PROJECTION OF GREENHOUSE GASES 2021-2040

Scientific Report from DCE – Danish Centre for Environment and Energy No. 505 2022

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Data sheet

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Abstract: This report contains a description of models, background data and projections of CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 for Denmark. The emissions are projected to 2040 using a 'with measures' scenario. Official Danish projections of activity rates are used in the models for those sectors for which projections are available, e.g. the latest official projection from the Danish Energy Agency. The emission factors refer to international guidelines and some are country-specific and refer to Danish legislation, Danish research reports or calculations based on emission data from a considerable number of industrial plants. The projection models are based on the same structure and method as the Danish emission inventories in order to ensure consistency.

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Contents

List of abbreviations

ARD	Afforestation, Reforestation & Deforestation
BOD	Biological Oxygen Demand
C	Carbon
CH_4	Methane
CHP	Combined Heat and Power
CHR	Central Husbandry Register
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand
COPERT	COmputer Programme to calculate Emissions from Road Transport
CORINAIR	CORe INventory on AIR emissions
CRF	Common Reporting Format
CL	Cropland
CM	Cropland Management
CO_2e	Equivalents of carbon dioxide
DCA	Danish Centre for Food and Agriculture
DCE	Danish Centre for Environment and Energy
DEA	Danish Energy Agency
DEPA	Danish Environmental Protection Agency
DM	Dry Matter
DSt	Statistics Denmark
EEA	European Environment Agency
EIONET	European Environment Information and Observation Network
EMEP	European Monitoring and Evaluation Programme
ENVS	Department of Environmental Science, Aarhus University
EU ETS	European Union Emission Trading Scheme
FL	Forest land
FM	Forest Management
FOD	First Order Decay
FSE	Full Scale Equivalent
GHG	GreenHouse Gas
GL	GrassLand
GM	Grazing Land Management
GWP	Global Warming Potential
HWP	Harvested Wood Products
HFCs	Hydrofluorocarbons
IDA	Integrated Database model for Agricultural emissions
IEF	Implied Emission Factor
IPCC	Intergovernmental Panel on Climate Change
LUC	Land Use Conversion
LUM	Land Use Matrix
LPG	Liquefied Petroleum Gas
LTO	Landing and Take Off
LULUCF	Land Use, Land-Use Change and Forestry
MC	Managed Cropland (under EU decision No. 527)
MCF	Methane Conversion Factor
MG	Managed Grassland (under EU decision No. 527)
MSW	Municipal Solid Waste
MW	Managed Wetlands (under EU decision No. 527)
N	Nitrogen
N_2O	Nitrous oxide

NFI	National Forest Inventory
NIR	National Inventory Report
OC	Organic carbon
ODS	Ozone Depleting Substance
OL	Other Land
P	Phosphorus
PFCs	Perfluorocarbons
SE	Settlements
SOC	Soil Organic Carbon
SF_6	Sulphur hexafluoride
SNAP	Selected Nomenclature for Air Pollution
SWDS	Solid Waste Disposal Sites
UNFCCC	United Nations Framework Convention on Climate Change
WE	Wetlands
WWTP	WasteWater Treatment Plant

Preface

This report contains a description of models and background data for projection of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) for Denmark. The emissions are projected to 2040 using a baseline scenario, which includes the estimated effects of policies and measures implemented in Denmark's greenhouse gas (GHG) emissions ('frozen policy' or 'with existing measures' projection) – meaning that the policies and measures are implemented or decided by December 2021.

DCE – Danish Centre for Environment and Energy, Aarhus University, has conducted the study. The project has been financed by the Danish Energy Agency (DEA).

This report has been made with contributions from several authors, the table below indicates the specific responsibilities for each chapter and the person responsible for providing a peer-review of that specific chapter.

Table 0.1 List of authors and reviewers.

Chapter	Authors	Reviewer
1	Ole-Kenneth Nielsen	Marlene S. Plejdrup
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4	Katja Hjelgaard	Ole-Kenneth Nielsen
5	Morten Winther	Ole-Kenneth Nielsen
6	Mette H. Mikkelsen & Rikke Albrektsen	Ole-Kenneth Nielsen
7	Ole-Kenneth Nielsen	Katja Hjelgaard
8	Steen Gyldenkærne	Ole-Kenneth Nielsen

As to the summary and conclusions chapter of the report (Chapter 9), all authors are responsible for the content.

The authors would like to thank:
The Danish Energy Agency (DEA) - for providing the energy consumption projection, the oil and gas projection and for valuable discussions during the project.

National Laboratory for Sustainable Energy, Technical University of Denmark (DTU), for providing the data on scenarios of the development of landfill deposited waste production.

Danish Centre for food and Agriculture (DCA) and the Knowledge Centre for Agriculture, the Danish Agricultural Advisory Service (DAAS) for providing data for the agricultural sector.

Tomas Sander Poulsen from Provice for the cooperation on the Danish emissions and projections of fluorinated gases.

Department of Geosciences and Natural Resource Management, Copenhagen University, for cooperation in the preparation of the Danish GHG inventory where the department carry out projections of emissions/removals from the forest category.

Summary

This report contains a description of the models, background data and projections of the greenhouse gases (GHG) carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) for Denmark. The latest historic year that has formed the basis of the projection is 2020. The emissions are projected to 2040 using a scenario, which includes the estimated effects of policies and measures implemented in Denmark's greenhouse gas (GHG) emissions based on 'frozen policy' (or 'with existing measures' projection) – meaning that the policies and measures are implemented or decided by December 2020. The official Danish energy projection, e.g. the latest official projection from the Danish Energy Agency (DEA), is used to provide activity rates (2020-2040) in the models for those sectors for which these projections are available. The emission factors refer to international guidelines or are country-specific and refer to Danish legislation, Danish research reports or calculations based on emission data from a considerable number of industrial plants in Denmark. The projection models are generally based on the same structure and methodology as the Danish emission inventories in order to ensure consistency. The numbers presented in this report are based on the global warming potentials (GWPs) from the IPCC 4th Assessment Report (AR4). In the data file published with the projections, the results are presented using GWPs from both AR4 and IPCC's 5th Assessment Report.

The main emitting sectors in 2020 are Energy industries (16 %), Transport (27 %), Agriculture (25 %) and Other sectors (8 %). For the latter sector, the most important sources are fuel combustion in the residential sector. GHG emissions show a decreasing trend in the projection period. The total emissions in 2020 are estimated to be 44.9 million tonnes CO_2 equivalents including LULUCF and indirect CO_2 and the corresponding total in 2040 is projected to be 28.2 million tonnes CO_2 equivalents. From 1990 to 2020 the emissions decreased by 42.5 %. From 2020 to 2040, the emission is projected to decrease by approximately 37 %.

The total greenhouse gas emissions in 1990 including LULUCF and indirect CO_2 is estimated at 78.0 million tonnes of CO_2 equivalents and the emission in 2030 is projected to be 34.7 million tonnes of CO_2 equivalents including LULUCF and indirect CO_2. This corresponds to a reduction of 55.5 % between 1990 and 2030. The effect of carbon capture and storage (CCS) in the projection is not attributable to any sector and not included in this figure.

In 2005, the emissions including LULUCF and indirect CO_2 was calculated to 72.1 million tonnes of CO_2 equivalents. It decreased by 37.8 % from 2005 to 2020 and is estimated to be reduced by 51.9 % from 2005 to 2030.

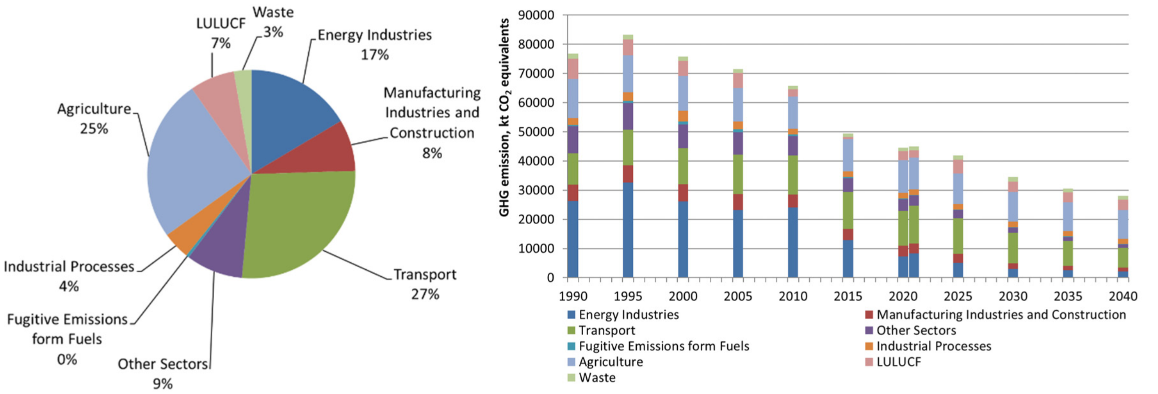


Figure S.1 Total GHG emissions in CO_2 equivalents. Distribution according to main sectors (2020) and time series for 1990 to 2040.

Stationary combustion

Stationary combustion includes Energy industries, Manufacturing industries and construction and Other sectors. Other sectors include combustion in commercial / institutional, residential and agricultural plants. The GHG emissions in 2020 from the main source, which is public power and heat production (43 %), are estimated to decrease in the period from 2020 to 2040 (90 %) due to a significant decrease in the fossil fuel consumption for electricity production in the later part of the time series. For residential combustion plants, a significant decrease in emissions is also projected; the emissions are expected to decrease by 91 % from 2020 to 2040, due to a lower consumption of fossil fuels. Emissions from manufacturing industries on the other hand only decreases by 72 %, due to a much smaller decrease in fossil fuel combustion.

Fugitive emissions from fuels

The greenhouse gas emissions from the sector "Fugitive emissions from fuels" show large fluctuations in the historical years 1990-2020, due to emissions from exploration, which occur only in some years with varying amounts of oil and gas flared. Emissions from exploration are not included in the projection, as no projected activity data are available. Emissions are estimated to decrease in the projection period 2020-2040 by 18 %. The decrease mainly owe to expected decrease of offshore flaring in the oil and natural gas extraction. Emissions from extraction of oil and natural gas are estimated to decline over the projection period due to the expectation of a decrease of extracted amounts of natural gas. Emissions of greenhouse gases from other sources are estimated to be constant or nearly constant over the projection period.

Industrial processes and product use

The GHG emission from industrial processes and product use increased during the nineties, reaching a maximum in 2000. Closure of a nitric acid / fertiliser plant in 2004 has resulted in a considerable decrease in the GHG emission. The most significant sources of GHG emission in 2020 are mineral industry (mainly cement production) with 70 % and use of substitutes (f-gases) for ozone depleting substances (ODS) (17 %). The corresponding shares in 2040 are expected to be 82 % and 7 %, respectively. Consumption of limestone and the emission of CO_2 from flue gas cleaning are assumed to follow the consumption of coal and waste for generation of heat and power. The GHG emission from this sector will continue to be strongly dependent on the cement production at Denmark's only cement plant.

Transport and other mobile sources

Road transport is the main source of GHG emissions from transport and other mobile sources in 2020 (80 %) and emissions from this source are expected to decrease in the projection period 2020 to 2040, but with the largest reduction happening after 2030. The emission shares for the remaining mobile sources (e.g. domestic aviation, national navigation, railways and non-road machinery in industry, households and agriculture) are small compared with road transport. Non-road machinery in agriculture, forestry and fishing contributes 8 % of the sectoral GHG emission in 2020.

Agriculture

The main sources in 2020 are agricultural soils (40 %), enteric fermentation (33 %) and manure management (25 %). The corresponding shares in 2040 are expected to be 41 %, 39 % and 18 %, respectively. From 1990 to 2020, the emission of GHGs in the agricultural sector decreased by 16 %. In the projection years 2020 to 2040, the emissions are expected to decline slightly by about 13 %. The reduction in the historical years can mainly be explained by improved utilisation of nitrogen in manure, a significant reduction in the use of fertiliser and a reduced emission from N-leaching. Measures in the form of technologies to reduce ammonia emissions in stables and expansion of biogas production are considered in the projections and emissions from enteric fermentation are estimated to increase due to an expected increase in the number of animals.

Waste

The total GHG emission from the waste sector has been decreasing in the years 1990 to 2020 by 36 %. From 2020 to 2040, the emissions are projected to increase slightly by 7 % driven by a large increase in emissions from anaerobic digestion. In 2020, the GHG emission from solid waste disposal contributed with 44 % of the emission from the sector as a whole. A decrease of 39 % is expected for this source in the years 2020 to 2040, due to less waste deposition on landfills. An almost constant level for emissions from wastewater is expected for the projection period. GHG emissions from wastewater handling in 2020 contribute with 22 %. Emissions from biological treatment of solid waste contribute with 37 % in 2020 and 57 % in 2040.

LULUCF

The LULUCF sector includes emissions from Afforestation, Deforestation, Forest land remaining forest land, Cropland, Grassland, Wetlands, Settlement and Other land. This projection include only Cropland, Grassland, Wetland, Settlement and Other land. Forestry and Harvested wood products (HWP) is reported separately in Johannsen et al. (2022) although these emission estimates has been included here. The overall picture of the LULUCF sector excl. Forestry and HWP is a net source of 6 874 kt CO_{2e} in 1990. In 2020, the estimated emission has been reduced to a net source of 3 107 kt CO_{2e} and a net source of 3 891 kt CO_{2e} in 2021-2030 (average of 2021-2030). A small decrease is expected in year 2031-2040 compared to 2021-2030. This decrease can very likely be attributed to an expected increase in crop yield and a lower area with agricultural organic soils. However, it should be noted that the overall emission from this sector is very variable as it is very difficult to predict climate related emission / stock development in the agricultural soils. Agricultural mineral soils are expected to store more carbon in the near future. Agricultural regulations will reduce the area with cultivated agricultural organic soils further in the future, but there will still be a large net emission from these soils.

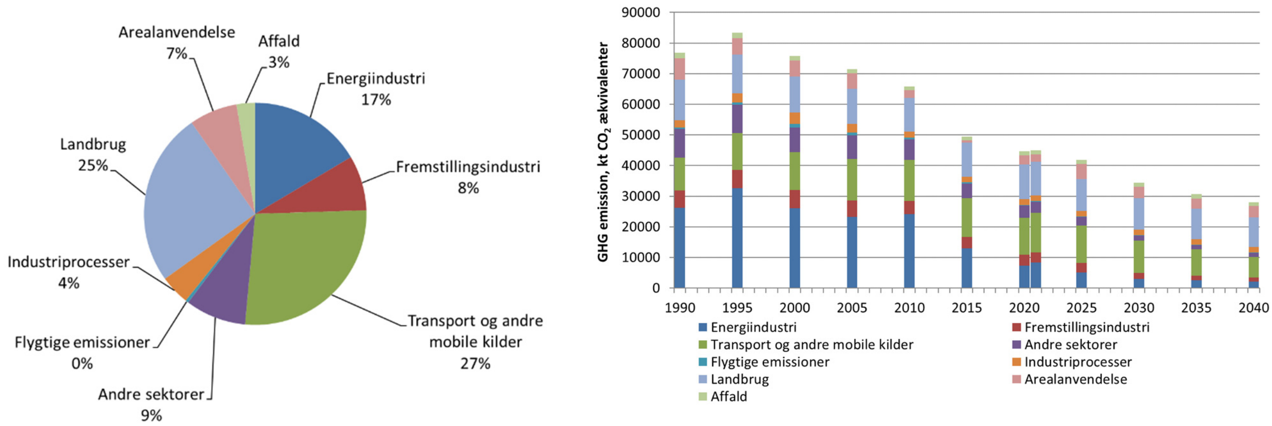
Sammenfatning

Denne rapport indeholder en beskrivelse af modeller, baggrundsdata og fremskrivninger af de danske emissioner af drivhusgasserne kuldioxid (CO_2), metan (CH_4), lattergas (N_2O), de fluorerede drivhusgasser HFC'ere, PFC'ere, svovlhexafluorid (SF_6). Det seneste historiske år ved udarbejdelsen af fremskrivningen var 2020. Emissionerne er fremskrevet til 2040 på baggrund af et scenarie, som medtager de estimerede effekter på Danmarks drivhusgasudledninger af virkemidler iværksat eller besluttet indtil december 2021 (såkaldt "frozen policy" eller "med eksisterende virkemidler" fremskrivning). I modellerne er der, for de sektorer, hvor det er muligt, anvendt officielle danske fremskrivninger af aktivitetsdata, f.eks. er den seneste officielle energifremskrivning fra Energistyrelsen (2020-2040) anvendt. Emissionsfaktorerne refererer enten til internationale vejledninger, dansk lovgivning, danske rapporter eller er baseret på målinger på danske anlæg. Fremskrivningsmodellerne bygger på samme struktur og metoder, som er anvendt for de danske emissionsopgørelser, hvilket sikrer, at historiske og fremskrevne emissionsopgørelser er konsistente. Data inkluderet i denne rapport er baseret på de globale opvarmningspotentialer (GWPs) fra IPCC's fjerde hovedrapport (AR4). I den data-fil, der publiceres sammen med fremskrivning, er resultaterne vist med anvendelse af GWPs fra både AR4 og IPCC's femte hovedrapport.

De vigtigste sektorer i forhold til emission af drivhusgas i 2020 forventes at være energiproduktion og -konvertering (16 %), transport (27 %), landbrug (25 %), og andre sektorer (8 %). For "andre sektorer", er den vigtigste kilde forbrænding i husholdninger (Figur R.1). Drivhusgasemissionerne viser et fald gennem fremskrivningsperioden. De totale emissioner er beregnet til 44,9 millioner tons CO_2-ækvivalenter i 2020 inklusiv LULUCF og indirekte CO_2 og er fremskrevet til 28,2 millioner tons i 2040 inklusiv LULUCF og indirekte CO_2. Fra 1990 til 2020 er emissionerne faldet med 42,5 %. Fra 2020 til 2040 er den fremskrevne reduktion ca. 37 %.

Den samlede drivhusgasemission i 1990 inklusiv LULUCF og indirekte CO_2 er beregnet til 78,0 millioner tons CO_2-ækvivalenter og emissionen i 2030 er fremskrevet til 34,7 million tons CO_2-ækvivalenter. Dette svarer til en reduktion på 55,5 % mellem 1990 og 2030. Effekten af CO_2 fangst og lagring (carbon capture and storage - CCS) er ikke muligt at tildele til enkelte sektorer og er derfor ikke medtaget i dette tal.

I 2005 er emissionen med LULUCF og indirekte CO_2 beregnet til 72,1 millioner tons CO_2-ækvivalenter. Emissionen var i 2020 faldet 37,8 % i forhold til 2005 og forventes reduceret med 51,9 % fra 2005 til 2030.



Figur S.1 Totale drivhusgasemissioner i CO_2-ækvivalenter fordelt på hovedsektorer for 2020 og tidsserier fra 1990 til 2040.

Stationær forbrænding

Stationær forbrænding omfatter Energiindustri (konvertering og olie/gas produktion), Fremstillingsindustri og Andre sektorer. Andre sektorer dækker over handel/service, husholdninger samt landbrug/gartneri. Drivhusgasemissionen fra kraft- og kraftvarmeværker, som er den største kilde i 2020 (43 %), er estimeret til at falde i perioden 2020 til 2040 (90 %) som følge af et markant fald i forbruget af fossile brændstoffer i elproduktionen i den sidste del af fremskrivningsperioden. Emissioner fra husholdningers forbrændingsanlæg falder ifølge fremskrivningen i perioden 2020 til 2040 med hele 91 % pga. lavere forbrug af de fossile brændstoffer. Emissioner fra fremstillingsindustrien falder kun med 72 % i samme periode pga. et meget lavere fald i anvendelsen af fossile brændstoffer.

Flygtige emissioner

Emissionen af drivhusgasser fra sektoren Emissioner af flygtige forbindelser fra brændsler udviser store fluktuationer i de historiske år 1990-2020 som følge af varierende omfang af efterforsknings- og vurderingsboringer (E/V-boringer). Emissioner fra E/V-boringer indgår ikke i fremskrivningen, da der ikke foreligger fremskrevne aktivitetsdata. Emissionerne fra de øvrige flygtige kilder forventes at falde med 18 % i perioden 2020-2040. Den største del af faldet skyldes reduceret flaring ved udvinding som følge af forventningen om en faldende produktion af naturgas. Emissionerne af drivhusgasser fra de øvrige kilder forventes at være konstante eller næsten konstante i fremskrivningsperioden.

Industriprocesser og anvendelse af produkter

Emissionen af drivhusgasser fra industrielle processer og anvendelse af produkter er steget op gennem halvfemserne med maksimum i 2000. Ophør af produktion af salpetersyre/kunstgødning i 2004 har resulteret i en betydelig reduktion af drivhusgasemissionen. De væsentligste kilder er mineralsk industri (især cementproduktion), som bidrager med omkring 70 % af drivhusgasemissionen i 2020, samt anvendelse af erstatningsgasser (f-gasser) for ozonnedbrydende stoffer (ODS), der bidrager med 17 %. De tilsvarende andele i 2040 forventes at ligge på hhv. 82 % og 7 %. Forbrug af kalk og derved emission af CO_2 fra røggasrensning antages at følge forbruget af kul og affald i kraftvarmeanlæg. Drivhusgasemissionen fra industrielle processer forventes også i fremtiden at være meget afhængig af cementproduktionen på Danmarks eneste cementfabrik.

Transport og andre mobile kilder

Vejtransport er den største emissionskilde for drivhusgasser fra sektoren transport og andre mobile kilder i 2020 (80 %), og emissionerne fra denne kilde forventes at falde i fremskrivningsperioden 2020 til 2040 med det største fald i perioden efter 2030. Den samlede emission for andre mobile kilder (indenrigsluftfart, jernbane, indenrigssøfart, ikke-vejgående industrimaskiner, maskiner i have/hushold, landbrugsmaskiner) er lave sammenlignet med vejtransport. Ikke-vejgående maskiner inden for landbrug, skovbrug og fiskeri bidrager med 8 % af sektorens drivhusgasser i 2019.

Landbrug

De største kilder i 2020 er emissioner fra landbrugsjorde (40 %), dyrenes fordøjelse (33 %) og gødningshåndtering (25 %). De tilsvarende andele i 2040 forventes at være hhv. 41 %, 39 % og 18 %. Fra 1990 til 2020 er emissionen fra landbrugssektoren faldet med 17 %. I fremskrivningsperioden forventes emissionerne at falde med ca. 13 %. Årsagen til faldet i de historiske år er en forbedring i udnyttelsen af kvælstof i husdyrgødningen, og hermed et markant fald i anvendelsen af handelsgødning samt lavere emission fra kvælstofudvaskning. I fremskrivningen er der taget højde for teknologiske tiltag i form af ammoniakreducerende teknologi og en øget vækst i biogasanlæg, og emissionerne fra dyrenes fordøjelse er estimeret til at stige pga. en forventet stigning i antallet af dyr.

Affald

Affaldssektorens samlede drivhusgasemissioner er faldet med 36 % i perioden 1990 til 2020. Fra 2020 til 2040 et emissionerne fremskrevet til at stige med 7 %, hvilket kan tilskrives en stor stigning i emissionen fra biogasbehandling. I 2020 udgør drivhusgasemissionen fra lossepladser 44 % af den totale emission fra affaldssektoren. Et fald på 39 % er forventet for denne kilde i perioden 2020 til 2040. Dette skyldes, at mindre organisk nedbrydeligt affald bliver deponeret. I samme periode forventes et stort set konstant niveau for emissioner fra spildevand. I 2020 udgør spildevandshåndteringen 22 % af sektorens samlede emission. Emissionerne fra biologisk behandling af affald (kompostering og biogasbehandling) udgør 37 % i 2020 og 57 % i 2040.

