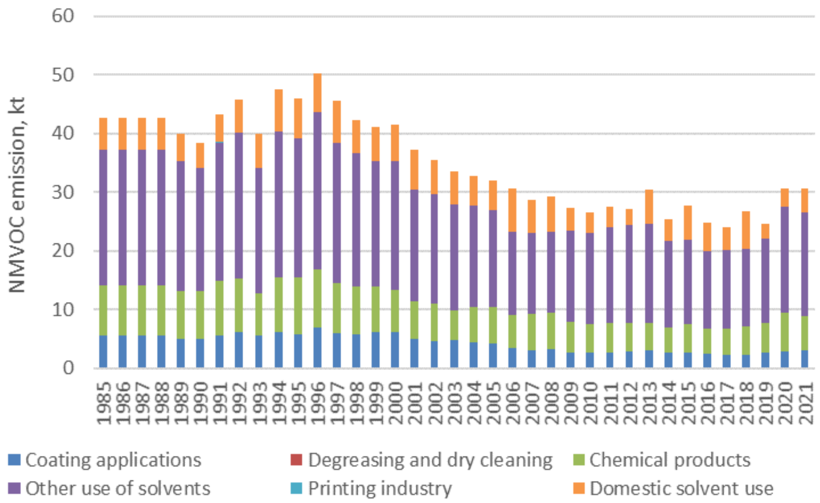


Figure 4.5.1 NMVOC emissions from solvent use, kt.

In Table 4.5.4 the emission for 2021 is split into individual pollutants. The most abundantly used solvents are ethanol and turpentine, or white spirit defined as a mixture of stoddard solvent and solvent naphtha and propylalcohol. Ethanol is used as solvent in the chemical industry and as windscreen washing agent. Turpentine is used as thinner for paints, lacquers and adhesives. Propylalcohol is used in cleaning agents in the manufacture of electrical equipment, flux agents for soldering, as solvent and thinner and as windscreen washing agent. Household emissions are dominated by propane and butane, which are used as aerosols in spray cans, primarily in cosmetics. For some pollutants the emission factors are precise but for others they are rough estimates. The division of emission factors into four categories implies that high emission factors are applicable for use of solvent containing products and lower emission factors are applicable for use in industrial processes.

Table 4.5.4 2021 NMVOC emissions of single pollutants or pollutant groups.

Pollutant	CAS no	Emissions, t
ethanol	64-17-5	10258
turpentine (white spirit: stoddard solvent and solvent naphtha)	64742-88-7 8052-41-3	7375
propyl alcohol	67-63-0	3992
pentane	109-66-0	2362
propylene glycol	57-55-6	1821
methanol	67-56-1	1157
cyanates	79-10-7	1003
acetone	67-64-1	664
1-butanol	71-36-3	292
propane	74-98-6	282
butane	106-97-8	282
phenol	108-95-2	229
xylenes	1330-20-7 95-47-6 108-38-3 106-42-3	174
glycol ethers	110-80-5 107-98-2 108-65-6 34590-94-8 112-34-5 and others	150
butanoles	78-92-2 2517-43-3 and others	146
toluene	108-88-3	124
cyclohexanones	108-94-1	63.4
ethylene glycol	107-21-1	61.4
styrene	100-42-5	52.2
ethyl acetate	141-78-6	50.2
butanone	78-93-3	45.7
formaldehyde	50-00-0	36.9
butyl acetate	123-86-4	20.3
acyclic aldehydes	78-84-2	5.1
tetrachloroethylene	127-18-4	2.3
acrylic acid	79-10-7	0.05
Total		30,650

4.5.3 Road paving with asphalt

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 following category is covered:

- Road paving with asphalt

The following pollutants are relevant for road paving with asphalt:

- NMVOC
- CO
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC

The raw materials for construction of transport facilities are prepared at 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.

Methodology

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 litre 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 solvent categories above with an emission factor of approximately unity. This means that NMVOC emissions from "cutback" asphalt in Road paving NFR 2D3b only include emissions from the asphalt fraction as quantified in Table 4.5.5.

Emissions are calculated as activity data multiplied with emission factors for all pollutants.

Activity data

The use amounts of asphalt for road paving have been compiled from production, import and export statistics of asphalt products in Statistics Denmark (2022) and are presented in Table 4.5.5 and Annex 3C-35.

Table 4.5.5 Activity data for asphalt in road paving, kt.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Road paving with asphalt	2743	2535	3144	2933	3879	3005	3440	3508	3833	3606

Emission factors

Default emission and abatement factors are derived from EMEP/EEA (2019) and US EPA (2004).

Table 4.5.6 Emission factors for road paving with asphalt.

	Unit	Road paving with asphalt (incl. cutback)	Abatement factors[1], %
NMVOC	g/t	16	-
CO	g/t	120	-
TSP	g/t	50	99.6
PM_{10}	g/t	49	98.4
$PM_{2.5}$	g/t	6.6	98.4
BC	g/t	0.37	98.4

[1] The abatement factors have already been subtracted from the presented emission factors

Emission trends

Emissions from road paving with asphalt are presented in Table 4.5.7 and Annex 3C-36.

Table 4.5.7 Emissions from road paving with asphalt, t.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
NMVOC	44	41	50	47	62	48	55	56	61	58
CO	330	305	378	353	466	361	414	422	461	433

TSP	-	128	158	148	195	151	173	177	193	182
PM_{10}	-	125	155	144	191	148	169	173	189	177
$PM_{2.5}$	-	16.6	20.6	19.2	25.4	19.7	22.6	23.0	25.1	23.7
BC	-	0.95	1.18	1.10	1.45	1.12	1.29	1.31	1.43	1.35

4.5.4 Asphalt roofing

Asphalt roofing covers the following category:

- Asphalt roofing

The following pollutants are relevant for asphalt roofing:

- NMVOC
- CO
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC

Methodology

Emissions are calculated by multiplying activity data and emission factors.

Activity data

The used amounts of asphalt for roofing have been compiled from production, import and export statistics of asphalt products in Statistics Denmark (2022) and are available in Table 4.5.8 and Annex 3C-37.

Table 4.5.8 Activity data for asphalt roofing, kt.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Asphalt roofing	55.7	56.1	57.0	88.5	69.6	43.9	47.0	59.1	60.0	63.9

Emission factors

Default emission and abatement factors are derived from EMEP/EEA (2019).

Table 4.5.9 Emission factors for asphalt roofing.

	Unit	Asphalt roofing	Abatement factors[1], %
NMVOC	g/t	130	-
CO	g/t	9.5	-
TSP	g/t	96	94
PM_{10}	g/t	24	94
$PM_{2.5}$	g/t	4.8	94
BC	mg/t	0.60	94

[1] The abatement factors have already been subtracted from the presented emission factors.

Emission trends

Emissions from asphalt roofing are presented in Table 4.5.10 and Annex 3C-38.

Table 4.5.10 Emissions from asphalt roofing.

	Unit	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
NMVOC	t	7.2	7.3	7.4	11.5	9.0	5.7	6.1	7.7	7.8	8.3
CO	t	0.53	0.53	0.54	0.84	0.66	0.42	0.45	0.56	0.57	0.61
TSP	t	-	5.4	5.5	8.5	6.7	4.2	4.5	5.7	5.8	6.1
PM_{10}	t	-	1.3	1.4	2.1	1.7	1.1	1.1	1.4	1.4	1.5
$PM_{2.5}$	t	-	0.27	0.27	0.42	0.33	0.21	0.23	0.28	0.29	0.31
BC	kg	-	0.034	0.034	0.053	0.042	0.026	0.028	0.035	0.036	0.038

4.6 Other product use

4.6.1 Source category description

The sub-sector *Other product use* (NFR 2G) covers the following processes relevant for the Danish inventories:

- 2G4 Use of fireworks
- 2G4 Use of tobacco
- 2G4 Use of shoes
- 2G4 Use of charcoal for barbeques
- 2G4 Paraffin wax use (Combustion of candles)

The time series for emission from *Other product use* is available in the NFR tables. Table 4.6.1 presents an overview of emissions from 2021.

Table 4.6.1 Overview of 2021 emissions from Other product use.

	Total emission from Other product use		Fraction of IPPU, %	Largest contributor in Other product use	Emission from largest contributor		Fraction of Other product use, %
SO_2	0.05	kt	5.4	Charcoal for barbeques	0.04	kt	76.9
NO_x	0.05	kt	70.0	Charcoal for barbeques	0.04	kt	76.5
NMVOC	0.07	kt	0.2	Charcoal for barbeques	0.04	kt	57.7
CO	3.23	kt	87.8	Charcoal for barbeques	2.65	kt	82.2
NH_3	0.02	kt	6.1	Use of tobacco	0.02	kt	95.1
TSP	0.35	kt	4.9	Use of fireworks	0.20	kt	56.5
HMs	3.87	t	54.1	Cu from use of fireworks	2.22	t	57.4
POPs	91.6	kg	91.4	PAH from charcoal for barbeques	90.0	kg	98.2

Emissions of Hg from product uses are a difficult area to assess. In Denmark, a lot of Hg, associated with uses in products, is collected annually and exported for disposal or reuse. In total, 2-4 tons of Hg are collected annually. In addition, some of the products containing Hg will end up in the regular waste stream and will be incinerated. The emissions from the incineration of waste is already included in the inventory as documented in the stationary combustion chapter. Considering the collection and the emissions already covered in the inventory, the emission estimate is considered accurate. No other data sources have been identified.

4.6.2 Use of other products

As listed above Table 4.6.1, this category includes the use of fireworks, tobacco, shoes, charcoal for barbeques and the use of paraffin wax candles.

The following pollutants are relevant for the other product use:

- SO_2
- NO_x
- NMVOC
- CO
- NH_3
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn
- POPs: HCB, PCDD/F, PAHs (benzo(a)pyrene, benzo(b)flouranthene, benzo(k)flouranthene, indeno(1,2,3-c-d)pyrene), PCBs

Methodology

Data on the used amounts of product are obtained from Statistics Denmark (2022), emission factors are primarily from international literature and guidelines.

For more information on what is included and descriptions of the trends, please refer to Hjelgaard & Nielsen (2018).

Activity data

Data on consumption of other products are presented in Table 4.6.2 and Annex 3C-39.

Table 4.6.2 Activity data for the use of other products.

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Fireworks	kt	1.0	1.0	1.3	3.0	4.9	3.7	5.4	5.8	4.3	4.2	5.0
Tobacco	kt	14.5	14.3	13.1	11.7	11.4	10.5	9.5	7.3	6.6	5.6	5.7
Shoes	million inhabitants	-	-	5.1	5.2	5.3	5.4	5.5	5.7	5.8	5.8	5.8
BBQs	kt	1.9	4.4	7.2	7.9	13.4	14.9	7.8	16.3	9.1	6.6	12.8
Paraffin wax	kt	-	10.9	7.4	9.1	16.9	34.4	35.2	24.0	20.7	19.4	22.5

Emission factors

The emission factor for fireworks for Pb was changed in 2000 and Hg and Pb, along with any compounds derived here from, were forbidden in 2003 and 2007, respectively. Emissions are therefore noted as not occurring for these years and forward.

Default emission factors are compiled from the scientific literature and are presented in Table 4.6.3.

Table 4.6.3 Emission factors for other product use.

Compound	Unit	Fireworks	Tobacco	Shoes	BBQs	Candles
SO_2	kg/t	1.94 (a)	0.40(e)		3.10 (i)	
NO_X	kg/t	0.26 (f)	1.80(f)		2.95 (j)[4]	
NMVOC	kg/t	-	4.84 (f)		2.95 (j)[4]	
CO	kg/t	6.90 (a)	55.10(f)		206.5 (j)[4]	10 (l)
NH_3	kg/t	-	4.15(f)		0.10 (e)	
TSP	kg/t	39.66 (b)	13.67(g)	0.75[5]	3.10 (i)	1.34 (m)
PM_{10}	kg/t	35.69 (b/f)	13.67(g)	NO	3.10 (i)	1.34
$PM_{2.5}$	kg/t	19.83 (b/f)	13.67(g)	NO	3.10 (i)	1.34
BC	% of $PM_{2.5}$	-	0.45 (f)		14.7 (e)	
As	g/t	1.33 (f)	0.16 (h)		0.10 (i)	
Cd	g/t	0.67 (c)	0.02(e)		0.04 (i)	
Cr	g/t	15.56 (f)	0.15 (h)		0.04 (e)	
Cu	g/t	444.4 (f)	0.35 (h)		0.15 (e)	
Hg	g/t	0.06 (f)[1]	0.01(e)		0.07 (i)	
Ni	g/t	30 (f)	0.03(e)		0.13 (i)	
Pb	g/t	2200 (d)[2]	0.64(e)		4.45 (i)	
		666.7 (c)[3]	-		-	
Se	g/t	-	0.01(e)		0.65 (i)	
Zn	g/t	260 (f)	1.61(e)		1.90 (e)	
HCB	mg/t	-	-		0.10 (e)	
PCDD/Fs	µg/t	-	0.10 (f)		10.50 (k)	0.027 (n)
Benzo(b)fluoranthene	g/t	-	0.05 (f)		2.14 (e)	
Benzo(k)fluoranthene	g/t	-	0.05 (f)		1.25 (e)	0.005 (m)
Benzo(a)pyrene	g/t	-	0.11 (f)		2.16 (e)	0.004 (m)
Indeno(1,2,3-cd)pyrene	g/t	-	0.05 (f)		1.46 (e)	0.001 (m)
PCB		-	-		0.13 (e)	

NO: Not occurring, NAV: Not available, [1] The emission of Hg from fireworks was banned in 2002, [2] 1980-1999, [3] 2000-2006, [4] Calculated from default uncontrolled combustion and a net calorific value of 30 MJ/kg, [5] Unit is g per inhabitant, (a) Van der Maas et al. (2010), (b) Klimont et al. (2002), (c) Passant et al. (2003), (d) Miljöförvaltningen (1999), (e) Emission factors for wood (111A) combustion 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), (f) EMEP/EEA (2019), (g) Martin et al. (1997), (h) Finstad & Rypdal (2003), (i) Environment Australia (1999), (j) IPCC (1996), (k) Hansen (2000), (l) Hamins et al. (2005), (m) Fine et al. (1999), (n) Lau et al. (1997).

Emission trends

An excerpt of the calculated emissions from other product use is shown in Table 4.6.4. The full time series for all pollutants is available in Annex 3C-40.

Table 4.6.4 Excerpt of the emissions from other product use.

		Unit	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
NO_x	Fireworks	t	0.3	0.3	0.8	1.3	1.0	1.4	1.5	1.1	1.1	1.3
	Tobacco	t	25.7	23.7	21.1	20.6	18.9	17.2	13.2	11.9	10.1	10.3
	BBQ	t	13.1	21.2	23.3	39.4	44.0	23.1	48.1	26.9	19.3	37.9
	Total	t	39.0	45.1	45.2	61.2	63.9	41.7	62.8	40.0	30.6	49.5
CO	Fireworks	t	6.9	8.8	20.7	33.5	25.4	37.4	40.0	29.4	29.3	34.4
	Tobacco	t	785.2	723.6	646.2	629.0	577.3	524.9	403.9	364.8	309.7	315.6
	BBQ	t	914.6	1481.1	1630.3	2758.4	3082.0	1617.8	3367.3	1884.6	1354.4	2649.8
	Paraffin wax	t	108.8	74.4	91.0	169.3	344.3	351.6	240.4	207.1	194.2	225.2
	Total	t	1815.6	2288.0	2388.1	3590.1	4029.1	2531.8	4051.6	2485.8	1887.5	3225.1
$PM_{2.5}$	Fireworks	t	-	25.4	59.4	96.3	73.1	107.5	114.8	84.5	84.2	99.0
	Tobacco	t	-	179.6	160.4	156.1	143.3	130.3	100.2	90.5	76.9	78.3
	BBQ	t	-	22.2	24.5	41.4	46.3	24.3	50.6	28.3	20.3	39.8
	Paraffin wax	t	-	10.0	12.2	22.7	46.1	47.1	32.2	27.7	26.0	30.2
	Total	t	-	237.2	256.5	316.5	308.7	309.2	297.8	231.0	207.4	247.2
Cu	Fireworks	kg	-	568.4	1332.3	2157.5	1637.1	2409.8	2573.8	1892.8	1886.5	2217.9
	Tobacco	kg	-	4.6	4.2	4.0	3.7	3.4	2.6	2.3	2.0	2.0
	BBQ	kg	-	1.1	1.2	2.0	2.3	1.2	2.5	1.4	1.0	2.0
	Total	kg	-	574.2	1337.6	2163.6	1643.1	2414.3	2578.9	1896.6	1889.5	2221.9
Hg	Fireworks	kg	-	0.1	0.2	0.3	-	-	-	-	-	-
	Tobacco	kg	-	0.08	0.07	0.07	0.06	0.06	0.04	0.04	0.03	0.03
	BBQ	kg	-	0.5	0.5	0.9	1.0	0.5	1.1	0.6	0.4	0.8
	Total	kg	-	0.6	0.8	1.2	1.0	0.6	1.1	0.6	0.5	0.9
Pb	Fireworks	kg	-	2813.9	6595.4	3236.7	2456.0	-	-	-	-	-
	Tobacco	kg	-	8.5	7.6	7.4	6.7	6.1	4.7	4.3	3.6	3.7
	BBQ	kg	-	31.9	35.1	59.4	66.4	34.9	72.6	40.6	29.2	57.1
	Total	kg	-	2854.3	6638.1	3303.5	2529.2	41.0	77.3	44.9	32.8	60.8
Zn	Fireworks	kg	-	332.6	779.5	1262.3	957.8	1409.8	1505.8	1107.4	1103.7	1297.6
	Tobacco	kg	-	21.1	18.9	18.4	16.9	15.3	11.8	10.7	9.0	9.2
	BBQ	kg	-	13.6	15.0	25.4	28.4	14.9	31.0	17.3	12.5	24.4
	Total	kg	-	367.3	813.3	1306.0	1003.0	1440.1	1548.6	1135.4	1125.2	1331.2
POPs	Tobacco	kg	-	3.2	2.9	2.8	2.6	2.3	1.8	1.6	1.4	1.4
	BBQ	kg	-	50.3	55.3	93.6	104.6	54.9	114.3	64.0	46.0	90.0
	Paraffin wax	kg	-	0.1	0.1	0.2	0.3	0.3	0.2	0.2	0.2	0.2
	Total	kg	-	53.6	58.3	96.6	107.5	57.6	116.3	65.8	47.5	91.6

4.7 Other industry production

4.7.1 Source category description

The sub-sector *Other production* (NFR 2H) covers the following process relevant for the Danish inventories: 2H2 Food and beverages industry.

4.7.2 Food and beverages industry

The following categories are covered:

- Bread
- Wine
- Beer
- Spirits
- Sugar production
- Flour production
- Meat, fish etc. frying/curing
- Margarine and solid cooking fats
- Coffee roasting

The pollutant relevant for the food and beverages industry is NMVOC and particles.

Methodology

The emissions from production of foods and alcoholic beverages are generally estimated from production statistics (Statistics Denmark, 2022) and standard emission factors from the EMEP/EEA (2019).

Activity data for beer production from Statistics Denmark are supplemented with data from Danish Brewers' Association.

Activity data and particle emissions from flour production are available for 2007-2014 (and partly for 2004-2006), data for 2015-2021 are estimated using surrogate data.

Activity data

The production statistics for the relevant processes have been aggregated based on data from Statistics Denmark and presented in Table 4.7.1 and Annex 3C-41. The activity data for white wine includes the production of apple and pear cider and red wine includes other fruit wines.

Activity data for whisky production is estimated based on direct contact to the Danish distilleries.

Table 4.7.1 Production of foods and beverages.

		1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Biscuits, cakes & other bakery prod.	kt	119	99	148	139	157	118	111	111	117	116
Bread (rye and wheat)	kt	193	190	231	244	257	245	208	201	186	186
Red wine	mill. l	12	10	5	5	1	4	1	1	2	2
White wine	mill. l	NO	3.2	0.5	0.9	3.1	18	10	9	10	12
Beer	mill. l	836	930	990	746	868	651	604	586	587	587
Malt whisky	mill. l	0.24	0.02	NO	NO	0.001	0.011	0.032	0.161	0.329	0.350
Grain whisky	mill. l	NO	NO	NO	NO	NO	0.003	0.008	0.090	0.330	0.350
Other spirits	mill. l	39	33	27	24	26	17	4	4	6	6
Sugar production	kt	533	506	444	443	503	262	468	439	421	430
Flour production	kt	-	180	182	210	175	140	239	350	438	386
Poultry curing	kt	4	11	14	24	35	54	64	78	75	82
Fish and shellfish curing	kt	35	52	31	44	41	73	69	61	60	64
Other meat curing	kt	531	448	464	393	361	303	211	181	173	183
Margarine and solid cooking fats	kt	222	161	144	123	109	105	100	95	82	76
Coffee roasting	kt	53	52	49	56	37	37	17	17	15	14

NO: not occurring

Emission factors

The emission factors used to calculate the NMVOC emissions from food and beverage production are shown in Table 4.7.2. Regarding refining of sugar, the default emission factor has been revised based on company specific measurements obtained from Nielsen (2011). TOC has been measured in order to solve odour issues. The emission of TOC has been used as indicator for NMVOC assuming a conversion factor at: 0.6 kg C/kg NMVOC.

It is assumed that Danish whisky is stored for six years.

The emission factor for particles from flour production is the calculated implied emission factor for 2004-2014 of 0.10-0.13 tonnes PM_{10} per kt flour produced.

Table 4.7.2 Emission factors for NMVOC emission from food and beverages production.

Production	Unit	Value	Reference
Bread (rye and wheat)	kg/t bread	4.5	EMEP/EEA (2019)
Biscuits, cakes and other bakery products	kg/t product	1	EMEP/EEA (2019)
Red wine	kg/m^3 wine	0.8	EMEP/EEA (2019)
White wine	kg/m^3 wine	0.35	EMEP/EEA (2019)
Beer	kg/m^3 beer	0.35	EMEP/EEA (2019)
Malt whisky	kg/m^3 alcohol	150	EMEP/EEA (2019)
Grain whisky	kg/m^3 alcohol	75	EMEP/EEA (2019)
Other spirits	kg/m^3 alcohol	4	EMEP/EEA (2019)
Sugar production	kg/t sugar	0.2	Nielsen (2011)
Meat, fish and poultry	kg/t product	0.3	EMEP/EEA (2019)
Margarine and solid cooking fats	kg/t product	10	EMEP/EEA (2019)
Coffee roasting	kg/t beans	0.55	EMEP/EEA (2019)

Emission trends

The emission trends for emission of NMVOC and particles from production of food and beverage are presented in Figure 4.7.1, Figure 4.7.2 and Annex 3C-42.

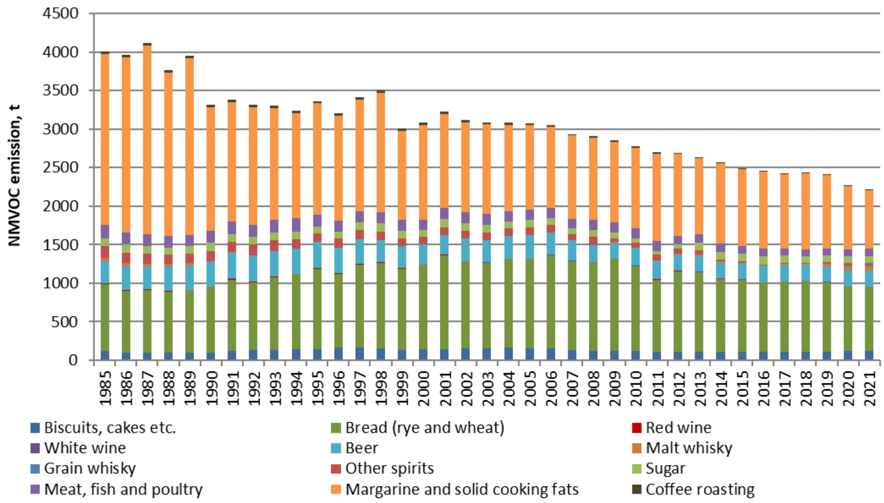


Figure 4.7.1 NMVOC emissions from the production of food and beverages, t.

The emission of NMVOC from production of food and beverage follows the activity as the same emission factors have been used for the entire period.

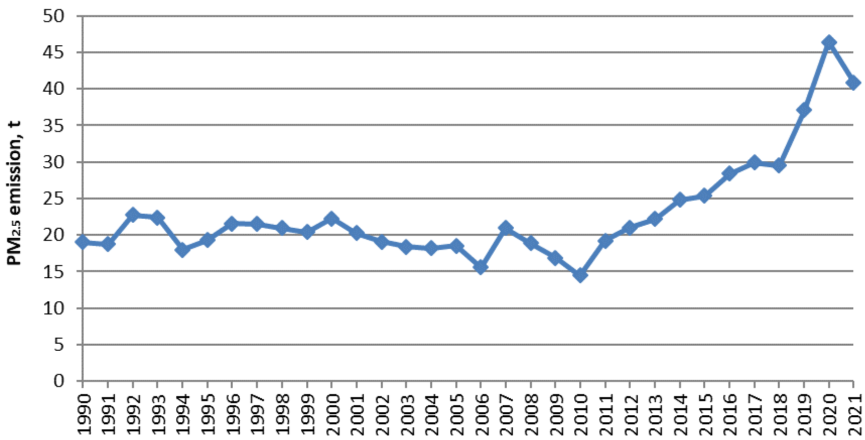


Figure 4.7.2 $PM_{2.5}$ emissions from the production of flour, t.

4.8 Wood processing

4.8.1 Source category description

The sub-sector *Wood processing* (NFR 2I) covers the production of wood products.

4.8.2 Wood processing

The following category is covered:

- Wood processing

The following pollutants are relevant for the wood processing industry:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$

Methodology

The emission of particles from production of wood products is estimated from production statistics (Statistics Denmark, 2022), standard emission factors from the EMEP/EEA (2019) and an assumption for the particle distribution TSP/PM_{10}/$PM_{2.5}$.

In addition to this, activity data from Statistics Denmark (m^3) are multiplied by a country specific density to gain the unit of kt wood product.

Activity data

The production data from Statistics Denmark (2022) are multiplied with the density 0.522 tonnes per m^3 for sawn wood and 0.595 tonnes per m^3 for wood-based panels (KP Sup., 2013, Table 2.8.1). The density for sawn wood is calculated from the carbon content of 0.261 tonnes C per m^3 (Schou, 2015) and the carbon fraction of 0.5 (KP Sup., 2013, Table 2.8.1). The resulting activity data are presented in Table 4.8.1 and Annex 3C-43.

Table 4.8.1 Activity data wood processing, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Wood processing	359.3	464.8	481.3	368.3	436.6	453.4	395.9	413.4	452.1	409.2

Emission factors

The emission factors used to calculate the particle emissions from wood processing are shown in Table 4.8.2.

Table 4.8.2 Emissions factors for wood processing.

Pollutant	Unit	Value	Reference
TSP	t/kt	1	EMEP/EEA (2019)
PM_{10}	% of TSP	40	Expert judgement
$PM_{2.5}$	% of TSP	20	Expert judgement

Emission trends

The emission trends for particles are available in Table 4.8.3 and Annex 3C-44.

Table 4.8.3 Particle emissions from wood processing, t.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
TSP	359.3	464.8	481.3	368.3	436.6	453.4	395.9	413.4	452.1	409.2
PM_{10}	143.7	185.9	192.5	147.3	174.6	181.4	158.4	165.4	180.8	163.7
$PM_{2.5}$	71.9	93.0	96.3	73.7	87.3	90.7	79.2	82.7	90.4	81.8

4.9 Other production, consumption, storage, transportation or handling of bulk products

4.9.1 Source category description

The sub-sector *Other production, consumption, storage, transportation or handling of bulk products* (NFR 2L) covers the treatment of slaughterhouse waste (NFR 2L3).

4.9.2 Slaughterhouse waste

One company treats slaughterhouse waste: Daka with five departments located in Løsning, Randers, Lunderskov, Ortved, and Nyker. The following category is covered:

- Slaughterhouse waste

The following pollutant is relevant for the treatment of slaughterhouse waste:

- NH_3

Methodology

The raw materials for the processes are by-products from slaughterhouses, animals dead from accident or disease, and blood. The output from the processes are protein and fat products as well as animal fat, meat and bone meal.

The emissions from the processes are related to the consumption of energy, emissions of NH_3 and odour. The last-mentioned emissions are related to storage of the raw materials as well as to the drying process.

The emission of NH_3 from treatment of slaughterhouse waste has been calculated from an average emission factor based on measurements from the Danish plants (Daka, 2002; 2004) and activity data from Statistics Denmark (2022).

Activity data

The activity data for treatment of slaughterhouse waste are compiled from different sources. Due to changes in the company structure, environmental reports are only available for some years (1997-2009). Therefore, data from

Statistics Denmark are used in combination with blood meal data (partly estimated based on data from the environmental reports). The activity data are presented in Table 4.9.1 and Annex 3C-45.

Table 4.9.1 Activity data for treatment of slaughterhouse waste, kt.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Meat/bone meal	134.4	128.8	197.0	156.0	164.1	104.6	98.5	114.8	115.1	113.0
Animal fat	11.1	72.1	54.2	71.3	89.5	75.3	54.0	36.1	40.8	46.7
Blood meal	11.0	11.0	11.0	11.4	10.2	7.5	7.5	7.5	7.5	7.5
Total	156.5	211.9	262.2	238.7	263.9	187.4	160.0	158.4	163.3	167.1

Emission factors

The emission of NH_3 from treatment of slaughterhouse waste has been calculated from an average emission factor based on measurements from the Danish plants (Daka, 2004). Measurements of NH_3 during the years 2002/3 from three locations (Lunderskov, Løsning and Randers) with different product mix have been included in the determination of an emission factor.

The weighted emission factors covering all the products within the sector have been estimated for 2000-2003 as 64-475 g per tonne product. The applied emission factor is the average 189 g per tonne product.

Emission trends

Emissions from the treatment of slaughterhouse waste are available in Table 4.9.2 and Annex 3C-46.

Table 4.9.2 Emissions from the treatment of slaughterhouse waste, t.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
NH_3	29.6	40.0	49.6	45.1	49.9	35.4	30.2	29.9	30.9	31.6

4.10 QA/QC and verification

Please refer to the sector specific reports Hjelgaard & Nielsen (2018).

4.11 Uncertainty estimates

The Danish uncertainty estimates are based on the simple "Approach 1".

The uncertainty estimates are based on emission data for the base year (1990) and year 2021 as well as on uncertainties for activity data and emission factors for each of the NFR source categories.

Table 4.11.1 presents the calculated Approach 1 uncertainties for the IPPU sector.

Table 4.11.1 Approach 1 uncertainties for Industrial processes and product use (NFR 2).

Pollutant	Uncertainty total emission %	Trend 1990-2020 %	Uncertainty trend %-age points
SO_2	134.27	-76.8	9.7
NO_x	73.31	-92.6	6.6
NMVOC	13.30	-22.1	7.3
CO	76.15	-73.3	46.0
NH_3	158.12	-38.8	116.3
TSP	635.86	-33.7	140.1
PM_{10}	264.08	-33.1	98.2
$PM_{2.5}$	131.36	-44.2	43.1
BC	112.35	-39.9	48.9
As	557.82	-40.9	103.5
Cd	515.36	-70.8	63.1
Cr	570.67	-23.2	139.3
Cu	286.60	223.0	423.6
Hg	675.34	-97.6	6.9
Ni	367.77	-78.1	170.9
Pb	772.14	-76.3	150.0
Se	383.71	-85.1	15.7
Zn	376.38	-82.2	130.8
HCB	702.66	-99.8	0.3
PCDD/F	169.80	-98.3	15.3
benzo(b)flouranthene	200.25	-69.1	257.4
benzo(k)flouranthene	200.25	-80.3	176.3
benzo(a)pyrene	199.02	-68.5	258.9
indeno(1,2,3-c,d)pyrene	200.25	-77.6	197.3
PCB	828.92	-96.2	4.7

4.12 Source specific recalculations and improvements

Table 4.12.1 presents the total IPPU recalculations from the previous submission to this submission, for chosen years is the time series. Table 4.12.2 presents the same recalculations for 2020 only, divided in subsectors.

Table 4.12.1 Total recalculations for industrial processes and product use, time series.

	Unit	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020
SO_2	t	-	-	-	-	-	-	-	0.10	-1.89	66.20
NO_x	t	-	-	-	-	-	-	-	0.43	-1.53	-0.18
NMVOC	t	-	-	-	-	-	-	-	-9.28	-188.40	-125.55
CO	t	-	-	-	-	-	-	-0.64	13.60	-123.65	-31.37
NH_3	t	-	-	-	-	-	-	-	0.98	0.75	0.88
TSP	kt	-	0.02	0.01	0.02	0.01	0.01	0.00	0.07	0.08	0.25
$PM_{2.5}$	kt	-	0.001	0.001	0.001	0.001	0.001	-0.011	-0.001	-0.003	0.003
As	kg	-	66.50	53.80	65.09	60.15	26.00	129.78	48.62	36.43	40.50
Cd	kg	-	-	-	-	-	-	-	0.00	-0.01	0.00
Hg	kg	-	-	-	-	-	-	-	0.001	-0.040	-0.011
Pb	kg	-	-	-	-	-	-	-	0.15	-2.72	-0.71
PCDD/F	mg	-	-	-	-	-	-	-	0.02	-6.71	-2.04
PAHs	kg	-	-	-	-	-	-	-	0.06	-4.45	-1.32

Table 4.12.2 Recalculations for the year 2019 for industrial processes and product use, subsectors.

		SO_2	NMVOC	CO	NH_3	$PM_{2.5}$	As	Hg	Pb	POPs
		t	t	t	t	t	kg	kg	kg	g
2A	**Mineral industry**	**-**	**-**	**0.5**	**-**	**0.8**	**40.5**		**-**	**-**
2A2	Lime production					-				-
2A3	Glass production		-	-	-	-	-		-	
2A5a	Quarrying and mining of minerals other than coal					-2.7				
2A5b	Construction and demolition					8.2				
2A5c	Storage, handling and transport of mineral products					0.7				
2A6	Ceramics	-								-
2A6	Stone wool production		-	0.5	-	-5.3	40.5			-
2B	**Chemical industry**	**66.7**	**-15.2**		**-**	**-**		**-**		**-**
2B10a	Catalysts/fertiliser production				-	-				
2B10a	Chemical ingredients		0.002							
2B10a	Pesticides	66.7	-15.2							
2B10a	Tar products	-	-					-		-
2C	**Metal industry**	**-**	**-**			**4E-4**	**0.002**	**2E-4**	**0.01**	**0.003**
2C1	Iron and steel production		-			4E-4	0.002	2E-4	0.01	0.003
2C5	Secondary lead production	-				-	-	-	-	-
2C7c	Allied metal production								-	
2D	**Non-energy products from fuels and solvent use**		**-143.4**	**-1E-3**		**-5E-4**				
2D3a	Domestic solvent use including fungicides		-73.7							
2D3b	Road paving with asphalt		-	-		-				
2D3c	Asphalt roofing		-0.01	-1E-3		-5E-4				
2D3d	Coating applications		-4.9							
2D3f	Dry cleaning		-							
2D3g	Chemical products		-108.2							
2D3h	Printing		0.13							
2D3i	Other solvent use		43.3							
2G	**Other product manufacture and use**	**-0.50**	**0.47**	**-31.9**	**0.9**	**2.1**	**0.03**	**-0.011**	**-0.73**	**-1317**
2G4	Charcoal	-0.60	-0.58	-40.3	-0.02	-0.6	-0.02	-0.013	-0.87	-1367
2G4	Tobacco	0.09	1.04	11.9	0.9	3.0	0.03	0.001	0.14	53
2G4	Fireworks	0.02		0.1		0.2	0.01	-	-	
2G4	Paraffin wax use			-3.6		-0.5				-3
2H2	**Food and beverages industry**		32.6			**-**				
2I	**Wood processing**					**-**				
2L	**Slaughterhouse waste**				**-**					

4.12.1 Mineral industry

Glass production

Rounding of numbers result in miniscule recalculations in emissions from glass production in 2016-2017 and 2019.

Quarrying and mining of minerals other than coal

Statistical data for quarrying and mining for the inventory year, is not available in time for submission. Activity data for the inventory year is therefore kept constant on the same level as the latest historical year. This method results in a recalculation of the latest historical year in every annual submission, for this year's submission that means 2020. In addition, statistical data from Statistics Denmark was updated for 2019 for this year's submission.

The activity data for 2019 and 2020 have decreased by 0.1 % and 1.9 % respectively; i.e. -0.8 tonnes $PM_{2.5}$ and -2.7 tonnes $PM_{2.5}$ respectively.

Construction and demolition
Updated statistical data from Statistics Denmark result in recalculations for 2016-2020. The recalculations for the five years amount to increases of 0.5 (+1%), 2.7 (+2%), 1.7 (+1%), 2.5 (+2%) and 8.2 tonnes $PM_{2.5}$ (+6%) respectively.

Storage, handling and transport of mineral products
Recalculations in the activity data for ceramics, soda ash, flue gas desulphurisation and mineral wool production will result in recalculations in this category. In addition, an error was corrected for this year's submission resulting in increased particle emissions from storage, handling and transport of mineral products for the entire time series of 0.5-0.9 tonnes $PM_{2.5}$ per year; i.e. +7-18 %.

Stone wool production
Emission estimates of As are new from stone wool production in this year's submission.

Measurements of CO emissions are made available for 2021, resulting in recalculations of CO for 2015-2020. The implied emission factor (IEF) for Vamdrup decreases from 0.26 to 0.24 kg CO per tonne product and IEF for Doense increases from 0.02 to 0.03 kg CO per tonne product. CO decreases 0.64 tonnes for 2015 and increases 0.32-0.59 tonnes for 2016-2020.

Measurements for PM_{10} for 2021 are also made available for this year's submission resulting in recalculations for particles (TSP, PM_{10}, $PM_{2.5}$, BC) for 2015-2020. $PM_{2.5}$ emissions decrease with 5.3-11.7 tonnes for each of the six years.

4.12.2 Chemical industry

Chemical ingredients
Recalculations in the activity data from Statistics Denmark results in recalculations of the NMVOC emission from the production of chemical ingredients for 2020. The recalculation amounts to +1.6 kg NMVOC (+0.02 %) for 2020.

Pesticide production
Measured VOC and SO_2 data for 2020 were not made available in time for last year's submission. These are now included, resulting in recalculations of +66.7 tonnes SO_2 and -15 tonnes NMVOC for 2020.

4.12.3 Metal industry

Iron and steel production
An update to the cast iron activity data for 2020 was made by Statistics Denmark for this year's submission. The recalculation results in an increase of emissions for 2020 of 0.01 %.

4.12.4 Non-energy products from fuels and solvent use

Asphalt roofing
Activity data from Statistics Denmark were updated for 2019-2020. The resulting recalculation is -1.1 % for 2019 and -0.2 % for 2020.

Solvent use

Changes made in the solvent use source category (2D3a, d, f, g, h, i) are caused by an update of activity data for 2019-2020 from Statistics Denmark. The recalculations are -187 tonnes NMVOC (-0.8 %) in 2019 and -143 tonnes NMVOC (-0.5 %) in 2020.

4.12.5 Other product use

Charcoal from barbeques

Activity data from Statistics Denmark were updated for 2019-2020. The resulting recalculations are -6.6 % in 2019 and -2.9 % in 2020.

Use of fireworks

Activity data from Statistics Denmark were updated for 2019-2020. The resulting recalculations are +0.3 % for each of the two years.

Tobacco

Data on cross border shopping was made available for 2017-2020 for this year's submission. The resulting recalculations are +1.3 %, +3.9 %, +3.1 % and +4.0 % for 2017, 2018, 2019 and 2020 respectively.

Paraffin wax use

Recalculations for 2019 and 2020 are a result of updated activity data from Statistics Denmark. Emissions have decreased with 1.2% and 1.8% for the two years respectively.

4.12.6 Other industry processing

Food and beverages industry

Emissions from coffee roasting have been recalculated for 2019-2020 due to an update in the import/export data from Statistics Denmark for these years. The resulting recalculations are -0.12 tonnes NMVOC and -0.11 tonnes NMVOC for 2019 and 2020 respectively.

Updates in the 2020 data for production of biscuits, meat and "other spirits" by Statistics Denmark, results in a recalculation of +1.2 tonnes NMVOC from the three categories together.

Activity data for production of whisky was updated for 2018-2020 by contacting all Danish whisky distilleries. This update resulted in recalculations of -10.4, -0.4 and +31.5 tonnes NMVOC for 2018, 2019 and 2020 respectively.

4.13 Source specific planned improvements

The following Table 4.13.1 lists the source specific planned improvements.

Table 4.13.1 List of planned improvements.

Main sector	Subsector	Improvement
Mineral industry	Ceramics	It will be investigated whether emissions of particulate matter can be included for production of ceramics.
Other industry production	Food and beverages industry	Other activities not currently included, such as grain drying and fish meal processing will be investigated further.

4.14 References

Asfaltindustrien, 2003: Asfalt 3/03, Asfalt vore veje. Direktion, Ib Frandsen.

Ardagh, 2014: Grønt regnskab 2013. Ardagh Glass Holmegaard A/S, CVR nr. 18445042. And previous years 1997-2012. (In Danish) (Environmental reports)

Ardagh, 2015: PRTR data for 2014. Ardagh Glass Holmegaard A/S, CVR nr. 18445042. Partially confidential. And previous years (2004, 2007-2013).

Ardagh, 2022: CO_2-udledningsrapport for 2021 for Ardagh Glass Holmegaard A/S (EU-ETS). Confidential. And previous years (2006-2020).

BREF: Best Available Techniques (BAT) Reference Document for the Non-Ferrous Metals Industries. Cusano, G., Gonzalo, M.R., Farrell, F., Remus, R., Roudier, S., Sancho, L.D., 2017. Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control). JRC Science for Policy Report, European Commission.

CEPMEIP: The Co-ordinated European Programme on Particulate Matter Emission Inventories, Projections and Guidance (CEPMEIP). Database. Available at: http://www.air.sk/tno/cepmeip/ (22/02-2023).

Cheminova, 2008: Grønt regnskab 2007 for Cheminova A/S. (Environmental reports) (In Danish).

Cheminova, 2010: Grønt regnskab 2009 for Cheminova A/S. (Environmental reports) (In Danish).

Cheminova, 2015: PRTR for 2014. Cheminova A/S, CVR-nr.: 12760043. (In Danish), partly confidential.

Cheminova, 2022: Personal contact with Inge Margrethe Jensen, Environmental Manager at FMC Agricultural Solutions, Cheminova A/S. Mail correspondence 19/10-2022.

Daka, 2002: Grønt regnskab for 2001-2002 (In Danish). (Environmental reports).

Daka, 2004: Grønt regnskab for 2003-2004 (In Danish). (Environmental reports).

Danisco Grindsted, 2014: Grønt regnskab for 2013. (Environmental reports) (In Danish).

Danish Brewers' Association: Tal fra Bryggeriforeningen, rapport Øl. (In Danish).

DanSteel, 2016: NLMK DanSteel A/S 2016, Grønt Regnskab for 2015. (Environmental reports).

DanSteel, 2022: Personal communication with Charlotte Pedersen, C7 Consulting A/S for NLMK DanSteel A/S. 09/11 2022.

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 ac-tivities and installations, Brüssel, 1999.

DMI, 2020: Danmarks Meteorologiske Institut (DMI). Available at: https://www.dmi.dk/vejrarkiv/ (21/02-2023)

Duferco, 2014: Grønt Regnskab for 2012-2013. Duferco Danish Steel A/S (Environmental reports).

Duferco, 2016: PRTR for 2015. Duferco Danish Steel A/S, CVR nr. 29600953 (In Danish), Partly confidential. (Environmental reports).

Duferco, 2021: Personal comunication with Elisabetta Bruno, Duferco Danish Steel A/S. 12/11-2021.

DuPont, 2017: Personal contact with Peder Eriksen, Environmental Coordinator at DuPont Nutrition Biosciences ApS. Mail correspondence 19/9-2017.

EMEP/Corinair, 2007: EMEP/CORINAIR Emission Inventory Guidebook – 2007. Available at: https://www.eea.europa.eu/publications/EMEPCORINAIR5 (22/02-2023).

EMEP/EEA (2019): EMEP/EEA air pollutant emission inventory guidebook 2019. Technical guidance to prepare national emission inventories. Available at: https://www.eea.europa.eu//publications/emep-eea-guidebook-2019 (21/02-2023).

Environment Australia, 1999: Emissions Estimation Technique Manual for Aggregated Emissions from Barbeques, September 1999, Version 1.

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.

Fine, P.M., Cass, G.R. & Simoneit, B.R.T., 1999: Characterization of Fine Particle Emissions from Burning Church Candles. Environmental Science and Technology 1999, Volume 33, Number 14, pages 2352-2362. Available at: http://lib3.dss.go.th/fulltext/Journal/Environ%20Sci.%20Technology1998-2001/1999/no.14/14,1999%20vol.33,no14,p.2352-2362.pdf (23/02-2023).

Finstad, A. & Rypdal, K., 2003: Utslipp til luft av kobber, krom og arsen i Norge – Dokumentasjon av metode og resultater 2003/7, Statistisk Sentralbyrå, Statistics Norway. (In Norwegian).

FORCE, 2009. Revision af beregninger af danske VOC emissioner fra opløsningsmidler og husholdninger. Arbejdsrapport fra Miljøstyrelsen nr. 5.

Hamins, A., Bundy, M. & Dillon, S.E., 2005: Characterization of Candle Flames. Journal of Fire Protection Engineering, Volume 15—November 2005. Available at: https://www.nist.gov/publications/characterization-candle-flames (23/02-2023).

Hansen, E., 2000: Substance Flow Analysis for dioxins in Denmark, Environmental Project No. 570, Miljøstyrelsen, 2000. Available at: http://www2.mst.dk/udgiv/publications/2000/87-7944-295-1/pdf/87-7944-297-8.pdf (23/02-2023).

Haldor Topsøe, 2013: Miljøredegørelse for katalysatorfabrikken 2012. inkl. 1996-2011. (In Danish).

Haldor Topsøe, 2022: PRTR for 2021. Haldor Topsøe A/S, CVR nr. 41853816 (In Danish). Partly confidential. And earlier years 2009-2020.

Hals Metal, 2021: Personal communication with Carsten Henriksen, 16/08-2021.

Henriksen, T.C., Illerup, J. B. & Nielsen, O.-K. 2006: Dioxin Air Emission Inventory 1990-2004, National Environmental Research Institute (NERI) Technical Report No. 602, 2006, Ministry of the Environment. Denmark. Available at: https://www2.dmu.dk/pub/fr602.pdf (21/02-2023).

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 (21/02-2023).

Illerup, J.B., Geertinger A.M., Hoffmann, L. & Christiansen, K. 1999: Emissionsfaktorer for tungmetaller 1990-1996. Faglig rapport fra DMU, nr. 301. Miljø- og Energiministeriet, Danmarks Miljøundersøgelse. Available at: https://www2.dmu.dk/1_viden/2_publikationer/3_fagrapporter/rapporter/fr301.pdf (in Danish) (21/02-2023).

IPCC, 1996: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html (23/02-2023).

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/ (22/02-2023).

Jensen. A. & Markussen, J. 1993: Forbrug af og forurening med cadmium (Miljøprojekt nr. 213). København: Miljøstyrelsen. (Referred to in Annex 3C-22).

Karjalainen, T. 2005: Commission research in Action: tackling the hormone disrupting chemicals issue, EUR report 21941.

Kemira GrowHow, 2004: Miljø & arbejdsmiljø. Grønt regnskab 2003. (Environmental reports). And previous years (1996-2003).

Kemira GrowHow, 2005: Personal communication with Gert Jacobsen, September 2005.

Klimont, Z., Cofala, J., Bertok, I., Amann, M., Heyes, C. & Gyarfas, F. 2002: Modellierung von Feinstaubemissionen in Europa, Entwicklung eines Technologie- und Kosten-Moduls für Staubemissionen im Rahmen des Integrated

Assessment Modelling zur Unterstützung europäischer Luftreinhaltestrategien, juni 2002. Internationales Institut für angewandte Systemanalyse Laxenburg, Austria. (In Dutch).

Koppers, 2014: Miljøredegørelse for Koppers Danmark A/S 2014 (Environmental report). (In Danish).

Koppers, 2017a: Miljøredegørelse 2016. Koppers European Operations, Carbon Materials and Chemicals, Nyborg Works, Denmark, 2017, incl. 2010-2014 (Environmental reports) (In Danish).

Koppers, 2017b: PRTR for 2016. Koppers Denmark ApS. CVR nr.: 11000738. (In Danish) Partly confidencial.

Koppers, 2022. Personal communication with Dorte Riis Sørensen, Miljø og sikkerhedschef at Koppers Denmark ApS. Mail correspondence 13/09-2022.

KP Sup., 2013: IPCC 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol. Task Force on National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/kpsg/pdf/KP_Supplement_Entire_Report.pdf (23/02-2023).

Lassen, C., Christensen, C.L. & Skårup, S. 2004: Cowi A/S, Massestrømsanalyse for bly 2000 - revideret udgave, Miljøprojekt Nr. 917 2004. (In Danish). Available at: https://www2.mst.dk/Udgiv/publikationer/2004/87-7614-231-0/pdf/87-7614-232-9.pdf (22/02-2023).

Lau, C., Fiedler, H., Hutzinger, O., Schwind, K.-H. & Hosseinpour, J. 1997: Levels of Selected Organic Compounds in Materials for Candle Production and Human Exposure to Candle Emissions. Chemosphere, volume 34, Issues 5- 7, pages 1623-1630. Available at: https://www.sciencedirect.com/science/article/pii/S004565359700458X (23/02-2023).

Martin, P., Heavner, D.L., Nelson, P.R., Maiolo, K.C., Risner, C.H., Simmons, P.S., Morgan, W.T. & Ogden, M.W., 1997: Environmental tobacco smoke (ETS): A market cigarette study. Environment International, Vol. 23, No. 1, pp. 75-90, 1997.

Miljöförvaltningen, 1999: Kemisk Analys av Fyrverkeripjäser, Fyrverkeriers miljöpåverkan - En undersökning av metaller i konsumentfyrverkerier, Miljöförvaltningen Göteborg, PM 1999:1, ISSN 1401-243X, ISRN GBG-M-PM-99/1- -SE (In Swedish).

NACE: Standard nomenclature for economic activities (NACE) system. Available at: https://circabc.europa.eu/sd/a/acbc9240-03b9-43df-97b5-146d102fc18e/NACE%20Rev.%201.1%20-%20NACE%20Rev.%202%20-%20short%20version.pdf (22/02-2023).

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Nielsen, M., Fauser, P., Mikkelsen, M.H., Albrektsen, R., Hjelgaard, K., Hoffmann, L., Thomsen, M. & Bruun, H.G. 2013: Danish emission inventory for hexachlorobenzene and polychlorinated biphenyls. Aarhus University, DCE – Danish Centre for Environment and Energy, 65 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 103. Available at: https://dce2.au.dk/pub/SR103.pdf (21/02-2023).

Nielsen, V.V. 2011: Personal communication Vibeke Vestergaard Nielsen, Danish EPA, September 2011.

Pärt, P. (main author) 2005: Environment and health, EEA Report No 10/2005, Copenhagen.

Passant, 2003: Passant, Neil, Characterisation of Emissions Of New Persistent Organic Pollutants, Department for Environment, Food and Rural Affairs, AEAT/ENV/R/1421 Issue 1.

Rambøll, 2004. Kortlægning af kemiske stoffer i forbrugerprodukter. Kortlægning nr. 45 fra Miljøstyrelsen.

Rockwool, 2014: Miljøredegørelse (Environmental report) 2013 for fabrikkerne i Hedehusene, Vamdrup og Øster Doense. And previous years (1996-2012). (In Danish).

Rockwool, 2022a: CO_2-udledningsrapport for 2021 (EU-ETS). Rockwool A/S Doense og Vamdrup (In Danish). And previous years (2006-2020). Confidential.

Rockwool, 2022b: PRTR for 2021. Rockwool A/S, CVR nr. 42391719 (In Danish) Partly confidential. And previous years (2001, 2004, 2007-2020).

Rockwool, 2022c: Personal contact with Berit Kjerulf, Miljøchef at Rockwool Nordics, mail correspondence of 7/09-2022.

Saint-Gobain Isover, 2015: Grønt regnskab for 2014. Saint-Gobain Isover A/S, CVR nr. 11933238 (In Danish) (Environmental reports). And previous years (1996-2013).

Saint-Gobain Isover, 2022a: CO_2-udledningsrapport for 2021 (EU-ETS). Saint-Gobain Isover A/S (In Danish). And previous years (2006-2020). Confidential.

Saint-Gobain Isover, 2022b: PRTR for 2020. Saint-Gobain Isover A/S, CVR nr. 11933238 (In Danish), Partly confidential. And previous years (2013-2014, 2017-2020).

Saint-Gobain Isover, 2022c: Personal contact with Pia Brodersen, HSE Coordinator at Saint-Gobain Denmark A/S Isover, mail correspondence 31/08-2022.

Schou, E. 2015: Personal communication with Erik Schou from Department of Geosciences and Natural Resource Management at University of Copenhagen.

SPIN on the Internet. Substances in Preparations in Nordic Countries. Available at: www.spin2000.net (22/02-2023).

Statistics Denmark, 2022: Statistics Denmark, StatBank Denmark (Danish/English). Available at: http://www.dst.dk/en (21/02-2023).

Stena Aluminium, 2008: Miljøredegørelse/Grønt Regnskab for Stena Aluminium A/S 2007/2008, CVR nr. 13801479. (Environmental reports).

Stålvalseværket, 2002: Grønt regnskab og miljøredegørelse 2001. Det Danske Stålvalseværk A/S. (Environmental reports).

UNFCCC, 2008: Available at: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/3929.php (22/02-2023).

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://www.epa.gov/air-emissions-factors-and-quantification/ap-42-fifth-edition-volume-i-chapter-11-mineral-products-0 (22/02-2023).

Van der Maas C.W.M., Coenen P.W.H.G., Zijlema P.J., Baas, K., van den Berghe, G., van den Born, G.J., Brandt, A.T., Guis, B., Geilenkirchen, G., te Molder, R., Nijdam, D.S., Peek, C.J. & van der Sluis, S.M. 2010: Greenhouse Gas Emissions in the Netherlands 1990-2008, National Inventory Report 2010. Netherlands Environmental Assessment Agency.

Visschedijk, A., Pacynab, J., Pullesa, T., Zandvelda, P. & Denier van der Gon, H. 2004: Coordinated European Particulate Matter Emission Inventory Program (CEPMEIP).

5 Agriculture

5.1 Overview of the sector

The emission from the agricultural activities covers a range of pollutants. Table 5.1 shows an overview of sources and pollutants.

Table 5.1 Overview of sources and pollutants.

NFR codes		Longname	Main pollutants (from 1990)				Particulate matter (from 1990)			
			NO_x (as NO_2)	NMVOC	SO_x (as SO_2)	NH_3	$PM_{2.5}$	PM_{10}	TSP	BC
3B		Manure management	x	x		x	x	x	x	
3D	3Da	Agricultural soils	x			x				
	3Dc	Farm-level agricultural operations					x	x	x	
	3De	Cultivated crops		x		x				
	3Df	Use of pesticides								
3F		Field burning of agricultural residues	x	x	x	x	x	x	x	x

NFR codes		Longname	Other (from 2000)				
			CO	HM[a]	POP[b]	HCB	PCB
3B		Manure management					
3D	3Da	Agricultural soils					
	3Dc	Farm-level agricultural operations					
	3De	Cultivated crops					
	3Df	Use of pesticides				x	
3F		Field burning of agricultural residues	x	x	x	x	x

[a] Heavy metals: As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn.

[b] dioxins and furanes (PCDD/F) and polycyclic aromatic hydrocarbons (PAH – benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoran-thene and indeno(1,2,3-cd)pyrene).

Buffalos, camels, lamas, mules and donkeys are not farmed in Denmark therefore no emission estimates from these animal categories.

Table 5.2 shows the agricultural contribution of total national emissions in 2021. The main part of the NH_3 emission (95 %) is related to the agricultural sector, while the agricultural contribution of TSP, PM_{10} and $PM_{2.5}$ are 77 %, 37 % and 9 %, respectively. The agricultural share of NMVOC emission accounts for 44 % of the total. The inventory also includes the NO_x emission from application of inorganic fertilisers and animal manure, which result in an agricultural part on 21 % of the total. The agricultural part of the total SO_x emission is lower than 1 %.

Table 5.2 Emission 2021, Agricultural share of the Danish total emission.

	NH_3	TSP	PM_{10}	$PM_{2.5}$	NMVOC	SO_X	NO_X
National total, kt	71	84	22	12	107	9	89
Agricultural total, Kt	66	64	8	1	46	<1	18
Agricultural part, %	95	77	37	9	44	<1	21

5.1.1 Ammonia

The majority of the Danish NH_3 emission, corresponding to 95 %, originates from the agricultural sector. The remaining 5 % is mainly related to emission from transport. Figure 5.1 shows the distribution of sources of NH_3 emission from the agricultural sector for 2021. The main part of the agricultural emission is directly related to the livestock production by 42 % from manure management, 26 % from manure applied to soils and 4 % from grazing animals. Emissions from use of inorganic fertiliser and cultivated crops contribute with 17 % and 9 %, respectively. Emissions from NH_3-treated straw, field burning of agricultural residues, sewage sludge used as fertiliser and other organic fertiliser amount to less than 2 %.

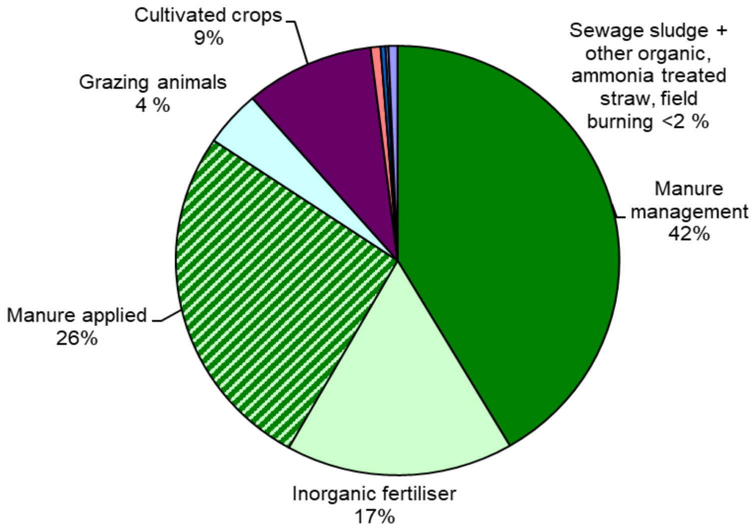


Figure 5.1 NH_3 emissions from the agricultural sector, 2021.

The NH_3 emission from the agricultural sector has decreased between 1985 and 2021 from 147.1 kt NH_3 to 67.5 kt NH_3, corresponding to a 54 % reduction (Table 5.3). This significant drop in NH_3 emissions should be read in a conjunction of a very active national environmental policy designed to reduce the loss of nitrogen to the aquatic environment. A string of measures have been introduced by action plans, for example the NPO (Nitrogen, phosphor, organic matter) Action Plan (1986), Action Plans for the Aquatic Environment (1987, 1998, 2004), the Action Plan for Sustainable Agriculture (1991), the Ammonia Action Plan (2001) and latest the action plan the Agreement on Green Growth (2009 and 2010). Based on these action plans have legislative changes and actions led to an optimization of manure as a resource.

Requirements to capacity of slurry storage and requirements to handling of manure during spreading has led to a decrease in animal nitrogen excretion, improvement in use of nitrogen in manure and a fall in the use of inorganic fertiliser. A Danish environmental approval act for livestock holdings was acted in January 2007 and according to the act, farmers are required to apply for an environmental approval if the farmer wants to change or expand the livestock production facilities. In order to get environmental approval farmers has to fulfil requirements concerning Best Available Technique (BAT) and specific environmental requirements as for example emission of ammonia. The action plans have helped to reduce the overall NH_3 emission significantly and the Danish environmental approval act for livestock will contribute to a further reduction in emissions in future.

From 2020 to 2021 a decrease in NH_3 emission from manure management is seen, this is mainly due to closing of the production of mink, which were closed due to risk of spreading of corona virus. All animals were put down in the end of 2020. This also affects emission from manure applied to soil.

Table 5.3 Total NH_3 emissions from the agricultural sector 1985 to 2021, kt NH_3.

		1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
3B	Manure management, total	52.85	50.54	46.57	46.86	47.35	39.75	36.01	35.06	32.80	33.75	28.03
	Cattle	*13.20*	*12.16*	*11.14*	*11.56*	*10.56*	*10.90*	*10.98*	*11.06*	*10.87*	*10.78*	*10.42*
	Swine	*31.67*	*28.92*	*26.29*	*25.27*	*24.81*	*17.51*	*15.77*	*14.85*	*13.98*	*15.34*	*14.20*
	Other animals	*7.98*	*9.46*	*9.14*	*10.03*	*11.98*	*11.34*	*9.26*	*9.15*	*7.96*	*7.62*	*3.42*
3Da1	Inorganic N-fertiliser	21.71	19.84	15.45	11.64	9.91	9.83	11.01	12.78	11.22	12.16	11.21
3Da2a	Manure applied to soil	53.94	47.95	35.00	27.78	20.87	20.92	18.29	18.95	18.35	19.14	17.73
3Da2b	Sewage sludge applied to soil	0.26	0.40	0.60	0.47	0.35	0.47	0.52	0.44	0.54	0.49	0.49
3Da2c	Other organic	0.12	0.12	0.36	0.41	0.19	0.27	0.36	0.39	0.46	0.43	0.45
3Da3	Urine and dung deposite by grazing animals	4.21	3.88	3.99	3.91	3.13	2.70	2.61	2.68	2.66	2.87	2.83
3De	Cultivated crops	5.97	5.92	5.28	5.31	5.64	5.85	6.22	6.25	6.26	6.42	6.34
3F	Field burning of agricultural residue	1.53	0.08	0.09	0.11	0.13	0.09	0.10	0.12	0.14	0.14	0.14
3I	NH_3 treated straw	6.55	10.21	6.65	2.47	0.26	0.16	0.16	0.16	0.16	0.16	0.24
3	Agricultural sector - total	147.15	138.95	114.00	98.96	87.83	80.05	75.28	76.83	72.60	75.54	67.47

The management of manure has to be considered as the most important emission source. Most of the emission originates from the production of swine and cattle, which contributed, respectively with 51 % and 37 % in 2021.

It is noteworthy that the overall emission from swine has decreased by 55 % from 1985 to 2021 despite a considerable increase in the swine production from 14.8 million produced fattening pigs in 1985 to 20.5 million in 2021. The most important reason for this is the improvement in feed efficiency. In 1985, the nitrogen excretion for a fattening pig was estimated to 5.09 kg N (Poulsen & Kristensen, 1998). In 2021, that figures were considerably lower at 2.70 kg N per fattening pig produced (Børsting & Hellwing, 2022). Due to the large contribution from the swine production, the lower level of N-excretion has a significant influence on total agricultural emissions.

Since 1985, changes in practice of manure application to the fields have taken place, which has reduced the emission from manure applied to soils. From the beginning of the 1990s, slurry has increasingly been spread using trailing hoses. From the late 1990s, the practice of slurry injection or mechanical incorporation into the soil has increased. This development is a consequence of a ban on broad spreading but it is also a consequence of the general requirement to improve the utilisation of nitrogen in the manure - e.g. requirements that a larger part of the nitrogen in manure has to be included in the farmer's nitrogen accounting. This has forced farmers to consider the manure as a fertiliser resource instead of a waste product.

5.1.2 Particulate matter

In NFR, the emission of particulate matter (PM) is reported for the years 1990 to 2021. The emission from the agricultural sector includes the emission of dust from animal housing systems, field operations and field burning of agricultural residues.

TSP (total suspended particulate) emission from the agricultural sector contributes with 77 % to the national TSP emission in 2021 and the emission shares for PM_{10} and $PM_{2.5}$ are 37 % and 9 % respectively. The majority of the TSP emission originates from the field operations 88 % while the emission from animal housings contributes with 12 % and field burning of agricultural residues, contributes with less than 1 % to the agricultural emission in 2021.

The PM emission from agricultural activities, given in TSP, is decreased 14 % during the period from 1990 to 2021 (Figure 5.2) mainly due to decrease in the emission from field operations.

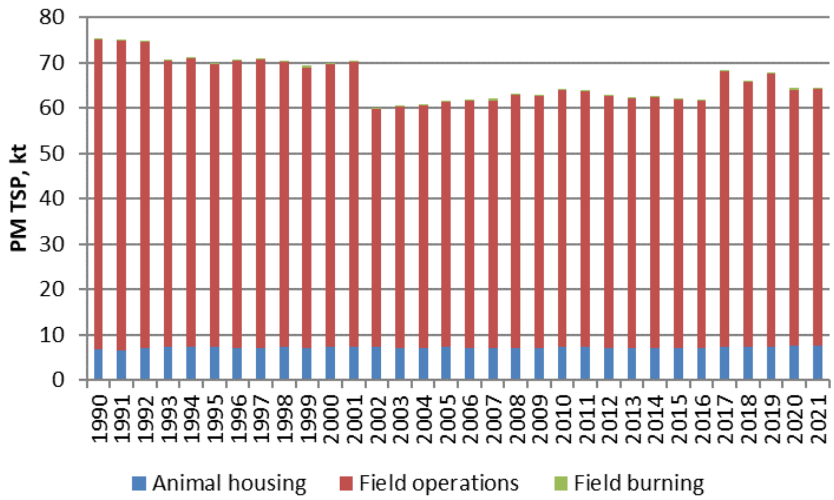


Figure 5.2 Emission of particulate matter (TSP) from the agricultural sector 1990 to 2021.

5.2 References – sources of information

DCE – the Danish Centre for Environment and Energy, Aarhus University, which is responsible for the emission inventory, has established data agreements with the institutes and organisations to assure that the necessary data are available for timely completion of the emission inventory. The main part of the emission is related to livestock production and most of the data are based on Danish standards.

Activity data, emissions factors (EF) and additional values are collected, evaluated and discussed in cooperation with Statistics Denmark, DCA - Danish Centre for Food and Agriculture, Aarhus University, SEGES, Danish Environmental Protection Agency and the Danish Agriculture Agency. It means that both the data and the methods used are evaluated continuously according to latest knowledge and information. Table 5.4 shows the source of data input from the different institutes.

Table 5.4 List of institutes involved in the emission inventory.

References	Abbreviation	Data / information
Statistics Denmark - Agricultural Statistics (www.dst.dk/en.aspx)	DSt	- livestock production - milk yield - slaughtering data - export of live animal - poultry - land use - crop production - crop yield
Danish Centre for Food and Agriculture, Aarhus University	DCA	- N-excretion - feeding situation - N-content in crops - NH_3 emissions factor - PM emissions factor
SEGES (www.seges.dk/)	SEGES	- housing type (until 2004) - grazing situation - manure application time and methods - estimation of extent of field burning of agricultural residue - acidification of slurry
Danish Environmental Protection Agency (www.mst.dk)	DEPA	- sewage sludge used as fertiliser (until 2004) - industrial waste used as fertiliser
The Danish Agriculture Agency (www.lbst.dk)	DAA	- inorganic fertiliser - number of animals from CHR - housing type (from 2005) - sewage sludge used as fertiliser(from 2005)

5.2.1 Methods

The emission calculation is based on the methodologies provided in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2019).

The agricultural sector includes emission from manure management (NFR 3B), agricultural soils (NFR 3D), field burning of agricultural residue (NFR 3F) and Agriculture other (NFR 3I). The field burning of agricultural residue has been prohibited since 1989. However, burning of straw may take place in connection with fields continuously cultivating seed grass or in cases where weather conditions result in surplus of straw in form of wet or broken bales.

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. The model, as shown in Figure 5.3, is implemented and used to calculate emissions of air pollutants NH_3, PM, NO_x, CO, NMVOC, SO_2, heavy metals, dioxin, PAH, HCB, PCB and greenhouse gases (N_2O, CH_4 and CO_2). Thus, the same activity data is used for both the air pollutants and the greenhouse gases and there is direct link between the NH_3 emission and the emission estimation of N_2O.

DCA, Danish Centre for Food and Agriculture, Aarhus University delivers Danish standards relating to feeding consumption, manure type in different housing types, nitrogen content in manure, etc. Previously, the standards were updated and published every third or fourth year. From year 2001, DCE receives updated data annually directly from DCA in the form of spreadsheets. These standards have been described and published in English in Poulsen & Kristensen (1998), and in Danish in Poulsen et al (2001) and Børsting et al (2021). From 2004, the standards are uploaded every year at http://anis.au.dk/forskning/sektioner/husdyrernaering-og-fysiologi/normtal/.

IDA - Integrated Database model for Agricultural emissions

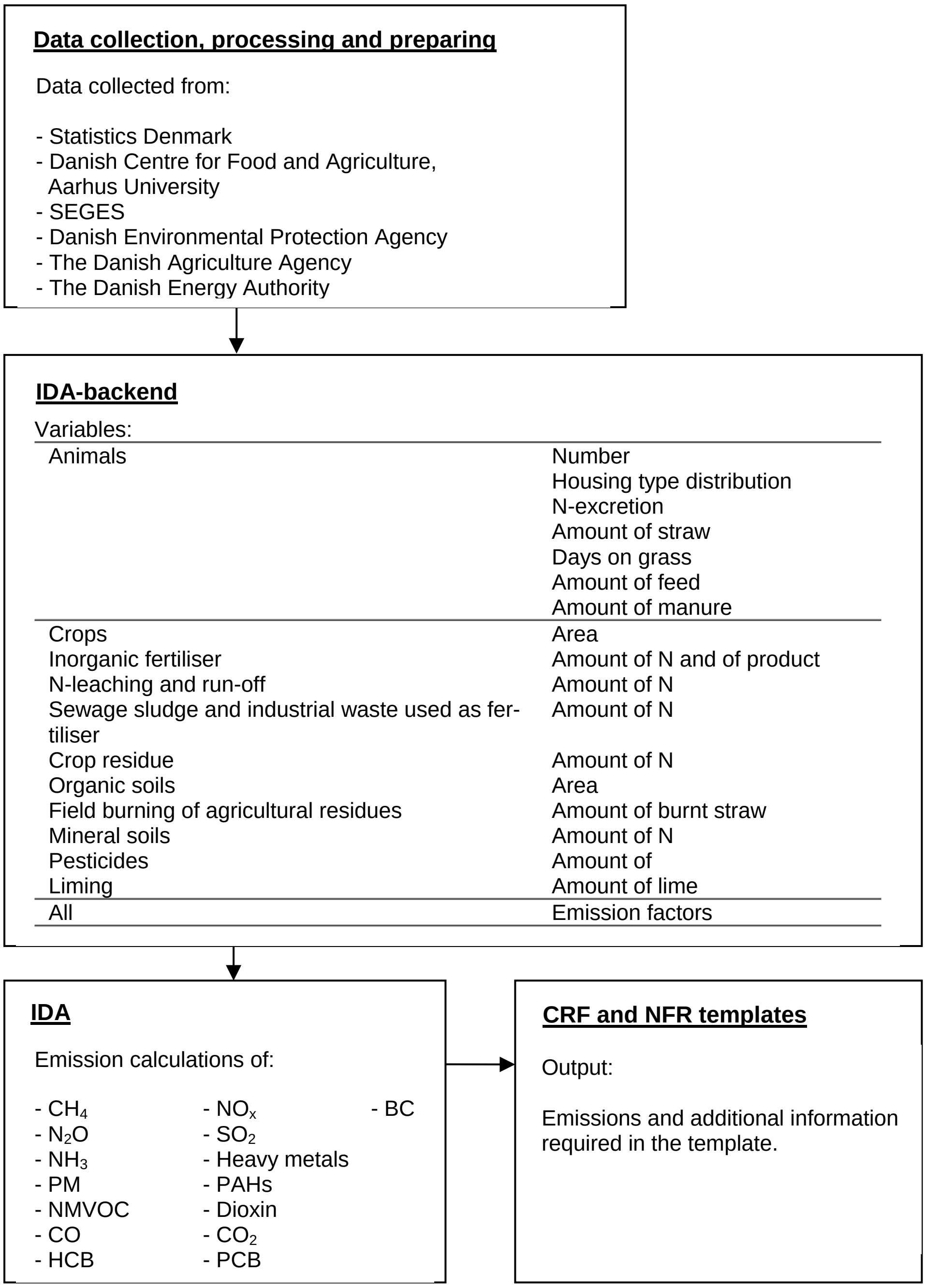


Figure 5.3 Overview of the data process for calculation of agricultural emissions.