LULUCF

LULUCF (Land Use, Land-Use Change and Forestry)-sektoren inkluderer emissioner fra og optag ved skovrejsning, afskovning, skovdyrkning, kultiverede landbrugsarealer, permanente græsarealer, vådområder, bebyggede arealer og øvrig land. Denne fremskrivning dækker kun kultiverede landbrugsarealer, permanente græsarealer, vådområder, bebyggede arealer og øvrig land. Emissioner fra skov og høstede træprodukter er opgjort i Johannsen et al. (2022). Fremskrevne emissioner herfra er inddraget i denne rapport. Overordnet er LULUCF-sektoren generelt en kilde til CO_2-udledning i Danmark. I 1990 udgjorde sektoren (ekskl. skov) en emission på 6 874 kt CO_2-ækvivalenter. I 2020 er emissionen beregnet til 3 107 kt CO_2-ækvivalenter og fremskrevet til 3 891 kt for gennemsnittet af 2021-2030. Et lille fald er beregnet i 2031-2040 i forhold til 2021-2030. Dette fald er meget usikkert og vanskeligt at estimere. Det skal bemærkes, at emissionen fra LULUCF-sektoren varierer betydeligt fra år til år, da det er behæftet med stor usikkerhed at forudsige skovdrift og de klimarelaterede effekter på emissionen fra især landbrugsjorde. Mineralske landbrugsjorde forventes at akkumulere mere kulstof i den nære fremtid. Regulering på landbrugsområdet vil reducere arealet af dyrkede organiske jorde i fremtiden, men der vil stadig være en betydelig emission fra disse jorde.

Fremskrivningerne af emissioner / optag fra skov udføres af Institut for Geovidenskab og Naturforvaltning ved Københavns Universitet.

1 Introduction

In the Danish Environmental Protection Agency's project "Projection models 2010" a range of sector-related partial models were developed to enable projection of the emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x,) non-methane volatile organic compounds (NMVOC) and ammonia (NH_3) forward to 2010 (Illerup et al., 2002). Subsequently, the project "Projection of GHG emissions 2005 to 2030" was carried out in order to extend the projection models to include the GHGs CO_2, CH_4, N_2O as well as HFCs, PFCs and SF_6, and project the emissions for these gases to 2030 (Illerup et al., 2007). This was further updated in later projects (Nielsen et al., 2008, 2010, 2011, 2013, 2014, 2016, 2017, 2018, 2019, 2020 and 2021). The purpose of the present project, "Projection of greenhouse gas emissions 2021 to 2040" has been to update the emission projections for all sectors based on the latest national energy projections, other relevant activity data and emission factors.

1.1 Obligations

The European Union (EU) has committed itself to reduce emissions of GHGs by 40 % in 2030[1] compared to the level in the so-called base year 1990; in Denmark's case 1990 for CO_2, CH_4, and N_2O and 1995 for industrial GHGs (HFCs, PFCs and SF_6). Within the EU, Denmark has an obligation according to the EU Effort Sharing Regulation to reduce emissions in the non-ETS (sectors not included in the EU Emission Trading Scheme) sector by 39 % in 2030 compared to 2005. A part of that obligation can be fulfilled by making use of so called LULUCF-credits under the EU LULUCF regulation as well as emission allowances from the EU Emission Trading Scheme.

Since 1990, Denmark has implemented policies and measures aiming at reducing Denmark's emissions of CO_2 and other GHGs. Furthermore, in June 2020 the Danish parliament adopted in the national Climate Change Act a target of reducing national emissions of greenhouse gases (including LULUCF) by 70 % in 2030 as compared to emissions in 1990.

In this report, the estimated effects of policies and measures implemented or decided as of December 2021 are included in the projections and the projection of total GHG emissions is therefore a so-called 'with existing measures' projection.

1.2 Greenhouse gases

The GHGs reported under the Climate Convention and projected in this report are:

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

[1] As part of the European Green Deal, the European Commission proposed in September 2020 to raise the 2030 greenhouse gas emission reduction target, including emissions and removals, to at least 55% compared to 1990.

Nitrogen trifluoride (NF_3) is also part of the reporting requirements, but this gas has never been used in Denmark, and is also not considered relevant for the projections.

The main greenhouse gas responsible for the anthropogenic influence on the heat balance is CO_2. The atmospheric concentration of CO_2 has increased from a pre-industrial value of about 278 ppm to about 410 ppm in 2019 (an increase of about 47 %) (IPCC, 2021), and exceeds the natural range of 180- 300 ppm over the last 650 000 years as determined by ice cores. The main cause for the increase in CO_2 is the use of fossil fuels, but changing land use, including forest clearance, has also been a significant factor. The greenhouse gases CH_4 and N_2O are very much linked to agricultural production; CH_4 has increased from a pre-industrial atmospheric concentration of about 729 ppb to 1866 ppb in 2019 (an increase of about 156 %) and N_2O has increased from a pre-industrial atmospheric concentration of about 270 ppb to 332 ppb in 2019 (an increase of about 23 %) (IPCC, 2021). Changes in the concentrations of greenhouse gases are not related in simple terms to the effect on the heat balance, however. The various gases absorb radiation at different wavelengths and with different efficiency. This must be considered in assessing the effects of changes in the concentrations of various gases. Furthermore, the lifetime of the gases in the atmosphere needs to be taken into account – the longer they remain in the atmosphere, the greater the overall effect. The global warming potential (GWP) for various gases has been defined as the warming effect over a given time of a given weight of a specific substance relative to the same weight of CO_2. The purpose of this measure is to be able to compare and integrate the effects of individual substances on the global climate. Typical lifetimes in the atmosphere of substances are very different, e.g. 12 and 109 years approximately for CH_4 and N_2O, respectively (IPCC, 2021). Therefore, the time perspective clearly plays a decisive role. The time frame chosen is typically 100 years. The effect of the various greenhouse gases can, then, be converted into the equivalent quantity of CO_2, i.e. the quantity of CO_2 giving the same effect in absorbing solar radiation. According to the IPCC and their Fourth Assessment Report (IPCC, 2007), which UNFCCC (UNFCCC, 2013) has decided to use as reference for reporting for inventory years throughout the commitment period 2013-2020, the global warming potentials for a 100-year time horizon are

- CO_2 1
- CH_4 25
- N_2O 298

Based on weight and a 100-year period, CH_4 is thus 25 times more powerful a GHG than CO_2, and N_2O is 298 times more powerful. Some of the other GHGs (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) have considerably higher global warming potential values. For example, sulphur hexafluoride has a global warming potential of 22 800 (IPCC, 2007).

For reporting under the Paris Agreement (starting in 2024), the Parties have decided to use GWP values from the Fifth Assessment Report (IPCC, 2013). Here CH_4 has a GWP of 28, while N_2O has a GWP of 265.

Denmark includes reporting of indirect CO_2 in the emission inventory and projection. Indirect CO_2 is the atmospheric oxidation of CO, NMVOC and CH_4. For more information, please see Nielsen et al. (2022).

1.3 Historical emission data

The greenhouse gas emissions are estimated according to the IPCC guidelines and are aggregated into six main sectors. The greenhouse gases include CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3, although NF_3 is not occurring in Denmark. Figure 1.1 shows the estimated total greenhouse gas emissions in CO_2 equivalents from 1990 to 2020. The emissions are not corrected for electricity trade or temperature variations.

CO_2 is the most important greenhouse gas contributing in 2020 to the national total in CO_2 equivalents excluding LULUCF (Land Use and Land Use Change and Forestry) and excluding indirect CO_2 emissions with 68.1%, followed by CH_4 with 17.1 %, N_2O with 13.8 %, and f-gases (HFCs, PFCs, SF_6 and NF_3) with 0.9 %. The energy sector and agricultural sector represent the largest sources, followed by industrial processes and product use and waste, see Figure 1. The total national greenhouse gas emission in CO_2 equivalents excluding LULUCF has decreased by 41.3 % from 1990 to 2020 when considering indirect CO_2, if excluding indirect CO_2 the emissions have decreased by 40.7 %. The emissions including LULUCF and indirect CO_2 have decreased by 42.5 % from 1990 to 2020. Comments on the overall trends etc. seen in Figure 1.1 are given in the sections below on the individual greenhouse gases.

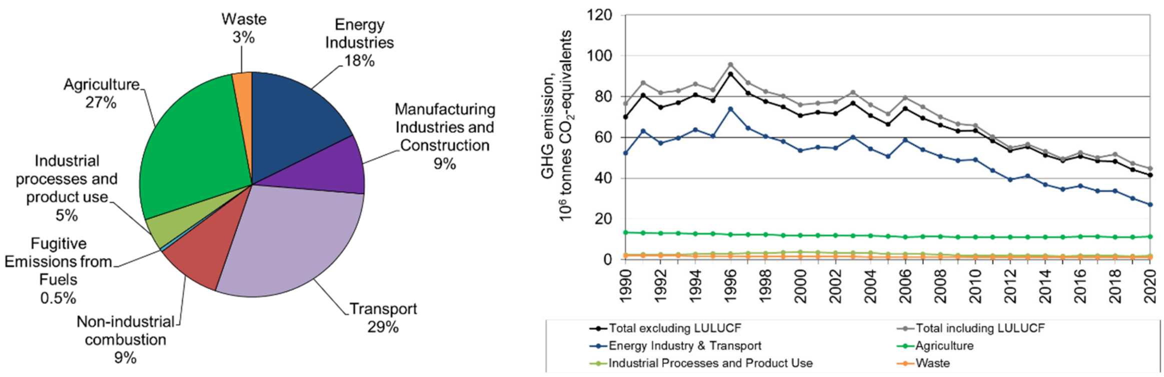


Figure 1.1 Greenhouse gas emissions in CO_2 equivalents distributed on main sectors for 2020 (excluding LULUCF and indirect CO_2) and time series for 1990 to 2020.

1.3.1 Carbon dioxide

The largest source to the emission of CO_2 is the energy sector, which includes combustion of fossil fuels like oil, coal and natural gas (Figure 1.2). The transport sector (dominated by road transport) is the largest sector in 2020 and contributes with 42 %, followed by energy industries with 25 %. The CO_2 emission (excl. LULUCF) decreased by 9.6 % from 2019 to 2020. The main reason for this large decrease is decreasing emissions across all sectors due to a decrease in the consumption of fossil fuels. Especially, the emissions from energy industries and transport were much lower in 2020 due to a significant lower consumption of fossil fuels, in particular a low consumption of coal and gasoline / diesel for road transport. The reduction in transport was to a large extent a result of the restrictions imposed during 2020 to combat the COVID-19 pandemic. In addition, there was considerable import of electricity in 2020; in fact, the electricity import was at its highest level since 1990. In general, CO_2 emissions fluctuate significantly as a result of the electricity trade with neighbouring countries.

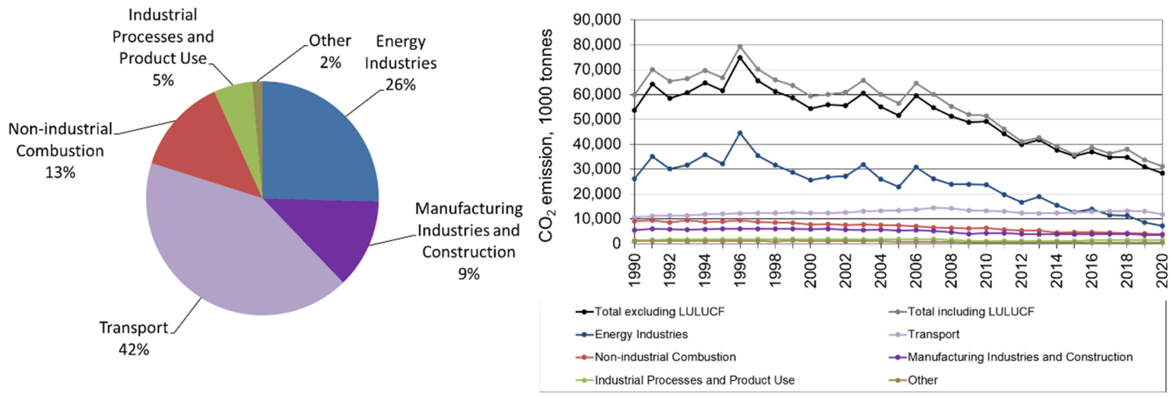


Figure 1.2 CO_2 emissions. Distribution according to the main sectors for 2020 and time series for 1990 to 2020.

1.3.2 Methane

The largest sources of anthropogenic CH_4 emissions are agricultural activities contributing with 82.6 % in 2020, waste (13.6 %) and the remaining emission sources covers 3.8 % - see Figure 1.3. The emission from agriculture derives from enteric fermentation (51.7 %) and management of animal manure (30.9 %).

Since 1990, the emission of CH_4 from enteric fermentation has decreased 8.8 % mainly due to the decrease in the number of cattle. However, this reduction is countered by an increase of 18.9 % in emissions from manure management caused by a change in housing type towards slurry-based systems. In later years, the emission from manure management has decreased due to changes in manure management, e.g. more biogas treatment and acidification of slurry. The emission of CH_4 from solid waste disposal has decreased significantly (65.2 %) from 1990 to 2020 due to an increase in the incineration of waste and extensive recycling thereby causing a decrease in the waste disposal on land. The CH_4 emission from the energy sector increases from mid 1990s from public power and district heating plants increases due to the increasing use of gas engines in the decentralised cogeneration plant sector. Due to the liberalisation of the electricity market the use of gas engines declined from 2005 onwards. The high emission from gas engines is caused by the fact that up to 3 % of the natural gas in the gas engines is not combusted.

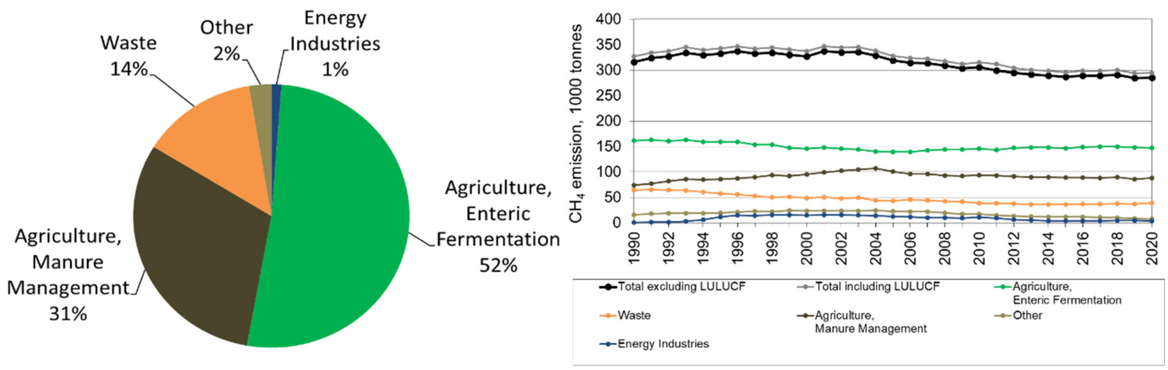
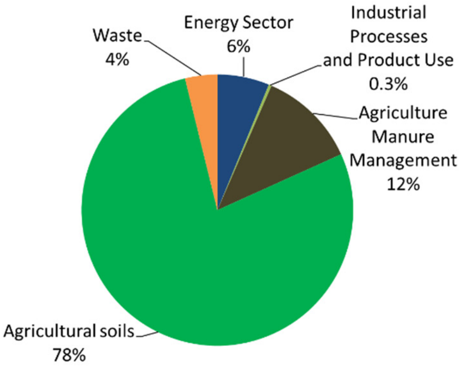


Figure 1.3 CH_4 emissions. Distribution according to the main sectors for 2020 and time series for 1990 to 2020.

1.3.3 Nitrous oxide

Agriculture is the most important N_2O emission source in 2020 contributing with 89.6 % (Figure 1.4) of which N_2O from soils dominates (77.9 % of total N_2O). Substantial emissions come from drainage water and coastal waters where nitrogen is converted to N_2O through bacterial processes. However, the nitrogen converted in these processes originates mainly from the agricultural use of manure and fertilisers.

The main reason for the decrease of N_2O emission is due to the agricultural sector, which has decreased with 24.8 % since 1990 caused by legislation to improve the utilisation of nitrogen in manure. Combustion of fuels contributes 6.2 % to the total whereof the N_2O emission from transport contributes with 2.3 % to the national total in 2020. Emission from industrial processes decreased significantly in 2004 due to the closure of the only nitric acid plant operating in Denmark and the emission from this emission source is therefore close to zero since then.



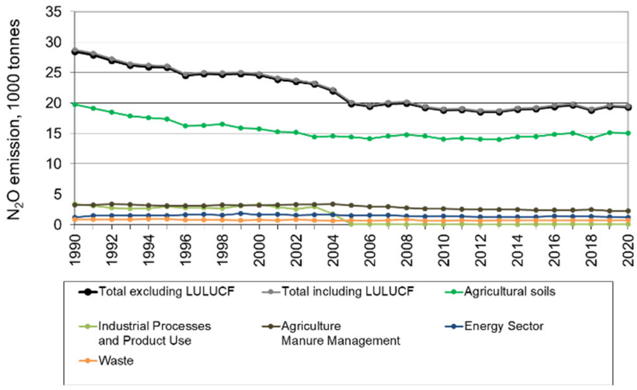


Figure 1.4 N_2O emissions. Distribution according to the main sectors for 2020 and time series for 1990 to 2020.

1.3.4 Fluorinated gases

This part of the Danish inventory only comprises a full data set for all substances from 1995 - see Figure 1.5. From 1995 to 2000, there was a continuous and substantial increase in the contribution from the range of f-gases as a whole (133.4 %), calculated as the sum of emissions in CO_2 equivalents. In 2000-2009, the increase of f-gas emissions continues with a lower increasing rate than for the years 1995 to 2000. Hereafter, the f-gas emission decreases.

The use of HFCs has increased several folds and HFCs have become the dominant f-gases, comprising 71.2 % in 1995 but 88.0 % in 2020. HFCs are mainly used as a refrigerant. SF_6 contributed considerably to the f-gas sum in earlier years, with 28.6 % in 1995 and reduced to 12.0 % in 2020. Due to environmental awareness the Danish legislation regulates the use of f-gases, e.g. since January 1, 2007 new HFC-based refrigerant stationary systems are forbidden. Refill of old systems are still allowed and the use of air conditioning in mobile systems increases.

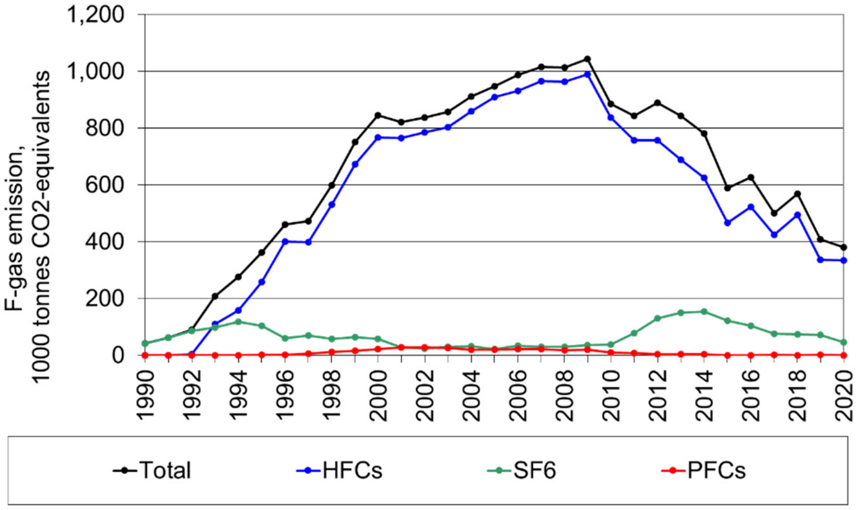


Figure 1.5 F-gas emissions. Time series for 1990 to 2020.

1.4 Projection models

Projection of emissions can be considered as emission inventories for the future in which the historical data is replaced by a number of assumptions and simplifications. In the present project, the emission factor method is used and the emission as a function of time for a given pollutant can be expressed as:

(1.1) $$E = \sum_s A_s(t) \cdot \overline{EF}_s(t)$$

where A_s is the activity for sector s for the year t and $EF_s(t)$ is the aggregated emission factor for sector s.

In order to model the emission development as a consequence of changes in technology and legislation, the activity rates and emission factors of the emission source should be aggregated at an appropriate level, at which relevant parameters such as process type, reduction targets and installation type can be taken into account. If detailed knowledge and information of the technologies and processes are available, the aggregated emission factor for a given pollutant and sector can be estimated from the weighted emission factors for relevant technologies as given in equation 1.2.

(1.2) $$EF_s(t) = \sum_k P_{s,k}(t) \times EF_{s,k}(t)$$

where P is the activity share of a given technology within a given sector, $EF_{s,k}$ is the emission factor for a given technology and k is the type of technology.

Official Danish projections of activity rates are used in the models for those sectors for which the projections are available. For other sectors, projected activity rates are estimated in co-operation with relevant research institutes and other organisations. The emission factors are based on recommendations from the IPCC Guidelines (IPCC, 2006 and the EMEP/EEA Guidebook (EMEP/EEA, 2019) as well as data from measurements made in Danish plants etc. The influence of changes in legislation and statutory orders on the development of the emission factors has been estimated and included in the models.

The projection models are based on the same structure and method as the Danish emission inventories in order to ensure consistency. In Denmark the emissions are estimated according to the EMEP/EEA Guidebook (EMEP/EEA, 2019) and the SNAP (Selected Nomenclature for Air Pollution) sector categorisation and nomenclature are used. The detailed level makes it possible to aggregate to both the UNECE/EMEP nomenclature (NFR) and the IPCC nomenclature (CRF).

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2 Stationary combustion

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/EEA Guidebook (EMEP/EEA, 2019). The emission projections are based on the official activity rates projection from the Danish Energy Agency and on 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. Some emission factors refer to the IPPC Guidelines (IPCC, 2006) and some are country-specific and refer to Danish legislation, EU ETS (Emission Trading System) reports from Danish plants, Danish research reports or calculations based on emission data from a considerable number of plants.

The fuel consumption used in the emission projection does not follow the exact same sector split as the official energy statistics elaborated by the DEA. The reason for this is that for some mobile sources the fuel consumption is calculated bottom-up and that this bottom-up calculation does not match the data in the energy projection. Therefore, fuel amounts can be transferred between stationary and mobile sectors. One example is gasoline used in the commercial and institutional sector, where the energy projection does not include any consumption; hence, the gasoline is taken from road transport to cover the bottom-up calculated consumption. For the emission projections, fuel consumption has not been transferred between sectors, so the methodology deviates from the historic inventory. It is important to stress that the overall fuel consumption as reported in the official energy statistics is followed by DCE, only the sectoral allocation is impacted.

Some of the large plants, such as e.g. power plants and municipal waste incineration plants are registered individually as large point sources and emission data from the actual plants are used. The CO_2 from incineration of the fossil part of municipal waste is included in the projected emissions.

2.2 Sources

The combustion of fossil fuels is one of the most important sources of greenhouse gas emissions and this chapter covers all sectors using fuels for energy production, with the exception of the transport sector and mobile combustion in e.g. manufacturing industries, households and agriculture. Table 2.1 shows the sector categories used and the relevant classification numbers according to SNAP and IPCC.

Table 2.1 Sectors included in stationary combustion.

Sector	IPCC	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 municipal waste incineration is utilised for heat and power production. Thus, incineration of waste is included as stationary combustion in the IPCC Energy sector (source categories *1A1, 1A2* and *1A4a).*

Fugitive emissions from fuels connected with extraction, transport, storage and refining of oil and gas are described in Chapter 3. Emissions from flaring in oil refineries and in oil and gas extraction are also included in Chapter 3 on fugitive emissions.

Stationary combustion is the largest sector contributing with roughly 30 % of the total greenhouse gas emission. As seen in Figure 1.1 in Section 1.3, the subsector contributing most to the greenhouse gas emission is Energy Industries.

2.3 Fuel consumption

Energy consumption in the model is based on the Danish Energy Agency's energy consumption projections to 2040 (Danish Energy Agency, 2022).

The emission projections are based on the amount of fuel, which is expected to be combusted in Danish plants and is not corrected for international trade with electricity, since this correction is not allowed for reporting to the EU and UNFCCC. Fuel use by fuel type is shown in Figure 2.1.

The largest fuel consumption throughout the time series can be observed for wood. The consumption of coal almost disappears and also the consumption of natural gas decreases significantly. Overall, the fuel consumption decreases significantly as a result of more renewable energy sources, e.g. wind and solar power.

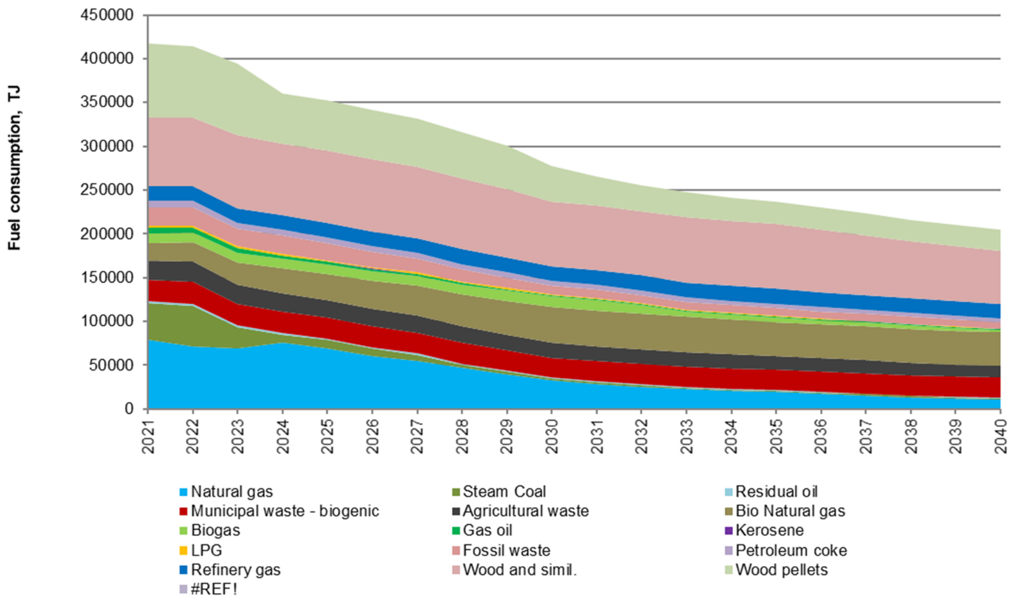

Figure 2.1 Projected energy consumption by fuel type.

Fuel use by sector is shown in Figure 2.2. The sectors consuming the most fuel are public power (including CHP), residential, manufacturing industries, district heating and off-shore oil / gas extraction.

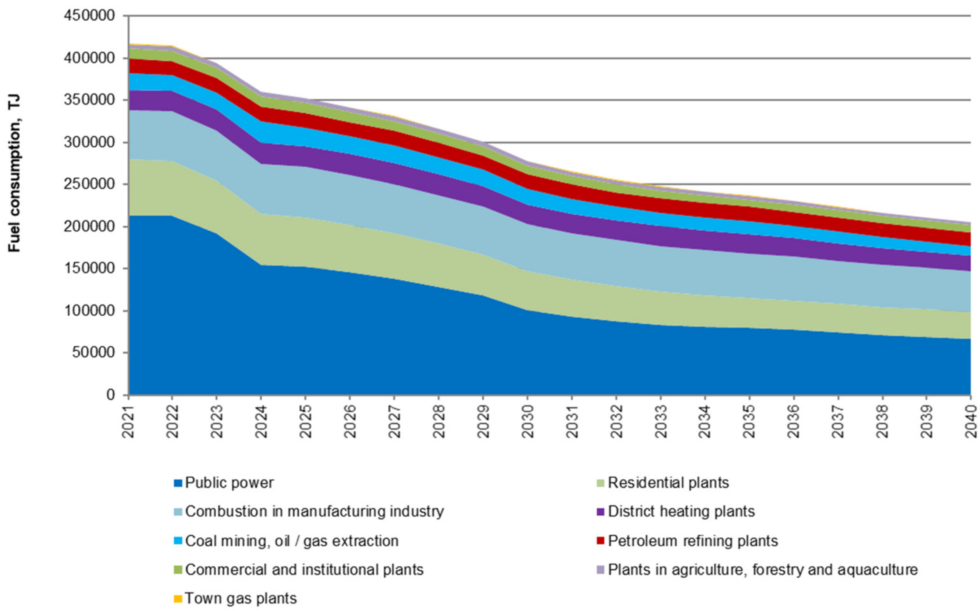

Figure 2.2 Energy use by sector.

2.4 Emission factors

In general, emission factors for area sources refer to the emission factors for 2019 applied in the 2021 emission inventory (Nielsen et al., 2021).

The emission factor for CO_2 is only fuel-dependent whereas the N_2O and CH_4 emission factors depend on the sector (SNAP) in which the fuel is used.

The CO_2 emission factors for coal, residual oil, refinery gas and offshore combustion of natural gas (offshore gas turbines) are all based on EU ETS data and updated annually in the historic emission inventories. In the projection, the average 2014-2020 emission factors have been applied rather than including only the 2020 data.

The offshore Tyra gas field in the North Sea is shut down from September 2019 to summer 2023. During this period, consumers in Denmark will primarily get their gas supply from Germany (Energinet.dk, 2021). The CO_2 emission factor applied for natural gas[2] in 2021-2023 is based on gas quality data for 2020. The CO_2 emission factor applied for 2024-2040 is the average value for the years 2014-2018.

Residential wood combustion is a large emission source for CH_4. The projections are based on total wood consumption in residential plants as reported by the DEA, data for technology distribution and replacement rate and finally technology specific emission factors. The technology specific emission factors are equal to the technology specific emission factors applied for the historic emission inventories. The replacement of old technologies with new technologies results in a decreasing implied emission factor for CH_4.

2.5 Emissions

Emissions for the individual GHGs are calculated by means of Equation 2.1, where A_s is the activity (fuel consumption) for sector *s* for year *t* and $EF_s(t)$ is the aggregated emission factor for sector *s*.

$$Eq.\ 2.1 \quad E = \sum_s A_s(t) \cdot \bar{EF}_s(t)$$

The total emission in CO_2 equivalents for stationary combustion is shown in Table 2.3.

Table 2.2 Total emission in CO_2 equivalents for stationary combustion.

Sector	1990	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
Public electricity and heat production	24791	23569	20597	21673	10458	5526	6136	2508	861	646	536
Petroleum refining plants	909	1003	940	855	980	917	970	970	970	970	970
Oil/gas extraction	557	1506	1659	1583	1468	907	1210	1201	1025	855	628
Commercial and institutional plants	1424	926	972	872	649	523	422	318	118	56	35
Residential plants	5121	4153	3820	3335	2134	1633	1566	817	292	162	146
Plants in agriculture, forestry and aquaculture	883	979	818	550	273	181	159	140	89	60	54
Combustion in industrial plants	5039	5354	4784	3715	3211	3027	2814	2351	1433	1025	856
Total	38724	37490	33591	32583	19172	12714	13277	8306	4789	3774	3226

From 1990 to 2040, the total emission falls by approximately 35 500 kt CO_2 equivalents or 92 % due to fossil fuels (mainly coal and natural gas) being partially replaced by renewable energy. The emission projections for the three GHGs are shown in Figures 2.4-2.9 and in Tables 2.4-2.6, together with the historic emissions for 1990, 2000, 2005, 2010, 2015 and 2020 (Nielsen et al., 2020).

[2] Except offshore gas turbines.

2.5.1 Carbon dioxide

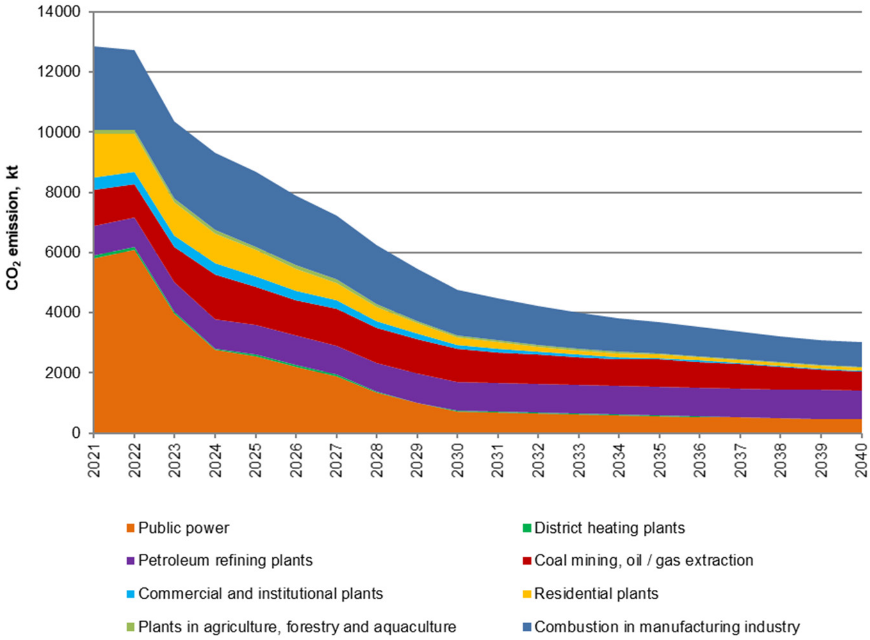

Figure 2.4 CO_2 emissions by sector.

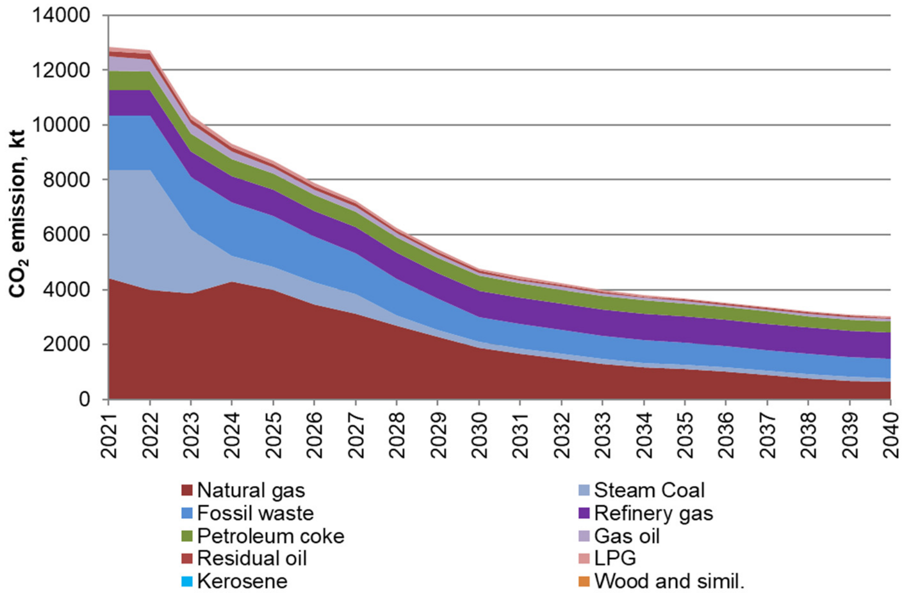

Figure 2.5 CO_2 emissions by fuel.

Table 2.3 CO_2 emissions by sector.

Sector	1990	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
Public electricity and heat production	24697	23109	20195	21297	10299	5373	5898	2265	701	545	451
Petroleum refining plants	908	1000	938	854	978	916	969	969	969	969	969
Oil/gas extraction	550	1488	1646	1574	1460	902	1203	1194	1020	851	625
Commercial and institutional plants	1415	899	947	850	635	509	416	312	112	51	31
Residential plants	4971	3992	3626	3125	1971	1523	1451	722	216	102	96
Plants in agriculture, forestry and aquaculture	849	912	758	511	246	153	133	113	61	37	32
Combustion in industrial plants	4977	5263	4710	3651	3157	2957	2777	2311	1393	980	810
Total	38368	36664	32821	31862	18746	12333	12846	7887	4471	3534	3013

CO_2 is the dominant GHG for stationary combustion and comprises in 2020 approximately 97 % of total emissions in CO_2 equivalents. The most important CO_2 source is public electricity and heat production, which contributes with about 44 % in 2020 to the total emissions from stationary combustion plants. Other important sources are combustion plants in industry, residential plants and oil / gas extraction. The emission of CO_2 decreases by 76 % from 2020 to 2040 due to decreasing fossil fuel consumption.

2.5.2 Methane

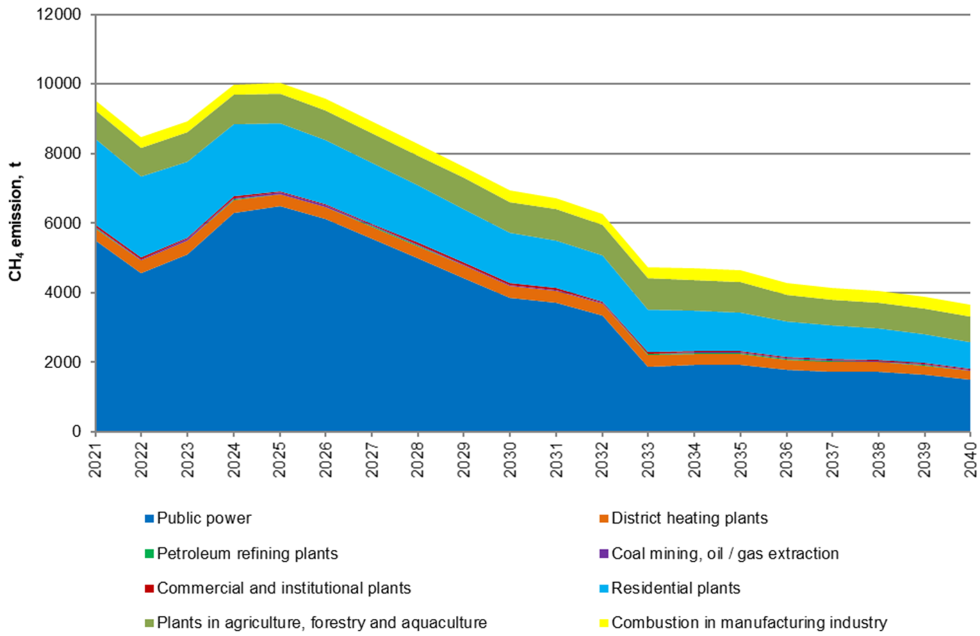

Figure 2.6 CH_4 emissions by sector.

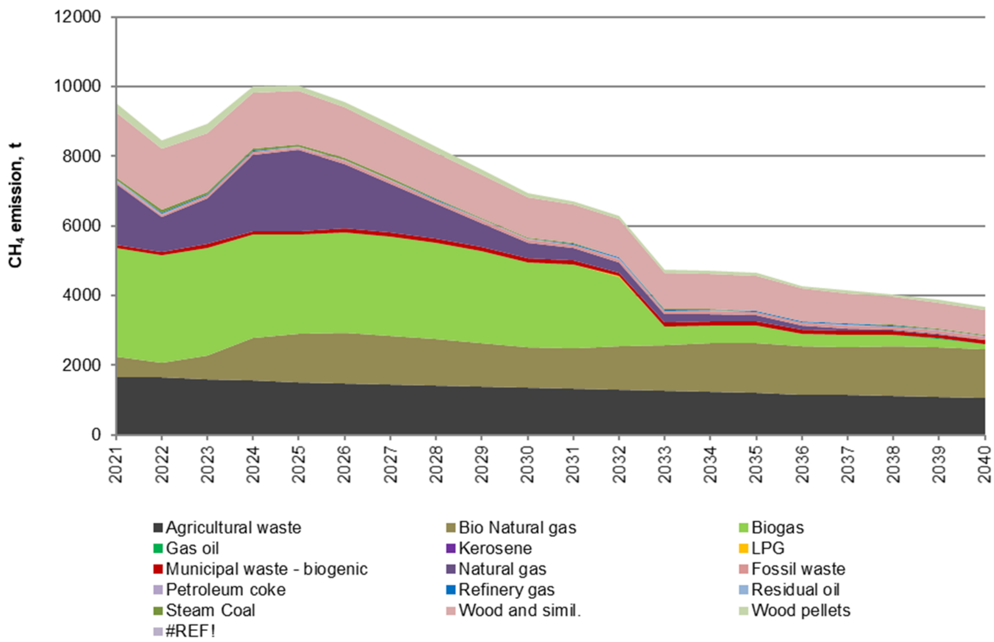

Figure 2.7 CH_4 emissions by fuel.

Table 2.4 CH_4 emissions by sector.

Sector	1990	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
Public electricity and heat production	585	14621	12359	10922	3360	3321	5846	6456	4040	2079	1750
Petroleum refining plants	18	21	19	17	19	18	17	17	17	17	17
Oil/gas extraction	16	38	48	46	43	26	36	35	30	25	19
Commercial and institutional plants	130	897	804	672	394	379	41	41	38	36	35
Residential plants	4749	5055	5832	5989	4235	2481	2471	1843	1379	1028	757
Plants in agriculture, forestry and aquaculture	1088	2464	2185	1380	936	973	824	861	888	753	732
Combustion in industrial plants	274	1020	818	540	470	894	290	315	324	343	349
Total	6861	24117	22065	19566	9458	8092	9525	9569	6717	4280	3660

The two largest sources of CH_4 emissions are public power and residential plants. This fits well with the fact that natural gas and biogas, especially when combusted in gas engines and wood when used in residential plants are the fuels contributing most to the CH_4 emission. There is a significant increase in emissions from 1990 to 2000 due to the increased use of gas engines during the 1990s. Beginning around 2004, the natural gas consumption has begun to show a decreasing trend due to structural changes in the Danish electricity market.

2.5.3 Nitrous oxide

The contribution from the N_2O emission to the total GHG emission is small and the emissions stem from various combustion plants.

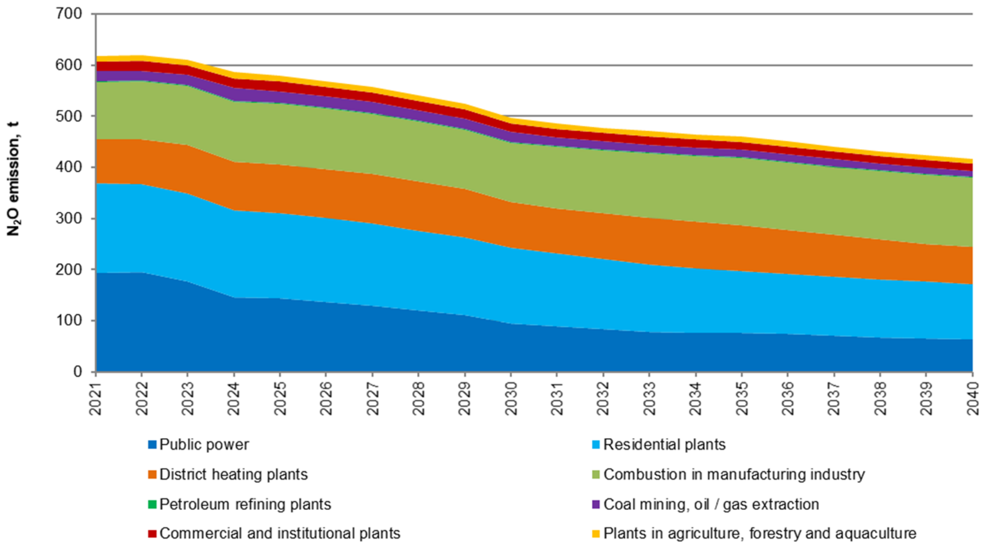

Figure 2.8 N_2O emissions by sector.

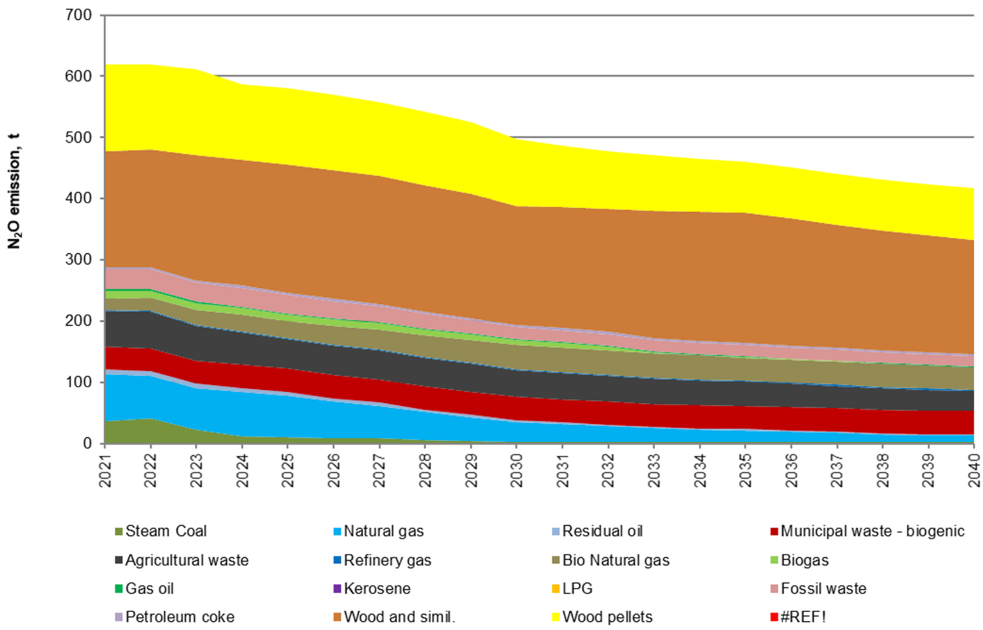

Figure 2.9 N_2O emissions by fuel.

Table 2.5 N_2O emissions by sector.

Sector	1990	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
Public electricity and heat production	264	317	311	345	249	263	235	280	233	178	159
Petroleum refining plants	2	7	5	3	4	4	4	2	2	2	2
Oil/gas extraction	21	56	39	27	25	22	15	21	20	18	15
Commercial and institutional plants	17	15	18	17	15	17	17	19	19	17	15
Residential plants	106	118	162	202	192	183	160	175	164	142	119
Plants in agriculture, forestry and aquaculture	22	17	17	15	13	13	12	11	11	11	10
Combustion in industrial plants	185	220	181	170	140	178	158	111	119	119	131
Total	617	751	734	779	637	680	601	618	569	487	451

2.6 Recalculations

2.6.1 Recalculations in fuel consumptions

Energy consumption in the model is based on the Danish Energy Agency's energy projections and energy projections for individual plants (Danish Energy Agency, 2022). All recalculations made in these projections are directly observable in the present emission projections.

2.6.2 Recalculations for emission factors

Emission factors have been updated according to the latest emission inventory (Nielsen et al., 2022).

The CO_2 emission factors for coal, residual oil, refinery gas and offshore combustion of natural gas (offshore gas turbines) are all based on EU ETS data and have been updated to the average 2015-2020 emission factors.

The offshore Tyra gas field in the North Sea is shut down from September 2019 until smmer 2023. During this period, consumers in Denmark will primarily get their gas supply from Germany (Energinet.dk, 2021). Thus, the CO_2 emission factor applied for natural gas[3] in 2021-2023 have been updated based

[3] Except offshore gas turbines.

on gas quality data for 2020 whereas the CO_2 emission factor applied for 2024-2040 have been updated to the average value for the years 2014-2018.

The implied emission factors for CH_4 from residential wood combustion have been updated according to the latest technology specific emission factors (Nielsen et al., 2022) and the updated energy projections.

2.7 References

Danish Energy Agency, 2022: Denmark's Energy and Climate Outlook. Available at: https://ens.dk/en/our-services/projections-and-models/denmarks-energy-and-climate-outlook

EMEP/EEA, 2019: EMEP/EEA air pollutant emission inventory guidebook 2019. Technical report No 13/2019. Available at: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

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

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

3 Oil and gas extraction (Fugitive emissions from fuels)

This chapter includes fugitive emissions from fuels in the CRF sector 1B. The sources included in the Danish emission inventory and in this projection are listed in Table 3.1. The following chapters describe the methodology, activity data, emission factors and emissions in the projection. Detailed descriptions of the emission inventory for the historical years are included in Plejdrup et al. (2021) and Nielsen et al. (2022).

Table 3.1 List of the IPCC sectors and corresponding SNAP codes for the categories included in the Danish emission inventory model for greenhouse gases from the fugitive emission sector.

IPCC sectors	SNAP code	SNAP name	Activity
1 B 1 a	050103	Storage of solid fuel	Coal (storage)
1 B 2 a 1	050204	Exploration of oil	Oil
1 B 2 a 2	050205	Production of oil	Oil
1 B 2 a 3	050206	Offshore loading of oil	Oil
1 B 2 a 3	050207	Onshore loading of oil	Oil
1 B 2 a 4	050208	Storage of crude oil	Oil
1 B 2 a 4	040101	Petroleum products processing	Oil
1 B 2 a 4	040103	Other processes in petroleum industries	Oil
1 B 2 a 4	040104	Storage and handling of petroleum products in refinery	Oil
1 B 2 a 4	040105	Other (catalytic regeneration)	Oil
1 B 2 a 5	050503	Service stations (including refuelling of cars)	Oil
1 B 2 b 1	050304	Exploration of gas	Natural gas
1 B 2 b 2	050305	Production of gas	Natural gas
1 B 2 b 2	050303	Off-shore activities	Natural gas
1 B 2 b 4	050601	Natural gas transmission	Natural gas
1 B 2 b 5	050603	Natural gas distribution	Natural gas
1 B 2 b 5	050604	Town gas distribution	Natural gas
1 B 2 c 2 1 ii	050699	Venting in gas storage	Venting
1 B 2 c 2 i	090203	Flaring in oil refinery	Flaring
1 B 2 c 2 ii	090298	Flaring in gas storage	Flaring
1 B 2 c 2 ii	090299	Flaring in gas transmission and distribution	Flaring
1 B 2 c 2 iii	090206	Flaring in oil and gas extraction	Flaring

3.1 Methodology

The methodology for the emission projection corresponds to the methodology in the annual emission inventory, based on the IPCC Guidelines (IPCC, 2006) and the EMEP / EEA Guidebook (EMEP / EEA, 2019).