IDA includes 42 different livestock categories, divided on weight class and age. Each of these subcategories is subdivided according to housing system and manure type, which results in 289 different combinations of subcategories and housing type (Table 5.5). The emissions are calculated from each of these subcategories and then aggregated in accordance with the livestock categories given in the NFR. It is important to point out that changes in the emission and the implied emission factor over the years, are not only a result of changes in the number of animals, but also depend on changes in the allocation of subcategories, changes in feed consumption, changes in housing type and changed practices with regard to the handling of livestock manure in relation to storage and application.

Table 5.5 Livestock categories and subcategories.

NFR 3B	Animal categories	Includes	No. of sub-categories in IDA, animal type/housing system/manure type
3B 1a	Dairy Cattle[1]	Dairy Cattle	40
3B 1b	Non-dairy Cattle[1]	Calves (<½ year), heifers, bulls, suckling cattle	129
3B 2	Sheep	Sheep and lambs	2
3B 3	Swine	Sows, weaners, fattening pigs	52
3B 4d	Goats	Including kids (meet, dairy and mohair)	3
3B 4e	Horses	<300 kg, 300 - 499 kg, 500 - 700 kg, >700 kg	4
3B 4gI-gIV	Poultry	Hens, pullet, broilers, turkey, geese, ducks, ostrich, pheasant	49
3B 4h	Other	Fur bearing animals, deer	9

1) For all cattle categories, large breed and jersey cattle are distinguished from each other.

5.3 Manure management

For the sector manure management, the emissions of NH_3, PM, NMVOC and NO_x are estimated.

5.3.1 Activity data

Animals

Table 5.6 shows the development in livestock production from 1985 to 2021 based on the Agricultural Statistics (Statistics Denmark). The number of animals corresponds to average annual production (AAP), which means the number of animals that are present on average within the year (EMEP/EEA, 2019). 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, because the total production cycle for these animals is less than one year and because the normative figures are based on one produced animal. See Annex 3D Table 3D-1 for number of animals allocated on subcategories.

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 (Holm, 2022).

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.).

Since 1985, the production of swine, poultry and fur has increased significantly, fur only until 2020. This is contrary to the production of cattle, which has decreased as a result of increasing milk yields. The production of non-dairy cattle follows same trend as dairy cattle, the production of beef cattle is negligible in the Danish agricultural production.

Table 5.6 Livestock production 1985 to 2021 given in AAP, 1000 head - NFR category 3B.

NFR	Animal category	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
3B 1a	Dairy Cattle	896	753	702	636	564	568	561	575	567	567	564
3B 1b	Non-dairy cattle	1 721	1 486	1 388	1 232	1 006	1 003	991	965	925	932	924
3B 2	Sheep[1]	99	230	202	279	316	278	210	205	220	200	196
3B 3	Swine	9 089	9 497	11 084	11 922	13 534	13 173	12 538	12 781	12 299	13 163	13 168
3B 4d	Goats[1]	8	7	7	8	11	16	11	10	12	10	10
3B 4e	Horses[1]	140	135	143	150	175	165	155	175	175	183	183
3B 4gI	Laying hens	5 577	5 696	6 088	4 935	5 168	5 248	5 765	7 001	7 772	7 385	7 398
3B 4gII	Broilers	8 490	9 802	12 585	16 047	11 905	12 836	11 122	12 350	14 690	13 950	14 056
3B 4gIII	Turkeys	308	238	456	456	518	463	275	293	302	319	209
3B 4gIV	Other poultry	1 822	1 600	1 563	1 374	1 509	1 510	1 447	1 421	1 484	1 620	1 379
3B 4h	Other											
3B 4h	Fur bearing animals[2]	1 906	2 264	1 850	2 199	2 552	2 699	3 388	3 363	2 466	2 216	NO
3B 4h	Deer	9	10	10	10	10	10	8	8	8	7	7

[1] Includes animals on small farms (less than 5 ha), which are not included in the Agricultural Statistics published by Statistics Denmark.

[2] In 2021, NO, because the production of mink were closed down due to risk of spreading of corona virus. All animals were put down at the end of year 2020.

See Annex 3D Table 3D-1 for number of animals allocated on subcategories.

N-excretion

The normative figures for both total nitrogen excretion and the content of Total Ammoniacal Nitrogen (TAN) are provided by DCA, Aarhus University.

The emission of NH_3 from manure management is calculated on the basis on nitrogen excreted from livestock. Most of the N excreted that is readily degradable and broken down to NH_4-N is found in the urine. The relationship between NH_4-N and total N will not remain constant over time due to changes in feed composition and feed use efficiency. In order to be able to implement the effect of NH_3 reducing measures as improvements in feed intake and composition in the emission inventory, it is necessary to calculate the emission based on the TAN content. Since 2007, DCA has established Danish standards based on TAN for liquid manure, which is incorporated in the inventory. The emission for solid manure and deep litter is based on the total N excreted because DCA's estimate of TAN follows urine-N.

In Annex 3D Table 3D.2 is given the average N-excretion based on Total-N for each NFR livestock category from 1985 to 2021 (Table 3D.2a) and N-excretion based on TAN for 2007-2021 (Table 3D.2b). These values include N excretion from grazing animals. Notice that each livestock category is an aggregated average of different subcategories (see Table 5.5).

Housing system

A systematic registration of the housing of husbandry for all farms does not exist from 1985 to 2004 and the housing type distribution is therefore based on estimates from Danish Agricultural Advisory Centre (now SEGES) (Rasmussen, 2006) and Lundgaard (2006). From 2005, the distribution of housing system is based on information from the Danish Agriculture Agency, which is based on information from the farmers.

The structural development in the agricultural sector has an influence on the changes in housing type distribution. The trend in housing system for dairy cattle goes from older tied-up housings, which is replaced by bigger housings with loose-holding. In 1985, 85 % of the dairy cattle were kept in tied-up housings and in 2021, the share is reduced to 3 %. In loose-holding systems, the cattle have more space and more straw bedding and this will in general increase the NH_3 emission per animal compared to the tied-up housings. In Annex 3D, Table 3D.3, the distribution of housing type for all animals for 1985-2021 is listed.

Use of NH_3 reducing technology in housings is in some extent implemented in the emission inventory. For the cattle production, share of animals housed in systems with acidification of the manure is estimated and for the swine production, the share of animals in systems with acidification and cooling of the manure is estimated. For mink, share of housings with frequent removal of manure and for broilers housings with heat exchanger systems are estimated. NH_3 reducing technology is implemented for the years 2007-2021. See Annex 3D Chapter 3D-1 for information on estimation of NH_3 reducing technology. In Table 5.7a-d is shown the share of animals in housings with NH_3 reducing technology.

Table 5.7a Share of animals in housings with NH_3 reducing technology. Acidification, %.

	2007	2010	2015	2018	2019	2020	2021
Dairy cattle, large breed	0.1	0.9	3.4	3.5	3.0	2.7	2.2
Dairy cattle, Jersey	0.5	2.1	4.7	4.2	4.1	4.1	3.4
Heifers, large breed	0.04	0.1	0.4	0.4	0.5	0.5	0.4
Heifers, large breed	-	-	-	0.2	0.1	0.1	0.1
Bulls, jersey	-	1.3	2.7	1.1	1.2	1.1	-
Bulls, jersey	-	-	-	-	-	0.02	-
Fattening pigs	0.3	1.0	1.9	2.0	2.7	2.3	2.5
Weaners	0.6	1.1	1.4	1.7	1.6	1.5	1.4
Sows	0.3	1.1	2.1	2.0	2.1	1.9	2.4

Table 5.7b Share of animals in housings with NH_3 reducing technology. Cooling, %.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017-2021
Fattening pigs	0.1	0.4	0.9	1.2	1.5	1.7	2.0	2.3	2.7	3.4
Weaners	0.0	0.4	0.9	1.2	1.7	2.3	2.9	3.7	4.4	5.3
Sows	0.4	0.9	1.6	2.2	3.1	4.4	5.0	6.1	6.9	7.4

Table 5.7c Share of animals in housings with NH_3 reducing technology. Frequent removal of manure, %.

	2010	2011	2012	2013	2014	2015	2016	2017-2021
Mink	1.0	1.4	3.0	3.9	5.2	6.9	8.2	11.3

Table 5.7d Share of animals in housings with NH_3 reducing technology. Heat exchanger, %.

	2012	2013	2014	2015	2016	2017-2021
Broilers	24	49	67	83	82	90

5.3.2 NH_3

Description

The main part of the NH_3 emission (42 %) is related to manure management – mainly from the cattle and swine production (Figure 5.4). The reduced emission from swine over time is due to an active environmental policy in combination with improvements within the genetic development and improvements of feed intake efficiency. The emission from cattle has decreased as a consequence of less number of cattle. The emission from "other" varies over the years, which is mainly due to variation in number of produced mink and due to the closing of the production of mink in the end of 2020 emission from "other" decreases significantly in 2021.

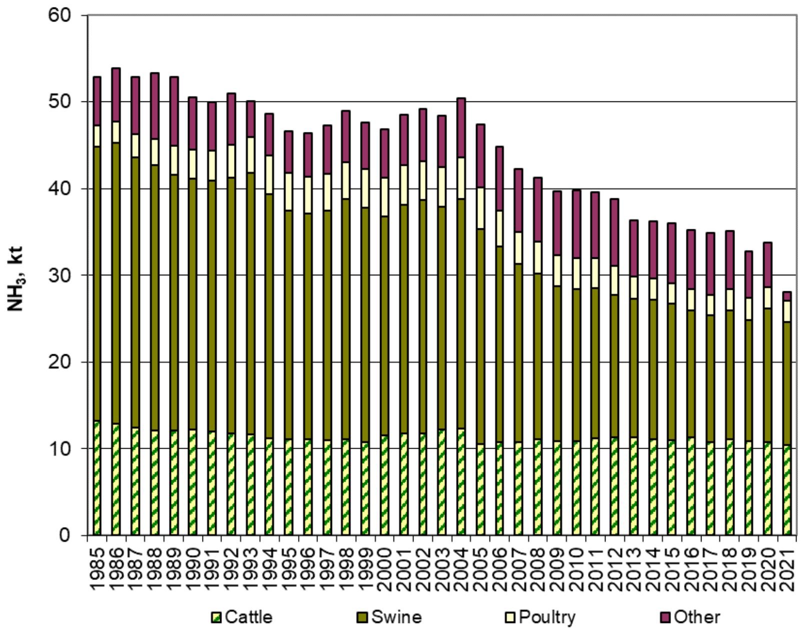


Figure 5.4 NH_3 emission from manure management 1985 to 2021.

Methodological issues

NH_3 emission from manure management covers emission from housings and storage and is based on N excreted and emission factors given in the normative figures (Børsting & Hellwing., 2022, Børsting et al., 2021).

Activity data

See Chapter 5.2.1

Emission factor

Emission factors - Housing

The emission from housings is thus determined by a number of different conditions that depends on housing type and the different kinds of manure disposal systems placed in these housings. Danish Centre for Food and Agriculture - DCA, Aarhus University has carried out a number of emission surveys and estimated emission coefficients for each type of housings (Poulsen et al., 2001 and Børsting & Hellwing, 2022, Børsting et al., 2021).

Table 5.8 shows the emission factors for the most important animal categories; dairy cattle and fattening pigs in different housing systems. For the slurry and liquid manure is given TAN emission factors (TAN ex animal) and for solid and deep litter manure is given N ex animal.

Table 5.8 NH_3 emission factors in different housing systems 2021 – dairy cattle and fattening pigs.

Manure system	Manure type	NH_3 emission	NH_3 emission
		Pct. NH_3-N of N ex Animal	Pct. NH_3-N of TAN ex Animal
Dairy cattle			
Tied-up	Solid manure	5.0	
	+ Liquid		6.0
Tied-up	Slurry		6.0
Loose-holding with beds, slatted floor	Slurry		13.5
Loose-holding with beds, slatted floor, scrapes	Slurry		13.5
Loose-holding with beds, solid floor	Slurry		20.0
Loose-holding with beds, drained floor	Slurry		10.4
Deep litter (all)	Deep litter	6.0	
Deep litter, slatted floor	Deep litter	6.0	
	+ Slurry		13.5
Deep litter, slatted floor, scrapes	Deep litter	6.0	
	+ Slurry		12.0
Deep litter, solid floor, scrapes	Deep litter	6.0	
	+ Slurry		20.0
Fattening pigs			
Full slatted floor	Slurry		24.0
Partly slatted floor (50-75% solid floor)	Slurry		13.0
Partly slatted floor (25-49% solid floor)	Slurry		17.0
Solid floor	Solid manure	15.0	
	+ Liquid		27.0
Deep litter	Deep litter	15.0	
Partly slatted floor and partly deep litter	Deep litter	15.0	
	+ Slurry		18.0

Emission factors - Storage

Livestock manure is collected either as solid manure or as slurry depending on housing type. In Table 5.9 are shown the emission factors used for storage. It is assumed that the part of solid manure taken directly from the housing into the field is 65 % from cattle, 25 % from pigs, 50 % from sows, 15 % from poultry, 5 % from hens and 15 % from mink (Kai et al, 2022a). The remaining part of the solid manure is deposited in stockpiles in the field before field application.

By law, all slurry tanks have to be covered by a fixed cover or a full floating cover in order to reduce NH_3 emission. Birkmose, T. & Hørfarter, R. (2019) have by a web based tool to machine learning estimated the amount of slurry tanks covered with tent cover in Denmark in 2018. Information about the amount of slurry tanks covered with concrete lid in 2018 is given from the supervisory body for slurry tanks (Anderson, 2019). A survey has been made to estimate the amount of slurry tanks with fixed cover in the years 1985-2018 (Mikkelsen & Albrektsen, 2020). For full floating cover, it can be difficult to establish a natural full floating cover every day all year especially for tank with pig slurry. In 2021, it is assumed that 5 % of the tanks with swine slurry and 2 % of tanks with cattle slurry are incompletely covered (Annex 3D Table 3D-4).

Table 5.9 NH_3 emission factors for storage, 2021.

		Liquid manure	Slurry	Solid manure	Deep litter
		Loss of NH_3-N in %			
Animal category		of TAN ex housing	of TAN ex housing	of N ex housing	of N ex housing
Cattle		2.2	3.4	4.0	1.05
Swine	Fattening pigs	2.2	2.7	19.0	9.75
	Sows		2.7	19.0	6.50
Poultry	Hens, pullet and ostrich		2.0[a]	7.5	4.75
	Broilers, geese and ducks				6.80
	Turkeys				8.00
Fur bearing animals			2.7	11.5	6.80
Sheep/goats					3.0
Horses					3.0

[a] Loss of NH_3-N in % of N ex housing.

Reduction factors

Use of the NH_3 reducing technologies, acidification, cooling of slurry, frequent removal of manure and heat exchanger in housings, have been implemented in the emission calculations.

Table 5.10 show the reduction factors used in the emission calculations. The reduced emission factor due to acidified slurry, frequent removal of manure and heat exchanger is based on the Environmental Technologies List (MST, 2021). The list include technologies, which through tests have been documented to be environmentally efficient. The Environmental Technologies List is continuously adjusted due to new developed emission reducing technology and to latest knowledge, which in practise can result in change of reduction factors.

The reduction factor for cooling of slurry is based on the average reduction factors in the Environmental Approval Register. If farmers plan to increase the livestock production and build or restore livestock housing, then a reduction of ammonia emission is required by law. The farmers have to apply for an Environmental Approval for livestock farming whit information for how to reach the reduction, and for approximately 20 % of the approval, the emission reducing technology in housing chosen.

Table 5.10 Reduction factors.

	Reduction factor, %
Acidification in housing, cattle	50[a]
Acidification in housing, swine	64[a]
Cooling, swine	20[b]
Frequent removal of manure, mink	27[a]
Heat exchanger, broilers	30[a]

[a] Based on values in the Environmental Technologies List (MST, 2021).
[b] Average value based on the Environmental Approval Register.

Implied emission factor

Table 5.11 shows the implied emission factors for each NFR livestock category from 1985 to 2021. The implied emission factors express the average emission of NH_3 from housing and storage per AAP (annual average population) per year. The implied emission factors are changing from year to year depending on a combination of several factors, such as:

- change in number of animals or change in the share of different subcategories,
- change in feed intake and N-excretion,
- change in housing type
- acidification of slurry

The emission from urine and dung deposited by grazing animals is included in the emission from agricultural soils (NFR – 3Da3).

For dairy cattle, the implied emission factor has increased from 1985 to 2021 and this is due to increase in feed intake and milk production per cow. For most of the other animal categories, the implied emission factor has decreased from 1985 to 2021, which is mainly the result of measures in relation to the environmental Action Plans. Strict requirements to obtain improvements in utilisation of nitrogen in feed and manure have resulted in reduction of N-excretion and especially for fattening pigs.

Table 5.11 Implied emission factor, manure management 1985 to 2021, kg NH_3 per AAP per year.

NFR	Animal category	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
3B 1a	Dairy cattle	9.09	9.99	9.96	11.33	13.72	13.24	13.45	13.61	13.67	13.54	13.01
3B 1b	Non-dairy cattle	2.93	3.12	2.99	3.54	2.80	3.36	3.47	3.34	3.38	3.33	3.33
3B 2	Sheep	0.44	0.44	0.44	0.44	0.44	0.40	0.40	0.40	0.40	0.40	0.40
3B 3	Swine	3.48	3.04	2.37	2.12	1.83	1.33	1.26	1.16	1.14	1.17	1.08
3B 4d	Goats	1.09	1.09	1.09	1.09	1.05	0.98	1.01	1.01	1.00	1.00	1.00
3B 4e	Horses	5.44	5.34	4.80	4.84	4.84	4.34	4.34	4.34	4.34	4.80	4.80
3B 4gI	Laying hens	0.15	0.20	0.25	0.27	0.34	0.27	0.22	0.20	0.19	0.20	0.20
3B 4gII	Broilers	0.15	0.20	0.18	0.17	0.21	0.15	0.08	0.07	0.06	0.06	0.06
3B 4gIII	Turkeys	0.49	0.51	0.65	0.63	0.64	0.51	0.55	0.54	0.54	0.55	0.54
3B 4gIV	Other poultry	0.10	0.10	0.14	0.10	0.08	0.03	0.02	0.02	0.02	0.01	0.01
3B 4h	Other*	2.47	2.28	2.16	2.13	2.44	2.55	1.82	1.73	1.84	1.84	NO

* NO in 2021 due closing of the production of mink.

Emissions

The NH_3 emission from manure management is estimated to 28.0 kt NH_3 in 2021 (Table 5.12). From 1985 to 2021, the emission is reduced by 47 %. As mentioned in Chapter 5.1.1 this development is mainly due to implementation of a number of action plans to reduce nitrogen losses from the agricultural production. Furthermore contributes the closing of the mink production also in 2021.

In 2021, cattle production contributes with 37 % of the total emission from manure management. The swine production contributes in 2021 with 51 % of the total emission from manure management. The number of cattle has decreased as a result of a growth in milk yield. The production of fattening pigs has increased by more than 50 % compared with 1985. However, despite this development the emission from swine is still decreasing. This is due to a breeding of pigs with focus on a biological development and improvement in fodder efficiency. Thus, the N-excretion for fattening pigs has decreased from 5.09 kg per pig per year in 1985 to 2.70 in 2021.

From 2005, storage of deep litter should be covered by law (BEK, 2002), which has resulted in decreasing emission factor for storage of deep litter from 8.75 % to 1.75 %.

The emission from other poultry decreases from 2005 to 2010. This is due to a change in the proportions of different types of poultry within the sector. Other poultry includes ducks, geese, pheasants and ostrich, and because of a huge decrease in the number of ducks and ostrich from 2006 to 2007 the emission decreases and the IEF decreases as well because the share of emission changes.

Table 5.12 Emission of NH_3 from manure management 1985 to 2021, kt NH_3.

NFR	Animal category	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
3B 1a	Dairy cattle	8.15	7.53	7.00	7.20	7.74	7.53	7.54	7.83	7.74	7.68	7.34
3B 1b	Non-dairy cattle	5.05	4.64	4.14	4.36	2.81	3.37	3.43	3.22	3.13	3.11	3.08
3B 2	Sheep	0.04	0.10	0.09	0.12	0.14	0.11	0.08	0.08	0.09	0.08	0.08
3B 3	Swine	31.67	28.92	26.29	25.27	24.81	17.51	15.77	14.85	13.98	15.34	14.20
3B 4d	Goats	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01
3B 4e	Horses	0.76	0.72	0.68	0.73	0.85	0.72	0.67	0.76	0.76	0.88	0.88
3B 4gI	Laying hens	0.86	1.17	1.51	1.35	1.76	1.44	1.24	1.38	1.47	1.48	1.49
3B 4gII	Broilers	1.24	1.99	2.31	2.68	2.52	1.89	0.89	0.91	0.89	0.88	0.84
3B 4gIII	Turkeys	0.15	0.12	0.29	0.29	0.33	0.23	0.15	0.16	0.16	0.18	0.11
3B 4gIV	Other poultry	0.18	0.16	0.22	0.14	0.12	0.04	0.02	0.03	0.03	0.02	0.01
3B 4h	Other*	4.73	5.19	4.02	4.71	6.26	6.90	6.19	5.83	4.55	4.10	NO
3B	Total	52.85	50.54	46.57	46.86	47.35	39.75	36.01	35.06	32.80	33.75	28.03

* NO in 2021 due closing of the production of mink.

Figure 5.5 shows the percentage distribution of the NH_3 emission from housing, storage and application of manure. The main part of the reduction in NH_3 emission has taken place in connection with the application of manure in fields, due to changes in manure application practice, see Chapter 5.4.2. There has been a reduction in emissions associated with storage of manure, which is a result of improvement in coverage of slurry tanks. As a consequence of this development, the percentage of emission from housing is increased from 32 % in 1985 to 48 % in 2021.

The possibilities for NH_3 reduction will likely be focused on measures in housings by various technological solutions. Some ammonia reducing technology is already implemented in housing e.g. air cleaning systems and slurry acidification, cooling and others. The reduced effect of air cleaning systems is not taken into account in the Danish inventory because improvement in documentation is needed. The slurry acidification and cooling of slurry in housings, frequent removal of manure in fur housings, heat exchanger in broiler housings and slurry acidification in storage and application is taken in to account.

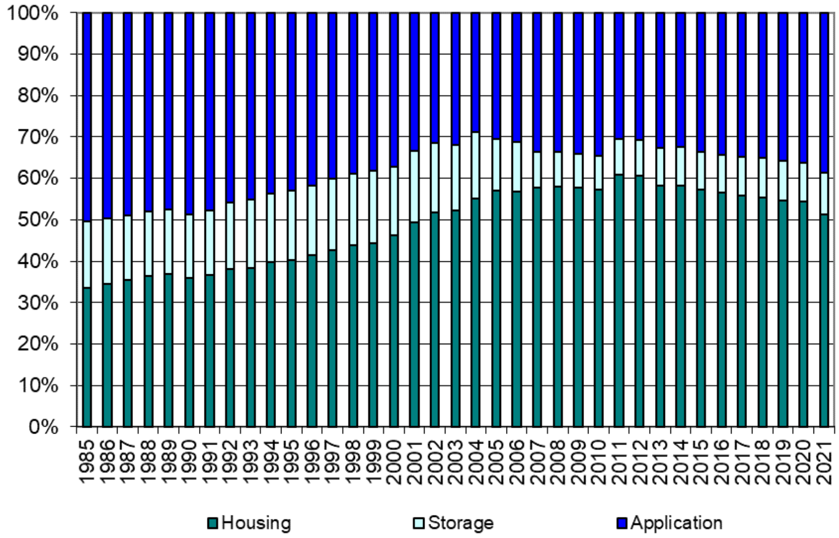


Figure 5.5 The percentage distribution of the NH_3 emission in manure management 1985-2021.

5.3.3 PM

Description

Investigations have shown that farmers, as well as livestock, are subject to an increased risk of developing lung and respiratory related diseases due to the particulate emissions (Hartung and Seedorf, 1999). This is because the particles are able to carry bacteria, viruses and other organic compounds.

In 2021, the PM emission from housings, given as TSP, is estimated to 7.50 kt, which correspond to 12 % of the emission of TSP from the agricultural sector. Of the 7.50 kt TSP, 55 % relates to swine production. The emission from cattle and poultry contributes with 18 % and 26 %, respectively and the remainder animals contribute with 1 %.

Methodological issues

The estimation of PM emission is based on the EMEP/EEA guidebook (2019) and includes primary particles in the form of dust from housings. The inventory includes PM emission from cattle, swine, poultry, horses, sheep, goats and fur bearing animals (Table 5.13). The number of grazing days is taken into account. Some animal categories are divided into subcategories and for some categories (if applicable) distinction is made between solid and slurry based housing systems.

The PM emission is related to the annual average population (AAP) and to the time the animal is housed. The PM emission from grazing animals is considered as negligible.

Table 5.13 Livestock categories used in the PM emission inventory.

Livestock categories as given in NFR	Subcategories as given in the EMEP/EEA guidebook	Danish inventory	Grazing days
Dairy Cattle	Dairy cattle	Dairy cattle	18
Non-Dairy Cattle	Calves	Calves < ½ yr	0
	Beef cattle	Bulls	0
		Heifers	132
		Suckling cattle	224
Swine	Sows	Sows (incl. weaners until 6.7 kg)	0
		Sows (incl. weaners until 15 kg), organic production	195
	Weaners	Weaners (6.7-31 kg)	0
	Fattening pigs	Fattening pigs (31-113 kg)	0
Poultry	Laying hens	Laying hens	0
	Broilers	Broilers	0
	Turkeys	Turkeys	0
	Other poultry	Ducks	0
		Geese	365
Horses	Horses	Horses	183
Sheep	Sheep	Sheep	265
Goats	Goats	Goats	265

Activity data

See Chapter 5.2.1

Emission factor

Emission factors for TSP, PM_{10} and $PM_{2.5}$ are based on the EMEP/EEA guidebook (EMEP/EEA, 2019). The same emissions factors are used for all years. Estimation of TSP is based on the transformation factors between TSP and PM_{10} as given in the EMEP/EEA emission inventory guidebook (2019).

Table 5.14 Emission factors for particle emission from animal housing system.

Livestock category	Housing system	Emission factor PM_{10}	$PM_{2.5}$	TSP	Transformation factor PM_{10} to TSP
		kg per AAP per year			
Cattle:					
Dairy cattle	Slurry	0.83	0.54	1.81	0.46
	Solid	0.43	0.28	0.94	0.46
Calves < ½ year	Slurry	0.15	0.10	0.34	0.46
	Solid	0.16	0.10	0.35	0.46
Beef cattle	Slurry	0.32	0.21	0.69	0.46
	Solid	0.24	0.16	0.52	0.46
Heifer[1)]	Slurry	0.49	0.32	1.07	0.46
	Solid	0.30	0.19	0.64	0.46
Suckling cattle[2)]	Slurry	0.32	0.21	0.69	0.46
	Solid	0.24	0.16	0.52	0.46
Swine:					
Sows	Slurry	0.17	0.01	0.62	0.27
	Solid	0.17	0.01	0.62	0.27
Weaners	Slurry	0.05	0.00	0.27	0.19
	Solid[3]	0.05	0.00	0.27	0.19
Fattening pigs	Slurry	0.14	0.01	1.05	0.13
	Solid	0.14	0.01	1.05	0.13
Poultry:					
Laying hens	Solid	0.04	0.003	0.19	0.21
Broilers	Solid	0.02	0.002	0.04	0.50
Ducks	Solid	0.14	0.02	0.14	1.00
Geese	Solid	0.24	0.03	0.24	1.00
Turkeys	Solid	0.11	0.02	0.11	1.00
Horses	Solid	0.22	0.14	0.48	0.46
Sheep	Solid	0.06	0.02	0.14	0.40
Goats	Solid	0.06	0.02	0.14	0.40
Fur bearing animals	Solid	0.008	0.004	0.02	0.45

1) Average of “calves” and “dairy cattle”.
2) Assumed the same value as for “Beef cattle”.
3) Same as slurry based systems.

Emissions

Figure 5.6 shows the PM emission, given in TSP for each animal category in the period 1990 to 2021. It is seen that the main part of the emission originates from swine housings. See Annex 3D Table 3D-5 for the PM emission, given in TSP, PM_{10} and $PM_{2.5}$. In the period 1990 to 2021, the total agricultural emission of TSP from housings is increased by 13 %. The increase is mainly due to increase in the number of swine.

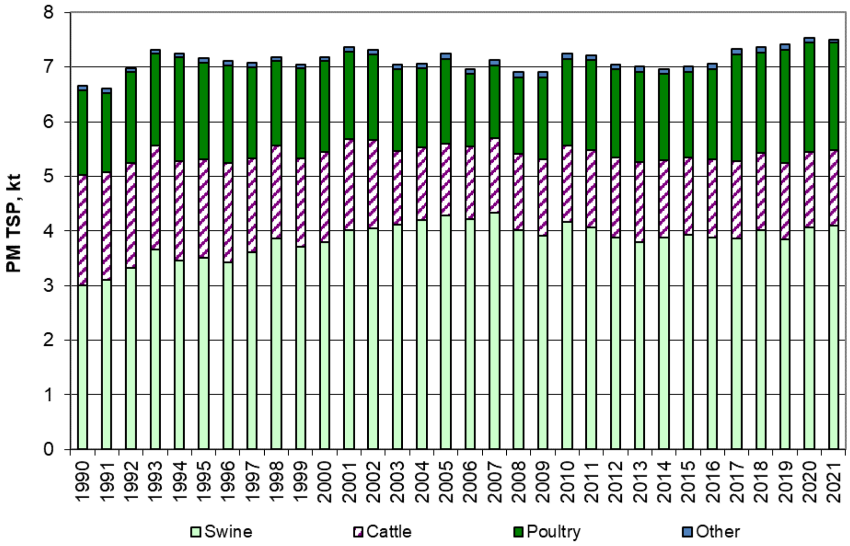


Figure 5.6 PM emission from housings 1990 – 2021, kt TSP.

5.3.4 NMVOC

Description

The emission of NMVOC from manure management contribute with 82 % of the agricultural NMVOC emission and is mainly related to the cattle production.

Methodological issues

The estimation of NMVOC emission is based on the EMEP/EEA guidebook (2019) Tier2 approach. NMVOC emissions from animal husbandry comes from feed, degradation of feed in the rumen and from undigested fat, carbohydrate and protein decomposition in the rumen and in the manure**.** The estimation includes NMVOC from silage storage and the feeding table if silage is used for feeding, because silage is a major source of NMVOC emissions. Furthermore includes the estimation emission from livestock housing and outdoor manure stores. Emission of NMVOC from manure application and grazing animals are reported in sector 3Da2a and 3Da3, respectively.

Activity data

The NMVOC emission is estimated on the number of animal, share of time spend in housing/on grass (time on grass in Table 5.13), gross energy for cattle (Annex 3D Table 3D-16), volatile solids (VS) for other animal categories (Annex 3D Table 3D-17) and fraction of silage in the feed (Table 5.15). The number of animal is given as the average annual population (AAP) – see Table 5.6.

Table 5.15 Fraction of silage in the feed.

	Fraction of silage in feed
Dairy Cattle	1
Non-Dairy Cattle	1
Sheep	0.5
Goats	0.5
Horses	0.5
Swine	0
Laying hens	0
Broilers	0
Turkeys	0
Other poultry	0
Other	0

Emission factor

NMVOC emission factors recommended in EMEP/EEA Guidebook 2019 Table 3-11 (cattle) and Table 3-12 (other animals) is used (Table 5.16).

Same emissions factors are used during all years, which mean that changes of the emission over time depends on change in animal production, feed practice or change in grazing days.

Table 5.16 NMVOC emission factors (EMEP/EEA Guidebook 2019, Tier2).

	EF NMVOC silage feeding	EF NMVOC housing
	Kg NMVOC per MJ feed intake	
Dairy Cattle	0.0002002	0.0000353
Non-Dairy Cattle	0.0002002	0.0000353
	Kg NMVOC per kg VS excreted	
Sheep	0.010760	0.001614
Swine – sows		0.007042
Swine – other		0.001703
Goats	0.010760	0.001614
Horses	0,010760	0.001614
Laying hens		0.005684
Broilers		0.009147
Turkeys		0.005684
Other poultry		0.005684
Fur bearing animals		0.005684

Emissions

The development of NMVOC emission from 1990 to 2021 shows a decrease from 41 kt to 38 kt with the highest fall in the beginning of the period (Figure 5.7). The greatest part of the emission originates from cattle. Emission from dairy cattle increases from 1990-2021 due to increase in feed intake, while emission from non-dairy cattle decreases.

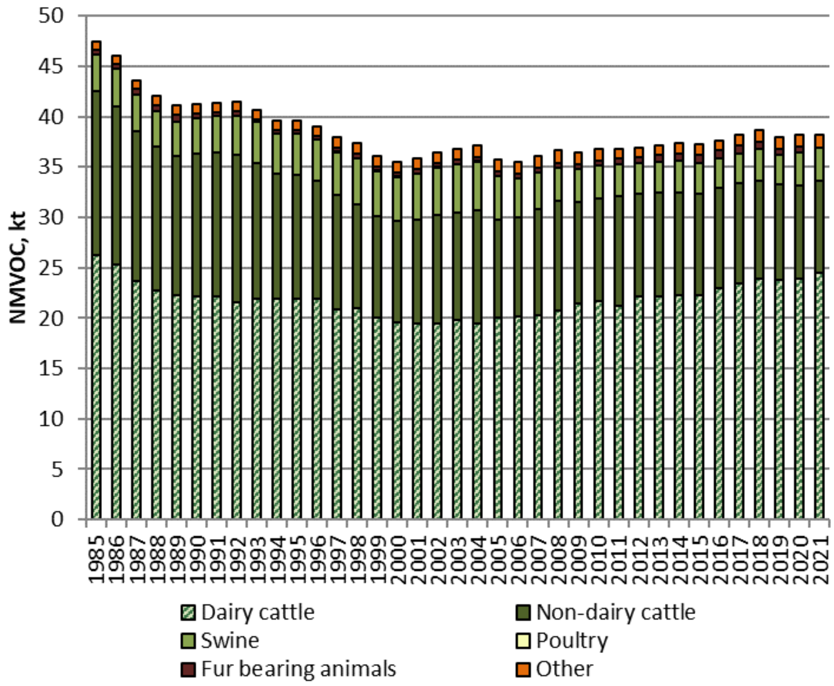


Figure 5.7 Emission of NMVOC from manure management, 1990-2021.

5.3.5 NO_x

Description

An estimate of NO_x from manure management has been calculated and shows that 4 % of the agricultural NO_x emission in 2021 is related to animal husbandry.

Methodological issues

The estimation of NO_x emission is based on the EMEP/EEA guidebook (2019) Tier1 approach.

Activity data

The Tier 1 approach is based on number of animal given as the average annual population (AAP). The Number is showed in Table 5.6.

Emission factor

Emission factor for estimation of NO_x emission from manure management is listed in Table 5.17. Some of the manure from the mink production is handled as slurry, but no EF for slurry is mentioned in the Guidebook. Therefore, the same emissions factor is used for both slurry and solid systems.

Table 5.17 NO emission factors (EMEP/EEA Guidebook 2019), kg NO_2 per AAP.

NFR code	Livestock	slurry	solid
3B 1a	Dairy cows	0.01	0.752
3B 1b	Non-dairy cattle	0.003	0.217
3B 2	Sheep		0.012
3B 3	Sows	0.005	0.471
3B 3	Sows, outdoor		0
3B 3	Fattening pigs	0.002	0.017
3B 4d	Goats		0.012
3B 4e	Horses		0.25
3B 4gi	Laying hens	0.014	0.0001
3B 4gii	Broilers		0.027
3B 4giii	Turkeys		0.027
3B 4giv	Ducks		0.022
3B 4giv	Geese		0.005
3B 4h	Fur bearing animals	0.001*	0.001

* Used the same EF as given for solid manure.

Emissions

The NO_x emission from 1990 to 2021 has decreased significantly from 1.00 kt NO_x to 0.76 kt NO_x corresponding to a 24 % reduction. The emission depends on number of animals and manure type and the decrease is mainly related to changes from solid based systems to slurry-based systems for both dairy cattle and swine production. Thus, the allocation of solid manure was 23 % in 1990 and dropped to 10 % in 2021. Poultry contributes with the main part of the emission and the emission from poultry increases from 1990-2021 due to increase in number of animals.

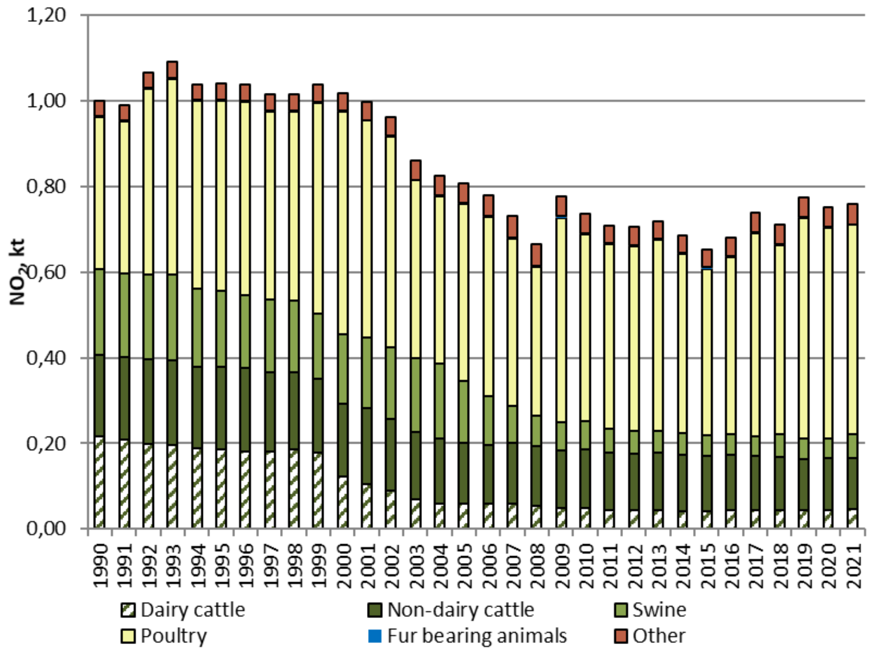


Figure 5.8 NO_x emission from manure management 1990–2021.

5.4 Soils

At present, farmed area covers about 60 % of the total land area in Denmark. In recent decades, farmed area has decreased, being replaced by built-up areas, roads, forest and nature habitats.

5.4.1 Inorganic N-fertilisers

Description

For the sector inorganic N-fertiliser the emission of NH_3 and NO_x are estimated.

The emission of NH_3 from inorganic fertiliser contributes in 2021 with 17 % of the emission from the agricultural sector. The emission of NO_x contributes in 2021 with 50 % of the emission from the agricultural sector.

Methodological issues

Emission of NH_3 from inorganic fertiliser is based on the consumption of fertiliser of different types and emission factors. In Table 5.18 are shown emission factors and consumption for 2021. See Annex 3D Table 3D-6 for assumptions for fertiliser type.

Emission of NO_x is based on the total consumption of N in inorganic N-fertiliser and emission factor given in EMEP/EEA (2019).

Table 5.18 Inorganic N-fertiliser consumption 2021 and emission factors.

	NH_3 Emission factor[1], Kg NH_3-N pr kg N	Consumption[2], kt N
Fertiliser type		
Calcium nitrate	0.012	0.2
Ammonium sulphate	0.106	7.0
Ammonium nitrate with/without sulphur	0.019	116.8
Calcium ammonium nitrate	0.010	9.8
Ammonium nitrate	0.019	0.9
Liquid ammonia	0.022	5.4
Urea	0.157	0.7
Liquid nitrogen	0.097	2.2
NPK-fertiliser	0.059	57.9
Diammonphosphate	0.059	0
NP-fertiliser	0.059	7.0
NK-fertiliser	0.019	1.1
Ammonium-urea solutions	0.097	11.7
Ammonium sulphate nitrate	0.106	9.6
Other N-fertiliser	0.019	0.8
Other	0.040[3]	0
Total consumption of N in inorganic N fertiliser		228.6

[1] EMEP/EEA (2019) weighted value of 79 % normal pH and 21 % high pH. See Annex 3D Table 3D-6 for assumptions for fertiliser type.
[2] The Danish Agriculture Agency, 2022. The fertiliser types magnesium fertiliser and nitrogenous calcium cyanamide are also included in the sales statistics from The Danish Agriculture Agency, but no NH_3 is emitted from these fertilisers.
[3] Implied emission factor, varies from year to year, see Table 5.19.

Activity data

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. As part of the QA/QC procedure, the sale statistics is compared with the actually consumption registered in the Danish fertiliser N accounts controlled by The Danish Agricultural Agency, which indicate a difference for the years 2009-2016 and especially a significant difference for 2016 (Figure 5.9). The difference is caused by farmer's import of inorganic fertilisers, which is confirmed by the Danish Agricultural Agency. It is allowed for the farmer to import fertiliser, if the consumption is related to own fields, but not for onward sale. For the years 2009-2016, the comparison shows a higher consumption of fertilisers registered in the Danish fertiliser N accounts. The farmers have no interest in counting a low estimate, which indicates that the N applied registered in the Danish fertiliser N accounts is more reliable for the years 2009-2016. The Danish Agricultural Agency is aware of the situation with farmers import, and for year 2017, the sales statistics include more companies selling inorganic N fertiliser.

For the years 1985-2008, 2017 and 2019-2021, the use of inorganic N fertiliser is based on the sales statistics. For 2018, a high uncertainty is indicated for the sales estimates (Skade, 2020, pers. Comm.) and therefore use of inorganic N fertiliser is based on the Danish fertiliser N accounts for 2018 and the distribution on types of fertiliser is based on the distribution in 2017.

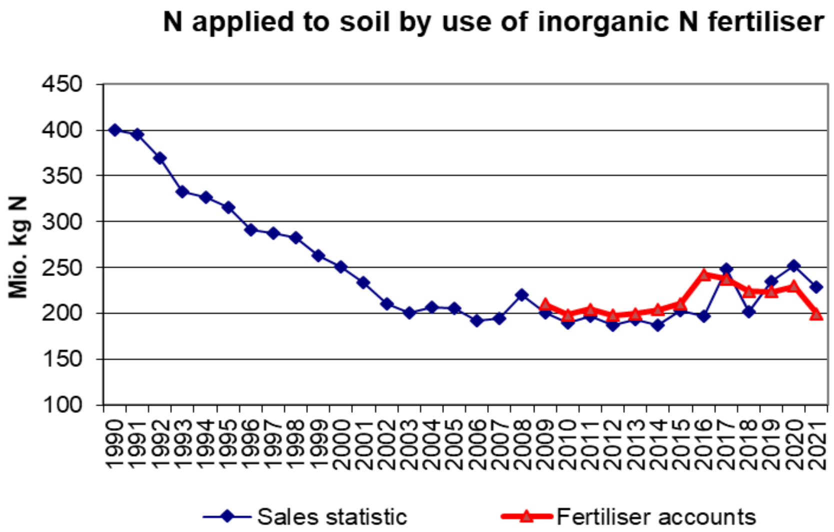


Figure 5.9 N applied from inorganic N fertiliser, sales statistic and N fertiliser account.

Emission factor

Emission factors for both NH_3 and NO_x are based on the values given in EMEP/EEA guidebook (EMEP/EEA, 2019) and the same emission factors are used for all years 1985-2021.

Studies (Hutchings & Sommer, 2020) have shown that 21 % of the Danish agricultural area have a soil pH > 7 (high pH), therefore are the emission factors estimated as a weighted value of 79 % EF for normal soil pH and 21 % EF for high pH given in EMEP/EEA (2019). See Table 5.18.

The implied emission factor for NH_3 is shown in Table 5.19 and it depends on consumption and type of fertiliser. It is also this emission factor, which is used for the fertiliser type "Other".

Table 5.19 Implied emission factor NH_3-N for inorganic N-fertiliser, 1985-2021.

	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Implied emission factor NH_3-N, % of total N	4.49	4.08	4.03	3.81	3.96	4.07	4.30	5.21	3.94	3.98	4.04

Emissions

Figure 5.10 shows the development NH_3 and NO_x emission 1985-2021. Since 1985, there has been a significant decrease in use of inorganic N-fertiliser. This is due to requirements to utilising of nitrogen in manure as outlined in various environmental action plans. Another explanation for a reduction of emission is a decrease in use of urea as currently accounting for less than 1 % of the total nitrogen (Table 5.18). From 2016, the emission has increased slightly, which is caused by increase in consumption of inorganics fertilisers, as a consequence of the Agreement on a 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, in interaction with projection of nature and environment. It was decided to initiate a series of measures to decrease the N-leaching, and in combination with expected higher crop yield, a higher consumption level of inorganic fertilisers was allowed.

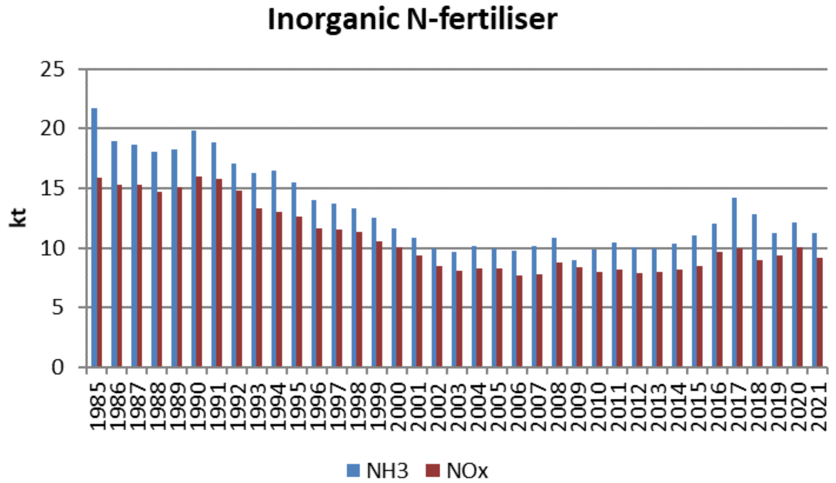


Figure 5.10 Emission of NH_3 and NO_x for 1985-2021, kt.

5.4.2 Animal manure applied to soils

Description

For the sector, animal manure applied to soils the emission of NH_3, NMVOC and NO_x are estimated.

Emission of NH_3 from animal manure applied to soils contributes in 2021 with 26 % of the NH_3 emission from the agricultural sector. NMVOC contributes in 2021 with 13 % of the NMVOC emission from the agricultural sector. Emission of NO_x from animal manure applied to soils contributes in 2021 with 44 % of the NO_x emission from the agricultural sector.

Methodological issues

NH_3

To calculate emissions of NH_3 from animal manure applied to soils weighted emission factors are estimated and multiplied with TAN ex storage for liquid manure and N ex storage for solid manure for each animal type. The weighted emission factors are estimated based on background estimates of time of application, application methods, application in growing crops or on bare soil and the time from application to ploughing in soil combined with emission from the given conditions – see further description below.

NMVOC

Emission of NMVOC from manure applied to soil is based on Tier 2 method given in EMEP/EEA guidelines 2019 Chapter 3B Manure management, but reported in sector 3Da2a.

$$EF_{NMVOC,app.} = EF_{NMVOC,housing} \cdot \left(\frac{E_{NH3,appl.}}{E_{NH3,housing}}\right)$$

Where:

$EF_{NMVOC, appl.}$ = Emission factor for NMVOC from manure applied to soil
$EF_{NMVOC, housing}$ = Emission factor for NMVOC from housing (estimated in sector 3B)
$E_{NH3, appl.}$ = Emission of NH_3 from manure applied to soil
$E_{NH3, housing}$ = Emission of NH_3 from housing (estimated in sector 3B)

NO_x

The NO_x emission is calculated as emission factor multiplied with N ex storage for each animal type.

Activity data

Based on the normative figures (Børsting & Hellwing, 2022) the amount of TAN ex storage for liquid manure and the amount of N ex storage for solid manure are estimated.

Emission factor NH_3

The emission factors are based on background estimates of time of application, application methods, application in growing crops or on bare soil and the time from application to ploughing in soil. The amount of manure there are acidified is also taken into account. In 2020, a survey was made by Birkmose (2020), which shows the share of manure applied to soil under the mentioned circumstances.

For each combination of time of application, application methods, application in growing crops or on bare soil, the time from application to ploughing in soil and year an emission factor have been estimated with the model ALFARM 2-model (Hafner et al., 2018, Hafner et al., 2019, Hafner et al., 2021). The ALFARM2-model is a semi-empiric model based on factual measurement of NH_3 emissions during application of manure. The emission factors are estimated for the decades 1980-1989, 1990-1999, 2000-2009 and 2010-2020.

Annex 3D, Table 3D-7-10 shows the distribution of manure applied and emission factors estimated by ALFARM2 for 2021. For solid manure, emission factors are based on Hansen et al (2008).

For use in the Danish inventory weighted emission factors based on the distribution of manure applied and emission factors estimated by ALFARM2 have been made for cattle and swine. For all other animals, same emission factor as for cattle is used.

Acidification of slurry just before application on fields is a used technique in Denmark and a result of environmental requirements. If slurry is applied on grass fields or on soil without vegetation, the slurry has to be injected or treated with acid to lower the ammonia emission. The slurry acidified in housings is also acidified during application.

The amount of manure acidified just before application is estimated by SEGES for the years 2011-2016 (Hansen, 2017) and 2017 (Nyord & Mikkelsen, 2019). No information on acidification is available for 2018-2021, so same amount as acidified in 2017 is used for 2018-2021. It is mainly cattle manure, which is acidified in storage and just before application.

Table 5.20 Share of liquid manure acidified in housing, storage and just before application, 2008-2021.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017-2021
	Share of cattle manure, %									
Housings	0.1	0.4	0.6	0.9	1.1	1.1	1.2	1.3	1.4	1.5
Storage	0	0	0	1.2	2.6	4.6	3.1	4.2	3.8	1.9
Just before application	0	0	0	1.1	2.5	4	7.4	8.8	8.3	7.5
Share of swine manure, %										
Housings	0.1	0.3	0.5	0.6	0.6	0.7	0.8	0,8	0.9	1.0
Storage	0	0	0	0.3	0.7	1.2	0.8	1	0.4	0.2
Just before application	0	0	0	0.4	0.8	1.3	2.5	2.9	1.5	1.3

The weighted emission factors will vary from year to year depending on changes in the practice of application and emission factor for the decade. In Table 5.21 are shown the weighted emission factors for slurry untreated/acidified during storage and application, slurry acidified in housing, biogas treated slurry and for solid manure. The decrease in emission factor for slurry untreated/acidified during storage and application from 2000-2005 is due to change in application practice where broad spreading of slurry is prohibited and for 2010-2015 is due to implementation acidification. For all years see Annex 3D Table 3D-11.

Table 5.21 Weighted emission factors for NH_3-N emission from application of manure, kg NH_3-N per kg TAN for slurry and kg NH_3-N per kg N for solid manure.

	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
	Slurry untreated/acidified during storage and application										
Cattle*	47.74	46.08	36.79	28.21	11.81	12.35	10.53	10.21	10.21	10.21	10.21
Swine	24.44	25.44	18.97	16.15	11.13	11.18	9.78	9.82	9.82	9.82	9.82
Acidified slurry in housing											
Cattle	NO	NO	NO	NO	NO	12.35	16.32	16.32	16.32	16.32	16.32
Swine	NO	NO	NO	NO	NO	11.18	7.04	7.04	7.04	7.04	7.04
Biogas treated slurry	42.62	42.62	34.56	29.80	22.62	22.76	14.47	14.47	14.47	14.47	14.47
Solid manure	10.28	8.49	7.96	7.12	7.55	7.55	7.62	7.62	7.62	7.62	7.62

NO – not occurring.
* EF also used for all other animals than swine.

Emissions factor NO_x

The emission factor for NO_x is based on EMEP/EEA guidebook (2019). The NO_x emission is estimated based on the Tier 1 emission factor at 0.04 kg NO_2 per kg N fertilised.

Emissions

The emission of NH_3 from manure applied to soils has decreased by 67 % from 1985 to 2021, this is due to decrease of N excreted by animals and by changes in the way manure is handled during application. Based on the action plans various initiatives has been implemented and include for example requirement for a minimum 9-month manure storage capacity, requirement that manure applied to soil be ploughed down within six hours, a ban on the application of manure in winter and broad spreading is no longer allowed. An increasing share of the slurry is injected to soil, which results in a lower emission.

NMVOC emission from manure applied to soil has decreased with 75 % from 1985 to 2021 and this is mainly due to decrease in the ratio between emission of NH_3 from manure applied to soil and NH_3 emission from housing.

Emission of NO_x from manure applied to soils has decreased by 12 % from 1985 to 2021 and this is mainly due to decrease of N excreted.

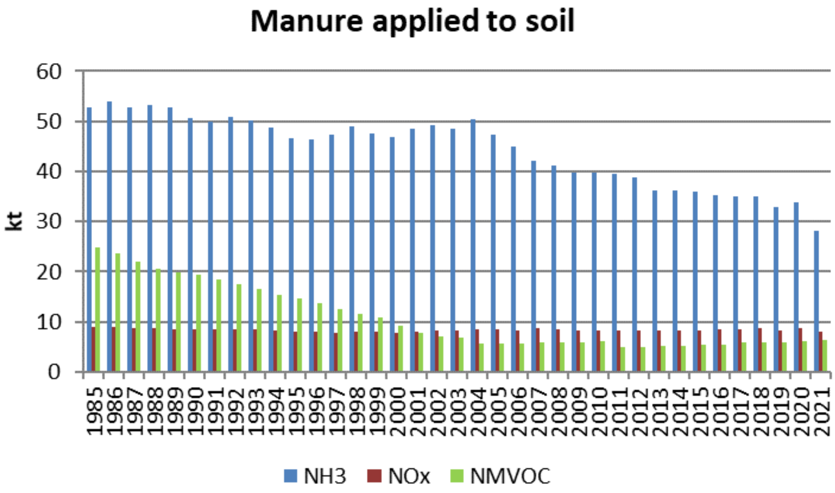


Figure 5.11 Emission of NH_3, NMVOC and NO_x from manure applied to soils, 1895-2021, kt NH_3, NO_x and NMVOC.

5.4.3 Sewage sludge applied to soils

Description

For the sector, sewage sludge applied to soils the emission of NH_3 and NO_x are estimated.

Emission of NH_3 and NO_x from sewage sludge applied to soils contributes in 2021 with 1 % from the agricultural sector.

Methodological issues

Amount of N applied are multiplied with the emission factor.

Activity data

Information regarding the amount of sewage sludge applied on agricultural soil as fertiliser, is based on information from and the Danish Environmental Protection Agency, and covers the years 1990-2002, 2005, 2008-2009, 2013-2020 (DEPA, 2001-2020). In the intervening years, the amount of sewage sludge applied is interpolated and 2021 is based on an average of the years 2018-2020. The N-content is assumed to be 4.75 kg N per kg dry matter (DEPA, 2009) for the years 2003-2019 and 6.0 kg N per kg dry matter for the years 2020-2021 (DEPA, 2022).

Table 5.22 Activity data used to estimate NH_3 and NO_x from sewage sludge, 1985-2021.

		1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Amount of sludge applied on soil	Tonnes of dry matter	50 000	77 883	112 235	83 727	57 053	76 250	85 000	71 000	88 000	82 000	80 333
N-content	%	4.00	4.00	4.13	4.33	4.75	4.75	4.75	4.75	4.75	6.00	6.00
N applied on soil	Tonnes N	2 000	3 115	4 635	3 625	2 710	3 622	4 038	3 373	4 180	4 920	4 820

Emission factor NH_3

The emission factor for NH_3 emission from sewage sludge applied to soil is based on EMEP/EEA guidebook 2019, 0.13 kg NH_3 per kg N applied.

Emission factor NO_x

The emission factor for NO_x is based on EMEP/EEA guidebook 2019 0.04 kg NO_2 per N applied.

Emissions

Emission of NH_3 and NO_x from sewage sludge is shown in Figure 5.12. The emission follow the amount of N applied.

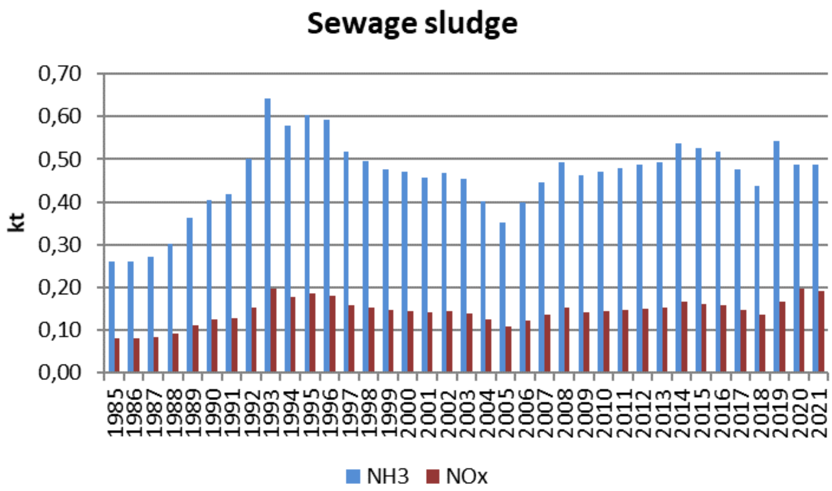


Figure 5.12 Emission of NH_3 and NO_x from sewage sludge, 1985-2021, kt.

5.4.4 Other organic fertilisers applied to soils

Description

For the sector, other organic fertilisers applied to soils the emission of NH_3 and NO_x are estimated. The category, "Other", includes emission from sludge from industries, which is applied to agricultural soils as fertiliser and biomass other than manure treated in biogas plants.

Methodological issues

Amount of N applied are multiplied with the emission factor.

Activity data

Information about industrial waste applied on agricultural soil and the content of nitrogen is obtained from a series of reports published by the Danish Environmental Protection Agency. The recent official figures regarding the amount of sludge from the industrial waste are data covering year 2001 (Petersen & Kielland, 2003). From 2005, the amount of sludge from industries is based on the information registered in the fertiliser accounts controlled by The Danish Agricultural Agency. Amounts in 2002- 2004 are interpolated.

Amount of nitrogen applied to soil from biomass treated in biogas plants (other than manure) are based on energy production in the biogas plants given in PJ and N per PJ were amount of N from NH_3 emission at the biogas plant are subtracted. Amount of NH_3 emission from feedstock at the biogas plants are reported in the waste Chapter 6.2.2. N per PJ are estimated to 9.4 ton N per PJ based on an average of N in feedstock and energy production in 2016-2019.

Table 5.23 Activity data used to estimate NH_3 and NO_x from other organic fertiliser, 1985-2021. Tonnes N.

	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Industrial waste	1 500	1 529	4 445	5 147	2 359	3 401	4 455	4 788	5 669	5 283	5 425
Other biomass	2.15	5.29	9.83	16.80	24.04	29.41	44.59	96.24	119.28	153.63	190.45
N applied on soil	1 502	1 534	4 455	5 164	2 383	3 430	4 500	4 884	5 788	5 437	5 615

Emission factor NH_3

The emission factor for NH_3 emission from other organic fertilisers applied to soils is based on EMEP/EEA guidebook 2019, 0.08 kg NH_3 per kg N applied.

Emission factor NO_x

The emission factor for NO_x is based on EMEP/EEA guidebook 2019, 0.04 kg NO_2 per N applied.

Emissions

Emission of NH_3 and NO_x from other organic waste is shown in Figure 5.13. The emission follow the amount of N applied.

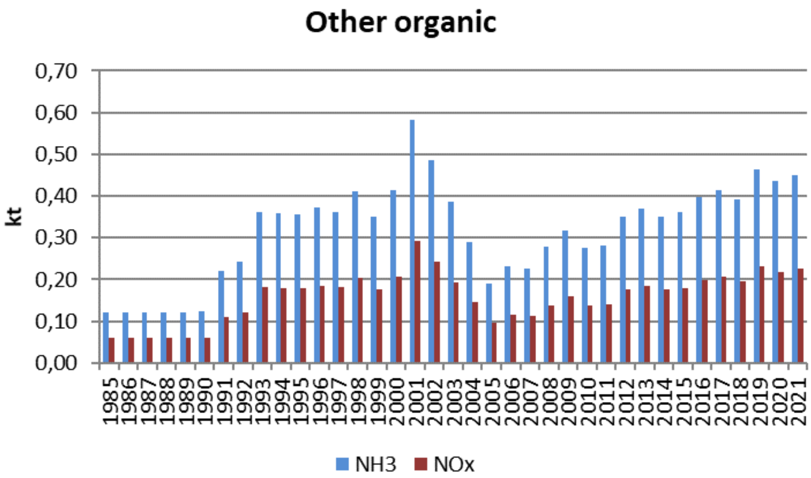


Figure 5.13 Emission of NH_3 and NO_x from other organic fertiliser, 1985-2021, kt.

5.4.5 Urine and dung deposited by grazing animals

Description

For the sector, urine and dung deposited by grazing the emission of NH_3 and NMVOC are estimated.

It is assumed that 5 % of the manure from dairy cattle is deposited in the field, which corresponding to 18 days per year (Aaes, 2008). For heifers 36 % of the nitrogen in the manure is estimated deposited during grazing (Aaes, 2008), 61 % for suckling cows (Poulsen et al, 2001), 50 % for horses (Clausen, 2008) and 73 % for sheep and goats (Poulsen et al, 2001).

Emission of NH_3 from urine and dung deposit by grazing animals contributes in 2021 with 4 % of the emission from the agricultural sector.

NMVOC emission from urine and dung deposit by grazing animals contributes in 2021 with less than 1 %.

Methodological issues

NH_3

Emission of NH_3 from urine and dung deposited by grazing animals is based on N excreted ab animal, number of days the animals are on grass and the emission factor. For the years 1985-2006 N excreted ab animal and emission factors is based on total N, while for the years 2007-2021 N excreted ab animal and emission factors for liquid manure is based on TAN. This is due to data for TAN ab animal from the normative figures are only available for the years 2007-2021.

NMVOC

Emission of NMVOC urine and dung deposited by grazing animals is based on Tier 2 method given in EMEP/EEA guidelines 2019 Chapter 3B Manure management, but reported in sector 3Da3.

Activity data

NH_3

The activity data are number of animals (see Chapter 5.2.1), N excreted ab animal and number of days on grass (see Table 5.13), which combined gives the N deposit on grass, see Table 5.24.

Table 5.24 N deposit on grass, 1985-2021, kt N.

	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
N deposited on grass*	37	34	35	34	26	17	17	17	17	17	17

* 1985-2006 based on total N and 2007-2021 based on TAN.

NMVOC

The NMVOC emission is estimated on the number of animal, share of time spend on grass (time on grass in Table 5.13), gross energy for cattle (Annex 3D Table 3D-16) and volatile solids (VS) for other animal categories (Annex 3D Table 3D-17).

Emission factor

NH_3

For cattle, swine, sheep, goats and horses are used default emission factor from EMEP/EEA guidebook (2019). For cattle and swine for the years 1985-2006 and for sheep, goats and horses for the years 1985-2021 the emission factors are converted to total N by using proportion of TAN from EMEP/EEA guidebook (2019), see Table 5.25. For deer are used same emission factor as for goats. Emission factor for poultry is based on Misselbrook et al. (2000). Poultry droppings is more solid than urine from swine and cattle and therefore the droppings is staying on the top of the soil instead of soaking in to the soil. Emission from outdoor poultry is therefore considered to be higher than (maybe twice) for swine (Jensen, H.B (pers. comm.), 2019, Hansen, M.N. (pers. comm.), 2019).

Table 5.25 Emission factors for NH3 emission from urine and dung deposited by grazing animals.

	Proportion of TAN[1]	EF default[1]	EF
		NH_3-N per TAN excreted	NH_3-N per total N excreted
Cattle	0.6	0.14[3]	0.084[4]
Swine	0.7	0.31[3]	0.217[4]
Sheep	0.5	0.09	0.045[5]
Goats	0.5	0.09	0.045[5]
Poultry	0.7		0.35[2]
Horses	0.6	0.35	0.21[5]

[1] EMEP/EEA guidebook (2019), Table 3.9.
[2] Misselbrook et al. (2000). Used for the years 1985-2021.
[3] Used for the years 2007-2021.
[4] Used for the years 1985-2006.
[5] Used for the years 1985-2021.

NMVOC

Default emission factors from EMEP/EEA guidebook (2019) are used, see Table 5.26.

Table 5.26 Emission factor for NMVOC for urine and dung deposited by grazing animals (EMEP/EEA Guidebook 2019, Tier2).

	EF NMVOC grazing
	Kg NMVOC per MJ feed intake
Dairy Cattle	0.0000069
Non-Dairy Cattle	0.0000069
	Kg NMVOC per kg VS excreted
Sheep	0.00002349
Swine – sows	
Swine – other	
Goats	0.00002349
Horses	0.00002349
Laying hens	
Broilers	
Turkeys	
Other poultry	
Fur bearing animals	

Emissions

The emission of NH_3 and NMVOC from urine and dung deposit by grazing animals has decreased by 33 % and 52 %, respectively, from 1985 to 2021 and this is mainly due to decrease in number of dairy cattle and decrease in number days on grass for dairy cattle.

Table 5.27 Emission of NH_3 and NMVOC from urine and dung deposit by grazing animals, 1985-2021, kt.

	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
NH_3	4.21	3.88	3.99	3.91	3.13	2.70	2.61	2.68	2.66	2.87	2.83
NMVOC	0.22	0.19	0.21	0.20	0.13	0.11	0.11	0.11	0.11	0.11	0.11

5.4.6 Farm-level agricultural operations including storage, handling and transport of agricultural products

Description

During agricultural operations such as soil cultivation, harvesting, cleaning, drying and transport an emission of PM occur. In the EMEP/EEA guidebook are only method and emission factors for the operations done in the field; that is soil cultivation, harvesting, cleaning and drying.

The emission of PM TSP from field operations contributes with 88 % of the total agricultural emission of TSP in 2021.

Methodological issues

The emission of PM from field operations is calculated by area of cultivated crops multiplied with number of operations and emission factor, for each crop type and type of operation.

Activity data

Areas of cultivated crops and number of operations for each crop are used for activity data. The area of crops is estimated by Statistic Denmark (DSt, 2022) and number of operations are based on budget estimates made by SEGES. See Annex 3D Table 3D-12 for area of cultivated crops and Annex 3D Table 3D-13a-13d for number of operations divided in soil cultivation, harvesting, cleaning and drying.

Emission factor

The emission factors used are given in Table 5.28 and they are based on EMEP/EEA guidebook (EMEP/EEA, 2019) and van der Hoek (2007).

Table 5.28 Emission factors for field operations, kg per ha.

PM_{10}	Soil cultivation	Harvesting	Cleaning	Drying
Wheat	0.25[a]	0.27[b]	0.19[a]	0.56[a]
Rye	0.25[a]	0.2[b]	0.16[a]	0.37[a]
Barley	0.25[a]	0.23[b]	0.16[a]	0.43[a]
Oat	0.25[a]	0.34[b]	0.25[a]	0.66[a]
Other arable	0.25[a]	0.26[c]	0.19[c]	0.51[c]
Grass	0.25[a]	0.25[a]	0[a]	0[a]
$PM_{2.5}$				
Wheat	0.015[a]	0.02[a]	0.009[a]	0.168[a]
Rye	0.015[a]	0.015[a]	0.008[a]	0.111[a]
Barley	0.015[a]	0.016[a]	0.008[a]	0.129[a]
Oat	0.015[a]	0.025[a]	0.0125[a]	0.198[a]
Other arable	0.015[a]	0.019[c]	0.009[c]	0.152[c]
Grass	0.015[a]	0.01[a]	0[a]	0[a]
TSP[d]				
Wheat	2.5	2.7	1.9	5.6
Rye	2.5	2	1.6	3.7
Barley	2.5	2.3	1.6	4.3
Oat	2.5	3.4	2.5	6.6
Other arable	2.5	2.6	1.9	5.1
Grass	2.5	2.5	0	0

[a] EMEP/EEA (2019).
[b] van der Hoek (2007).
[c] average of wheat, rye, barley and oat.
[d] PM_{10} multiplied by 10 (van der Hoek, 2007).

Emissions

The emission of PM_{10}, $PM_{2.5}$ and TSP are shown in Table 5.29. The emission of TSP has decreased 17 % from 1990 to 2021 due to decrease in the area of cultivated crops and number of treatments of the fields. A marked decrease is seen from 2001 to 2002 (see figure 5.2) this is due to decrease in number of soil cultivating treatments from 2001 to 2002 for many crop types, such as wheat, barley, rye, oats, rape, grass and others (See Annex 3D Table 8a-8d). In 2017, the number of soil cultivating treatments increases for some crop types, such as wheat, barley, rye, triticale and sugar and fodder beet. The number of operations are based on budget estimates made by Knowledge Centre for Agriculture, SEGES.

Table 5.29 Emissions of PM_{10}, $PM_{2.5}$ and TSP from field operations, 1990-2021, tonnes.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
PM_{10}	6 837	6 247	6 238	5 415	5 665	5 490	5 849	6 021	5 654	5 665
$PM_{2.5}$	522	475	476	431	446	434	452	463	435	437
TSP	68 373	62 474	62 377	54 146	56 655	54 903	58 486	60 206	56 544	56 648

5.4.7 Cultivated crops

Description

For the sector, cultivated crops the emission of NH_3 and NMVOC are estimated.