Activity data are based on an official projection by the Danish Energy Agency (Denmark's Energy and Climate Outlook – DECO22) on production of oil and gas, and on flaring in upstream oil and gas production and on fuel consumption (DEA, 2022).

Emission factors are based on either the EMEP / EEA guidelines (EMEP / EEA, 2019), IPCC guidelines (IPCC 2006), or are country-specific based on data for the latest historical years.

3.2 Activity data

The projection for the production of oil and gas (DEA, 2022) is shown in Figure 3.1. 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.

The projection 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. 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 2033-2040. 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.

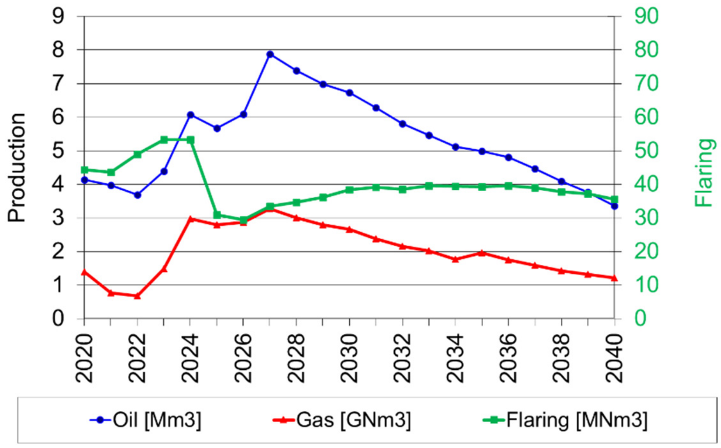

Figure 3.1 Projection for the production of oil and gas (DEA, 2022).

The DEA projection of the production of oil and gas is used in the projection of emissions from a number of sources: production of oil and natural gas, transport of oil in pipelines, onshore and offshore loading of ships and flaring in upstream oil and gas production.

Data from the Denmark's Energy and Climate Outlook by the DEA (2022) are applied in the projection of fugitive emissions from fuels for the sources transmission of natural gas, and distribution of natural gas and town gas. Consumption of natural gas is used as proxy to project transmission of natural gas and the consumption of town gas is used as a proxy for the fugitive losses from town gas distribution.

The fuel consumption and flaring rates for refineries are assumed to be constant for the projection period according to the Energy and Climate Outlook (DEA, 2022).

3.3 Emission factors

For some sources, the emission factors are based on the IPCC Guidelines (IPCC, 2006) and the EMEP/EEA Guidebook (EMEP/EEA, 2019). This is the case for offshore loading of oil to ships and flaring in upstream 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 CH_4 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. CH_4 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 standard emission factor from IPCC (2006) for CO_2 from transport of oil in pipelines is applied.

Emissions of CO_2 for flaring in upstream oil and gas production and at refineries are based on EU ETS for the emission inventory for historical years. For calculation of CO_2 emissions from flaring in upstream oil and gas production, the average emission factor based on EU ETS data for the latest five historical years is applied for the projection years.

The CH_4 emission factor for flaring in refineries in historical years is based on detailed fuel data from one of the two refineries (Statoil, 2009).

The N_2O emission factor is taken from the 2006 IPCC Guidelines for flaring in upstream oil and gas production and at refineries.

In the projection of emissions from flaring in refineries the emission factors for the latest historical year are applied, in correspondence with the approach in the Energy and Climate Outlook, where the activity and flaring rates for refineries are kept constant for the projection period, at the level for the latest historical year. Emissions from processing in refineries are kept constant for the projection years at the average level for the latest five historical years.

For remaining sources where the emissions in historical years are given by the companies in annual reports or environmental reports, implied emission factors for the average of the latest five historical years are applied for the projection years. This approach is applied for transmission of natural gas, distribution of natural gas and town gas, processing and flaring at refineries, and for venting and flaring in gas storage and treatment plants.

3.4 Emissions

The majority of the emissions are calculated due to the standard formula (Equation 3.1) while the emissions in the latest five historical years (only the last historical year for refineries, see Section 3.3), given in e.g. annual reports, are adopted for the remaining sources.

(3.1) $$E_{s,t} = AD_{s,t} * EF_{s,t}$$

where E is the emission, AD is the activity data and EF is the emission factor for the source s in the year t.

Figure 3.2 includes CH_4 emission on sub-sector level in selected historical years and projection years. The total fugitive CH_4 emission is expected to show a significant decrease from 2020 to 2021 followed by an increase in the years 2022 to 2024. A decreasing trend is expected for the remaining years in the projection period. The trend is mainly caused by a variation in emissions from gas (production, transmission and distribution). The low emissions in 2021-2022 are due to the expected decrease in oil and especially gas production, mainly due to the shutdown of the Tyra platform for redevelopment.

The fuel consumption and flaring amounts for refineries are assumed to be constant for the projection period according to the Energy and Climate Outlook (DEA, 2022), and correspondingly the emissions from fugitive emissions and flaring in refineries for the latest historical year are applied for the projection years.

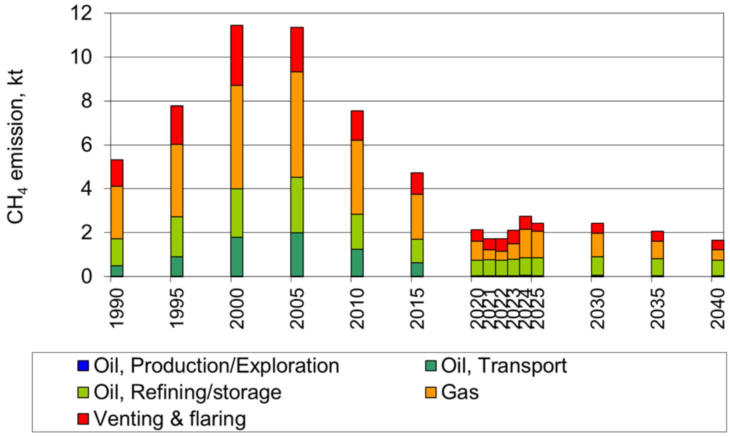

Figure 3.2 CH_4 emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2015 and 2020, including exploration of oil and gas) and projection years (2021-2025, 2030, 2035, 2040, excluding exploration of oil and gas).

By far the largest source of fugitive emissions of CO_2 is flaring in upstream oil and gas production (Figure 3.3). CO_2 emissions peaked in 1999 and have shown a decreasing trend over the following historical years. In the projection years, the annual emission from flaring in upstream oil and gas production is more constant. The CO_2 emission from offshore flaring is estimated from the projected flaring rates (DEA, 2022) and an average emission factor for the latest five historical years. The average CO_2 emission factor applied in the projection years is 2.504 kg per Nm^3.

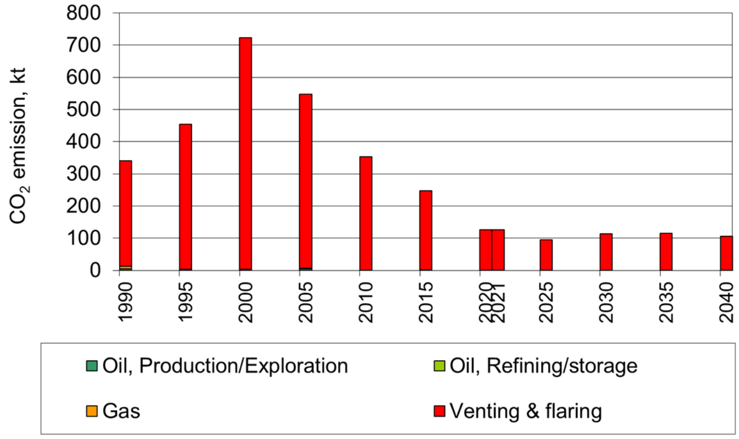

Figure 3.3 CO_2 emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2015 and 2020, including exploration of oil and gas) and projection years (2021, 2025, 2030, 2035, 2040, excluding exploration of oil and gas).

The summarised greenhouse gas emissions for selected historical years and projection years are shown in Figure 3.4 on sub-sector level. The main source of fugitive GHG emissions is CO_2 from offshore flaring, but also upstream oil and gas production, oil storage at the crude oil terminal, and fugitive emissions from refineries contribute. Emissions from onshore activities (storage of oil and loading of ships) have shown a large decrease from 2005 to 2016 due to new technology at the oil terminal and the harbour terminal. The only source of N_2O emissions in the fugitive emission sector is flaring in upstream oil and gas production, at refineries and in gas storage and treatment plants. The fugitive N_2O emission is very limited.

The GHG emissions from flaring and venting dominate the summarised GHG emissions. The GHG emissions reached a maximum in year 1999 and show a decreasing trend in the later historical years and to a lesser degree in the projection years. The decrease owe to decreasing production amounts of oil and natural gas, and to better technologies leading to less flaring on the offshore installations.

Emissions from exploration of oil and gas are not included in the projected emissions, but only in historical years. The maximum GHG emission from exploration occurred in 2002, where this source contributed 3.2 % of the total fugitive GHG emission (second and third highest emission occurred in 1990 and 1998 and contributed 2.9 % and 0.9 %, respectively).

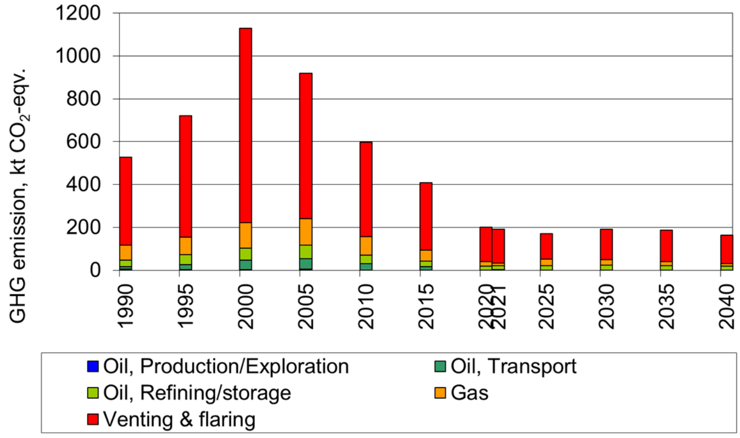

Figure 3.4 GHG emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2015 and 2020, including exploration of oil and gas) and projection years (2021, 2025, 2030, 2035, 2040, excluding exploration of oil and gas).

3.5 Model description

The model for projecting fugitive emissions from fuels, the “Fugitive emissions projection model”, is created in Microsoft Excel. The projection model is built in accordance with the model used in the national emission inventory system; the “Fugitive emission model”. For sources where data for the historical years are used to estimate emissions in the projection years, the “Fugitive emissions projection model” links to the “Fugitive emission model”. Historical emission from Refineries and transmission / distribution of gas are treated in separate workbook models (“Refineries” and “Gas losses”). The names and content of the models for the fugitive sector are listed in Table 3.2.

Table 3.22 Names and content of the models for the fugitive sector.

Name	Content
Fugitive emissions projection model	Activity data and emission factors for extraction of oil and gas, loading of ships and storage in oil tanks at the oil terminal for the historical years plus projected years and projected activity rates and emission factors for the projection years. Further, the resulting emissions for the projection years for all sources in the fugitive sector are stored in the worksheet "Projected emissions".
Fugitive emissions model	Activity data and emission factors for extraction of oil and gas, loading of ships and storage in oil tanks at the oil terminal for the historical years.
Refineries	Activity data and emission factors for refining and flaring in refineries for the historical years.
Gas losses	Activity data and emission factors for transmission and distribution of natural gas and town gas for the historical years.

Activity data, emission factors, calculations and results are kept in separate sheets in the sub models. Changing the data in the input data tables or emission factor tables will automatically update the projected emissions.

3.6 References

Danish Energy Agency, 2022: Denmark's Energy and Climate Outlook.

EMEP/EEA, 2019: EMEP/EEA air pollutant emission inventory guidebook – 2019. Available at: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (04-03-2022).

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (04-03-2022).

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: https://dce2.au.dk/pub/SR494.pdf

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. Available at: http://dce2.au.dk/pub/SR463.pdf (04-03-2022).

Statoil A/S, 2009: Personal communication. September 2009.

4 Industrial processes and product use

4.1 Sources

Industrial Processes and Product Use (IPPU) includes the CRF categories 2A Mineral Industries, 2B Chemical Industries, 2C Metal Industries, 2D Non-Energy Products from Fuels and Solvent Use, 2E Electronics Industry, 2F Product Use as Substitutes for Ozone Depleting Substances and 2G Other Product Manufacturing and Use. A range of sources is covered within each of these categories; the included sources are shown in Table 4.1.

Table 4.1 Sources/processes included in the projection of process emissions.

IPCC code			Sources/processes	SNAP code
2A	Mineral industry	2A1	Cement production	04 06 12
		2A2	Lime production	04 06 14
		2A3	Glass production	04 06 13
		2A4	Other process uses of carbonates	
		-	2A4a Ceramics	04 06 91/92
		-	2A4b Other uses of soda ash	04 06 19
		-	2A4d Flue gas cleaning	04 06 18
		-	2A4d Stone wool production	04 06 18
2B	Chemical industry	2B10	Catalysts/fertilisers	04 04 16
2C	Metal industry	2C5	Lead production	03 03 07
2D	Non-energy products	2D1	Lubricant use	06 06 04
	from fuels and solvent	2D2	Paraffin wax use	06 06 04
	use	2D3	Other	
		-	Solvent use	06 04 00
		-	Use of urea in catalysts	06 06 07
		-	Asphalt roofing	04 06 10
		-	Road paving with asphalt	04 06 11
2E	Electronics industry	2E5	Fibre optics	06 05 08
2F	Product use as substi-	2F1	Refrigeration and air conditioning	06 05 02
	tutes for ozone deplet-	2F2	Foam blowing agents	06 05 04
	ing substances	2F4	Aerosols	06 05 06
		2F5	Solvents	06 05 08
2G	Other product manu-	2G1	Electrical equipment	
	facture and use	-	2G1b Use of electrical equipment	06 05 07
		2G2	SF_6 and PFCs from product use	
		-	2G2c Double-glazed windows	06 05 08
		2G3	N_2O from product use	
		-	2G3a Medical applications	06 05 01
		-	2G3b Propellant in aerosol cans	06 05 06
		2G4	Other product use	
		-	Fireworks	06 06 01
		-	Barbeques	06 06 04
		-	Tobacco	06 06 02

The projection of emissions from industrial processes is based on the national emission inventory (Nielsen et al., 2022).

4.2 Methodology

The projection of greenhouse gas (GHG) emissions includes CO_2, N_2O, CH_4, NMVOC, HFCs, PFCs and SF_6.

For HFCs, PFCs and SF_6, also known as F-gases, emission projections are based on an F-gas projection done by Poulsen (2022a and 2022b).

The fluorinated gases all contain fluorine, hence the name F-gases. None of the F-gases are produced in Denmark. The emission of these gases is therefore associated only with their use.

Emissions from cement production, construction related sources (e.g. stone wool production) and flue gas desulphurisation are projected using different activity / energy projections from the Danish Energy Agency.

For the remaining sources, emission projections are based on historical emissions.

For more detailed information on the methodologies and sources used within the different categories, find the relevant category descriptions in the sections 4.2.1 to 4.2.8 below.

4.2.1 F-gases

An account of the annual consumption and emission of F-gases is prepared by a consultant on behalf of the Danish Environmental Protection Agency (DEPA) (Poulsen, 2022a). In this work, projections to 2030 are also prepared. Annual reports that contain both consumption and emission data are available. From 2030 to 2040 the emission projections are available from Poulsen (2022b).

F-gases are powerful GHGs with global warming potentials (GWPs) between 124 and 22 800. F-gases therefore, receive a great deal of attention in connection with GHG emission inventories. For many F-gas applications, the gases can be controlled and / or replaced, which has been, and continues to be, the case in Denmark. Data for the projections in this report take this into consideration. EU legislations are already covered by different existing Danish legislation. Exemptions from the Danish bans on e.g. refrigeration equipment have been taken into account in the projections.

Emissions are calculated with a model for the individual substance's life-cycle over the years, taking the emissions associated with the actual processes into consideration. The processes for refrigeration and high voltage equipment are filling up / topping up, operation and destruction. For foam, the processes are production of the products in which the substances are used as well as use and destruction of the product. The model has been developed and used in connection with the annual historic emission inventories for the Climate Convention; see Nielsen et al. (2022). As a result, the model corresponds with the guidelines produced for this purpose. For details on the model and the calculation methodologies, refer also to the DEPA's annual reports produced as a basis for the F-gas inventories (Poulsen, 2022).

The report and the data collected in Poulsen (2022) provide emission projections based on 'steady state' consumption with 2020 as the reference year. Cut-off dates in relation to the phasing out of individual substances, in connection with Danish regulation concerning the phasing out of powerful GHGs, are taken into account. HFCs used in foaming agents in hard PUR insulation foam were phased out from 1 January 2006. Furthermore, a tax effect has been introduced for relevant applications and, as far as possible, expected increases in the use of these substances will be taken into consideration in a number of application areas – as will reductions expected.

It should be noted that the basic data for the years before 1995 are not entirely adequate with regard to coverage, in relation to actual emissions. Under the Kyoto Protocol, it is possible to choose 1995 as base year for F-gases. Due to the lack of coverage prior to 1995 this option is used by Denmark.

4.2.2 Mineral Industry

There are nine sources of GHG emissions within the CRF category 2A Mineral Industry; production of cement, lime, glass, glass wool, bricks / tiles, expanded clay and mineral wool along with other uses of soda ash and flue gas cleaning (desulphurisation), see Table 4.2.

Table 4.2 Sources/processes included in 2A Mineral Industry.

		Sources/processes
2A1	Cement production	Cement production
2A2	Lime production	Lime production (incl. lime produced in the sugar industry)
2A3	Glass production	Glass production
		Glass wool production
2A4	Other process uses of carbonates	Ceramics
		- Production of bricks/tiles
		- Production of expanded clay
		Other uses of soda ash
		Flue gas cleaning
		- at CHPs
		- at WIPs
		Mineral wool production

CHP: Combined Heat and Power plants, WIP: Waste Incineration Plants.

Cement production is the major CO_2 source within industrial processes. Information on the emission of CO_2 until 2020 is based on the company reporting to EU ETS (Aalborg Portland, 2021). The emission from cement production for 2021-2040 is estimated by the Danish Energy Agency (2022), see Table 4.3.

Table 4.3 Projected emission from cement production, kt CO_2.

Year	2021	2025	2030	2035	2040
Cement production	1268	1328	1324	1308	1296

Lime is used for a number of different applications. There are no projected production values available for lime production and the emission for 2021-2040 is therefore estimated to be the constant average value for 2016-2020. Like lime, soda ash has many applications and like lime, the category of “other uses of soda ash” is projected as the average emission for the years 2016-2020.

The production of building materials i.e. stone wool, glass wool, glass, bricks / tiles and expanded clay products for 2021-2040 is estimated by extrapolating the 2020 emission for each category with the projected production value for the construction sector.

Consumption of lime for flue gas cleaning depends primarily on the consumption of coal at CHPs and waste at WIPs. The emissions for 2021-2040 are estimated as a sum for the two sources by extrapolating using the trend of the projected consumption of coal and waste.

The calculated emission projections are shown in Table 4.9 and Table 4.10.

4.2.3 Chemical Industry

There is only one source of GHG emissions within the emission projection of CRF category 2B Chemical Industry; production of catalysts / fertilisers categorised under 2B10 Other.

There are no projected production values available for the production of catalysts / fertilisers; the emission for 2021-2040 is therefore estimated using the average of the five latest historical years.

Historically the emission in CO_2 equivalents (CO_2e) declines sharply in 2004 as the production of nitric acid ceased in mid-2004.

Calculated emission projections are shown in Table 4.9.

4.2.4 Metal Industry

There has been no production at Danish steelworks since 2006. There is also no planned reopening.

There is a small emission of CO_2 from lead production. However, the production ceased during 2021, and 2021 is therefore the only year for which any GHG emissions are projected for metal industry categories.

Calculated emission projection is shown in Table 4.9.

4.2.5 Non-Energy Products from Fuels and Solvent Use

This category includes CO_2, CH_4, N_2O and NMVOC emissions from the source categories 2D1 Lubricant use, 2D2 Paraffin wax use, 2D3 Other solvent use (Paint application, Degreasing and dry cleaning, Chemical products, manufacture and processing and Other solvent and product use), Road paving with asphalt and Asphalt roofing.

Table 4.4 Global Warming Potentials (GWPs) for substances in category 2D.

Substance	Typical use	GWP CO_2e
CO_2	Lubricants, Paraffin wax use	1
CH_4	Paraffin wax use	25
N_2O	Paraffin wax use	298

The contribution to GHG emissions from NMVOC is based on carbon content in the VOCs respectively and a calculation into CO_2, NMVOC is therefore not included in Table 4.4.

The projections are based on the average emission of the historical years 2016-2020. Calculated emission projections are shown in Table 4.9 and Table 4.11.

4.2.6 Electronic Industry

Fibre optics is the only source in CRF category 2E Electronic Industry. Fibre optics can lead to emissions of both HFC (HFC-23) and PFCs (PFC-14 and PFC-318). No emissions from fibre optics occurred in 2020, and no emissions are expected for 2021-2040 (Poulsen, 2022a).

4.2.7 Product Uses as Substitutes for Ozone Depleting Substances

There are three sources of GHG emissions within the projection of the CRF category 2F Product Uses as Substitutes for Ozone Depleting Substances (ODS); refrigeration and air conditioning, foam blowing agents and aerosols.

Emission projections from this source category include five HFCs (HFC-32, HFC-125, HFC-134a, HFC-143a and HFC-152a) and one PFC (PFC-14).

HFCs

HFCs comprise a range of substances, of which the following, relevant for Denmark, are approved for inventory under the Climate Convention and the Kyoto Protocol (KP) with stated and approved GWP values.

Table 4.5 Global Warming Potentials (GWPs) for the HFCs.

Substance	Typical use	GWP CO_2e
HFC-32	Refrigeration (K2)	675
HFC-125	Refrigerants (K1-4)	3 500
HFC-134a	Refrigerants (K1-4), foam blowing and aerosols	1 430
HFC-143a	Refrigerants (K1-4)	4 470
HFC-152a	Refrigerants (K2) and foam blowing	124

However, HFCs in Denmark are estimated in accordance with the trade names for HFC mixtures, Table 4.6 provides the “pure” HFC content of the mixtures.

Table 4.6 Relationship (mass %) between HFCs as calculated for the Climate Convention (“‘pure” HFCs) and the HFC mixtures used under trade names in Denmark.

Pure HFCs / HFC mixtures	HFC-32 %	HFC-125 %	HFC-134a %	HFC-143a %	HFC-152a %
HFC-401a					13
HFC-402a		60			
HFC-404a		44	4	52	
HFC-407c	23	25	52		
HFC-507a		50		50	

HFCs are mostly used as refrigerants in stationary and mobile air-conditioning and refrigeration systems. A minor application is in insulation foams and foams of other types.

PFCs

PFCs comprise a range of substances, of which only PFC-14 (CF_4) is relevant for the projection of source category 2F and approved for inventory under the Climate Convention and KP with stated and approved GWP values. The GWP value for PFC-14 7 390. PFC-14 is used as cleaning fluid. The use of PFCs in Denmark is limited.

Calculated emission projections from 2F Product uses as substitutes for ODS are shown in Table 4.9 and Table 4.12.

4.2.8 Other Product Manufacture and Use

There are four sources of GHG emissions within the CRF category 2G Other Product Manufacture and Use; Use of electrical equipment, SF_6 from other product uses, N_2O from product uses and Other product uses.

Table 4.7 Sources/processes included in category 2G Other Product Manufacture and Use.

		Sources/processes
2G1	Electrical equipment	Use of electrical equipment
2G2	SF_6 and PFCs from other product use	SF_6 from other product uses: - Double glazed windows - Laboratories/research - Running shoes*
2G3	N_2O from product uses	N_2O from medical applications Propellant for pressure and aerosol products
2G4	Other	Other product uses - Fireworks - Tobacco - Charcoal for barbeques

* Only for historic years

The different substances reported within category 2G are shown in Table 4.8 along with the source categories responsible for their release and their respective GWPs.

Table 4.8 Global Warming Potentials (GWPs) for substances in category 2G.

Substance	Typical use	GWP CO_2e
CO_2	Fireworks	1
CH_4	Fireworks, tobacco, charcoal for BBQs	25
N_2O	Anaesthetics, propellant, fireworks, tobacco, charcoal for BBQs	298
SF_6	High voltage electrical equipment, double glazing, laboratories/research, running shoes	22,800

The annual F-gas report from Poulsen (2022a) contains both SF_6 consumption and emission data for both historic years and projected years until 2030. For more details on this report and the model it is based on, see the section 4.2.1 F-gases.

The emission projections for the sources Use of electrical equipment and SF_6 from other product uses are available from Poulsen (2022a and 2022b). Emissions from the Use of electrical equipment cover SF_6 from high voltage equipment. The emissions from SF_6 from other product uses cover SF_6 from double glazed windows and use of SF_6 in laboratories / research. The use of SF_6 in connection with double-glazing was banned in 2002, and according to the F-gas model, the last remaining double-glazing panes where SF_6 has been used will be disposed of in 2021 where the last emissions therefore will occur.

The third source, N_2O from product uses, covers N_2O from medical use i.e. anaesthetics and N_2O used as propellant for pressure and aerosol products i.e. canned whipped cream. The emission projections for these sources are calculated as the constant average value of the five latest historical years.

The fourth source, Other product use, covers CO_2, CH_4 and N_2O emissions from the use of fireworks, tobacco and charcoal for barbeques. The emission projections for these sources are calculated as the constant average of the five latest historical years, except for the use of tobacco where emissions are estimated based on the trend of the historical years.

The calculated emission projections are shown in Table 4.9.

4.3 Emissions

The results of the GHG emission projections for the entire Industrial Processes and Product Use sector are presented in Table 4.9.

In 2020, 70 % of GHG emissions from IPPU originate from Mineral Industry. By 2040, the number will have increased to 82 % because emissions from Product uses as ODS substitutes and Other Product Manufacture and Use decrease more than those from Mineral Industry.

The second largest source category is Product uses as substitutes for ODS with up to 14 % of GHG emissions early in the projection period.

Table 4.9 Projection of CO_2 process emissions, kt CO_2e

Source Categories		1990	2005	2015	2020	2021	2025	2030	2035	2040
2A	Mineral industry	1081	1567	1049	1353	1395	1458	1455	1441	1431
	Hereof cement production	882	1363	932	1227	1268	1328	1324	1308	1296
2B	Chemical industry	1003	1.1	1.5	1.4	1.4	1.4	1.4	1.4	1.4
2C	Metal industry	60	16	0.20	0.09	0.04	NO	NO	NO	NO
2D	Non-energy products from fuels and solvent use	166	216	174	169	165	165	165	165	165
2E	Electronic industry	NO	NO	NO	NO	NO	NO	NO	NO	NO
2F	Product uses as ODS substitutes	-	927	467	335	261	232	148	128	117
2G	Other product manufacture and use	33	43	144	67	36	35	36	36	35
	Total	2343	2770	1835	1925	1858	1892	1805	1771	1751

NO: Not occurring.

The emission projections for the individual categories are presented in the following sections 4.3.1-4.3.7.

Figure 4.1 illustrates CO_2e emission projections for the entire industrial sector divided between pollutants. Different legislation on F-gases were introduced during the 2000s, this involved regulations such as taxes and bans. As a result, F-gas emissions started to decrease in the end of the 2000s; this decreasing trend is expected to continue. The figure shows that emissions from the IPPU sector are dominated by CO_2 and that of the F-gases HFCs contributes the most to GHG emissions.

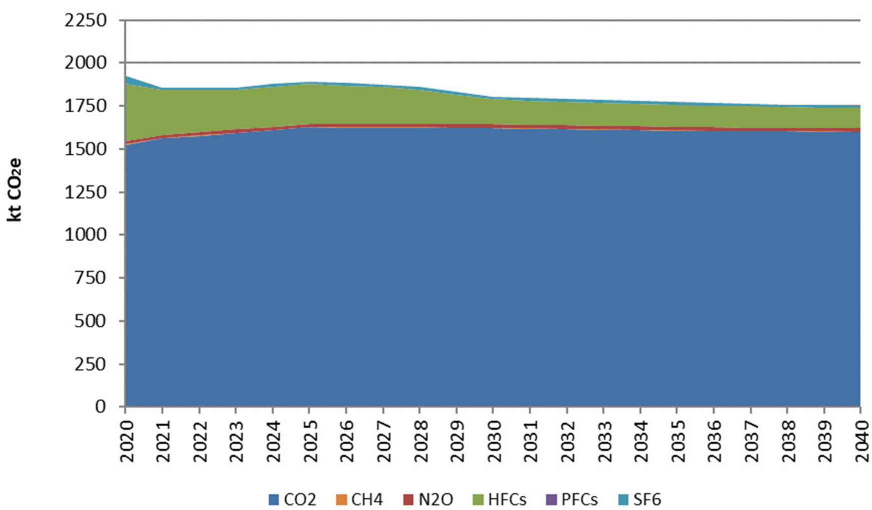

Figure 4.1 Time series for emissions, divided into individual pollutants.

4.3.1 Mineral Industry

Emission projections for mineral industries are shown in Table 4.10.

Table 4.10 Some historical emissions and emission projections for mineral industries, kt CO_2e.

		1990	2005	2015	2020	2021	2025	2030	2035	2040
2A1	Cement production	882	1363	932	1227	1268	1328	1324	1308	1296
2A2	Lime production	105	60	51	43	44	44	44	44	44
2A3	Glass production	14	11	8	8	8	9	9	10	10
2A3	Glass wool production	2	2	1	2	2	2	2	2	2
2A4a	Bricks/tiles production	26	35	20	27	27	30	31	32	33
2A4a	Expanded clay production	20	19	9	16	17	18	19	19	20
2A4b	Other uses of soda ash	14	18	7	17	16	16	16	16	16
2A4d	Flue gas cleaning	10	51	16	7	8	6	4	4	4
2A4d	Stone wool production	7	8	6	5	5	6	6	6	6
	Total	1081	1567	1049	1353	1395	1458	1455	1441	1431

The largest source of emissions in Mineral Industry is cement production; 82-91 %. Cement production has a slight increasing trend in the projected years until 2025 followed by a decreasing trend, the development is due to the projected cement production presented in Table 4.3. The second largest emission source for all projected years is lime production; 3-10 %.

In 2020, the contribution from category 2A was 4.8 % of the Danish total greenhouse gas emission without LULUCF. In 2040, this contribution is estimated to have increased to 11.0 %.

4.3.2 Chemical Industry

There is only one source of GHG emissions within this category; production of catalysts / fertilisers categorised under 2B10 Other. There is therefore no additional disaggregation available to the data presented in Table 4.9.

4.3.3 Metal Industry

There is only one source of GHG emissions within this category; 2C5 Lead Production. There is therefore no additional disaggregation available to the data presented in Table 4.9.

The single Danish lead producer closed down during 2021, 2021 is therefore the only projected emission year for Metal Industry.

4.3.4 Non-Energy Products from Fuels and Solvent Use

All sources within this category were projected as the constant average of the five latest historical years. Category 2D makes up 9-11 % of IPPU CO_2 equivalent emissions in 2021-2040.

Table 4.11 Emissions for Non-Energy Products from Fuels and Solvent Use.

		Pollutant	Unit	1990	2005	2015	2020	2021	2025	2030	2035	2040
2D1	Lubricant use	CO_2	kt	50	38	32	32	32	32	32	32	32
2D2	Paraffin wax use	CO_2	kt	22	100	70	58	63	63	63	63	63
2D3	Other (urea, asphalt, solvent use)	CO_2	kt	94	77	71	79	69	69	69	69	69
2D	Total CO_2	CO_2	kt	166	215	173	168	165	165	165	165	165
2D2	Paraffin wax use	CH_4	t	0.9	4.2	2.9	2.4	2.6	2.6	2.6	2.6	2.6
2D3	Other	CH_4	t	11	17	15	17	16	16	16	16	16
2D	Total CH_4	CH_4	t	12	21	18	19	19	19	19	19	19
2D2	Paraffin wax use	N_2O	t	0.2	0.8	0.6	0.5	0.5	0.5	0.5	0.5	0.5
2D	Total N_2O	N_2O	t	0.2	0.8	0.6	0.5	0.5	0.5	0.5	0.5	0.5
2D	Total CO_2e	CO_2e	kt	166	216	174	169	165	165	165	165	165

4.3.5 Electronic Industry

There is only one source in category 2E; i.e. Fibre optics. There is therefore no additional disaggregation available to the data presented in Table 4.9. Since no emissions occurred in later years, no emissions have been projected.

4.3.6 Product Uses as Substitutes for Ozone Depleting Substances

The category *2F Product Uses as Substitutes for ODS* is dominated by emissions from refrigeration and air conditioning.

Table 4.12 Emissions for Product Uses as Substitutes for Ozone Depleting Substances, kt CO_2e.

		1990	2005	2015	2020	2021	2025	2030	2035	2040
2F1a	Commercial refrigeration	-	582	293	166	108	99	40	23	14
2F1b	Domestic Refrigeration	-	18	7	2	2	0.9	0.3	0.3	0.3
2F1d	Transport Refrigeration	-	23	21	12	10	11	7	7	7
2F1e	Mobile Air-Conditioning	-	62	59	62	49	20	7	4	2
2F1f	Stationary air-conditioning	-	88	59	80	80	89	83	83	83
2F2a	Closed Cells	-	113	14	0.64	0.58	0.30	0.02	0.02	0.02
2F2b	Open Cells	-	17	NO	NO	NO	NO	NO	NO	NO
2F4a	Metered Dose Inhalers	-	8	6	11	11	11	11	11	11
2F4b	Other aerosols	-	15	8	NO	NO	NO	NO	NO	NO
2F5	Solvents*	-	NO	NO	NO	NO	NO	NO	NO	NO
	Total	-	927	467	335	261	232	148	128	117

* Occured in 2000-2003.

4.3.7 Other Product Manufacture and Use

Emission projections for other product manufacture and use are not shown at a more disaggregated level due to the low emissions from this source. Overall emissions from this category are presented in Table 4.9.

4.4 Recalculations

Recalculations compared to the previous projection are caused by the update of the historical years, updates in the activity/energy projections from the Danish Energy Agency and F-gas projection done by Poulsen (2022a and 2022b).

4.5 References

Danish Energy Agency, 2022: Denmark's Energy and Climate Outlook.

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Poulsen, 2022a: Danish consumption and emission of F-gases in 2020. Environmental Report no. 2196, January 2022. Including projections for 2021-2030. Available at:
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Poulsen, 2022b: Excel spreadsheet containing projection assumptions for F-gasses for 2031-2040. Prepared by Tomas S. Poulsen, Provice ApS.

Aalborg Portland, 2021: CO_2-opgørelse og afrapportering 2020. Aalborg Portland A/S. Fremstilling af klinker (cement).

5 Transport and other mobile sources

In the Danish emission database, all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution), according to the CollectER system. The emission inventories are prepared from a complete emission database based on the SNAP sectors.

For mobile sources, the aggregation of emission results into the formats used by the UNFCCC and UNECE Conventions is made by using the code correspondence information shown in Table 5.1. In the case of mobile sources, the CRF (Common Reporting Format) and NFR (National Format for Reporting) used by the UNFCCC and UNECE Conventions, respectively, are similar.

Table 5.1 SNAP – CRF/NFR correspondence table for mobile sources.

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 Domestic airport traffic (LTO < 1000 m)	1A3aii (i) Civil aviation (Domestic, LTO)
080502 International airport traffic (LTO < 1000 m)	1A3ai (i) Civil aviation (International, LTO)
080503 Domestic cruise traffic (> 1000 m)	1A3aii (ii) Civil aviation (Domestic,Cruise)
080504 International 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 includes recreational craft (SNAP code 0803).

Road traffic gasoline evaporation, brake and tire wear, and road abrasion (SNAP codes 0706-0708) is not a part of the CRF list since no greenhouse gases are emitted from these sources.

For aviation, LTO (Landing and Take Off)[4] refers to the part of flying, which is below 3000 ft. According to the UNFCCC reporting guidelines, the emissions from domestic LTO (0805010) and domestic cruise (080503) and flights

[4] 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.

between Denmark and Greenland or the Faroe Islands are regarded as domestic flights.

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.

The description of methodologies and references for the transport part of the Danish inventory is given in two sections; one for road transport and one for the other mobile sources.

The fuel consumption used in the emission projection follow the sector split as the official energy statistics elaborated by the DEA. However, based on bottom up calculations within sectors, DCE in some cases make different splits of non-road mobile and stationary consumption compared to the fuel splits provided by DEA in the energy forecast.

5.1 Methodology and references for road transport

For road transport, the detailed methodology is used to make annual estimates of the Danish emissions, as described in the EMEP / EEA Emission Inventory Guidebook (EMEP / EEA, 2019). The actual calculations are made with a model developed by DCE, 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.

A final fuel balance adjustment is made in order to account for the statistical fuel sold according to Danish energy statistics / projections.

5.1.1 Vehicle fleet and mileage data

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. The layer classification is a further division of vehicle sub-classes into groups of vehicles with the same average fuel consumption and emission behaviour according to EU emission legislation levels. Table 5.2 gives an overview of the different model classes and sub-classes.

Table 5.2 Model vehicle classes and sub-classes.

Vehicle classes	Fuel type	Engine size/weight
PC	Gasoline	< 0.8 l.
PC	Gasoline	0.8 - 1.4 l.
PC	Gasoline	1.4 – 2 l.
PC	Gasoline	> 2 l.
PC	Diesel	< 0.8 l.
PC	Diesel	0.8 - 1.4 l.
PC	Diesel	< 1.4 - 2 l.
PC	Diesel	> 2 l.
PC	2-stroke	
PC	LPG	
PC	CNG	
PC	Plug-in hybrid	
LCV	Gasoline	<1305 kg
LCV	Gasoline	1305-1760 kg
LCV	Gasoline	>1760 kg
LCV	Diesel	<1305 kg
LCV	Diesel	1305-1760 kg
LCV	Diesel	>1760 kg
LCV	LPG	<1305 kg
LCV	LPG	1305-1760 kg
LCV	LPG	>1760 kg
Trucks	Gasoline	
Trucks	Diesel/CNG	Rigid 3,5 - 7,5t
Trucks	Diesel/CNG	Rigid 7,5 - 12t
Trucks	Diesel/CNG	Rigid 12 - 14 t
Trucks	Diesel/CNG	Rigid 14 - 20t
Trucks	Diesel/CNG	Rigid 20 - 26t
Trucks	Diesel/CNG	Rigid 26 - 28t
Trucks	Diesel/CNG	Rigid 28 - 32t
Trucks	Diesel/CNG	Rigid >32t
Trucks	Diesel/CNG	TT/AT 14 - 20t
Trucks	Diesel/CNG	TT/AT 20 - 28t
Trucks	Diesel/CNG	TT/AT 28 - 34t
Trucks	Diesel/CNG	TT/AT 34 - 40t
Trucks	Diesel/CNG	TT/AT 40 - 50t
Trucks	Diesel/CNG	TT/AT 50 - 60t
Trucks	Diesel/CNG	TT/AT >60t
Urban buses	Gasoline	
Urban buses	Diesel/CNG	< 15 tonnes
Urban buses	Diesel/CNG	15-18 tonnes
Urban buses	Diesel/CNG	> 18 tonnes
Coaches	Gasoline	
Coaches	Diesel/CNG	< 15 tonnes
Coaches	Diesel/CNG	15-18 tonnes
Coaches	Diesel/CNG	> 18 tonnes
Mopeds	Gasoline	
Motorcycles	Gasoline	2 stroke
Motorcycles	Gasoline	< 250 cc.
Motorcycles	Gasoline	250 – 750 cc.
Motorcycles	Gasoline	> 750 cc.

To support the emission projections fleet and annual mileage data are provided by DTU Transport for the vehicle categories present in COPERT 5 (Jensen, 2020). The latter source also provides information of the mileage split between urban, rural and highway driving. 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). For information on the historical vehicle stock and annual mileage, please refer to Nielsen et al. (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. This mileage contribution has been added to the total mileage for Danish trucks on Danish roads, for trucks > 16 tonnes of gross vehicle weight. The data has been further processed by DTU Transport; by using appropriate assumptions, the mileage have been backcasted to 1985 and projected to 2040.

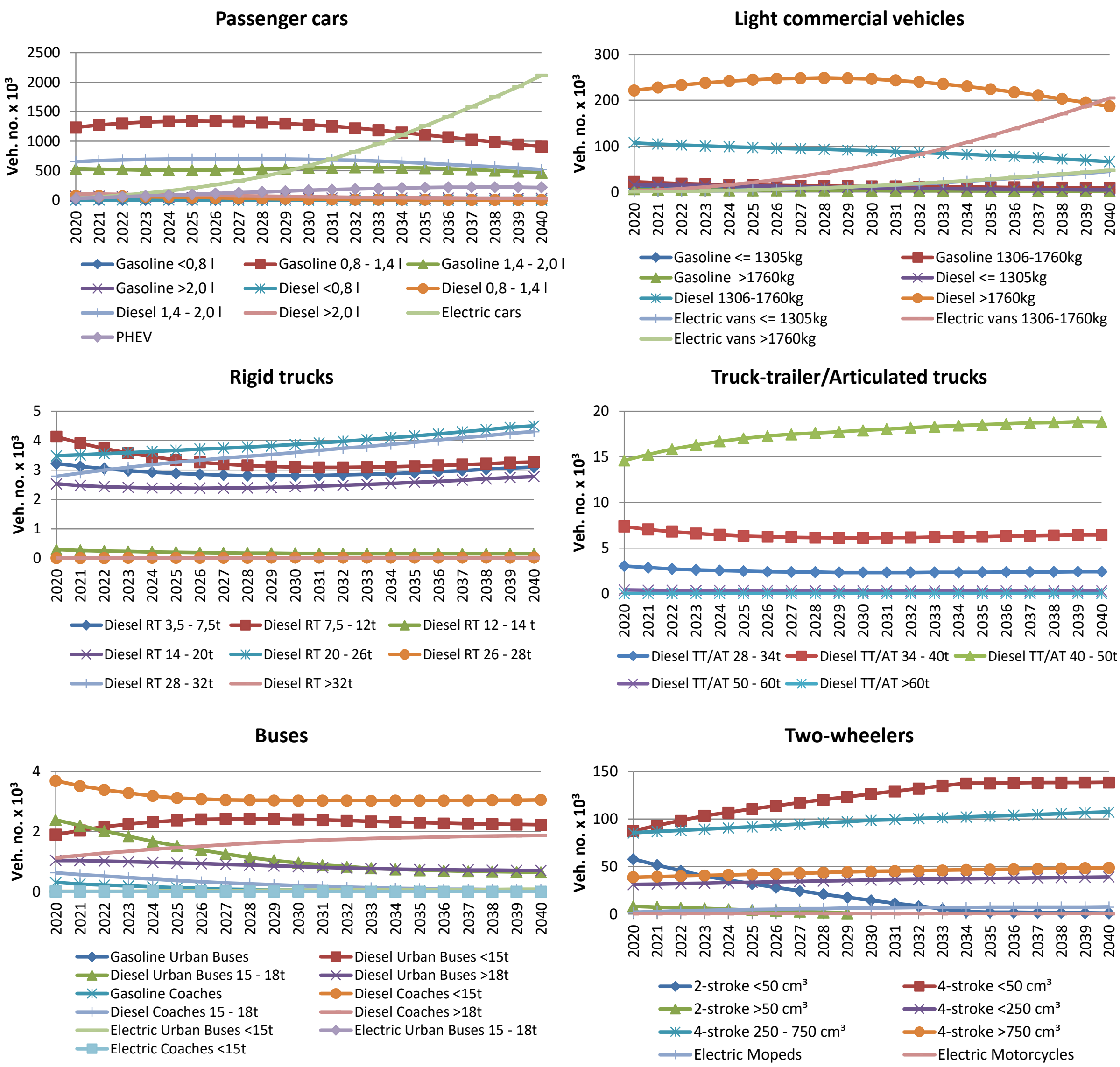

Figure 5.1 Number of vehicles in sub-classes from 2020-2040. PHEV = Plugin Hybrid Electric Vehicles.

The vehicle numbers per sub-class are shown in Figure 5.1. The engine size differentiation is associated with some uncertainty.

The vehicle numbers are summed up in layers for each year (Figure 5.2) by using the correspondence between layers and first registration year:

(5.1)
$$N_{j,y} = \sum_{i=FYear(j)}^{LYear(j)} N_{i,y}$$

where N = number of vehicles, j = layer, y = year, i = first registration year.

Weighted annual mileages per layer are calculated as the sum of all mileage driven per first registration year divided with the total number of vehicles in the specific layer.

(5.2)
$$M_{j,y} = \frac{\sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \cdot M_{i,y}}{\sum_{i=FYear(j)}^{LYear(j)} N_{i,y}}$$

The trends in vehicle numbers per EU layer are also shown in Figure 5.2 for the 2020-2040 periods. The latter figure clearly shows how vehicles complying with the gradually stricter EU emission levels (EURO 5/V, Euro 6/VI and Euro 6d) are introduced into the Danish motor fleet in the projection period.

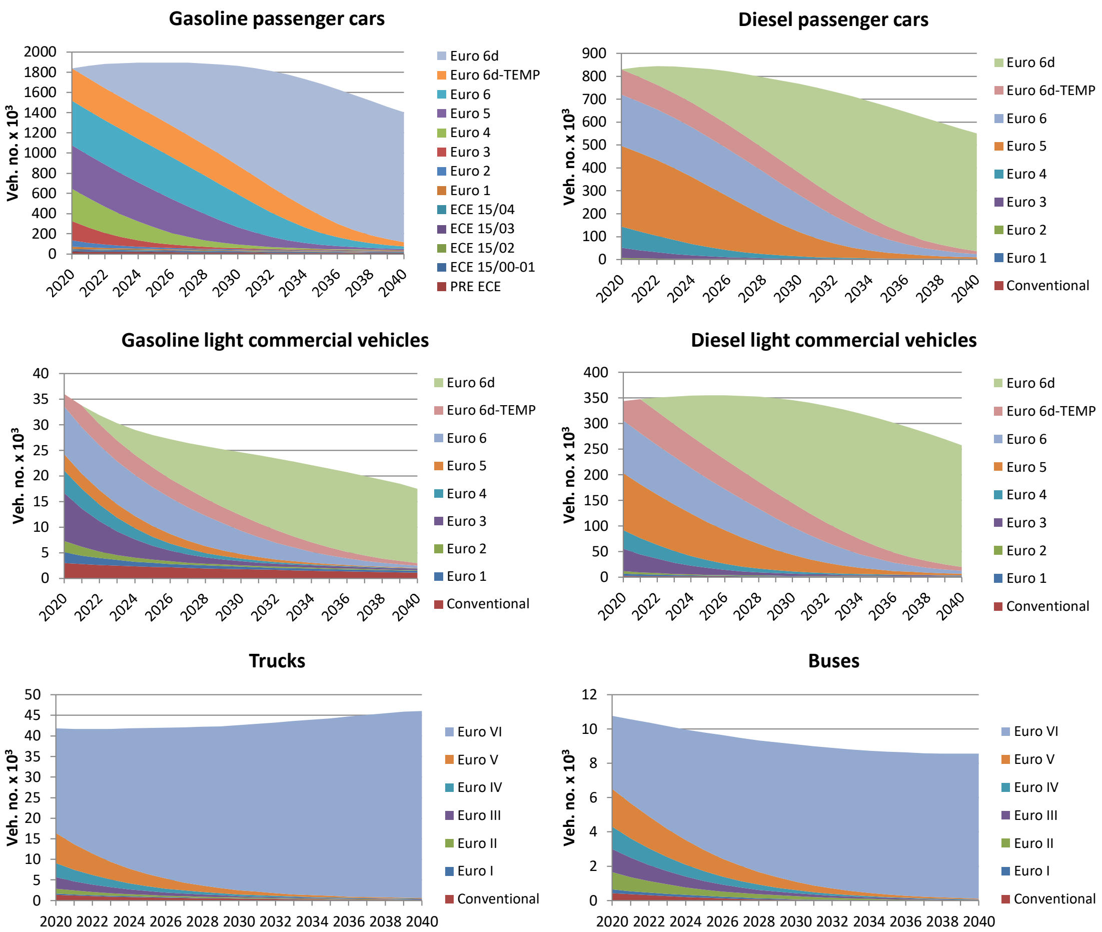

Figure 5.2 Layer distribution of vehicle numbers per vehicle type in 2020-2040.