The Danish emission inventory includes NH_3 emission from crops, despite the uncertainties related to this emission source. Literature research shows that the volatilisation from crop types differs considerably. However, as for the emission ceiling given in the Gothenburg-Protocol and the EU NEC Directive the emission from crops is not taken into account.

Methodological issues

The emission is calculated based on area of agricultural land and emission factors.

Activity data

Activity data are obtained from Statistics Denmark, see Annex 3.D Table 3D-12.

Emission factor NH_3

EF´s for crops are estimated to 2 % for crops and 0.5 % for grass based on a literary survey (Gyldenkærne and Albrektsen, 2009).

Table 5.30 EF used to estimate the emission of NH_3 from crops.

Crops	kg NH_3-N per ha
Cash crops, beets and silage maize	2
Grass/clover in rotation	0.5
Permanent grass	0.5
Set-a side	0

Emission factor NMVOC

The calculation of the NMVOC emission is based on emission factors recommended in EMEP/EEA Guidebook 2019 Table 3-3 for cultivation of wheat, rye, rape and grassland. A Tier 2 IEF is estimated corresponding to Danish yield level dry matter content (DM) for these crop types. The emission from other crop types is not available in the Guidebook. However, the total NMVOC emission is estimated as the Tier 2 IEF multiplied with the total cultivated area.

The NMVOC emission from cultivated crops is estimated to 1.9 kt in 2021 based on an IEF at 0.72 kg NMVOC per hectare and a cultivated area of 2 620 thousand hectare. The IEF varies annually from 0.51-0.81 kg NMVOC per hectare depending on the allocation of the four mentioned crop types. Higher allocation of rape and rye result in higher IEF due to a higher emission factor for these two crop types.

Table 5.31 Estimation of a Tier 2 NMVOC emission factor, 2021.

	EEA/EMEP, Emission factor	Fraction of year emitting	Total	Mean dry matter of crop	NMVOC EF	Cultivated area	NMVOC emission	Tier 2 DK
Crop	Kg NMVOC /kg DM/yr		Kg/kg DM//yr	kg DM/ha	Kg/ha/yr	ha	Kg/ha/yr	IEF, kg NMVOC/ha
Wheat	2.60E-08	0.3	6.82E-05	6 605	0.45	519 634	234 045	
Rye	1.41E-07	0.3	3.70E-04	5 338	1.98	108 310	214 008	
Rape	2.02E-07	0.3	5.30E-04	3 681	1.95	165 478	322 741	
Grass land*	1.03E-08	0.5	4.51E-05	7 182	0.32	509 322	165 019	
Total						1 302 744	935 813	0.72

*Grass land 15 C.

Emissions

Emission of NH_3 and NMVOC are shown in Figure 5.14. The emission of NH_3 has increased by 6 % from 1985 to 2021 and the emission of NMVOC has increased by 0.5 %.

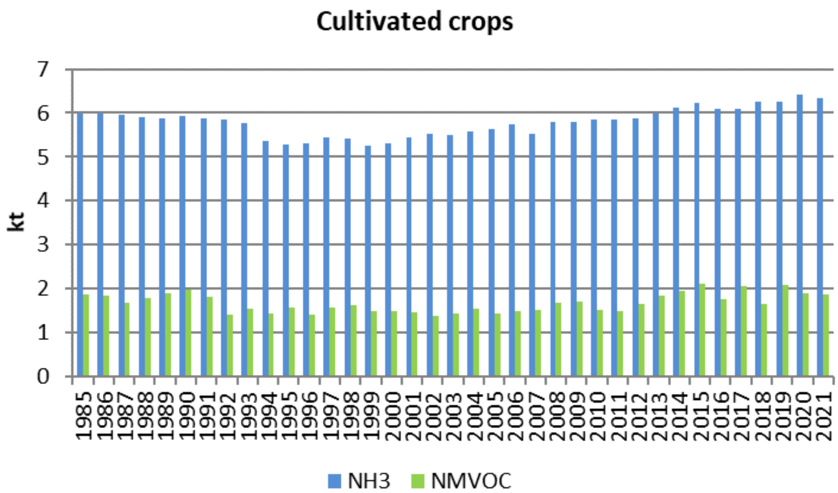


Figure 5.14 Emission of NH_3 and NMVOC from cultivated crops, 1985-2021, kt.

5.4.8 Use of pesticides

Description

A range of pesticides is use in the Danish agricultural sector and some of them contain Hexachlorobenzene (HCB), but pure HCB used as pesticide is banned. HCB is a poisonous substance, which is dangerous to human and animal health but is used as agent in pesticides.

The emission of HCB from use of pesticides contributes with 5 % of the Danish total HCB emission in 2021.

Methodological issues

Emission of HCB from use of pesticides is based on amount of effectual substance used and emission factors for each type of pesticides.

Activity data

A range of pesticides is used in Denmark. In the period from 1990 to 2021, six types of pesticides containing HCB have been identified as used in Denmark. These are atrazine, chlorothalonil, clopyralid, lindane, pichloram and simazine. Data of amounts of effectual substance used in Denmark are collected from Danish Environmental Protection Agency (DEPA), see Table 5.32. The use of atrazine and lindane stopped in 1994 and the use of chlorothalonil and simazine ceased in 2000 and 2004, respectively.

Table 5.32 Amounts of effectual substance used in Denmark, 1990-2021, kg.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021*
Atrazine	91 294	-	-	-	-	-	-	-	-	-
Chlorothalonil	10 512	10 980	7 340	-	-	-	-	-	-	-
Clopyralid	16 461	22 587	7 446	5 874	9 122	10 229	2 707	2 331	3 102	3 102
Lindane	8 356	-	-	-	-	-	-	-	-	-
Pichloram	-	-	-	-	723	328	2 735	1 831	2 265	2 265
Simazine	30 234	19 865	23 620	-	-	-	-	-	-	-

*Same as 2020 due to lack of data.

Emission factor

Default emission factors from EMEP/EEA Guidebook 2019 are used in the calculation of the emissions, see Table 5.33.

Table 5.33 Emission factors for HCB from pesticides, 1990-2021, g per tonnes.

	1990	1995	2000	2005	2010-2021
Atrazine	2.5	-	-	-	-
Chlorothalonil	300	300	40	-	-
Clopyralid	2.5	2.5	2.5	2.5	2.5
Lindane	100	-	-	-	-
Pichloram	-	-	-	-	50
Simazine	1	1	1	-	-

- Not used in the given year in Denmark.

Emissions

Table 5.34 shows the emission of HCB from the use of pesticides for the years 1990-2021. The emission has decreased significantly from 1990 to 2021 due to decrease in use of pesticides containing HCB. An increase is seen from 2016 to 2017, this is due to increase in use of pichloram.

Table 5.34 Emission of HBC, 1990-2021, kg.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Pesticides	4.29	3.37	0.34	0.01	0.06	0.04	0.14	0.10	0.12	0.12

5.5 Field burning of agricultural residues

5.5.1 Description

Field burning of agricultural residues has been prohibited in Denmark 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.

Emissions of NH_3, NO_x, CO, NMVOC, SO_2, PM, BC, heavy metals, dioxin, PAHs, HCB and PCB are included under the NFR category 3F. The emission of NH_3, NO_x, NMVOC and TSP from field burning contributes in 2021 with less than 1 % of the agricultural emission. PM_{10} and $PM_{2.5}$ contributes with 1 % and 9 % of the agricultural emission. The emission of BC, CO, SO_2, heavy metals, dioxin and PCB from field burning contribute with less than or around 2 % of the total national emission, while the emission of PAHs and HCB contribute with around 1-6 % of the national emission. From 1989 to 1990, all emissions decrease significantly due to the ban on field burning.

5.5.2 Methodological issues

Emissions from field burning of agricultural residues are calculated based on the amount of burnt straw given in tons dry matter and emission factors given in the EMEP/EEA guidebook (EMEP/EEA, 2019). See equation below:

$$E_{i,j} = A_j \cdot d_j \cdot Cf \cdot EF_i$$

Where:

$E_{i,j}$	= Emission of pollutant *i*, kg
A_j	= Amount of burnt residue *j*, kg
d_j	= dry matter content of *j*, %
Cf	= Combustion factor, %
EF_i	= Emission factor for pollutant *i*, g per kg dry matter (see Tabel 5.35)

Types of burnt residue *j* are straw from grass seed production and from bales of wet straw. For straw from grass seed production the dry matter content (d_j) is 20 % and for other straw it is 85 % (Møller et al, 2005) and the combustion factor 90 % (EMEP/EEA, 2019).

5.5.3 Activity data

The amount of burnt straw from the grass seed production is estimated as 15-20 % of the total amount produced. The amount of burnt bales of wet straw is estimated as 0.1 % of total amount of straw. Both estimates are based on expert judgement by SEGES (Feidenhans'l, 2009, pers. comm.). The total amounts are based on data from Statistics Denmark. See Annex 3D Table 3D-14 for activity data.

5.5.4 Emission factors

For most of the pollutants the default emission factors from the EMEP/EEA guidebook (EMEP/EEA, 2019) are used, but for PAH, HCB and PCB the emission factors are based on Jenkins (1996), Hübner (2001) and Black et al. (2012), respectively – see Table 5.35.

Table 5.35 EF for field burning of agricultural residues.

Pollutant	EF	Unit
NO_x[1]	2.3	g/kg DM
CO[1]	66.7	g/kg DM
NMVOC[1]	0.5	g/kg DM
SO_x[1]	0.5	g/kg DM
NH_3[1]	2.4	g/kg DM
TSP[1]	5.8	g/kg DM
PM_{10}[1]	5.7	g/kg DM
$PM_{2.5}$[1]	5.4	g/kg DM
BC[1]	0.5	g/kg DM
PCDD/F[1]	500	ng TEQ/t
Pb[1]	0.11	mg/kg DM
Cd[1]	0.88	mg/kg DM
Hg[1]	0.14	mg/kg DM
As[1]	0.0064	mg/kg DM
Cr[1]	0.08	mg/kg DM
Ni[1]	0.052	mg/kg DM
Se[1]	0.02	mg/kg DM
Zn[1]	0.56	mg/kg DM
Cu[1]	0.073	mg/kg DM
Benzo(a)pyrene[2]	0.41	mg/kg DM
benzo(b)fluoranthene[2]	1.14	mg/kg DM
benzo(k)fluoranthene[2]	0.48	mg/kg DM
Indeno(1,2,3-cd)pyrene[2]	0.67	mg/kg DM
HCB (broken bales)[3]	0.003	g/tonnes
HCB (seed production)[3]	0.002	g/tonnes
PCB (broken bales)[4]	3	ng TEQ/t
PCB (seed production)[4]	0.05	ng TEQ/t

[1] EMEP/EEA (2019).
[2] Jenkins (1996).
[3] Hübner (2001).
[4] Black et al. (2012).

5.5.5 Emissions

See Annex 3D Table 3D-15 for emissions of all pollutants 1985 to 2021.

5.6 Agriculture other

5.6.1 NH_3 treated straw

Description

NH_3 is used for conservation of straw for feeding. As for the emission ceiling given in the Gothenburg-Protocol and the EU NEC Directive the emission from NH_3 treated straw is not taken into account.

Methodological issues

Emissions are calculated as NH_3 used for treatment of straw multiplied the emission factor.

Activity data

Information on NH_3 used for treatment of straw is collected from the suppliers, but from 2021 the Danish Agriculture Agency collect these information. NH_3 treated straw has been prohibited from 2006, but in some areas exemption are given due to wet weather.

Table 5.36 Activity data for NH_3 treated straw 1985 to 2021.

	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Tonnes NH_3-N	8 300	12 936	8 421	3 131	329	200	200	200	200	200	306

Emission factor

Investigations show that up to 80-90% of the supplied NH_3 (given in NH_3-N) can emit (Andersen et al., 1999). However, the emissions can be reduced particularly if the right dose is used. Based on expert judgement (Andersen, 1999) the emission factor is 65 % of the applied NH_3-N.

Emissions

Emission of NH_3 from NH_3-treated straw is shown in Figure 5.15.

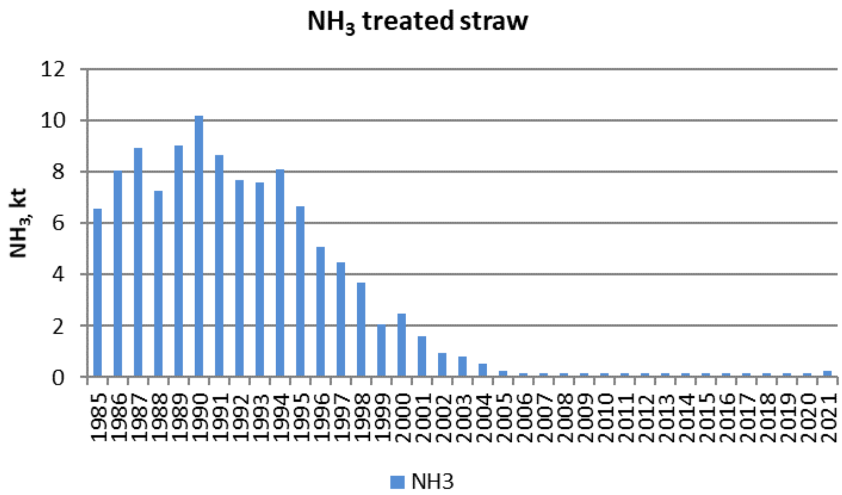


Figure 5.15 Emission of NH_3 from NH_3-treated straw, 1985-2021.

5.7 Uncertainties

Table 5.37 shows the estimated uncertainties for activity data and emissions factor for each pollutant.

5.7.1 NH_3

3B Manure management

It is defined that activity for manure management covers both the number of animals and housing type. The allocation of animals on different housing types determines if the manure is handled as slurry or solid manure.

The number of animals for the most important animal categories is estimated by Statistic Denmark. The uncertainties for the most important livestock categories are relatively low e.g. for swine and cattle the uncertainties is estimated to 1.3 % and 0.9 %, respectively. The uncertainty is higher for less important animal groups, e.g. fur bearing animals (3.4 %), poultry, horses and sheep (10.4 %). The uncertainty for number of animals overall is estimated to 2 %. The allocation of housing system is based on information from the farm nitrogen budgets handled and controlled by the Danish Agriculture Agency. All farmers have to submit the information regarding the housing type annually and the uncertainty is assumed as relatively low.

The uncertainties for the activity data is thus a combination of low uncertainty in animal numbers, a relatively low uncertainty for housing type, which assumed to result in an overall uncertainty by 5 %.

The uncertainty for the emission factor covers nitrogen excretion, grazing days and NH_3 emission factors from housing and during storage of the manure. 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, pig production, etc., to optimise productivity in Danish agriculture. Feeding plans from 15-18 % of the Danish dairy productions, 25-30 % of swine productions, 80-90 % of poultry productions and approximately 100 % of fur productions are collected annually. These basic feeding plans are used to develop the standard values of the "Danish Normative System". 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.

Regarding the uncertainties for the emission factor, it has to be included that the emission comes from three different places in the livestock production; from manure in housing, from stored manure and from application of manure. The uncertainties for emission measurements in housing, which are the basement for the normative standards varies from 15 -25 % (Poulsen et al., 2001). However, there is no specified uncertainty estimates for emission factors for storage and application of manure. The overall uncertainty value for NH_3 emission factor for manure management is assumed approximately 25 %.

3Da1 Inorganic fertilisers

The activity data for the emission from inorganic N-fertiliser depends on the amount of sold fertiliser and the N-content for each fertiliser type, which is based on annually information given by the Danish Agriculture Agency. Uncertainty is considered to be low; 3 %, based on expert judgement.

No uncertainty values for the emission factor are given in the EMEP/EEA guidebook. The Danish inventory assume an uncertainty value at 25 %, which indicated a uncertainty in the translation of the Danish fertiliser types to types specified in the guidebook but also indicate an uncertainty of the emission factors specified in the guidebook.

3Da2a Animal manure applied to soils

Besides the number of animals, the uncertainty for activity data covers N-excretion, grazing days and the NH_3 emission from housing and storage. It is assumed that the most important variables are the number of animals, which has a low uncertainty 2 %. However, the uncertainty is also affected by the other variables, which have a higher uncertainty estimate. Thus, the uncertainty for the activity data is assumed around 15 %.

The emission factor depends on the uncertainty regarding the information on application time, application technics and plant cover. The uncertainty is estimated to 25 %.

3Da2b Sewage sludge applied to soils

From 2005 and onwards, the amount of N applied from wastewater treatment is based on the fertiliser accounts controlled by the Danish Agriculture Agency. Farmers with more than 10 animal units have to be registered and have to keep account of the N content in manure, received manure or other organic fertiliser. The uncertainty for the activity data is assumed to be 15 %.

The emission factor depends on the application of time, application technic and the climate conditions and the uncertainty is assumed relatively high – around 50 %.

3Da2d Other organic fertilisers applied to soils

The uncertainty are estimated to be at the same level as for sewage sludge applied to soils.

3Da3 Urine and dung deposited by grazing animals

The overall uncertainty for the activity is estimated to 5 %. Besides the number of animals, the uncertainty depends on number of grassing days.

Regarding the uncertainty for the emissions factor, this depends on the N excretion and the climate conditions as temperature, wind and precipitation. The uncertainty value is estimated to 25 %.

3De Cultivated crops

The activity data covers the cultivated area, which is based on Statistics Denmark. For the major crops, the uncertainty is relatively low – e.g. winter wheat it is 1.1 %. The overall uncertainty for the activity is estimated to 2 %. Knowledge concerning the emission is relatively limited and therefore the uncertainty is assumed to be 50 %.

3F Field burning of agricultural residues

An uncertainty of 25 % for the activity for field burning of agricultural residues is used. The uncertainty is a combination of the uncertainty for area of grass for seed production, which has a low uncertainty, amount of burned straw and yield, which have a high uncertainty. The uncertainties for the emission factor are based on the EMEP/EEA Guidebook (EMEP/EEA, 2019) and Jenkins et al. (1996).

3I Agriculture other

Under NFR category 3I emissions from NH_3 treated straw is entered. NH_3 treated straw was until 2006 used as cattle feed. By law in 2006, the NH_3 treatment of straw was banned. However, due to wet weather conditions exemption are given in some areas. The activity depends on the amount of ammonia used in the second half of the year and is based on information from the Agriculture Agency. The uncertainty value is assumed to be 20 %. The uncertainty level for the emission factor is assumed to be 50 %.

5.7.2 PM

Uncertainty estimates due to the activity data is estimated to 7 %. Besides number of animal and housing type, also uncertainty related to the production cycles plays a role.

The activity data covers the cultivated crops and number of operations for each crop type. The area of crops is estimated by Statistic Denmark and number of operations is based on budget estimates made by Knowledge Centre for Agriculture. The uncertainty is assumed to be 10 %.

The uncertainties for the PM emission factors have been considered to be very high and especially for animal husbandry and manure management.

The uncertainty estimates regarding the PM emission factors for manure management and farm level agricultural operations are based on the EMEP/EEA guidebook.

5.7.3 Other pollutants

For both the NO_x and NMVOC emission, the activity data is based on the same conditions as mentioned in NH_3 chapter and therefore the same uncertainty estimates is used.

The uncertainty for the NO_x and NMVOC emission factor is based on expert judgment and is considered to be very high; 100 - 500 % based on the on the EMEP/EEA guidebook.

Emission of BC, CO, SO_2, heavy metals, dioxin, PAHs, HCB and PCB from the agricultural sector originates from field burning of agricultural residues. The uncertainty for activity data for these emissions is a combination of the uncertainty for crop production, which is low and the uncertainty of the amount of burned straw, which is high. The uncertainties for the emission factors are based on EMEP/EEA guidebook. All uncertainties for field burning are relatively high. The uncertainty for activity data for the emission of HCB from pesticides are estimated to 5 % and the uncertainty for the emission factor are relatively high.

Table 5.37 Estimated uncertainty associated with activities and emission factors for the agricultural sector, 2021.

Compound	NFR sector	Emission	Activity data, %	Emission factor, %	Combined Uncertainty, %	Total Uncertainty, %
NH_3, kt	3.B Manure management	28.03	5	25	25	15
	3.Da1 Inorganic fertilisers	11.21	3	25	25	
	3.Da2a Animal manure applied	17.73	15	25	29	
	3.Da2b Sewage sludge applied	0.63	15	50	52	
	3.Da2c Other organic fertiliser	0.45	15	50	52	
	3.Da3 Deposited by grazing	2.83	5	25	25	
	3.De Cultivated crops	6.34	2	50	50	
	3.F Field burning	0.04	25	50	56	
	3.I Agriculture other	0.24	20	50	54	
TSP, kt	3.B Manure management	7.49	7	300	300	267
	3.Dc Farm-level agri. operations	56.65	10	300	300	
	3.F Field burning	0.10	25	50	56	
PM_{10}, kt	3.B Manure management	2.53	7	300	300	225
	3Dc Farm-level agri. operations	5.66	10	300	300	
	3.F Field burning	0.10	25	50	56	
$PM_{2.5}$, kt	3.B Manure management	0.53	7	300	300	195
	3Dc Farm-level agri. operations	0.44	10	300	300	
	3.F Field burning	0.09	25	50	56	
NMVOC, kt	3 B Manure management	38.20	2	300	300	251
	3.Da2a Animal manure applied	6.25	15	300	300	
	3.Da3 Deposited by grazing	0.11	15	300	300	
	3.De Cultivated crops	1.88	5	500	500	
	3.F Field burning	0.01	25	100	103	
NO_x, kt	3.B Manure management	0.76	5	100	100	265
	3.Da1 Inorganic fertilisers	9.14	3	400	400	
	3.Da2a Animal manure applied	7.96	15	400	400	
	3.Da2b Sewage sludge applied	0.19	15	400	400	
	3.Da2c Other organic fertiliser	0.22	15	400	400	
	3.F Field burning	0.04	25	25	35	
HCB, kg	3.F Field burning	0.12	5	500	500	355
HCB, kg	3 G Agriculture other	0.14	25	500	501	
PCB, kg	3.F Field burning	0.00002	25	500	501	501
SO_2, kt	3.F Field burning	0.01	25	100	103	103
BC, kt	3.F Field burning	0.01	25	100	103	103
CO, kt	3.F Field burning	1.15	25	100	103	103
Pb, Mg	3.F Field burning	0.00	25	50	56	56
Cd, Mg	3.F Field burning	0.015	25	100	103	103
Hg, Mg	3.F Field burning	0.002	25	200	202	202
As, Mg	3.F Field burning	0.0001	25	100	103	103
Cr, Mg	3.F Field burning	0.001	25	200	202	202
Cu, Mg	3.F Field burning	0.001	25	200	202	202
Ni, Mg	3.F Field burning	0.001	25	200	202	202
Se, Mg	3.F Field burning	0.0003	25	100	103	103
Zn, Mg	3.F Field burning	0.010	25	200	202	202
Dioxin, g I-Teq	3.F Field burning	0.03	25	500	501	501
Benzo(a)pyrene, Mg	3.F Field burning	0.01	25	500	501	501
Benzo(b)fluoranthen, Mg	3.F Field burning	0.02	25	500	501	501
Benzo(k)fluoranthen, Mg	3.F Field burning	0.01	25	500	501	501
Indeno(1,2,3 cd)pyrene, Mg	3.F Field burning	0.01	25	500	501	501

5.8 Quality assurance and quality control (QA/QC)

A general QA/QC and verification plan for the agricultural sector is continuously under development and will be improved and developed in line with the deficiencies are identified and corrected. The objectives for the quality planning, as given in the CLRTAP Emission Inventory Guidebook, which is closely related to the IPCC Good Practice Guidance, are to improve the transparency, consistency, comparability, completeness and confidence.

To ensure consistency a procedure for internal quality check are provided. Input of external data is checked and certain time series have been prepared for both the activity data, the emission factors and implied emission factors, 1985 - 2021. The annual change for each emission source on activity will be checked for significant differences and if necessary explained. Considerable variation between years can reveal miscalculations or changes in methods. All checks of all activity data, emission factor, implied emission factor and other important key parameters are provided and achieved in excel spread sheet.

Activity data and emission factors are collected and discussed in cooperation with specialists and researchers at different institutes and research departments. As a consequence, both data and methods are evaluated continuously according to latest knowledge and information. A more detailed description of quality assurance and quality control is given in Denmark´s National Inventory Report 2022 (Nielsen et al, 2022)- submitted under the United Nations Framework Convention on Climate Change (https://dce2.au.dk/pub/SR494.pdf).

5.9 Recalculations

Compared with the previous NH_3, NOx NMVOC and PM emissions inventory (submission 2022), some changes and updates have been made, see Table 5.38. These changes cause an increase/decrease in the total NH_3 emission for all years (1985-2020), increase/decrease in NMVOC emission for all years (1985-2020), increase/decrease for NOx emission for years (2005-2019) and increase/decrease for the PM emission for the years (2005–2019).

Table 5.38 Changes in NH_3, NOx NMVOC and PM emission in the agricultural sector compared to NFR reported last year.

NH_3 emission, kt NH_3	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020
2022 submission	147.12	138.93	113.94	98.73	87.19	79.11	73.95	75.86	71.63	72.96
2023 submission	147.15	138.95	114.00	98.96	87.83	80.05	75.28	76.83	72.60	75.54
Difference, %	0.02	0.01	0.05	0.23	0.73	1.20	1.80	1.28	1.35	3.54

NOx emission, kt NO_x	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020
2022 submission	27.65	25.74	22.03	19.33	17.87	17.38	17.88	18.82	19.05	19.75
2023 submission	27.65	25.74	22.03	19.35	17.89	17.39	17.88	18.83	19.06	19.96
Difference, %	0.00	0.00	0.04	0.11	0.08	0.05	0.03	0.04	0.04	1.05

NMVOC emission, kt	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020
2022 submission	74.87	62.76	56.11	46.45	43.10	44.66	45.04	46.41	46.13	46.22
2023 submission	74.78	62.70	56.05	46.38	42.99	44.45	44.87	46.34	46.00	46.32
Difference, %	-0.12	-0.11	-0.09	-0.14	-0.24	-0.47	-0.39	-0.15	-0.30	0.21

PM emission, kt TSP		1990	1995	2000	2005	2010	2015	2018	2019	2020
2022 submission		86.01	80.19	80.29	71.20	73.72	71.45	76.06	78.11	74.26
2023 submission		86.01	80.21	80.32	71.22	73.73	71.45	76.07	78.12	74.23
Difference, %		0.00	0.02	0.03	0.03	0.01	0.01	0.01	0.01	-0.04

5.9.1 NH_3

A range of changes is made for the emission of NH_3 and this has decreased the overall emission from agriculture with less than 1 % for the years 1985-1996 and increased the emission with up to 4 % for the years 1997-2020 compared to submission 2022. Recalculations for the subcategories are mentioned below.

3B Manure management

For emission from manure management, some changes has been made and it increases the emission with up to 3 % compared to submission 2022.

Updated information on share of housings with acidification was received from JH Agro (2022) and has been incorporated in the inventory for the years 2007-2020.

For cattle in the housing system loose-holding with beds, slatted floor and scrape the emission factor has been changed from 12 % to 13.5 %, based on information from Kai et al (2022b) and Kai, P. (Pers. Comm., 2022). This changes the emission for all years 1985-2020.

For sows some changes in distribution in housing systems and normative figures has been made for the years 1991-2020 due to some mismatch in the data.

The number of weaners, fattening pigs and hens has been recalculated for 2020 due to updated data from Statistics Denmark.

3Da1 Inorganic N-fertilisers

No recalculations

3Da2a Animal manure applied to soils

Emission from animal manure applied to soils has been recalculated for the years 1991-2020 due to the changes in acidification in housings, changes for sows and number of animals mentioned above. These changes decreases the emission for the years 1991-2011 whit less than 1 %, increases the emission for years 2012-2019 with less than 1 % and increases the emission in 2020 with 2 %.

3Da2b Sewage sludge applied to soils

A recalculation of NH_3 is made for 2020 due to updated values from statistics. In submission 2022 no statistic were available for the amount of N from sewage sludge for 2020 and the amount were therefore based on an average of previous years. The statistic is now available (DEPA, 2020). Furthermore are the amount of N in sewage sludge updated based in information from DEPA (2022). This increase the emission with 32 % in 2020.

3Da2c Other organic fertilisers applied to soils

Small recalculations of NH_3 is made for all years 2017-2020, which changes the emission with less than 0.05 %. The change is due to updated data from the Danish Energy Agency. The updated data changes the amount of NH_3 emission from the biogas plants reported in the waste sector and derive from this the amount of N in storage of biogas treated biomass.

No recalculations of emission from sludge from industries.

3Da3 Urine and dung deposited by grazing animals

The emission of NH_3 from grazing animals has been recalculated for the years 1991-2011 due to changes for sows housed outdoor. The emission has decreased 0.5-5 %. Change in number of animals increases the emission in 2020 with 0.1 %.

3De Cultivated crops

Area with catch crops has been included in the calculation of NH_3 from cultivated crops. This increases the emission with 2-20 % in the yeas 2000-2020 with higher increase in recent years due increased area with catch crops over the years.

3F Field burning of agricultural residues

Recalculations has been made for all years 1985-2020 due to change in dry matter content in grass seeds. The type of residue from grass seed production has been re-evaluated and the dry matter content has been lower from 85 % to 20 % (Møller et al., 2005). This decreases the emission of NH_3 from field burning with 3-71 %.

3I Agriculture other

No recalculations.

5.9.2 NOx

Emission of NOx has been recalculated for the years 1985-2020 and changes the emission with less than 1 %.

3B Manure management

The changes for sows in distribution in housing systems and normative figures due to mismatch in the data and updated number of weaners, fattening pigs and hens in 2020 increases the emission of NOx with less than 0.3 % in the years 2010-2020.

3Da1 Inorganic N-fertilisers
No recalculations.

3Da2a Animal manure applied to soils
Emission from animal manure applied to soils has been recalculated for the years 1991-2020 due to changes for sows and number of animals mentioned above. These changes increases the emission for the years 1991-2019 with less than 0.3 %, increases the emission for 2020 with 2 %.

3Da2b Sewage sludge applied to soils
A recalculation of NOx is made for 2020 due to updated values from statistics. In submission 2022, no statistic were available for the amount of N from sewage sludge for 2020 and the amount were therefore based on an average of previous years. The statistic is now available (DEPA, 2020). Furthermore are the amount of N in sewage sludge updated based in information from DEPA (2022). This increase the emission with 32 % in 2020.

3Da2c Other organic fertilisers applied to soils
Recalculations of NOx is made for all years 2017-2020, which changes the emission with up to 2 %. The change is due to updated data from the Danish Energy Agency. The updated data changes the amount of NH_3 emission from the biogas plants reported in the waste sector and derive from this the amount of N in storage of biogas treated biomass.

No recalculations of emission from sludge from industries.

3F Field burning of agricultural residues
Recalculations has been made for all years 1985-2020 due to change in dry matter content in grass seeds. The type of residue from grass seed production has been re-evaluated and the dry matter content has been lower from 85 % to 20 % (Møller et al., 2005). This decreases the emission of NOx from field burning with 3-71 %.

5.9.3 NMVOC

Recalculations of NMVOC has decreased the emission with less than 0.5 % for the years 1985-2019 and increased the emission with 0.8 % for 2020 compared with submission 2022 mainly due to recalculation of emission from manure management and manure applied to soil. Recalculations for the subcategories are mentioned below.

3B Manure management
Changes in the proportion of emissions of NH_3 from housing and storage affect the calculation of NMVOC. This decreases the emission for years 1985-2019 with less than 0.1 %. For 2020 the emission increase 0.3 %.

3Da2a Animal manure applied to soil
Emission of NMVOC from manure applied to soil increases with 0.3-2.9 % for all years 1985-2020. This is due to update of NH_3 emission because the calculation of emission of NMVOC from manure applied to soil is depended on the proportion of emissions of NH_3 from housing and application.

3Da3 Urine and dung deposited by grazing animals

No recalculations.

3De Cultivated crops

For 2019-2020 the emission of NMVOC from crops has been recalculated due to updated data from Statistics Denmark. The emission decrease with 2.6 % in 2019 and increase with 0.2 % in 2020.

3F Field burning of agricultural residues

Recalculations has been made for all years 1985-2020 due to change in dry matter content in grass seeds. The type of residue from grass seed production has been re-evaluated and the dry matter content has been lower from 85 % to 20 % (Møller et al., 2005). This decreases the emission of NMVOC from field burning with 3-71 %.

5.9.4 PM

Emission of PM is recalculated for all years 1990-2020 and it has changed the emission of PM_{10}, $PM_{2.5}$ and TSP.

3B Manure management

Changes for sows in distribution in housing systems and normative figures due to mismatch in the data increase the emission with up to 0.2 % in the years 1991-2019. Updated number of weaners, fattening pigs and hens in 2020 decrease the emission of TSP with 1 %.

3Dc Farm-level agricultural operations

No recalculations.

3F Field burning of agricultural residues

Recalculations has been made for all years 1990-2020 due to change in dry matter content in grass seeds. The type of residue from grass seed production has been re-evaluated and the dry matter content has been lower from 85 % to 20 % (Møller et al., 2005). This decreases the emission of PM from field burning with 3-71 %.

5.9.5 HCB

Recalculations of HCB from use of pesticides have been recalculated for 2020. For submission 2022 of NFR no data were available for the use of pesticides in 2020 and the use were set to the same level as in 2019. Now data for the use of pesticides for 2020 are available and the emission is recalculated. This increase the emission of HCB from use of pesticides with 24 %.

5.10 Planned improvements

Reduction of emission as a consequence of using NH_3 reducing technologies as acidification, cooling of slurry, heat exchanger (broilers) and frequent removal of manure (mink) in housings, has been implemented in the emission inventory. Other NH_3 reducing technologies will be taken into account as soon as activity data and NH_3 reduction potential is available and documented. These reducing technologies could be using of air scrubbers in swine housing or frequent removal of manure for hens housing.

Based on the recommendation from the TERT review team, DK plan to search for information and data regarding the NH_3 emission for digested manure.

The TERT has noted a lack of transparency with regards to the national Integrated Database model for Agricultural emissions (IDA), and whether the calculation takes into account the immobilisation of nitrogen in solid manure in housing systems and mineralisation of nitrogen in liquid manure storage for NFR category 3B. The IDA calculation is based on the Danish normative data, which reflecting the N excreted for animal, in housing and storage, which mean through each step in the manure management chain. The Danish normative system for N-excretion and NH_3 emission is planned to be extended, to also include carbon and CH_4 emission and in this work the N-excretion through the system will be evaluated. This work is planned for the years 2021-2024. When results are available, they will be incorporated in the Danish emission inventory as far as possible.

New regulations for application of some inorganic fertiliser types will be implemented for emission year 2020 and possibilities to take this into account will be investigated.

5.11 References

Aaes, Ole, 2008: Personal communication. Knowledge Centre for Agriculture.

Andersen, J.M., Sommer, S.G., Hutchings, N., Kristensen, V.F. & Poulsen, H.D., 1999: Emission af ammoniak fra landbruget – status og kilde. National Environmental Research Institute and the Danish Institute of Agricultural Sciences. (In Danish).

Anderson, J., 2019: Mail from Jack Anderson, Teknological Institute. Recived from Heidi Ravnborg, Ministy of Environment and Food. Mail received 04.03.2019.

BEK, 2002: BEK nr. 604 af 15/07/2002 Bekendtgørelse om erhvervsmæssigt dyrehold, husdyrgødning, ensilage m.v. Available at (in Danish): https://www.retsinformation.dk/Forms/R0710.aspx?id=12574 (Feb. 2023).

Birkmose, T., 2020: Aktivitetsdata for udbragt husdyrgødning, 2016-2020. Af Landskonsulent Torkild Birkmose, SEGES. Juni 2020. (In Danish).

Birkmose, T. & Hørfarter, R., 2019: Opgørelse af antal gylletanke i Danmark. SEGES, Danish Agriculture & Food Council, Manure team, December 2019.

Black, R.R., Meyer, C.P., Touati, A., Gullett, B.K., Fiedler, H. & Mueller, J.F., 2012: Emission factors for PCDD/PCDF and dl-PCB from open burning of biomass, Environment International, Volume 38, Issue 1, January 2012, Pages 62-66.

Børsting, C.F. & Hellwing A.L.F., 2022: Normtal for husdyrgødning – 2022/23, 40 sider Forudsætninger og beregninger kan findes i DCA rapport, nr. 191, 2021 eller på https://anis.au.dk/forskning/sektioner/husdyrernaering-og-fysiologi/normtal (Feb. 2023).

Børsting, C.F., Hellwing, A.L.F., Sørensen, M.T., Lund, P., van der Heide, M., Møller, S.H., Kai, P., Nyord, T., Aaes, O., Clausen, E., Tybirk, P., Holm, M., Hansen, M.N., Jensen, H.B., Bækgaard, H., 2021: Normtal for husdyrgødning, DCA Rapport nr. 191, 306 sider. (in Danish). Available at: https://dcapub.au.dk/djfpublikation/djfpdf/DCArapport191.pdf (Feb. 2023).

Clausen, E.F., 2008: Personal communication. Knowledge Centre for Agriculture.

Danish Agricultural Agency, 2022: Inorganic N fertiliser sold in Denmark 2020/2021. (in Danish). Available at: https://lbst.dk/fileadmin/user_upload/NaturErhverv/Filer/Virksomheder/Handelsgoedning/Statistik_salg_af_handelsgoedning/Rapport_over_solgt_goedning_for_2020-2021.pdf (Feb. 2023).

Danish Environmental Protection Agency (DEPA), 2009: Spildevandsslam fra kommunale og private renseanlæg i 2005. Orientering fra Miljøstyrelsen Nr. 3. Available at (In Danish): https://mst.dk/service/publikationer/publikationsarkiv/2009/maj/spildevandsslam-fra-kommunale-og-private-renseanlaeg-i-2005/ (Feb. 2023).

Danish Environmental Protection Agency (DEPA), 2001-2020: Affaldsstatistik. Available at (In Danish): https://mst.dk/affald-jord/affald/affaldsdatasystemet/find-affaldsdata/affaldsstatistikker/ (Feb. 2023).

Danish Environmental Protection Agency (DEPA), 2022: Gennemførelse og anvendelse af slamdirektivet. Afrapportering. Orientering fra Miljøstyrelsen Nr. 57, August 2022. Available at (In Danish): https://mst.dk/service/publikationer/publikationsarkiv/2022/aug/gennemfoerelse-og-anvendelse-af-slam-direktivet/ (Feb. 2023).

EMEP/EEA air pollutant emission inventory guidebook, 2019: Available at: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (Feb. 2023).

Feidenhans'l, B., 2009: Amount of straw burnt. Barthold Feidenhans'l, SEGES, personal communication.

Gyldenkærne, S. & Albrektsen, R., 2009: Report on the emission of NH_3 and NMVOC emission from agricultural crops. In process.

Hafner, S.D., Nyord, T., Sommer, G.S. & Adamsen, A.P., 2021: Estimation of Danish emission factors for ammonia from field-applied liquid manure for 1980 to 2019. 138 pages. Advisory report from DCA – Danish Centre for Food and Agriculture, Aarhus University, submitted: 23-09-2021. Available at: https://pure.au.dk/portal/files/223538048/EFreport23092021.pdf (Feb. 2023).

Hafner, S.D., Pacholski, A., Bittman, S., Burchill, W., Bussink, W., Chantigny, M., Carozzi, M., Génermont, S., Häni, C., Hansen, M.N., Huijsmans, J., Hunt, D., Kupper, T., Lanigan, G., Loubet, B., Misselbrook, T., Meisinger, J.J., Neftel, A. & Sommer, S.G., 2018: The ALFAM2 database on ammonia emission from fieldapplied manure: Description and illustrative analysis. Agricultural and Forest Meteorology. 258, 66-79. Available at: https://doi.org/10.1016/j.agrformet.2017.11.027 (Feb. 2023).

Hafner, S.D., Pacholski, A., Bittman, S., Carozzi, M., Chantigny, M., Génermont, S., Häni, C., Hansen, M.N., Huijsmans, J., Kupper, T., Misselbrook, T., Neftel, A., Nyord, T. & Sommer, S.G., 2019. A flexible semi-empirical model for estimating ammonia volatilization from field-applied slurry. Atmos. Environ. Available at https://doi.org/10.1016/j.atmosenv.2018.11.034 (Feb. 2023).

Hansen, N.H., Sommer, S.G., Hutchings, N.J. & Sørensen, P., 2008: Emission factors for calculation of ammonia volatilization by storage and application of animal manure. DJF husdyrbrug nr. 84 • december 2008. Available at (In Danish): https://dcapub.au.dk/djfpublikation/djfpdf/djfhus84.pdf (Feb. 2023).

Hansen, M.N., 2017: Personal communication, data received per mail 25.08.2017. Martin Nørregaard Hansen, SEGES.

Hansen, M.N., 2019: Martin Nørregaard Hansen, personal communication. SEGES.

Hartung, J. & Seedorf, J. 1999: Characterisation of Airborne Dust in Livestock Housing and its Effects on Animal and Environment. International Symposium on Dust control in animal production facilities. June 1999.

van der Hoek, K.W. 2007: Landbauforschung Völkenrode Special Issue 308.

Holm, M., 2022: Number of horses in Denmark in 2021, received per mail 15.09.2022.

Hutchings, N.J. & Sommer, S.G., 2020: Vurdering af emissionsfaktorer ved ændret udbringningspraksis for urea og svovlsur ammoniak. Aarhus University, DCA – Danish Centre for Food and Agriculture.

Hübner, C., 2001: Österreichische Emissionsinventur für POPs 1985–1999. Studie im Auftrag des Umweltbundesamt. Interner Bericht, Bd. IB-650. FTU – Forschungsgesellschaft Technischer Umweltschutz GmbH, Wien.

Jenkins, B.M., 1996: Atmospheric Pollutant Emission Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulations; Final Report (3 Vols.); CARB Project A932-126; California Air Resources Board, Sacramento, California.

Jensen, H.B., 2019: Henrik Bang Jensen, personal communication. Danish Agriculture & Food Council.

Kai, P., 2022: Peter Kai, Personal communication, mail received 29.08.2022. Aarhus University, Department of Biological and Chemical Engineering

Kai, P., Nyord, T. & Hansen, M.N., 2022a: Kapitel 9 Tab under lagring afhusdyrgødning – Normtal for husdyrgødning 2022/2023. 221 pages. Available at (in Danish): https://anivet.au.dk/fileadmin/DJF/Anis/dokumenter_anis/normtal/Normtal_fra_Emma_2022/Kap_9_Lager_2022-2023_med_datablad.pdf (Feb. 2023).

Kai, P., Tybirk, P, Holm, M., Jensen, H.B. & Bækgaard, H., 2022: Kapitel 8 Tab af næringsstoffer fra stalde - Normtal for husdyrgødning 2022/2023. 89 sider. Kan findes på: https://anivet.au.dk/forskning/sektioner/husdyrernaering-ogfysiologi/normtal/ (Feb. 2023).

Lundgaard. N.H., 2006: Personal Communication: Department of Farm buildings and Machinery. Danish Agricultural Advisory Centre.

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 (Feb. 2023).

Mikkelsen, M.H. & Albrektsen, R., 2020: Forbedring af datagrundlaget for opgørelse af ammoniakemissionen fra landbruget. DCE – Danish Centre for Environment and Energy, Aarhus University. (in Danish).

Misselbrook, T.H., Van Der Weerden, T.J., Pain, B.F., Jarvis, S.C., Chambers, B.J., Smith, K.A., Phillips, V.R. & Demmers, T.G.M., 2000: Ammonia emission factors for UK agriculture. Atmospheric Environment 34 (2000) 871-880. Available at:
https://www.sciencedirect.com/science/article/pii/S1352231099003507 (Feb. 2023).

MST, 2021: List of Environmental Technologies for Livestock Holdings. Available at:
http://eng.mst.dk/trade/agriculture/environmental-technologies-for-livestock-holdings/list-of-environmental-technologies/ (Feb. 2023).

Møller, J., Thøgersen, R., Helleshøj, M.E., Weisbjerg, M.R., Søegaard, K. & Hvelplund, T., 2005: Fodermiddeltabel - Sammensætning og foderværdi af fodermidler til kvæg.

Nyord, T. & Mikkelsen, M.H., 2019: Aktivitetsdata for udbringning af gylle i Danmark. Note - Delleverance af opgave 4.07 planteaftalen 2018. In Danish.

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., Stupak, I., Scott-Bentsen, N., Rasmussen, E., Petersen, S.B., Baunbæk, L., & Hansen, M.G. 2022: Denmark's National Inventory Report 2022. Emission Inventories 1990-2020 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Aarhus University, DCE – Danish Centre for Environment and Energy, 969 pp. Scientific Report No. 494 http://dce2.au.dk/pub/SR494.pdf (Feb. 2023).

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. The Danish Institute of Agricultural Sciences. (In Danish).

Poulsen, H.D. & Kristensen, V.F., 1998: Standards Values for Farm Manure – A revaluation of the Dansih Standards Values concerning the Nitrogen. Phosphorus and Potassium Content of Manure. DIAS Report No. 7 - Animal Husbandry. Danish Institute of Agricultural Sciences.

Rasmussen, J.B., 2006: Personal Communication. Department of Farm buildings and Machinery. Danish Agricultural Advisory Centre.

Skade, M., 2020: Personal communication. The Danish Agricultural Agency.

Statistics Denmark (DSt), 2022: Agricultural Statistics. Available at: www.dst.dk/en.aspx (Feb. 2023).

Stenkjær, K., 2010: Number of pheasants. Personal communication.

6 Waste

6.1 Overview of the sector

The waste sector consists of the following five main NFR categories

- Solid waste disposal (NFR 5A)
- Biological treatment of solid waste (NFR 5B)
- Incineration and open burning of waste (NFR 5C)
- Wastewater treatment and discharge (NFR 5D)
- Other waste (NFR 5E)

Table 6.1 below shows the relevant NFR codes for the waste sector and an indication of which sources are included in the Danish inventories.

Table 6.1 Overview of NFR sectors.

NFR code	SNAP name	Included
5A	Managed Waste Disposal on Land	Yes
5A	Unmanaged Waste Disposal Sites	NO
5A	Other	NO
5B1	Compost production	Yes
5B2	Biogas production	Yes
5C1a	Incineration of domestic or municipal wastes	NO*
5C1bi	Incineration of industrial wastes	NO*
5C1bii	Incineration of hazardous waste	NO*
5C1biii	Incineration of clinical waste	NO*
5C1biv	Sewage sludge incineration	NO*
5C1bv	Incineration of corpses and carcasses	Yes
5C2	Open burning of wastes	NE
5D2	Wastewater treatment in industry	Yes
5D1	Wastewater treatment in residential/commercial sector	Yes
5D3	Other wastewater handling	NO
5E	Other waste: Accidental fires	Yes

NO: Not occurring, NE: Not estimated (negligible), *Incineration with energy recovery is not included in the waste sector, please refer to Chapter 3.2 for information on energy production.

Incineration of waste (municipal, industrial, clinical and hazardous) in Denmark is done with energy recovery and therefore the emissions are included under the relevant sectors under NFR sector 1A. The documentation for waste incineration is included in Chapter 3.2 Stationary combustion.

Sludge from wastewater treatment plants is only spread on agricultural land. Emissions that derive from this activity are included in Chapter 5.

6.2 Solid waste disposal

Major emissions from landfills are emissions of greenhouse gases, i.e. CH_4. Particulate matter (PM) emissions are emitted from waste handling and small quantities of NMVOC, CO, NH_3 and NO_x may be released as well. This report includes emissions of NMVOC, TSP, PM_{10} and $PM_{2.5}$. The remaining pollutants are acknowledged by the EMEP/EEA Guidebook (EEA, 2019) as applicable, but no default emission factors are available. For information on greenhouse gasses emissions (i.e. CH_4), please refer to Nielsen et al. (2022).

6.2.1 Methodology

Emissions of NMVOC are estimated using the Tier 1 methodology, while PM emissions from waste handling at solid waste disposal sites are calculated according to the Tier 3 emission modelling and use of facility data as described in the EMEP/EEA air pollutant emissions inventory guidebook 2019 (EEA, 2019).

For a more comprehensive description on landfills in Denmark over time and the regulatory framework, please refer to Nielsen et al. (2022).

Activity data

For the purpose of calculating particulate matter emissions from operations associated with depositing waste at landfills, the annual amount of deposited waste at still active solid waste disposal sites was applied, while for the calculation of the emissions of NMVOC, the total amount of organic waste deposited at the Danish landfills was applied. Figure 6.1 illustrates the deposited amounts of waste divided in the two categories: total waste and total organic waste, these data are also presented in Annex Table 3E-1.1 for the entire time series since 1940.

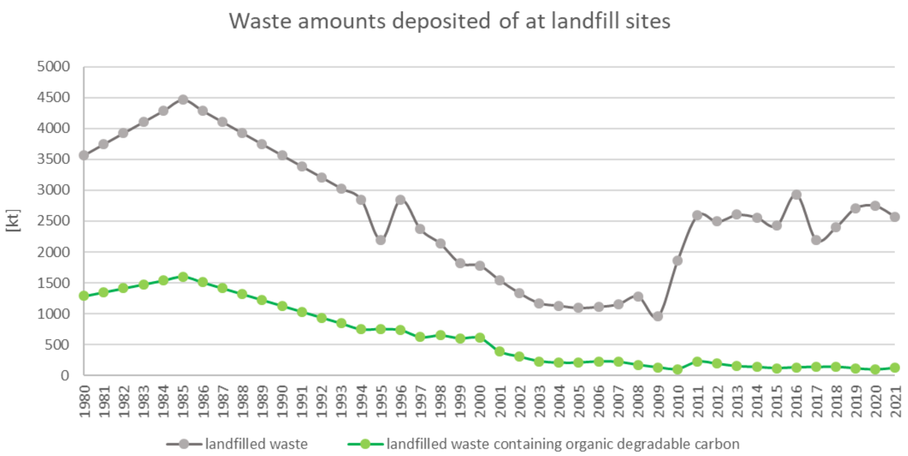


Figure 6.1 Waste delivered to solid waste disposal sites.

Emission factors

For NMVOC, the default Tier 1 value of 1.56 kg per tonne organic waste is applied. For the particle emissions, the emission factors are derived following the Tier 3 methodology (EEA, 2019) using equation 6.1:

$$E = k(0.0016)\ [U/2.2]^{\wedge}1.3\ /[M/2]^{\wedge}1.4 \qquad \text{Eq. 6.1}$$

where k is the particle size multiplier, U is the average Danish wind speed of 1.95 m/s based on daily measurements in the time period 2006-2017 (Annex Table 3E-1.2) as recommended (EEA, 2019) and M is the moisture content for municipal solid waste, which were set equal to the default value of 11 % (EEA, 2019). An overview of parameters and resulting emission factors, E, are provided in Table 6.2.

Table 6.2 Input parameters to equation 6.1 and resulting emission factor values for TSP, PM_{10} and $PM_{2.5}$.

Parameter	Explanation, Unit	Unit	Value
*M**	Moisture content	%	11
*U***	Mean wind speed, 2006-2017	m/s	1.95
	TSP		0.74
*K**	PM_{10}		0.35
	$PM_{2.5}$		0.053
	E(TSP)	kg/kg	9E-08
E	E(PM_{10})	kg/kg	4E-08
	E($PM_{2,5}$)	kg/kg	7E-09

*default values (EEA, 2019).

**Annex Table 3E-1.2.

Emissions

Table 6.3 show the total national emissions from waste handling at solid waste disposal sites. The full time series is shown in Annex Table 3E-1.3.

Table 6.3 National emissions from waste handling at solid waste disposal sites.

	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
NMVOC, kt	2.50	1.76	1.17	0.95	0.33	0.16	0.18	0.22	0.18	0.15	0.19
TSP, kg	-	321.20	197.98	160.29	98.58	167.87	218.24	216.07	244.10	247.30	231.51
PM_{10}, kg	-	142.76	87.99	71.24	43.81	74.61	97.00	96.03	108.49	109.91	102.89
$PM_{2.5}$, kg	-	24.98	15.40	12.47	7.67	13.06	16.97	16.81	18.99	19.23	18.01

The NMVOC emissions are decreasing through the time series due to the reduced amount of organic waste being deposited at Danish landfills. For particulate emissions, the emissions fluctuate with the total amount of waste landfilled, a big part of which is soil and stone that varies greatly from year to year.

6.3 Biological treatment of solid waste

This sector covers two activities: composting and anaerobic digestion at biogas facilities. These are described in more detail below.

6.3.1 Compost production

This section covers the biological treatment of solid organic waste called composting. Pollutants that are emitted during composting are CO and NH_3.

Methodology

Emissions from composting have been calculated according to a Tier 2 method.

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 2001, 123 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 as 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 fraction of the degradable organic carbon (DOC) in the waste material is converted into CO. Even though the windrows are occasionally turned to support aeration, anaerobic sections are inevitable and will cause a small emission of CH_4. In the same manner, aerobic biological digestion of N leads to an emission of NO_X, while the anaerobic decomposition leads to the emission of NH_3 (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, 2010). For 2010-2021, data from the new waste reporting system (https://www.ads.mst.dk/Default.aspx) have been used and allocation according to the four compost types have been performed using the fractional distribution in 2009 to allocate the total amount of compost.

Figure 6.2 illustrates the composted amount of waste divided in the four categories mentioned earlier.

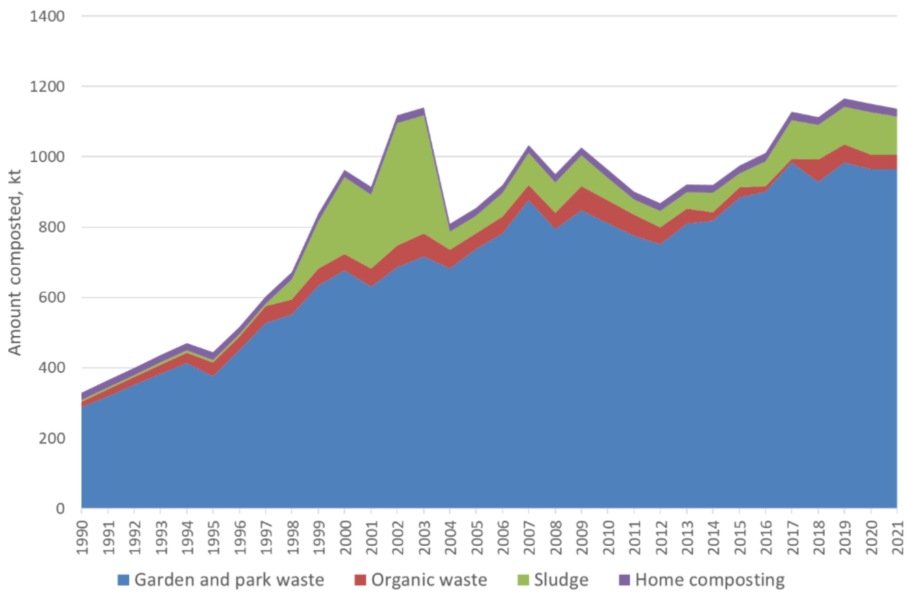


Figure 6.2 Amount of composted waste divided in garden and park waste (GPW), organic municipal solid waste (MSW), sludge and home composting of garden and food waste, these data are also shown in Table 6.5.

Activity data for the years 1995-2009 are collected from the Danish waste statistics (DEPA, 2022a) for the categories: GPW, organic waste from households and other sources and sludge. For sludge, activity data are also collected from the waste statistics for 2011-2020 (DEPA, 2022a).

For sludge, activity data in the period 1990-1994 were interpolated based on sludge known to be composted in 1987 (DEPA, 1993). The Danish legislation on sludge (MIM, 2006) 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 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 6.4 shows the number of composting sites divided in the three types, where type 1 is mainly receiving source separated organic waste, type 2 receive only garden & park waste, while type 3 receive garden & park waste in combination with other organic waste types (Petersen, 2001 and Petersen & Hansen, 2003).

Table 6.4 Number of composting facilities in the years 1990-2001.

Facility type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
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	123	130	139	138	142

Type 1 waste treatment sites normally includes biogas-producing facilities, but these have been excluded from this table.

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 waste statistics activity data for GPW. Activity data for GPW for the years 1990-1994 are estimated by extrapolating the trend.

Activity data for 2011-2019 for composting of GPW and organic waste are available from DEPA (2022b).

Activity data for 2020-2021 are kept constant on the average 2017-2019 level for GPW and organic waste composting and at the average 2018-2020) level for sludge composting. Activity data for 2010 are interpolated between 2009 and 2011.

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 in the time series.

- 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 quite 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 gathered from Statistics Denmark (2022) for the entire time series.

The calculated activity data for home composting of garden and vegetable waste are shown in Table 6.5 and Annex Table 3E-2.1.

Table 6.5 Activity data composting, kt.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Garden and park waste	130	288	376	677	737	811	884	983	965	965
Organic waste	5	16	40	47	45	65	29	53	41	41
Sludge	4	5	7	218	50	65	39	106	121	108
Home composting	19	20	21	21	22	23	23	23	24	24
Total	158	329	444	963	854	964	975	1166	1151	1138

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 provided in Table 6.6 are considered the best available for the calculation of Danish national emissions from composting.

Table 6.6 Composting emission factors, per tonnes.

	Composting of garden and park waste (GPW)	Composting of organic waste	Composting of sludge	Home composting of garden and vegetable food waste
Unit	kg	kg	kg	kg
NO_x	NAV	NAV	NAV	NAV
CO	0.56	NAV	NAV	0.075
NH_3	0.66	0.24	0.31	0.63
Source	Boldrin et al., 2009	EEA, 2009	MST, 2013	Boldrin et al., 2009

Emissions from Boldrin et al. (2009) are given in percentage of total degraded carbon or nitrogen respectively. The factors shown in Table 6.6 are calculated by assuming 37.5 % DOC in dry matter, 2 % N in dry matter and 50 % moisture in the waste (Boldrin et al., 2009).

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 6.6:

- 0.5 % N per dry matter waste water sludge
- 25 % moisture in wastewater sludge
- 2 % N per dry matter garden waste (incl. home composting)
- DOC is 25-50 % in garden waste (incl. home composting)
- 50 % moisture in garden waste (incl. home composting).

Emissions

Table 6.7 show the total national emissions from composting. The full time series is shown in Annex Table 3E-2.2.

Table 6.7 National emissions from composting, tonnes.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
CO	74	163	212	381	414	456	497	552	542	542
NH_3	100	208	273	539	527	585	617	709	699	695

6.3.2 Biogas production

Emissions from biogas production are divided and reported in different sectors according to waste type and method.

Methodology

Emissions from the combustion of biogas regardless of the origin are included in the energy sector and are allocated to the appropriate subsector in the Danish energy statistics. See this IIR Chapter 3, Energy.

NH_3 emissions from livestock manure processed in biogas facilities and afterwards spread on agricultural soils are included in the agricultural sector in Chapter 5.

Emissions in this section include emissions of NH_3 from feedstock (not livestock manure) stored at the biogas facility before and after the anaerobic digestion. Based on the Tier 1 methodology given in EEA (2019).

Activity data

Data regarding the amount of N from feedstock delivered to biogas facilities is available for the years since 2015. The data are 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 the Danish Energy Agency (DEA).

For the entire time series, the data for amount of N from feedstock delivered to the biogas production is calculated based on the relation between the amount of N in feedstock delivered and the total energy production produced at the biogas facilities for the years 2016-2019. The average amount of N per PJ is estimated to be 7.5 tonnes N per PJ. The total energy production from biogas facilities for all years is based on the Energy Statistics (DEA, 2022).

In 1985, the energy production produced at the biogas facilities is estimated by DEA to 294 TJ. Based on the assumptions mentioned above, this corresponds to 2.2 tonnes N delivered to the biogas production plants. In 2021, the energy production is increased to 26.1 PJ and the amount of slurry delivered to the biogas facilities is 195.8 tonnes N. Time series for the energy production at biogas facilities and amount of N in feedstock are shown in Table 6.8 and Annex Table 3E-2.3.

Table 6.8 Energy production from biogas facilities and amount of N in feedstock.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Energy production, PJ	0.29	0.72	1.34	2.30	3.29	4.02	6.18	16.44	21.24	26.06
Total N, tonnes	2.21	5.44	10.10	17.28	24.72	30.25	45.85	122.65	157.98	195.84

Emission factor

The emission factor for Tier 1 given in Table 3.1 in Chapter 5.B.2 Biological treatment of waste – anaerobic digestion at biogas facilities in EEA (2019) is 0.0275 kg NH_3-N per kg N in feedstock. This corresponds to 0.0334 kg NH_3 per kg N in feedstock.

Emission

The emission of NH_3 from storage of feedstock to biogas production is presented in Table 6.9. For all years of the time series, see Annex Table 3E-2.3. The emission is increasing from 1985 to 2021 due to increase in the production of biogas.

Table 6.9 Emission of NH_3 from storage and separation of feedstock to biogas production, t.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Emission NH_3	0.07	0.18	0.34	0.58	0.83	1.01	1.53	4.10	5.28	6.54

6.4 Waste incineration

Incineration of municipal, industrial, clinical and hazardous waste takes place with energy recovery, therefore the emissions are included in the relevant subsectors under NFR sector 1A. For documentation, please refer to Chapter 3.2. Flaring off-shore and in refineries are included under NFR sector 1B2c, for documentation please refer to Chapter 3.4. No flaring in chemical industry occurs in Denmark.

6.4.1 Human cremation

The incineration of human corpses is a common practice that is performed on an increasing percentage of the deceased. All Danish crematoria use optimised and controlled cremation facilities, with temperatures reaching 800-850 °C, secondary combustion chambers, controlled combustion air flow and regulations for coffin materials.

However, the emissions of especially Hg caused by cremations can still contribute to a considerable part of the total national emissions. In addition to the most frequently discussed emissions of Hg and PCDD/Fs (dioxins and furans), are the emissions of compounds like SO_2, NO_x, NMVOC, CO, other heavy metals (As, Cd, Cr, Cu, Ni, Pb, Se, Zn), particulate matter, HCB, PAHs and PCBs.

Crematoria are usually located within cities, close to residential areas and normally, their stacks are relatively low. Therefore, environmental and human exposure is likely to occur as a result of emissions from cremation facilities.

Methodology

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 burn-out 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 6.10 shows a comparison of the emission limit values from February 1993 and the new standard limits.

Table 6.10 Emission limit values mg per Nm^3 at 11 % O_2.

Component	1993 standard*	2011 standard**
Total dust	80	10
CO	50	50
Hg	No demands	0.1
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
Odour	The crematory must not cause noticeable odour in the surroundings	The crematory must not cause odour nuisance outside the crematory perimeter, that is significant according to the supervisory authority

*Schleicher et al., 2001; **Schleicher & Gram, 2008.

To meet the new standards, some crematoria have been rebuilt to larger capacity while others are closed (KM, 2006). In 2021, there were 19 operating crematoria in Denmark, some with multiple furnaces. In 2010, there were 31 operating crematoria (DKL, 2022).

Crematoria that are not closed are equipped with flue gas cleaning (bag filters with activated carbon). The use of air pollution control devices and activated carbon, for the removal of Hg will also reduce the flue gas concentration of dioxins, PAHs and odour. Existing knowledge on the reduction efficiencies justifies are presented in Schleicher & Gram (2008).

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.

Activity data

Table 6.11 shows the time series of total number of deceased persons (Statistics Denmark, 2022), number of cremations and the fraction of cremations in relation to the total number of deceased (DKL, 2022). Annex Table 3E-3.1 presents data for the entire time series.

Table 6.11 Data human cremations (DKL 2022, Statistics Denmark 2022).

	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Nationally deceased	55939	58378	60926	63127	57998	54962	54368	52555	53958	54645	57152
Cremations	33986	36705	40991	43847	41651	40758	42050	43238	46126	46910	48951
Cremation fraction, %	60.756	62.8	67.28	69.46	71.81	74.16	77.34	82.3	85.5	85.8	85.7

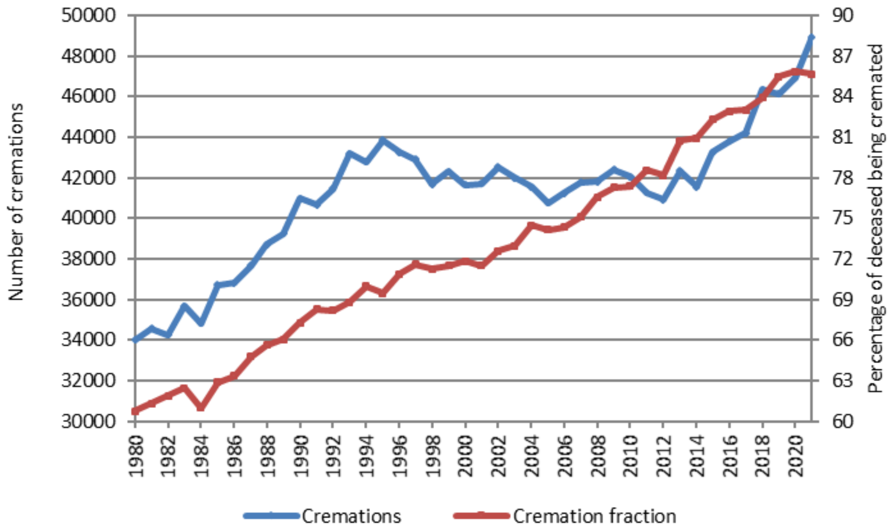


Figure 6.3 Illustration of the development in cremations (DKL 2022), where the number of cremations is shown at the left Y-axis. The right Y-axis shows the percentage of deceased being cremated. Data for 1980-1983 are estimated values, for details on the estimation, see Annex Table 3E-3.1.

Even though the total number of annual cremations is fluctuating, the cremation percentage has been steadily increasing since 1984, and it is likely to continue to increase.

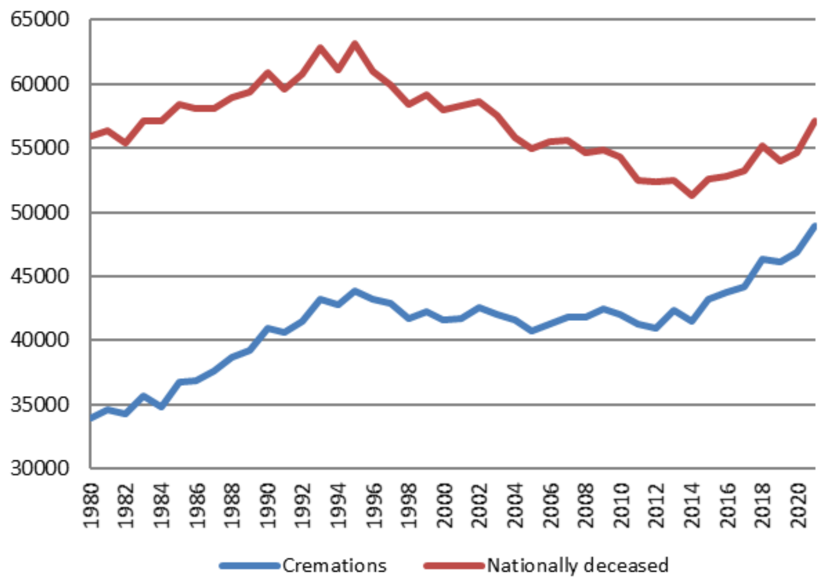


Figure 6.4 Trends of the activity data for cremation of human corpses and the number of deceased persons.

Figure 6.4 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 6.4 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. The percentage of the deceased being cremated has increased from 67 % in 1990 to 86 % in 2021 as shown in Figure 6.3, Table 6.11 and Annex Table 3E-3.1.

Emission factors

For crematoria, emissions are calculated by multiplying the total number of cremations by the emission factors. The emission factors are gathered from literature and are based on the measurements performed in countries that are comparable with Denmark. By comparable is meant countries that use similar incineration processes, similar cremation techniques including support fuel and have a similar composition of sources to lifetime exposure, lifetimes and coffins.

Table 6.12 lists the emission factors in the time period 1980-2010 and their respective references. As mentioned earlier, 2011 is year one after installation of bag filters with activated carbon at all Danish crematoria, causing the emission factors for particles, heavy metals, PAHs and PCDD/Fs to decrease significantly (Schleicher & Gram, 2008).

Table 6.12 Emission factors for human cremation with references.

Pollutant name	Unit	Emission factor*	Reference
SO_2	kg/body	0.113	Santarsiero et al., 2005
NO_X	kg/body	0.825	Santarsiero et al., 2005
NMVOC	kg/body	0.013	EEA, 1996
CO	kg/body	0.010	Schleicher et al., 2001
NH_3		NA	
TSP	kg/body	0.039	Webfire, 2012
PM_{10}	kg/body	0.035	Webfire, 2012
$PM_{2.5}$	kg/body	0.031	Webfire, 2012
As	g/body	0.014	Webfire, 2012
Cd	g/body	0.005	Webfire, 2012
Cr	g/body	0.014	Webfire, 2012
Cu	g/body	0.012	Webfire, 2012
Hg	g/body	1.12	Kriegbaum and Jensen, 2005
Ni	g/body	0.017	Webfire, 2012
Pb	g/body	0.030	Webfire, 2012
Se	g/body	0.020	Webfire, 2012
Zn	g/body	0.160	Webfire, 2012
HCB	mg/body	0.152	Toda, 2006
PCDD/F	µg I-TEQ/body**	0.350	Schleicher et al., 2001
Benzo(b)flouranthene	µg/body	7.21	Webfire, 2012
Benzo(k)flouranthene	µg/body	6.44	Webfire, 2012
Benzo(a)pyrene	µg/body	13.20	Webfire, 2012
Indeno(1,2,3-c-d)pyrene	µg/body	6.99	Webfire, 2012
PCBs	mg/body	0.414	Toda, 2006

*NA = not applicable. ** I-TEQ: International Toxicity Equivalents.

The average body weight of cremated corpses is assumed to be 65 kg.

Flue gas cleaning efficiencies are based on measurements performed at Danish crematoria and expert judgements, and set equal to 99 % for PCDD/Fs, particles, PAHs and heavy metals. These abatement efficiencies are implemented from 2011. For all other pollutants, the emission factors are as listed in Table 6.12.

It has not been possible to find data for ammonia. Ammonia might appear in lesser amounts, but will most likely be converted to NO_X at the high incineration temperatures.

There might for some emission factors be included a small part of the support fuel (natural gas) if the measurements were taken early in the burning process.

This would then be a double counting since fuel for cremation is reported under NFR code 1A4a, commercial and institutional. However, this double counting is considered negligible.

Emissions

Table 6.13 shows the total emissions from selected years. To view the entire time series 1980-2021, see Annex Table 3E-3.2. The dioxin emission is given in I-TEQ; i.e. International Toxicity Equivalents which is a weighted addition of congener toxicity with reference to 2,3,7,8-TCDD (Seveso-dioxin).

Emissions from human cremations have been steady over the last two decades but have decreased strongly for the pollutants TSP, PM_{10}, $PM_{2.5}$, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn, PCDD/Fs and PAHs from 2010 to 2011 because of the installation of bag filters with activated carbon.