5.1.2 Emission legislation

Several regulations have been enacted to set emission performance standards over the past years. In the following they are described in chronological order with the emphasis on the latest regulation.

The EU 443/2009 regulation sets new emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles. Some key elements of the adopted text are as follows:

- **Limit value curve:** the fleet average to be achieved by all cars registered in the EU is 130 gram CO_2 per kilometre (g per km). A so-called limit value curve implies that heavier cars are allowed higher emissions than lighter cars while preserving the overall fleet average.
- **Further reduction:** a further reduction of 10 g CO_2 per km, or equivalent if technically necessary, will be delivered by other technological improvements and by an increased use of sustainable biofuels.
- **Phasing-in of requirements:** in 2012, 65 % of each manufacturer's newly registered cars had to comply on average with the limit value curve set by the legislation. This raised to 75 % in 2013, 80 % in 2014, 100 % in 2015-2019, 95 % in 2020, and it will rise to 100 % from 2021 onwards.
- **Lower penalty payments for small excess emissions until 2018:** if the average CO_2 emissions of a manufacturer's fleet exceed its limit value in any year from 2012, the manufacturer has to pay an excess emissions premium for each car registered. This premium amounts to €5 for the first g per km of exceedance, €15 for the second g per km, €25 for the third g per km, and €95 for each subsequent g per km. From 2019, already the first g per km of exceedance costs €95.
- **Long-term target:** a target of 95 g CO_2 per km is specified for the year 2021.
- **Eco-innovations:** manufacturers can be granted a maximum of 7 g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.

The EU 510/2011 regulation sets new emission performance standards for new light commercial vehicles (vans). Some key elements of the regulation are as follows:

- **Target dates:** the EU fleet average of 175 g CO_2 per km was phased in between 2014 and 2017. In 2014, an average of 70 % of each manufacturer's newly registered vans had to comply with the limit value curve set by the legislation. This proportion raised to 75 % in 2015, 80 % in 2016, and 100 % from 2017 onwards.
- **Limit value curve:** emissions limits are set according to the mass of vehicle, using a limit value curve. The curve is set in such a way that a fleet average of 175 g of CO_2 per kilometre is achieved. A so-called limit value curve of 100 % implies that heavier vans are allowed higher emissions than lighter vans while preserving the overall fleet average. Only the fleet average is regulated, so manufacturers will still be able to make vehicles with emissions above the limit value curve provided these are balanced by other vehicles, which are below the curve.
- **Vehicles affected:** the vehicles affected by the legislation are vans, which account for around 12 % of the market for light-duty vehicles. This includes vehicles used to carry goods weighing up to 3.5 t (vans and car-derived vans, known as N1) and which weigh less than 2610 kg when empty.

- **Long-term target:** a target of 147 g CO_2 per km is specified for the year 2020.
- **Excess emissions premium for small excess emissions until 2018:** if the average CO_2 emissions of a manufacturer's fleet exceed its limit value in any year from 2014, the manufacturer has to pay an excess emissions premium for each van registered. This premium amounts to €5 for the first g per km of exceedance, €15 for the second g per km, €25 for the third g per km, and €95 for each subsequent g per km. From 2019, the first g per km of exceedance costs €95. This value is equivalent to the premium for passenger cars.
- **Super-credits:** vehicles with extremely low emissions (below 50 g per km) will be given additional incentives whereby each low-emitting van was counted as 3.5 vehicles in 2014 and 2015, 2.5 in 2016 and 1.5 vehicles in 2017.
- **Eco-innovations:** manufacturers can be granted a maximum of 7 g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.
- **Other flexibilities:** manufacturers may group together to form a pool and act jointly in meeting the specific emissions targets. Independent manufacturers who sell fewer than 22 000 vehicles per year can also apply to the Commission for an individual target instead.

On 17 April 2019, the European Parliament and the Council adopted Regulation (EU) 2019/631 setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles (vans) in the EU.

This Regulation started applying on 1 January 2020, replacing and repealing the former Regulations setting CO_2 emission standards for cars ((EC) 443/2009) and vans ((EU) 510/2011).

The following description of the regulation (EU) 2019/631 is given on the EU Commission Climate Action web page (https://ec.europa.eu/clima/policies/transport/vehicles/regulation_en). The main elements of the regulation are:

Target levels

New EU fleet-wide CO_2 emission targets are set for the years 2025 and 2030, both for newly registered passenger cars and newly registered vans.

These targets are defined as a percentage reduction from the 2021 starting points:

- Cars: 15% reduction from 2025 on and 37.5% reduction from 2030 on
- Vans: 15% reduction from 2025 on and 31% reduction from 2030 on

The specific emission targets for manufacturers to comply with, are based on the EU fleet-wide targets, taking into account the average test mass of a manufacturer's newly registered vehicles.

Incentive mechanism for zero- and low-emission vehicles (ZLEV)

A ZLEV is defined in the Regulation as a passenger car or a van with CO_2 emissions between 0 and 50 g/km.

To incentivise the uptake of ZLEV, a crediting system is introduced from 2025 on.

The specific CO_2 emission target of a manufacturer will be relaxed if its share of ZLEV registered in a given year exceeds the following benchmarks:

- Cars: 15% ZLEV from 2025 on and 35% ZLEV from 2030 on
- Vans: 15% ZLEV from 2025 on and 30% ZLEV from 2030 on

A one percentage point exceedance of the ZLEV benchmark will increase the manufacturer's CO_2 target (in g CO_2/km) by one percent. The target relaxation is capped at maximum 5% to safeguard the environmental integrity of the Regulation.

For calculating the ZLEV share in a manufacturer's fleet, an accounting rule applies. This gives a greater weight to ZLEV with lower CO_2 emissions.

In addition, for cars only, during the period 2025 to 2030, a greater weight is given to ZLEV registered in Member States with a low ZLEV uptake in 2017, and this as long as the ZLEV share in the Member State's fleet of newly registered cars does not exceed 5%.

Pooling, exemptions and derogations

The provisions on pooling between manufacturers are the same as under the previous Regulations. Pooling between car and van manufacturers is not possible.

The exemption of manufacturers registering less than 1 000 cars or vans per year, as well as the derogation possibility for "small volume" car and van manufacturers, have also been maintained.

The derogation possibility for "niche" car manufacturers, i.e. those registering between 10 000 and 300 000 cars per year, will end after the year 2028. In the years 2025 to 2028, the derogation target for those manufacturers will be 15% below the 2021 derogation target.

Eco-innovations

The provisions regarding the "eco-innovation" credits for emission savings due to the application of innovative emission reduction technologies not covered by the standard test cycle CO_2 measurement are largely unchanged compared to the previous Regulations.

New is that the efficiency improvements for air conditioning systems will become eligible as eco-innovation technologies as of 2025 and that the cap of 7 g/km may be adjusted by the Commission through a delegated act.

Governance

Two new elements have been introduced to reinforce the effectiveness of the Regulation.

These concern:

- the verification of CO_2 emissions of vehicles in-service and
- measures to ensure that the emission test procedure yields results which are representative of real-world emissions.

In-service verification

Manufacturers are required to ensure correspondence between the CO_2 emissions recorded in the certificates of conformity of their vehicles and the CO_2 emissions of vehicles in-service measured according to WLTP.

This correspondence shall be verified by type-approval authorities in selected vehicles. The authorities shall also verify the presence of any strategies artificially improving the vehicle's performance in the type-approval tests.

On the basis of their findings, type-approval authorities shall, where needed, ensure the correction of the certificates of conformity and may take other necessary measures set out in the Type Approval Framework Regulation.

Deviations found in the CO_2 emissions of vehicles in service shall be reported to the Commission, who shall take them into account for the purpose of calculating the average specific emissions of a manufacturer.

Real-world emissions

To prevent the gap between emissions tested in the laboratory and real-world emissions from increasing, the Commission shall, from 2021 on, regularly collect data on the real-world CO_2 emissions and energy consumption of cars and vans using the on-board fuel consumption monitoring devices (OBFCM).

The Commission shall monitor how that gap evolves between 2021 and 2026 and, on that basis, assess the feasibility of a mechanism to adjust the manufacturer's average specific CO_2 emissions as of 2030.

The detailed procedures for collecting and processing the data shall be adopted by means of implementing acts.

Life-cycle emissions

By 2023, the Commission shall evaluate the possibility of developing a common methodology for the assessment and reporting of the full life-cycle CO_2 emissions of cars and vans.

Review

The Commission shall review the effectiveness of the Regulation and report on this to the European Parliament and the Council.

This review shall cover i.a. the following:

- real world representativeness of the CO_2 emission and energy consumption values,
- deployment of ZLEV,
- roll-out of recharging and refuelling infrastructure,
- role of synthetic and advanced alternative fuels produced with renewable energy,
- emission reductions observed for the existing fleet,
- ZLEV incentive mechanism,
- impacts for consumers,
- aspects related to the just transition,
- impacts for consumers, aspects related to the just transition,
- 2030 targets and identification of a pathway for emission reductions beyond 2030.

As part of the review, the Commission shall assess the feasibility of developing real-world emission test procedures, as well as the possibility to assign revenues from the fines to a specific fund or relevant programme with the objective to ensure a just transition towards a climate neutral economy.

Finally, the Commission shall review the Car Labelling Directive by end 2020, covering both CO_2 and air pollutant emissions of cars and evaluating the options for introducing a fuel economy and CO_2 emissions label for vans.

The Regulation (EU) 2019/1242 setting CO_2 emission standards for heavy-duty vehicles entered into force on 14 August 2019.

The following description of the EU regulation 2019/1242 is taken from the EU Commission Climate Action web page (https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en). The main elements of the regulation are:

Target levels

From 2025 on, manufacturers will have to meet the targets set for the fleet-wide average CO_2 emissions of their new lorries registered in a given calendar year. Stricter targets will start applying from 2030 on.

The targets are expressed as a percentage reduction of emissions compared to EU average in the reference period (1 July 2019–30 June 2020):

- from 2025 onwards: 15% reduction
- from 2030 onwards: 30% reduction

The 2025 target can be achieved using technologies that are already available on the market. The 2030 target will be assessed in 2022 as part of the review of the Regulation.

As a first step, the CO_2 emission standards will cover large lorries, which account for 65% to 70% of all CO_2 emissions from heavy-duty vehicles.

As part of the 2022 review, the Commission should assess the extension of the scope to other vehicle types such as smaller lorries, buses, coaches and trailers.

Incentive mechanism for zero- and low-emission vehicles (ZLEV)

The Regulation includes an incentive mechanism for

- zero-emission vehicles (ZEV), lorries with no tailpipe CO_2 emissions
- low-emission vehicles (LEV), lorries with a technically permissible maximum laden mass of more than 16t, with CO_2 emissions of less than half of the average CO_2 emissions of all vehicles in its group registered in the 2019 reporting period.

To incentivise the uptake of ZLEV and reward early action, a super-credits system applies from 2019 until 2024, and can be used to comply with the target in 2025. A multiplier of 2 applies for ZEV, and a multiplier between 1 and 2 applies for LEV, depending on their CO_2 emissions. An overall cap of 3% is set to preserve the environmental integrity of the system.

From 2025 onwards, the super-credits system is replaced by a benchmark-based crediting system, with a benchmark set at 2%. The 2030 benchmark level will have to be set in the context of the 2022 review.

As a result, the average specific CO_2 emissions of a manufacturer are adjusted downwards if the share of ZLEV in its entire new heavy-duty vehicles fleet exceeds the 2% benchmark, out of which at least 0.75 percentage points have to be vehicles subject to the CO_2 targets, i.e. the largest vehicles. Each percentage point of exceedance of the benchmark will decrease the manufacturer's average specific CO_2 emissions by one percent.

In both systems, ZEV not subject to the CO_2 targets are accounted in the incentive mechanism. Buses and coaches are excluded from the scheme. The ZEV not subject to the CO_2 targets can contribute to a maximum of 1.5% CO_2 emissions reduction.

Cost-effective achievement of targets

The Regulation includes several elements to support cost-effective implementation:

Banking and borrowing to take account of long production cycles, including a reward for early action, while maintaining the environmental integrity of the targets.

Full flexibility for manufacturers to balance emissions between the different groups of vehicles within their portfolio.

Vocational vehicles, such as garbage trucks and construction vehicles, are exempted due to their limited potential for cost-efficient CO_2 reduction.

Governance

The following measures will ensure the effectiveness and enforcement of the targets. They are based on the experience from cars and vans:

- Assess the robustness and representativeness of the reference CO_2 emissions as a basis for calculating the EU fleet-wide emissions targets.
- Collect, publish and monitor real-world fuel consumption data reported by manufacturers, based on mandatory standardised fuel consumption meters.
- Introduce in-service conformity tests and mandate the reporting of deviations and the introduction of a correction mechanism.
- Apply financial penalties in case of non-compliance with the CO_2 targets. The level of the penalties is set to 4,250 euro per gCO_2/tkm in 2025 and 6,800 euro per gCO_2/tkm in 2030.

Review

The Commission shall review the effectiveness of the Regulation and report on this to the European Parliament and the Council by 2022.

This review shall cover i.a.

- 2030 target and possible targets for 2035 and 2040;
- inclusion of other types of heavy-duty vehicles, including buses, coaches, trailers, vocational vehicles and considerations of EMS (European modular system);
- ZLEV incentive mechanism;
- real world representativeness of the CO_2 emission and energy consumption values;

- role of synthetic and advanced alternative fuels produced with renewable energy;
- possible introduction of a form of pooling;
- level of the excess emission premium.

By 2023, the Commission shall evaluate the possibility of developing a common methodology for the assessment and reporting of the full life-cycle CO_2 emissions of heavy-duty vehicles.

Monitoring and reporting of CO_2 emissions from heavy-duty vehicles

The following measures enable the implementation of the emission standards:

- Certification Regulation on the determination of the CO_2 emissions and fuel consumption of new lorries
- Regulation (EU) 2018/956 on monitoring and reporting.

The monitoring and reporting Regulation requires that, as of 1 January 2019:

- Member States monitor and report to the Commission information on the heavy-duty vehicles registered for the first time in the Union; and lorry manufacturers monitor and report to the Commission CO_2 emission and fuel consumption data as determined pursuant to the certification Regulation for each new vehicle produced for the EU market. This information will be calculated using the Vehicle Energy Consumption Calculation Tool (VECTO).
- The collected data on CO_2 emissions and fuel consumption together with other relevant technical information on the vehicles, including the aerodynamic drag, will be made publicly available by the European Environment Agency on behalf of the Commission, starting in 2021 to cover data monitored between 1 January 2019 and 30 June 2020.
- The new system will complement the existing EU reporting system for cars and vans.

Vehicle Energy Consumption Calculation Tool (VECTO)

VECTO is a simulation software that can be used cost-efficiently and reliably to measure the CO_2 emissions and fuel consumption of heavy-duty vehicles for specific loads, fuels and mission profiles (e.g. long haul, regional delivery, urban delivery, etc.), based on input data from relevant vehicle components.

The tool has been developed by the Commission in close cooperation with stakeholders.

Related policy measures

This legislation complements other policy measures such as the Certification Regulation, Monitoring and Reporting Regulation, EU type-approval system, Eurovignette Directive, Fuel Quality Directive, Clean Vehicles Directive, Directive on maximum authorised weights and dimensions and Directive on the deployment of alternative fuels infrastructure.

For Euro 1-6 passenger cars and vans, the chassis dynamometer test cycle used in the EU for emission approval is the NEDC (New European Driving Cycle), see e.g. www.dieselnet.com. The test cycle is also used for fuel consumption measurements. The NEDC cycle consists of two parts, the first part being a 4-time repetition (driving length: 4 km) of the ECE test cycle. The latter test cycle is the so-called urban driving cycle[5] (average speed: 19 km per h). The second part of the test is the run-through of the EUDC (Extra Urban Driving Cycle) test driving segment, simulating the fuel consumption under rural and highway driving conditions. The driving length of EUDC is 7 km at an average speed of 63 km per h. More information regarding the fuel measurement procedure can be found in the EU directive 80/1268/EØF.

The NEDC test cycle is not adequately describing real world driving 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, the "World-Harmonized Light-Duty Vehicles Test Procedure" (WLTP), has been developed which simulates much more closely real world driving behavior. The WLTP test procedure gradually took effect from 2017.

For the new Euro 6 vehicles, it has been decided that emission measurements must also be made with portable emission measurement systems (PEMS) during real traffic driving conditions with random acceleration and deceleration patterns. During the new Real Driving Emission (RDE) test procedure in a temporary phase, the emissions of NO_x are not allowed to exceed the NEDC based Euro 6 emission limits by more than 110 % by 1/9 2017 for all new car models and by 1/9 2019 for all new cars (Euro 6d-TEMP). From 1/1 2020 in the final phase, the NO_x emission not-to-exceed levels were adjusted downwards to 50 % for all new car models and by 1/1 2021 for all new cars (Euro 6d). Implementation dates for vans are one year later.

In the road transport emission model, compromise dates for enter into service of the Euro 6d-TEMP technology are set to 1/9 2018 and 1/9 2019 for diesel cars and vans respectively. For Euro 6d, the 'enter into service' dates are set to 1/1 2021 and 1/1 2022 for cars and vans, respectively. (pers. comm. Katja Asmussen, Danish EPA, 2018).

For NOx, VOC (NMVOC + CH_4), CO and PM, the emissions from road transport vehicles have to comply with the different EU directives listed in Table 5.3. For cars and vans, the emission directives distinguish between three vehicle classes according to vehicle reference mass[6]: passenger cars and light-duty trucks (< 1305 kg), light-duty trucks (1305-1760 kg) and light-duty trucks (> 1760 kg). The specific emission limits are shown in Nielsen et al. (2021).

For heavy-duty vehicles (trucks and buses), the emission limits are given in g per 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.

[5] For Euro 3 and on, the emission approval test procedure was slightly changed. The 40 s engine warm up phase before start of the urban driving cycle was removed.
[6] Reference mass: net vehicle weight + mass of fuel and other liquids + 100 kg.

Table 5.3 Overview of the existing EU emission directives for road transport vehicles.

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.

5.1.3 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 a vehicle fleet as such.

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).

Trip speed dependent base factors for fuel consumption and emissions are taken from the COPERT 5 model[7], using trip speeds representative for urban, rural and highway driving. The factors can be seen in Nielsen et al. (2021). The scientific basis for COPERT 5 is fuel consumption figures and emission information from various European measurement programmes, transformed into trip speed dependent fuel consumption and emission factors for all vehicle categories and layers.

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 (2020)[8]. 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 report, 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 fuel efficient vehicles

For passenger cars, COPERT 5 include measurement based fuel consumption factors until Euro 4. A calculation function is provided for newer cars that one hand compensate for the trend towards more fuel efficient vehicles being sold during the later years and on the other hand compensate for the increasing fuel gap between fuel consumption measured during vehicle type approval and real world fuel consumption.

The COPERT calculation function and supporting data material basis is, however, not able to account for the fuel gaps between fuel consumption measured during vehicle type approval and real world fuel consumption for vehicles after 2014, as monitored by e.g. the International Council on Clean Transportation (ICCT), Tietge et al. (2019).

[7] For vans, fuel consumption factors are not stratified according to vehicle weight classes in the COPERT model. For this vehicle category fuel consumption factor data are obtained from the HBEFA (Handbook of Emission Factors) model version 4.1 (e.g. Matzer et al., 2019).

[8] 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.

The baseline COPERT 5 fuel consumption factors for Euro 4, Euro 5 and Euro 6 passenger cars are adjusted in the following way.

In the Danish fleet and mileage database kept by DTU Transport, the type approval fuel efficiency value based on the NEDC driving cycle (TA_{NEDC}) is registered for each single car. Further, DTU Transport calculates a modified fuel efficiency value (FC_{inuse}) with the calculation function provided by COPERT 5 that better reflects the fuel consumption in real ("inuse") traffic conditions.

The latter function uses TA_{NEDC}, vehicle weight, engine size and regression coefficients by first registration year, as input parameters (EMEP/EEA, 2019). For each new registration year, i, fuel type, f, and engine size, k, number based average values of TA_{NEDC} and FC_{inuse} are summed up and referred to as $\overline{TA_{NEDC}}(i, f, k)$ and $\overline{FC_{inuse}}(i, f, k)$. 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 2015-2019, the $\overline{FC_{inuse}}(i, f, k)$ values for 2014 are adjusted for the years 2015-2019[9] 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 2014-2019.

The most recent emission projections use the assumption from The Danish Energy Agency that Danish vehicle sales meet a slightly softer national target of 99.3 g CO_2/km in 2021, instead of the EU 95 g CO_2/km, due to increases in new sales of electric cars and plug-in hybrids.

In order to meet the 99.3 g CO2/km target, the following approach is used to forecast the average TA_{NEDC} values ($\overline{TA_{NEDC}}(i)$) until 2021. As a starting point, the average CO_2 emission factor (average from all new registrations) is calculated for the last historical year (2019) based on the registered average TA_{NEDC} values from DTU Transport. Next, the average CO_2 emission factor (and $\overline{TA_{NEDC}}(i)$) for each future year's new sold cars is reduced with a linear function, C_{2021} (i), until the emission factor reaches 99.3 g CO_2/km in 2021. For years beyond 2021 annual fuel efficiency, improvement rates are used for new cars depending on fuel type as suggested by DEA (2020a).

The reduction function C_{2021} (i) is then used to reduce the in use type approval fuel efficiency values, $\overline{FC_{inuse}}(i, f, k)$, for the years between last historical year and 2021, for each of the fuel type/engine size fleet segments.

Subsequently these $\overline{FC_{inuse}}(i, f, k)$ values are aggregated by mileage into layer specific values for each inventory year ($\overline{FC_{inuse}}(layer)$).

9 The ICCT monitoring report include new cars up to 2017. For new cars from 2018 and 2019, fuel gap figures are used for cars from 2017.

At the same time, COPERT provides fuel consumption factors for Euro 4 vehicles for a specific driving pattern composition[10] that better describes real world driving for these specific vehicles. The factors build on the actual fuel measurements for the Euro 4 sample of COPERT vehicles ($FC_{COPERT,\ sample}$), used in the development of the Euro 4 emission factors in the COPERT model.

In a final step the ratio between the layer specific fuel factors for the Danish fleet ($\overline{FC_{inuse}}(layer)$) and the COPERT Euro 4 vehicles ($FC_{COPERT,\ sample}$) are used to scale the trip speed dependent COPERT 5 fuel consumption factors for Euro 4 layers onwards.

For vans, trucks, urban buses and coaches, annual fuel efficiency improvement rates are used for future new vehicles depending on fuel type as suggested by DEA (2020a).

5.1.4 Fuel consumption and emission calculations

The fuel consumption and emissions are calculated for operationally hot engines and for engines during cold-start. A final fuel balance adjustment is made in order to account for the statistical fuel sold according to Danish energy statistics / projections.

The calculation procedure for hot engines is to combine basis fuel consumption and emission factors, number of vehicles and annual mileage numbers and mileage road type shares. For additional description of the hot and cold-start calculations and fuel balance approach, please refer to Nielsen et al. (2021).

5.2 Other mobile sources

Other mobile sources are divided into several sub-sectors: sea transport, fishery, air traffic, railways, military, and working machinery and equipment in the sectors agriculture, forestry, industry and residential. The emission calculations are made using the detailed method as described in the EMEP / EEA Emission Inventory Guidebook (EMEP / EEA, 2019) for air traffic, off-road working machinery and equipment, and ferries, while for the remaining sectors the simple method is used.

5.2.1 Activity data

Air traffic

For aviation, air traffic statistics for the latest historical year is used in combination with flight specific emission data to determine the share of fuel used for LTO and cruise by domestic and international flights and to derive the corresponding emission factors. The LTO and cruise fuel shares are then used to make a LTO / cruise split of the fuel consumption projections for domestic and international aviation from Denmark’s Energy and Climate Outlook – DECO21 (DEA, 2021) due to lack of a projection of air traffic movements.