Table 6.13 Total national emissions from human cremations.

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
SO_2	t	3.8	4.1	4.6	4.9	4.7	4.6	4.7	4.9	5.2	5.3	5.5
NO_X	t	NR	30.3	33.8	36.2	34.4	33.6	34.7	35.7	38.1	38.7	40.4
NMVOC	t	NR	0.5	0.5	0.6	0.5	0.5	0.5	0.6	0.6	0.6	0.6
CO	t	NR	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5
TSP	t	NR	NR	1.6	1.7	1.6	1.6	1.6	0.02	0.02	0.02	0.02
PM_{10}	t	NR	NR	1.4	1.5	1.4	1.4	1.5	0.02	0.02	0.02	0.02
$PM_{2.5}$	t	NR	NR	1.3	1.4	1.3	1.3	1.3	0.01	0.01	0.01	0.02
As	kg	NR	NR	0.6	0.6	0.6	0.6	0.6	0.01	0.01	0.01	0.01
Cd	kg	NR	NR	0.2	0.2	0.2	0.2	0.2	0.002	0.002	0.002	0.002
Cr	kg	NR	NR	0.6	0.6	0.6	0.6	0.6	0.01	0.01	0.01	0.01
Cu	kg	NR	NR	0.5	0.5	0.5	0.5	0.5	0.01	0.01	0.01	0.01
Hg	kg	NR	NR	45.9	49.1	46.6	45.6	47.1	0.5	0.5	0.5	0.5
Ni	kg	NR	NR	0.7	0.8	0.7	0.7	0.7	0.01	0.01	0.01	0.01
Pb	kg	NR	NR	1.2	1.3	1.3	1.2	1.3	0.01	0.01	0.01	0.01
Se	kg	NR	NR	0.8	0.9	0.8	0.8	0.8	0.01	0.01	0.01	0.01
Zn	kg	NR	NR	6.6	7.0	6.7	6.5	6.7	0.07	0.07	0.08	0.08
HCB	g	NR	NR	6.2	6.6	6.3	6.2	6.4	6.6	7.0	7.1	7.4
PCDD/F	mg I-TEQ	NR	NR	14.3	15.3	14.6	14.3	14.7	0.2	0.2	0.2	0.2
benzo(b)flouranthene	g	NR	NR	0.3	0.3	0.3	0.3	0.3	0.003	0.003	0.003	0.004
benzo(k)flouranthene	g	NR	NR	0.3	0.3	0.3	0.3	0.3	0.003	0.003	0.003	0.003
benzo(a)pyrene	g	NR	NR	0.5	0.6	0.5	0.5	0.6	0.006	0.006	0.006	0.006
indeno(1,2,3-c-d)pyrene	g	NR	NR	0.3	0.3	0.3	0.3	0.3	0.003	0.003	0.003	0.003
PCB	g	NR	NR	17.0	18.1	17.2	16.9	17.4	17.9	19.1	19.4	20.2

NR: Not reported.

6.4.1 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 burned in special designed plastic (PE) bags rather than coffins. Emissions from animal cremation are similar to those from human cremation, with the exception of Hg, which mainly stems from amalgam tooth fillings.

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.

Methodology

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. Consequently, this crematorium is included in Chapter 3.2 Stationary combustion. Therefore, only three animal crematoria are included in this sector.

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) (EC, 2000) on waste incineration or with Regulation (EC) No. 1069/2009 (EC, 2011).

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.

Emissions from pet cremations are calculated for SO_2, NO_x, NMVOC, CO, NH_3, particles, heavy metals (As, Cd, Cr, Cu, Ni, Pb, Se, Zn), HCB, dioxins/furans, PAHs and PCBs. For the pollutants SO_2, NO_x, CO, As, Se, HCB, PAHs and PCBs, emissions are estimated by using the same emission factors as for human cremation.

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.

The following Table 6.14 lists the four Danish pet crematoria, their foundation year and provides each crematorium with an id letter.

Table 6.14 Animal crematoria in Denmark.

Id	Name of crematorium	Founded in
A	Dansk Dyrekremering ApS	May 2006
B	Ada's Kæledyrskrematorium ApS	Unknown, existed in more than 40 years, assumed 1980
C	Kæledyrskrematoriet	2006
D	Kæledyrskrematoriet v. Modtagestation 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 as waste incineration with energy recovery. Therefore, only crematoria A-C are considered in this chapter.

Table 6.15 lists the activity data for crematoria A-C. The entire dataset for 1980-2021 is available in Annex Table 3E-3.3.

Table 6.15 Activity data. Source: direct contact with all Danish crematoria.

	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Total, t	50	100	150	200	443	762	1449	1119	1131	995	945

Crematorium B delivered exact annual activity data for the years 1998-2021. They were not certain about the founding year but believe to have existed since the early 1980es. It is assumed that crematorium B was founded at January 1st 1980 and activity data for 1980-1997 must therefore be estimated.

Statistical data describing the national consumption for pets including food and equipment for pets were evaluated as surrogate data. These statistical data show an increase of consumption of 6 % from 1998 to 2000, in the same period the amount of cremated animal carcasses increased with 89 % and no correlation seems to be present. Since there are no other available data on the subject of pets, it is concluded that there are no surrogate data available.

It is not possible to extrapolate data linearly back to 1980 because the activity, due to the steep increase, in this case would become negative from 1993 and back in time.

The activity data for animal cremation for the period of 1980-1997 are estimated by expert judgement. The estimated data are shown in Table 6.15, Figure 6.5 and Annex Table 3E-3.3.

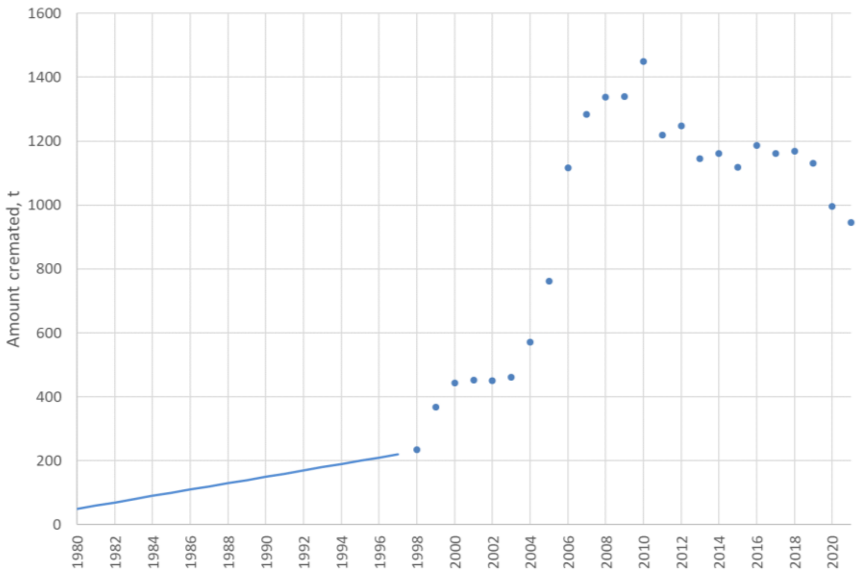


Figure 6.5 The amount of animal carcasses cremated, in tonnes. Data from 1998-2021 are delivered by the crematoria and is considered to be exact; these data are marked as points. Data from 1980-1997 are estimated and are shown as the thick line in the figure.

Emission factors

Concerning the incineration of animal carcasses in animal crematoria there is not much literature to be found. The EMEP/EEA Guidebook (EEA, 2019) is the best available source to emission factors for NMVOC, NH_3, TSP, PM_{10}, $PM_{2.5}$ and PCDD/F.

Chen et al. (2004) is the only available source to emission factors for the heavy metals Cd, Cr, Cu, Ni, Pb and Zn.

There is a good agreement between the emission factors for animal and human cremation for PCDD/F and a relatively good agreement for NMVOC, TSP, PM_{10}, $PM_{2.5}$ and heavy metals.

The emission factors of the remaining pollutants SO_2, NO_x, CO, As, Se, HCB, PAHs and PCBs 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, emission per tonnes.

No data were available for the emission of Hg in animal cremations. The Hg emission factor for human cremation is not transferable to animal cremations, because the Hg emission from human cremations primarily stems from tooth fillings.

Table 6.16 lists the emission factors and their respective references.

Table 6.16 Emission factors for animal cremation with references, per tonnes.

Pollutant	Unit	Emission factor	Source
SO_2	kg	1.73*	Santarsiero et al, 2005
NO_X	kg	12.69*	Santarsiero et al, 2005
NMVOC	kg	2.00	EEA, 2009
CO	kg	0.15*	Schleicher et al., 2001
NH_3	kg	1.90	EEA, 2009
TSP	kg	2.18	EEA, 2019
PM_{10}	kg	1.53	EEA, 2019
$PM_{2.5}$	kg	1.31	EEA, 2019
As	g	0.21*	Webfire, 2012
Cd	g	0.01	Chen et al., 2004
Cr	g	0.07	Chen et al., 2004
Cu	g	0.02	Chen et al., 2004
Hg	-	NAV	-
Ni	g	0.06	Chen et al., 2004
Pb	g	0.18	Chen et al., 2004
Se	g	0.30*	Webfire, 2012
Zn	g	0.19	Chen et al., 2004
HCB	mg	2.33*	Toda, 2006
PCDD/F	µg I-TEQ	10.00	EEA, 2009
Benzo(b)flouranthene	mg	0.11*	Webfire, 2012
Benzo(k)flouranthene	mg	0.10*	Webfire, 2012
Benzo(a)pyrene	mg	0.20*	Webfire, 2012
Indeno(1,2,3-c-d)pyrene	mg	0.11*	Webfire, 2012
PCB	mg	6.36*	Toda, 2006

* Emission factors from human cremations.

Emissions

For the incineration of animal carcasses, emissions are calculated by multiplying the amount of incinerated animals by the emission factors.

Emissions are summarised in Table 6.17, while emissions for the full time series are shown in Annex Table 3E-3.4.

Table 6.17 Emissions from animal cremation.

	unit	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
SO_2	t	0.1	0.2	0.3	0.3	0.8	1.3	2.5	1.9	2.0	1.7	1.6
NO_X	t	NR	1.3	1.9	2.5	5.6	9.7	18.4	14.2	14.4	12.6	12.0
NMVOC	t	NR	0.2	0.3	0.4	0.9	1.5	2.9	2.2	2.3	2.0	1.9
CO	t	NR	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.1
NH_3	t	NR	0.2	0.3	0.4	0.8	1.4	2.8	2.1	2.1	1.9	1.8
TSP	t	NR	NR	0.3	0.4	1.0	1.7	3.2	2.4	2.5	2.2	2.1
PM_{10}	t	NR	NR	0.2	0.3	0.7	1.2	2.2	1.7	1.7	1.5	1.4
$PM_{2.5}$	t	NR	NR	0.2	0.3	0.6	1.0	1.9	1.5	1.5	1.3	1.2
As	kg	NR	NR	0.03	0.04	0.09	0.16	0.30	0.23	0.24	0.21	0.20
Cd	kg	NR	NR	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Cr	kg	NR	NR	0.01	0.01	0.03	0.05	0.10	0.08	0.08	0.07	0.07
Cu	kg	NR	NR	0.00	0.00	0.01	0.02	0.03	0.02	0.02	0.02	0.02
Ni	kg	NR	NR	0.01	0.01	0.03	0.05	0.09	0.07	0.07	0.06	0.06
Pb	kg	NR	NR	0.03	0.04	0.08	0.14	0.26	0.20	0.20	0.18	0.17
Se	kg	NR	NR	0.05	0.06	0.13	0.23	0.44	0.34	0.34	0.30	0.29
Zn	kg	NR	NR	0.03	0.04	0.08	0.14	0.28	0.21	0.21	0.19	0.18
HCB	g	NR	NR	0.3	0.5	1.0	1.8	3.4	2.6	2.6	2.3	2.2
PCDD/F	mg	NR	NR	1.5	2.0	4.4	7.6	14.5	11.2	11.3	10.0	9.5
benzo(b)flouranthene	g	NR	NR	0.02	0.02	0.05	0.08	0.16	0.12	0.13	0.11	0.10
benzo(k)flouranthene	g	NR	NR	0.01	0.02	0.04	0.08	0.14	0.11	0.11	0.10	0.09
benzo(a)pyrene	g	NR	NR	0.03	0.04	0.09	0.15	0.29	0.23	0.23	0.20	0.19
indeno(1,2,3-c-d)pyrene	g	NR	NR	0.02	0.02	0.05	0.08	0.16	0.12	0.12	0.11	0.10
PCB	g	NR	NR	1.0	1.3	2.8	4.8	9.2	7.1	7.2	6.3	6.0

6.5 Wastewater handling

According to the EMEP/EEA Guidebook wastewater handling can be a source for emissions of NMVOC, NH_3 and CO. For the current submission, Denmark has estimated the NMVOC emission from wastewater handling as default emission factors are not available for other pollutants. Latrines are not used in Denmark.

6.5.1 Activity data and EF value

The EMEP/EEA Guidebook contains a default NMVOC emission factor for wastewater handling of 15 mg NMVOC per m^3 wastewater treated at tier 1 and 2 (EEA, 2019). For Tier 2 the relevant activity data are the amount of wastewater handled as provided in table 6.18 and the full time series are shown in Annex Table 3E-4.1.

Table 6.18 Amount of wastewater treated in Denmark, million m^3/yr.

Year	1990	1995	2000	2005	2010	2015	2019	2020	2021
Influent wastewater at municipal WWTPs	757	802	825	701	683	767	737	693	659
Wastewater treated at industrial WWTPs*	88	79	74	62	54	49	41	40	38
Total influent wastewater	846	881	899	763	737	816	778	733	697

*set equal to the amount of reported effluent wastewater from separate industries.

6.5.2 Emissions

NMVOC emissions from wastewater handling is calculated by multiplying the amount of influent wastewater by the default emission factor of 15 mg NMVOC/m^3 wastewater handled.

Emissions are summarised in Table 6.19, while emissions for the full time series are shown in Annex Table 3E-4.2.

Table 6.19 NMVOC emissions from wastewater handling, t/yr.

	1990	1995	2000	2005	2010	2015	2019	2020	2021
Municipal WWTPs	11.4	12.0	12.4	10.5	10.2	11.5	11.1	10.4	9.9
Industrial WWTPs	1.3	1.2	1.1	0.9	0.8	0.7	0.6	0.6	0.6
Total NMVOC emissions	12.7	13.2	13.5	11.4	11.1	12.2	11.7	11.0	10.5

6.6 Other waste

This category is a catch all for the waste sector. Emissions in this category could stem from e.g. sludge spreading, accidental fires and other combustion without energy recovery.

6.6.1 Sludge spreading

Sludge from wastewater treatment plants is only spread out in the open with the purpose of fertilising agricultural land. Emissions that derive from this activity are included in Chapter 5.

6.6.2 Accidental building fires

Emissions from accidental fires are categorised under the NFR category 5E Other waste. Pollutants that are emitted from building fires include SO_2, NO_x, NMVOC, CO, heavy metals (As, Cd, Cr, Cu, Hg, Pb), particles, PCDD/F and PAHs.

Methodology

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 houses, 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, ODIN is developed and run by* the Danish Emergency Management Agency (DEMA, 2007).

Activity data for accidental building fires are given by ODIN (DEMA, 2022). 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 1989-2021. For the years 2007-2021, the total number of registered building fires is known with a very high degree of detail based on information given in the yearly statistic reports (DEMA, 2022). For container fires, numbers are registered for the years 2008-2016 (DEMA, 2017).

Table 6.20 shows the occurrence of all types of fires (registered for 1989-2021) and the occurrence of building fires (2007-2021) registered at DEMA. The 1980-1988 data for all fires are estimated to be the average of 1989-2014 data. In 2007-2011, the average per cent of building fires, in relation to all fires, was 40 %. The total numbers of building fires 1980-2006 are calculated using this percentage. The full time series is presented in Annex Table 3E-5.1.

Table 6.20 Occurrence of all fires and building fires.

	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
All fires	17967	17967	17025	19543	17174	16551	16802	12777	12670	12538	13447
Building fires	7209	7209	6832	7842	6891	6641	7094	6245	6436	6534	6721

The building fires that occurred in the years 2007-2021 are subcategorised into five building types; detached houses, undetached houses, apartment buildings, industrial buildings and additional buildings and in sizes. The average distribution of subcategories and sizes for 2007-2011 are used to estimate the distribution of building fires in 1980-2006. These are shown in Table 6.21.

Table 6.21 Average of registered occurrence of building fires, 2007-2011, %. (DEMA, 2016).

Type		Size	
Detached	41	Full	8
Undetached	19	Large	21
Apartment	25	Medium	40
Industry	14	Small	31
Additional	1		

For 2008-2016 the number and sizes of container fires is known. For the years 1980-2007 the number of container fires are based on the average share of all fires for 2008-2011 and for the years 2017-2021 the number is based on the average share of all fires for 2012-2016. In Table 6.22 are shown the average share and sizes of container fires for 2008-2011 and 2012-2016.

Table 6.22 Average of registered occurrence of container fires, 2008-2011 and 2012-2016, %. (DEMA, 2017).

	Average 2008-2011, %	Average 2012-2016, %
Share of al l fires	11.1	8.8
Size:		
Full	0	0
Large	8	11
Medium	84	77
Small	8	12

By applying the damage rates of 100 %, 75 %, 30 % and 5 % corresponding to the damage sizes full, large, medium and small, a full-scale equivalent can be determined. Table 6.23 shows the calculated full-scale equivalents (FSE). The full time-series is presented in Annex Table 3E-5.2.

Table 6.23 Accidental building fires full-scale equivalent activity data.

	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Detached house fires	1124	1124	1065	1223	1075	1036	1185	920	907	945	889
Undetached house fires	507	507	480	551	484	467	447	398	226	242	218
Apartment building fires	766	766	726	833	732	706	726	635	885	899	748
Industrial building fires	432	432	409	470	413	398	408	662	702	660	614
Additional buildings	37	37	35	40	35	34	25	14	36	37	25
Container fires	626	626	593	681	598	577	513	331	356	353	331

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 do 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 6.24 lists the used emission factors and their respective references.

Table 6.24 Emission factors, building fires.

Compound	Unit /fire	Detached house	Undetached house	Apartment building	Industrial building	Additional building	Container	Reference
SO_2	kg	256.3	210.4	121.7	802.9	32.1	2.4	Blomqvist et.al. 2002
NO_x	kg	19.2	15.7	9.1	24.0	1.0	3.0	NAEI, 2009
NMVOC*	kg	95.8	78.6	45.5	120.0	4.8	0.7	NAEI, 2009
CO	kg	268.1	220.1	127.3	336.0	13.4	42.0	NAEI, 2009
TSP	kg	143.8	61.6	43.8	27.2	1.1	23.2	Aasestad, 2008**
PM_{10}	kg	143.8	61.6	43.8	27.2	1.1	23.2	Aasestad, 2008**
$PM_{2.5}$	kg	143.8	61.6	43.8	27.2	1.1	23.2	Aasestad, 2008**
As	g	1.35	0.58	0.41	0.25	0.01	0.22	Aasestad, 2008**
Cd	g	0.85	0.36	0.26	0.16	0.01	0.14	Aasestad, 2008**
Cr	g	1.29	0.55	0.39	0.24	0.01	0.21	Aasestad, 2008**
Cu	g	2.99	1.28	0.91	0.57	0.02	0.48	Aasestad, 2008**
Hg	g	0.85	0.36	0.26	0.16	0.01	0.14	Aasestad, 2008**
Pb	g	0.42	0.18	0.13	0.08	0.003	0.07	Aasestad, 2008**
PCDD/F*	mg	3.4	2.8	1.6	4.2	0.2	1.1	Hansen, 2000
Benzo[b]fluoranthene	g	12.1	10.0	5.8	15.2	0.6	1.9	NAEI, 2009
Benzo[k]fluoranthene	g	4.3	3.5	2.0	5.4	0.2	0.7	NAEI, 2009
Benzo[a]pyrene	g	7.7	6.8	3.6	9.6	0.4	1.2	NAEI, 2009
Indeno[1,2,3-cd]pyrene	g	8.3	6.8	3.9	10.4	0.4	1.3	NAEI, 2009

*Container fires have a different source than the other five categories; Blomqvist et.al. 2002, ** Personal contact with Kristin Aasestad has provided a correction of the units which are inaccurate in the text of Aasestad (2008)

Emission factors for detached, undetached and apartment fires depend on the annual average floor space in 1990 to 2014; see Table 6.25. 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 Table 3E-5.3.

The SO_2 emission factor is derived based on the typical amount of gypsum in buildings based on Blomqvist et al. (2002) together with an emission factor from Persson & Simonson (1998). The calculation is adjusted for the difference between the standard size used in Blomqvist et al. (2002) and the average Danish building size as further described below.

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 for 1980-2014 is stated in Table 6.25. The data are collected from Statistics Denmark and takes into account possible multiple building floors but not attics and basements. For the full time series 1980-2014, see Annex Table 3E-5.4. 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 6.25 Average floor space in building types (Statistics Denmark, 2016).

	1980	1985	1990	1995	2000	2005	2010	2013	2014
Detached houses	154	154	156	155	156	162	163	166	167
Undetached houses	130	130	129	129	131	131	134	133	132
Apartment buildings	74	75	75	75	75	76	77	78	78

Emission factors from literature are given in mass emission per mass burned. For the calculation of these emission factors to a unit that matches, the activity data, the building masses are estimated using the same methodology as in Hansen (2000).

The total building masses are calculated using an average weight loss rate of 12.4 % (Persson and Simonson, 1998) and data for the amount of combustible material in the building structure itself (Blomqvist et al., 2002) and the amount of combustible interior (Persson and Simonson, 1998).

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 tonne and covers all types of containers, from small residential garbage containers to large shipping containers and waste/goods in storage piles.

Building masses for 2014 are presented in Table 6.26.

Table 6.26 Building mass per building type.

	Unit	Detached house	Undetached house	Apartment building	Industry building	Additional building	Container
Average floor area	m^2	167	132	78	500	20	-
Building mass per floor area	kg/m^2	40	40	35	30	30	-
Total building mass*	t/fire	6.7	5.4	2.7	15.0	0.6	1

For further detail on the emission factors and calculations, please refer to Hjelgaard (2013).

Emissions

Table 6.27 shows the total emissions from building fires. The entire time series 1980-2020 is shown in Annex Table 3E-5.5.

Table 6.27 Emissions from building fires.

	unit	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
SO_2	t	837.4	837.4	793.2	911.0	800.5	771.7	815.7	929.5	953.3	934.4	859.3
NO_x	t	NR	48.7	46.2	53.0	46.6	44.9	47.7	46.5	46.9	47.0	43.0
NMVOC	t	NR	234.8	222.4	255.4	224.4	216.3	231.0	228.0	229.5	230.0	210.3
CO	t	NR	682.4	646.4	742.3	652.3	628.8	667.5	651.6	656.9	658.1	602.1
TSP	t	NR	NR	239.5	275.0	241.6	232.9	252.8	210.4	210.5	216.4	198.5
PM_{10}	t	NR	NR	239.5	275.0	241.6	232.9	252.8	210.4	210.5	216.4	198.5
$PM_{2.5}$	t	NR	NR	239.5	275.0	241.6	232.9	252.8	210.4	210.5	216.4	198.5
As	kg	NR	NR	2.2	2.6	2.3	2.2	2.4	2.0	2.0	2.0	1.9
Cd	kg	NR	NR	1.4	1.6	1.4	1.4	1.5	1.2	1.2	1.3	1.2
Cr	kg	NR	NR	2.1	2.5	2.2	2.1	2.3	1.9	1.9	1.9	1.8
Cu	kg	NR	NR	5.0	5.7	5.0	4.8	5.3	4.4	4.4	4.5	4.1
Hg	kg	NR	NR	1.4	1.6	1.4	1.4	1.5	1.2	1.2	1.3	1.2
Pb	kg	NR	NR	0.7	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6
PCDD/F	g I-TEQ	NR	NR	8.4	9.7	8.5	8.2	8.6	8.3	8.4	8.4	7.7
BbF[1]	kg	NR	NR	29.2	33.6	29.5	28.4	30.2	29.5	29.7	29.8	27.2
BkF[2]	kg	NR	NR	10.3	11.8	10.4	10.0	10.6	10.4	10.5	10.5	9.6
BaP[3]	kg	NR	NR	18.5	21.2	18.6	18.0	19.1	18.6	18.8	18.8	17.2
Indeno[4]	kg	NR	NR	20.0	23.0	20.2	19.5	20.7	20.2	20.3	20.4	18.6

[1] Benzo(b)fluoranthene.

[2] Benzo(k)fluoranthene.

[3] Benzo(a)pyrene.

[4] Indeno(1,2,3-cd)pyrene.

6.6.3 Accidental vehicle fires

Pollutants that are emitted from accidental vehicle fires include SO_2, NO_x, NMVOC, CO, particulate matter, heavy metals (As, Cd, Cr, Cu, Ni, Pb, Zn), PCDD/F and PAHs.

Methodology

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

DEMA (2017) 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 are for all vehicle categories estimated by using surrogate data.

Table 6.28 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 20 %. The total numbers of vehicle fires in 1980-2007 and 2013-2021 are calculated using this percentage. The full time series is presented in Annex Table 3E-5.1.

Table 6.28 Occurrence of all fires and vehicle fires.

Year	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
All fires	17967	17967	17025	19543	17174	16551	16802	12777	12670	12538	13447
Vehicle fires	3618	3618	3428	3936	3458	3333	3454	2573	2551	2525	2708

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 passenger cars and heavy duty vehicles for 2008-2016 and other vehicle categories for 2008-2012.

The total number of registered vehicles is known from Jensen & Kveiborg (2013) and Statistics Denmark (2022). 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 1980-2007 and 2017-2021 for passenger cars and heavy duty and 2013-2021 other vehicles. The numbers of registered vehicles from 1980 to 1984 are extrapolated based on the years 1985 to 1989, where a clear trend has been visible this trend has been extrapolated (e.g. passenger cars), otherwise the average value of 1985 to 1989 has been used (e.g. buses).

Table 6.29 states the total number of national registered vehicles and the number of full-scale equivalent vehicle fires. The full time series 1980-2021 is shown in Annex Table 3E-5.6.

Table 6.29 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	Registered	FSE fires	Registered	FSE fires
1980	1 475 109	405	8 070	10	99 168	8	47 443	57
1985	1 500 946	412	8 010	10	211 380	18	46 976	57
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
2015	2 392 282	454	12 438	16	395 397	33	41 369	38
2019	2 653 640	729	11 557	15	379 871	31	42 445	51
2020	2 725 313	749	10 973	14	376 128	31	42 131	51
2021	2 788 299	766	10 940	14	373 185	31	43 095	52

Continued

	Motorcycles/Mopeds		Caravans		Train		Ship	
	Registered	FSE fires	Registered	FSE	Registered	FSE fires	Registered	FSE fires
1980	220 273	73			7 284	8	2 222	24
1985	192 395	64			7 284	8	2 222	24
1990	164 111	55	86 257	22	7 156	8	2 324	25
1995	166 137	55	95 831	25	6 854	7	1 911	20
2000	233 711	78	106 935	28	4 907	5	1 759	19
2005	274 258	91	121 350	32	3 195	3	1 792	19
2010	304 717	83	142 354	37	2 740	2	1 773	16
2015	286 621	95	139 654	36	3 642	4	1 742	19
2019	261 536	87	127 705	33	3 179	3	1 721	18
2020	263 041	87	124 399	32	3 234	3	1 727	18
2021	262 356	87	121 672	32	3 218	3	1 852	20

Continued

	Airplane		Tractor		Combined Harvester		Bicycle	Other Transport	Machine
	Registered	FSE fires	Registered	FSE fires	Registered	FSE fires	FSE fires	FSE fires	FSE fires
1980	1 060	1	189 631	126	40 557	67			
1985	1 060	1	169 270	112	37 484	62			
1990	1 055	1	162 760	108	35 118	58			
1995	1 058	1	151 233	100	29 291	48			
2000	1 070	1	123 432	82	24 128	40			
2005	1 073	1	105 208	70	21 436	35			
2010	1 155	1	95 374	77	16 451	32	4	58	94
2015	1 064	1	89 398	59	12 467	21			
2019	1 008	1	82 716	55	10 475	17			
2020	1 007	1	80 636	53	9 977	16			
2021	1 015	1	78 900	52	9 675	16			

The average weights of a passenger car, bus, light- and heavy commercial vehicle and motorcycle/moped are known for every year back to 1993 (Statistics Denmark, 2022), the weight of combined harvesters is based on an expert judgement. The corresponding weights from 1980 to 1992 and the average weight of the units from the remaining categories are estimated by an expert judgment; see Table 6.30 and Annex Table 3E-5.7.

Table 6.30 Average weight of different vehicle categories, kg.

	Cars	Buses	Light Duty Vehicles	Heavy Duty Vehicles	Motorcycles/ Mopeds
1980	850	10 000	2 000	15 000	75
1985	850	10 000	2 000	15 000	75
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	1.144	9.160	2.517	13.902	133
2015	1.158	9.698	2.502	16.303	143
2019	1.171	9.920	2.539	16.646	156
2020	1 178	9 973	2 558	16 773	158
2021	1 189	10022	2 578	16 932	160

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, 150 % 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 6.31 and in Annex Table 3E-5.8.

Table 6.31 Burnt mass of different vehicle categories, tonnes.

	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Passenger cars	345	351	371	425	509	577	830	526	854	882	911
Buses	101	101	102	161	171	174	207	152	144	138	138
Light duty vehicles	16	35	41	55	69	88	96	82	80	80	79
Heavy duty vehicles	857	849	825	860	910	867	828	621	851	851	865
Motorcycle, moped	6	5	5	5	8	11	11	14	14	14	14
Other transport	0	0	0	0	0	0	33	0	0	0	0
Caravan	0	0	29	35	42	51	63	63	58	57	34
Train	115	115	113	107	78	49	28	63	56	57	57
Boat	236	236	247	182	170	175	147	180	182	183	187
Airplane	9	9	9	9	9	9	8	10	10	10	10
Bicycle	0	0	0	0	0	0	0	0	0	0	0
Tractor	251	224	216	234	203	176	194	148	139	137	135
Combine harvester	535	541	550	495	438	416	398	273	239	230	220
Machine	0	0	0	0	0	0	43	0	0	0	0
Total	2 473	2 466	2 509	2 570	2 606	2 592	2 885	2 131	2 626	2 639	2 650

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 6.32 lists the accepted emission factors and their respective references.

Table 6.32 Emission factors vehicle fires.

	Unit, per t	Emission factor	Source
SO_2	kg	5	Lönnermark and Blomqvist., 2006
NO_x	kg	2	Lemieux et al., 2004
NMVOC	kg	8.5	Lönnermark and Blomqvist., 2006
CO	kg	63	Lönnermark and Blomqvist., 2006
TSP	kg	38	Lönnermark and Blomqvist., 2006
PM_{10}	kg	38	Lönnermark and Blomqvist., 2006
$PM_{2.5}$	kg	38	Lönnermark and Blomqvist., 2006
As	g	0.26	Lönnermark and Blomqvist., 2006
Cd	g	1.70	Lönnermark and Blomqvist., 2006
Cr	g	3.80	Lönnermark and Blomqvist., 2006
Cu	g	27.0	Lönnermark and Blomqvist., 2006
Ni	g	2.80	Lönnermark and Blomqvist., 2006
Pb	g	820	Lönnermark and Blomqvist., 2006
Zn	g	3200	Lönnermark and Blomqvist., 2006
PCDD/F	mg	0.04	Hansen, 2000
Benzo(b)fluoranthene	g	32.3	Lemieux et al., 2004
Benzo(k)fluoranthene	g		Lemieux et al., 2004
Benzo(a)pyrene	g	14.7	Lemieux et al., 2004
Indeno(1,2,3-cd)pyrene	g	23.3	Lemieux et al., 2004

No data are available for Hg, Se, HCB and PCBs. NH_3 is assumed not to be emitted.

Emissions

Table 6.33 shows the total national emissions from vehicle. The entire time series is shown in Annex Table 3E-5.9.

Table 6.33 National emissions from vehicle fires.

	unit	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
SO_2	t	12.1	12.3	12.5	12.9	13.0	13.0	14.4	10.7	13.1	13.2	13.3
NO_X	t	NR	4.9	5.0	5.1	5.2	5.2	5.8	4.3	5.3	5.3	5.3
NMVOC	t	NR	21.0	21.3	21.8	22.2	22.0	24.5	18.1	22.3	22.4	22.5
CO	t	NR	155.4	158.1	161.9	164.2	163.3	181.8	134.3	165.4	166.3	167.0
TSP	t	NR	NR	95.3	97.7	99.0	98.5	109.6	81.0	99.8	100.3	100.7
PM_{10}	t	NR	NR	95.3	97.7	99.0	98.5	109.6	81.0	99.8	100.3	100.7
$PM_{2.5}$	t	NR	NR	95.3	97.7	99.0	98.5	109.6	81.0	99.8	100.3	100.7
As	kg	NR	NR	0.7	0.7	0.7	0.7	0.8	0.6	0.7	0.7	0.7
Cd	kg	NR	NR	4.3	4.4	4.4	4.4	4.9	3.6	4.5	4.5	4.5
Cr	kg	NR	NR	9.5	9.8	9.9	9.8	11.0	8.1	10.0	10.0	10.1
Cu	kg	NR	NR	67.7	69.4	70.4	70.0	77.9	57.5	70.9	71.3	71.6
Ni	kg	NR	NR	7.0	7.2	7.3	7.3	8.1	6.0	7.4	7.4	7.4
Pb	t	NR	NR	2057.4	2107.4	2136.9	2125.4	2365.7	1747.4	2153.3	2164.0	2173.0
Zn	t	NR	NR	8028.8	8224.0	8339.2	8294.4	9232.0	6819.2	8403.2	8444.8	8480.0
PCDD/F	g I-TEQ	NR	NR	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
BbF[1]	kg	NR	NR	40.5	41.5	42.1	41.9	46.6	34.4	42.4	42.6	42.8
BkF[2]	kg	NR	NR	40.5	41.5	42.1	41.9	46.6	34.4	42.4	42.6	42.8
BaP[3]	kg	NR	NR	36.9	37.8	38.3	38.1	42.4	31.3	38.6	38.8	39.0
Indeno[4]	kg	NR	NR	58.5	59.9	60.7	60.4	67.2	49.7	61.2	61.5	61.7

[1] Benzo(b)fluoranthene. [2] Benzo(k)fluoranthene. [3] Benzo(a)pyrene. [4] Indeno(1,2,3-cd)pyrene, NR: Not reported.

6.6.4 Other

Other combustion sources include 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 sectors Agriculture and 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, and 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, 2011). There is no registration of private waste burning and the activity data on this subject are impossible to estimate, additionally, no emission factors are available in the EMEP/EEA Guidebook. Citizens are generally encouraged to compost their yard waste or to dispose of it through one of the many waste disposal/recycling sites, which is free of charge and hence there is no incentive for back yard burning.

The occurrence of bonfires at midsummer night 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.

Burning at an industrial scale does not occur, and therefore the guidance in the 2019 EMEP/EEA Guidebook ("The average amount of waste burned for arable farmland is therefore estimated to be 25 kg/hectare") is not relevant for Danish conditions as no waste burning occur in connection with farming. The EMEP/EEA Guidebook states that "For small scale waste incineration, the national annual quantity of agricultural waste incinerated is required". This number is impossible to estimate as there is no obligations for private citizens to report these activities nor any requirements for municipalities or other authorities to monitor or collect data for backyard burning.

6.7 Uncertainties and time series consistency

This section covers the uncertainty estimates

6.7.1 Input data

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 %.

The uncertainty of the number of human cremations is miniscule. However, for the purpose of the calculation it has been set to 1 %.

The uncertainty of the activity data from animal cremations is also minimal for the most recent years (1998-2021) but is increasing back in time (to 200 % in 1980). The uncertainty is set to 40 % for all years.

Activity data for composting are estimated for the years 1990-1994 and 2010-2021 resulting in a higher level of uncertainty these years; this is set at 40 %.

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.

Activity data for biogas production is an estimated N content the feedstock; the uncertainty for this activity is set to 20 %.

Table 6.34 lists the uncertainties for activity data in the waste sector.

Table 6.34 Estimated uncertainty rates for activity data.

	Solid Waste disposal	Human cremation	Animal cremation	Com-posting	Domestic wastewater handling	Industrial wastewater handling	Building fires	Vehicle fires	Biogas Production
Activity data uncertainty. %	10	1	40	40	24	24	10	10	20

The uncertainties for emission factors in the waste sector and at the present level of available information are listed in Table 6.35. The uncertainties are assumed valid for all years 1990-2021.

Table 6.35 Estimated uncertainty rates for emission factors, %.

Pollutant	Solid waste disposal	Human cremation	Animal cremation	Compos-ting	Domestic wastewater handling	Industrial wastewater handling	Building fires	Vehicle fires	Biogas production
SO_2		100	100				300	500	
NO_x		150	150				500	500	
NMVOC	200	100	300		300	300	500	500	
CO		150	150	100			500	500	
NH_3			300	100					75
TSP	500	500	300				500	700	
PM_{10}	500	500	300				500	700	
$PM_{2.5}$	500	500	300				500	700	
As		700	700				500	500	
Cd		700	500				500	500	
Cr		700	500				500	500	
Cu		700	500				500	500	
Hg		150					500		
Ni		700	500					500	
Pb		600	500				500	500	
Se		700	700						
Zn		700	500					500	
HCB		500	500						
PCDD/F		300	300				100	100	
(b)[1]		1 000	1 000				500	500	
(k)[2]		1 000	1 000				500	500	
(a)[3]		1 000	1 000				500	500	
(1,2,3-cd)[4]		1 000	1 000				500	500	
PCB		1 000	1 000						

[1] Benzo(b)fluoranthene.

[2] Benzo(k)fluoranthene.

[3] Benzo(a)pyrene.

[4] Indeno(1,2,3-cd)pyrene.

6.7.2 Uncertainty results

The Tier 1 uncertainty estimates for the waste sector are calculated from 95 % confidence interval uncertainties. Results are shown in Table 6.36.

Table 6.36 Tier 1 uncertainty results for waste.

Pollutant	Emission 2021	Unit	Total emission uncertainty. %	Trend 1990-2021. %	Trend Uncertainty %-age points
SO_2	879.7	t	293.3	8.5	15.0
NO_x	100.7	t	224.2	15.8	63.3
NMVOC	440.4	t	256.1	-78.2	44.5
CO	1311.8	t	242.3	35.6	150.3
NH_3	703.5	t	106.4	237.4	188.6
TSP	301.5	t	403.8	-10.6	40.6
PM_{10}	300.7	t	404.8	-10.7	40.6
$PM_{2.5}$	300.4	t	405.2	-10.7	40.6
As	2.8	kg	363.8	-21.1	98.0
Cd	5.7	kg	409.2	-3.4	44.6
Cr	11.9	kg	429.1	-2.7	47.6
Cu	75.7	kg	473.5	3.4	19.3
Hg	1.7	kg	344.2	-96.4	12.4
Ni	7.5	kg	495.8	-3.3	74.6
Pb	2173.8	kg	499.9	5.6	14.9
Se	0.3	kg	678.6	-65.3	312.8
Zn	8480.3	kg	500.1	5.5	14.9
HCB	9.6	g	402.2	46.6	182.3
PCDD/F	7.8	g	99.0	-8.3	12.8
Benzo(b)flouranthene	70.0	kg	362.2	0.4	23.7
Benzo(k)flouranthene	52.4	kg	418.6	3.1	18.7
Benzo(a)pyrene	56.2	kg	379.2	1.5	22.3
Indeno(1.2.3-c.d)pyrene	80.4	kg	401.3	2.4	20.3
PCB	26.3	g	804.4	46.6	363.0

6.8 QA/QC and verification

A list of QA/QC tasks are performed directly in relation to the emissions from the waste sector part of the Danish emission inventories. The following procedures are carried out to ensure the data quality:

- Checking of time series in the NFR and SNAP source categories. Considerable changes are controlled and explained
- Comparison with the inventory of the previous year. Any major changes are verified
- A manual log table is applied to collect information about recalculations
- Some automated checks have been prepared for the emission databases
- Check of units for fuel rate and emission factors
- Additional checks on database consistency.

The QC work will continue in future years.

6.8.1 Data deliveries

Table 6.37 lists the external data deliveries used for the waste emission inventory. Further, the table holds information on the contacts at the data delivery companies.

Table 6.37 List of external data sources.

Category	Data description	Activity data. emission factors or emissions	Reference	Contact(s)	Data agreement/ Comment	http. file or folder name
Human cremation	Annual number of cremated persons	Activity data	Association of Danish Crematories		Public access	http://www.dkl.dk
Human cremation	Population statistics	Activity data	Statistics Denmark		Public access	http://www.statistik-banken.dk/BEF5
Animal cremation	Annual number of cremated carcasses	Activity data	Dansk Dyrekremering ApS	Gert Linding Nielsen	Personal contact	
Animal cremation	Annual number of cremated carcasses	Activity data	Ada's Kæledyrs-krematorium ApS	Anders Oxholm	Personal contact	
Animal cremation	Annual number of cremated carcasses	Activity data	Kæledyrs-krematoriet	Annette Laursen	Personal contact	
Accidental building fires	Average floor space in buildings	Activity data	Statistics Denmark		Public access	http://www.statisti-kbanken.dk/BOL511
Accidental fires	Categorised fires	Activity data	The Danish Emergency Man-agement Agency		Public access	https://statisti-kbank.brs.dk
Accidental building fires	Building type statistics	Activity data	Statistics Denmark		Public access	http://www.statistik-banken.dk/ BOL11. BOL3. BOL33 AND BYGB11
Accidental vehicle fires	Weight categorisation of vehicles (passenger cars. bus-ses. vans and trucks)	Activity data	Statistics Denmark		Public access	http://www.statistik-banken.dk BIL10. BIL12. BIL15 and BIL18
Compost-ing	Waste categories for composting	Activity data	Waste Statistics (Affaldsstatistik) (DEPA, 2022a)		Public access	https://www.ads.mst.dk/Default.aspx

6.9 Source-specific recalculations and improvements

Some recalculations have been made. See details for each emission sector below.

6.9.1 Solid waste disposal on land

Prior to this year's submission, all aspects of the sub-sector of Solid waste disposal on land has gone through a thorough assessment. This assessment has resulted in recalculations in the amounts of both total waste and total degradable waste deposited, for all years in the time series.

Resulting recalculations are between -183 tonnes NMVOC (in 2017) and +101 tonnes NMVOC (in 2006) for 1990-2020; i.e. -51 % to +42 %.

NMVOC emissions for 1985-1989 are new in this year's submission, resulting in increases of 1.9-2.5 kt NMVOC for these years.

For particle emissions, recalculations are between -4.4 kg $PM_{2.5}$ and +2.7 kg $PM_{2.5}$; i.e. -25 % to +23 %.

6.9.2 Biological treatment of solid waste

For sub-sector *5B1 Composting*, the emission factor for CO from composting of GPW was adjusted from 0.5625 to 0.56 kg per tonne for 1985-1989, so that the same factor is now applied for the entire time series. The CO emissions factor for home composting is also adjusted for 1990-2020; from 0.08 to 0.75 kg per tonne. Activity data for composting of sludge was by mistake not previously reported for 1985-1989, correcting this results in an increase of NH_3 emissions of 1.2-1.4 tonnes for 1985-1989. There is also recalculations for the activity data for 1990-2000 and 2002-2020. The resulting overall recalculations from Composting are -0.76 to +0.52 tonnes CO and -6.3 to -25.0 tonnes NH_3.

For sub-sector *5B2 Anaerobic digestion at biogas facilities* updated data from the BIB register for the years 2016-2020 are the reason for recalculations of NH_3 emission in the same years. Recalculations are decreases between 0.3 and 60.5 kg NH_3.

6.9.3 Waste incineration and open burning

No recalculations have been made.

6.9.4 Wastewater treatment and discharge

Recalculations were made for both domestic and industrial wastewater handling. The resulting NMVOC recalculations are between -5.6 tonnes NMVOC (in 2009) and +3.2 tonnes NMVOC (in 2015); i.e. -35 % to +36 %.

6.9.5 Other

No recalculations have been made.

6.10 Source-specific planned improvements

There are currently no planned improvements for this sector.

6.11 References

Aasestad, K. (eds.). 2008: Norwegian Emission Inventory 2008**.** Documentation of methodologies for estimating emissions of greenhouse gases and long-range transboundary air pollutants. Report 2008/48. Statistics Norway. Available at:
http://www.ssb.no/english/subjects/01/04/10/rapp_emissions_en/rapp_200848_en/rapp_200848_en.pdf (24/02-2023).

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:
https://journals.sagepub.com/doi/pdf/10.1177/0734242X07088432
(03/02-2023).

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 (09/02-2023) (In Swedish).

Boldrin, A., Andersen, J.K., & Christensen, T.H. 2009: LCA-report: Environmental assessment of garden waste management in Århus Kommune (Miljøvurdering af haveaffald i Århus Kommune). Department of Environmental Engineering, Technical University of Denmark.

Chen, S.-J., Hung, M.-C., Huang, K.-L. & Hwang, W.-I. 2004: Emission of heavy metals from animal carcass incinerators in Taiwan. Chemosphere 55 (2004) 1197-1205. Elsevier.

DEA, Danish Energy Agency, 2022: The Danish Annual Energy Statistics. Available at:
https://ens.dk/service/statistik-data-noegletal-og-kort/maanedlig-og-aarlig-energistatistik (24/02-2023).

DEMA, 2007: The Danish Emergency Management Agency (DEMA). Beredskabsstyrelsen. Redningsberedskabets Statistiske Beretning 2007.

DEMA, 2016: Redningsberedskabet i tal 2016. Beredskabsstyrelsen. Sagsnr.: 2017/002384 Juni 2017. ISBN: 978-87-91590-86-3. Available at:
https://www.brs.dk/globalassets/brs---beredskabsstyrelsen/dokumenter/forskning-statistik-og-analyse/2017/-redningsberedskabet-i-tal-2016-.pdf (24/02-2023).

DEMA, 2017: The Danish Emergency Management Agency (DEMA). Beredskabsstyrelsen. Data received per mail.

DEMA, 2022: The Danish Emergency Management Agency (DEMA). Beredskabsstyrelsen. Statistikbanken. Available at:
https://statistikbank.brs.dk/sb#page=1c572bbd-e3fe-40cf-bc71-4244c3b750e8 (24/02-2023) (In Danish).

Danish Environmental Protection Agency (DEPA), 1993: Affaldsstrømme 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 (10/05-2022). (In Danish).

Danish Environmental Protection Agency (DEPA), 2011: Legislation on waste (Affaldsbekendtgørelsen). BEK nr. 1415 af 12/12/2011 Gældende. Chapter 7. §46 and §47. Available at:
https://www.retsinformation.dk/eli/lta/2011/1415
(In Danish) (24/02-2023).

Danish Environmental Protection Agency (DEPA), 2022a: Affaldsstatistik (Waste statistics) 2020. Miljøprojekt nr. 2217, December 2022. And previous versions 1996-2019 (In Danish).

Danish Environmental Protection Agency (DEPA), 2022b: Personal communication with Maja Hornung Thorndahl, 2. December 2022.

DKL, 2009: Danske Krematoriers Landsforening. Røggasrensning, miljøbehandling og varmeudnyttelse. Status juni 2009. Available at:
http://www.ft.dk/samling/20081/almdel/mpu/spm/591/svar/641398/714098/index.htm
(24/02-2023).

DKL, 2022: Danske krematoriers landsforening. Statistisk materiale. Available at: http://www.dkl.dk/info/statistik (24/02-2023) (In Danish).

European Commission (EC), 2011: Regulations. Commission Regulation (EU) No 142/2011 of 25 February 2011. Available at: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:054:0001:0254:EN:PDF
(24/02-2023).

European Commission (EC), 2000: DIRECTIVE 2000/76/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 December 2000 on the incineration of waste. Available at:
https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32000L0076&from=EN (06/02-2023).

EEA, 1996: European Environmental Agency. Emission Inventory Guidebook 2007. SNAP 090901. December 2006.

EEA, 2009: EMEP/EEA air pollutant emission inventory guidebook — 2009. Technical report No 6/2009. Available at:
http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009 (24/02-2023).

EEA, 2019: EMEP/EEA air pollutant emission inventory guidebook — 2019 https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (24/02-2023).

Hansen, E. 2000: Substance Flow Analysis for dioxins in Denmark. Environmental Project No. 570. Miljøprojekt. The Danish Environmental Protection Agency. Available at:
http://www2.mst.dk/udgiv/publications/2000/87-7944-295-1/pdf/87-7944-297-8.pdf (In Danish) (24/02-2023).

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/ (09/02-2023).

IPCC, 2006: Guidelines for National Greenhouse Gas Inventories. Chapter 4: Biological Treatment of Solid Waste. Available at:
http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_4_Ch4_Bio_Treat.pdf (24/02-2023).

ISAG: Det Danske InformationsSystem for Affald og Genanvendelse. The Danish Environmental Protection Agency. Database on all registered Danish waste 1994-2009. Available at:
http://mst.dk/affald-jord/affald/affaldsdatasystemet/find-affaldsdata/isag-udtraek/ (27/06-2022).

Jensen, T.C. & Kveiborg, O., 2013: Dokumentation af konvertering af trafiktal til emissionsopgørelser. Arbejdsnotat. DTU Transport. 2013.

Kriegbaum, M. & Jensen, E. 2005: Input til branchebilag for krematorie-anlæg. Kommentarer og begrundelser. Dato 23. september 2005. Available at:
http://mst.dk/media/mst/68544/060116Inputkrematorie-anl%C3%A6g.pdf (In Danish) (24/02-2023).

Lemieux, P.M., Lutes, C.C. & Santoianni, D.A. 2004: Emissions of organic air toxics from open burning: a comprehensive review. Elsevier. science direct; Progress in Energy and Combustion Science 30. Available at:
http://www.fire.uni-freiburg.de/vfe/Emissions-Open-Burning-Lemieux-etal-2004.pdf (24/02-2023).

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 (11/02-2023).

Kirkeministeriet (KM) (Ministry for Ecclesiastical Affairs), 2006: Arbejdsgruppe foreslår at der skal være færre krematorier. december 2006. Available at: https://www.km.dk/aktuelt/singlevisning/arbejdsgruppe-foreslaar-at-der-skal-vare-farre-krematorier (In Danish) (Feb. 2022).

MIM, 2006: Miljøministeriet (Ministry of Environment of Denmark). Bekendtgørelse om anvendelse af affald til jordbrugsformål (Slambekendtgørelsen) (Legislation on sludge). BEK nr. 1650 af 13/12/2006. Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=13056 (07/07-2022). (In Danish).

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 (In Danish) (24/02-2023).

NAEI, 2009: The UK National Atmospheric Emission Inventory. Available at: http://naei.beis.gov.uk/ (24/02-2023).

Nielsen et al., 2022: 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., Stupak, I., Scott-Bentsen, N., Rasmussen, E., Petersen, S.B., Baunbæk, L. & Hansen, M.G. 2022: Denmark's National Inventory Report 2022. Emission Inventories 1990-2020 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Aarhus University, DCE – Danish Centre for Environment and Energy, 969 pp. Scientific Report No. 494. Available at: http://dce2.au.dk/pub/SR494.pdf (24/02-2023).

Persson, B. & Simonson, M. 1998: Fire Emissions Into the Atmosphere. Swedish National Testing and Research Institute. Birås. Sweden. Fire Tech-nology. Vol. 34. No. 3. 1998.

Petersen, C. 2001: Statistik for behandling af organisk affald fra husholdninger – Revideret udgave. 1999 (Statistics for treatment of organic waste from households – revised version). ECONET A/S. Miljøprojekt Nr. 654. Miljøstyrelsen. Miljøministeriet. Available at: http://www2.mst.dk/Udgiv/publikationer/2001/87-7944-932-8/pdf/87-7944-933-6.pdf (In Danish) (24/02-2023).

Petersen, C. & Hansen, V.L. 2003: Statistik for behandling af organisk affald fra husholdninger 2001 (Statistics for treatment of organic waste from households). ECONET A/S. Miljøprojekt Nr. 856. Miljøstyrelsen. Miljøministeriet. Available at: http://www2.mst.dk/Udgiv/publikationer/2003/87-7972-962-2/pdf/87-7972-963-0.pdf (In Danish) (24/02-2023).

Petersen, C. & Kielland, M. 2003: Statistik for hjemmekompostering 2001 (Statistics on home composting). ECONET A/S. Miljøprojekt Nr. 855. Miljøstyrelsen. Miljøministeriet. Available at:
http://www2.mst.dk/udgiv/publikationer/2003/87-7972-960-6/pdf/87-7972-961-4.pdf (In Danish) (24/02-2023).

Santarsiero, A., Settimo, G., Cappiello, G., Viviano, G., Dell'Andrea, E. & Gentilini, L. 2005: Urban crematoria pollution related to the management of the deceased. Microchemical Journal. Vol. 79. Issues 1-2. Pp 299-306.

Schleicher, O. & Gram, L.K. 2008: Miljøprojekt Nr. 1191. Analyse af omkostningerne for rensning for kviksølv på krematorier i Danmark. Miljø-ministeriet. Miljøstyrelsen. Available at:
https://www2.mst.dk/udgiv/publikationer/2008/978-87-7052-594-7/pdf/978-87-7052-595-4.pdf (In Danish) (23/02-2023).

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 (In Danish) (23/02-2023).

Statistics Denmark, 2016: Data on floor size 1980-2014. Table BOL511: Beboede boliger efter område, boligart, boligstørrelse i kvm. og husstandsstørrelse.

Statistics Denmark, 2022: Available at:
http://www.statistikbanken.dk/statbank5a/default.asp?w=1024 (In Danish and English) (23/02-2023).

Toda, E. 2006: POPs and heavy metals emission inventory of Japan. Ministry of the Environment. Japan.

WEBFIRE, 2012: United States Environmental Protection Agency database. Available at:
http://cfpub.epa.gov/oarweb/index.cfm?action=fire.simpleSearch (23/02-2023).

7 Other and natural emissions

Denmark does not report emissions in the NFR category "Other" (NFR 6). Regarding natural emissions, volcanoes do not occur in Denmark and hence the category is reported as NO (Not Occurring).

Emissions from forest fires are for most years negligible, but have not been estimated. Any other natural emissions, to be reported under NFR category 11C, have also not been estimated.

8 Recalculations and Improvements

8.1 Recalculations

In general, considerable work is being carried out to improve the inventories. Investigations and research carried out in Denmark and abroad produce new results and findings, which are given consideration and, to the extent which is possible, are included as the basis for emission estimates and as data in the inventory databases. Furthermore, the updates of the EMEP/EEA Guidebook, and the work of the Task Force on Emission Inventories and its expert panels are followed closely in order to be able to incorporate the best scientific information as the basis for the inventories.

The implementation of new results in inventories is made in a way so that improvements, as far as possible, better reflect Danish conditions and circumstances. This is in accordance with good practice. Furthermore, efforts are made to involve as many experts as possible in the reasoning, justification and feasibility of implementation of improvements.

In improving the inventories, care is taken to consider implementation of improvements for the whole time series of inventories to make it consistent. Such efforts lead to recalculation of previously submitted inventories. This submission includes recalculated inventories for the whole time series. The recalculations are shown in Table 8.1 below. The table shows the difference between the latest and the previous submission, i.e. a positive number indicates an increase in emission.

Table 8.1 Recalculations by selected pollutants and main sectors.

NO_x, kt	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Stationary combustion		0.33	0.35	0.34	0.36	0.27	0.20	0.21	0.23	0.25	0.25	0.32
Mobile combustion	-3.16	-3.45	-3.55	-3.64	-3.27	-3.32	-3.42	-3.21	-2.94	-2.80	-0.27	-0.11
Fugitive emissions from fuels	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial processes									0.00	0.00	0.00	0.00
Agriculture	-0.05	-0.05	-0.05	-0.05	-0.07	-0.05	-0.06	-0.05	-0.06	-0.08	-0.08	0.16
Waste												
Total	-3.21	-3.17	-3.25	-3.35	-2.97	-3.09	-3.28	-3.05	-2.77	-2.62	-0.11	0.37

NMVOC, kt	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Stationary combustion		0.03	0.03	0.04	0.03	0.04	0.04	0.05	0.06	0.10	0.09	0.08
Mobile combustion	-0.60	-0.53	-0.42	-0.26	-0.13	-0.23	0.07	0.08	0.09	0.10	0.18	0.16
Fugitive emissions from fuels	0.01	0.01	0.01	-1.09	-0.89	-0.44	-0.35	-0.34	-0.27	-0.20	-0.18	-0.15
Industrial processes									0.00	-0.01	-0.19	-0.13
Agriculture	-0.10	-0.08	-0.07	-0.08	-0.12	-0.21	-0.18	-0.17	-0.07	-0.08	-0.15	0.08
Waste	2.50	0.00	-0.04	0.01	0.09	-0.12	-0.16	-0.16	-0.18	-0.16	-0.15	-0.16
Total	1.81	-0.56	-0.48	-1.39	-1.01	-0.95	-0.58	-0.55	-0.38	-0.25	-0.39	-0.11

SO_2, kt	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Stationary combustion		0.35	0.09	0.08	0.08	0.05	0.02	0.02	0.02	0.02	0.01	0.07
Mobile combustion	-0.84	-0.35	-0.31	0.01	0.08	0.04	-0.03	-0.03	-0.03	-0.03	0.04	0.04
Fugitive emissions from fuels	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial processes									0.00	0.00	0.00	0.07
Agriculture	-0.01	-0.01	-0.01	-0.02	-0.02	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.02
Waste												
Total	-0.85	-0.01	-0.24	0.08	0.15	0.08	-0.02	-0.02	-0.03	-0.03	0.03	0.16

NH_3, kt	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Stationary combustion							0.00	0.00	0.00	0.01	0.00	0.00
Mobile combustion	0.00	0.00	0.00	-0.01	-0.01	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Fugitive emissions from fuels												
Industrial processes									0.00	0.00	0.00	0.00
Agriculture	-0.03	-0.03	-0.01	0.15	0.55	0.89	1.27	1.01	0.77	0.88	0.87	2.64
Waste	0.00	0.00			0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02
Total	-0.03	-0.03	-0.01	0.14	0.54	0.86	1.26	1.02	0.78	0.90	0.89	2.65

TSP, kt	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Stationary combustion	NR	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.04	0.01	-0.09
Mobile combustion	NR	-0.45	-0.35	-0.20	-0.14	-0.09	-0.02	-0.01	0.00	0.01	0.05	0.04
Fugitive emissions from fuels	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial processes	NR	0.02	0.01	0.02	0.01	0.01	0.00	0.02	0.10	0.07	0.08	0.25
Agriculture	NR	-0.12	-0.14	-0.17	-0.20	-0.14	-0.15	-0.15	-0.17	-0.21	-0.23	-0.25
Waste	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	NR	-0.54	-0.46	-0.34	-0.31	-0.20	-0.16	-0.13	-0.06	-0.09	-0.09	-0.05

PM_{10}, kt	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Stationary combustion	NR	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.04	0.01	-0.06
Mobile combustion	NR	-0.45	-0.35	-0.20	-0.14	-0.09	-0.02	-0.01	0.00	0.01	0.05	0.04
Fugitive emissions from fuels	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial processes	NR	0.01	0.01	0.01	0.01	0.01	-0.01	0.00	0.03	0.02	0.02	0.07
Agriculture	NR	-0.12	-0.14	-0.18	-0.21	-0.14	-0.15	-0.15	-0.17	-0.21	-0.23	-0.24
Waste	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	NR	-0.54	-0.47	-0.36	-0.32	-0.21	-0.16	-0.14	-0.13	-0.14	-0.15	-0.19

Continued

$PM_{2.5}$, kt	1985	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Stationary combustion	NR	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.04	0.01	-0.03
Mobile combustion	NR	-0.54	-0.46	-0.32	-0.26	-0.22	-0.14	-0.14	-0.13	-0.12	-0.08	-0.08
Fugitive emissions from fuels	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial processes	NR	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
Agriculture	NR	-0.11	-0.14	-0.18	-0.20	-0.13	-0.14	-0.14	-0.16	-0.20	-0.22	-0.22
Waste	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	NR	-0.64	-0.58	-0.47	-0.44	-0.34	-0.28	-0.27	-0.28	-0.28	-0.29	-0.33

BC, kt	1985	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Stationary combustion	NR	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Mobile combustion	NR	-0.33	-0.29	-0.22	-0.20	-0.21	-0.13	-0.12	-0.11	-0.10	-0.09	-0.08
Fugitive emissions from fuels	NR											0.00
Industrial processes	NR						0.00	0.00	0.00	0.00	0.00	0.00
Agriculture	NR	-0.01	-0.01	-0.02	-0.02	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.02
Waste	NR											
Total	NR	-0.33	-0.29	-0.22	-0.21	-0.22	-0.13	-0.13	-0.12	-0.11	-0.11	-0.10

CO, kt	1985	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Stationary combustion		0.21	0.20	0.19	0.20	0.16	0.12	0.12	0.12	0.14	0.02	-0.15
Mobile combustion	-0.59	-0.48	-0.27	0.28	0.73	-0.17	2.10	1.98	1.90	1.80	1.93	1.57
Fugitive emissions from fuels	-0.02	-0.01	-0.02	-0.03	-0.02	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Industrial processes							0.00	0.00	0.01	0.01	-0.12	-0.03
Agriculture	-1.45	-1.37	-1.70	-2.18	-2.48	-1.67	-1.78	-1.76	-2.00	-2.41	-2.67	-2.67
Waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	-2.06	-1.65	-1.79	-1.73	-1.57	-1.69	0.44	0.33	0.02	-0.47	-0.85	-1.29

Pb, t	1985	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Stationary combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Mobile combustion	NR	2.05	2.60	2.81	3.03	3.11	3.08	3.07	3.11	3.17	3.14	2.87
Fugitive emissions from fuels	NR											
Industrial processes	NR								0.00	0.00	0.00	0.00
Agriculture	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste	NR											
Total	NR	2.05	2.60	2.81	3.03	3.10	3.07	3.07	3.11	3.17	3.14	2.90

Cd, t	1985	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Stationary combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mobile combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fugitive emissions from fuels	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial processes	NR								0.00	0.00	0.00	0.00
Agriculture	NR	-0.02	-0.02	-0.03	-0.03	-0.02	-0.02	-0.02	-0.03	-0.03	-0.04	-0.04
Waste	NR											
Total	NR	-0.02	-0.02	-0.03	-0.03	-0.02	-0.02	-0.02	-0.02	-0.03	-0.03	-0.03

Hg, t	1985	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Stationary combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mobile combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fugitive emissions from fuels	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial processes	NR								0.00	0.00	0.00	0.00
Agriculture	NR	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01
Waste	NR											
Total	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	0.00

Continued

PCDD/F, g I-TEQ	1985	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Stationary combustion	NR	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.09	0.02	0.03
Mobile combustion	NR	0.00	0.00	0.01	0.01	0.01	-0.01	-0.01	-0.01	-0.01	0.01	0.01
Fugitive emissions from fuels	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial processes	NR								0.00	0.00	-0.01	0.00
Agriculture	NR											0.00
Waste	NR											
Total	NR	0.02	0.02	0.02	0.02	0.03	0.01	0.01	0.01	0.09	0.02	0.04

HCB, t	1985	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Stationary combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mobile combustion	NR	-0.02	-0.03	-0.03	-0.03	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
Fugitive emissions from fuels	NR											
Industrial processes	NR										0.00	0.00
Agriculture	NR											0.02
Waste	NR											
Total	NR	-0.02	-0.02	-0.02	-0.03	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	0.01

BaP, t	1985	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Stationary combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
Mobile combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fugitive emissions from fuels	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial processes	NR								0.00	0.00	0.00	0.00
Agriculture	NR	-0.01	-0.01	-0.01	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02
Waste	NR											
Total	NR	-0.01	-0.01	-0.01	-0.02	-0.01	-0.01	-0.01	-0.01	0.02	-0.02	-0.02

PCBs, t	1985	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Stationary combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mobile combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fugitive emissions from fuels	NR											
Industrial processes	NR										0.00	0.00
Agriculture	NR											0.00
Waste	NR											
Total	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

NR = Not Reported. This notation key is used for years preceding the base year of the relevant protocol.

0.00 indicates that the recalculation is between -0.0049 and 0.0049.

The reasoning for the recalculations performed is to be found in the sectoral chapters of this report. For sector specific planned improvements please also refer to the relevant sectoral chapters.

8.2 Improvements

Improvements are continuously made to the extent that resources allow. Priority is given to key categories with a significant impact on the national total emissions.

Improvements are most often initiated by the inventory team, but improvements can also be caused by recommendations through national or international reviews.

8.2.1 Improvements in response to the review process

In 2017, there was the first review under the National Emission Ceilings Directive. The review formulated a number of recommendations for the Danish inventory mostly related to transparency. This review has been followed up annually since with additional reviews focussing on following up on the outcome of the previous reviews and additional focus areas. The recommendations contained in the latest review report[1], recommendations due for the next reporting of gridded and LPS data and the responses by Denmark as to the current state of implementation are provided in Table 8.2.

[1] https://environment.ec.europa.eu/topics/air/reducing-emissions-air-pollutants/emissions-inventories_en

Table 8.2 Recommendations form the 2022 review under the NECD and recommendations related to gridded and LPS reporting and responses by Denmark.

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Response by Denmark
DK-3-2022-0001	Yes	3 Agriculture, SO2, NOX, NH3, NMVOC, PM2.5, PM10, 1990-2020	For 3 Agriculture, all pollutants, and all years, the TERT noted that there is a lack of transparency regarding the lack of a key category analysis, so that it is not possible to determine whether a higher Tier method is used for key categories. This does not relate to an over- or under-estimate of emissions. In response to a question raised during the review, Denmark acknowledged the lack of a key category analysis, but explained that that all data sources, assumptions, and methodologies are explained in the IIR. The TERT thanks Denmark for their detailed answer. The TERT recommends that Denmark report a key category analysis in the next submission.	No	A key category analysis has been carried out and reported in Annex 1.
DK-5E-2022-0002	Yes	5E Other Waste, SO2, 2005-2020	For 5E Other Waste, which is a key category for SOX emissions, the TERT noted that there is a lack of transparency regarding the use of the country specific emission factor and the origin of SOX emissions from this category. This does not relate to an over- or under-estimate of emissions. In response to a question raised during the review, Denmark pointed out that the EMEP/EEA Guidebook does not contain default EFs for SO2 and explained that for building fires, the emission factors are derived based on the typical amount of gypsum in buildings based on Blomqvist et al. (2002) together with an emission factor from Persson and Simonson (1998). The calculation is adjusted for the difference between the standard size used in Blomqvist et al. (2002) and the average Danish building size. The TERT recommends that Denmark include this information in its IIR 2023.	No	This has been added to Chapter 6.5.2.
DK-LPS-E-2021-0001	NA	E Solvents, 2019	The TERT noted that for the year 2019, emissions are reported for NFR code 2D3g Chemical Products in the national inventory but not for GNFR code E_Solvents in the LPS submission. The TERT would expect emissions to be reported for this GNFR given that emissions are reported for these source categories in the national inventory. In response to the review Denmark explained that the inventory for solvents is based on a top-down approach which means that the inventory methodology is not compatible with using information from individual plants, as highlighted this in the IIR Chapter 10.4. The TERT recommends that Denmark consider developing an approach which enables reporting of emissions in GNFR sector E_Solvents, particularly for the 3 large plants identified in Table 10.3 of the IIR.	No	Denmark disagrees with this recommendation. Denmark is currently using a higher tier method to estimate NMVOC emissions from solvent use. This method is not compatible with reporting for single point sources. There is no basis in the reporting guidelines or the directive for the TERT to recommend that Denmark changes it current higher tier methodology.
DK-GRID-GEN-2021-0001	NA	General, NOX, NH3, NMVOC, Cd, Pb, PCDD/F, CO, 2019	The TERT notes with reference to Annex V submitted in 2021, that there are a number of locations (grid cells) where gridded and LPS data are inconsistent. The TERT had compared gridded emissions for each grid cell with LPS emissions (allocated to the respective grid cell), where several inconsistencies were found, i.e. cases where LPS emissions exceeded gridded emissions. In response to a question raised during the review, Denmark explained that the Danish gridding model are based on the national 1 km x 1 km grid (DKN) and for reporting purposes, the emissions are allocated to the 0.1 degree x 0.1 degree EMEP grid (EMEP). The allocation is done using weighting factors for the share of area of each DKN grid cell allocated in relevant EMEP cells. In the 2021 submission, the allocation is done for the total emissions including LPS emission. Hence, in cases where a given LPS is located in a DKN cell, which overlap more EMEP cells, the LPS emissions are split to these EMEP cells. This method will be changed in the next submission, so that LPS emissions are excluded from the area-weighted allocation and added afterwards to ensure that the total LPS emissions are allocated to the correct EMEP cell.. The TERT recommends that for the next submission, Denmark changes the process for reporting on the EMEP grid as outlined to avoid any inconsistencies between the LPS reporting and the gridded reporting and that the process for generating the gridded reporting is explained in chapter 11 of the IIR.	No	This will be implemented in the next submission of gridded data in 2025.

9 Gridded emissions

The gridded emissions were reported on 1 May 2021 and the information contained in this chapter is consistent with the information as reported 1 May 2021. The next submission is planned for 1 May 2025.

This chapter include descriptions on input data, methodology and results of the Danish gridded emissions for the year 2019. A detailed methodological description is given in Plejdrup et al. (2021).

The gridded emissions are consistent with the national total emissions reported in the NFR template submitted 15 February 2021 and includes all emissions, i.e. including LPS emissions. The gridded emissions incorporates the LPS emissions so full consistency is ensured. For further information on the LPS emissions, please refer to Chapter 10.

9.1 Background for reporting

According to the UNECE Convention on Long-Range Transboundary Air Pollution parties are obligated to report gridded emissions.

In December 2013, the Executive Body for the Convention on Long-range Transboundary Air Pollution adopted new reporting guidelines, which include requirement of four-year reporting of gridded emissions from 2017. The new reporting guidelines have been implemented for gridded emissions.

In the 2021 reporting Denmark reported gridded emissions for the year 2019. The mandatory reporting of gridded emissions includes the following 13 pollutants: NO_x, NMVOC, SO_x, NH_3, $PM_{2.5}$, PM_{10}, BC, CO, Pb, Cd, Hg, PCDD/PCDF (dioxins/furans), PAHs (benzo(b)flouranthene, benzo(k)flouranthene, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene), HCB and PCBs. The reporting includes GNFR sectoral emissions as well as national total emissions disaggregated to the standard EMEP grid with a resolution of 0.1 degree x 0.1 degree. Table 9.1 lists the categories (sectors) used for reporting gridded emission data based on the Danish inventories.

Table 9.1 GNFR categories and corresponding NFR categories and SNAP categories in the Danish gridded emission inventory.

GNFR	NFR	SNAP	Note
A_PublicPower	1A1a	0101, 0102	
B_Industry	1A1b, 1A1c, 1A2a, 1A2c, 1A2d, 1A2e, 1A2f, 1A2gviii, 2A, 2B, 2C, 2D3b, 2D3c, 2H2, 2I, 2L	0103, 0105, 03, 0402, 0403, 0404, 0405, 0406	
C_OtherStationaryComb	1A4ai, 1A4bi, 1A4ci	0201, 0202, 0203	
D_Fugitive	1B	0401, 0501, 0502, 0503, 0505, 0506, 0902	
E_Solvents	2D (excl. 2D3b and 2D3c), 2G	06	
F_RoadTransport	1A3b	07	
G_Shipping	1A3dii	080402	
H_Aviation	1A3ai(i), 1A3aii(i)	080501, 080502	
I_Offroad	1A2gvii, 1A3c,1A4aii, 1A4bii, 1A4cii, 1A4ciii, 1A5b	0801, 0802, 0803, 080403, 0806, 0807, 0808, 0809, 0811	
J_Waste	5	0901, 0909, 0910, 0911, 0912	
K_AgriLivestock	3B	*	
L_AgriOther	3D, 3F, 3G	*	
M_Other			NO
N_Natural			NO
O_AviCruise	1A3ai(ii), 1A3aii(ii)	080503, 080504	
P_IntShipping	1A3di(i)	080404	
T_IntAviCruise			
z_Memo			NO

* The Danish national emission inventory system for agriculture builds on NFR categories and not SNAP categories as is the case for the remaining sectors in the Danish emission inventory system.

The Guidelines used for this reporting are included in UNECE (2015). The methodology in Danish emission gridding model SPREAD follows the EMEP/EEA Guidebook (EEA, 2019). The gridded emission data in the 2021 reporting are available at the EIONET Central Data Repository homepage:

https://cdr.eionet.europa.eu/dk/un/clrtap

Further, a detailed methodological description is given in Plejdrup et al. (2021).

9.2 Methods and data for disaggregation of emission data

A national model for high-resolution spatial distribution of emissions to air, the SPREAD model, has been developed at Department of Environmental Science, Aarhus University. SPREAD includes all sources and pollutants in the Danish emission inventory system, and generates emissions on a resolution of 1 km x 1 km.

SPREAD covers the area defined by the Exclusive Economic Zone (EEZ) and the national border. Denmark is geographically the peninsula of Jutland and 443 named islands and islets, of which approximately 72 are inhabited. The country is located in Scandinavia neighbouring the sea (the Baltic Sea, Skagerrak, Kattegat and the North Sea) as well as Germany, which Jutland are adjacent to the south (Figure 9.1).

The spatial emission distribution is carried out on the most disaggregated level possible and therefore SPREAD includes a large number of distribution keys related to single sources, sub categories or sectors. Gridded emissions reported to UNECE LRTAP are based on the results from SPREAD, aggregated on the 0.1 degree x 0.1 degree EMEP grid.

The spatial distribution in SPREAD is based on a number of national geographical data sets. As the model is very complex and include many spatial data, only the most important input data and methodology descriptions are included in the IIR report. For a more detailed description, please refer to Plejdrup et al. (2021).

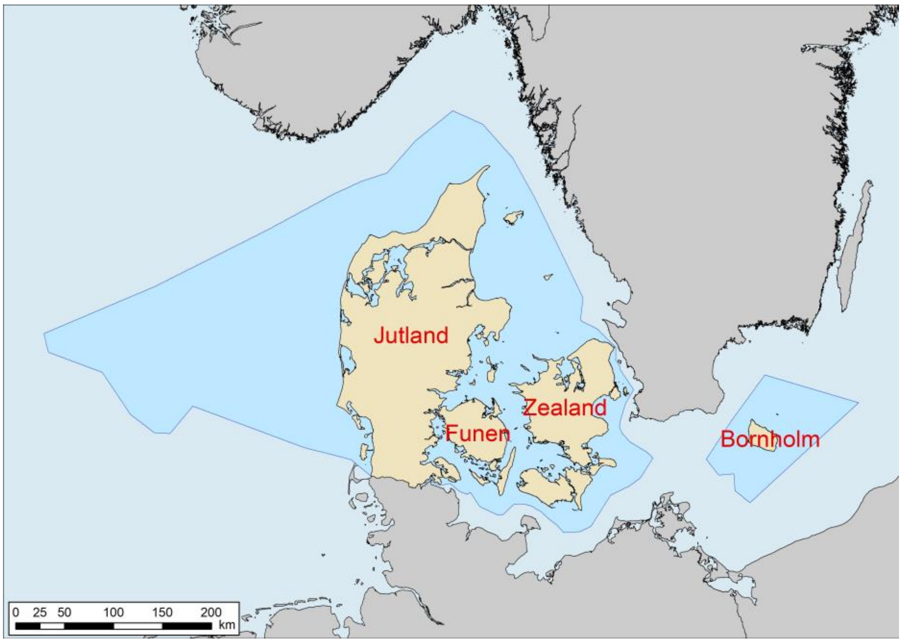


Figure 9.1 Map of Denmark including names of regions and the Exclusive Economic Zone.

9.2.1 The SPREAD model

The distribution in SPREAD is made on SNAP category level to assure the most accurate distribution of the emissions. It has been aimed to use the most disaggregated SNAP level (SNAP 3 level) but for some categories and sectors SNAP 2 or SNAP 1 level has been applied in the distribution model, due to a lack of detailed geographical information. An exception is the agricultural sector, as this sector is not treated on SNAP level in the Danish inventory system. Instead the agricultural data processing is carried out for the relevant NFR categories, and the same approach is applied in SPREAD. The SPREAD model is prepared in order to be applicable for the mandatory reporting of gridded emissions under CLRTAP.

Emissions from all Large Point Sources (LPS) are treated separately in SPREAD. LPSs represent emissions at all SNAP 1 categories except solvents (SNAP 06) and road traffic (SNAP 07). Point Sources, for which the fuel consumption is known at plant level but emissions are calculated using standard emission factors, are included as point sources with an exact location in SPREAD.

General methodology

The distribution of emissions in the Danish emission inventory is carried out in an integrated MS SQL and MS Access database system and in the geographical information system (GIS) ArcGIS.

The methodology applied in the part of the distribution carried out in GIS is shortly described in this chapter. The description is made for Non-Metallic Minerals as a case, as this distribution is rather simple.

The emission inventory for Non-Metallic Minerals covers both point sources and area sources. Emissions from point sources are allocated to the coordinates for the individual plants included in the Danish inventory system and are not relevant in relation to the GIS procedure. Emissions from area sources are calculated from production statistics and the resulting emissions are national totals as allocation of the sources (non-metallic minerals plants) is not possible with the available data. Instead a proxy for the distribution is applied, in this case the location of industrial areas as given in the national topographic map KORT10 by the National Survey and Cadastre (Figure 9.2). The map of industrial areas is not reflecting differences in the location for different industries, but only holds industrial buildings (referred to as the industrial area as the buildings are treated as areas rather than units). The map is a shape file and the industrial areas are polygons.

Figure 9.2 Segment around Avedoere (close to Copenhagen) of the map of industrial areas (KORT10).

As SPREAD gives emissions on 1 km x 1 km, the map of industrial areas must be combined with the Danish 1 km x 1 km Grid Net. The grid is an orthogonal coordinate system and the cells are defined and named by their lower left corner coordinates. The grid net map is a shape file and the grid cells are polygons (Figure 9.3).

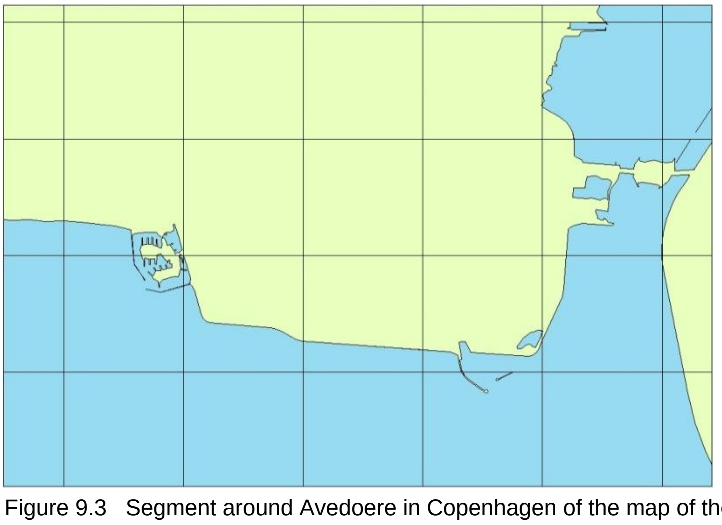


Figure 9.3 Segment around Avedoere in Copenhagen of the map of the Danish 1 km x 1 km grid net (KORT10).

To be able to distribute the emissions on 1 km x 1 km it is necessary to split the industrial polygons between the grid cells and thereby be able to calculate the industrial area in each grid cell (Figure 9.4). These functionalities are available in GIS, in this case ArcMAP. The split is made using the intersect tool, and afterwards the areas are applied to each cell using the Calculate Area function.

Figure 9.4 Segment around Avedoere in Copenhagen of the map of industrial areas and the Danish 1 km x 1 km grid net (KORT10).

The remaining part of the emission distribution for Non-Metallic Minerals is carried out in a database. The share of the national emissions that should be allocated to each grid cell is calculated as the industrial area of the cell divided by the total industrial area. The same distribution key is applied for all pollutants.

In the case of the Non-Metallic Minerals only one map is combined with the grid, but more maps or layers can be combined to make a distribution key. This is the case e.g. for emissions from organic soils in the agricultural sector, where the distribution key is based on a map of organic soils, a map of the agricultural fields and the Danish Grid Net. A number of area sources are distributed on line features, e.g. emissions from railways and road traffic. In these cases the lines are split into segments by intersection with the 1 km x 1 km grid net. The emission in each grid cell is calculated as the national emission multiplied by the length of the line segment(s) in the cell and divided by the total length of the line feature.

For some sources the same distribution key can be applied for more or all years, while other sources demands a separate distribution key for each year. For Non-Metallic Minerals the distribution key can be applied for more years, as the dataset is not available on annual basis. Further, the industrial area does not change much from year to year. In other cases the distribution keys must be set up on annual basis as large changes occur from year to year. This is the case for e.g. agricultural soils and plants with annual emissions data and or fuel consumption data in the energy sector and the industrial sector.

National geographical data

A large number of national geographical data sets are implemented in the SPREAD model in preparation of the various distribution keys. The data sets are listed in Table 9.2 with specification of data owner and a short description of the content of each data set.

Table 9.2 Non-exhaustive list of geographic data applied in the emission gridding.

Data owner	Data set	Contents
The National Survey and Cadastre	Topographic map	Geo-referenced basic map layers on administrative units, Land cover, territorial borders, coastline and infrastructure.
The National Agency for Enterprise and Construction	Central Dwelling and Building Register (Danish abbreviation BBR)	Geo-referenced information on dwellings and buildings
The Directorate for Food, Fisheries and Agri Business	The Central Husbandry Register (CHR)	Information on stock of livestock at farm level
	The General Agricultural Register (GLR)	Information on agricultural farms and crops on field level
Ministry of food, agriculture and fisheries	The fertilizer and husbandry register (Danish abbreviation GHI)	Information on manure and fertiliser amounts on farm level
	The Land Parcel Identification System (LPIS)	Geo-referenced data on agricultural land parcels, including field IDs for fields located in the parcels
The Central Business Register	Central Business Register (Danish abbreviation CVR)	Geo-referenced information on businesses with a CVR number, e.g. farms
Centre for Integrated Register-based Research (CIRRAU)	The Civil Registration System (Danish abbreviation CPR)	Geo-referenced information on population on address level
The Department of Environmental Science, Aarhus University	National road and traffic database	Geo-referenced traffic load on the Danish road network
The Danish Energy Agency	Energy producer accountings	Geo-referenced information on fuel consumption for district heating and/or power producing plants
	The regional inventory	Regional inventory of energy consumption for heating for oil boilers, natural gas boilers and solid fuel installations on municipality level
	Off-shore oil/gas facilities	Map of oil and gas production facilities in the North Sea
The Danish Chimneysweeper Association	Small combustion appliances (SFL)	Location and types of small combustion appliances in Denmark
DCE - Danish Centre for Environment and Energy	Large Point Sources (LPS)	Geo-referenced information on power plants, large industrial plants and offshore installations
Danish Petroleum association	Service stations	Geo-referenced information on addresses for all Danish service stations
Aarhus University	The Danish land use matrix (LUM)	Geo-referenced data on agricultural areas and forest areas
Energinet.dk	Measurement and regulator stations	Geo-referenced information on location of measurement and regulator stations in the Danish natural gas transmission network
The Danish Forest and Nature Agency	Military training terrain	Geo-referenced information on military training terrains
The Danish Environmental Protection Agency	Information system for waste and recycling (Danish abbreviation ISAG)	Data on waste treatment companies on address level
The Danish Nature Agency	Waste water treatment	Annual BI5 data per waste water treatment plant
Statistics Denmark	Employment statistics	Annual number of employed by region and industry
	Catch statistics	Catch amounts per ICES area/shellfish catch area and per species
The Danish Road Directorate	Road construction projects	Map of larger road construction projects
Danish Fisheries Agency	Catch areas	Shell fish catch areas
International Council for the Exploration of the Sea (ICES)	ICES area	ICES catch areas

9.3 Gridded emission data

In this section selected maps of gridded emissions are presented, all referring to the year 2019 as reported in the March 2021. The selected maps in Figure 9.5 illustrate the emissions included in the national total in the NFR table (all emissions excluding Civil Aviation - Domestic and International Cruise, and International Maritime Navigation). All figures illustrate the sum of all included GNFR sectors. The Danish high resolution gridded emissions are aggregated on the 0.1 degree x 0.1 degree EMEP grid for reporting to CLRTAP. The share of each 1 km x 1 km grid cell located in the relevant EMEP grid cells are calculated and the aggregated emissions are calculated as the weighted sum of emissions in the 1 km x 1 km grid cells intersecting each EMEP grid cell being partial or fully part of the Danish Exclusive Economic Zone, EEZ.

a b c d e f

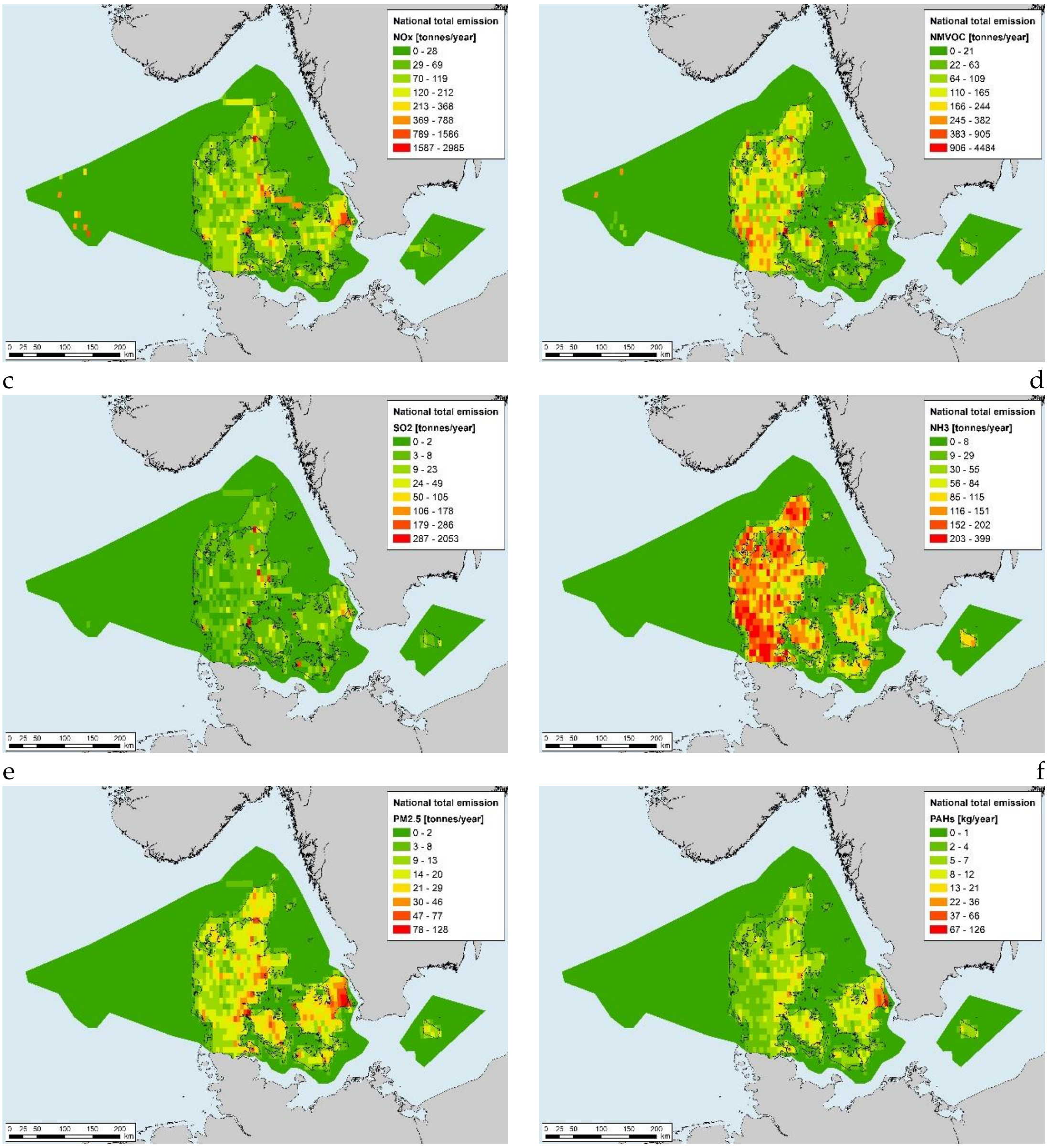


Figure 9.5 National total gridded emissions excluding civil aviation and international navigation of a) NO_x, b) NMVOC, c) SO_2, d) NH_3, e) $PM_{2.5}$ and f) PAHs (the sum of benzo(b)flouranthene, benzo(k)flouranthene, benzo(a)pyrene and indeno(1,2,3-c,d)pyrene) for the year 2019.

On the 0.1 degree x 0.1 degree aggregated level spatial patterns from the major sectors are visible for different pollutants, but the high resolution results in SPREAD provides even more detailed data.

9.3.1 NO_X

The major GNFR source to NO_x emissions is RoadTransport followed by AgriOther, Offroad, Industry and PublicPower contributing 28 %, 19 %, 14 %, 11 % and 11 %, respectively. The pattern of the gridded NO_x emissions reflect the major road network located in the eastern part of Jutland and across Funen and Zealand to Copenhagen (Figure 9.5). The large emission from agricultural soils is causing a large 'background emission' that obscures the spatial pattern somewhat. Further, large emissions from PublicPower and Industry are seen around the major cities. Part of the fugitive emissions is located offshore, due to extraction of oil and gas on the North Sea.

9.3.2 NMVOC

The major source of NMVOC is AgriLivestock followed by Solvents, OtherStationaryComb, Fugitive, AgriOther and RoadTransport contributing 37 %, 24 %, 9%, 7 %, 7 % and 6 %, respectively. Emissions from Solvents, OtherStationaryComb and Offroad are to a large degree allocated according to population density and location of one-storey settlements. Part of the fugitive emissions is located offshore due to extraction of oil and gas on the North Sea.

9.3.3 SO_2

The major sources of SO_2 are Industry and PublicPower followed by Other StationaryComb and Waste contributing 44 %, 20 %, 11 %, and 9 %, respectively. Even though the SO_2 emission has decreased over the years due to implementation of techniques for reduction of sulphur in the flue gas, it still produces a distinct pattern reflecting the location of large power plants in Denmark. The allocation of emissions from Industry reflect the location of a large number of CHP plants not reported as LPS due to no plant specific emission factors. The allocation of emissions from OtherStationaryComb reflects the areas with high population density and mainly one-storey settlements.

For the ferries operating between Copenhagen and Bornholm and routes to Greenland and the Faroe Islands part of the route is outside the Danish EEZ. The emissions from all these ferries are included in Shipping and distributed on the part of the route line located inside the Danish EEZ. This leads to an aggregation of the emissions in few EMEP cells, and thereby artificial high emissions at the part of the route inside the EEZ.

9.3.4 NH_3

The agricultural sector is by far the major contributor to the NH_3 emission. 52% of the national emissions excluding civil aviation and international navigation derive from AgriOther and another 44 % from AgriLivestock. Emission of NH_3 is mainly related to livestock farming and especially to manure management and its application to soil. Emissions are distributed according to very detailed data on animals and fields, and the geographical pattern is in good agreement with the localisation of the major Danish livestock farming in Jutland.

9.3.5 $PM_{2.5}$

The major source of $PM_{2.5}$ emissions is OtherStationaryComb contributing 60 %. RoadTransport is the second largest source contributing 11 % of the $PM_{2.5}$ emission. Emissions from OtherStationaryComb are allocated rather evenly on the land area as a major source is residential wood combustion.

9.3.6 PAHs

Emissions of PAHs are the sum of benzo(b)flouranthene, benzo(k)flouranthene, benzo(a)pyrene and indeno(1,2,3-c,d)pyrene. The major source to emissions of PAHs in Denmark is OtherStationaryComb contributing 81 %. Hereof the all-important source is residential wood combustion. As described for $PM_{2.5}$ the distribution are made on municipality level leading to a rather even distribution on the land area.

9.4 References

EEA, 2019: EMEP/EEA air pollutant emission inventory guidebook - 2019 Available at:
https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (10-01-2023).

Plejdrup, M.S., Nielsen, O.-K., Gyldenkærne, S. & Bruun, H.G. 2021: Spatial high-resolution distribution of emissions to air – SPREAD 3.0. Aarhus University, DCE – Danish Centre for Environment and Energy. In prep.

UNECE, 2015: Guidelines for Reporting Emissions and Projections Data under the Convention on Long-range Transboundary Air Pollution (ECE/EB.AIR/128). Available at:
https://unece.org/fileadmin/DAM/env/documents/2015/AIR/EB/English.pdf (10-01-2023).

10 Large Point Sources

Reporting of large point sources (LPS) is mandatory every four years. The next deadline is 1 May 2025. The information in this chapter is consistent with the data submission made on 1 May 2021.

The Danish emission inventory makes use of point source data, where emissions are available at point source level, either through annual measurements or established plant-specific emission factors. The definition of point sources in the inventory differs from e.g. the PRTR definition. Under PRTR, large pig and poultry producing sites are considered as point sources. However, as these facilities do not have any annual measurements or site-specific measurements, they do not fall within the definition of a point source in the inventory. For that reason, there are no agricultural farms included in the LPS reporting. The data reported under the PRTR is calculated by the emission inventory team and as such the methodology is consistent and the result would not differ, if it were included as LPS.

Another difference between the PRTR reporting and the LPS reporting is for solvent use. The Danish inventory is based on a top-down approach for a number of specific solvents; see Chapter 4 for further information. As companies usually does not disclose the specific solvents used in the production it is not possible to harmonise the inventory methodology with data reported under PRTR. It should also be noted that PRTR reporting only consists of an emission value with no supporting documentation. The specific differences between the datasets are discussed in Chapter 10.4.

10.1 Reported LPS emissions

The Danish LPS inventory consists of many facilities. The general rule of thumb for including a facility as LPS is that plant-specific information should be available so that the emission estimate is more accurate than if the facility was handled as part of a group, i.e. as an area source. In the Danish LPS inventory, all CHP plants with a capacity of more than 25 MW_e are included. The same with all waste incineration plants and refineries. For industrial point sources, there is no fixed definition other than the before mentioned that plant-specific data need to be available and the emissions should not be insignificant. A graphical illustration of the Danish LPS in 2019 (without considering pollutant thresholds) is provided in Figure 10.1.

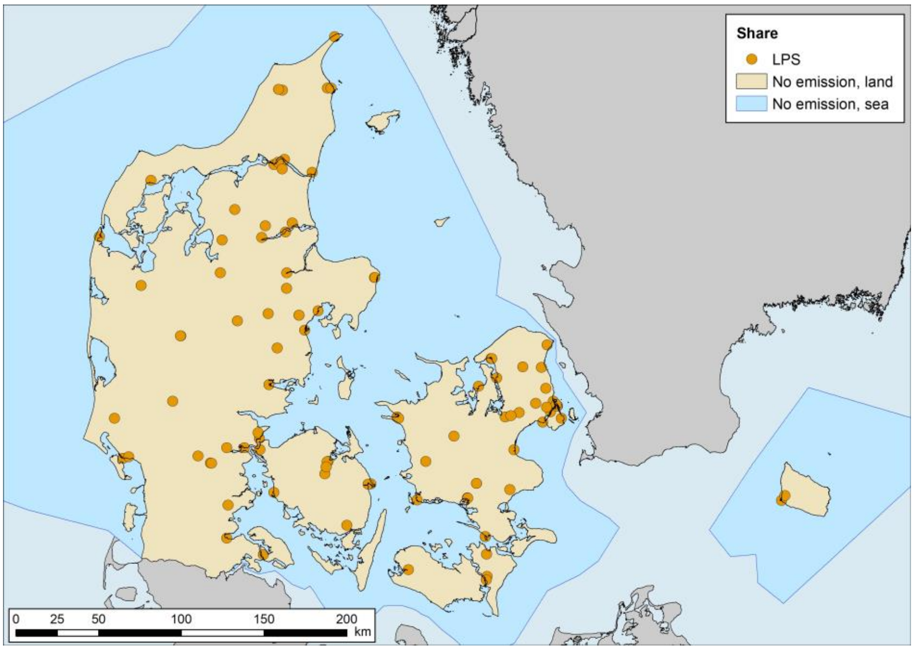


Figure 10.1 Location of Danish LPS in 2019.

In many cases, a LPS consists of multiple parts, e.g. a power plant can have multiple boilers. In some cases, they will have different stacks (and sometimes of different heights) and in other cases the flue gas from multiple boilers are emitted using the same stack, sometimes with separate channels in the stack.

The LPS reporting does not cover the full range of pollutants covered by the inventory as only a subset is required in the reporting guidelines (UNECE, 2014). The pollutants included and the threshold value for reporting is shown in Table 10.1.

Table 10.1 List of pollutants and threshold values.

Pollutant	Threshold (kg/year)
SO_x	150 000
NO_x	100 000
CO	500 000
NMVOCs	100 000
NH_3	10 000
$PM_{2.5}$	50 000
PM_{10}	50 000
Pb	200
Cd	10
Hg	10
PAHs	50
PCDD/F	0.0001
HCB	10
PCBs	0.1

The relatively high threshold values mean that for the majority of pollutants, only very few Danish LPS exceed the threshold values.

Emissions are reported for a LPS, only if the emission exceeds the threshold value listed in Table 10.1. The emission is calculated on a part level. However, the whole plant is considered in the reporting, e.g. in case of a power plant, with three boilers with individual stacks, where the emission for one part exceeds the threshold, but for the other two parts emissions are below all three parts are included in the reporting. If a boiler has a different stack height class then it will be reported even though the emission will be below the threshold.

The number of LPS reported for each pollutant for 2019 are shown in Table 10.2. It is seen that NO_x is the pollutant where most Danish LPS exceeds the threshold. However, for the heavy metals and persistent organic pollutants, there are very few or none LPS exceeding the threshold.

Table 10.2 Number of LPS exceeding the threshold value in 2019.

Pollutant	Number
SO_x	5
NO_x	30
CO	3
NMVOCs	4
NH_3	5
$PM_{2.5}$	0
PM_{10}	2
Pb	3
Cd	1
Hg	0
PAHs	1
PCDD/F	3
HCB	0
PCBs	0

10.2 Consistency with the emission inventory

The underlying purpose of the LPS reporting is to provide improved input for air quality modelling; as such, the reporting of LPS data only makes sense if they are consistent with the emission inventory. In the Danish inventory, the LPS emissions are an integrated part of the national emission inventory. For example, the fuel consumption used in LPS is subtracted from the national energy statistics and the residual fuel amount is considered as area source consumption. In cases where a plant does not report an emission for one year, an emission is calculated using an emission factor to ensure a consistent time-series.

The need for consistency is also, why PRTR emissions are not automatically considered LPS emissions in the inventory.

10.3 Use of LPS data in gridded emissions

The full LPS dataset in the Danish emission database system is used in the spatial distribution of emissions. The thresholds used for LPS reporting are not used and all LPS emissions are considered when gridding emissions. For more information, please see Chapter 9 and Plejdrup et al. (2021).

10.4 Comparison with PRTR data

As mentioned previously, there are a number of important differences between PRTR data and the inventory. This is especially the case for agriculture and solvents, where PRTR includes facilities as point sources that are not considered LPS in the Danish inventory, due to the reasons outlined previously on the consistency with the inventory.

PRTR only includes emissions of PM_{10} and not $PM_{2.5}$, while there is a reporting requirement for LPS emissions of both.

The data used for comparison with the inventory data are collected from a website hosted by the Danish Environmental Protection Agency (DEPA, 2021). The data used were correct as of 1 January 2021.

Some specific examples on facilities reporting emissions above the threshold in the PRTR, yet are not included in the Danish LPS inventory or reporting are provided in Table 10.3 with the reason for the exclusion.

Table 10.3 List of PRTR facilities not included in the LPS reporting.

Facility	Pollutant	Reason
Novo Nordisk A/S	NMVOC	The emission relates to use of solvents. This is not compatible with the Danish emission inventory methodology.
AarhusKarlshamn Denmark A/S	NMVOC	The emission relates to use of solvents. This is not compatible with the Danish emission inventory methodology.
AMCOR FLEXIBLES HORSENS	NMVOC	The emission relates to use of solvents. This is not compatible with the Danish emission inventory methodology.

In addition to the mentioned facilities in Table 10.3, all agricultural facilities are excluded, as they are not considered as point sources in the inventory.

10.5 References

DEPA, 2021: Miljøoplysninger (Environmental information). Website of the Danish EPA collecting environmental reporting from companies used for the PRTR reporting. Available at: https://miljoeoplysninger.mst.dk/PrtrPublicering/Index

Plejdrup, M.S., Nielsen, O.-K., Gyldenkærne, S. & Bruun, H.G. 2021: Spatial high-resolution distribution of emissions to air – SPREAD 3.0. Aarhus University, DCE – Danish Centre for Environment and Energy, 186 pp. Scientific Report from DCE – Danish Centre for Environment and Energy. (In press).

UNECE, 2014: Guidelines for Reporting Emissions and Projections Data under the Convention on Long-range Transboundary Air Pollution. ECE/EB.AIR/125. Available at:
http://www.unece.org/fileadmin/DAM/env/documents/2013/air/eb/ece.eb.air.125_E_ODS.pdf

11 Projections

Projections of emissions are carried out by DCE periodically. The most recent projection was made in 2022, projecting the emissions of NO_x, SO_2, NMVOC, NH_3, TSP, PM_{10}, $PM_{2.5}$ and BC to 2040. This projection is reported to the EU and UNECE on 15 March 2023. This projection was based on the historic inventory until 2020 reported to the EU and UNECE on 15 February 2022. The projections therefore do not reflect recalculations in the historic emissions as reported in this report.

Major recalculations have occurred for NO_x from road transport, NMVOC emissions from fugitive emissions and NH_3 from agriculture. These recalculations will have an impact on the projections when the projections are updated, expectedly in 2024.

The total projected emissions for these pollutants for 2025, 2030, 2035 and 2040 are shown in the table below together with the historic emissions for 2005 and 2020 (as reported in 2022). The general methodology is based on the methodologies used in the emission inventory as documented in this report.

Table 11.1 2005 and 2020 emissions and projected emissions for 2025, 2030, 2035 and 2040, tonnes.

Pollutant	2005	2020	2025	2030	2035	2040
SO_2	26293	9145	8917	8094	7467	7019
NO_x	201517	89025	79427	63186	52864	47041
NO_x*	183768	69403	61980	46045	35851	30155
NMVOC	154607	106584	106694	106031	103585	100719
NMVOC*	111538	60393	59295	56270	54015	51475
NMVOC**	134554	82633	81398	78839	76389	73649
NH_3	92554	76254	69337	66300	62813	59498
$PM_{2.5}$	21522	12310	11173	9523	8368	7153
BC	3969	1876	1540	1217	1020	840

* Excluding manure management and agricultural soils.

** Including adjustment for dairy cattle.

The detailed results of the projection are available online at:
https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/air-pollutants/projection/

11.1 Trend by Pollutant

11.1.1 Nitrogen oxides, NO_x

The largest sources of NO_x are road transport, agriculture, energy industries and non-road mobile machinery in agriculture and fishing, accounting for 25 %, 22 %, 15 % and 11 % of the NO_x emission in 2020, respectively.

The NO_x emission is expected to decrease by 29 % from 2020 to 2030 and by 47 % from 2020 to 2040. The decrease is mainly related to road transport and other mobile sources due to the introduction of stricter demands at EU level (new EURO norms).

NO_x emissions from manure management and agricultural soils are not part of the reduction commitment under the revised NEC Directive. This is due to the fact that methodologies were only recently included in the EMEP/EEA Guidebook, that the emissions from mineral fertiliser are very high and that this source was not included at the time when the reduction commitments were established.

Compared to 2005, the emission is projected to be 68.6 % lower in 2030, but 74.9 % lower when excluding emissions from animal husbandry, manure management and agricultural soils.

11.1.2 Sulphur dioxide, SO_2

The largest sources of SO_2 emissions are manufacturing industries and energy industries accounting for 29 % and 23 % respectively of the national SO_2 emission in 2020.

The SO_2 emission is expected to decrease by 11.5 % from 2020 to 2030 and by 23.2 % from 2020 to 2040. The emissions are projected to decrease mainly from combustion in power plants, district heating plants and non-industrial plants. This decrease is due to decreased overall fuel consumption.

Compared to 2005, the emission is projected to be 69.2 % lower in 2030.

11.1.3 Non methane volatile organic compounds, NMVOC

The largest sources of emissions of NMVOC are agriculture followed by industrial processes, small combustion, fugitive emissions from fuels and transport. These sources account for 43 %, 31 %, 11 %, 7 % and 6 %, respectively, of the total NMVOC emission in 2020.

The NMVOC emission is expected to decrease by 0.5 % from 2020 to 2030 and by 5.5 % from 2020 to 2040. The largest decrease in emission is expected for residential plants but substantial decreases in emissions are also expected for road transport, other mobile sources and industrial processes. Emissions from agriculture are projected to increase.

NMVOC emissions from manure management and agricultural soils are not part of the reduction commitment under the revised NEC Directive. This is due to the fact that methodologies were only recently included in the EMEP/EEA Guidebook, that the emissions from animal husbandry and manure management are very high and that this source was not included at the time when the reduction commitments were established.

Under the UNECE, Denmark has an accepted adjustment for dairy cattle based on this being a new source.

Compared to 2005, the emission is projected to be 31.4 % lower in 2030, but 49.6 % lower when excluding emissions from animal husbandry, manure management and agricultural soils. The corresponding reduction including the effect of the adjustment is 41.4 %.

11.1.4 Ammonia (NH_3)

The dominant source of emissions of NH_3 is agriculture accounting for about 95 % of the total emission. The remaining 5 % is mainly emissions from small combustion, transport and composting. The largest sources are animal manure applied to soils followed by swine, mineral fertiliser, dairy cattle and crops. These sources account for 26 %, 19 %, 16 %, 10 % and 7 %, respectively, of the total NH_3 emission in 2020.

The NH_3 emission is expected to decrease by 13.1 % from 2020 to 2030 and by 22.0 % from 2020 to 2040. The largest decrease in emission is expected for manure management especially swine mainly due to implementation of emission reducing technology in the animal housing systems.

Additionally, all mink in Denmark were culled towards the end of 2020 due to fear of COVID-19 mutations and the keeping of mink was banned in 2021 and 2022. It must therefore be assumed that mink production will not resume the same scale and emissions and therefore will be significantly lower from 2023 onwards.

Compared to 2005, the emission is projected to be 28.4 % lower in 2030.

11.1.5 Particulate matter with diameter less than 2.5 µm - PM2.5

The single major source of the $PM_{2.5}$ emission is non-industrial combustion, mainly wood combustion in residential plants, which accounted for 51% of the national $PM_{2.5}$ emission in 2020. Other important sources are road transport, agriculture and other mobile sources with 10 %, 10 % and 8 %, respectively.

The $PM_{2.5}$ emission is expected to decrease by 22.6 % from 2020 to 2030 and by 41.9 % from 2020 to 2040. The emission reduction is mainly due to a decreasing emission from residential plants caused by the continued phase-in of new technologies with lower emissions.

Compared to 2005, the emission is projected to be 55.8 % lower in 2030.

11.1.6 Black carbon, BC

The single major source of the BC emission is small-scale combustion, mainly biomass combustion in residential and agricultural plants, which accounted for 52 % of the national BC emission in 2020. Other important sources are transport and agricultural machinery with 21 % and 10 %, respectively.

The BC emission is expected to decrease by 35.1 % from 2020 to 2030 and by 55.2 % from 2020 to 2040. The emission reduction is mainly due to decreasing emissions from transport and other mobile sources, due to lower emission limit values for particulate matter and residential plants due to decreased wood consumption.

11.2 Stationary combustion

Annual emissions are available for the years until 2020, while the presented emissions for other years are projections.

The combustion of fossil fuels is one of the most important sources of emission of SO_2, NO_x, NMVOC and PM. This chapter covers all sectors, which use fuels for energy production, with the exception of mobile combustion. Table 11.2.1 shows the sector categories used and the relevant classification.

Table 11.2.1 Sectors included in stationary combustion.

Sector	NFR	SNAP
Public power	1A1a	0101
District heating plants	1A1a	0102
Petroleum refining plants	1A1b	0103
Oil/gas extraction	1A1c	0105
Commercial and institutional plants	1A4a	0201
Residential plants	1A4b	0202
Plants in agriculture, forestry and aquaculture	1A4c	0203
Combustion in industrial plants	1A2	03

In Denmark, all waste incineration is utilised for heat and power production. Thus, incineration of waste is included as stationary combustion in the NFR Energy sector (source categories *1A1*, *1A2* and *1A4)*.

11.2.1 Methodology

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

The methodology for emission projections is, just as the Danish emission inventory for stationary combustion plants, based on the CORINAIR system described in the EMEP/CORINAIR Guidebook (EMEP-/CORINAIR, 2002). The projections are based on official activity rates forecast from the Danish Energy Agency (DEA) and on emission factors that are either emission factors for 2018 or projected emission factors for different fuels, plants and sectors. For each of the fuels and categories (sector and e.g. type of plant), a set of general emission factors has been determined. References for the 2020 emission factors are included in Chapter 3.2 and annex 3A and the projected emission factors that differ from the historic emission factors are discussed in Chapter 11.2.5.

Some of the large plants, such as power plants and waste incineration plants are registered individually as large point sources. Projected data for fuel consumption and emission are included for these plants. Projected fuel consumption refers to RAMSES, which is a plant specific projection of fuel consumptions estimated by the DEA as part of the energy projection. Projected plant specific emission factors are either based on 2020 emission data from annual environmental reports/PRTR data or projected emission factors provided by plant owners.

11.2.2 Model description

The software used for the energy model is Microsoft Access 2013, which is a Relational Database Management System (RDBMS) for creating databases. The database is called the 'Projection 2021-2040' and the overall construction of the database is shown in Figure 3.1 and Figure 3.2.

The model consists of input data collected in tables containing fuel consumption and emission factors for combustion plants larger than 25 MW_e and combustion plants smaller than 25 MW_e. 'Area' and 'Point' in the model refer to small and large combustion plants, respectively. In Table 11.2.2, the names and the content of the tables are listed.

Table 11.2.2 Tables in the 'Projection 2021-2040' database.

Name	Content
tblEmfArea	Emission factors for small combustion plants
tblActArea	Fuel consumption for small combustion plants
tblEmfPoint	Emission factors for large combustion plants
tblActPoint	Fuel consumption for large combustion plants

From the data in these tables, a number of calculations and unions are created by means of queries. The names and the functions of the queries used for calculating the total emissions are shown in Table 11.2.3.

Table 11.2.3 Queries for calculating the total emissions.

Name	Function
EmissionArea	Calculation of the emissions from small combustion plants.
	Input: tblActArea and tblEmfArea
EmissionPoint	Calculation of the emissions from large combustion plants.
	Input: tblActPoint and tblEmfPoint
EmissionAll	Union of EmissionArea and EmissionPoint

Based on some of the queries a number of summation queries are available in the 'Projection 2021-2040' database. Output from the summation queries is in the form of Excel Pivot tables.

Table 11.2.4 Summation queries.

Name	Output
xlsBrændselsforbrug fordelt på snap_Crosstab	Query containing total fuel consumptions for SNAP groups and years
xlsBrændselsforbrug fordelt på fuel_Crosstab	Query containing fuel consumptions for each fuel and years
xls_Brændselsforbrug fordelt på fuel punkt-kilder_Crosstab	Query containing fuel consumptions for large combustion plants for each fuel and years
xlsEmissionAll	Query containing emissions for SNAP groups, pollutants and years
xlsEmissionArea	Query containing emissions for small combustion plants for SNAP groups, years and pollutants
xlsEmissionPoint	Query containing emissions for large combustion plants for SNAP groups, years and pollutants

All the tables and queries are connected and changes in one or more of the parameters in the tables result in changes in the output tables.

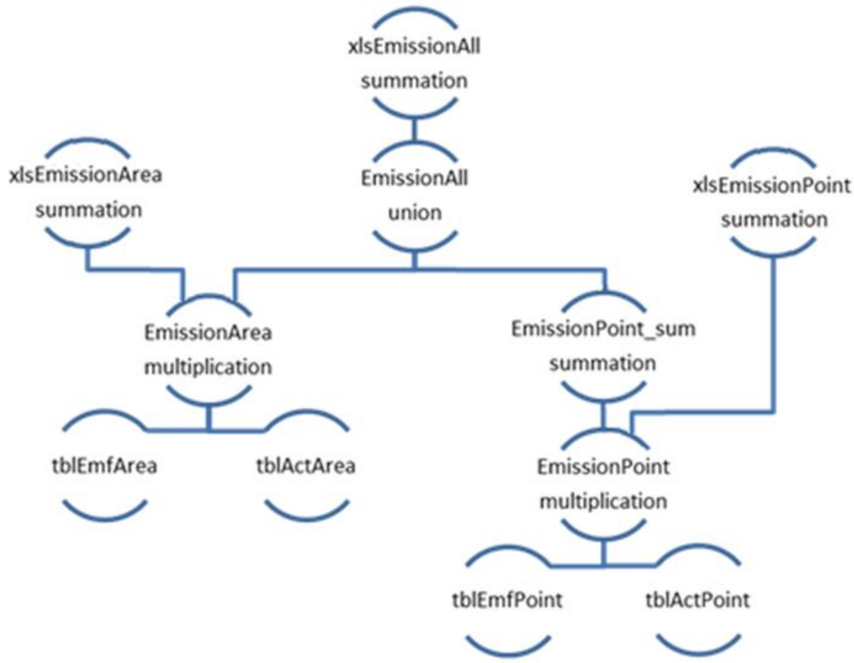


Figure 11.2.1 Overall construction of the database and calculation of emissions.

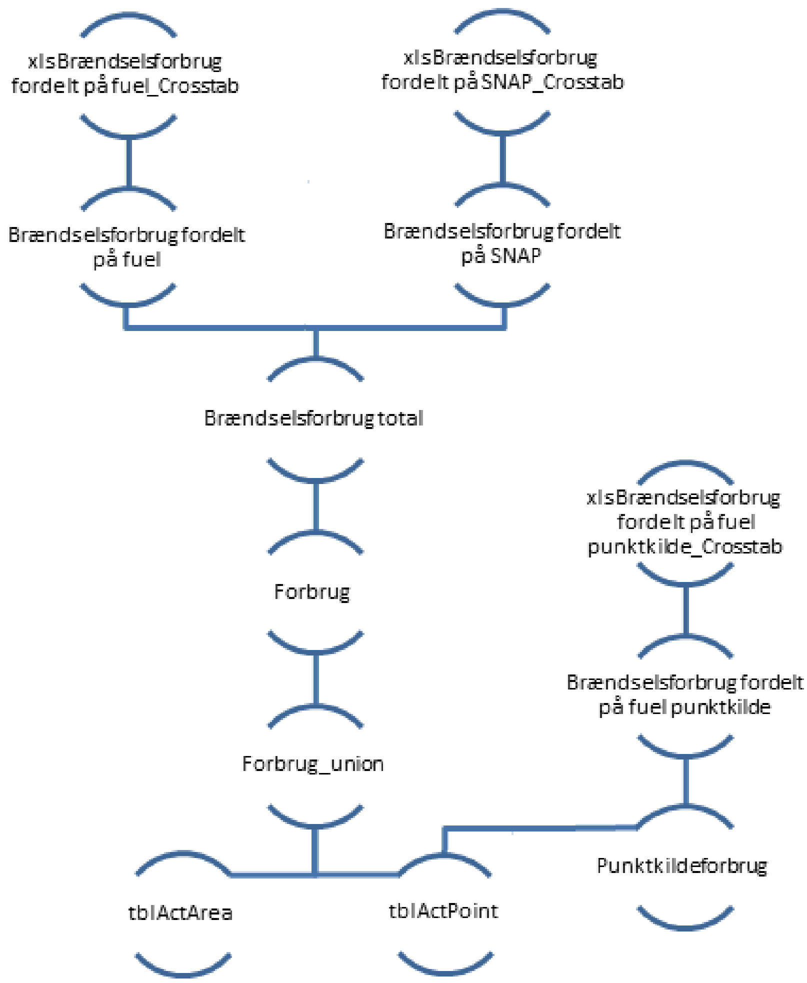


Figure 11.2.2 Overall construction of the database and calculation of fuel consumptions.

11.2.3 Activity data

The fuel consumption data in the model are based on the general projection of the energy consumption by the Danish Energy Agency (DEA, 2022a).

Fuel consumption data distributed according to fuel types is shown in Table 11.2.5 and Figure 11.2.3.

The most important fuel is wood and wood pellets followed by natural gas in the first years of the projection period. It can also be seen that coal is significantly reduced to a very low level.

The projection of the future energy consumption is highly dependent on the development in fuel prices as well as structural changes in the Nordic electricity market.

Table 11.2.5 Fuel consumption for stationary combustion, TJ.

	2021	2025	2030	2035	2040
Natural gas	78879	69661	32790	19374	10843
Wood and simil.	77814	82757	73186	74374	60216
Wood pellets	84468	57460	41240	25359	24635
Biogas	10698	11053	11713	5267	2367
Municipal waste - biogenic	24697	24578	22783	23148	23551
Steam Coal	41556	8975	2196	1597	1508
Fossil waste	21022	19640	9739	8568	7540
Refinery gas	16724	16724	16722	16721	16722
Gas oil	6954	3069	1476	1035	1209
Bio Natural gas	19747	29120	40956	38841	37821
Petroleum coke	7600	6285	5881	5140	4293
Agricultural waste	22239	19806	17023	15808	13115
Residual oil	2547	1637	889	646	570
LPG	2146	1801	1135	825	741
Kerosene	41	21	12	9	10
Total	417134	352586	277741	236714	205140

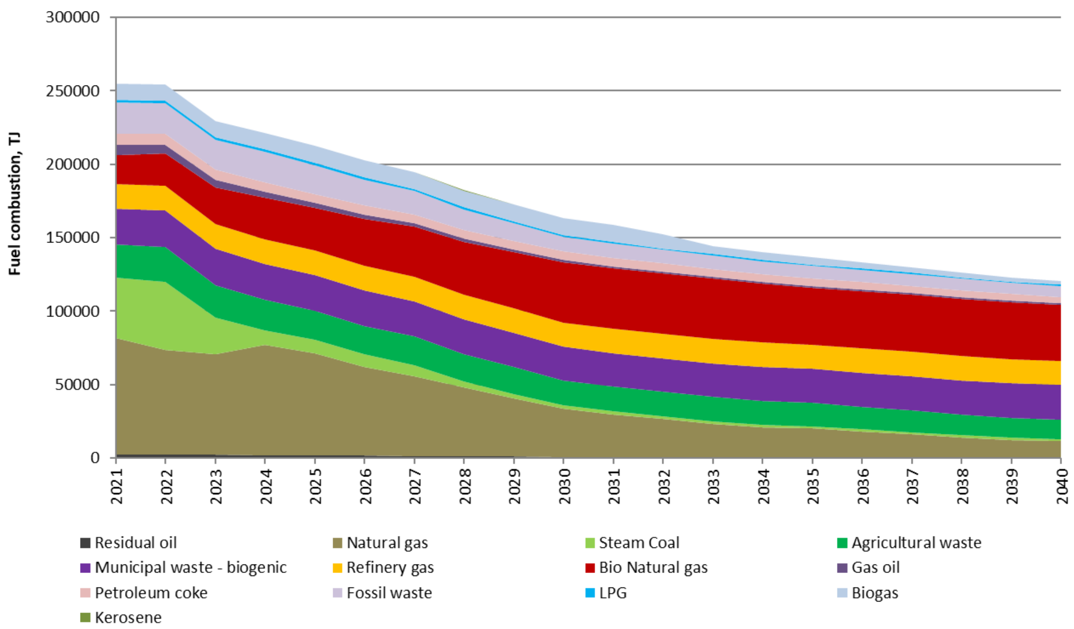


Figure 11.2.3 Fuel consumption distributed according to fuel type.

The sectors consuming the most fuel are public power, residential plants, manufacturing industries, off-shore and district heating.

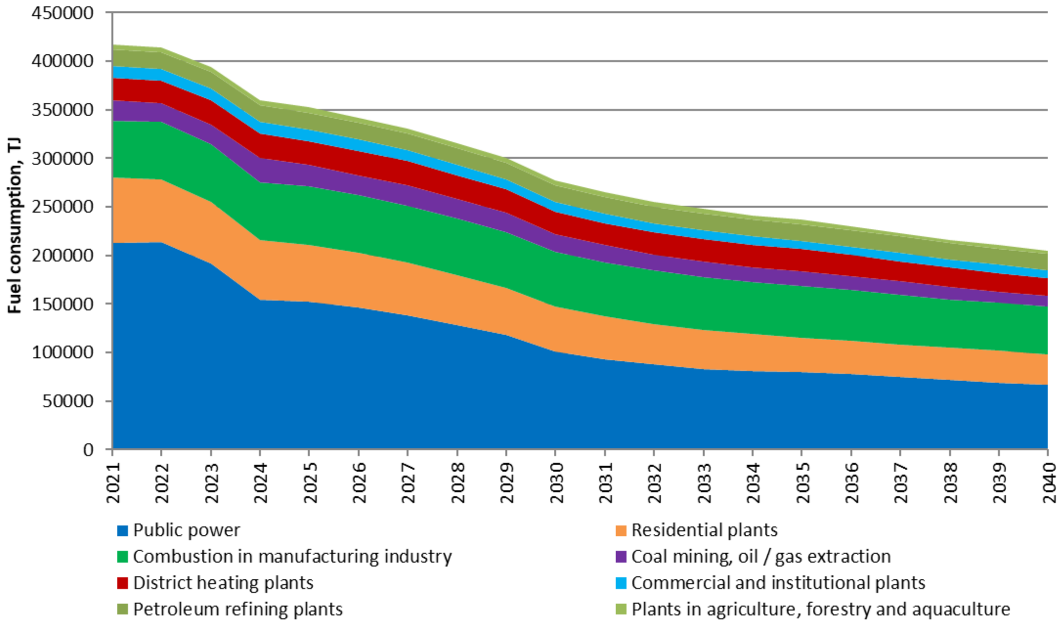


Figure 11.2.4 Fuel consumption distributed by sector.

For a description of the models used in the energy projections, please refer to the Danish Energy Agency (DEA, 2022b).

11.2.4 Emission factors

The emission factors are assumed equal to the emission factors applied for 2020 in the latest emission inventory (Nielsen et al., 2022). The projection of the energy consumption is not disaggregated to technologies, and thus in some cases, the emission factors have been aggregated based on the technology distribution in 2020.

For residential wood combustion, the same emission factors have been applied for each technology. However, a time series have been estimated for implementation of new boilers and stoves, see Chapter 3.2.

In addition, the projected emission factors take into account:

- The decreasing NO_x emission factor for small gas boilers < 120 kW (Schweitzer & Kristensen, 2014)
- The decreasing NO_x emission factor gas boilers above 120 kW (Schweitzer & Kristensen, 2015)
- Decreasing emission factors for TSP, PM_{10}, $PM_{2.5}$ and BC based on new legislation for straw combustion (Brændeovnsbekendtgørelsen[1], 2022)
- Revised PM emission factors for wood and wood pellets applied in power plants
- Plant specific emission data for cement production in 2020.

[1] Bekendtgørelse om regulering af luftforurening fra fyringsanlæg til fast brændsel under 1 MW, Bekendtgørelse 199 af 04-02-2022

11.2.5 Emissions

NO_x

The estimated NO_x emissions are shown in Figure 11.2.6.

The total NO_x emission decreases slowly throughout the time-series following closely the overall fuel consumption. The increase in 2023/2024 is driven by an increase in emissions from gas extraction, due to the restart of one gas field after renovation in the North Sea and hence lower production in preceding years.

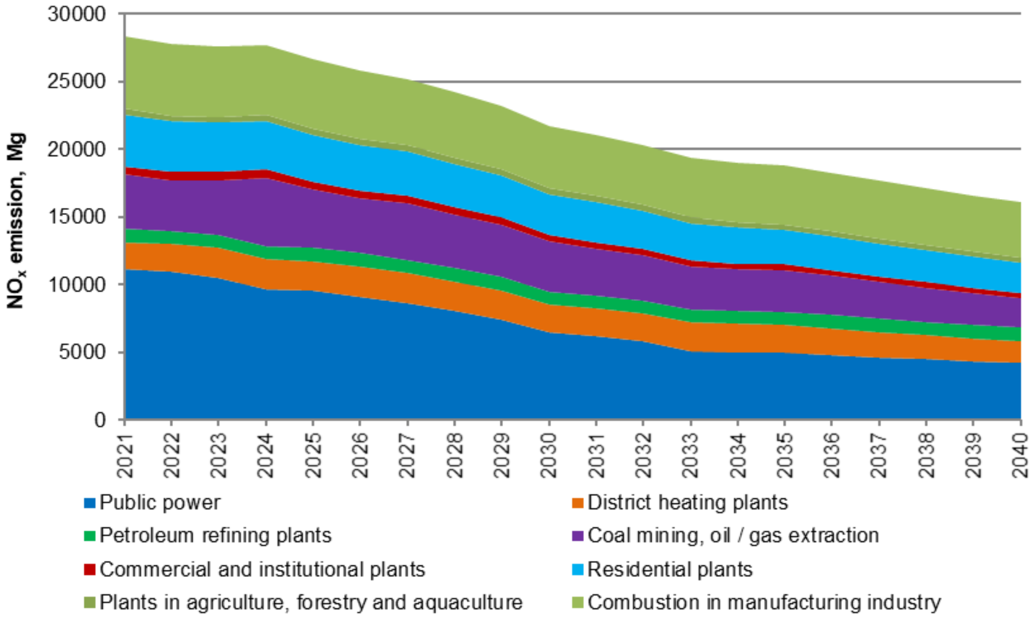


Figure 11.2.6 Projected NO_X emissions by sector.

SO_2

The estimated SO_2 emission is shown in Figure 11.2.7.

The total SO_2 emission decreases slightly throughout the projection period due to lower fuel consumption, e.g. for coal and residual oil.

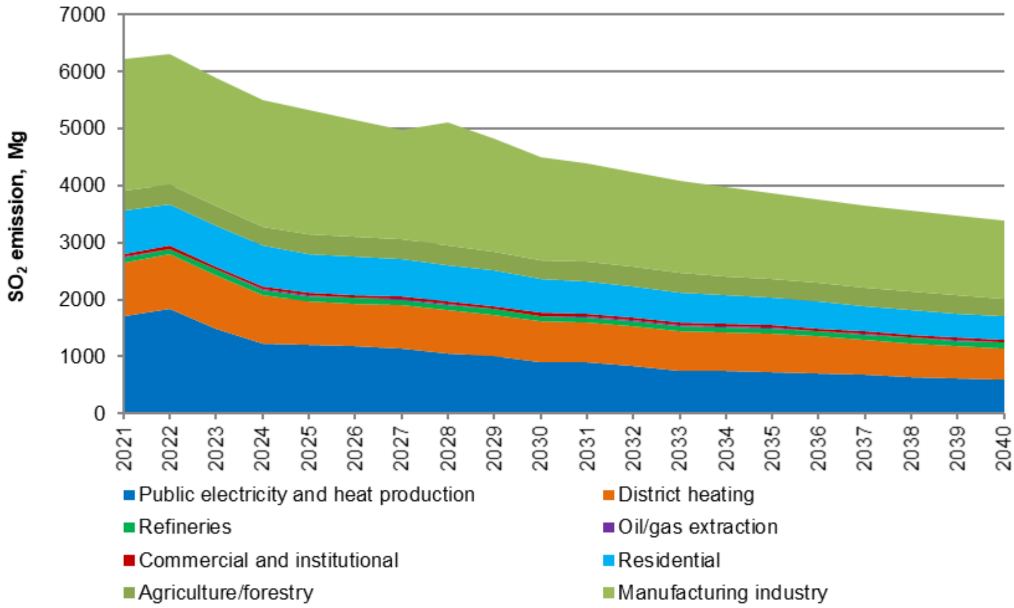


Figure 11.2.7 Projected SO_2 emissions by sector.

NMVOC

The estimated NMVOC emission is shown in Figure 11.2.8.

From 2021 to 2040, the NMVOC emission is projected to decrease due to a lower emission from wood combustion in residential plants. This is due to the replacement of old wood stoves and boilers with new technologies that have considerably lower emissions. The residential sector will account for between 48 % and 69 % of the total NMVOC emission from stationary combustion plants, with the higher share being in the early part of the projection period.

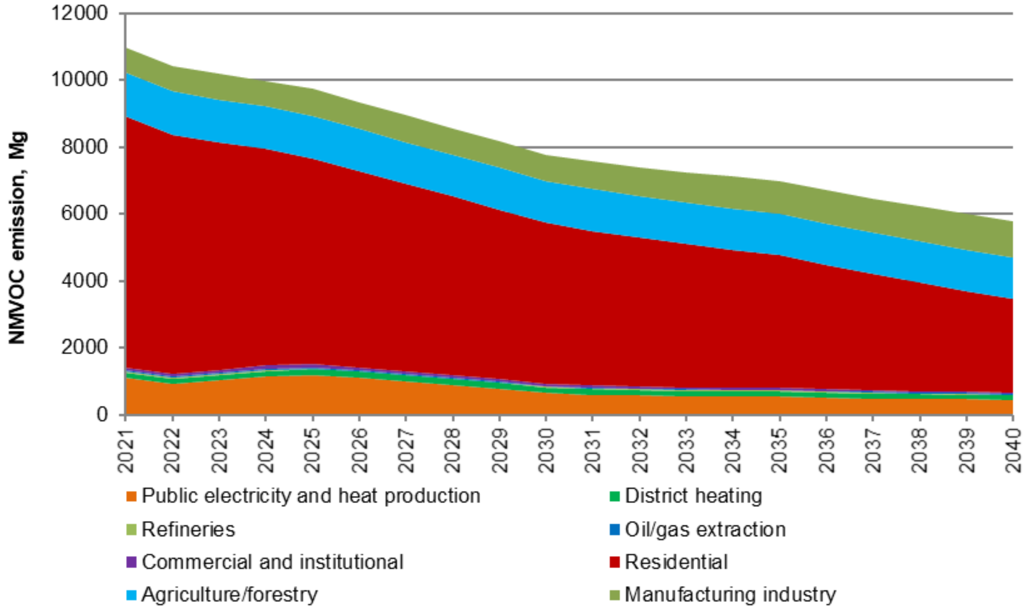


Figure 11.2.8 Projected NMVOC emissions by sectors.

$PM_{2.5}$

The estimated $PM_{2.5}$ emissions are shown in Figure 11.2.9.

The $PM_{2.5}$ emission has increased in the historic years (until 2007) due to increasing wood combustion in residential plants. However, from 2021 to 2040 the $PM_{2.5}$ emission is expected to decrease due to lower emissions from wood combustion in residential plants. This is due to the replacement of old wood stoves and boilers with new technologies that have considerably lower emissions. The residential sector will account for between 73 % and 79 % of the total $PM_{2.5}$ emission from stationary combustion plants in the period 2021-2040 with the share being highest in the beginning of the period.

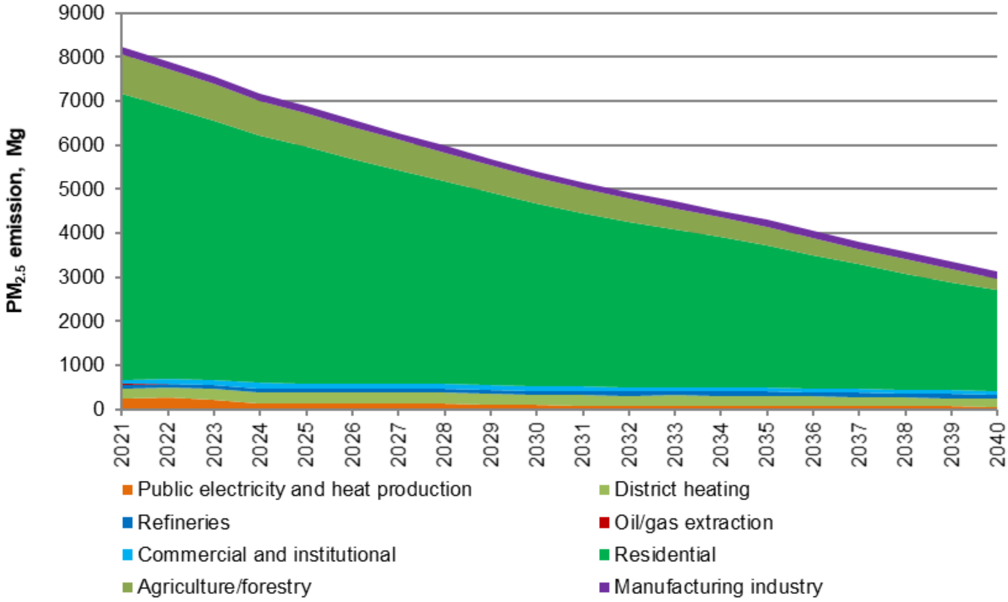


Figure 11.2.9 Projected $PM_{2.5}$ emissions by sector.

Black Carbon

The estimated black carbon (BC) emissions are shown in Figure 11.2.10.

The BC emission has increased in the historic years due to increasing wood combustion in residential plants. However, from 2021 to 2040 the BC emission is expected to decrease due to lower emissions from wood combustion in residential plants. The residential sector will account for around 69 % for the entire projection period.

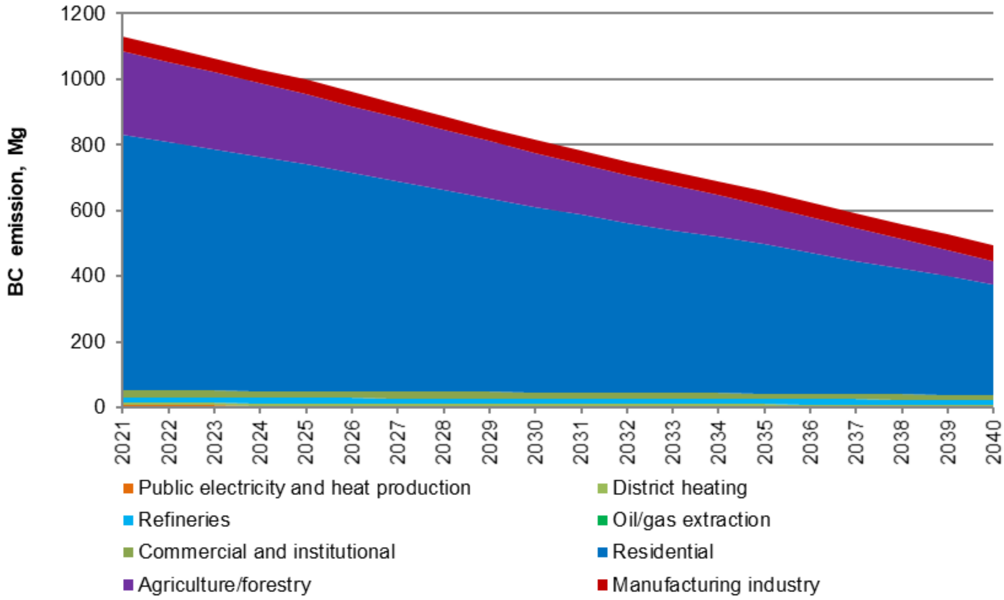


Figure 11.2.10 Projected BC emissions by sector.

11.2.6 References

DEA, 2022a: Projection of national energy consumption. May 2022.

DEA, 2022b: Denmark's Energy and Climate Outlook 2022. Baseline Scenario Projection Towards 2030 With Existing Measures (Frozen Policy). Available at: https://ens.dk/service/fremskrivninger-analyser-modeller/klimastatus-og-fremskrivning-2023 (23-02-2023). (In Danish)

Brændeovnsbekendtgørelsen, 2022: Bekendtgørelse om regulering af luftforurening fra fyringsanlæg til fast brændsel under 1 MW, Bekendtgørelse 199 af 04/02/2022

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., Stupak, I., Scott-Bentsen, N., Rasmussen, E., Petersen, S.B., Baunbæk, L., & Hansen, M.G. 2022. Denmark's National Inventory Report 2022. Emission Inventories 1990-2020 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Aarhus University, DCE – Danish Centre for Environment and Energy, 969 pp. Scientific Report No. 494. Available at: http://dce2.au.dk/pub/SR494.pdf

Schweitzer & Kristensen, 2014: Evaluation of the NO_x emissions of the Danish population of gas boilers below 120 kW, Project report, October 2014, DGC.

Schweitzer & Kristensen, 2015: Evaluation of the NO_x emissions of the Danish population of gas boilers above 120 kW, Project report, October 2015, DGC.

11.3 Mobile combustion

The emission projections for road transport and other mobile sources include the emissions of SO_2, NO_x, NMVOC, $PM_{2.5}$ and BC.

The projections are regularly updated in national emission forecast projects carried out by DCE at Aarhus University on behalf of the Ministry of Environment of Denmark.

The most recent emission projections being described in this chapter was made in February 2022. Hence the latter projections uses the historical year 2020 as a basis for the forecasted input data; e.g. fleet and mileage for road transport, stock composition for non-road machinery, aircraft types and specific ferries in use, and fuel consumption forecasted by the Danish Energy Agency (DEA, 2022).

11.3.1 Methodology

Road transport

For road transport, the detailed COPERT 5 methodology from EMEP/EEA (2019) is used to calculate the annual emission inventories and projections. The methodology include fuel consumption and emissions 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. A thorough description of the COPERT 5 calculation methodology is given in paragraph 3.3.2.

The calculated fuel consumption in COPERT 5 must equal the projected fuel sale totals according to the UNFCCC and UNECE emissions reporting format. The projected fuel sales for road transport comes from the Danish energy projections provided by DEA (2022). A thorough description of the fuel balance calculation is given in paragraph 3.3.2.

Air traffic

DCE annually splits the historical jet fuel sales from DEA into landing and take-off (LTOs < 3000 ft) and cruise (> 3000 ft) for domestic and international flights. The fuel split is made based on the number of flights per aircraft type, origin and destination airport, representative aircraft types and corresponding fuel consumption factors.

The fuel split for the latest historical year (2020) is used to split the forecasted total jet fuel sales by DEA in the projection years into LTO (national total) and cruise (international total) as prescribed by the UNECE inventory reporting rules. The latest historical year is used as key for the fuel split due to lack of specific prognosis data for flight traffic.

Fuel related emission factors for LTO and cruise for the latest historical year are also derived from the DCE model, and subsequently the emissions for national aviation (LTO) and international aviation (cruise) are calculated in each case as the product of the forecasted fuel consumption and the fuel related emission factors.

A thorough description of the DCE aircraft emission model, historical flight activity data, representative aircraft types and fuel consumption and emission factors is given in paragraph 3.3.3.

Non-road working machinery and recreational craft

The DCE non road model estimates the fuel consumption and emissions for non road machinery in agriculture, forestry, industry, commercial/institutionnal and residential as well as recreational craft. The fuel consumption and emissions are calculated in the model as the product of the number of engines, annual working hours, average rated engine size, load factors and fuel consumption/emission factors per engine size class and emission level.

For the most important types of non road equipment the machinery stock is projected in the model by assuming that annual machinery new sales in the forecast years equals the average of the later historical year’s new sales, and by using machinery scrappage curves as a function of engine age.

For diesel and gasoline engines, the deterioration effects (due to engine ageing) are included in the emission calculation equation by using deterioration factors according to engine type, size, age, lifetime, and emission level. For diesel engines before Stage IIIB, IV and V, transient operational effects are also taken into consideration by using average transient factors. For more details regarding the calculation procedure please refer to paragraph 3.3.3.

A thorough description of the machinery types in the model, engine load factors, annual working hours and fuel consumption and emission factors are given in paragraph 3.3.3.

The total bottom-up estimated gasoline consumption for non road machinery is subtracted from the DEA forecast total for road transport, in order to maintain the national fuel balance (see also paragraph 3.3.3).

The bottom-up estimated diesel consumption for recreational craft is subtracted from DEA forecast total for fisheries, in order to maintain the national fuel balance (see also paragraph 3.3.3).

National sea transport and fisheries

For Danish ferries, fuel consumption and emissions are calculated as the product of the number of round trips, sailing time per round trip, engine size, load factor, and fuel consumption/emission factors. The ferry traffic (number of round trips per ferry route) remain unchanged in the projections due to lack of forecast data for ferry traffic. For each ferry, engine replacement is assumed to occur every 30 year, thus enabling the selection of engine build year specific fuel consumption and emission factors as input for the emission projection calculations.

The fuel consumption for other national sea transport is calculated per fuel type as the total fuel consumption from the DEA forecast minus the bottom-up estimated fuel consumption for ferries. The emission factors per fuel type for other national sea transport is selected as a rolling 30 year-average (average engine life time) in the individual forecast years.

The diesel consumption for fisheries is found as the total fuel consumption from the DEA forecast minus the bottom-up estimated diesel consumption for recreational craft. For fisheries, fuel consumption and emissions are calculated for each fishing trip as the product of vessel engine size, engine load factor, hours at sea and fuel consumption/emission factors. In order to account for all fuel sold, the bottom up calculated fuel consumption and emission results in the model are scaled with the ratio between fuel sales and model based bottom up fuel consumption.

Please refer to paragraph 3.3.3 for more details regarding the calculations for national sea transport and fisheries.

Railways

The emissions from railways are calculated as the product of average fuel-related emission factors for the future railway machinery provided by Danish Railways (Mølgård, 2021) and total fuel consumption from the DEA energy forecast (see also paragraph 3.3.3).