In more details the historical activity data used in the DCE emission model for aviation consists of records per flight (city-pairs) provided by the Danish Transport Authority. Each flight record consists of e.g. ICAO (International Civil Aviation Organization) codes for aircraft type, origin and destination

[10] The factors are derived from the Common Artemis Driving Cycle (CADC), with a 1 / 3 weight for each of the urban, rural and highway parts of CADC.

airport, maximum take-off mass (MTOM), flight call sign and aircraft registration number.

In the DCE model, each aircraft type is paired with a representative aircraft type, for which fuel consumption and emission data exist in the EMEP / EEA databank. As a basis, the type relation table is taken from the Eurocontrol AEM model, which is the primary source for the present EMEP / EEA fuel consumption and emission data. Supplementary aircraft types are assigned to representative aircraft types based on the type relation table already established in the DCE model (e.g. Nielsen et al., 2021).

Non road working machinery

Non road working machinery and equipment are used in agriculture, forestry and industry, for household / gardening purposes and inland waterways (recreational craft). The specific machinery types comprised in the Danish inventory are shown in Table 5.4.

Table 5.4 Machinery types comprised in the Danish non road inventory.

Sector	Diesel	Gasoline/LPG
Agriculture	Tractors, harvesters, machine pool, other	ATV's (All Terrain Vehicles), other
Forestry	Silvicultural tractors, harvesters, forwarders, chippers	-
Industry	Construction machinery, fork lifts, building and construction, airport ground service equipment, other	Fork lifts (LPG), building and construction, other
Residential and Commercial/institutional	-	Riders, lawn movers, chain saws, cultivators, shrub clearers, hedge cutters, trimmers, other, port/airport handling equipment (commercial/institutional)

Please refer to the reports by Winther et al. (2006) and Winther (2020) for detailed information of the number of different types of machines, their load factors, engine sizes and annual working hours.

National sea transport

For national sea transport, the energy projections from DECO21 for the sectors “National sea transport” and “Greenland / Faroe Islands maritime” are used as activity data input for the subsequent emission calculations. The projected energy totals for national sea transport are disaggregated into subcategories based on fleet activity estimates for ferries, sailing activities between Denmark and Greenland / Faroe Islands, and other national sea transport (Winther, 2020; Nielsen et al., 2021).

Table 5.5 lists the most important domestic ferry routes in Denmark in 2019. The complete list of ferries is shown in e.g. Nielsen et al. (2021). For the ferry routes the following detailed traffic and technical data have been gathered: ferry name, year of service, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size and sailing time (single trip). Please refer to e.g. Nielsen et al. (2021) for more details.

Table 5.5 Ferry routes comprised in the Danish inventory.

Ferry service	Service period
Esbjerg-Torshavn	1990-1995, 2009+
Hanstholm-Torshavn	1991-1992, 1999+
Hou-Sælvig	1990+
Frederikshavn-Læsø	1990+
Kalundborg-Samsø	1990+
Køge-Rønne	2004+
Sjællands Odde-Ebeltoft	1990+
Sjællands Odde-Århus	1999+
Svendborg-Ærøskøbing	1990+
Tårs-Spodsbjerg	1990+

Other sectors

The activity data for military, railways, international sea transport and fishery consists of fuel consumption information from DECO21. For international sea transport, the basis is expected fuel sold in Danish ports for vessels with a foreign destination, as prescribed by the IPCC guidelines.

5.2.2 Emission legislation

For other modes of transport and non-road machinery, the engines have to comply with the emission legislation limits agreed by the EU and different UN organisations in terms of NO_x, CO, VOC and TSP emissions and fuel sulphur content. In terms of greenhouse gases, the emission legislation requirements for VOC influence the emissions of CH_4, the latter emission component forming a part of total VOC. Only for ships legislative limits for specific fuel consumption have been internationally agreed in order to reduce the emissions of CO_2.

For non-road working machinery and equipment, recreational craft and railway locomotives / motor cars, the emission directives list specific emission limit values (g per kWh) for CO, VOC, NO_x (or VOC + NO_x) and TSP, depending on engine size (kW for diesel, ccm for gasoline) and date of implementation (referring to engine market date).

For diesel, the directives 97 / 68 and 2004 / 26 (Table 5.6) relate to Stage I-IV non-road machinery other than agricultural and forestry tractors and the directives have different implementation dates for machinery operating under transient and constant loads. The latter directive also comprises emission limits for Stage IIIA and IIIB railways machinery (Table 5.10). For Stage I-IV tractors the relevant directives are 2000 / 25 and 2005 / 13 (Table 5.6).

For emission approval of the EU Stage I, II and IIIA engine technologies, emissions (and fuel consumption) measurements are made using the steady state test cycle ISO 8178 C1, referred to as the Non-Road Steady Cycle (NRSC), see e.g. www.dieselnet.com. In addition to the NRSC test, the newer Stage IIIB and IV (and optionally Stage IIIA) engine technologies are tested under more realistic operational conditions using the new Non-Road Transient Cycle (NRTC).

For gasoline, the directive 2002 / 88 distinguishes between Stage I and II handheld (SH) and not hand-held (NS) types of machinery (Table 5.7). Emissions are tested using one of the specific constant load ISO 8178 test cycles (D2, G1, G2, G3) depending on the type of machinery.

For Stage V machinery, EU directive 2016/1628 relate to non-road machinery other than agricultural tractors and railways machinery (Table 5.6) and non-road gasoline machinery (Table 5.7). EU directive 167/2013 relate to Stage V agricultural and forestry tractors (Table 5.6).

Table 5.6 Overview of EU emission directives relevant for diesel fuelled non-road machinery.

Stage	**Engine size**	**CO**	**VOC**	**NO_x**	**$VOC+NO_x$**	**PM**	**Diesel machinery**			**Tractors**	
								Impl. date		**EU**	**Impl.**
	[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 revises Article 19 in 167/2013 to include Stage V limits as described in 2016/1628.

Table 5.7 Overview of the EU emission directives relevant for gasoline fuelled non-road machinery.

	Category	Engine size [ccm]	CO [g/kWh]	HC [g/kWh]	NO_x [g/kWh]	HC+NO_X [g/kWh]	Impl. 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) × $CO^{0.784}$ ≤ 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 1 emission legislation limits for diesel engines, and for 2-stroke and 4-stroke gasoline engines, respectively. The CO and VOC emission limits depend on engine size (kW) and the inserted parameters presented in the calculation formulas in Table 5.8. 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 5.9, the Stage II emission limits are shown for recreational craft. CO and HC+NO_x limits are provided for gasoline engines depending on the rated engine power and the engine type (stern-drive vs. outboard) while CO, HC+NO_x, and particulate emission limits are defined for Compression Ignition (CI) engines depending on the rated engine power and the swept volume.

Table 5.8 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 5.9 Overview of the EU emission directive 2013/53 for recreational craft.

Diesel engines					
Swept Volume, SV l/cyl.	Rated Engine Power, P_N kW	Impl. date	CO g/kWh	HC + NO_x g/kWh	PM g/kWh
SV < 0.9	P_N < 37				
	37 ≤ P_N < 75 (*)	18/1 2017	5	4.7	0.30
	75 ≤ P_N < 3 700	18/1 2017	5	5.8	0.15
0.9 ≤ SV < 1.2	P_N < 3 700	18/1 2017	5	5.8	0.14
1.2 ≤ SV < 2.5		18/1 2017	5	5.8	0.12
2.5 ≤ SV < 3.5		18/1 2017	5	5.8	0.12
3.5 ≤ SV < 7.0		18/1 2017	5	5.8	0.11
Gasoline engines					
Engine type	Rated Engine Power, P_N kW		CO g/kWh	HC + NO_x g/kWh	PM g/kWh
Stern-drive and in-board 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 5.10 Overview of the EU emission directive 2004/26 for railway locomotives and motor cars[11].

	EU directive	Engine size [kW]		CO	HC	NO_x	HC+NO_x	PM	Impl. date
				g/kWh					
Locomotives	2004/26	Stage IIIA							
		130≤P<560	RL A	3.5	-	-	4	0.2	1/1 2007
		560<P	RH A	3.5	0.5	6	-	0.2	1/1 2009
		2000<=P and piston displacement >= 5 l/cyl.	RH A	3.5	0.4	7.4	-	0.2	1/1 2009
	2004/26	Stage IIIB	RB	3.5	-	-	4	0.025	1/1 2012
	2016/1628	Stage V							
		0<P	RLL-v/c-1	3.5	-	-	4	0.025	2021
Motor cars	2004/26	Stage IIIA							
		130<P	RC A	3.5	-	-	4	0.2	1/1 2006
	2004/26	Stage IIIB							
		130<P	RC B	3.5	0.19	2	-	0.025	1/1 2012
	2016/1628	Stage V							
		0<P	RLR-v/c-1	3.5	0.19	2	-	0.015	2021

Aircraft engine emissions of NO_x, CO, VOC and smoke are regulated by ICAO (International Civil Aviation Organization). The engine emission certification standards are contained in Annex 16 — Environmental Protection, Volume II — 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

[11] Rail cars: Self-propelled on-track vehicles specifically designed to carry goods and / or passengers. Locomotives: Self-propelled pieces of on-track equipment designed for moving or propelling cars that are designed to carry freight, passengers and other equipment, but which themselves are not designed or intended to carry freight, passengers (other than those operating the locomotive) or other equipment.

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 increasingly strengthened emission regulations fall in five categories depending on date of manufacture of the first individual production model and production date of the individual engine. The emission limits are further grouped into engine pressure ratio intervals and levels of rated engine thrust.

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.

A further description of the technical definitions in relation to engine certification, the emission limit values for NO_x, CO, HC and smoke as well as actual engine exhaust emission measurement data can be found in the ICAO Engine Exhaust Emission Database. The latter database is accessible from "http://www.easa.europa.eu" hosted by the European Aviation Safety Agency (EASA)**.**

On 8 February 2016, at the tenth meeting of the International Civil Aviation Organization (ICAO) Committee for Environmental Protection (CAEP) a performance standard was agreed for new aircraft that will mandate improvements in fuel efficiency and reductions in CO_2 emissions. The standards will on average require a 4 % reduction in the cruise fuel consumption of new aircraft starting in 2028 compared to 2015 deliveries, with the actual reductions ranging from 0 to 11 %, depending on the maximum takeoff mass (MTOM) of the aircraft (ICCT, 2017).

The CO_2 certification standards are contained in a new Volume III - CO_2 Certification Requirement - to Annex 16 of the Convention on civil aviation (ICAO, 2017).

Embedded applicability dates are:

- **Subsonic jet aeroplanes**, including their derived versions, of greater than 5 700 kg maximum take-off mass for which the application for a type certificate was submitted on or after 1 January 2020, except for those aeroplanes of less than or equal to 60 000 kg maximum take-off mass with a maximum passenger seating capacity of 19 seats or less;
- **Subsonic jet aeroplanes**, including their derived versions, of greater than 5 700 kg and less than or equal to 60 000 kg maximum take-off mass with a maximum passenger seating capacity of 19 seats or less, for which the application for a type certificate was submitted on or after 1 January 2023;
- **All propeller-driven aeroplanes**, including their derived versions, of greater than 8 618 kg maximum take-off mass, for which the application for a type certificate was submitted on or after 1 January 2020;

- **Derived versions of non-CO_2-certified subsonic jet aeroplanes** of greater than 5 700 kg maximum certificated take-off mass for which the application for certification of the change in type design is submitted on or after 1 January 2023;
- **Derived versions of non-CO_2 certified propeller-driven aeroplanes** of greater than 8 618 kg maximum certificated take-off mass for which the application for certification of the change in type design is submitted on or after 1 January 2023;
- **Individual non-CO_2-certified subsonic jet aeroplanes** of greater than 5 700 kg maximum certificated take-off mass for which a certificate of airworthiness is first issued on or after 1 January 2028; and
- **Individual non-CO_2-certified propeller-driven aeroplanes** of greater than 8 618 kg maximum certificated take-off mass for which a certificate of airworthiness is first issued on or after 1 January 2028.

Marpol 73/78 Annex VI agreed by IMO (International Maritime Organisation) concerns the control of NO_x emissions (Regulation 13 plus amendments) and SO_x and particulate emissions (Regulation 14 plus amendments) from ships (DNV, 2009). 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 new built ships larger than 400 GT (Lloyd’s Register, 2012).

EEDI is a design index value that expresses how much CO_2 is produced per work done (g CO_2/tonnes/nautical mile). At present, the IMO EEDI scheme comprises the following ship types; bulk carriers, gas carriers, tankers, container ships, general cargo ships, refrigerated and combination cargo carriers.

The EEDI percentage reductions that need to be achieved for new built ships relative to existing ships, are shown in Table 5.11 stratified according to ship type and dead weight tonnes (DWT) in the temporal phases (new built year in brackets); 0 (2013-14), 1 (2015-19), 2 (2020-24) and 3 (2025+).

Table 5.11 EEDI percentage reductions for new built ships relative to existing ships.

Ship type	Size	Phase 0	Phase 1	Phase 2	Phase 3
		1/1-2013 to 31/12-2014	1/1-2015 to 31/12-2019	1/1 2020 to 31/12-2024	1/1-2025 onwards
Bulk carrier	20 000 DWT and above	0	10	20	30
	10 000 – 20 000 DWT	n/a	0 -10*	0-20*	0-30*
Gas carrier	10 000 DWT and above	0	10	20	30
	2 000 – 10 000 DWT	n/a	0-10*	0-20*	0-30*
Tanker	20 000 DWT and above	0	10	20	30
	4 000 – 20 000 DWT	n/a	0-10*	0-20*	0-30*
Container ship	15 000 DWT and above	0	10	20	30
	10 000 – 15 000 DWT	n/a	0-10*	0-20*	0-30*
General cargo ship	15 000 DWT and above	0	10	15	30
	3 000 – 15 000 DWT	n/a	0-10*	0-15*	0-30*
Refrigerated cargo carrier	5 000 DWT and above	0	10	15	30
	3,000 – 5 000 DWT	n/a	0-10*	0-15*	0-30*
Combination carrier	20 000 DWT and above	0	10	20	30
	4 000 – 20 000 DWT	n/a	0-10*	0-20*	0-30*

It is envisaged that also ro-ro (roll on – roll off) cargo, ro-ro passenger and cruise passenger ships will be included in the EEDI scheme in the near future.

5.2.3 Emission factors

The CO_2 emission factors are country-specific and come from Fenhann and Kilde (1994). For LNG, however, the CO_2 emission factor is estimated by the Danish gas transmission company, Energinet.dk, based on gas analysis data. For LPG, the emission factor source is EMEP/EEA (2019).

The N_2O emission factors are taken from the EMEP/EEA guidebook; EMEP/EEA (2019) for road transport and non-road machinery, and IPCC (2006) for national sea transport and fisheries as well as aviation.

In the case of military ground equipment, due to lack of fleet/activity and emission data, aggregated CH_4 emission factors for gasoline and diesel are derived from total road traffic emission results. For piston engine aircraft using aviation gasoline, the CH_4 emission factors are derived from VOC factors from EMEP/EEA (2019) and a NMVOC/CH_4 split, based on expert judgement.

The CH_4 emission factors for railways are derived from specific Danish VOC measurements from the Danish State Railways (Mølgård, 2020) and a NMVOC/CH_4 split, based on expert judgement.

For agriculture, forestry, industry, household gardening and recreational craft, the VOC emission factors are derived from various European measurement programs; see IFEU (2004, 1999) and Winther et al. (2006). The NMVOC/CH_4 split is taken from IFEU (1999).

For national sea transport and fisheries, the VOC emission factors come from The Ministry of Transport (2015). Specifically for the ferries used by Mols Linjen, VOC emission factors are provided by Kristensen (2008), originating from engine measurements (Hansen et al., 2004; Wismann, 1999; PHP, 1996). Complimentary VOC emission factor data for new ferries is provided by Kristensen (2013) and engine load specific VOC emission data is provided by Nielsen (2019).

For the LNG fueled ferry in service on the Hou-Sælvig route, CH_4 and NMVOC emission factors are taken from Bengtsson et al. (2011).

For ship diesel and residual oil fuelled engines, VOC/CH_4 splits are taken from EMEP/EEA (2019).

The source for CH_4 emission factors for aircraft main engines (jet fuel) is the EMEP/EEA guidebook (EMEP/EEA, 2019). For aircraft auxiliary power units (APU), ICAO (2011) is the data source for VOC emission factors and VOC/CH_4 splits for aviation are taken from EMEP/EEA (2019).

5.2.4 Calculation method

Air traffic

For aviation, the emissions are calculated as the product of the projected fuel consumption and emission factors derived from flight activity statistics (see paragraph 5.2.1). The calculations are made separately for domestic and international flights and a furthermore split into LTO and cruise. For more details regarding the calculation procedure, please refer to Nielsen et al. (2021).

Non-road working machinery and recreational craft

The fuel consumption and emissions are calculated as the product of the number of engines, annual working hours, average rated engine size, load factor and fuel consumption / emission factors. 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 and IV, transient operational effects are also considered by using average transient factors. For more details regarding the calculation procedure, please refer to Nielsen et al. (2021).

National sea transport

The fuel consumption and emissions for Danish ferries are calculated bottom up as the product of the number of round trips, sailing time per round trip, engine size, load factor, and fuel consumption / emission factors. For other national sea transport, fuel based calculations are made using fuel-related emission factors and fuel consumption estimates, derived as explained in Nielsen et al. (2021).

Other sectors

The emissions for fishing vessels, military and railways are estimated with the simple method using fuel-related emission factors and fuel consumption from Denmark's Energy and Climate Outlook – DECO21 (DEA, 2021).

Subsectoral fuel transferals between DECO21 and the emission projections

The DECO21 fuel totals for the CRF sectors 1A2 (manufacturing industries), 1A4a (commercial / institutional), 1A4b (residential) and 1A4c (agriculture / forestry / aquaculture / fisheries) are used in the emission projections as totals for these sectors in order to obtain a fuel balance. However, based on bottom up calculations for non road mobile machinery, DCE makes a different split into non road mobile and stationary fuel consumption compared to the sub-sectoral fuel splits also provided by DEA in the energy forecast.

5.3 Fuel consumption and emission results

An overview of the emission results is given in Table 5.12 for all mobile sources in Denmark.

Table 5.12 Overview of emission results for all mobile sources in Denmark.

		1990	2005	2015	2019	2020	2025	2030	2035	2040
CO_2, kt	Industry - Other (1A2g)	629	720	637	596	524	504	449	448	449
	Civil Aviation national (1A3a)	224	150	139	150	146	154	163	166	168
	Road - Cars (1A3bi)	5017	6527	6443	6720	7012	6706	6017	5166	4128
	Road - Light duty trucks (1A3bii)	1460	2154	1694	1625	1997	1860	1620	1372	1089
	Road - Heavy duty vehicles (1A3biii)	2833	3591	3424	3678	3071	2916	2650	2587	2659
	Road - Motorcycles and mopeds (1A3biv)	46	71	72	75	51	51	49	48	46
	Railways (1A3c)	297	232	248	224	209	183	60	60	60
	Navigation (1A3d)	714	724	564	514	563	538	511	492	480
	Commercial/institutional (1A4a)	45	88	84	79	20	19	0	14	17
	Residential (1A4b)	19	25	24	22	20	17	16	15	15
	Agriculture/forestry/fisheries (1A4c)	1928	1587	1401	1288	1168	990	890	840	806
	Other (1A5b, military mobile)	119	271	98	101	101	101	101	101	101
	Other (1A5b, recreational craft)	48	103	97	97	97	97	97	97	97
	Navigation international (1A3d)	3005	2352	2293	2215	2223	2223	2223	2223	2223
	Civil Aviation international (1A3a)	1755	2559	2615	3098	3009	3129	3240	3257	3270
		1990	2005	2015	2019	2020	2025	2030	2035	2040
CH_4, t	Industry - Other (1A2g)	59	41	25	19	11	9	8	8	8
	Civil Aviation national (1A3a)	3	2	1	1	2	2	2	2	2
	Road - Cars (1A3bi)	2557	915	280	222	219	194	180	161	132
	Road - Light duty trucks (1A3bii)	198	106	16	8	8	5	4	3	2
	Road - Heavy duty vehicles (1A3biii)	290	330	66	46	38	33	36	39	42
	Road - Motorcycles and mopeds (1A3biv)	89	116	84	75	52	48	45	41	37
	Railways (1A3c)	12	9	5	3	0	0	0	0	0
	Navigation (1A3d)	15	17	32	34	407	407	406	406	406
	Commercial/institutional (1A4a)	24	68	34	30	0	0	0	0	0
	Residential (1A4b)	37	45	17	16	15	12	11	10	10
	Agriculture/forestry/fisheries (1A4c)	265	122	99	76	32	26	23	21	20
	Other (1A5b, military mobile)	5	12	2	3	3	3	3	3	3
	Other (1A5b, recreational craft)	77	62	7	7	6	5	5	5	5
	Navigation international (1A3d)	64	55	57	57	58	59	60	60	60
	Civil Aviation international (1A3a)	6	8	9	12	11	12	12	12	12
		1990	2005	2015	2019	2020	2025	2030	2035	2040
N_2O, t	Industry - Other (1A2g)	25	30	28	28	25	25	23	23	23
	Civil Aviation national (1A3a)	10	8	7	7	8	8	9	9	9
	Road - Cars (1A3bi)	180	229	173	153	163	150	136	121	102
	Road - Light duty trucks (1A3bii)	10	60	54	47	56	52	48	42	34
	Road - Heavy duty vehicles (1A3biii)	101	45	194	238	201	220	238	258	273
	Road - Motorcycles and mopeds (1A3biv)	1	1	1	1	1	1	1	1	1
	Railways (1A3c)	9	7	8	7	7	6	2	2	2
	Navigation (1A3d)	18	18	14	13	18	18	18	18	18
	Commercial/instutional (1A4a)	1	2	2	2	1	1	0	1	1
	Residential (1A4b)	0	0	0	0	0	0	0	0	0
	Agriculture/forestry/fisheries (1A4c)	65	59	58	55	50	43	39	38	36
	Other (1A5b, military mobile)	4	7	4	4	4	4	4	4	4
	Other (1A5b, recreational craft)	1	3	4	4	4	4	4	4	4
	Navigation international (1A3d)	76	59	58	56	56	56	56	56	56
	Civil Aviation international (1A3a)	59	87	89	103	100	104	108	109	109
		1990	2005	2015	2019	2020	2025	2030	2035	2040
CO_2-eq., kt	Industry - Other (1A2g)	638	730	646	605	532	511	456	455	456
	Civil Aviation national (1A3a)	227	153	141	152	149	157	166	168	171
	Road - Cars (1A3bi)	5134	6618	6502	6771	7066	6755	6062	5206	4162
	Road - Light duty trucks (1A3bii)	1468	2175	1711	1639	2014	1876	1635	1385	1099
	Road - Heavy duty vehicles (1A3biii)	2871	3613	3483	3750	3132	2983	2722	2665	2742
	Road - Motorcycles and mopeds (1A3biv)	49	74	74	77	53	52	51	49	48
	Railways (1A3c)	300	234	251	226	211	185	61	61	61
	Navigation (1A3d)	720	730	569	519	578	554	527	507	495
	Commercial/institutional (1A4a)	46	91	85	80	20	19	0	14	17
	Residential (1A4b)	20	27	24	22	20	18	16	15	15
	Agriculture/forestry/fisheries (1A4c)	1954	1607	1421	1307	1183	1003	902	852	817
	Other (1A5b, military mobile)	120	273	100	102	102	102	102	102	102
	Other (1A5b, recreational craft)	50	105	99	99	98	98	98	98	98
	Navigation international (1A3d)	3029	2371	2312	2233	2241	2241	2241	2241	2241
	Civil Aviation international (1A3a)	1773	2585	2641	3129	3039	3160	3272	3290	3303

5.3.1 Road transport

The total CO_2 emissions decrease is expected to be 35 % from 2020-2040. Passenger cars have the largest fuel consumption share followed by heavy duty vehicles, light commercial vehicles, buses and 2-wheelers in decreasing order, see Figure 5.3.