Military

The emissions from military equipment is calculated in each forecast year as the product of fuel consumption and fuel related emission factors. For land based equipment (gasoline and diesel) average fuel based emission factors derived from road transport results is used, whereas for jet fuel the emission factors comes from EMEP/EEA (2019), see also paragraph 3.3.3.

11.3.2 Activity data

Road transport

Corresponding to the COPERT fleet classification, all present and future vehicles in the Danish traffic fleet are grouped into vehicle classes, sub-classes and layers, as explained in paragraph 3.3.2. For each vehicle sub-class and first registration year, fleet and annual mileage projection data are provided by DTU Transport (Jensen, 2022).

The trends in vehicle numbers and total mileages per EU layer are shown in the Figures 11.3.1 and 11.3.2 for the 2022-2040 periods. The latter figure clearly shows how vehicles complying with the gradually stricter EU emission levels (EURO 5/V, Euro 6/VI, Euro 6d-TEMP and Euro 6d) are introduced into the Danish motor fleet in the forecast period.

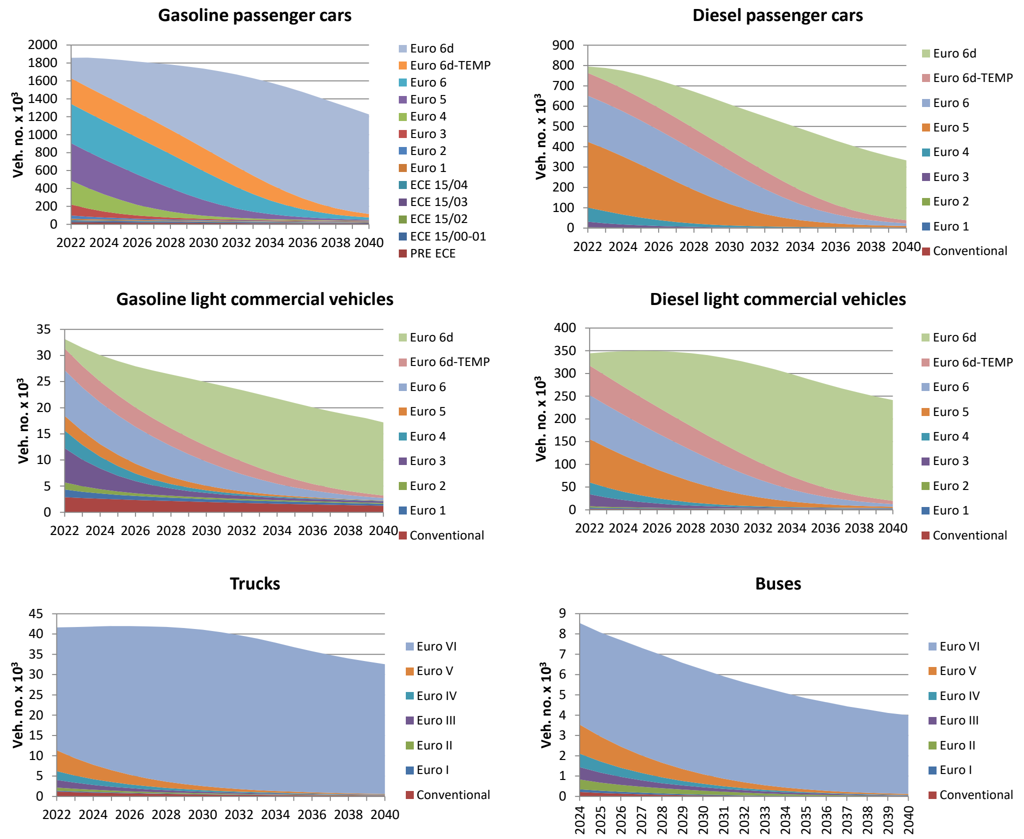


Figure 11.3.1 Layer distribution of vehicle numbers per vehicle type in 2022-2040.

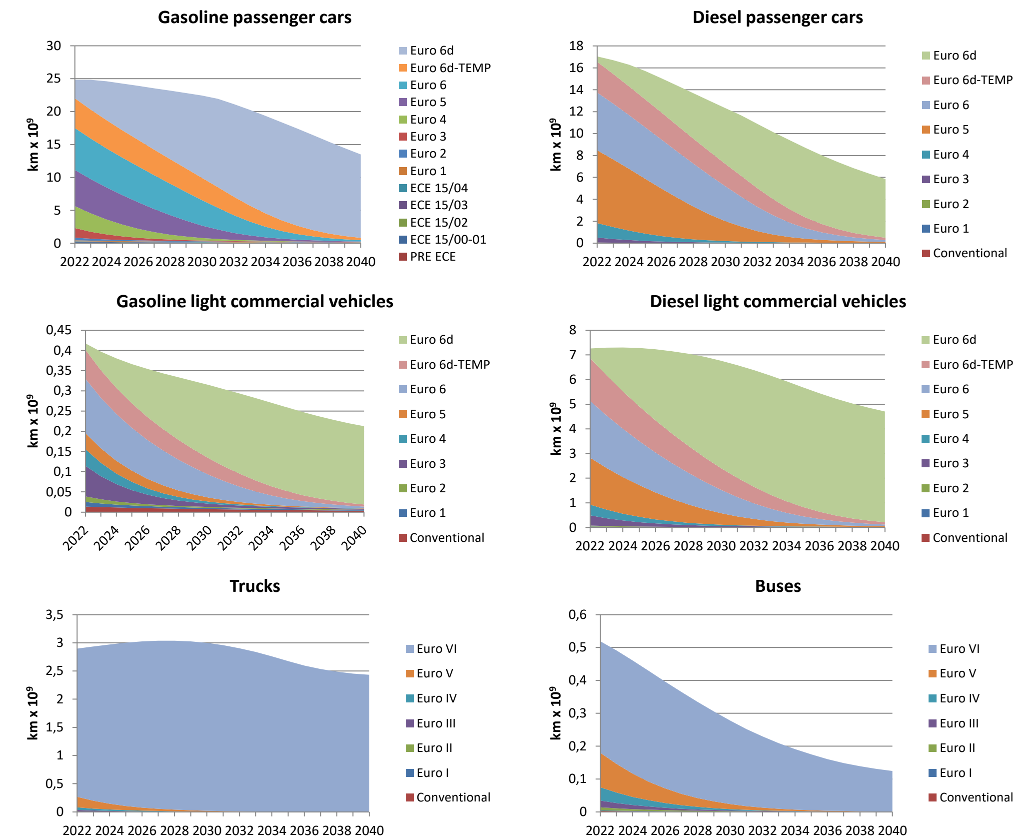


Figure 11.3.2 Layer distribution of total mileage per vehicle type in 2022-2040.

Agriculture

The predominant part of the fuel consumption and emissions from non road agricultural sources is associated with the use of tractors and harvesters. In the DCE model, tractors and harvesters are subdivided into a large number of engine sizes (see paragraph 3.3.3) that corresponds with the grouping of annual new sales provided by the Association of Danish Agricultural Machinery Dealers. The machinery stock is projected in the model by assuming that annual machinery new sales in the forecast years equals the average of the four latest historical year's new sales, and by assuming life times of 30 years and 25 years for tractors and harvesters, respectively (see paragraph 3.3.3).

For agriculture, the projection of the total number of agricultural tractors and harvesters and average engine sizes from 2020-2030 are shown in Figure 11.3.3. In the historical years, there has been a decrease in the total number of tractors and harvesters and an overall increase in the average engine size. By using the above-mentioned assumptions regarding new sales and life times in the projections, the trend continues towards decreasing number and increasing average engine sizes in the projection periods.

Figure 11.3.3 also shows the total stock of tractors and harvesters, and kWh's produced split into emission layers from 2020-2040. The annual working hours are highest for new machinery, and hence the share of kWh's produced becomes higher than number share for the most modern technologies in the projection periods.

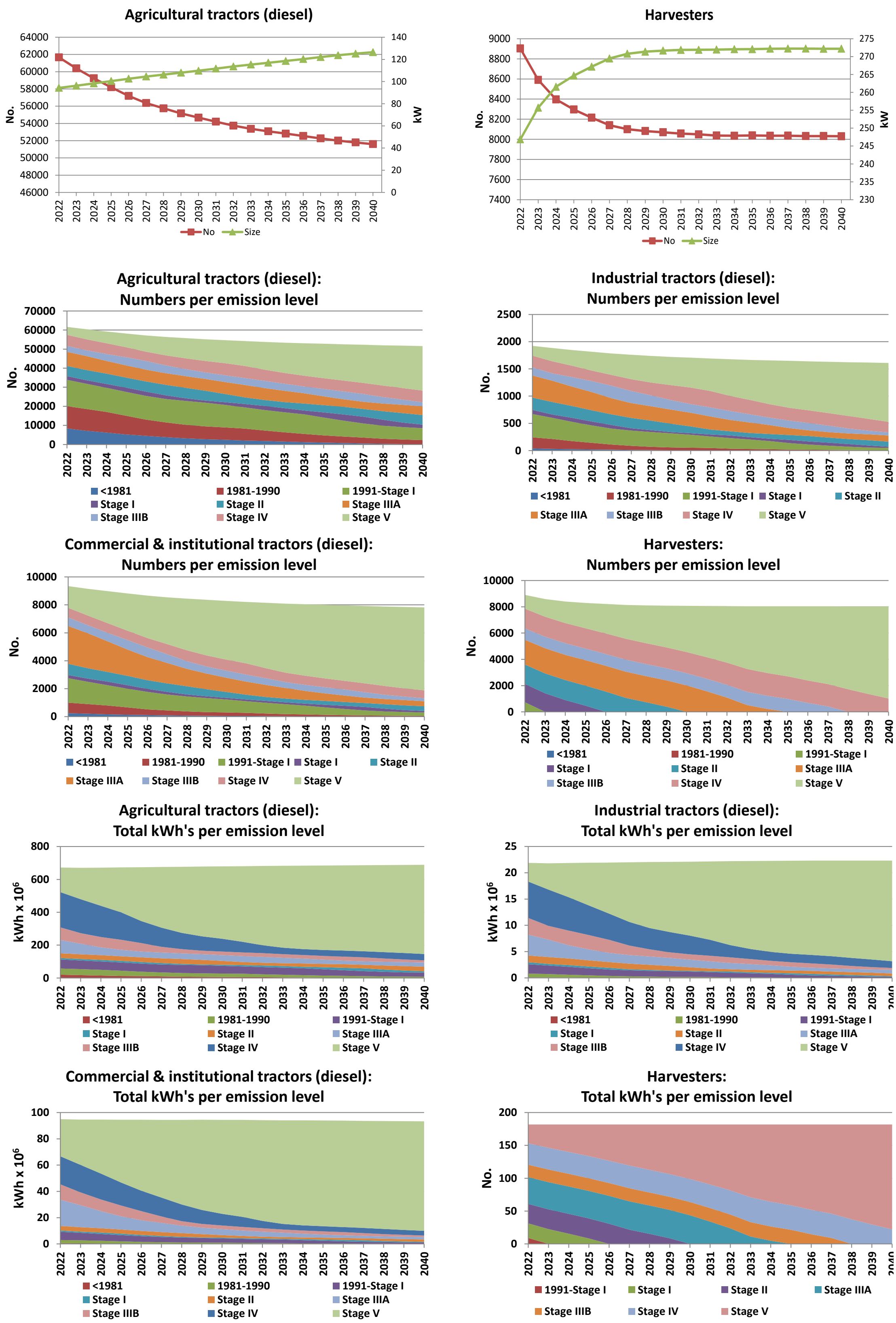


Figure 11.3.3 Total number of tractors and harvesters, average engine sizes, and numbers and kWh's produced per emission level from 2022-2040.

Industry

The most important machinery types for industrial non road are different types of diesel fuelled building and construction machinery (e.g. excavators/loaders, dump trucks) and fork lifts.

In the DCE model, the most important types of building and construction machinery and forklifts are subdivided into a large number of engine sizes (see paragraph 3.3.3) that corresponds with the grouping of annual new sales provided by the Association of Danish Agricultural Machinery Dealers and the Association of Producers and Distributors of Fork Lifts in Denmark.

The machinery stock is projected in the model by assuming that annual machinery new sales in the forecast years equals the average of new sales in the four latest historical years, and by using machinery scrappage curves as a function of engine age (see paragraph 3.3.3).

The number of machinery and total kWh's produced from 2020-2040 are shown in Figure 11.3.4 split into emission layers for the most important types of building and construction machinery and fork lifts. For the most modern technologies the phasing in of kWh's is faster than the phasing in of numbers throughout the forecast period, due to more annual working hours for new machinery.

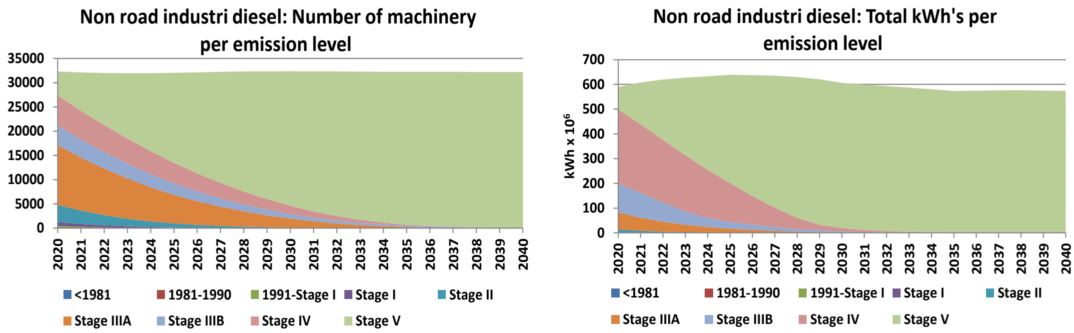


Figure 11.3.4 Number of diesel fueled machinery (most important types) and kWh's produced for non road industry from 2020-2040 split into emission levels.

Residential and commercial/institutional

The most important household and gardening machinery types in the residential and commercial/institutional sectors are gasoline-fuelled riders, lawn movers, shrub clearers and trimmers, chain saws and hedge cutters.

As a basis for the fleet projections in the DCE model, annual new sales data are used for the most important household and gardening machinery types provided by the Association for Industrial Technics, Tools and Automation. The machinery stock is projected in the model by assuming that annual machinery new sales in the forecast years equals the average of new sales in the five latest historical years, and by using machinery scrappage curves as a function of engine age (see paragraph 3.3.3).

The total stock development from 2020-2040 for the most important household and gardening machinery types is shown in Figure 11.3.5 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 11.3.5. 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.

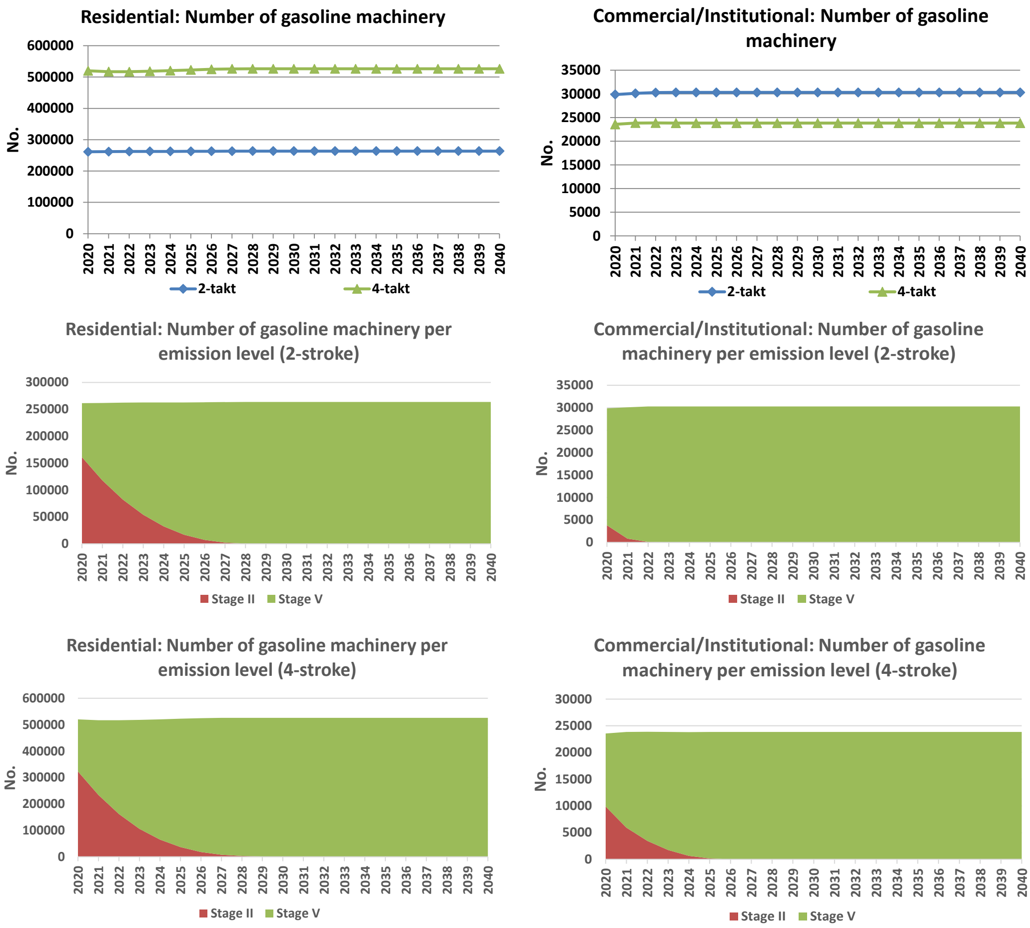


Figure 11.3.5 Number of gasoline fueled working machinery (most important types) from 2020-2040, split into 2-stroke/4-stroke engines and emission levels for residential and commercial/institutional.

Figure 11.3.6 shows the total number of kWh's produced from 2020-2040 for the most important household and gardening machinery types, split into 2-stroke and 4-stroke machinery for Residential (1.A.4b) and Commercial/Institutional (1.A.4.a).

Although the number of machines in commercial/institutional are much smaller than the number of residential machinery, the total number of kWh's are quite similar for 2-stroke machinery, and more than three times higher in the case of 4-stroke machinery. The reason is that annual working hours is much higher and engines (kW) are generally larger for professional equipment compared with private machinery.

For Stage V equipment, the phasing in of kWh's produced is faster than the phasing in of numbers throughout the forecast period, due to more annual working hours for new machinery.

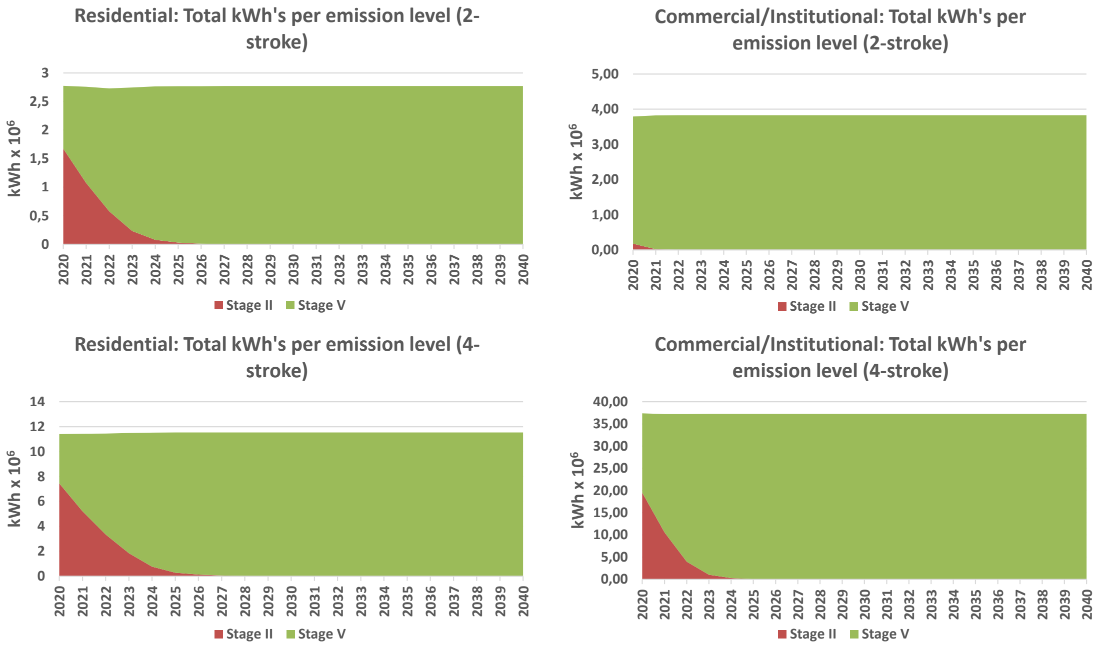


Figure 11.3.6 Number of kWh's produced for gasoline-fuelled working machinery (most important types) from 2020-2040, split into 2-stroke/4-stroke engines and emission levels for residential and commercial/institutional

National sea transport, fisheries and recreational craft

The fuel activity data for national sea transport (diesel and heavy fuel oil) in the projections is composed by the sum of fuel consumption for the sectors ”national sea transport” and ”Greenland/Faroe Islands maritime” in the Danish energy forecast (DEA, 2022).

The diesel fuel activity data for fisheries in the projections is calculated as the total diesel fuel consumption from the DEA forecast “Fisheries” minus the bottom-up diesel consumption for recreational craft estimated with the DCE model (see also paragraph 3.3.3).

The gasoline fuel activity data for recreational craft in the projections is estimated with the DCE model (see also paragraph 3.3.3). The latter gasoline fuel consumption is subtracted from the DEA forecast total for road transport, in order to maintain the national fuel balance (see also paragraph 3.3.3).

The fuel activity data used for national sea transport, fisheries and recreational craft in the projections are shown in Figure 11.3.7.

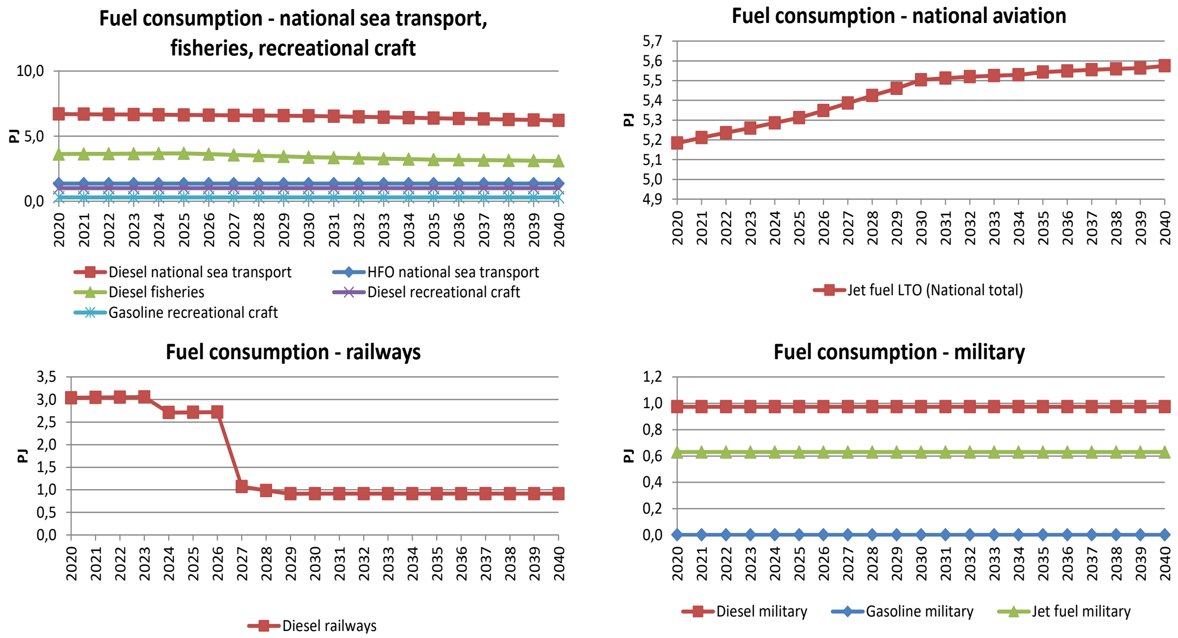


Figure 11.3.7 Fuel consumption for national sea transport, fisheries, recreational craft, aviation, railways and military from 2020-2040.

Air traffic

The basis activity data for aviation shown consist of the fuel consumption figures from the DEA energy forecast (DEA, 2022) split into domestic and international aviation.

The DCE model divides the DEA fuel consumption forecast figures into LTO (Landing and Take Off: Flight activities below 3.000 ft) and cruise (flight activities above 3.000 ft), for domestic and international flights respectively, based on the DCE model fuel consumption distribution for the latest historical year (2016).

For each year in the projection period, the total fuel sum is calculated for LTO. The latter fuel sum (shown in Figure 11.3.7), defined as the national total for aviation according to the UNECE inventory reporting rules, constitute the fuel activity data for national aviation.

A thorough description of the DCE aircraft emission model, historical flight activity data, representative aircraft types and fuel consumption and emission factors is given in paragraph 3.3.3.

Railways

The diesel fuel activity data for railways used in the projections from 2020-2040 comes from the DEA energy forecast (DEA, 2022). The railways activity data used in the projections for 2020-2040 are shown in Figure 11.3.7.

Military

The diesel and gasoline fuel consumption data for land based military activities and jet fuel consumption for military aviation activities comes from the DEA energy forecast (DEA, 2022). The military activity data used in the projections for 2020-2040 are shown in Figure 11.3.7.

11.3.3 Emission factors

The fuel consumption and emission factors used in the Danish emission inventories and projections come from the COPERT 5 model. The fuel consumption and emission factors are thoroughly explained in paragraph 3.3.2.

The fuel consumption and emission factors used in the Danish emission inventories and projections for other mobile sources are described in the previous paragraph 11.3.2 and in paragraph 3.3.3.

Table 11.3.1 shows the aggregated fuel related emission factors (g/GJ) for SO_2, NO_x NMVOC, $PM_{2.5}$ and BC for road transport and other mobile sources in Denmark in 2020, 2025, 2030, 2035 and 2040.

Table 11.3.1 Aggregated fuel related SO_2, NO_x NMVOC, $PM_{2.5}$ and BC emission factors (g/GJ) for road transport and other mobile sources in Denmark in 2020, 2025, 2030, 2035 and 2040.

	Category	2020	2025	2030	2035	2040
SO_2	Industry - Other (1A2g)	0,45	0,45	0,45	0,45	0,45
	Civil Aviation nat. (1A3a)	22,99	22,99	22,99	22,99	22,99
	Road (1A3b) - exhaust	0,43	0,44	0,44	0,44	0,44
	Railways (1A3c)	0,44	0,45	0,45	0,45	0,45
	Navigation (1A3d)	40,20	40,14	40,14	38,66	39,83
	Comm./Inst. (1A4a)	0,46	0,46	0,46	0,46	0,46
	Residential (1A4b)	0,46	0,46	0,46	0,46	0,46
	Agriculture/forestry (1A4c)	0,47	0,47	0,47	0,47	0,47
	Fisheries (1A4c)	46,84	46,84	46,84	46,84	46,84
	Other (1A5b)	9,28	9,29	9,29	9,29	9,29
	Navigation int. (1A3d)	47,53	47,53	47,53	47,53	47,53
	Civil Aviation int. (1A3a)	22,99	22,99	22,99	22,99	22,99
NO_x	Industry - Other (1A2g)	268,9	193,2	179,8	179,4	180,5
	Civil Aviation nat. (1A3a)	338,2	338,3	338,3	338,3	338,4
	Road (1A3b) - exhaust	149,1	99,9	69,6	50,8	41,6
	Railways (1A3c)	411,4	411,4	411,4	411,4	411,4
	Navigation (1A3d)	1399,8	1248,9	1059,3	846,0	662,6
	Comm./Inst. (1A4a)	85,5	59,9	60,2	60,7	60,9
	Residential (1A4b)	94,0	81,5	81,2	81,2	81,2
	Agriculture/forestry (1A4c)	278,5	180,4	108,7	76,2	57,4
	Fisheries (1A4c)	1178,7	848,8	510,5	399,5	286,3
	Other (1A5b)	216,8	178,1	153,2	136,1	127,2
	Navigation int. (1A3d)	1744,0	1503,2	1243,9	1003,6	760,3
	Civil Aviation int. (1A3a)	363,4	363,4	363,4	363,4	363,4
NMVOC	Industry - Other (1A2g)	65,6	53,1	51,1	53,8	55,6
	Civil Aviation nat. (1A3a)	29,5	29,7	30,0	30,1	30,2
	Road (1A3b) - exhaust	24,7	20,9	20,7	21,2	21,0
	Railways (1A3c)	3,0	3,0	3,0	3,0	3,0
	Navigation (1A3d)	59,0	59,9	60,5	60,4	60,9
	Comm./Inst. (1A4a)	657,2	619,5	630,5	645,5	653,4
	Residential (1A4b)	2686,5	2559,9	2540,9	2540,9	2540,9
	Agriculture/forestry (1A4c)	70,6	65,6	63,9	67,8	70,8
	Fisheries (1A4c)	59,3	59,8	60,1	60,3	60,3
	Other (1A5b)	11,7	11,0	10,9	11,0	11,1
	Navigation int. (1A3d)	62,8	64,2	65,0	65,4	65,8
	Civil Aviation int. (1A3a)	4,8	4,8	4,8	4,8	4,8
$PM_{2.5}$	Industry - Other (1A2g)	19,7	9,3	5,1	4,1	3,8
	Civil Aviation nat. (1A3a)	2,5	2,5	2,5	2,5	2,5
	Road (1A3b) - exhaust	2,3	1,2	0,9	0,8	0,8
	Railways (1A3c)	0,3	0,3	0,3	0,3	0,3
	Navigation (1A3d)	32,6	33,4	34,0	34,3	34,9
	Comm./Inst. (1A4a)	13,1	12,5	12,5	12,8	12,9
	Residential (1A4b)	39,7	39,3	39,3	39,3	39,3
	Agriculture/forestry (1A4c)	17,4	11,3	6,7	4,9	3,5
	Fisheries (1A4c)	22,6	22,9	23,0	23,1	23,1
	Other (1A5b)	2,2	1,3	1,0	0,9	0,9
	Navigation int. (1A3d)	46,9	48,8	49,8	50,3	50,8
	Civil Aviation int. (1A3a)	4,7	4,7	4,7	4,7	4,7
BC	Industry - Other (1A2g)	13,3	6,0	2,7	1,7	1,5
	Civil Aviation nat. (1A3a)	1,0	1,0	1,0	1,0	1,0
	Road (1A3b) - exhaust	1,4	0,5	0,2	0,2	0,1

Continued					
Railways (1A3c)	0,2	0,2	0,2	0,2	0,2
Navigation (1A3d)	3,3	3,3	3,3	3,3	3,3
Comm./Inst. (1A4a)	1,6	0,9	0,7	0,7	0,7
Residential (1A4b)	2,0	2,0	2,0	2,0	2,0
Agriculture/forestry (1A4c)	10,5	6,3	3,4	1,9	0,7
Fisheries (1A4c)	4,1	4,1	4,1	4,1	4,1
Other (1A5b)	1,7	0,9	0,4	0,4	0,4
Navigation int. (1A3d)	3,1	3,1	3,1	3,1	3,1
Civil Aviation int. (1A3a)	2,5	2,4	2,4	2,4	2,4

11.3.4 Emissions

Table 11.3.2 shows the total fuel consumption and emissions of SO_2, NO_x NMVOC, $PM_{2.5}$ and BC for road transport and other mobile sources in Denmark in 2020, 2025, 2030, 2035 and 2040.

Table 11.3.2 Total fuel consumption and emissions of SO_2, NO_x NMVOC, $PM_{2.5}$ and BC for road transport and other mobile sources in Denmark in 2020, 2025, 2030, 2035 and 2040.

	Category	2020	2025	2030	2035	2040
Energy	Industry - Other (1A2g)	8,4	8,6	8,0	7,2	6,8
	Civil Aviation nat. (1A3a)	5,2	5,3	5,5	5,5	5,6
	Road (1A3b) - exhaust	179,9	183,3	177,6	155,0	131,5
	Railways (1A3c)	3,0	2,7	0,9	0,9	0,9
	Navigation (1A3d)	8,1	8,1	8,0	7,8	7,7
	Comm./Inst. (1A4a)	1,1	1,1	1,1	1,0	1,0
	Residential (1A4b)	0,3	0,3	0,3	0,3	0,3
	Agriculture/forestry (1A4c)	14,0	13,5	12,2	10,9	10,1
	Fisheries (1A4c)	3,6	3,7	3,4	3,2	3,1
	Other (1A5b)	1,6	1,6	1,6	1,6	1,6
	Navigation int. (1A3d)	23,1	23,1	23,1	23,1	23,1
	Civil Aviation int. (1A3a)	38,7	39,6	40,9	41,2	41,4
SO_2	Industry - Other (1A2g)	4	4	4	3	3
	Civil Aviation nat. (1A3a)	119	122	127	127	128
	Road (1A3b) - exhaust	78	81	78	68	58
	Railways (1A3c)	1	1	0	0	0
	Navigation (1A3d)	328	324	321	303	305
	Comm./Inst. (1A4a)	1	1	0	0	0
	Residential (1A4b)	0	0	0	0	0
	Agriculture/forestry (1A4c)	7	6	6	5	5
	Fisheries (1A4c)	170	172	159	150	145
	Other (1A5b)	15	15	15	15	15
	Navigation int. (1A3d)	1097	1097	1097	1097	1097
	Civil Aviation int. (1A3a)	889	909	941	947	951
NO_x	Industry - Other (1A2g)	2261	1669	1440	1293	1228
	Civil Aviation nat. (1A3a)	1753	1797	1862	1875	1886
	Road (1A3b) - exhaust	26818	18325	12366	7868	5476
	Railways (1A3c)	1250	1117	376	376	376
	Navigation (1A3d)	11406	10087	8479	6623	5071
	Comm./Inst. (1A4a)	94	65	65	63	63
	Residential (1A4b)	28	25	24	24	24
	Agriculture/forestry (1A4c)	3892	2432	1331	831	582
	Fisheries (1A4c)	4278	3124	1729	1279	888
	Other (1A5b)	348	286	246	219	204
	Navigation int. (1A3d)	40260	34701	28716	23168	17551
	Civil Aviation int. (1A3a)	14052	14374	14867	14962	15035
NMVOC	Industry - Other (1A2g)	551	459	409	388	378
	Civil Aviation nat. (1A3a)	153	158	165	167	168
	Road (1A3b) - exhaust	4450	3831	3672	3288	2764
	Road (1A3b) - non exhaust	1307	1322	1318	1206	1052
	Railways (1A3c)	9	8	3	3	3
	Navigation (1A3d)	481	484	484	473	466
	Comm./Inst. (1A4a)	721	676	675	675	675
	Residential (1A4b)	802	772	767	767	767
	Agriculture/forestry (1A4c)	987	885	782	740	717
	Fisheries (1A4c)	215	220	204	193	187
	Other (1A5b)	19	18	17	18	18
	Navigation int. (1A3d)	1450	1483	1500	1509	1518
	Civil Aviation int. (1A3a)	187	191	198	199	200
$PM_{2.5}$	Industry - Other (1A2g)	165	80	41	30	26
	Civil Aviation nat. (1A3a)	13	13	14	14	14

Continued						
	Road (1A3b) - exhaust	409	218	154	126	104
	Road (1A3b) - non exhaust	994	1084	1190	1287	1376
	Railways (1A3c)	1	1	0	0	0
	Navigation (1A3d)	266	270	272	268	267
	Comm./Inst. (1A4a)	14	14	13	13	13
	Residential (1A4b)	12	12	12	12	12
	Agriculture/forestry (1A4c)	243	152	82	54	35
	Fisheries (1A4c)	82	84	78	74	72
	Other (1A5b)	4	2	2	1	1
	Navigation int. (1A3d)	1084	1127	1149	1161	1173
	Civil Aviation int. (1A3a)	183	187	193	195	196
BC	Industry - Other (1A2g)	112	52	21	13	10
	Civil Aviation nat. (1A3a)	5	5	6	6	6
	Road (1A3b) - exhaust	255	91	37	23	18
	Road (1A3b) - non exhaust	174	190	208	225	240
	Railways (1A3c)	1	1	0	0	0
	Navigation (1A3d)	27	27	26	26	25
	Comm./Inst. (1A4a)	2	1	1	1	1
	Residential (1A4b)	1	1	1	1	1
	Agriculture/forestry (1A4c)	147	85	42	21	7
	Fisheries (1A4c)	15	15	14	13	13
	Other (1A5b)	3	1	1	1	1
	Navigation int. (1A3d)	71	71	71	71	71
	Civil Aviation int. (1A3a)	95	97	100	101	101

Road transport

Figure 11.3.8 shows the projections of fuel consumption and emissions per vehicle category for road transport from 2020-2040.

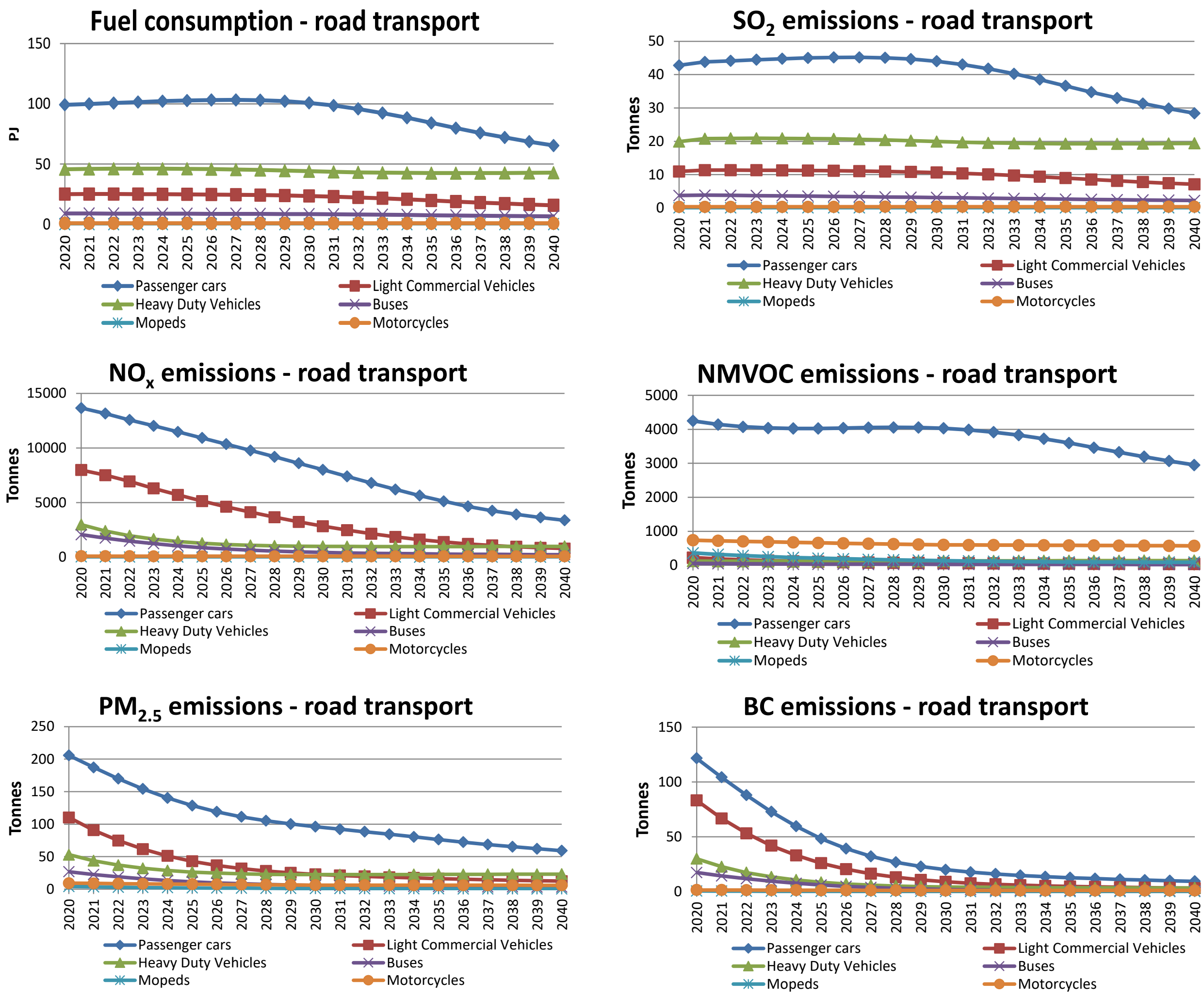


Figure 11.3.8 Fuel consumption, NO_X, SO_2, NMVOC, $PM_{2.5}$ and BC emissions from 2020-2040 for road traffic.

Total fuel consumption and SO_2 emissions for road traffic approximately stays at the same level from 2020 to 2030. From 2030 to 2040 the fuel consumption and SO_2 emissions decrease for passenger cars and light commercial vehicles due to the increasing number of electric vehicles and plug in hybrids expected to enter the fleet during the forecast period (not shown). The largest fuel consumption and SO_2 emissions shares are calculated for passenger cars in the forecast period, followed by heavy-duty vehicles, light duty vehicles, buses and two-wheelers in decreasing order. The sulphur content of gasoline and diesel is 10 ppm, and hence the development of the total SO_2 emissions follow the trend in total fuel consumption.

The majority of the NMVOC emission from road transport comes from gasoline passenger cars (Figure 11.3.8). The NMVOC emission is projected to decrease around 34 % from 2020 to 2040 for passenger cars, explained by the introduction of gradually more efficient catalytic converters for gasoline cars and a very pronounced decrease in the total mileage driven for gasoline cars during the 2030's (Figure 11.3.2).

In terms of $PM_{2.5}$ and BC the total exhaust emission is expected to decline by 75 % and 93 %, respectively, from 2020 to 2040, in particular due to the introduction of diesel particulate filters (DPF) for Euro 5 cars/vans, and Euro VI trucks/buses. The largest emission source is passenger cars, followed by light duty vehicles, heavy-duty vehicles and buses. Emission reductions are generally higher for BC than for $PM_{2.5}$ due to the very efficient removal of BC by the DPF technology.

The NO_X emission for road transport declines by 80 % from 2020 to 2040. For cars and vans the expected emission reductions (75 % and 90 %, respectively) are large due to the introduction of Euro 6d diesel cars and vans associated with very small NO_x emissions in compliance with the EU emission standards for these vehicles. For trucks and buses the relative emission declines of 67 % and 89 %, respectively, are also quite significant during the forecast period, due to the automatic fleet turnover towards newer EU emission standards that in practice reduce the emission factors from Euro III onwards.

Other mobile sources

Figure 11.3.9 shows the projections of fuel consumption and emissions for other mobile sources from 2020-2040.

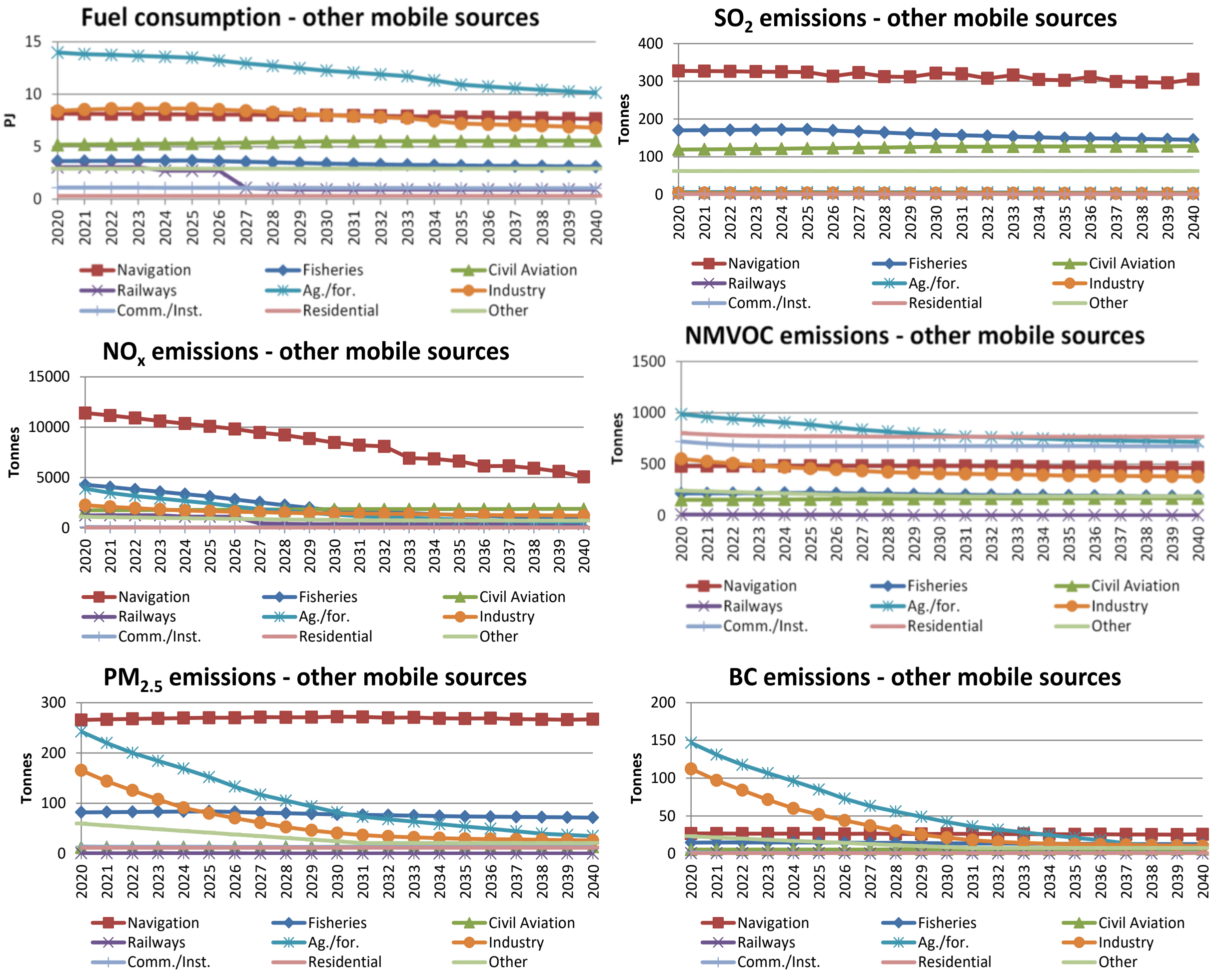


Figure 11.3.9 Fuel consumption, NO_X, SO_2, NMVOC, $PM_{2.5}$ and BC emissions from other mobile sources 2020-2040.

From 2020 to 2040 the total fuel consumption decreases by 18 % for other mobile sources. The emissions of SO_2 decrease by 2 %, due to an increase in fuel consumption for fishery that uses marine diesel with a relatively high content of sulphur. For other mobile sources the emissions of SO_2, NO_x, NMVOC, $PM_{2.5}$ and BC decreased by 6 %, 59 %, 14 %, 45 % and 80 %, respectively.

The development in fuel consumption is forecasted by the DEA (2022). Agriculture/forestry/fisheries is by far the largest fuel consumption source followed by industry, navigation and civil aviation. Rather small fuel consumption totals are noted for railways, other (military and recreational boats), residential and commercial/institutional.

The SO_2 emissions for other mobile sources are insignificant except for seagoing vessels. However, for navigation and fisheries, the reduction of the sulphur content in heavy fuel oil used in the Baltic and North Sea SO_x emission control areas (SECAs) has had a major emission impact from 2015.

Agriculture/forestry is the largest source of emissions of NMVOC until 2030, and in this case the most important emission contributors are diesel-fuelled tractors and gasoline-fuelled chain saws and ATV's. Large NMVOC emission contributions are also calculated for gasoline working machinery in residential and commercial/institutional and for diesel-fuelled machinery in industry.

For agriculture/forestry and industry, the gradually stricter emission standards for diesel engines (figures 11.3.3 and 11.3.4) will cause the NMVOC emission to decrease during the forecast period. For commercial/-institutional and residential the projected NMVOC emission reductions are due to the phasing in of the most stringent stage V emission technology (figure 11.3.5) for some types of equipment.

For $PM_{2.5}$, navigation is the largest emission source for the other mobile sector. The $PM_{2.5}$ emissions from navigation and fisheries rely on the fuel consumption development (Figure 11.3.7 and Figure 11.3.9) and the sulphur content of the fuels used. For the latter sectors, the $PM_{2.5}$ emissions are significant due to the relatively high sulphur content of marine fuels compared to the fuel types used by other mobile sources.

The $PM_{2.5}$ emissions from agriculture/forestry and industry decrease substantially throughout the forecast period due to the introduction of particulate filters for diesel engines > 19 kW, in compliance with the Stage V emission standards. Particulate filters are very efficient removers of BC, explaining the large BC emission decreases for agriculture/forestry and industrial machinery shown in Figure 11.3.9.

For NO_x, navigation is by far the largest emission source for the other mobile sector. For agriculture/forestry, industry, navigation, fisheries and railways, substantial NO_x emission improvements are expected during the course of the forecast period due to the penetration of cleaner engine technologies, in compliance with future emission standards. Rather small NO_x emissions are calculated for railways, civil aviation, residential, commercial/institutional and other.

11.3.5 References

Danish Energy Agency, 2022: Energy consumption prognosis 2021-2040. February 2022.

Jensen, T.C. 2021: Dokumentation af konvertering af trafiktal til emissionsopgørelser, arbejdsnotat 81834, 38 pp. DTU Transport, 2021.

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).

Mølgård, J. 2021: Unpublished data material from the Danish State Railways.

11.4 Fugitive emissions from fuels

The projection of fugitive emissions from fuels includes sources related to exploration, production, refining, storage, handling, and transport of fuels. The projection include emissions of

- SO_2 from oil and gas exploration, sulphur recovery in oil refineries and flaring of oil and gas,
- NO_X from flaring of oil and gas,
- particulate matter (PM) from storage of coal, exploration of oil and gas, and flaring of oil and gas, and
- NMVOC from refining of oil, extraction of oil and gas, storage and transport of oil and gas, venting of gas, and flaring of oil and gas.

The following chapters describe the methodology, activity data, emission factors and emissions in the projection.

The description refer to the most recent emission projection, which was made in February 2022. The historical year 2020 is used as basis for the projection.

11.4.1 Methodology

The methodology for the emission projection correspond the methodology in the annual emission inventory, based on the EMEP/EEA Guidebook (EMEP/EEA, 2019).

Activity data are based on Denmark's Energy and Climate Outlook (DEA, 2022), including official forecasts on fuel consumption and offshore production and flaring of oil and natural gas.

Emission factors are based on the EMEP/EEA guidelines (EMEP/EEA, 2019), or are country-specific based on data for one or more of the historical years. For a number of sources the emissions are given in annual reports, e.g. environmental reports, self-regulation reports and environmental accounts, and these are adopted in the Danish emission inventory and used as basis for the projection.

11.4.2 Activity data

Prognosis of oil and gas production

The prognosis for the production of oil and gas and for flaring (DEA, 2022) is shown in Figure 10.4.1. The prognosis includes production from existing fields and new fields based on existing technology, technological resources (estimated additional production due to new technological initiatives) and prospective resources (estimated production from new discoveries). Further, the projected production includes flaring in upstream oil and gas production.

The production of both oil and gas is assumed to decrease from 2020 to 2022, followed by an increase until 2027, and then levelling out to a decreasing trend. The overall trend for the projection years 2020-2040 is decreasing for oil production and almost constant for gas production. The large variations in the first years of the projection owe to the shutdown of the Tyra platform for redevelopment and restart of the production from 2023.

According to Denmark's Energy and Climate Outlook (DEA, 2022), the flaring amounts are expected to increase from 2020 to 2024, a significant decrease 2024 to 2026, followed by a more levelled out trend showing an increase 2026 to 2033 and decrease 2026-2040. The overall trend for the projection years shows a decrease. Flaring related to exploration of oil and gas is not included in the oil and gas projection, and therefore this activity is not included in the projection.

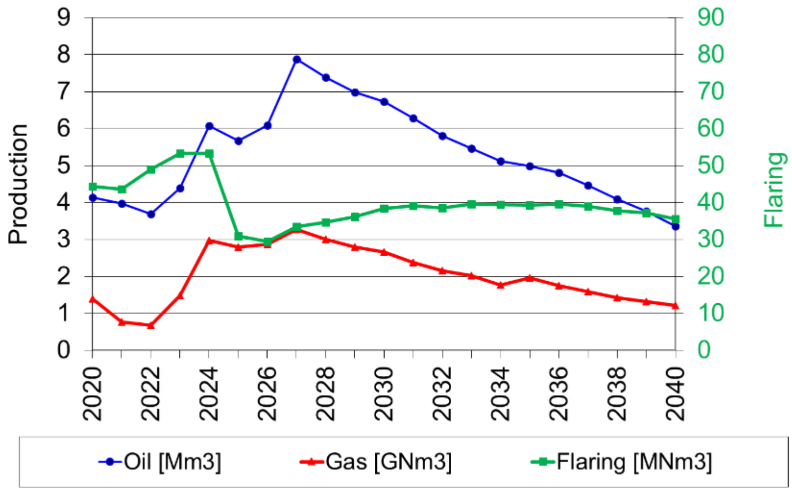


Figure 10.4.1 Prognosis for the production of oil and gas and flaring in offshore oil and gas production (DEA, 2022).

The DEA prognosis of the production of oil and gas are used in projection of a number of sources; production of oil and natural gas, emissions from the raw oil terminal, onshore and offshore loading of ships, and flaring in upstream oil and gas production.

The same methodology is applied to estimate activity data for these sources, where the amount in the projection year is estimated as the amount in the latest historical year multiplied by the share of the oil production in the projection year and the latest historical year. Equation 10.4.1 shows the estimation methodology for onshore loading.

Eq. 10.4.1 Formula for estimating onshore loading amount in projection year p

$$\mathrm{OL}_p = \mathrm{OL}_h \times \frac{\mathrm{OP}_p}{\mathrm{OP}_h}$$

where OL = onshore loading, OP = oil production, p = projection year and h = latest historical year

Prognosis of energy consumption

The prognosis of energy consumption (DEA, 2022) is applied in the projection of fugitive emissions from fuels. The annual prognosis of consumption of natural gas as a total for all sectors is used as proxy to project transmission of natural gas.

Emissions from transmission and distribution of natural gas and town gas show variations from year to year, because of varying extent of leakages due to maintenance and accidental excavations. In order to include these unpredictable events, the emissions from transmission and distribution of natural gas and town gas are estimated as the average emissions in the last five historical years scaled to the annual total natural gas consumption from the energy consumption prognosis by the DEA (2022).

Summarised gasoline and coal consumptions for all sectors are used as proxy activity data to project emissions from service stations and storage of solid fuels, respectively.

Large point sources

The sector fugitive emissions from fuels cover only few large point sources (LPS). These are the two Danish refineries and the natural gas storage and treatment plants. Fugitive emissions from refineries are related to three sources; 1) fugitive losses from tanks, pipes, valves etc., 2) sulphur recovery, and 3) flaring. Projections of emissions from these sources are associated with large uncertainties, as the emissions are not related to the production amounts or other predictable parameters. Fugitive losses are dependent of the number and character of leakages and the maintenance conditions. SO_2 emissions form sulphur recovery show large annual variations due to interruptions of the sulphur recovery system. When the sulphur recovery plant does not work optimally, the gas is lead to the flare, which results in larger SO_2 emissions from the flare. In the energy consumption prognosis, the rates for refinery gas consumption and flaring in refineries are assumed constant. In order to be consistent with this approach, the emissions in the latest historical year are applied for all projection years.

Fugitive emissions from the natural gas storage and treatment plants are very limited and owe to flaring and venting. The amounts of natural gas that is vented and flared vary from year to year, and the emissions in the projection years are estimated as the average emission in the last five historical years. Following, the same emission is applied for all projection years.

11.4.3 Emission factors

Emission factors from the EMEP/EEA Guidebook (EMEP/EEA, 2019) are used to estimate emissions from exploration of oil and gas, offshore loading of ships and offshore flaring in oil and gas production.

For loading of ships, the EMEP/EEA Guidebook provides emission factors for different countries. The Norwegian emission factors are applied in the Danish projection. The NMVOC emission factors for onshore loading in historical years are based on data from the harbour terminal. The emission factor for the latest historical year is used in the projection. NMVOC emissions from the raw oil terminal in the projection period are estimated as the emission in the latest historical year scaled to the annual oil production. The NMVOC emission factors for the projection years are listed in Table 10.4.1.

The emission factor for service stations are the summarised emission factors for reloading of tanker trucks and refuelling of cars based on the IPCC Guidelines (IPCC, 2006). The NMVOC emission factor for service stations is listed in Table 10.4.1.

Table 10.4.1 NMVOC emission factors for the projection years.

Source	EF	Unit	Reference
Ships offshore	0.001	Fraction of loaded	EMEP/EEA, 2019
Ships onshore	8.494	g/ton loaded	A/S Dansk Shell - Havneterminalen, 2021
Service stations	541	g/Mg gasoline	EMEP/EEA, 2019*

**modified to 70% abatement according to Danish act for conditions occurring in practice.*

Emission factors for offshore flaring are listed in Table 10.4.2. The SO_2 emissions are calculated using a country specific SO_2 emission factor for Danish natural gas. The emission factor for NO_x is based on a survey by the Danish Environmental Protection Agency (Danish EPA, 2008). Emission factors for NMVOC and PM are based on the EMEP/EEA Guidebook (2019).

Table 10.4.2 SO_2, NO_x and PM emission factors for offshore flaring.

Pollutant	EF	Unit	Reference
SO_2	0.013	g/Nm3	EMEP/EEA, 2019
NO_x	1.230	g/Nm3	Danish EPA, 2008
NMVOC	1.480	g/Nm3	EMEP/EEA, 2019
TSP	0.042	g/Nm3	EMEP/EEA, 2019
PM_{10}	0.042	g/Nm3	EMEP/EEA, 2019
$PM_{2.5}$	0.042	g/Nm3	EMEP/EEA, 2019
BC	0.0009	g/Nm3	EMEP/EEA, 2019

Emissions of particulate matter (PM) from coal storage are estimated by the emission factors from the Coordinated European Particulate Matter Emission Inventory Program, CEPMEIP (Visschedijk et al., 2004). The emission factors are listed in Table 10.4.3. The emission factor for black carbon (BC) is estimated based on the TSP EF and the C content in Other bituminous coal according to IPCC (2006).

Table 10.4.3 Emission factors for PM emissions from coal storage.

Pollutant	EF	Unit	Reference
TSP	15	g/Mg	Visschedijk et al., 2004
PM_{10}	13	g/Mg	Visschedijk et al., 2004
$PM_{2.5}$	4	g/Mg	Visschedijk et al., 2004
BC	10	g/Mg	Visschedijk et al., 2004; IPCC, 2006

The NMVOC emissions from the oil terminal, covering storage and handling of raw oil, are given in annual reports for the raw oil terminal from Danish Oil Pipe A/S (Boesen, 2020). Emissions from storage tanks at the oil terminal are provided annually by Danish Oil Pipe A/S. During 2009 new emission reducing technologies (degassing unit) were installed at the crude oil terminal, leading to a significant decrease of the emissions. Estimation of emissions from the oil terminal in the projection years is based on the average emission factor for the latest five historical years and the activity data for the latest historical year scaled to the annual oil production given in the oil and gas production prognosis (DEA, 2022).

A similar approach has been applied for transmission and distribution of natural gas and distribution of town gas. The emission in the projection years are estimated as the average emission in the last five historical years scaled to the annually gas consumption given in the energy consumption prognosis (DEA, 2022). Emissions from refineries (processes and flaring) are kept constant at the level in the latest historical year in agreement with the approach in the energy consumption prognosis.

Emissions from venting in gas storage plants and flaring in the gas treatment plant are calculated as the average emission of the last five historical years, and consequently no emission factors have been used to estimate projected emissions.

11.4.4 Emissions

Tables and figures in this section show data for every fifth historical year (1990-2020), including the latest historical year as in this projection (2020), the first year of the projection period (2021), and every fifth projection year (2025-2040).

The SO_2 emissions (Figure 10.4.2) are high in the first years of the time series, mainly for refineries, due to the presence of a third refinery. SO_2 emissions from refineries show large annual fluctuations due to unpredictable circumstances and therefore the projected emissions must be expected to have large uncertainties. By using a five-year mean, part of the annual variations are taken into account.

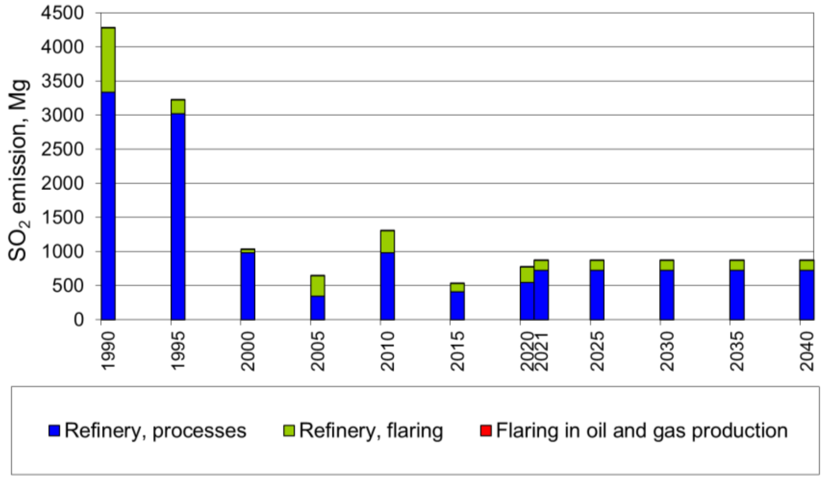


Figure 10.4.2 SO_2 emissions for selected historical years (1990-2020) and projection years (2021-2040).

Projected SO_2 emissions are listed in Table 10.4.4. The major source is refinery processes followed by flaring in refineries and flaring in oil and gas production, the latter being of only minor importance.

Table 10.4.4 Projected SO_2 emissions for selected historical years (1990-2020) and projection years (2021-2040).

NFR code	Source	1990	1995	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
		Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
1B2a iv	Refinery, processes	3335	3022	981	347	981	406	548	728	728	728	728	728
1B2c	Refinery, flaring	943	203	51	296	326	126	224	139	139	139	139	139
1B2c	Flaring in oil and gas production	1.4	2.0	3.3	2.4	1.6	1.2	0.6	0.6	0.4	0.5	0.5	0.5

The only source to emissions of NO_x in the fugitive sector is flaring, which occur in refineries, offshore in oil and gas production, at the gas treatment plant and in gas transmission and distribution (Figure 10.4.3). Emissions of NO_x peaked around year 2000 and have been decreasing until 2020 due to the decreasing trend for offshore flaring.

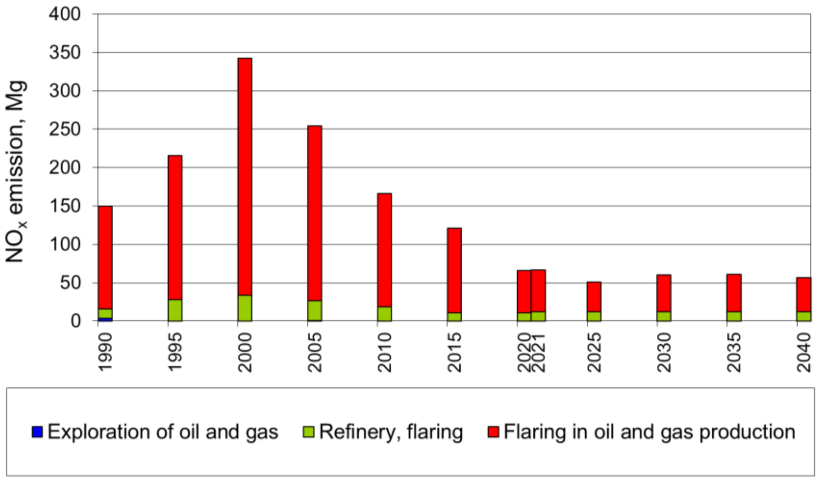


Figure 10.4.3 NO_x emissions for selected historical years (1990-2020) and projection years (2021-2040).

The most important source is offshore flaring in oil and gas extraction, which account for 96 % in year 1992, 83 % in 2020 and 78 % in 2040. Table 10.4.5 lists NO_x emissions for selected historical and projection years. Emissions from flaring in oil and gas extraction include offshore flaring and flaring in gas storage and treatment plants. Exploration of oil and gas is not included in the projection, as activity data are not available and due to the unpredictability of this source.

Table 10.4.5 Projected NO_x emissions for selected historical years (1990-2020) and projection years (2021-2040).

NFR code	Source	1990	1995	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
		Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
1B2a i	Exploration of oil and gas	3.56	0.002	0.07	0.88	0	0.04	0	0	0	0	0	0
1B2c	Refinery, flaring	12	28	34	26	18	11	11	12	12	12	12	12
1B2c	Flaring in oil and gas production	134	188	309	228	148	110	55	54	39	48	49	44

The fugitive sector is an important source of NMVOC emissions. In 2020, the sector accounted for 9 % of the national total NMVOC emission. The major fugitive NMVOC sources are refinery processes, onshore and offshore activities in oil and gas production, and service stations (Figure 10.4.4). In the later historical years and in the projection years, refinery processes are by far the major single source. As mentioned, fugitive emissions from refineries are highly unpredictable and only very few measurements are available as basis for the emission estimation. Improvement of the emission estimation and projection for refinery processes require more measurements at the refineries.

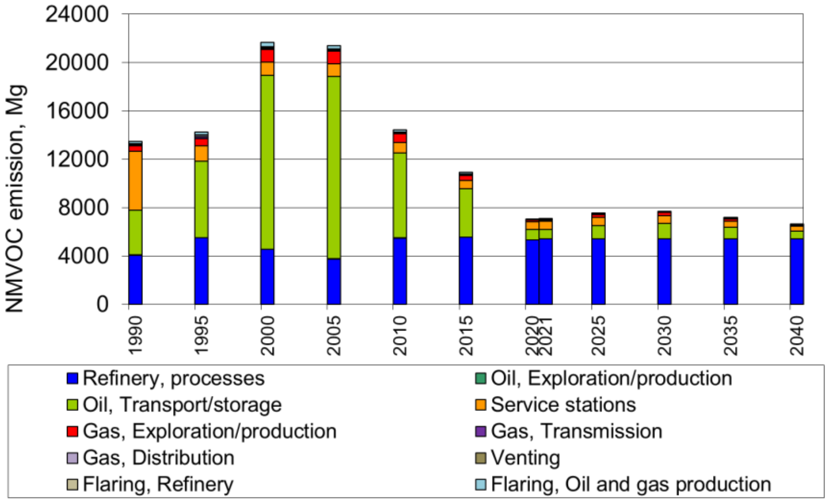


Figure 10.4.4 NMVOC emissions for selected historical years (1990-2020) and projection years (2021-2040).

Emissions of NMVOC are listed in Table 10.4.6. Emissions from offshore activities for oil and gas, from onshore activities for oil, and from flaring in oil and gas production fluctuate in the projection years according to the oil and gas production prognosis. These sources have a decreasing trend in the projection years. Emissions from service stations, and gas transmission and distribution follow the prognosis for consumption of gasoline and natural gas, respectively. Emissions from service stations decrease significantly in the early historical years, followed by a more constant level from 1996 onwards. Consumption of natural gas are decreasing in the projection period, leading to decreasing NMVOC emissions. Venting occur due to safety reasons in connection with construction work, inspection and maintenance, and fluctuates in an unpredictable way. The emissions are constant in the projection period, as an average of the emissions in the latest five historical years.

Table 10.4.6 Projected NMVOC emissions for selected historical years (1990-2020) and projection years (2021-2040).

NFR code	Source	1990	1995	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
		Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
1B2a iv	Refinery, processes	4072	5500	4530	3742	5477	5556	5318	5408	5408	5408	5408	5408
1B2a i	Oil, Exploration & production	5	8	16	16	11	7	3	3	4	5	4	2
1B2a i	Oil, Transport & Storage	3721	6316	14384	15101	7041	3982	859	761	1089	1290	955	646
1B2a v	Service stations	4856	1301	1119	1031	851	721	638	706	684	636	525	385
1B2b	Gas, Exploration & production	*472*	*575*	*1030*	*1049*	*733*	*411*	*127*	*70*	*255*	*242*	*179*	*110*
1B2b	Gas, Transmission	31	135	53	50	41	45	14	13	11	3	1	0
1B2b	Gas, Distribution	111	139	111	107	61	53	25	33	29	19	15	13
1B2c	Venting	15	28	24	14	22	8	3	9	9	9	9	9
1B2c	Flaring, Refinery	31	31	26	32	27	19	21	21	21	21	21	21
1B2c	Flaring, Oil & gas production	160	229	373	276	177	132	66	65	46	57	59	53

* Offshore loading of ships were not occurring until 1999.

The major fugitive source of PM and BC emissions is coal storage, while emissions from flaring are of only minor importance especially regarding BC (Figure 10.4.5, Figure 10.4.6, Table 10.4.7 and Table 10.4.8). Emissions from coal storage follow the trend of the annual coal consumption, which is decreasing for the projection years.

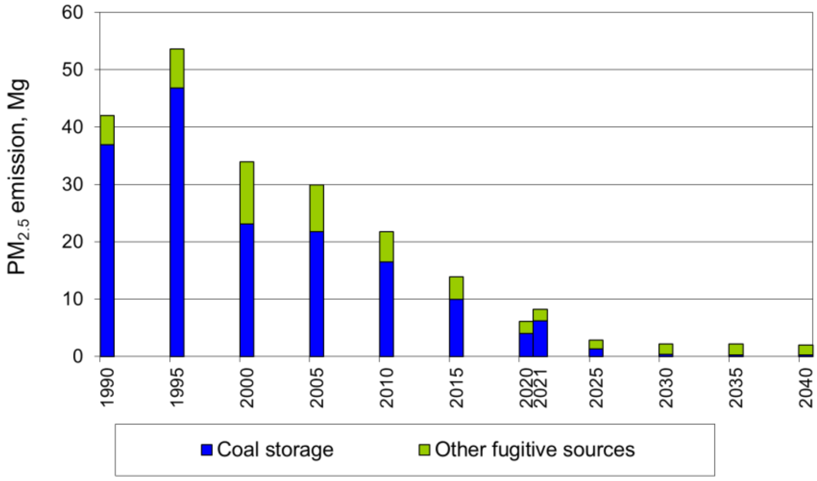


Figure 10.4.5 $PM_{2.5}$ emissions for selected historical years (1990-2020) and projection years (2021-2040).

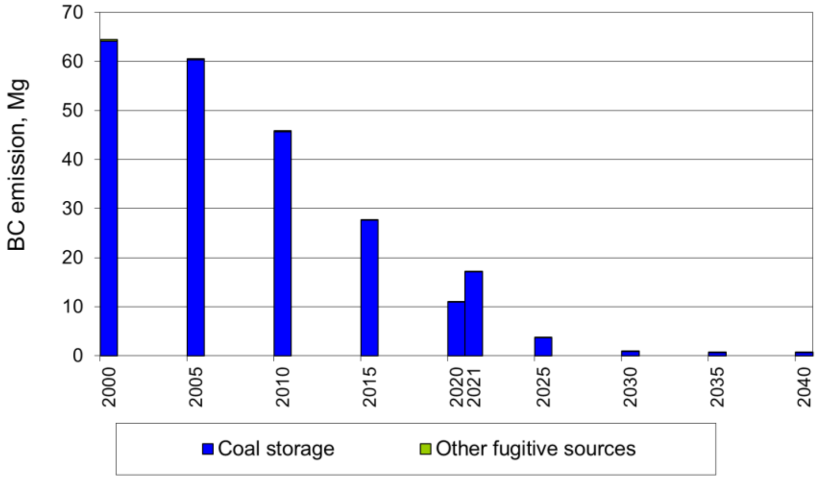


Figure 10.4.6 BC emissions for selected historical years (1990-2020) and projection years (2021-2040).

Table 10.4.7 Projected $PM_{2.5}$ emissions for selected historical years (1990-2020) and projection years (2021-2040).

NFR code	Source	1990	1995	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
		Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
1B1a	Coal storage	37	47	23	22	16	10	4	6	1	0	0	0
1B2a + 1B2b	Exploration of oil and gas	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1B2c	Refinery, flaring	0.4	0.4	0.3	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
1B2c	Flaring in oil and gas production	4.6	6.4	10.5	7.8	5.0	3.8	1.9	1.9	1.3	1.6	1.7	1.5

Table 10.4.8 Projected BC emissions for selected historical years (1990-2020) and projection years (2021-2040).

NFR code	Source	1990	1995	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
		Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
1B1a	Coal storage	103	130	64	60	46	28	11	17	4	1	1	1
1B2a + 1B2b	Exploration of oil and gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1B2c	Refinery, flaring	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1B2c	Flaring in oil and gas production	0.1	0.1	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0

11.4.5 References

A/S Dansk Shell - Havneterminalen, 2021: Annual Report for the Harbour Terminal (in Danish).

Boesen, S. 2020: Personal communication, e-mail correspondence 1/7 2020, Orsted.

Danish Energy Agency, 2022: Denmark's Energy and Climate Outlook (Feb. 2022).

Danish Environmental Protection Agency, 2008: Emissionsfaktorer for NOx-emissioner fra flaring fra platforme i Nordsøen (in Danish). Not published.

EMEP/EEA, 2019: EMEP/EEA air pollutant emission inventory guidebook – 2019. Available at: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (17-03-2022).

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (17-03-2022).

Visschedijk, A.J.H., Pacyna, J., Pulles, T., Zandveld, P. & Denier van der Gon, H., 2004: Coordinated European Particulate Matter Emission Inventory Program (CEPMEIP). In: Dilara, P. et al. (eds.), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004. EUR 21302 EN, JRC, pp. 163–174.

11.5 Industrial processes and product use

Industrial processes and product use covers a very large range of sources, some with very limited contributions to the total national emissions. However, some sources are significant in terms of overall emissions.

For some sub-sectors, it is not possible to distinguish between energy and process related emissions e.g. cement production. These sub-sectors are included in the chapter on stationary combustion.

11.5.1 Methodology

In most cases, no information is available to project emissions in a sophisticated manner. Therefore, in these cases the projection is done as the average of the three latest historical years. In the case of activities related to construction, growth factors for the projection time series are available (DEA, 2022).

Projected growth values for the construction sector are applied when projecting emissions from:

- Glass wool production
- Stone wool production
- Quarrying and mining of minerals other than coal
- Construction and demolition
- Storage, handling and transport of mineral products
- Production of brick, tiles and expanded clay products.

The growth factor time series is illustrated in Figure 11.5.1.

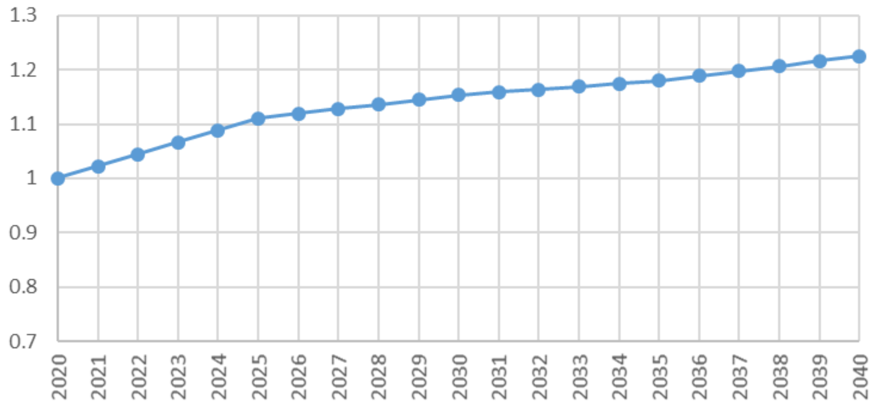


Figure 11.5.1 Expected development of the construction sector in relation to the 2020 level (DEA, 2022).

For the remaining sources (i.e. not construction related) the trends of the historical years are analysed, to ensure that there is not a significant increasing or decreasing trend that should be reflected in the projection. If such a trend is present, this is used in the projection, as is the case with the use of tobacco. When no convincing trend is present, the average value of the latest thee historical years is applied. In cases where these years are not representable, other historical years are chosen, e.g. if they contain significant outliers, like the 2018 SO_2 emission from pesticide production where measured emissions were 60 times higher than the three previous years.

An exception to the projection methodology described above, is the emission from the use of shoes. This sub-sector is projected using the population projection from Statistics Denmark (2022).

11.5.2 Emissions

Overall projected emissions from the IPPU sector are presented in Table 11.5.1 below. Detailed emission data for each sector in IPPU (e.g. Mineral industries, Chemical industries, etc.) are available online (https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/projection) and not repeated here.

Table 11.5.1 Historical and projected emissions from IPPU.

	Unit	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
SO_2	kt	4.1	4.2	3.8	3.7	1.6	1.0	1.0	1.1	1.1	1.1	1.2
NO_x	kt	1.0	0.8	0.6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
NMVOC	kt	42.5	49.8	45.0	35.5	29.6	30.5	33.2	33.3	33.3	33.3	33.3
CO	kt	13.7	11.6	15.4	16.4	2.9	4.5	2.4	2.7	2.7	2.6	2.6
NH_3	kt	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.4	0.4
TSP	kt	-	-	11.3	11.4	11.2	6.6	7.1	7.8	8.0	8.2	8.4
PM_{10}	kt	-	-	4.4	4.2	4.0	2.7	2.8	3.0	3.1	3.1	3.2
$PM_{2.5}$	kt	-	-	1.4	1.0	0.9	0.8	0.8	0.8	0.8	0.8	0.8
BC	t	-	-	18.5	13.2	8.0	11.8	7.4	8.4	8.4	8.4	8.4

11.5.3 References

DEA, 2022: Projected growth factors for construction companies. Personal communication.

Statistics Denmark, 2022: Danmarks Statistik, Befolkningsfremskrivning 2021 for hele landet efter tid (FRDK121). Available at: https://www.dst.dk/da/ (Danish/English).

11.6 Agriculture

The projection of air pollutants from the agricultural sector includes emission of ammonia (NH_3), particulate matter (PM) given as TSP, PM_{10} and $PM_{2.5}$, non-methane volatile organic compounds (NMVOC), sulphur dioxide (SO_2), nitrogen oxide (NO_X) and black carbon (BC).

The projection on emissions of air pollutants is regularly updated in line with new scientific knowledge as a consequence of new emission sources, changes of emission factors or changes of the agricultural production conditions e.g. changes regarding the export market or the legislation and regulation. Some of the changes can lead to revision in the historical emission inventory as well and therefore, some deviations are apparent in comparison with the projection scenarios published in previous reports.

11.6.1 Methodology

The methodology used to estimate the projected emission is based on the same methodology as used in the annual emission inventories, which is described in the EMEP/EEA air pollutant emission inventory guidebook (EMEP, 2019). Thus, the same database setup is used, same estimation approach and principally the same emission factors. In cases where the future conditions will change, e.g. by implementation of emission reducing technology, an adjustment of the emission factor will follow.

11.6.2 Assumptions

The data used to in this projection is based on information from a range of agricultural related institutions and organisations. Data from the model AGMEMOD is used to project the trend in livestock production and agricultural area, AGMEMOD is managed by IFRO – Department of Food and Resource Economics, Copenhagen University. Projection of trend in housing of animals and implementation of ammonia reducing technology in housings is based on estimates from SEGES – the agricultural advisory centre.

Livestock

For cattle, swine, hens and broilers, the number of animals is based on the model AGMEMOD (Jensen, 2022) until 2040. For non-dairy cattle, the number of bulls and heifers are projected based on AGMEMOD combined with estimates from DCA (Kristensen and Lund, 2016), to make it convertible with the cattle categories used in the national inventory setup.

The production of horses, sheep, goats, turkeys, ducks and geese is less important, because the contribution for these categories is relatively small compared to production of cattle, swine and fur animals. Therefore, the number of animal is kept at the same level as in 2020. When it comes to fur bearing animals (mink) the situation changes dramatically compared with historic years. Because of the risk for developing a COVID-19 variant, the government required to destroy all fur animals, which supports the assumption of no Danish mink production in 2021-2022. The mink production can be continued from 2023, but it will be very difficult and costly to restart the mink production especially because of the loss of breeding animals, so the production is projected to be only 10 % of the production in 2020.

Figure 11.6.1 shows the projected trend in number of animals given in percent change compared to 2020. In Table 11.6.1 are the actual numbers shown. An increase in number of cattle is expected up to 2030 but is expected to decrease again up to 2040 due to expected development in milk production and for number of non-dairy cattle the same trend is expected as a spillover effect.

The number of swine increases from 2020 to 2021 due increase in export of pork to China, because there were an outbreak of swine fever in 2019. The consequences of swine fever is expected to fade out and the production of swine is expected to decrease up to 2040. The number of sows is expected to decrease with almost 30 %, but due to expected increase in number of piglets per sow, number of weaners is only expected to decrease with around 15 %. Export of weaners is expected to stagnate at the same level as in 2020.

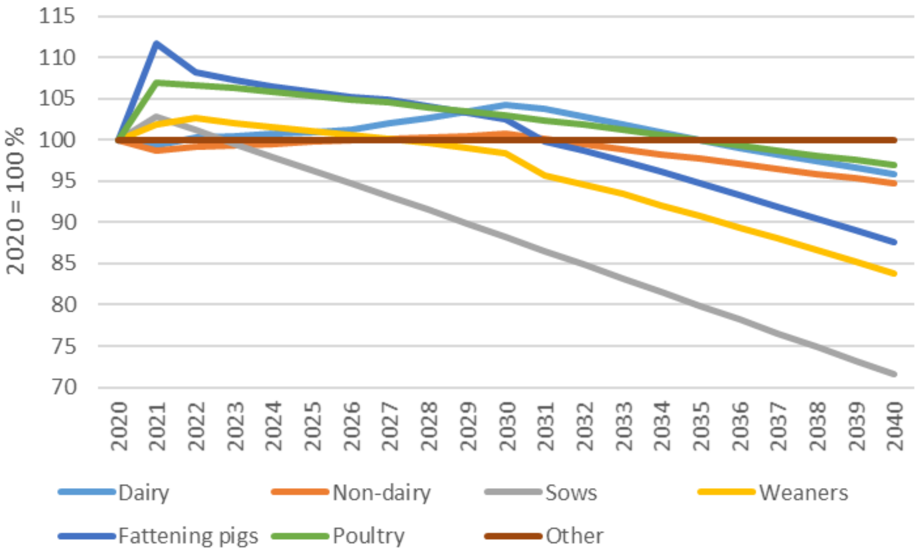


Figure 11.6.1 Trend of number of animals in 2020-2040 in relation to 2020.

Table 11.6.1 Projected number of animals, 1000 pc.

	2020	2021	2025	2030	2035	2040
Dairy cattle	567	563	572	591	567	543
Non-dairy cattle	1 121	1 118	1 130	1 140	1 106	1 073
Sows	1 055	1 085	1 017	931	843	755
Weaners (prod.)	33 246	33 875	33 599	32 702	30 178	27 863
Fattening pigs (prod.)	19 066	21 292	20 188	19 551	18 059	16 692
Poultry (prod.)	232	248	245	239	232	225
Mink	2 216	0	222	222	222	222
Other	281	281	281	281	281	281

Housing systems

Projection of distribution for cattle in different types of housing systems is provided by SEGES (Freudendal, 2021). The estimates are for 2030 and 2040 for dairy cattle and heifers. Distribution for the years 2021-2029 and 2031-2039 are interpolated. The projection takes into account legislation about animal welfare (space requirement, straw etc.) and environment requirement. In 2020, 89 % of the dairy cattle were housed in systems with cubicles. It is assumed that 91 % of dairy cattle will be housed in systems with cubicles in 2040, and tethering are phased out before 2030. For heifers, the tethering housing is also assumed to be phased out before 2030. Around 25 % expects to be housed in deep litter systems in 2040 and the remaining part is assumed to be placed in housing systems with cubicles.

For bulls and suckling cattle, the distribution on different housing systems for 2021-2040 is set at the same level as 2020.

For swine, SEGES (Hansen, 2021) estimates the distribution of animals on different housing systems. The estimates are made for 2030 and 2040 and for the years 2021-2029 and 2031-2039 the distribution is interpolated. Approximately 99 % of the fattening pigs and weaners are housed in systems with drained or partly slatted floor in 2020 and this is assumed to be the same in 2040. For sows, a decrease in systems where the sow is housed individually is assumed.

Jensen (2021, Pers. Comm.) projects distribution of hens and broilers on different housing systems. The estimates are made for 2030 and for the years 2020-2029, the distribution is interpolated and 2031-2040 is set at the same level as 2030. For broilers, it is assumed that the share of barn and organic broilers increase, while the share of 35 days broilers decrease in the years up to 2030.

For mink, there are two types of housing systems in the projection; housings where the manure is removed once a week and housings where manure is removed two times a week. In 2020, 11 % of mink were in systems where manure is removed two times a week. No production of mink are expected for 2021-2020 due to legislation brought on by COVID-19. For the years 2023-2040 same distribution as for 2020 are used.

Table 11.6.2 Projected distribution on housing systems (*2020 are historic year).

	2020*	2021	2025	2030	2035	2040
Dairy cattle						
Tethered with urine and solid manure	1.4	1.3	0.7	0	0	0
Tethered with slurry	2.0	1.8	1.0	0	0	0
Loose-holding with beds, solid floor	15.9	15.3	13.0	10.0	6.0	2.0
Loose-holding with beds, slatted floor	44.9	43.0	35.5	26.0	26.0	26.0
Loose-holding with beds, slatted floor, scrape	21.8	21.1	18.4	15.0	15.0	15.0
Loose-holding with beds, solid floor with tilt	5.9	9.3	23.1	40.3	44.3	48.3
Deep litter (all)	5.5	5.6	5.8	6.0	6.0	6.0
Deep litter, long eating space, solid floor	0.6	0.7	1.1	1.5	1.5	1.5
Deep litter, slatted floor	1.2	1.2	1.0	0.8	0.8	0.8
Deep litter, slatted floor, scrape	0.8	0.8	0.6	0.4	0.4	0.4
Fattening pigs						
Partly slatted floor (50-75 % solid floor)	10.7	10.5	9.9	9.0	8.0	7.0
Partly slatted floor (25-49 % solid floor)	39.0	40.1	44.5	50.0	58.5	67.0
Solid floor	0.4	0.4	0.3	0.1	0.1	0.1
Deep litter	0.5	0.5	0.5	0.4	0.4	0.4
Partly slatted floor and partly deep litter	0.5	0.5	0.5	0.5	0.5	0.5
Partly slatted and drained floor	48.9	48.0	44.5	40.0	32.5	25.0
Broilers						
Broilers, (conv. 30 days)	1.2	1.2	1.1	1.0	1.0	1.0
Broilers, (conv. 32 days)	30.5	29.9	27.3	24.0	24.0	24.0
Broilers, (conv. 35 days)	56.6	53.4	40.8	25.0	25.0	25.0
Broilers, (conv. 40-45 days)	6.2	7.1	10.6	15.0	15.0	15.0
Broilers, barn (56 days)	3.8	6.4	16.9	30.0	30.0	30.0
Organic broilers (81 days)	1.7	2.0	3.4	5.0	5.0	5.0

NH_3 reducing technology

The technologies included in this projection is; acidification of slurry, cooling of manure, air cleaning, frequent removal of manure (mink) and heat exchanger (broilers).

The environmental technologies are closely related to the growth in livestock production. An expansion of existing or new farms will be met by environmental requirements and the emission reducing technology will, for some farmers, be chosen as an opportunity to reduce the ammonia emission. The economic conditions can make it difficult for farmers to expand the livestock production, but animal housing systems will be outdated over time, and thus need to be replaced.

The assumptions regarding the expansion and development of emission reducing technologies in livestock production used in the historic emission inventory is based on data from the environmental approvals register 2007-2016 (Annex 3D Chapter 3D-1).

For cattle the only available technology in housings are, for now, acidification and projection of this is made by SEGES (Freudendal, 2021). The projection is used for dairy cattle and heifers.

Projection of distribution of housings with acidification and cooling of manure are based Hansen (2021) and distribution of housings with air cleaning is based on Wiborg (2022).

Manure cooling is the most frequently used technology for the overall swine production, but in particular in housings for sows and weaners and this trend is expected to continue. For new build housings cooling of manure is expected to be installed extensively. Acidification of manure in housings for swine is expected to continue at the same level in the future as at present. Air cleaning is expected to be phased out in 2040 based on the low distribution at present and because air cleaning only reduces ammonia and no greenhouse gasses.

Acidification in housings for cattle is expected to continue at the same level in the future as at present.

Table 11.6.3 Percentage of total production of swine and cattle with NH_3 reducing technology in housings, %.

Cooling of manure	2020	2021	2025	2030	2035	2040
Sows	7	11	24	40	55	70
Weaners	5	8	18	30	43	55
Fattening pigs	3	5	12	20	28	35
Acidification in housing	2020	2021	2025	2030	2035	2040
Dairy cattle	3	3	4	4	4	4
Heifer	1	1	1	2	2	2
Sows	3	3	3	4	4	4
Weaners	1	1	2	2	2	2
Fattening pigs	2	2	3	5	5	5
Air cleaning	2020	2021	2025	2030	2035	2040
Sows	0	1	3	5	3	0
Weaners	0	0	0	0	0	0
Fattening pigs	0	1	2	4	2	0

In 2020, almost 90 % of broiler housings have heat exchanger installed and it is expected that this increase to 100 % by 2030 (Jensen, 2021, Pers. Comm.). As mentioned the mink production is not existing in 2021-2022, but a small production is expected from 2023 and is expected that 90 % of this will remove the manure 2 times weekly.

Projection of acidification during application of manure is based on Birkmose (2021). The acidification during application is estimated to increase due to increasing demands for utilisation of N in manure and reduction of emission, which will increase the need for acidification (Birkmose, 2021).

Table 11.6.4 Percentage of total production of broilers and mink with NH_3 reducing technology in housings and percentage of acidification during application of manure, %.

Heat exchanger	2020	2030	2040
Broilers	92	100	100
Removal of slurry - 2 times weekly	2020	2030	2040
Mink	11	90	90
Acidification during application	2020	2030	2040
Cattle manure	8	12	16
Swine manure	1	2	4

Reducing potential for NH_3 reducing technology

The List of Environmental Technologies managed by Danish Environmental Protection Agency (DEPA, 2022) includes a range of NH_3 reducing technologies, and for each technology is provided a maximum reducing effect for full use of the technology. The listed factors for cooling and acidification of slurry, heat exchanging and frequent removal of manure are used.

Assessment of the environmental approval register shows a high variation in the NH_3 reducing effects in practice for air cleaning, dependent on the conditions on the farm – e.g. the amount of air in housing which is cleaned etc. Based on the review of this reducing factors have been estimated.

In Table 11.6.5 are shown the reduction factors used.

Table 11.6.5 NH_3 reducing factors, %.

	Animal type	NH_3 reducing factors %
Cooling of manure	Swine	20*
Acidification of slurry in housings	Cattle	50*
	Swine	64*
Acidification of slurry during application	Cattle	49*
	Swine	40*
Air cleaning	Sows	61**
	Weaners	54**
	Fattening pigs	56**
Heat exchanger	Broilers	30*
Frequent removal of manure	Mink	27*

*List of Environmental Technologies (DEPA, 2022).
** Based on the review of the register of environmental approvals 2007-2016.

N-excretion

Development in N-excretion for dairy cattle and swine are based on projection made by Lund (2021) and Nørgaard & Hellwing (2021), respectively. For all other animal categories, N-excretion is set at the same level as in 2020.

N-excretion for dairy cattle is expected to increase 15 % in 2040 due to increase in feed intake and increase in milk yield. For fattening pigs and weaners N-excretion is expected to decrease around 20 % mainly due to decrease in feed intake and an increase in feed efficiency.

Table 11.6.6 N-excretion, kg per year.

	2020	2021	2025	2030	2035	2040
Dairy cattle						
Large breed	160.7	161.9	166.9	172.6	179.5	185.4
Jersey	131.0	132.2	137.0	142.1	147.5	152.6
Swine						
Sows	23.8	23.9	24.0	23.9	23.8	23.7
Weaners	0.5	0.5	0.4	0.4	0.4	0.4
Fattening pigs	2.9	2.9	2.8	2.6	2.4	2.3

Agricultural area

The projection of the agricultural area is based on the area in 2020 subtracted the projected area for extraction of organic soils and wetlands (DAA, 2021), afforestation (Krogh, 2021) and area for increasing infrastructure (Gyldenkærne, 2021).

The production of different crops dependents on the development in prices and yields and are estimated by AGMEMOD (Jensen, 2022). The area of the different crop types are projected by a combination of estimates from AGMEMOD and historic development, to include all agricultural area in the projection calculations.

Table 11.6.7 Agricultural land area in the projection, 1 000 ha.

	2020	2021	2025	2030	2035	2040
Agricultural land area	2 620	2 607	2 558	2 507	2 493	2 479
Organic soils and wetlands[1]	0	10	38	60	60	60
Afforestation[2]	0	0	11	26	26	26
Infrastructure[3]	0	3	14	27	41	54

[1] Extraction of organic soils and wetlands (DAA, 2021).

[2] (Krogh, 2021).

[3] (Gyldenkærne, 2021).

Use of inorganic N-fertiliser

Use of inorganic fertiliser depends on the agricultural area and the amount of available nitrogen in animal manure and sewage sludge (amount of N in the farmers nitrogen fertiliser account). The use of inorganic fertiliser is also affected by the policy decision regarding lower nitrogen quota for cultivated organic soils, lower nitrogen quota for §3 areas and increased area with perennial grass and fallow, which will lower the total amount of N applied to the agricultural area.

The estimate for the expected inorganic fertiliser consumption is basically based on the total amount of N applied to agricultural land, as an average for the years 2018-2020, which is estimated at 147 kg N/ha. A decrease in the total cultivated area leads to lower total N need. No significant changes in the allocation between fertiliser types is assumed to take place until 2040, so allocation for 2020 is used for all projected years.

The requirements of lower N quota for organic soils enters into force from year 2021, where it is expected that the nitrogen fertilisation will be reduced by 4 600 ton N. This estimate has been obtained by comparing the fertiliser levels in the guidelines for the planning years 2019/2020 and 2020/2021 (Vejledning om gødsknings- og harmoniregler) (DAA, 2019, DAA, 2020) and a list of crops cultivated on organic soils for 2020. This reduction effect will decrease from 2021 to 2032 (4 100 ton N) because the cultivated area of organic soils is expected to be reduced by approximately 17 000 hectare until 2032 (estimated by the Danish Agricultural Agency).

In legislation for § 3 areas is introduced a general ban on spraying, fertilising and conversion of §3 protected areas (Law no. 1057 of 30/06/2020). In comments to this regulation is mentioned that a decrease of 5 800 ton N per year is expected and the law enters into force from 1/7-2022.

The increasing interest and demand for reduction of loss of N-surplus to the aquatic environment and reduction of the air emission as well as the emission of greenhouse gases, a political agreement has been reached; Agreement on the Green Transition for Danish Agriculture (AGTDA, 2021). This agreement includes subsidy schemes and based on this, an increase in the area of perennial grass must be expected. Development in the agricultural land follows the hectare and allocation of crops given in the AGMEMOD model. Besides, it is assumed that the area of grass seed is at the same level as for 2018-2020, which is also the case for fallow area, area for Christmas trees and vegetables and fruit. Expansion of perennial grassland is expected to take place on the remaining area, and thus it is assumed that the area of perennial grass will increase by 83 000 hectares from 2020 until 2040.

Table 11.6.8 shows background data for estimation of the amount of N consumption for use of inorganic fertiliser. The regulation of lower N fertilisation of organic soils, §3 areas and perennial grass and fallow leads to a decrease of the average N applied to soils from 152 kg/ha in 2020 to 140 kg N/ha in 2040.

Table 11.6.8 Consumption of inorganic nitrogen fertilisers.

	2020	2021	2022	2023	2024	2025	2030	2040
Agricultural area, ha	2619987	2606943	2594292	2581672	2569305	2557586	2506621	2479441
Total N quota, kt N	398.7	382.1	380.2	378.4	376.6	374.9	367.4	363.4
Reduced N quota:								
Organic soils, kt N		-4.6	-4.5	-4.5	-4.4	-4.4	-4.2	-4.1
§3 areas, kt N				-5.8	-5.8	-5.8	-5.8	-5.8
Perennial grass and fallow, kt N				-8.1	-8.0	-8.5	-8.4	-5.9
Adjusted total N quota, kt N	398.7	377.5	375.7	360.0	358.4	356.1	349.0	347.6
N fulfilled by manure + sewage, kt N*	144.0	155.8	154.4	154.6	153.8	153.3	151.7	136.7
N fulfilled by inorganic fertiliser, kt N	251.9	221.7	221.4	205.4	204.6	202.8	197.4	210.9
Kg N fertilised per ha	152	145	145	139	139	139	139	140

* Amount of N, which have to be counted for in the farmers nitrogen fertiliser account.

Field operations

The emission of PM from field operations is calculated by area of cultivated crops multiplied with number of operations and emission factor, for each crop type and type of operation. Operations are divided in soil cultivation, harvesting, cleaning and drying. The projection of PM from field operations is based on a level equivalent to the average emission from the years 2016-2020 combined with the area.

11.6.3 Emissions

This projection covers the latest official Danish reporting, which includes historical emission until 2020. Thus, the projection comprises an assessment of the emissions from the agricultural sector from 2021 to 2040. Emission of NH_3, NOx and $PM_{2,5}$ are expected to decrease by 24, 14 and 7 %, respectively, while emission of NMVOC are expected to increase by 7 %.

Table 11.6.9 Projected emissions from the agricultural sector.

Tonnes	2020	2021	2025	2030	2035	2040	2020-2040	%
NH_3	72.959	67.834	64.660	61.646	58.661	55.796	-17.164	-24
NO_x	19.753	18.434	17.557	17.250	17.122	16.994	-2.759	-14
SO_2	28	25	24	24	24	23	-5	-18
NMVOC	46.219	46.046	47.423	49.784	49.593	49.268	3.048	7
$PM_{2,5}$	1.291	1.259	1.251	1.247	1.222	1.196	-95	-7
BC	28	25	24	24	24	23	-5	-18

NH_3 emission

NH_3 emission is expected to decrease by 17 000 t NH_3 in the period 2020 to 2040, corresponding to a decrease of 24 %. The emission from animal manure is expected to decrease by 12 500 t NH_3, corresponding to a decrease of 38 % compared to 2020. The decrease is due to a combination of decrease in number of animals, changes in distribution of animals in housings and implementation of NH_3 reducing technology.

For manure applied to soil a decrease in emission of 15 % is expected and this is mainly due to decrease in N from swine manure.

Emission from use of inorganic N-fertiliser is expected to decrease by 1 400 t NH_3 until 2040, corresponding to a decrease of 11 % compared to 2020. This is due to increase in area with low or no application of fertiliser and decrease in agricultural area. The emission from growing crops and other sources is expected to decrease by 3-5 %, caused by decrease of the agricultural area.

Table 11.6.10 Changes in NH_3 emission 2020-2040.

Tonnes NH_3	2020	2021	2025	2030	2035	2040	Difference 2020-2040	pct
Manure	32 657	28 887	27 055	24 826	22 411	20 125	-12 532	-38
Inorganic N-fertiliser	12 158	11 312	10 347	10 068	10 413	10 760	-1 397	-11
Manure applied to soil	18 698	18 223	17 936	17 531	16 705	15 868	-2 830	-15
Cultivated crops	5 369	5 367	5 265	5 160	5 132	5 104	-265	-5
Other*	4 078	4 045	4 057	4 061	3 999	3 938	-140	-3
Sum	72 959	67 834	64 660	61 646	58 661	55 796	-17 164	-24

* Sewage sludge, grazing, field burning, ammonia treated straw.

In Table 11.6.11, are shown the emission from manure in housings and storage for the period 2020-2040 distributed on animal categories. Emission of NH_3 from swine is expected to decrease by 49 % from 2020 to 2040, due to a combination of decrease in production of animals, lower N-excretion for weaners and fattening pigs and increase in implementation of NH_3 reducing technology.

Emission of NH_3 from dairy cattle is expected to decrease by 18 % from 2020 to 2040 due to a combination of decrease in number of animals and changes in the distribution of housings, where it is assumed that systems with high

NH_3 emission (solid floor) are replaced with systems with a lower NH_3 emission such (drained floor). Emission from non-dairy cattle is expected to decrease by 6 % mainly due to decrease in number of animals.

The mink production is closed down in 2021 and 2022 and only expected to continue with very low production from 2023-2040, therefor a high decrease in the emission is expected. For poultry, the production and emission is assumed to decrease.

Table 11.6.11 Changes in NH_3 emission from manure (housing and storage).

Tonnes NH_3	2020	2021	2025	2030	2035	2040	Difference 2020-2040	pct
Dairy cattle	7 523	7 390	7 279	7 192	6 698	6 167	-1 356	-18
Non-dairy cattle	3 081	3 069	3 089	3 106	3 001	2 898	-184	-6
Swine	14 470	14 746	12 686	10 643	8 929	7 377	-7 092	-49
Poultry	2 519	2 715	2 662	2 593	2 490	2 391	-128	-5
Mink	4 098	0	371	325	325	325	-3 773	-92
Other	966	967	967	967	967	967	1	0
Sum	32 657	28 887	27 055	24 826	22 411	20 125	-12 532	-38

PM emission

The emission of $PM_{2,5}$ is expected to decrease by 7 % in the period 2020-2040. Emission from animals is assumed to decrease due to decrease in number of animals and emission from field operations and field burning due to decrease in the agricultural area.

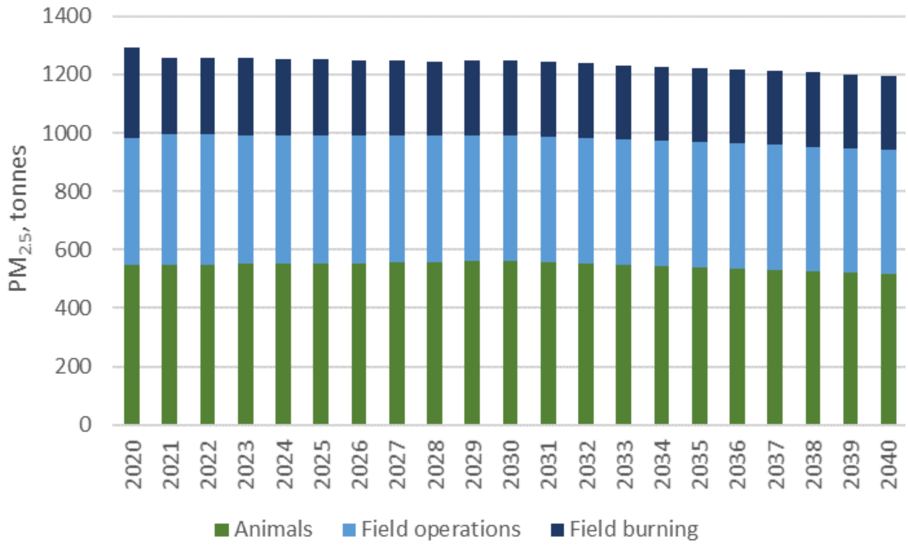


Figure 11.6.2 Projected $PM_{2,5}$ emission 2020-2040.

NMVOC emission

The NMVOC emission from the agricultural sector is expected to increase by 7 %in the period from 2020 to 2040. This is due to increase in the emission from manure management and manure applied, which is mainly due to increase in feed intake for dairy cattle.

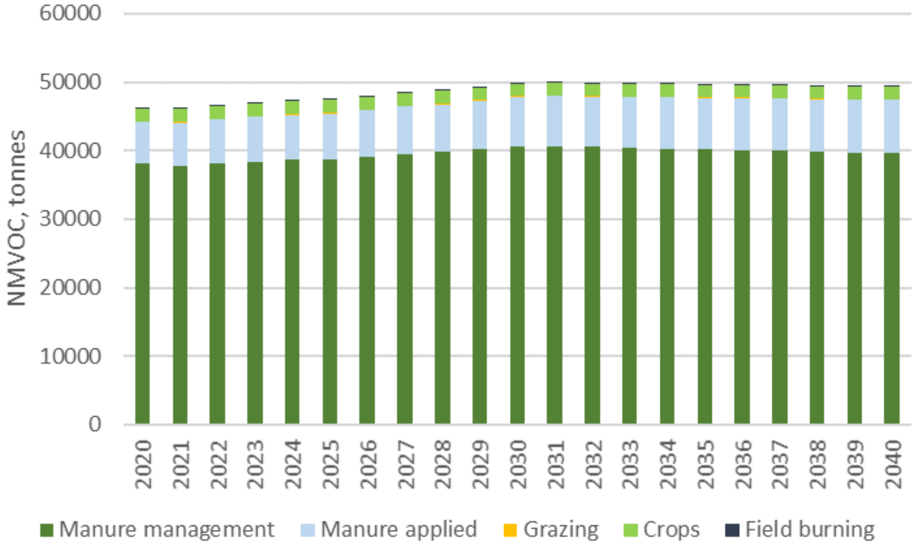


Figure 11.6.3 Projected NMVOC emission 2020-2040.

NO_x emission

NO_x emission is expected to decrease by 14 % in 2020-2040, mainly due to decrease in emission from inorganic N-fertiliser and manure applied to soil.

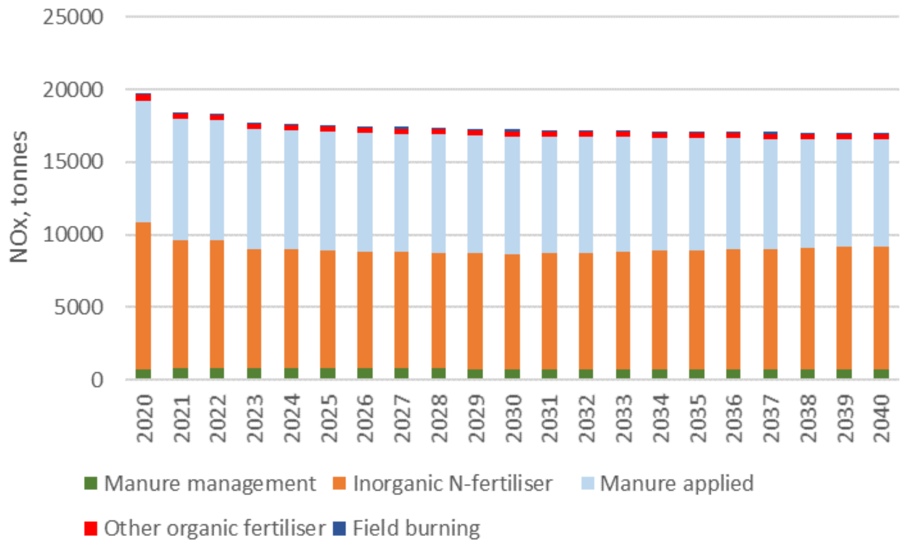


Figure 11.6.4 Projected NO_x emission 2020-2040.

SO_x and BC emission

The agricultural sector contributes with less than one percent of the national emission of SO_2 and BC. The agricultural emission of SO_2 and BC comes from field burning of agricultural residues. The projected emission is based on the average emission from 2016-2020 combined with the projection of the agricultural area. The emission is estimated to decrease due to decrease in agricultural area.

11.6.4 References

AGTDA, 2021: Agreement on the Green Transition for Danish Agriculture (in Aftale om grøn omstilling af dansk landbrug). af 4. oktober 2021 mellem regeringen, Venstre, Dansk Folkeparti, Socialistisk Folkeparti, Radikale Venstre, Enhedslisten, Det Konservative Folkeparti, Nye Borgerlige, Liberal Alliance og Kristendemokraterne. Available at: https://fm.dk/media/25215/aftale-om-groen-omstilling-af-dansk-landbrug.pdf

Birkmose, T. 2021: Projection of manure application methods and acidification of manure during application. Torkild Birkmose, SEGES. Data received in Excel sheet.

DAA, 2019: Vejledning om gødskningsog harmoniregler Planperioden 1. august 2019 til 31. juli 2020. Danish Agricultural Agency. (In Danish). Available at: https://lbst.dk/fileadmin/user_upload/NaturErhverv/Filer/Landbrug/Goedningsregnskab/Vejledning_om_goedsknings-_og_harmoniregler_i_planperioden_2019_2020_version2.pdf (Feb. 2022)

DAA, 2020: Vejledning om gødsknings og harmoniregler Planperioden 1. august 2020 til 31. juli 2021. Danish Agricultural Agency. (In Danish). Available at: https://lbst.dk/fileadmin/user_upload/NaturErhverv/Filer/Landbrug/Goedningsregnskab/Vejledning_om_goedsknings-_og_harmoniregler_2020_2021.pdf (Feb. 2022)

DAA, 2021: Bilag 2 - KF22 forudsætninger udtagning af lavbundsjorder. Danish Agricultural Agency. Data received in Excel sheets.

DEPA, 2022: List of Environmental Technologies. Danish Environmental Protection Agency. Available at: https://eng.mst.dk/trade/agriculture/environmental-technologies-for-livestock-holdings/list-of-environmental-technologies/ (March 2022).

EMEP/EEA air pollutant emission inventory guidebook, 2019: Available at: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (March 2022).

Freudendal, A.J. 2021: Projection of distribution on housing types and emission reducing technology for cattle. Anja Juul Freudendal, SEGES. Received by mail December 2021.

Gyldenkærne, S. 2021: Projection of area extraction for infrastructure used in projection of emissions greenhouse gases from LULUCF. Data received in Excel sheets.

Hansen, B.I. 2021: Projection of distribution on housing types and emission reducing technology for swine, plus projection on covering of slurry tanks. Bent Ib Hansen, SEGES. Received by mail December 2021.

Jensen, H.B. 2021: Henrik Bang Jensen. Pers. Comm. Danish Agriculture and Food Council.

Jensen, J. D. 2022: Landbrugsfremskrivning – efteråret 2021. Department of Food and Resource Economics (IFRO), University of Copenhagen. Revised January 2022

Kristensen, T. & Lund, P. 2016: Fordeling af kvæg i kategorier. Aarhus University, DCA – Danish Center for Food and Agriculture.

Krogh, M. 2021: Forudsætninger for skovrejsning til klimafremskrivning 2022. Morgens Krogh, Danish Agricultural Agency. Memorandum of 6. October 2021

Law nr. 1057 af 30/06/2020, 2020: Lov om ændring af lov om naturbeskyttelse (Forbud mod sprøjtning, gødskning og omlægning af § 3-beskyttede arealer). Available at: https://www.retsinformation.dk/eli/lta/2020/1057

Lund, P. 2021: Prædiktion af udskillelse af kvælstof hos malkekøer i 2025, 2030, 2035 og 2040 på baggrund af data fra AGMEMOD-modellen for 2020, data fra ydelseskontrollen 2020 og NORMTALS-modellen for 2021/2022. 13 sider. Rådgivningsnotat fra DCA – Nationalt Center for Fødevarer og Jordbrug, Aarhus Universitet, leveret: 21. december 2021. (in Danish).

Nørgaard, J.V. & Hellwing, A.L.F. 2021: Fremskrivning af grises N-udskillelse fra dyr, stald og lager i år 2025, 2030, 2035 og 2040. 8 sider. Rådgivningsnotat fra DCA – Nationalt Center for Fødevarer og Jordbrug, Aarhus Universitet, leveret: 21. november 2021.

Wiborg, I.A. 2021: Pers. Comm. Irene Asta Wiborg, SEGES. Data received by mail 05.01.2022

11.7 Waste

All waste incineration of municipal, industrial and hazardous waste in Denmark is done with energy recovery. Hence, the emissions from these activities are included under the stationary combustion part of both the emission inventory and the emission projection. The sources included in the waste emission projection are:

- Solid waste deposit sites (SWDS) – NMVOC, TSP, PM_{10} and $PM_{2.5}$
- Biological treatment of waste, i.e. composting and anaerobic digestion – CO and NH_3
- Waste incineration, i.e. cremations of corpses and carcasses – SO_2, NO_x, NMVOC, CO, NH_3, TSP, PM_{10} and $PM_{2.5}$
- Wastewater treatment - NMVOC
- Accidental building and vehicle fires - SO_2, NO_x, NMVOC, CO, TSP, PM_{10} and $PM_{2.5}$

11.7.1 Methodology

The methods used in the emission projections follow the methodologies for the emission inventory as described in Chapter 6.

Particle emissions from solid waste deposit sites are estimated from the projected total amount of deposited waste, while NMVOC emissions are based on only the organic waste for SWDS.

NH_3 emission projections from anaerobic digestion are calculated from the expected development of the biogas energy production (PJ) from the Danish Energy Agency (DEA, 2022).

Emissions from both composting, cremations, wastewater and accidental fires are projected as the constant average emissions from the three latest historical years.

Regarding emission factors, please refer to Chapter 6 of this report.

11.7.2 Emissions

Overall projected emissions from the waste sector are presented in Table 11.7.1 below. Detailed emission data for each sub-sector in waste (e.g. SWDS, Biological treatment of waste, etc.) are available online (https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/projection) and not repeated here.

Table 11.7.1 Historical and projected emissions from the waste sector.

	Unit	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
SO_2	kt	0.81	0.93	0.82	0.79	0.84	0.95	0.95	0.99	0.99	0.99	0.99
NO_x	kt	0.09	0.10	0.09	0.09	0.11	0.10	0.10	0.11	0.11	0.11	0.11
NMVOC	kt	2.02	1.50	1.20	0.48	0.55	0.61	0.58	0.82	0.85	0.87	0.91
CO	kt	0.97	1.12	1.20	1.21	1.31	1.28	1.37	1.38	1.38	1.38	1.38
NH_3	kt	0.21	0.27	0.54	0.53	0.59	0.62	0.69	0.69	0.69	0.69	0.69
TSP	kt	-	-	0.34	0.33	0.37	0.29	0.32	0.32	0.32	0.32	0.32
PM_{10}	kt	-	-	0.34	0.33	0.37	0.29	0.32	0.32	0.32	0.32	0.32
$PM_{2.5}$	kt	-	-	0.34	0.33	0.37	0.29	0.32	0.32	0.32	0.32	0.32

11.7.3 References

DEA, 2022: Projection of biogas production. Unpublished.

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. 2021: 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, 580 pp. Scientific Report No. 435. Available at: http://dce2.au.dk/pub/SR435.pdf

12 Adjustments

Decision 2012/3 of the Executive Body (UNECE, 2012a) decided that adjustments may be made under specific circumstances to the national emission inventories for the purpose of comparing the inventories with emission reduction commitments.

Under the revised NEC Directive (Directive 2016/2284/EU) Article V specifies flexibilities one of which is the possibility to establish adjusted emission inventories, where non-compliance with the national emission reduction commitments would result from applying improved emission inventory methods updated in accordance with scientific knowledge.

The circumstances under which an adjustment may be applied fall into three broad categories where:

- Emission source categories are identified that were not accounted for at the time when emission reduction commitments were set;
- Emission factors used to determine emissions levels for particular source categories for the year in which emissions reduction commitments are to be attained are significantly different than the emission factors applied to these categories when emission reduction commitments were set;
- The methodologies used for determining emissions from specific source categories have undergone significant changes between the time when emission reduction commitments were set and the year they are to be attained.

The supporting documentation required by Parties applying for an adjustment is set out in Decision 2012/12 (UNECE, 2012b) and in Annex IV Part 4 of Directive 2016/2284/EU and is summarised below.

A Party's/MS supporting documentation for an adjustment to its emission inventory or emission reduction commitments shall include:

- Evidence that the Party/MS exceeds its emission reduction commitments;
- Evidence of to what extent the adjustment to the emission inventory reduces the exceedance and possibly brings the Party/MS in compliance;
- An estimation of whether and when the reduction commitment is expected to be met based on emission projections without the adjustment, thereby using best available science;
- A full demonstration that the adjustment is consistent with one or more of the three broad categories above. Reference can be made, as appropriate, to relevant previous adjustments:
  - For new emission source categories:
    - Evidence that the new emission source category is acknowledged in scientific literature and/or the EMEP/EEA air pollutant emission inventory guidebook;
    - Evidence that this source category was not included in the relevant historic national emission inventory at the time when the emission reduction commitment was set;
    - Evidence that emissions from a new source category contribute to a Party being unable to meet its reduction commitments, support-

ed by a detailed description of the methodology, data and emission factors used to arrive at this conclusion;
- For significantly different emission factors used for determining emissions from specific source categories:
  - A description of the original emission factors, including a detailed description of the scientific basis upon which the emission factor was derived;
  - Evidence that the original emission factors were used for determining the emission reductions at the time when they were set;
  - A description of the updated emission factors, including detailed information on the scientific basis upon which the emission factor was derived;
  - A comparison of emission estimates made using the original and the updated emission factors, demonstrating that the change in emission factors contributes to a Party/MS being unable to meet its reduction commitments; and
  - The rationale for deciding whether the changes in emission factors are significant;
- For significantly different methodologies used for determining emissions from specific source categories:
  - A description of the original methodology used, including detailed information on the scientific basis upon which the methodology was based;
  - Evidence that the original methodology was used for determining the emission reductions at the time when they were set;
  - A description of the updated methodology used, including a detailed description of the scientific basis or reference upon which it has been derived;
  - A comparison of emission estimates made using the original and updated methodologies demonstrating that the change in methodology contributes to a Party/MS being unable to meet its reduction commitment; and
  - The rationale for deciding whether the change in methodology is significant.

12.1 Differences between UNECE and NECD

Under Directive 2016/2284/EU, the emissions of NO_x and NMVOC from animal husbandry and manure management (NFR category 3B) and crop production and agricultural soils (NFR category 3D) are excluded from the accounting as per Article 4, paragraph 3d of the Directive.

Under the amended Gothenburg Protocol (UNECE, 2013), emissions of NO_x from crop production and agricultural soils (NFR category 3D) are excluded from the accounting as per Annex II, footnote a to Table 3.

The differences in definitions on the emissions to be accounted leads to different compliance totals even in the absence of adjustments and can lead to a need for an adjustment under one reporting obligation without being needed for the other.

12.2 Accepted adjustments

Denmark applied for an adjustment under the UNECE in the 2022 submission that was approved (CEIP, 2022).

The adjustment pertains to NMVOC from Dairy Cattle (NFR 3B1a) on the basis that this is a new source compared to when the ERCs were set. In the 2009 version of the Guidebook (EEA, 2009), no default emission factors were available for NMVOC emissions from animal husbandry and manure management.

Table 122.1 NMVOC emissions with and without emissions from Dairy Cattle (NFR 3B1a).

Emissions, kt	2005	2021	Emission reduction, %	ERC, %
NMVOC	153.60	106.62	30.6	35
NMVOC from 3B1a	20.03	24.45	-19.4	
NMVOC excluding 3B1a	133.57	82.17	38.6	35
Accepted adjustment	-20.03	-24.45		

The latest emission projection was done in 2022 and reported in 2023. This indicated that without an adjustment, Denmark would not meet the reduction target throughout the projection period (until 2040).

A detailed methodological description is provided in Chapter 5.3.4 and is only summarised here.

The estimation of NMVOC emission is based on the EMEP/EEA guidebook (2019) Tier 2 approach. The NMVOC emission is estimated on the number of animals, share of time spend in housing/on grass (time on grass in Table 5.13), gross energy for cattle (Annex 3D Table 3D-16), volatile solids (VS) for other animal categories (Annex 3D Table 3D-17) and fraction of silage in the feed (Table 5.15). The number of animals is given as the average annual population (AAP) – see Table 5.6.

NMVOC emission factors are used from the EMEP/EEA Guidebook (EEA, 2019) Table 3-11 (cattle) and Table 3-12 (other animals) is used, see Table 5.16. The same emissions factors are used for all years, which means that changes in the emission over time are caused by changes in animal production, feeding practice or grazing days.

12.3 Application for adjustment(s)

12.3.1 Gothenburg Protocol

No application for adjustment is made in this submission.

12.3.2 National Emission Ceilings Directive

No application for adjustment is made in this submission.

12.4 References

CEIP, 2022: Review of the 2022 Adjustment Application Denmark Expert Review Team Report. Available at:
https://www.ceip.at/fileadmin/inhalte/ceip/00_pdf_other/2022/adjustment/review_of_the_2022_adjustment_application_dk_final.pdf (20-02-2023).

Directive 2016/2284/EU, 2016: Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016L2284&from=EN (20-02-2023).

EEA, 2013: EMEP/EEA air pollutant emission inventory guidebook – 2009. Technical guidance to prepare national emission inventories. EEA Technical report No 9/2009. Available at: https://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009 (20-02-2023).

EEA, 2019: EMEP/EEA air pollutant emission inventory guidebook — 2019. Technical guidance to prepare national emission inventories. EEA Report No 13/2019. Available at: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (20-02-2023).

UNECE, 2012a: Decision 2012/3 'Adjustments under the Gothenburg Protocol to emission reduction commitments or to inventories for the purposes of comparing total national emissions with them'. Available at: http://www.unece.org/fileadmin/DAM/env/documents/2013/air/ECE_EB.AIR_111_Add.1__ENG_DECISION_3.pdf (20-02-2023).

UNECE, 2012b: Decision 2012/12 'Guidance for adjustments under the 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone to emission reduction commitments or to inventories for the purposes of comparing total national emissions with them'. Available at: http://www.unece.org/fileadmin/DAM/env/documents/2012/EB/Decision_2012_12.pdf (20-02-2023).

UNECE, 2013: 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone to the Convention on Longrange Transboundary Air Pollution, as amended on 4 May 2012. Available at: https://unece.org/sites/default/files/2021-10/ECE.EB_.AIR_.114_ENG.pdf (20-02-2023).

Annexes

Annex 1 – Key category analysis

Denmark has carried out a key category analysis (KCA) level and trend assessment based on the NFR categories for all pollutants, i.e. no further disaggregation has been made. Denmark has applied Approach 1 based on the 2019 EMEP/EEA Guidebook and applied the recommended threshold value of 80 %. The results of the KCA for 2021 and the trend between 1990 and 2021 is presented in Table A1.1-A1.3 below.

Table A1.1 Categories identified as key based on emission level in 2021, main pollutants.

NFR	NO_x	NMVOC	SO_x	NH_3	$PM_{2.5}$	PM_{10}	TSP	BC	CO
1A1a Public electricity and heat production	L1, T1		L1, T1		L1	L1			L1
1A2e Stationary combustion in manufacturing industries and construction: Food processing, beverages and tobacco			L1, T1						
1A2f Stationary combustion in manufacturing industries and construction: Non-metallic minerals	L1		L1						L1
1A2gvii Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)					T1	T1	T1	L1, T1	
1A3bi Road transport: Passenger cars	L1, T1	T1			T1	T1		T1	L1, T1
1A3bii Road transport: Light duty vehicles	L1	T1			T1	T1	T1	T1	
1A3biii Road transport: Heavy duty vehicles and buses	L1, T1				T1	T1	T1	T1	
1A3biv Road transport: Mopeds & motorcycles									L1
1A3bv Road transport: Gasoline evaporation		T1							
1A3bvi Road transport: Automobile tyre and brake wear					L1	L1, T1		L1	
1A3bvii Road transport: Automobile road abrasion					L1	L1			
1A3dii National navigation (shipping)	L1		T1		L1, T1	T1			
1A4aii Commercial/institutional: Mobile									L1
1A4bi Residential: Stationary	L1	L1, T1	L1, T1		L1, T1	L1, T1	L1, T1	L1	L1, T1
1A4bii Residential: Household and gardening (mobile)									L1
1A4ci Agriculture/Forestry/Fishing: Stationary			L1		L1, T1	L1, T1	T1	L1, T1	
1A4cii Agriculture/Forestry/Fishing: Off-road vehicles and other machinery		T1			T1	T1	T1	L1, T1	T1
1A4ciii Agriculture/Forestry/Fishing: National fishing	L1								
1B2ai Fugitive emissions oil: Exploration, production, transport		T1							
1B2aiv Fugitive emissions oil: Refining / storage		L1	L1						
1B2av Distribution of oil products		T1							
2A5a Quarrying and mining of minerals other than coal						L1			
2A5b Construction and demolition						L1, T1	L1, T1		
2A6 Other mineral products (please specify in the IIR)			L1						
2B2 Nitric acid production					T1	T1			
2D3a Domestic solvent use including fungicides		L1							
2D3d Coating applications		L1							
2D3g Chemical products		L1, T1							
2D3i Other solvent use (please specify in the IIR)		L1, T1							
3B1a Manure management - Dairy cattle		L1		L1	L1				
3B1b Manure management - Non-dairy cattle		L1, T1							
3B3 Manure management - Swine		L1		L1, T1		L1	T1		
3Da1 Inorganic N-fertilizers (includes also	L1			L1, T1					

NFR	NO_x	NMVOC	SO_x	NH_3	$PM_{2.5}$	PM_{10}	TSP	BC	CO
urea application)									
3Da2a Animal manure applied to soils	L1	L1, T1		L1, T1					
3Dc Farm-level agricultural operations including storage, handling and transport of agricultural products					L1	L1, T1	L1, T1		
3De Cultivated crops				L1					
3I Agriculture other (please specify in the IIR)				T1					
5E Other waste (please specify in IIR)			L1		L1				

Many of the categories within fuel combustion are identified as key categories based on the Approach 1 level assessment for one or multiple pollutants. Within fugitive emissions, refining and storage of crude oil has been identified as key together with oil exploration/production/transport and distribution of oil products. For IPPU, the majority of identified categories are various types of solvent use for NMVOC. However, PM_{10} and $PM_{2.5}$ emissions from construction and demolition, PM_{10} from quarrying and mining as well as SO_2 emissions from other mineral products (production of bricks, tiles and expanded clay products) are also identified as key. In agriculture, the main animal types (cattle and swine) have been identified as key for NH_3 and in some cases also for PM. Application of mineral fertiliser and animal manure are key categories for NH_3 and NO_x. Other key categories within agriculture are farm level operations for PM, NH_3 treated straw (NFR 3I) and cultivated crops for NH_3. Finally, in the waste sector, the only category identified as key is other waste, which is emissions from accidental fires.

Table A1.2 Categories identified as key based on emission level in 2021, heavy metals.

NFR	Pb	Cd	Hg	As	Cr	Cu	Ni	Se	Zn
1A1a Public electricity and heat production	T1	L1, T1	L1, T1	L1, T1	L1, T1	T1	L1, T1	L1, T1	T1
1A1b Petroleum refining		L1			L1				
1A2e Stationary combustion in manufacturing industries and construction: Food processing, beverages and tobacco			L1	L1			L1, T1	L1	
1A2f Stationary combustion in manufacturing industries and construction: Non-metallic minerals			L1	L1			L1	L1	
1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)							T1		
1A3bi Road transport: Passenger cars	T1	L1	L1						L1
1A3bvi Road transport: Automobile tyre and brake wear	L1				L1	L1, T1		L1	L1, T1
1A3dii National navigation (shipping)				L1			L1, T1	L1	
1A4bi Residential: Stationary		L1, T1	L1		L1, T1				L1, T1
2A3 Glass production				T1				L1	
2A6 Other mineral products (please specify in the IIR)				L1					
2C1 Iron and steel production			T1	L1	L1		T1		T1
2C5 Lead production	L1			L1					
2G Other product use (please specify in the IIR)					L1		L1		
5E Other waste (please specify in IIR)	L1								L1

Most of the key categories for heavy metals are in the fuel combustion sector, but several categories in IPPU are also key for one or more heavy metals, see Table A1.2. Other waste (accidental fires) has also been identified as key for some heavy metals.

Table A1.3 Categories identified as key based on emission level in 2021, persistent organic pollutants.

NFR	PCDD/F	BaP	BbF	BkF	Ind	Total_PAH	HCB	PCBs
1A1a Public electricity and heat production	T1			L1			L1, T1	L1, T1
1A2f Stationary combustion in manufacturing industries and construction: Non-metallic minerals								L1
1A3bi Road transport: Passenger cars				L1			L1	
1A3bii Road transport: Light duty vehicles							L1	
1A3biii Road transport: Heavy duty vehicles and buses							L1	
1A4ai Commercial/institutional: Stationary			L1					
1A4bi Residential: Stationary	L1, T1	L1, T1	L1, T1	L1, T1	L1, T1	L1, T1	L1	L1
1A4ci Agricul-ture/Forestry/Fishing: Stationary		L1	L1		L1	L1		
2C1 Iron and steel production	T1						T1	L1, T1
3Df Use of pesticides							T1	
3F Field burning of agricultural residues							L1	
5E Other waste (please specify in IIR)	L1			L1	L1	L1		

The only categories outside fuel combustion identified as key are iron and steel production, use of pesticides, field burning and other waste (accidental fires).

Annex 2 – Information on the energy balance

The official Danish energy balance is prepared by the Danish Energy Agency (DEA). The DEA is responsible for reporting of energy data to Eurostat and the IEA. DCE uses the energy balance as published by the DEA. However, some reallocations between sectors are made in connection with the bottom-up modelling done at DCE for different subsectors within transport and mobile sources. For a more in-depth discussion of the energy statistics, please see Annex 3A-9. For information on the reallocation of fuels, please see Chapter 3.3.

Annex 3 Energy

Annex 3A - Stationary combustion

Annex 3A-1:	Correspondence list for SNAP/NFR
Annex 3A-2:	Fuel rate
Annex 3A-3:	Default Lower Calorific Value (LCV) of fuels and fuel correspondance list
Annex 3A-4:	Emission factor time series
Annex 3A-5:	Implied emission factors for power plants and municipal waste incineration plants
Annex 3A-6:	Large point sources
Annex 3A-7:	Uncertainty estimates
Annex 3A-8:	Emission inventory 2021 based on SNAP sectors
Annex 3A-9:	Description of the Danish energy statistics
Annex 3A-10:	QA/QC for stationary combustion

Annex 3A-1 Correspondence list for SNAP/NFR

Table 3A-1.1 Correspondence list for stationary combustion SNAP/NFR.

snap_id	snap_name	nfr_id_EA	nfr_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
030106	Other stationary equipments	1A2g viii	Other manufacturing industry

snap_id	snap_name	nfr_id_EA	nfr_name
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	Mineral wool	1A2f	Non-metallic minerals
030702	Glass	1A2f	Non-metallic minerals
030703	Tile	1A2f	Non-metallic minerals
030704	Gas turbines	1A2f	Non-metallic minerals
030705	Stationary engines	1A2f	Non-metallic minerals
030706	Other non-metallic minerals	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_id	snap_name	nfr_id_EA	nfr_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 of stationary combustion plants 1990-2021, 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	73.4	76.8	67.3	73.1	64.2	64.2	67.9	61.1	57.8	56.8
	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	Biomethane										
Total			**511.0**	**620.3**	**560.1**	**591.5**	**633.8**	**611.2**	**767.1**	**662.9**	**624.1**	**595.0**
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	50.0	52.2	47.1	47.1	44.0	40.0	35.3	30.9	30.4	32.5
	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	2.1	2.1	2.1	2.2	1.9	1.7	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	173.0	165.7
WASTE	114A	Waste	29.8	31.3	33.3	35.1	35.3	35.8	37.8	38.9	40.1	38.1
	115A	Industrial waste	0.5	1.4	1.9	1.5	2.0	2.0	0.6	0.9	1.4	1.2
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	Biomethane										
Total			**552.3**	**578.5**	**576.2**	**635.6**	**576.4**	**540.0**	**626.0**	**567.4**	**539.9**	**532.3**

Sum of Fuel_rate_PJ			Year									
fuel_type	**fuel_id**	**fuel_gr_abbr**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
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	37.8
	103A	Fly ash (fossil)		0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.0	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	0.3
LIQUID	110A	Petroleum coke	5.1	6.5	6.7	6.1	6.6	6.6	7.6	7.9	6.9	7.7
	203A	Residual oil	12.8	7.8	7.2	5.5	4.5	4.2	4.1	4.1	3.2	3.0
	204A	Gas oil	31.8	25.5	21.7	20.0	13.1	13.9	14.0	12.1	13.5	10.4
	206A	Kerosene	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
	225A	Orimulsion										
	303A	LPG	1.6	1.5	1.7	1.6	1.3	1.8	2.1	2.3	2.3	2.3
	308A	Refinery gas	14.3	13.7	14.8	14.8	15.4	16.2	14.4	15.6	15.0	16.1
GAS	301A	Natural gas	185.7	157.3	147.1	139.3	119.3	120.6	122.5	116.5	113.1	105.5
WASTE	114A	Waste	37.2	37.1	36.1	35.9	37.1	37.7	37.8	38.1	37.1	38.4
	115A	Industrial waste	0.9	1.3	1.2	1.6	1.6	2.2	2.6	2.7	3.4	3.1
BIOMASS	111A	Wood	51.3	48.8	48.6	46.4	45.0	50.1	51.6	51.6	52.7	52.3
	117A	Straw	23.3	20.2	18.3	20.3	18.6	19.8	19.7	20.2	17.6	18.0
	122A	Wood pellets	29.9	30.0	33.2	35.0	36.3	36.5	44.3	57.4	55.2	53.3
	215A	Bio oil	2.0	0.8	1.1	0.9	0.7	0.6	0.3	0.2	0.2	0.1
	309A	Biogas	4.3	4.1	4.4	4.6	5.2	5.3	5.9	5.8	6.3	6.9
	310A	Bio gasification gas	0.2	0.3	0.4	0.1	0.4	0.5	0.5	1.0	1.4	1.5
	315A	Biomethane					0.3	1.0	3.1	5.2	7.1	9.4
Total			**564.3**	**491.3**	**449.5**	**467.6**	**413.2**	**393.6**	**419.0**	**407.0**	**402.8**	**366.5**

Sum of Fuel_rate_PJ			Year	
fuel_type	**fuel_id**	**fuel_gr_abbr**	**2020**	**2021**
SOLID	101A	Other solid fossil		
	102A	Coal	33.2	44.3
	103A	Fly ash (fossil)	0.0	0.1
	106A	BKB		
	107A	Coke oven coke	0.3	0.3
LIQUID	110A	Petroleum coke	7.9	6.9
	203A	Residual oil	3.1	2.7
	204A	Gas oil	9.5	11.7
	206A	Kerosene	0.0	0.0
	225A	Orimulsion		
	303A	LPG	2.3	2.7
	308A	Refinery gas	15.3	15.7
GAS	301A	Natural gas	85.3	85.5
WASTE	114A	Waste	38.2	37.8
	115A	Industrial waste	3.4	2.8
BIOMASS	111A	Wood	57.6	63.1
	117A	Straw	18.9	21.6
	122A	Wood pellets	47.2	66.2
	215A	Bio oil	0.1	0.2
	309A	Biogas	6.7	6.5
	310A	Bio gasification gas	1.6	1.7
	315A	Biomethane	13.5	19.6
Total			**344.2**	**389.3**

Table 3A-2.2 Detailed fuel consumption data for stationary combustion plants, PJ. 1990 – 2021.

This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Annex 3A-3 Default Lower Calorific Value (LCV) of fuels and fuel correspondance list

Table 3A-3.1 Time series for calorific values of fuels (DEA, 2022a).

		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
Gas Works Gas	GJ per 1000 m^3							17.00	17.00	17.00	17.00
Liquefied Natural Gas	GJ per 1000 m^3										
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 m^3	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Wood Chips	GJ per tonne	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 tonne	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70
Wood Waste	GJ per 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 1000 m^3								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
Gas Works 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
Liquefied Natural Gas	GJ per 1000 m^3										
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										
Brown Coal Briquettes	GJ per tonne										
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 m^3	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Wood Chips	GJ per tonne	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 tonne	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70
Wood Waste	GJ per 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 1000 m^3	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	2019
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	27.65	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	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	39.46	39.51	39.55	38.99	39.53	39.64	39.63	39.66	39.59	38.81
Gas Works Gas	GJ per 1000 m^3	21.35	21.37	19.30	19.31	20.20	19.80	20.28	20.80	20.82	20.80
Liquefied Natural Gas	GJ per 1000 m^3						26.50	26.50	26.50	26.50	26.50
Electricity Plant Coal	GJ per tonne	24.44	24.38	24.23	24.49	24.70	24.10	24.29	24.33	24.13	23.89
Other Hard Coal	GJ per tonne	24.44	24.38	24.23	24.49	24.70	24.10	26.10	26.88	26.64	24.17
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 m^3	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Wood Chips	GJ per tonne	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 tonne	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70
Wood Waste	GJ per 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 1000 m^3	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	10.60	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	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	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		2020	2021
Crude Oil, Average	GJ per tonne	43.00	43.00
Crude Oil, Golf	GJ per tonne	41.80	41.80
Crude Oil, North Sea	GJ per tonne	43.00	43.00
Refinery Feedstocks	GJ per tonne	42.70	42.70
Refinery Gas	GJ per tonne	52.00	52.00
LPG	GJ per tonne	46.00	46.00
Naphtha (LVN)	GJ per tonne	44.50	44.50
Motor Gasoline	GJ per tonne	43.80	43.80
Aviation Gasoline	GJ per tonne	43.80	43.80
JP4	GJ per tonne	43.80	43.80
Other Kerosene	GJ per tonne	43.50	43.50
JP1	GJ per tonne	43.50	43.50
Gas/Diesel Oil	GJ per tonne	42.70	42.70
Fuel Oil	GJ per tonne	40.65	40.65
Orimulsion	GJ per tonne	27.65	27.65
Petroleum Coke	GJ per tonne	31.40	31.40
Waste Oil	GJ per tonne	41.90	41.90
White Spirit	GJ per tonne	43.50	43.50
Bitumen	GJ per tonne	39.80	39.80
Lubricants	GJ per tonne	41.90	41.90
Natural Gas	GJ per 1000 Nm^3	36.70	36.62
Gas Works Gas	GJ per 1000 m^3	20.78	20.84
Liquefied Natural Gas	GJ per 1000 m^3	26.50	26.50
Electricity Plant Coal	GJ per tonne	24.09	23.96
Other Hard Coal	GJ per tonne	25.63	25.42
Coke	GJ per tonne	29.30	29.30
Brown Coal Briquettes	GJ per tonne	18.30	18.30
Straw	GJ per tonne	14.50	14.50
Wood Chips	GJ per m^3	2.80	2.80
Wood Chips	GJ per tonne	9.30	9.30
Firewood, Hardwood	GJ per m^3	10.40	10.40
Firewood, Conifer	GJ per tonne	7.60	7.60
Wood Pellets	GJ per tonne	17.50	17.50
Wood Waste	GJ per tonne	14.70	14.70
Wood Waste	GJ per m^3	3.20	3.20
Biogas	GJ per 1000 m^3	23.00	23.00
Wastes	GJ per tonne	10.60	10.60
Bioethanol	GJ per tonne	26.70	26.70
Liquid Biofuels	GJ per tonne	37.50	37.50
Bio Oil	GJ per tonne	37.20	37.20

Table 3A-3.2 Fuel category correspondence list, DEA, DCE and NFR.

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
Gas Works 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	Wood	Biomass
Wastes, Renewable	Municipal wastes	Biomass
Biooil	Liquid biofuels	Biomass
Biogas	Biogas	Biomass
(Wood applied in gas engines)	Biomass gasification gas	Biomass
Bio methane	Biomethane	Biomass
Biogas distributed in the town gas grid	Biogas	Biomass
Wastes, Non-renewable	Fossil waste	Other fuel

Annex 3A-4 Emission factor time series

Table 3A-4.1 SO_2 emission factors time series, g per GJ for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.2 NO_x emission factors time series, g per GJ for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.3 NMVOC emission factors time series, g per GJ for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.4 CO emission factors time series, g per GJ for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.5 NH_3 emission factors time series, g per GJ for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.6 TSP emission factors, time series, g per GJ for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.7 PM_{10} emission factors, time series, g per GJ for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.8 $PM_{2.5}$ emission factors, time series, g per GJ for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.9 BC emission factors, time series, g per GJ for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.10 As emission factors time series, mg per GJ, for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.11 Cd emission factors time series, mg per GJ, for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.12 Cr emission factors time series, mg per GJ, for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.13 Cu emission factors time series, mg per GJ, for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.14 Hg emission factors time series, mg per GJ, for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.15 Ni emission factors time series, mg per GJ, for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.16 Pb emission factors time series, mg per GJ, for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.17 Se emission factors time series, mg per GJ, for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.18 Zn emission factors time series, mg per GJ, for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.19   PAH emission factors time series, µg pr GJ for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.20 HCB emission factors time series, ng per GJ for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.21 PCDD/F emission factors time series, ng per GJ for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.22 PCB emission factors time series, ng per GJ for the years 1990 to 2021. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Annex 3A-5 Implied emission factors for waste incineration plants and power plants combustion coal

Table 3A-5.1 Implied emission factors for municipal waste incineration plants 2021.

Pollutant	Implied emission factor	Unit
SO_2	5.1	g /GJ
NO_x	85	g / GJ
TSP	0.49	g / GJ
PM_{10}	0.48	g / GJ
$PM_{2.5}$	0.46	g / GJ
As	0.40	mg / GJ
Cd	0.32	mg / GJ
Cr	1.22	mg / GJ
Cu	1.31	mg / GJ
Hg	1.41	mg / GJ
Ni	2.08	mg / GJ
Pb	3.82	mg / GJ
Se	1.19	mg / GJ
Zn	2.68	mg / GJ

Table 3A-5.2 Implied emission factors for power plants combusting coal, 2021.

Pollutant	Implied emission factor	Unit
SO_2	7.3	g / GJ
NO_x	13.8	g / GJ
TSP	2.69	g / GJ
PM_{10}	2.33	g / GJ
$PM_{2.5}$	1.89	g / GJ
As	0.49	mg / GJ
Cd	0.03	mg / GJ
Cr	0.54	mg / GJ
Cu	0.38	mg / GJ
Hg	0.67	mg / GJ
Ni	0.94	mg / GJ
Pb	0.57	mg / GJ
Se	2.50	mg / GJ
Zn	1.27	mg / GJ

Annex 3A-6 Large point sources

Table 3A-6.1 Large point sources, 2021.

Large point sources
Aalborg Portland
AarhusKarlshamn Denmark A/S
AffaldPlus+, Naestved Forbraendingsanlaeg
Affaldplus+, Slagelse Forbr. and DONG Slagelse KVV
Affaldscenter aarhus - Forbraendsanlaegget
Affaldsforbraendingsanlaeg I/S REFA
Amagerforbraending
Amagervaerket
Ardagh Glass Holmegaard A/S
Asnaesvaerket
Avedoerevaerket
AVV Forbraendingsanlaeg
Bofa I/S
Cheminova
Dalum Kraftvarmevaerk
Danisco Grindsted Dupont
DanSteel
DTU
Duferco Danish Steel
Esbjergvaerket
Faxe Kalk
Fjernvarme Fyn, Centrum Varmecentral
Frederikshavn Affaldskraftvarmevaerk
Fynsvaerket
H.C.Oerstedsvaerket
Haldor Topsoee
Hammel Fjernvarmeselskab
Herningvaerket
Hilleroed Kraftvarmevaerk
Horsens Kraftvarmevaerk
I/S Kara Affaldsforbraendingsanlaeg
I/S Kraftvarmevaerk Thisted
I/S Nordforbraending
I/S Reno Nord
I/S Reno Syd
I/S Vestforbraending
Koege Kraftvarmevaerk
Kolding Forbraendingsanlaeg TAS
Kommunekemi
Kyndbyvaerket
L90 Affaldsforbraending
LECA Danmark
Maabjergvaerket
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

Continued
Skaerbaekvaerket
Soenderborg Kraftvarmevaerk
Statoil Raffinaderi
Studstrupvaerket
Svanemoellevaerket
Svendborg Kraftvarmevaerk
Viborg Kraftvarme
Vordingborg Kraftvarme

Table 3A-6.2 Large point sources, aggregated fuel consumption in 2021.

nfr_id_EA	**fuel_id**	**fuel_gr_abbr**	**Fuel, TJ**
1A1a	102A	Coal	39071
	103A	Fossil fly ash	97
	111A	Wood	31248
	114A	Waste	36855
	117A	Straw	5827
	122A	Wood Pellets	45056
	203A	Residual oil	730
	204A	Gas oil	499
	215A	Bio oil	1
	301A	Natural gas	6293
	303A	LPG	1
	309A	Biogas	7
	315A	Biomethane	1752
1A1a Total			167437
1A1b	203A	Residual oil	140
	204A	Gas oil	16
	301A	Natural gas	654
	303A	LPG	0
	308A	Refinery gas	15714
	315A	Biomethane	182
1A1b Total			16706
1A1c	204A	Gas oil	0
	301A	Natural gas	91
	315A	Biomethane	0
1A1c Total			91
1A2a	204A	Gas oil	3
	301A	Natural gas	1360
	303A	LPG	2
	315A	Biomethane	379
1A2a Total			1743
1A2c	204A	Gas oil	0
	301A	Natural gas	838
	303A	LPG	1
	315A	Biomethane	233
1A2c Total			1073
1A2e	102A	Coal	372
	107A	Coke oven coke	102
	111A	Wood	719
	203A	Residual oil	1717
	204A	Gas oil	529
	215A	Bio oil	103
	301A	Natural gas	246
	303A	LPG	45
	309A	Biogas	73
	315A	Biomethane	68
1A2e Total			3975
1A2f	102A	Coal	3851
	107A	Coke oven coke	220
	110A	Petroleum coke	6473
	111A	Wood	1061
	114A	Waste	8
	115A	Industrial waste	2829
	203A	Residual oil	64
	204A	Gas oil	112
	215A	Bio oil	0
	301A	Natural gas	1394
	303A	LPG	242

nfr_id_EA	fuel_id	fuel_gr_abbr	Fuel, TJ
	315A	Biomethane	388
1A2f Total			16643
1A4a i	111A	Wod	203
	114A	Waste	0
	309A	Biogas	0
1A4a i Total			203
Grand Total			207869

Table 3A-6.3 Large point sources, plant specific emissions[1].

Year	2021																				
nfr_id	lps_name	SO_2	NO_x	NMVOC	CO	NH_3	TSP	PM_{10}	$PM_{2.5}$	BC [2]	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	PCDD/F	PCB
1A1a	AffaldPlus+, Naestved Forbraendings-anlaeg	x	x	x	x	x	x	x	x	x		x			x					x	
1A1a	Affaldplus+, Slagelse Forbr. and DONG Slagelse KVV	x	x		x	x	x	x	x	x		x			x					x	
1A1a	Affaldscenter aarhus - Forbraendsan-laegget	x	x	x			x	x	x	x					x					x	
1A1a	Affaldsforbraendingsanlaeg I/S REFA														x						
1A1a	Amagerforbraending	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	
1A1a	Amagervaerket	x	x				x	x	x	x	x	x	x	x	x	x	x				
1A1a	Asnaesvaerket	x	x								x	x	x	x	x	x	x	x	x		
1A1a	Avedoerevaerket	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x		
1A1a	AVV Forbraendingsanlaeg	x	x		x							x			x					x	
1A1a	Bofa I/S	x	x		x						x	x	x	x	x	x	x			x	
1A1a	DTU		x																		
1A1a	Esbjergvaerket	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x		
1A1a	Fjernvarme Fyn, Centrum Varmecen-tral		x																		
1A1a	Frederikshavn Affaldskraftvarmevaerk	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x			x	
1A1a	Fynsvaerket	x	x				x	x	x	x	x	x	x	x	x	x	x	x	x		
1A1a	H.C.Oerstedsvaerket	x	x	x	x																
1A1a	Herningvaerket	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x		
1A1a	Hilleroed Kraftvarmevaerk		x																		
1A1a	Horsens Kraftvarmevaerk		x			x														x	
1A1a	I/S Kara Affaldsforbraendingsanlaeg	x	x		x		x	x	x	x					x					x	
1A1a	I/S Nordforbraending		x																		
1A1a	I/S Reno Nord	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x
1A1a	I/S Reno Syd	x	x		x		x	x	x	x					x					x	
1A1a	I/S Vestforbraending	x	x		x		x	x	x	x	x	x	x	x	x	x	x			x	x
1A1a	Koege Kraftvarmevaerk		x																		
1A1a	Kolding Forbraendingsanlaeg TAS	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	
1A1a	Kommunekemi	x	x	x	x		x	x	x	x											
1A1a	Kyndbyvaerket	x	x		x						x	x	x	x	x	x	x	x	x		
1A1a	L90 Affaldsforbraending	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x			x	
1A1a	Maabjergvaerket		x																		
1A1a	Nordjyllandsvaerket	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x		
1A1a	Odense Kraftvarmevaerk	x	x				x	x	x	x										x	
1A1a	Oestkraft	x	x				x	x	x	x											
1A1a	Silkeborg Kraftvarmevaerk		x																		
1A1a	Skaerbaekvaerket		x	x	x																

1A1a	Soenderborg Kraftvarmevaerk	x	x		x															x	
1A1a	Studstrupvaerket	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x		
1A1a	Svanemoellevaerket		x		x																
1A1a	Svendborg Kraftvarmevaerk	x	x		x		x	x	x	x	x	x	x	x	x	x	x			x	
1A1a	Viborg Kraftvarme		x																		
1A1a	Vordingborg Kraftvarme	x	x																		
1A1a	Dalum Kraftvarmevaerk	x	x				x	x	x	x											
1A1a	Randersvaerket Verdo	x	x				x	x	x	x											
1A1a	I/S Kraftvarmevaerk Thisted	x	x		x	x	x	x	x	x										x	
1A1a	Hammel Fjernvarmeselskab	x	x		x		x	x	x	x					x						
1A1b	Shell Raffinaderi	x	x																		
1A1b	Statoil Raffinaderi	x	x																		
1A1c	Nybro Gasbehandlingsanlaeg		x																		
1A2a	DanSteel		x																		
1A2a	Duferco Danish Steel		x																		
1A2c	Haldor Topsoee		x																		
1A2e	Maricogen		x		x																
1A2e	Nordic Sugar Nakskov	x	x																		
1A2e	Nordic Sugar Nykoebing	x	x				x	x	x	x											
1A2e	AarhusKarlshamn Denmark A/S	x	x				x	x	x	x											
1A2e	Danisco Grindsted Dupont		x																		
1A2f	Ardagh Glass Holmegaard A/S		x																		
1A2f	Faxe Kalk	x	x																		
1A2f	Rockwool A/S Doense	x	x																		
1A2f	Rockwool A/S Vamdrup	x	x																		
1A2f	Saint-Gobain Isover A/S		x																		
1A2f	Aalborg Portland	x	x		x	x	x	x	x	x					x						
1A2f	LECA Danmark		x		x	x									x						
1A4a i	Rensningsanlaegget Lynetten	x	x		x		x	x	x	x		x			x		x			x	
Total		**2711**	**11090**	**47**	**10501**	**89**	**338**	**293**	**237**	**10**	**33**	**14**	**59**	**53**	**103**	**70**	**71**	**149**	**274**	**750**	**2180**
Total emission from stationary combustion		5856	24422	10282	77837	1511	8507	8000	7733	1074	132	543	1132	513	193	1128	1705	275	19492	21488	298264
Share of total emission from stationary combustion based on plant specific data, %		46%	45%	0.5%	13%	5.9%	4%	4%	3%	0.9%	**25%**	**2.6%**	**5%**	**10%**	**53%**	**6%**	**4%**	**54%**	**1.4%**	**3.5%**	**0.7%**

1) Emissions of the pollutants marked with "x" are plant specific. Emission of other pollutants is estimated based on emission factors. The total shown *in this table* only includes plant specific data.

2) Based on particle size distribution and BC fractions.

Annex 3A-7 Uncertainty estimates, 2021

Table 3A-7.1 Uncertainty estimates.

This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Annex 3A-8 Emission inventory 2021 based on SNAP sectors

Table 3A-8.1 Emission inventory 2021 based on SNAP sectors.

This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Annex 3A-9 Description of the Danish energy statistics

This description of the Danish energy statistics has been prepared by Denmark's National Environmental Research Institute, NERI (now DCE) in co-operation 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. 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 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.
  - 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 (former NERI), 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 NFR 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 SNAP	Fuel (in Danish)	Fuel-code	Transformation 1980-1993 SNAP	Fuel-code
Foreign Trade					
- Border Trade					
- - Motor Gasoline					
- - Gas-/Diesel Oil					
- - Petroleum Coke	0202	Petrokoks	110A		
Vessels in Foreign Trade					
- International Marine Bunkers					
- - Gas-/Diesel Oil					
- - Fuel Oil					
- - Lubricants					
Energy Sector					
Extraction and Gasification					
- Extraction					
- - Natural Gas	010504	Naturgas	301A		
- Gasification					
- - Biogas, Landfill	091006	Biogas	309A		
- - Biogas, Other	091006	Biogas	309A		
Refineries					
- Own Use					
- - Refinery Gas	010306	Raffinaderigas	308A		
- - LPG	010306	LPG	303A		
- - Gas-/Diesel Oil	010306	Gas & Dieselolie	204A		
- - Fuel Oil	010306	Fuelolie & Spildolie	203A		
Transformation Sector					
Large-scale Power Units					
- Fuels Used for Power Production					
- - Gas-/Diesel Oil				0101	204A
- - Fuel Oil				0101	203A
- - Electricity Plant Coal				0101	102A
- - Straw				0101	117A
Large-Scale CHP Units					
- Fuels Used for Power Production					
- - Refinery Gas				0103	308A
- - LPG				0101	303A
- - Naphtha (LVN)				0101	210A
- - Gas-/Diesel Oil				0101	204A
- - Fuel Oil				0101	203A
- - Petroleum Coke				0101	110A
- - Orimulsion				0101	225A
- - Natural Gas				0101	301A
- - Electricity Plant Coal				0101	102A
- - Straw				0101	117A
- - Wood Chips				0101	111A
- - Wood Pellets				0101	111A
- - Wood Waste				0101	111A
- - Biogas, Landfill				0101	309A
- - Biogas, Others				0101	309A
- - Waste, Non-renewable				0101	114A
- - Wastes, Renewable				0101	114A
- Fuels Used for Heat Production					
- - Refinery Gas				0103	308A

Unit: TJ	End-use			Transformation 1980-1993	
	SNAP	Fuel (in Danish)	Fuel-code	SNAP	Fuel-code
- - LPG				0101	303A
- - Naphtha (LVN)				0101	210A
- - Gas-/Diesel Oil				0101	204A
- - Fuel Oil				0101	203A
- - Petroleum Coke				0101	110A
- - Orimulsion				0101	225A
- - Natural Gas				0101	301A
- - Electricity Plant Coal				0101	102A
- - Straw				0101	117A
- - Wood Chips				0101	111A
- - Wood Pellets				0101	111A
- - Wood Waste				0101	111A
- - Biogas, Landfill				0101	309A
- - Biogas, Other				0101	309A
- - Waste, Non-renewable				0101	114A
- - Wastes, Renewable				0101	114A
Small-Scale CHP Units					
- Fuels Used for Power Production					
- - Gas-/Diesel Oil				0101	204A
- - Fuel Oil				0101	203A
- - Natural Gas				0101	301A
- - Hard Coal				0101	102A
- - Straw				0101	117A
- - Wood Chips				0101	111A
- - Wood Pellets				0101	111A
- - Wood Waste				0101	111A
- - Biogas, Landfill				0101	309A
- - Biogas, Other				0101	309A
- - Waste, Non-renewable				0101	114A
- - Wastes, Renewable				0101	114A
- Fuels Used for Heat Production					
- - Gas-/Diesel Oil				0101	204A
- - Fuel Oil				0101	203A
- - Natural Gas				0101	301A
- - Coal				0101	102A
- - Straw				0101	117A
- - Wood Chips				0101	111A
- - Wood Pellets				0101	111A
- - Wood Waste				0101	111A
- - Biogas, Landfill				0101	309A
- - Biogas, Other				0101	309A
- - Waste, Non-renewable				0101	114A
- - Wastes, Renewable				0101	114A
District Heating Units					
- Fuels Used for Heat Production					
- - Refinery Gas				0103	308A
- - LPG				0102	303A
- - Gas-/Diesel Oil				0102	204A
- - Fuel Oil				0102	203A
- - Waste Oil				0102	203A
- - Petroleum Coke				0102	110A
- - Natural Gas				0102	301A
- - Electricity Plant Coal				0102	102A
- - Coal				0102	102A

Unit: TJ	End-use			Transformation 1980-1993	
	SNAP	Fuel (in Danish)	Fuel-code	SNAP	Fuel-code
- - Straw				0102	117A
- - Wood Chips				0102	111A
- - Wood Pellets				0102	111A
- - Wood Waste				0102	111A
- - Biogas, Landfill				0102	309A
- - Biogas, Sludge				0102	309A
- - Biogas, Other				0102	309A
- - Waste, Non-renewable				0102	114A
- - Wastes, Renewable				0102	114A
- - Fish Oil				0102	215A
Autoproducers, Electricity Only					
- Fuels Used for Power Production					
- - Natural Gas				0320	301A
- - Biogas, Landfill				0320	309A
- - Biogas, Sewage Sludge				0320	309A
- - Biogas, Other				0320	309A
Autoproducers, CHP Units					
- Fuels Used for Power Production					
- - Refinery Gas				0103	308A
- - Gas-/Diesel Oil				0320	204A
- - Fuel Oil				0320	203A
- - Waste Oil				0320	203A
- - Natural Gas				0320	301A
- - Coal				0320	102A
- - Straw				0320	117A
- - Wood Chips				0320	111A
- - Wood Pellets				0320	111A
- - Wood Waste				0320	111A
- - Biogas, Landfill				0320	309A
- - Biogas, Sludge				0320	309A
- - Biogas, Other				0320	309A
- - Fish Oil				0320	215A
- - Waste, Non-renewable				0320	114A
- - Wastes, Renewable				0320	114A
- Fuels Used for Heat Production					
- - Refinery Gas				0103	308A
- - Gas-/Diesel Oil				0320	204A
- - Fuel Oil				0320	203A
- - Waste Oil				0320	203A
- - Natural Gas				0320	301A
- - Coal				0320	102A
- - Wood Chips				0320	111A
- - Wood Waste				0320	111A
- - Biogas, Landfill				0320	309A
- - Biogas, Sludge				0320	309A
- - Biogas, Other				0320	309A
- - Waste, Non-renewable				0320	114A
- - Wastes, Renewable				0320	114A
Autoproducers, Heat Only					
- Fuels Used for Heat Production					
- - Gas-/Diesel Oil				0320	204A
- - Fuel Oil				0320	203A
- - Waste Oil				0320	203A
- - Natural Gas				0320	301A

Unit: TJ	End-use			Transformation 1980-1993	
	SNAP	Fuel (in Danish)	Fuel-code	SNAP	Fuel-code
- - Straw				0320	117A
- - Wood Chips				0320	111A
- - Wood Chips				0320	111A
- - Wood Waste				0320	111A
- - Biogas, Landfill				0320	309A
- - Biogas, Sludge				0320	309A
- - Biogas, Other				0320	309A
- - Waste, Non-renewable				0102	114A
- - Wastes, Renewable				0102	114A
Town Gas Units	030106	Naturgas	301A		
- Fuels Used for Production of District Heating	030106	Kul (-83) / Gasolie (84-)	102A / 204A		
Transport sector					
Military Transport					
- Aviation Gasoline					
- Motor Gasoline					
- JP4					
- JP1					
- Gas-/Diesel Oil					
Road					
- LPG					
- Motor Gasoline					
- Other Kerosene	0202	Petroleum	206A		
- Gas-/Diesel Oil					
- Fuel Oil					
Rail					
- Motor Gasoline					
- Other Kerosene					
- Gas-/Diesel Oil					
- Electricity					
Domestic Sea Transport					
- LPG					
- Other Kerosene					
- Gas-/Diesel Oil					
- Fuel Oil					
Air Transport, Domestic					
- LPG					
- Aviation Gasoline					
- Motor Gasoline					
- Other Kerosene	0201	Petroleum	206A		
- JP1					
Air Transport, International					
- Aviation Gasoline					
- JP1					
Agriculture and Forestry					
- LPG					
- Motor Gasoline					
- Other Kerosene	0203	Petroleum	206A		
- Gas-/Diesel Oil					
- Fuel Oil	0203	Fuelolie & Spildolie	203A		
- Petroleum Coke	0203	Petrokoks	110A		
- Natural Gas	0203	Naturgas	301A		
- Coal	0203	Kul	102A		

Unit: TJ	End-use			Transformation 1980-1993	
	SNAP	Fuel (in Danish)	Fuel-code	SNAP	Fuel-code
- Brown Coal Briquettes	0203	Brunkul	106A		
- Straw	0203	Halm	117A		
- Wood Chips	0203	Træ	111A		
- Wood Waste	0203	Træ	111A		
- Biogas, Other	0203	Biogas	309A		
Horticulture					
- LPG					
- Motor Gasoline					
- Gas-/Diesel Oil					
- Fuel Oil	0203	Fuelolie & Spildolie	203A		
- Petroleum Coke	0203	Petrokoks	110A		
- Natural Gas	0203	Naturgas	301A		
- Coal	0203	Kul	102A		
- Wood Waste	0203	Træ	111A		
Fishing					
- LPG					
- Motor Gasoline					
- Other Kerosene					
- Gas-/Diesel Oil					
- Fuel Oil					
Manufacturing Industry					
- Refinery Gas	0320	Raffinaderigas	308A		
- LPG					
- Naphtha (LVN)					
- Motor Gasoline					
- Other Kerosene	0320	Petroleum	206A		
- Gas-/Diesel Oil					
- Fuel Oil	0320	Fuelolie & Spildolie	203A		
- Waste Oil	0320	Fuelolie & Spildolie	203A		
- Petroleum Coke	0320	Petrokoks	110A		
- Natural Gas	0320	Naturgas	301A		
- Coal	0320	Kul	102A		
- Coke	0320	Koks	107A		
- Brown Coal Briquettes	0320	Brunkul	106A		
- Wood Pellets	0320	Træ	111A		
- Wood Waste	0320	Træ	111A		
- Biogas, Landfill	0320	Biogas	309A		
- Biogas, Other	0320	Biogas	309A		
- Wastes, Non-renewable	0320	Affald	114A		
- Wastes, Renewable	0320	Affald	114A		
- Town Gas	0320	Naturgas	301A		
Construction					
- LPG	0320	LPG	303A		
- Motor Gasoline					
- Other Kerosene	0320	Petroleum	206A		
- Gas-/Diesel Oil					
- Fuel Oil	0320	Fuelolie & Spildolie	203A		
- Natural Gas	0320	Naturgas	301A		
Wholesale					
- LPG	0201	LPG	303A		
- Motor Gasoline	0201	Petroleum	206A		
- Other Kerosene	0201	Gas & Dieselolie	204A		
- Gas-/Diesel Oil	0201	Fuelolie & Spildolie	203A		
- Petroleum Coke	0201	Petrokoks	110A		

Unit: TJ	End-use			Transformation 1980-1993	
	SNAP	Fuel (in Danish)	Fuel-code	SNAP	Fuel-code
- Natural Gas	0201	Naturgas	301A		
- Wood Waste	0201	Træ	111A		
Retail Trade					
- LPG	0201	LPG	303A		
- Other Kerosene	0201	Petroleum	206A		
- Gas-/Diesel Oil	0201	Gas & Dieselolie	204A		
- Fuel Oil	0201	Fuelolie & Spildolie	203A		
- Petroleum Coke	0201	Petrokoks	110A		
- Natural Gas	0201	Naturgas	301A		
Private Service					
- LPG	0201	LPG	303A		
- Other Kerosene	0201	Petroleum	206A		
- Gas-/Diesel Oil	0201	Gas & Dieselolie	204A		
- Fuel Oil	0201	Fuelolie & Spildolie	203A		
- Waste Oil	0201	Fuelolie & Spildolie	203A		
- Petroleum Coke	0201	Petrokoks	110A		
- Natural Gas	0201	Naturgas	301A		
- Wood Chips	0201	Træ	111A		
- Wood Waste	0201	Træ	111A		
- Biogas, Landfill	0201	Biogas	309A		
- Biogas, Sludge	0201	Biogas	309A		
- Biogas, Other	0201	Biogas	309A		
- Wastes, Non-renewable	0201	Affald	114A		
- Wastes, Renewable	0201	Affald	114A		
- Town Gas	0201	Naturgas	301A		
Public Service					
- LPG	0201	LPG	303A		
- Other Kerosene	0201	Petroleum	206A		
- Gas-/Diesel Oil	0201	Gas & Dieselolie	204A		
- Fuel Oil	0201	Fuelolie & Spildolie	203A		
- Petroleum Coke	0201	Petrokoks	110A		
- Natural Gas	0201	Naturgas	301A		
- Coal	0201	Kul	102A		
- Brown Coal Briquettes	0201	Brunkul	106A		
- Wood Chips	0201	Træ	111A		
- Wood Pellets	0201	Træ	111A		
- Town Gas	0201	Naturgas	301A		
Single Family Houses					
- LPG	0202	LPG	303A		
- Motor Gasoline					
- Other Kerosene	0202	Petroleum	206A		
- Gas-/Diesel Oil	0202	Gas & Dieselolie	204A		
- Fuel Oil	0202	Fuelolie & Spildolie	203A		
- Petroleum Coke	0202	Petrokoks	110A		
- Natural Gas	0202	Naturgas	301A		
- Coal	0202	Kul	102A		
- Coke	0202	koks	107A		
- Brown Coal Briquettes	0202	Brunkul	106A		
- Straw	0202	Halm	117A		
- Firewood	0202	Træ	111A		
- Wood Chips	0202	Træ	111A		
- Wood Pellets	0202	Træ	111A		
- Town Gas	0202	Naturgas	301A		

Unit: TJ	End-use			Transformation 1980-1993	
	SNAP	Fuel (in Danish)	Fuel-code	SNAP	Fuel-code
Multi-family Houses					
- LPG	0202	LPG	303A		
- Other Kerosene	0202	Petroleum	206A		
- Gas-/Diesel Oil	0202	Gas & Dieselolie	204A		
- Fuel Oil	0202	Fuelolie & Spildolie	203A		
- Petroleum Coke	0202	Petrokoks	110A		
- Natural Gas	0202	Naturgas	301A		
- Coal	0202	Kul	102A		
- Coke	0202	Koks	107A		
- Brown Coal Briquettes	0202	Brunkul	106A		
- Town Gas	0202	Naturgas	301A		

Annex 3A-10 QA/QC for stationary combustion

The quality work for the Danish GHG emission inventories are accounted for in *Quality manual for the Danish emission greenhouse gas inventory, Version 3* (Nielsen et al., 2020a). The quality manual outlines the quality work undertaken by the emission inventory group at the Department of Environmental Science, Aarhus University in connection with the preparation and reporting of the Danish greenhouse gas inventory.

Information on the Danish quality work is also included in NIR Chapter 1.6. Sector specific QA/QC for stationary combustion is accounted for in this chapter.

The QA/QC defined in the Quality manual defines Critical control points and a Points of measurement. Some points of measurement are sector specific whereas others are general.

Sector specific points of measurement

Table 3.2.37 lists the sector specific points of measurement and specification about the points of measurement for stationary combustion.

Table 3A-10.1 List of sectoral points of measurement, and QC for stationary combustion.

Level	CCP	Id	Description		Stationary combustion 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.	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 values this is discussed in NIR chapter 3.2.5. This documentation is improved annually based on reviews. 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 is shown and discussed below (Table 3.2.43).
	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. All original data for stationary combustion are archived in the emission inventory archive: ST_ENVS-Luft-Emi/Inventory/(year)/1A1 1A2 and 1A4 Stationary combustion All original data for 1) the reference approach, 2) the comparison of EU ETS sum and CRF and 3) the comparison of Eurostat data and CRF are archived in the emission inventory archive: ST_ENVS-Luft-Emi/Inventory/(year)/1A Other Energy
	6.Robustness	DS.1.6.1	Explicit agreements between the external institution holding the data and AU, 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.

Level	CCP	Id	Description		Stationary combustion QC
					Most of the other external data sources are available due to legislation. See Table 3.2.43.
	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 3.2.43 below.
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 (the basic data sheet) is considered complete. Total fuel consumption is based on the energy statistics whereas other data sources are used for specification of technology, subsectors, plant specific data etc.
	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 and 2021, both differ less than 2.0 % in 1990-2021. The reference approach is included in NIR Chapter 3.4. The chapter gives an account of the differences between the national approach and the reference approach.
	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	A manual log is implemented in the emission database.

Level	CCP	Id	Description		Stationary combustion QC
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	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.	Sectoral	Large dips/jumps in time series are discussed and explained in NIR chapter 3.2.3 and 3.2.4.
	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.	Sectoral	(Not relevant for stationary combustion)

Table 3A-10.2 List of external data sources for stationary combustion.

Dataset	Data reference	Contact(s)	Description	Years included	Data agreement/ Comment
Energy Producers Survey	The Danish Energy Agency (DEA)	Kaj Stærkind	Dataset for all plants producing electricity and district heating for the public grids. For each production unit, the dataset includes the consumption of each fuel, production of heat and electricity, technology and year of installation. The dataset is regarded as complete for fuel consumption since the plants are obliged to report the data to DEA.	1994 onwards	Data agreement 2014.
Gas consumption for gas engines and gas turbines 1990-1993	The Danish Energy Agency (DEA)	Kaj Stærkind	Historical dataset for gas engines and gas turbines. 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. The 1994 data were based on the Energy Producers Survey. DCE assesses that the DEA estimate is the best available data for 1990-1993.	1990-1993	No data agreement. Historical data
Basic data	The Danish Energy Agency (DEA)	Jane Rusbjerg	The Danish energy statistics. The dataset is applied for both the reference approach and the national approach. 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 dataset applied in the national approach.	1972 and 1975 onwards	Data agreement 2014. However, the dataset is also published as part of national energy statistics.
Energy statistics for industrial subsectors	The Danish Energy Agency (DEA)	Jane Rusbjerg and Ali Zarnaghi	Disaggregation of the industrial fuel consumption. The data includes disaggregation of the fuel consumption for industrial plants. The dataset is estimated for the reporting to Eurostat. The data are included in the 2014 update of the agreement with DEA.		Included in data delivery agreement 2014.
Emission factors	See chapter regarding emission factors		Emission factors refer to a large number of sources. For specific references, see the Chapter 3.2.6 regarding emission factors. Some of the annually updated		Some of the annually updated CO_2 emission factors are based on EU ETS data, and thus included in the data delivery agreement with DEA.

Dataset	Data reference	Contact(s)	Description	Years included	Data agreement/ Comment
			CO_2 emission factors are based on EU ETS data, see below.		For other emission factors there is no formal data delivery agreement.
Annual environmental reports / environmental data / PRTR	Various plants		Emissions from plants defined as large point sources Some large plants are obligated to report annual environmental data including emission data to PRTR. In addition, some plants publish annual environmental reports. And finally, some plant owners non-compulsory report annual emission data to DCE.		No data agreement. Some plants are obligated to report data (DEPA, 2010b; DEPA, 2015) and data are published on the Danish EPA homepage.
EU ETS data	The Danish Energy Agency (DEA)	Rikke Brynaa Lintrup	Plant specific CO_2 emission factors and fuel consumption data. 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.		Plants are obligated by law. The availability of detailed information is part of the data agreement with DEA (2014 update).

Additional sector specific QC procedures

Some additional sector specific QC procedures are performed.

- 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 NIR Chapter 3.2.5.
- Most country-specific emission 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.

Sector specific verification

The IPCC reference approach for CO_2 emission is the primary verification of the CO_2 emission from the energy sector. The reference approach for the energy sector is shown in NIR Chapter 3.4.

In addition, as part of the EU review of the reported GHG emission data, EU performs for each member state a comparison of Eurostat energy data in terms of TJ with energy data provided in the CRF. The comparison has been performed in accordance with the Commission implementing regulation (EU) No 749/2014 of 30 June 2014 and with the IPCC Guidelines (2006). The latest comparison included comparisons of the reference approach (RA) and the sectoral approach (SA) for the years 2005 and 2008-2021. The comparison of fuel consumption data in CRF and energy statistics from Eurostat is shown in NIR Annex 9 including explanation of the differences.

Finally, a verification of the Danish GHG emission inventories has been published by Fauser et al. (2013).

National external review for stationary combustion

The 2004, 2006, 2009, 2014, 2018 and 2021 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; Nielsen, 2021). The national external review forms a vital part of the QA activities for stationary combustion.

The 2004, 2006, 2009, 2014, 2018 and 2021 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, energy statistics experts from the Danish Energy Agency and Jytte Boll Illerup, The Danish Environmental Protection Agency.

Annex 3B - Transport and other mobile sources

Annex 3B-12-5: Engine load factor (% MCR) per route per ferry for Danish ferries 1990-2021

Annex 3B-12-6: Ferry service, ferry name, engine type, engine year, fuel type, main engine MCR (kW), aux. engine (kW), engine load factors (%), Number of round trips, Sailing time (mins), MWh produced, fuel consumption (tonnes and GJ), specific fuel consumption (g/kWh), SO_2, NO_x, NMVOC, CH_4, VOC, CO, CO_2, N_2O, NH_3, TSP, PM_{10}, $PM_{2.5}$ and BC emission factors for 2021 (g/kWh, g/GJ, g/kg fuel).

Annex 3B-12-7: Hours at sea, engine load (%), MWh produced, fuel consumption (PJ), specific fuel consumption (g/kWh), SO_2, NO_x, NMVOC, CH_4, VOC, CO, CO_2, N_2O, NH_3, TSP, PM_{10}, $PM_{2.5}$ and BC emission factors (g/kWh, g/GJ, g/kg fuel) for Danish fishing vessels 1985-2021 distributed into overall length classes.

Annex 3B-13-1: Specific fuel consumption, NO_x, CO, VOC, NMVOC and CH_4 emission factors (g pr kWh) per engine year for marine 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 national sea transport, international sea transport and fisheries

Annex 3B-13-3: Engine load adjustment functions for sfc, NO_x, VOC, CO, N_2O and TSP emission factors for marine engines

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 2021 in CollectER format

Annex 3B-15-3: Emissions for 1990 in CollectER format

Annex 3B-15-4: Emissions for 2021 in CollectER format

Annex 3B-15-5: Non-exhaust emission factors, activity data and total non-exhaust emissions of TSP, PM_{10}, $PM_{2.5}$, BC and heavy metals in 2021

Annex 3B-16-1: Fuel consumption 1985-2021 in CRF format

Annex 3B-16-2: Emissions 1985-2021 in CRF format

Annex 3B-16-3: Fuel consumption 1985-2021 in NFR format

Annex 3B-16-4: Emissions 1985-2021 in NFR format

Annex 3B-17-1: Uncertainty estimates for greenhouse gases

Annex 3B-17-2: Uncertainty estimates for emission components reported to the LRTAP Convention

All annexes are available at:
https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/air-pollutants/supporting-documentation/

Annex 3C - Industrial processes (NFR 2)

Non-energy products from fuels and solvent use (NFR 2D)

Annex 3C-1:	Activity data for production of burnt lime, t
Annex 3C-2:	Emissions from production of burnt lime
Annex 3C-3:	Activity data for production of container glass and glass wool, kt product
Annex 3C-4:	Emissions from production of container glass and glass wool
Annex 3C-5:	Activity data for extracted minerals other than coal, kt
Annex 3C-6:	Emissions from quarrying and mining of other minerals than coal, t
Annex 3C-7:	Activity data for construction and demolition, mill. m^2
Annex 3C-8:	Emissions from construction and demolition, kt
Annex 3C-9:	Activity data for storage, handling and transport of mineral products, kt mineral
Annex 3C-10:	Emissions from storage, handling and transport of mineral products, t
Annex 3C-11:	Activity data for production of Other mineral products
Annex 3C-12:	Emissions from Other mineral products
Annex 3C-13:	Activity data for production of nitric and sulphuric acid, kt
Annex 3C-14:	Emissions from the production of nitric and sulphuric acid
Annex 3C-15:	Activity data for production of catalysts and fertilisers
Annex 3C-16:	Emissions from the production of catalysts and fertilisers
Annex 3C-17:	Emissions from the production of chemical ingredients, t
Annex 3C-18:	Activity data for production of pesticides, t
Annex 3C-19:	Emissions from the production of pesticides, t

Annex 3C-46:	Emissions from the treatment of slaughterhouse waste, t

All annexes are available online at:

https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Please note that data found via this link are updated annually. This means that data in the annexes always match the newest version of the Informative Inventory Report (IIR).

Annex 3D - Agriculture

Table 3D-1: Number of animals allocated on subcategories. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values)

Table 3D-2a: Nitrogen excretion rates in average, kg N per head per year. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation most recently submitted values)

Table 3D-2b: Nitrogen excretion given as TAN (Total Ammonia Nitrogen), kg N per head per year. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values)

Table 3D-3: Changes in housing type. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values)

Table 3D-4: Cover of slurry tanks. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values)

Table 3D-5: PM emission from housings, Gg TSP, PM_{10} and $PM_{2.5}$. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values)

Table 3D-6 Assumptions for synthetic fertiliser.

EMEP/EEA fertiliser types[1]	Danish fertiliser types[2]
Anhydrous ammonia (AH)	Liquid ammonia
Ammonium nitrate (AN)	Pure ammonium nitrate Ammonium nitrate with/without sulphur Other N-fertiliser
Ammonium phosphates (MAP, DAP)	Diammonphosphate
Ammonium sulphate (AS)	Ammonium sulphate Ammonium sulphate nitrate
Calcium ammonium nitrate (CAN)	Calcium ammonium nitrate
NK mixtures	NK-fertiliser
NPK mixtures	NPK-fertiliser
NP mixtures	NP-fertiliser
Nitrogen solutions	Liquid nitrogen Ammonium-urea solutions
Other straight N compounds	Calcium and boron calcium nitrate
Urea	Urea

[1] EMEP/EEA emission inventory guidebook 2019, Table 3-2 EFs for NH_3 emissions from fertilisers.
[2] The fertiliser types magnesium fertiliser and nitrogenous calcium cyanamide are also included in the sales statistics from The Danish Agriculture Agency, but no NH_3 is emitted from these fertilisers.

Table 3D-7 Distribution and EF of untreated slurry applied to soil, 2021.

Application methods	Crop status	Time of application	Time before incorporation	Distribution[1], %		EF[2], %	
				Cattle	Swine	Cattle	Swine
Incorporated	-	March	0	8	8	1.6	1.8
	-	April	0	41	24	1.6	1.8
	+	March	0	9	2	12	9.7
	+	April	0	9	3	14	9.8
	+	Summer, grass	0	19	2	15	10
	-	Summer, before winter rape	0	1	3	1.6	1.8
	+	Autumn	0	2	1	15	10
Trailing hoses	+	March		3	14	22	14
	+	April		6	30	27	15
	+	May		2	9	30	15
	+	Summer		0	1	33	16
	+	Autumn		0	3	26	15
Broad spreading				NO	NO	NO	NO

[1] Birkmose (2020).
[2] Hafner et al (2021).

Table 3D-8 Distribution and EF of acidified slurry applied to soil, 2021.

Application methods	Crop status	Time of application	Time before incorporation	Distribution[1], %		EF, acidified in housing/storage		EF, acidified during application	
				Cattle	Swine	Cattle	Swine	Cattle	Swine
Trailing hoses	-	March	4 hours	0	20	3.1	2.2	4.7	3
	+	March		20	20	9.6	7	14	9.2
	+	April		20	40	13	8.2	18	10
	+	May		25	10	17	9.3	22	11
	+	Summer		30	0	22	10	27	12
	+	Autumn		5	10	19	9.9	25	12
Broad spreading	-			NO	NO	NO	NO	NO	NO

[1] Birkmose (2020).
[2] Hafner et al (2021).

Table 3D-9 Distribution and EF of biogas treated slurry applied to soil, 2021.

Application methods	Crop status	Time of application	Time before incorporation	Distribution[1], %	EF[2], %
Incorporated	-	March	0	6	2.6
	-	April	0	34	2.6
	+	March	0	6	16
	+	April	0	7	17
	+	Summer, grass	0	14	17
	-	Summer, before winter rape	0	2	2.6
	+	Autumn	0	1	17
Trailing hoses	+	March		7	28
	+	April		18	29
	+	May		4	30
	+	Summer		1	30
Broad spreading	-			NO	NO

[1] Birkmose (2020).
[2] Hafner et al (2021).

Table 3D-10 Distribution and EF of solid manure applied to soil, 2021.

Application methods	Crop status	Time of application	Time before incorporation	Distribution[1], %	EF[2], %
Broad spreading	-	Winter-spring	4 hours	66	5
	+	Winter-spring		8	16
	-	Spring-summer	4 hours	7	8
	+	Spring-summer		7	20
	+	Late summer-autumn		9	11
	-	Late summer-autumn	4 hours	3	3

[1] Birkmose (2020).
[2] Hansen et al (2008).

Table 3D-11: Weighted emission factors for NH3-N emission from application of manure, kg NH3-N per kg TAN for slurry and kg NH3-N per kg N for solid manure. See https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values).

Table 3D-12: Area of cultivated crops. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values).

Table 3D-13a-d: Number of treatments. See:
https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values).

Table 3D-14: Activity data for field burning of agricultural residues. See:
https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values).

Table 3D-15: Emissions of pollutants from field burning of agricultural residues. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values).

Table 3D-16 Gross energy cattle, MJ per AAP per day. See:
https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values).

Table 3D-17 Volatile solids, kg VS per animal per day. See:
https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values).

Chapter 3D-1 NH_3 reducing technology in housings

Over the past ten years, is seen a growing interest in using technology to reduce the ammonia emission in livestock housing. In the inventory estimations are included reduction from cooling of manure in swine housings, acidification in cattle and swine housings, frequent removal of manure in mink housings and use of heat exchanger in housings with broilers.

The environmental technologies are closely related to the expansion of the livestock production. Due to the enlargement of the animal production, the farmer will be met by a statutory environmental requirements implemented in the Environmental Approval Act for Livestock Holdings (BEK no 1467 af 06/12/2018). For some farmers, the emission reducing technology will be chosen as an opportunity to reduce the ammonia emission. The farmers apply for an Environmental Approval for livestock farming and include information on, which environmental technologies are planned to be implemented to achieve the reduction of ammonia emission, as well as information regarding the expected reduction effect and the number of animals placed in the housing with the respective environmental technology. This Environmental Approvals Register for livestock farming is administrated by the Danish Environmental Protection Agency. This register also include information on air cleaning system, but these data is still in processing, and thus the reducing effect is not yet included in the inventory.

Information from the Environmental Approval Register are used to estimate the distribution of cooling of manure in swine housings and frequent removal of manure in mink housings.

Estimation of distribution of housings with acidifications are based on information from the main distributor of acidification systems in Denmark.

Distribution of the use of heat exchanger in broiler housings is based on a combination of information from distributors of heat exchanger and subsidy schemes, which include subsidy to installation of heat exchangers.

Below is described the background for estimating the distribution of the included NH_3 reducing technologies in the Danish inventory.

Environmental Approval Register 2007-2016

DCE has received data sets for the Environmental Approval Register for livestock farming for the years 2007 – 2016, which are used to estimate the prevalence of ammonia emission technology in Danish livestock housing. However, it must be emphasized, that the data set covers the Environmental Approvals, which not in all cases necessarily has been implemented. It could be poor financial conditions or other circumstances, which lead to a situation, where the approval is not being realised. Therefore, the Register of Environmental Approvals for livestock farming is inserted in a database, and combined with the Central Husbandry Register (CHR), which is the central register of farms and animals managed by the Ministry of Environment and Food of Denmark. It makes it possible to compare each approval with the actual development of the livestock production. In these cases where the CHR register show an expansion of the livestock production contemporary with the Environmental Approval, indicate that the approval are implemented. Around 20 % of all Environmental Approvals includes emission-reducing technologies in livestock housing.

The data set for Environmental Approval Register for the years 2007 – 2016 corresponds to approximately 1800 approvals, which includes emission reducing technologies solution in housing. Data processing showed that many farmers have applied more than one approval, which is caused by no realization of the first approval because of problems with e.g. financial conditions. In some cases, the second approval also could indicate a further expansion of the livestock production. Figure 3D-1 shows the percentage distribution of the different reducing technologies for the 1800 farms, and slurry cooling is the most frequently used technology. Particularly the pig production seems to be active regarding use of reducing technology and thus approval for swine accounts for 76 % of all farms, cattle for 17 % and poultry for the remaining 7 %.

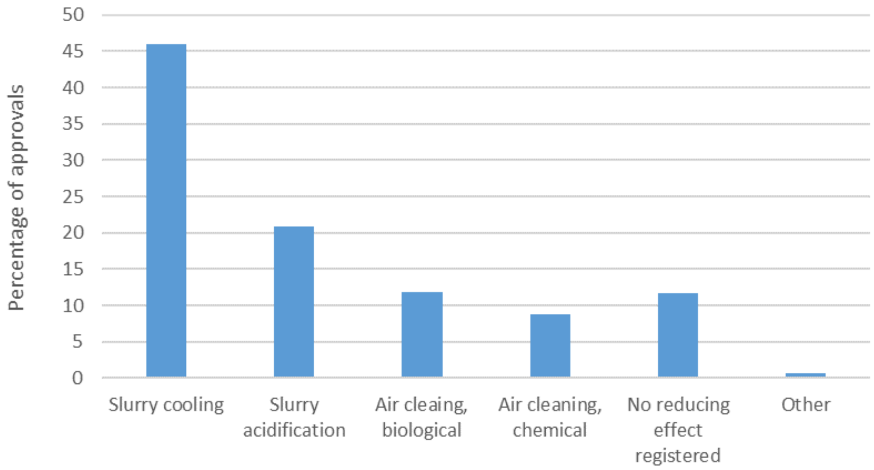


Figure 3D-1 Distribution of ammonia reducing technologies in housing, based on data from the Environmental Approval Register 2007 – 2016.

The review of Environmental Approval Register 2007-2016 indicate that slurry cooling seems to be the most common choose of reducing technology for the swine production, while the cattle production primarily use slurry acidification.

Slurry cooling

Cooling of slurry only occur in swine housing. Cooling is not only an advantage for the environment, but also profitably due to the operational cost for energy use, if the heat can be used in other production facilities – e.g. in piglet barns or farmhouse.

The estimation of distribution of slurry cooling is based on data from the Environmental Approval Register. Approximately 600 farmers has an approval, which include a housing system with slurry cooling. A sorting process of the data has been performed, in order to avoid double counting of approvals or avoid counting approvals, which in all probability has not been realized. This sorting process leads to the conclusion, that approximately 460 approvals is considered as implemented. Following assumption is taken in to account during the sorting process:

- It is assumed, that the Environmental Approval is not implemented, if the production has not been increased, or increased by less than 10 %. This is based on the argument, that the farmer does not invest large costs for new technology, if no extension of the production take place.
- The extension of the animal production has to occur within maximum four years after the approval date; otherwise, it is assumed that the approval is not realized.
- Based on the information from the distributors of slurry cooling system, it is assumed that farmers choose to implement slurry cooling system in relation to new housing buildings. Slurry cooling system can principally be established in existing building, but almost never take place in praxis.
- If CHR data shows a production increase above 10 % in year 2017, it is assumed that approvals for year 2014-2016 is realized.

Based on the 460 approvals (CHR numbers), which is considered as realized, the number of swine is summarized for each year, distinguished between three types of swine; fattening pigs, weaners and sows. Table 3D-18 shows the estimated number of animals, in housing with slurry cooling system. In 2008, 0.2 million swine is placed in housing with slurry cooling system increasing to 2.2 million swine in 2017.

Table 3D-18 Number of animals in housing with slurry cooling, based on the data from the Environmental Approval Register.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Fattening pigs	18 428	84 439	194 095	253 899	299 762	342 337	396 743	457 236	529 249	639 288
Weaners	0	124 205	259 149	368 078	512 387	686 390	889 685	1 175 157	1 410 678	1 713 473
Sows	4 140	9 476	17 578	22 899	31 075	42 590	51 514	62 638	69 166	75 294

Estimation of distribution of slurry cooling

In Table 3D-19 is the number of animals in housing with slurry cooling system, converted to the percentage of the total livestock production. It shows that slurry cooling most frequently take place in sow housing and for weaners, which confirm the profitably of using the heat in weaners housing. No data is available for 2018-2021, and therefore the slurry cooling system is kept at the same level as 2017.

Table 3D-19 Distribution of slurry cooling in housing, percentage of animals.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018-2021*
Fattening pigs	0.1	0.4	0.9	1.2	1.5	1.7	2.0	2.3	2.7	3.4	3.4
Weaners	<0.0	0.4	0.9	1.2	1.7	2.3	2.9	3.7	4.4	5.3	5.3
Sows	0.4	0.9	1.6	2.2	3.1	4.4	5.0	6.1	6.9	7.4	7.4

* No data for 2018-2021 available, therefore maintained the same level as year 2017.

Slurry cooling - NH_3 reducing potential

Reduction potential for the NH_3 emission due to slurry cooling in housing, is based on data from the Environmental Approvals. The approvals include information on NH_3 reduction factors for each farm depending on cooling system (temperature), the volume of air exchange in housing and pH level in manure regarding acidification. A weighted average of the NH_3 reduction factor is estimated to 19.6 % and is consistent with the Environmental Technology List estimate by 20 %.

Table 3D-20 Weighted average of NH_3 reduction emission factor for slurry cooling, based on the data from the Environmental Approval Register compared with the Environmental Technologies List, percentage.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average	**Tech list***
Cattle/swine	19.6	24.4	21.2	20.0	20.7	20.7	19.5	17.0	17.4	15.9	19.6	**20**

* Environmental Technologies List (MST, 2021) – the reduction unit is given as Watt per M2 (28 W/m^2 = 20 % reduction).

Acidification

Information on acidification in Danish livestock housings is based on information received from a distributor of acidification systems. Today, only one single company is the main distributor of acidification systems for housings in Denmark, from where DCE have received information regarding number of sold acidification systems (JH Agro A/S, 2022). The information included:

- Name and CHR number
- Type – cattle or swine
- Animal type – dairy cattle, heifer, bulls, sows, weaners and fattening pigs
- Year the system was put into service
- If the system is closed again, year the system was taken out of service
- If there is a service agreement
- If acid are receive from JH Agro

Estimation of distribution of slurry acidification

Years the acidification systems is counted as active includes both the year it is put into service and the year it is taken out of service. For all farms (CHR number) with active systems number of animals and housing type are collected from the Danish fertiliser N accounts for the years 2009-2021.

The Danish fertiliser N accounts only goes back to 2009, so information on number of animals for 2007 and 2008 are collected from CHR and type of housing is presume as given in the fertiliser account in 2009. For years with lack of information in the fertiliser accounts number of animals are interpolated.

The estimated number of animals in housings with acidification are shown in Table 3D-21.

Table 3D-21: Number of animals in housings with acidification

	2007	2008	2009	2010	2011	2012	2013	2014
Dairy cattle, large breed	551	1 311	3 371	4 587	6 451	11 038	14 427	15 833
Dairy cattle, jersey	350	359	926	1 595	2 340	3 354	3 540	3 752
Heifers, large breed	169	220	546	569	941	1 443	2 021	2 131
Heifers, jersey	-	-	-	-	-	-	-	-
Bulls, large breed	-	-	909	3 143	3 200	6 060	6 322	6 405
Bulls, jersey	-	-	-	-	-	1	1	
Sows	3 371	6 095	9 425	12 667	14 003	16 327	16 928	20 984
Fattening pigs	66 481	135 424	177 927	218 503	247 569	300 750	354 208	390 413
Weaners	152 315	197 691	241 033	314 336	290 369	305 240	326 843	378 523
	2015	2016	2017	2018	2019	2020	2021	
Dairy cattle, large breed	16 089	17 306	17 321	17 120	14 462	13 324	10 385	
Dairy cattle, jersey	3 824	4 166	3 298	3 374	3 284	3 378	2 871	
Heifers, large breed	1 924	1 809	1 806	1 654	1 931	1 837	1 784	
Heifers, jersey	-	-	34	77	42	39	76	
Bulls, large breed	5 901	2 412	2 442	2 475	2 481	2 296	-	
Bulls, jersey	-	-	-	-	-	1	-	
Sows	21 667	23 566	21 589	21 349	21 184	20 095	24 577	
Fattening pigs	387 080	442 096	391 384	382 939	486 239	490 252	515 277	
Weaners	427 591	501 451	541 091	549 071	519 264	486 390	494 800	

The number of animals in housings with acidification are converted to share of all animals.

Table 3D-22: Share of animals in housings with acidification, %.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Dairy cattle, large breed	0.12	0.27	0.69	0.93	1.32	2.18	2.88	3.29	3.35	3.53	3.54	3.46	2.97	2.75	2.16
Dairy cattle, jersey	0.51	0.51	1.27	2.14	3.07	4.17	4.31	4.60	4.73	5.13	4.07	4.19	4.08	4.11	3.42
Heifers, large breed	0.04	0.05	0.13	0.13	0.22	0.32	0.43	0.47	0.43	0.42	0.42	0.40	0.47	0.46	0.45
Heifers, jersey	-	-	-	-	-	-	-	-	-	-	0.08	0.18	0.09	0.08	0.14
Bulls, large breed	-	-	0.38	1.32	1.27	2.74	2.87	3.02	2.71	1.11	1.11	1.12	1.18	1.13	-
Bulls, jersey	-	-	-	-	-	0.01	0.01	-	-	-	-	-	-	0.02	-
Sows	0.29	0.58	0.87	1.13	1.32	1.62	1.73	2.03	2.10	2.36	2.13	2.04	2.11	1.90	2.36
Fattening pigs	0.28	0.61	0.85	1.01	1.13	1.48	1.76	1.96	1.95	2.26	2.11	1.99	2.68	2.33	2.52
Weaners	0.55	0.71	0.86	1.08	0.97	1.03	1.10	1.24	1.36	1.55	1.68	1.65	1.59	1.46	1.44

Slurry acidification - NH_3 reducing potential

The Environmental Technologies List (MST, 2021) includes reduction factors for a series of NH_3 reduction technologies, among these a reduction factor by 50 % for acidification of cattle slurry and 64 % for acidification of swine slurry. These are used in the emission calculations.

Frequent removal of manure regarding mink housing

Frequent removal of manure reduces the emission of NH_3 from housings. A standard mink housing is defined as manure removal by once a week, while a frequent removal of manure minimum two times per week.

Estimation of distribution of frequent removal of manure

The Environmental Approval Register includes approvals for 89 farms (CHR numbers) with mink production in the period 2007-2016. However, the number of approvals is reduced to 60, because information regarding removal of manure (ones a week) and the design of manure system (slurry channel width), shows that 19 farms was considered as standard housing, with no further NH_3 reducing potential. For 2007-2009, no approvals are registered.

In Table 3D-23 are shown the number of mink (breeding females) registered in the Environmental Approval Register with frequent removal of manure for the years 2010-2017 and the percentage of the total production of mink. For 2018-2020, no data is available and therefore the percentage of production with frequent removal of manure is considered at the same level (in percentage) as year 2017. In the end of 2020 the mink production were closed down and all animals put down, so no production in 2021.

Table 3D-23 Number of breeding female mink in approvals with frequent removal of manure.

Approvals	2010	2011	2012	2013	2014	2015	2016	2017	2018[3]	2019[3]	2020[3]
Number of mink[1], approval for the concerned year	27 360	11 920	49 087	32 499	51 365	61 635	33 099	119 926	-	-	
Total number of mink with frequent removal of manure	27 360	39 280	88 367	120 866	172 231	233 866	266 965	386 891	-	-	
Total number of breeding females, millions[2]	2.70	2.75	2.95	3.12	3.31	3.39	3.25	3.42	3.36	2.47	2.21
Percentage of production with frequent removal of manure	1.0	1.4	3.0	3.9	5.2	6.9	8.2	11.3	11.3	11.3	11.3

[1] Mink = breeding female.

[2] Production based on data from Danish Statistic.

[3] For 2018-2020, no data is available. The percentage is maintained as year 2017.

Frequent removal of manure - NH_3 reducing potential

The Environmental Technologies List (MST, 2021) includes reduction factors for frequent removal of manure in mink housings, which are set to a 27 % NH_3 reduction.

Heat exchanger

Installation of heat exchanger in broiler housings have various positive effects; an economic cost saving for heat expense; quick drying of the bedding, which decreases the risk of NH_3 emission and better air quality in the housing, which is of benefit for both animals and humans.

Estimation of distribution of heat exchanger

Estimation of the use of heat exchanger in broiler housings is based on information from the largest distributor of heat exchanger system, which account for approximately 70 % of the marked (Rokkedahl Energy, 2019). DCE has received data for years 2012-2018. In addition to the information from the distributor, the estimation is also based on knowledge from subsidy schemes. Data is received from the Agency of Agriculture and Fisheries. The Danish farmers had the opportunity to apply for funding for activities, with replacing of old equipment to more modern technology, hereunder technology with ammonia reducing technology as heat exchanger, see Table 3D-24. Based on the data from the subsidy schemes, it is possible to register the number of farms, which have received confirmation of subsidy and also information of the animal production at these farms.

Both information from the distributor and the subsidy schemes pointed out the same development for the prevalence of heat exchanger.

It is concluded that the information based on the Environmental Approval Register is not reliable in the case of heat exchanger. Data registered in the approvals shows a very limited use of heat exchanger and this underestimate is undoubtedly due to the main reason for installation of heat exchanger is reduction of operational cost. Therefore, an installation of heat exchanger is not necessarily an act that occurs in connection with an expansion of the animal production, and thus not releases an environmental approval.

Table 3D-24 Subsidy schemes where subsidy for heat exchanger were possible.

Year	Subsidy schemes	Legislation
2015	Subsidy to investments in new green processes and technology in the main agriculture production	BEK no. 250 of 16. March 2015
2014	Subsidy to investments in green processes and technology in the main agriculture production	BEK no. 897 of 21. July 2014
2013	Subsidy to investments in new green processes and technology in the main agriculture production	BEK no. 569 of 31. May 2013
2012/2011	Subsidy to projects with investments in new green processes and technology in the main agriculture production	BEK no. 744 of 28. June 2011
2010	Subsidy to projects with investments in new green processes and technology in the main agriculture production	BEK no. 502 of 11. May 2010

Based on the data from the main distributor of heat exchanger and the data regarding the subsidy schemes, it is concluded that use of heat exchanger in broiler housing takes place from year 2012. Converted to the percentage of the total production in Denmark, the percentage of broiler production in housing with heat exchanger is estimated to 24 % in 2012 increasing to 90 % in 2018, Table 3D-25. For 2019-2021, no data is available and therefore the percentage of production with heat exchanger is considered at the same level (in percentage) as year 2018.

Table 3D-25 Distribution of heat exchangers in broiler housings.

Number of produced broilers, 1000 broilers	2012	2013	2014	2015	2016	2017	2018	2019[2]	2020[2]	2021[2]
Main distributor	24 246	27 639	17 433	14 785	1 834	3 875	999 000	-	-	-
Other distributors	2 780	2 780	2 780	2 780	2 780	2 780	2 780	-	-	-
Summed[1]	27 026	57 445	77 658	95 223	99 837	106 493	110 271	-	-	-
Total number of produced broilers	112 459	117 341	115 997	114 738	121 185	118 102	122 768	124 476	121 008	118 931
% of production	24	49	67	83	82	90	90	90	90	90

[1] Sum of number of broilers in housings with heat exchanger from the years before and the current year.

[2] For 2019-2021, no data is available. The percentage is maintained as year 2018.

Heat exchanger - NH_3 reducing potential

In the Environmental Technologies List (MST, 2021) is given a NH_3 reduction factor at 30 % for Rokkedahl heat exchanger, which is a product developed by the main distributor. Information from one of the other distributors of heat exchanger – Big Dutchman – shows a reduction factor of 29 % (LUFA Nord-West, 2012, Big Dutchman, 2019), which mean nearly at the same level as for the Rokkedahl product. A reduction factor of 30 % for all housings with heat exchanger are used.

References

BEK nr. 1467 af 06/12/2018, 2018: Bekendtgørelse om godkendelse og tilladelse m.v. af husdyrbrug (Husdyrgodkendelsesbekendtgørelsen).

Big Dutchman, 2019: Salgsmateriale. Heat exchanger Earny saves heating costs, improves the house climate and reduces emissions. Available at: http://images.proultry.com/files/company/4249/Big_Dutchman_Stallklima_poultry_climate_control_Broiler_Earny_en.pdf (Feb. 2023).

Birkmose, T., 2020: Aktivitetsdata for udbragt husdyrgødning, 2016-2020. Af Landskonsulent Torkild Birkmose, SEGES. Juni 2020. (In Danish).

Hafner, S.D., Nyord, T., Sommer, G.S. & Adamsen, A.P., 2021: Estimation of Danish emission factors for ammonia from field-applied liquid manure for 1980 to 2019. 138 pages. Advisory report from DCA – Danish Centre for Food and Agriculture, Aarhus University, submitted: 23-09-2021. Available at: https://pure.au.dk/portal/files/223538048/EFreport23092021.pdf (Feb. 2023).

Hansen, N.H., Sommer, S.G., Hutchings, N.J. & Sørensen, P., 2008: Emission factors for calculation of ammonia volatilization by storage and application of animal manure. DJF husdyrbrug nr. 84 • december 2008. (In Danish). Available at: https://dcapub.au.dk/djfpublikation/djfpdf/djfhus84.pdf (Feb. 2023).

JH Agro A/S, 2022: List of acidification systems. JH Agro A/S, Lundholmvej 41, 7500 Holstebro. Received by email from Lars Forsbech 03.10.2022.

LUFA Nord-West, 2012: Report on the emission measurements in a broiler house with heat exchanger as well as a reference house. Report No.: 20120208-838 Date: 15.05.2012. Institut für Boden und Umwelt.

MST, 2021: The Environmental Technologies List. Available at: http://eng.mst.dk/trade/agriculture/environmental-technologies-for-livestock-holdings/list-of-environmental-technologies/ (Feb. 2023).

Rokkedahl Energy, 2019: Pers. comm. Anja Møller fra Rokkedahl Energy ApS, Nymøllevej 126 B, Kølby, 9240 Nibe. Tlf. 29/10 og 18/11-2019 and mail correspondence.

Annex 3E - Waste

Annex 3E-1.1:	Solid waste disposal activity data
Annex 3E-1.2:	Average wind speed data, 2006-2017
Annex 3E-1.3:	National emissions from waste handling at solid waste disposal sites
Annex 3E-2.1:	Compost production activity data
Annex 3E-2.2:	Emissions from composting
Annex 3E-2.3:	Energy production, N in feedstock and NH_3 emission from biogas production
Annex 3E-3.1:	Human cremation activity data
Annex 3E-3.2:	Emissions from human cremation
Annex 3E-3.3:	Animal cremation activity data
Annex 3E-3.4:	Emissions from animal cremation
Annex 3E-4.1:	Influent wastewater
Annex 3E-4.2:	NMVOC emissions from wastewater treatment
Annex 3E-5.1:	Occurrence of all fires, building and vehicle fires
Annex 3E-5.2:	Accidental building fires full-scale equivalent activity data
Annex 3E-5.3:	Emission factors for detached houses, undetached houses and apartment buildings for 1990-2014 and average used for all years
Annex 3E-5.4:	Average building floor space, 1980-2014
Annex 3E-5.5:	Emissions from building fires
Annex 3E-5.6:	Number of nationally registered vehicles and full-scale equivalent (FSE) vehicle fires
Annex 3E-5.7:	Average vehicle weight
Annex 3E-5.8:	Burnt mass of different vehicle categories, tonnes
Annex 3E-5.9:	Emissions from accidental vehicle fires

All annexes are available online at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Annex 4 – Completeness and use of notation keys

Not estimated categories

The Danish air emission inventory is generally complete. However, some categories and/or pollutants are reported as NE (Not estimated).

Fugitive emissions from fuels

NMVOC emissions for 1B1a Fugitive Emission from Solid Fuels: Coal Mining and Handling are NE (Not Estimated) in accordance with the 2019 EMEP/EEA Guidebook.

Industrial processes

- Some pollutants from iron and steel production (Rolling mills and iron foundries) due to lack of emission factors.
- Some pollutants from aluminium production (secondary) due to lack of emission factors.
- Some pollutants from lead production (secondary) due to lack of emission factors.
- Some pollutants from other metal production due to lack of emission factors.
- Emissions of BC from construction and demolition are not estimated due to lack of emission factors.
- Emissions of PM and BC from secondary pulp and paper production have not been estimated due to lack of emission factors. There is no primary pulp and paper production in Denmark.
- Emissions of mercury from its use as a pure substance have not been estimated due to lack of activity data and emission factors.
- Emissions of PAH from road paving with asphalt and asphalt roofing have not been estimated.
- Emissions of CO from other chemical industry have not been estimated due to lack of emission factors.

Agriculture

- Emissions of PM from off-farm storage, handling and transport of bulk agricultural products have not been estimated, due to lack of emission factors.
- NO_x emissions from cultivated crops have not been estimated, due to lack of emission factors.

Waste

- Emissions of NH_3 and BC from solid waste disposal on land have not been estimated as no emission factors are available
- Emissions of NMVOC and particulate matter from composting have not been estimated due to lack of emission factors.
- Emissions of NMVOC from anaerobic digesters have not been estimated due to lack of emission factors.
- Emissions from small-scale waste burning have not been estimated. The emission factors in the EMEP/EEA Guidebook refers to burning of residues from tree pruning and similar that does not occur on any significant scale in Denmark. No activity data are available for bonfires, and similar activities.
- Black carbon emissions from cremations have not been estimated due to lack of emission factors.

- Technology specific emissions of NH_3 emissions from 5.D.1 latrines are not applicable to Denmark (i.e. not occurring). For 5.D.2 Wastewater treatment plants, NH3 emissions are considered insignificant and no emission factors are available.
- The emission of NH_3, BC, selenium, PCBs and HCB from accidental fires has not been estimated due to lack of available emission factors.

Categories reported as IE (Included Elsewhere)

The table below indicates the categories where the notation key IE has been used in the reporting for some or all pollutants.

Table A3.1 List of categories reported as included elsewhere.

Category reported as IE	Emissions where emissions are included
1A5a Other stationary (including military)	1A4ai Commercial/institutional: Stationary
2A1 Cement production	1A2f Manufacturing industries and construction: Non-metallic minerals
2A2 Lime production	1A2f Manufacturing industries and construction: Non-metallic minerals
2A3 Glass production	1A2f Manufacturing industries and construction: Non-metallic minerals
2A6 Other mineral products	1A2f Manufacturing industries and construction: Non-metallic minerals
2C5 Lead production	1A2b Manufacturing industries and construction: Non-ferrous metals
2D3e Degreasing	2D3f Dry cleaning
3Da3 Urine and dung deposited by grazing animals	3B Manure management

Emissions from military stationary sources are not reported separately in the Danish energy statistics and hence it is not possible to report them separately. Emissions and fuel consumption are reported under commercial and institutional plants.

Emissions from cement production (2A1), lime production (2A2) and glass production (2A3) are included in manufacturing industries and construction (1A2f). For some or all pollutants, it is not possible to separate the process emissions from the energy related emissions.

Emission of NO_X from grazing (3Da3) is included in the emission of NO_X from manure management (3B) because this is included in the Tier 1 method and Denmark estimates NO_X from animals using the Tier 1 method.

For some pollutants in other categories, IE is also used. An example is solid fuels used in railways, this consumption is only for historic trains and no solid fuel consumption is reported in the energy statistics for railways. However, the coal consumption will be accounted for in the energy balance in a different sector. The specific reasons for instances of IE are explained in the sectoral chapters of the report.

Annex 5 – Summary Information on condensables included in PM emission estimates

The table below provides an overview of the NFR sectors and whether the condensable component of PM is included in the PM emission estimates. In cases, where emission factors from the EMEP/EEA Guidebook are used, no assessment has generally been made as to what the emission factors included in the EMEP/EEA Guidebook represent. The references for the PM emission factors used in the Danish inventory are included in the sectoral chapters of this report and will not be repeated here, due to the high level of detail.

The sectors listed below does not contain sources of fugitive particulate matter, as the issue of condensable and filterable particulate matter is only relevant with combustion related emissions.

NFR	Source/sector name	PM emissions: the condensable component is		EF reference and comments
		included	excluded	
1A1a	Public electricity and heat production		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A1b	Petroleum refining		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A1c	Manufacture of solid fuels and other energy industries		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A2a	Stationary combustion in manufacturing industries and construction: Iron and steel		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A2b	Stationary combustion in manufacturing industries and construction: Non-ferrous metals		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A2c	Stationary combustion in manufacturing industries and construction: Chemicals		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A2d	Stationary combustion in manufacturing industries and construction: Pulp, Paper and Print		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A2e	Stationary combustion in manufacturing industries and construction: Food processing, beverages and tobacco		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A2f	Stationary combustion in manufacturing industries and construction: Non-metallic minerals		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A2gvii	Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)			EMEP/EEA guidebook
1A2gviii	Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A3ai(i)	International aviation LTO (civil)			EMEP/EEA guidebook
1A3aii(i)	Domestic aviation LTO (civil)			EMEP/EEA guidebook
1A3bi	Road transport: Passenger cars			EMEP/EEA guidebook
1A3bii	Road transport: Light duty vehicles			EMEP/EEA guidebook
1A3biii	Road transport: Heavy duty vehicles and buses			EMEP/EEA guidebook
1A3biv	Road transport: Mopeds & motorcycles			EMEP/EEA guidebook
1A3c	Railways	✓		Danish National Railways
1A3di(ii)	International inland waterways	Not occurring		
1A3dii	National navigation (shipping)	✓		
1A3ei	Pipeline transport	Not applicable as no fuel combustion related to pipeline transport occurs in Denmark		
1A3eii	Other (please specify in the IIR)	Not occurring		
1A4ai	Commercial/institutional: Stationary		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A4aii	Commercial/institutional: Mobile			EMEP/EEA guidebook
1A4bi	Residential: Stationary	Wood	Other fuels	Please refer to Chapter 3.2, Table 3.2.29
1A4bii	Residential: Household and gardening (mobile)			EMEP/EEA guidebook
1A4ci	Agriculture/Forestry/Fishing: Stationary		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A4cii	Agriculture/Forestry/Fishing: Off-road vehicles and other machinery			EMEP/EEA guidebook

1A4ciii	Agriculture/Forestry/Fishing: National fishing			EMEP/EEA guidebook
1A5a	Other stationary (including military)	Included under 1A4ai		
1A5b	Other, Mobile (including military, land based and recreational boats)	✓		MWI
1B2c	Venting and flaring (oil, gas, combined oil and gas)		✓	EMEP/EEA guidebook
2A2	Lime production			EMEP/EEA (2016) - Unknown
2A3	Glass production			Container glass: EMEP/EEA (2019) - Unknown Glass wool: Environmental reports – Measurement method unknown
2C1	Iron and steel production			Electric arc furnace: Environmental reports – Measurement method unknown Rolling mills: Environmental reports – measurement method unknown & EMEP/EEA (2019) - Filterable Grey iron foundries: EMEP/Corinair 2007 - Unknown
2C5	Lead production			Abated: BREF (2017) - Unknown Unabated: EMEP/EEA(2019) - Filterable
2D3b	Road paving with asphalt		✓	EMEP/EEA (2019) - Filterable
2D3c	Asphalt roofing			EMEP/EEA (2019) - Unknown
2G	Other product use (please specify in the IIR)			Fireworks: Klimont Z. et al. (2002) - Unknown Barbeques: Environment Australia (1999) - Unknown Shoes: Sambat et al. (2001) Tobacco: Martin et al. (1997) - Filterable
3F	Field burning of agricultural residues			EMEP/EEA guidebook
5C1bv	Cremation			Human cremation: US EPA Webfire (2012) - Filterable Animal cremation: EMEP/EEA (2019) - Unknown
5E	Other waste (please specify in IIR)			Building fires: EMEP/EEA (2019) - Unknown Vehicle fires: Lönnermark et al. (2004) - Electrical low-pressure impactor

ANNUAL DANISH INFORMATIVE INVENTORY REPORT

Emission inventories from the base year of the protocols to year 2021

This report is a documentation report on the emission inventories for Denmark as reported to the UNECE Secretariat under the Convention on Long Range Transboundary Air Pollution and the European Commission under the National Emission Ceilings Directive due by 15 March 2023. The report contains information on Denmark's emission inventories regarding emissions of (1) SO_X for the years 1980-2021, (2) NO_X, CO, NMVOC and NH_3 for the years 1985-2021, (3) Particulate matter: TSP, PM_{10}, $PM_{2.5}$ for the years 1990-2021, (4) Heavy Metals: Pb, Cd, Hg, As, Cr, Cu, Ni, Se and Zn for the years 1990-2021, (5) Polyaromatic hydrocarbons (PAH): Benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene and indeno(1,2,3-cd)pyrene, PCDD/F and HCB for the years 1990-2021. Further, the report contains information on background data for emissions inventory.

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