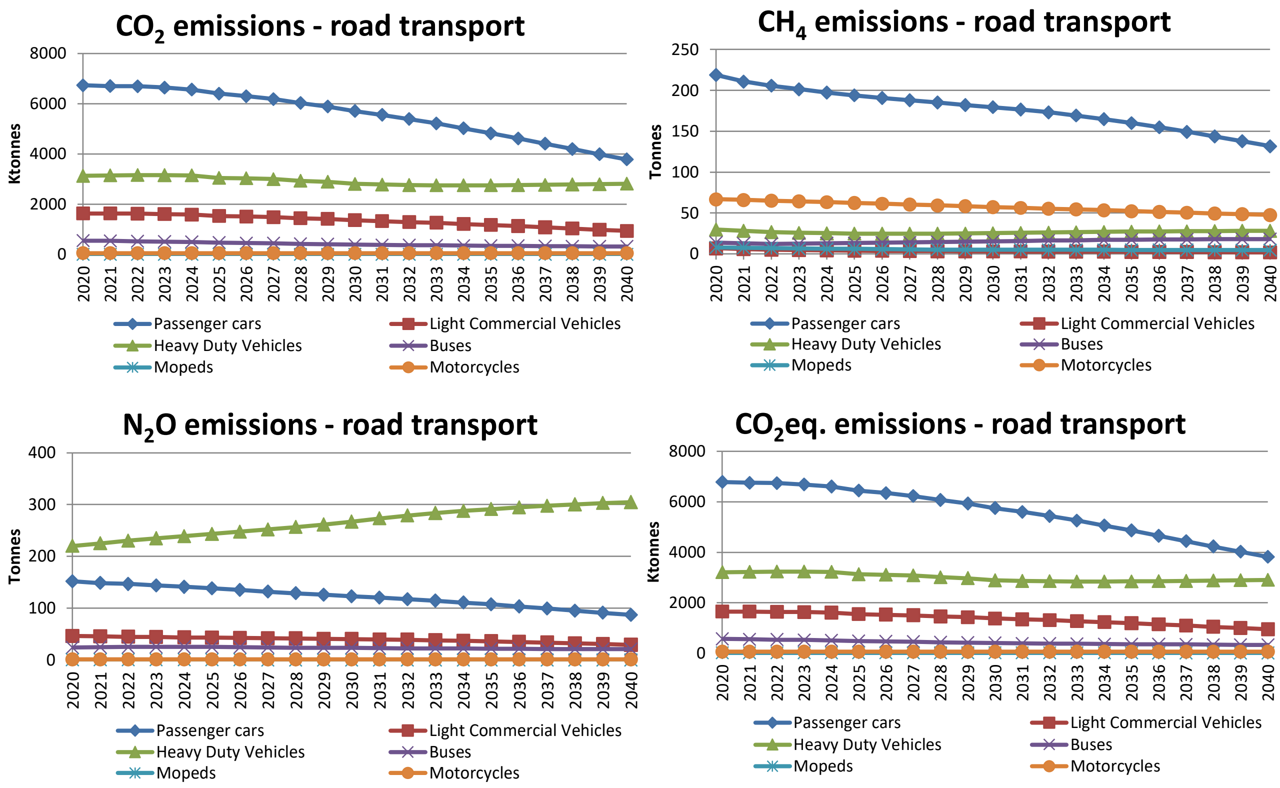

Figure 5.3 CO_2, CH_4, N_2O and CO_{2e} emissions from 2019-2040 for road traffic.

The majority of the CH_4 and N_2O emissions from road transport come from gasoline passenger cars (Figure 5.3). The CH_4 and N_2O emissions decrease by 32 % and 0 %, respectively, from 2020 to 2040.

5.3.2 Other mobile sources

The development in CO_2 emissions for other mobile sources, see Figure 5.4, corresponds with the development in fuel consumption. Agriculture / forestry / fisheries (1A4c) is by far the largest source of CO_2 emissions followed by Navigation (1A3d) and Industry (1A2g). Minor CO_2 emission contributing sectors are Commercial / institutional (1A4a), Other (1A5), Domestic aviation (1A3a), Railways (1A3c) and Residential (1A4b).

Agriculture / forestry / fisheries (1A4c) is the most important source of N_2O emissions, followed by Industry (1A2g) and Navigation (1A3d). The emission contributions from Railways (1A3c), Commercial / institutional (1A4a) and Residential (1A4b) are small compared to the overall N_2O total for other mobile sources.

The majority of the CH_4 emissions comes from Navigation (1A3d). Only small emission contributions are noted for the remaining other mobile sectors.

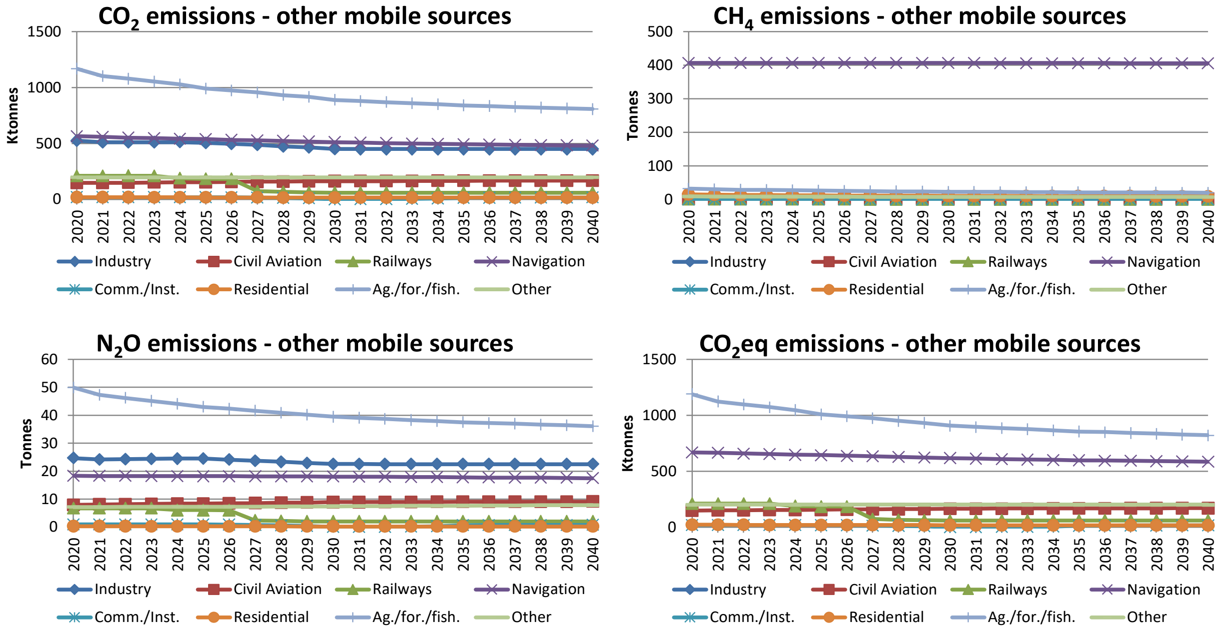

Figure 5.4 CO_2, CH_4, N_2O and CO_{2e} emissions from 2020-2040 for other mobile sources.

5.4 Model structure for DCE transport models

More detailed emission models for transport comprising road transport, air traffic, non-road machinery and sea transport have been developed by DCE. The emission models are organised in databases. The basis is input data tables for fleet and operational data as well as fuel sale figures. Output fuel consumption and emission results are obtained through linked database queries.

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6 Agriculture

The emission of greenhouse gases from the agricultural sector includes the emissions of methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). The emission is mainly related to the livestock production and includes CH_4 emission from enteric fermentation and manure management as well as N_2O emission from manure management and agricultural soils. Furthermore, minor CH_4 and N_2O emissions are estimated from burning of straw on fields. The CO_2 emission from the agricultural sector covers emissions from liming, urea applied to soils and use of inorganic N fertiliser.

It must be noted that CO_2 removals / emissions from agricultural soils are not included in the agricultural sector. According to the IPCC guidelines, these removals / emissions should be included in the LULUCF sector (Land-Use, Land-Use Change and Forestry). The same comment applies to the emissions related to agricultural machinery (tractors, harvesters and other non-road machinery); these emissions are included under mobile combustion.

Regarding the environmental regulation for the agricultural production, it has until now primarily focused on the ammonia emission and nitrogen losses to the aquatic environment. However, improvements of the nitrogen utilization and subsequent decrease in nitrogen losses will indirectly reduce the greenhouse gas emission, because changes in nitrogen also affect the emission of nitrous oxide. Continuous changes in allocation of housing types and the enlargement of the biogas production, influences the management of animal manure and thus also affect the methane emission.

The expectations to the livestock production and the agricultural area is based on estimates provided by University of Copenhagen, Department of Food and Resource Economics (IFRO). The projection also take into account the effect from emission reducing technologies, which is based on estimates made by SEGES (agricultural advisory company).

The current projection takes into account the elements included in the Political agreements and regulation initiated or decided until December 2021 (so called “frozen policy” or projection “with existing instruments”). For this projection, the Agreement on the Green Transition for Danish Agriculture (AGTDA, 2021) is taken into account for measures, which can be considered as frozen policy. This means that the following measures are taken into account: removal of organic soils as cultivated area, lower nitrogen quota for cultivated organic soils, lower nitrogen quota for §3 areas, increased areas with perennial grass and fallow and extended hectare with catch crops. The initiatives mentioned have an impact, which lead to lowering the total nitrogen supply of the agricultural land and furthermore to a decrease in the N leaching. For farmers with animal production, agreements on frequent removal of slurry from swine housings and an increase in the content of fatty acids in fodder for dairy cattle, has been taken into account.

The future biogas production is based on a projection provided by the Danish Energy Agency (DEA, 2021).

6.1 Projected agricultural emission 2021 - 2040

The latest official reporting of emissions includes time series until 2020 for all emission sources. The development of agricultural greenhouse gases from 1990 to 2020 (Table 6.1) shows a decrease from 13.3 million tonnes CO_2 equivalents to 11.3 million tonnes CO_2 equivalents, which correspond a 16 % reduction. In the current projection, based on the assumptions provided, the emission decreases by 13 % from 2020 to 2040, and thus the total emission is estimated to 9.8 million tonnes CO_2 equivalents by 2040. The development towards lower total greenhouse gas emissions are particularly driven by an expected decrease of CH_4 and N_2O emission from manure management due to an expansion of the biogas production and frequent removal of slurry from swine housings. Furthermore, the emission decrease is also caused by a lower consumption of inorganic fertiliser due to a requirement to higher utilisation of nitrogen content in animal manure. Another explanation is also the regulation regarding lower N supply for organic soils and §3 areas and an increase in areas with grass outside rotation and fallow. The last explanation for the emission decrease, which have to be mentioned, is a reduction of the cultivation of organic soils and a lower emission from N-leaching caused by the catch crop area.

Table 6.1 Historic and projected emission from the agricultural sector given in CO_2 equivalents.

Kt CO_2 equivalents	1990	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
Enteric fermentation	4 039	3 631	3 483	3 631	3 667	3 680	3 742	3 802	3 942	3 874	3 798
Manure management	2 822	3 319	3 478	3 120	2 960	2 871	2 759	2 320	2 041	1 932	1 791
Agricultural soils	5 860	4 649	4 255	4 159	4 285	4 458	4 250	4 091	3 972	3 956	3 962
Field burning of agricultural residue	3	4	5	3	4	5	4	4	4	4	4
Liming	565	261	220	153	166	250	218	214	209	208	207
Urea application (CO_2 emission)	15	2	0	1	1	1	1	1	1	1	1
Other carbon-containing fertilisers	33	5	1	2	9	4	3	3	3	3	3
Total	13 338	11 871	11 443	11 069	11 092	11 268	10 976	10 435	10 173	9 979	9 767

6.2 Comparison with previous projection

The emission given in CO_2 equivalents has increased up to 3 % in 2021-2024 and decreased up to 7 % for the period 2025-2040 by comparing the current projection with the latest provided greenhouse gas projection (Nielsen et al., 2021a), Figure 6.1 shows the emission trend for CH_4 and N_2O for the current projection compared with the latest projection. For CH_4, the emission is almost on the same level in 2021-2022 compared to the latest projection, while it is lower for the years 2023-2040. This is mainly due to a change in the number of animals and inclusion of frequent removal of slurry from swine housings. The N_2O emission is increased for all years 2021-2040 in the current projection compared to the latest projection and this is mainly due to an increase of the emission from crop residue, which is also the case for the historical emission inventory due to adjusted calculation because of updated parameters and including emission from catch crops. Figure 6.1 shows that no significant recalculation has taken place for CH_4 emission for the historical years 1990-2019. However, an increase in the emission of N_2O of 5-7 % due to update of the calculation method and inclusion of emission from catch crops is observed.

Some of the changes of the emission trend for the current projection are related to update of the latest historical year, from 2019 to 2020. The yearly update can for some emission sources have a particularly impact for the projected emission trend, because the assumption is based on an interpolation between 2040 and the latest historical year.

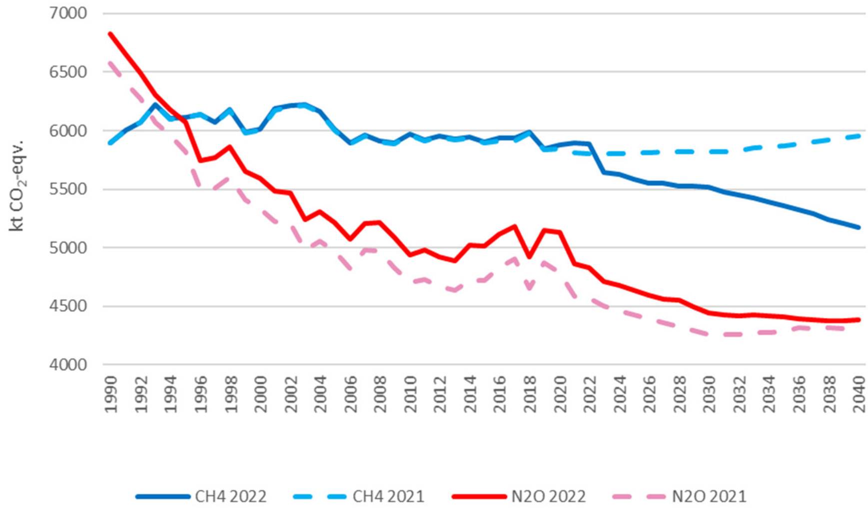

Figure 6.1 Projection 2022 compared with projection 2021.

The CH_4 emission is 1-13 % lower in all years 2021-2040 compared to the previous projection. Part of the lower emission can be explained by a decrease in the number of cattle due to an updated projection from IFRO (Jensen, 2022) and lower emission of enteric fermentation from dairy cattle due to an updated projection of Ym from DCA (Lund et al., 2021). However, the predominant explanation of a lower CH_4 emission compared to the 2021 projection, is caused by a significant change in assumption of share of slurry in swine production, which is frequently removed from the housings. More frequently removal from animal housing leads to a lower methane emission in housing expressed in the calculation by a lower MCF – methane conversion factor, which decreases significantly from 2023 and forward. This decrease in 2023 and forward is due to expected implementation of requirement for farmers to reduce storage time of slurry inside housings for fattening pigs and newly built housings for sows and weaners.

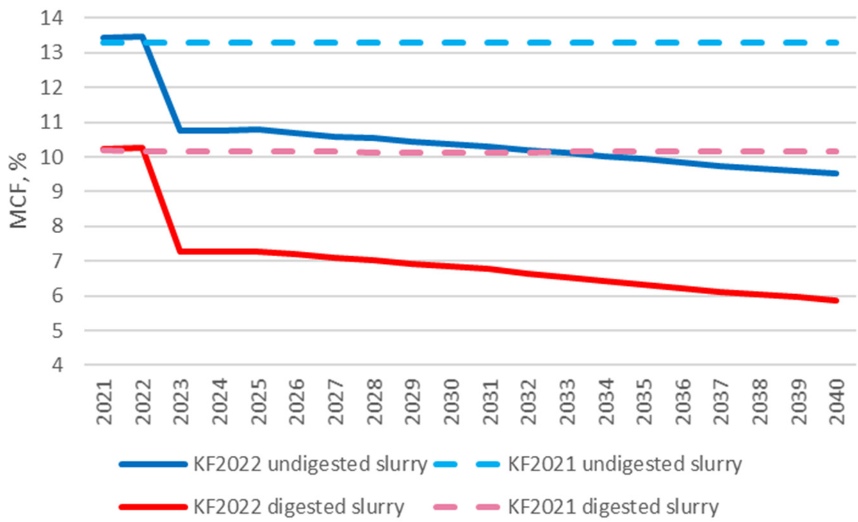

Figure 6.2 MCF for undigested and digested swine slurry in current (KF2022) and latest projection (KF2021).

Compared to the previous projection 2021, the current projected N_2O emission is 1-6 % higher for all years 2021-2040.

The predominant change in emission of N_2O between the current projection and the latest projection is change in the calculation of emission from crop residue, which now includes emission from catch crops. Changes in the number of animals and distribution in housing types based on updated projections from IFRO (Jensen, 2022) and SEGES (Hansen, 2021, Freudendal, 2021), respectively, also have an impact on the higher emission of N_2O in the current projection.

6.3 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 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). Thus, the same database setup is used, as well as the same estimation approach and the same emission factors.

The main part of the emissions is related to the livestock production and thus the expectations to the development in the number of livestock are a key element and have a substantial impact on the emission. The assumptions related to the expected development on the livestock production and the agricultural area are based on estimates provided by IFRO by using a model called AGMEMOD (AGriculture MEmber states MODelling).

The AGMEMOD model is an econometric, dynamic, multi-product partial equilibrium model, which can be used to provide projections and simulations. The model follows the market for agricultural products such as cereals, potatoes, protein products, milk and meat and the flows between countries. The model does not represent a closed economy, but the concept of key markets and key prices has been introduced in order to take into account the influence of other member states on a given country market. For more information and a description of the AGMEMOD model, please refer to Jensen (2017).

Increasing demands to reduce unwanted environmental effects of the livestock production has led to additional legislation regarding approvals and establishment of new animal houses with focus on ammonia reducing technologies. The current projection includes an increase in the uptake of ammonia reducing technologies, which has an indirect impact on N_2O emissions, as well as on CH_4 emissions. In the current projection, ammonia reducing technology includes acidification of slurry (housing, storage and application), cooling of manure in housing, air cleaning in housing, heat exchanger for poultry housing, manure removal in mink housing two times a week, and slurry delivered to biogas plants.

The assumptions regarding the expansion and development of emission reducing technologies in livestock production are based on estimations made by SEGES (Hansen, 2021, Freudendal, 2021). The expectations to expansion of the biogas production are based on assumptions provided by DEA - the Danish Energy Agency.

Measurements to reduce CH_4 emissions has also been taken in to account, i.a. frequent removal of slurry from swine housings and higher ratio of fatty acids in fodder for dairy cattle. Frequent removal of slurry from housings influences the estimation of MCF, while higher ratio of fatty acids in the fodder influences the estimation of Ym.

6.4 Livestock production

For cattle, swine, hens and broilers, the number of animals is based on the model AGMEMOD (Jensen, 2022). 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 the production of cattle, swine and fur animals. Therefore, the number of animals 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 of developing a COVID-19 variant, the government required mink farmers 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, hence the production is projected to be only 10 % of the production in 2020.

6.4.1 Cattle

In AGMEMOD, the projection of the number of dairy cattle is based on the projection of milk production, which in AGMEMOD is based on the projection of milk yield, milk prices and production costs (Jensen, 2022).

The milk yield and the N-excretion are closely related. Increasing milk yield leads to higher need for feed intake, which results in an increase of N-excretion. The estimation of feed intake, N-excretion and methane conversion factor (Ym) for dairy cattle is provided by DCA - Danish Centre for Food and Agriculture (Lund, 2021; Lund et al., 2021). The average milk yield for large breed is expected to increase from 10 900 l/cow/year in 2020 to 13 700 l/cow/year in 2040, which correspond to a rise of 25 %. This development corresponds to an N-excretion in 2020 for large breed cattle at 161 kg N, increasing to 185 kg N in 2040.

For the estimation of Ym, a higher ratio of fatty acids in fodder for dairy cattle from the year 2025 and onwards is taken into account. Given in the Agreement on the Green Transition for Danish Agriculture (AGTDA, 2021), it is expected that the farmers will reduce the emissions of GHG and one of the used methods is by increasing the ratio of fatty acids in the fodder. The same is not allowed for organic farmers (the used high ratios of fatty acids) and thus, Ym used in the projection calculations is therefore a weighted value of Ym for fodder with high fatty acids and Ym with a basic amount of fatty acid given in Lund (2021). Equation for weighted Ym:

$$Ym_{weigthed} = Ym_{Basic} \cdot S_O + Ym_{High} * (1 - S_O)$$

Where:

$Ym_{weighted}$	= weighted Ym of Ym for fodder with high fatty acids and Ym with basic amount of fatty acid
Ym_{Basic}	= Ym for fodder with basic amount of fatty acid (Lund, 2021)
Ym_{High}	= Ym for fodder with high amount fatty acid (Lund, 2021)
S_O	= share of organic dairy cattle (13.9 % for all years 2021-2040)

Table 6.2 Number of dairy cattle and milk yield - figures used in the projection to 2040.

Dairy cattle	2020	2021	2025	2030	2035	2040
No. of dairy cattle, 1000 unit	567	563	572	591	567	543
Milk yield, kg milk per cow per year						
Large breed	10 948	11 088	11 648	12 316	13 038	13 724
Jersey	7 545	7 650	8 068	8 530	9 031	9 506
N-excretion, kg per year						
Large breed	161	162	167	173	180	185
Jersey	131	132	137	142	148	153
Feed intake, kg dm per year						
Large breed	8 246	8 321	8 619	8 968	9 345	9 703
Jersey	6 713	6 783	7 063	7 362	7 685	7 991
Ym, %						
Large breed	5.76	5.75	5.50	5.46	5.42	5.39
Jersey	5.80	5.80	5.56	5.53	5.49	5.46

* weighted Ym for fodder with basic amount and high amount of fatty acid.

For non-dairy cattle, historic normative data for N-excretion for all cattle subcategories show few changes. In the projection, no significant changes in N-excretion is expected and therefore kept at the same level as in 2020.

6.4.2 Swine

AGMEMOD estimates the number of sows, weaners and fattening pigs based on projections of prices for pig meat and production costs (Jensen, 2022). The number of swine estimated in AGMEMOD is not exactly the same as calculated in the national emission inventory, which partly has to do with the definition of one produced pig. The emission inventory take into account the discarded animals during the slaughtering process. In order to ensure the consistency between the swine production given in the inventory and AGMEMOD's expectations, the projection trend estimated in AGMEMOD is applied. Thus, an increase of production is expected until 2025, thereafter a decrease.

Table 6.3 Number of produced sows, weaners and fattening pigs.

Swine	2020	2021	2025	2030	2035	2040
Trend*						
Sows	100	103	96	88	80	72
Weaners	100	102	101	98	91	84
Fattening pigs	100	112	106	103	95	88
Numbers, millions produced						
Sows	1.05	1.08	1.02	0.93	0.84	0.76
Weaners	33.25	33.87	33.60	32.70	30.18	27.86
Fattening pigs	19.07	21.29	20.19	19.55	18.06	16.69

* Based on AGMEMOD (Jensen, 2022).

The projection of N-excretion for sows, weaners and fattening pigs is based on projections made by DCA (Nørgaard & Hellwing, 2021).

Table 6.4 N-excretion, kg N-excretion.

Swine	2020	2021	2025	2030	2035	2040
Sows	23.84	23.87	24.01	23.87	23.80	23.74
Weaners	0.45	0.45	0.43	0.40	0.38	0.36
Fattening pigs	2.93	2.89	2.75	2.59	2.44	2.29

6.4.3 Housing system

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 regarding animal welfare (space requirement, straw etc.) and environment requirements. 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 twice a week. In 2020, 11 % of mink were in systems where manure is removed twice a week. No production of mink is expected for 2021-2022 due to legislation brought on by COVID-19. For the years 2023-2040, the same distribution of housing systems as for 2020 are used.

6.5 Emission reducing technology

In the historic emission inventory is included reduction from the emission reducing technologies: acidification of slurry, cooling of manure, heat exchanger in broiler housing and frequent removal of manure in mink housings. The inventory also takes into account the reduced emission as a result of slurry delivered to the biogas production.

Other emission reducing technologies, such as air cleaning and frequent removal of slurry from swine housings, are not included in the historical emission inventory due to lack of data. It is expected that the reduction of emission from use of technology will expand in the future, which is mainly caused by the requirements in the Environmental Approval Act for Livestock Holdings (LOV nr. 1057 af 30/06/2020), and therefore also reductions from other emission reducing technologies are included in the projection.

The following technologies are included in the projection; cooling of manure in pig housing, acidification of cattle- and swine manure (housing, storage and application), air cleaning in swine housing, frequent removal of slurry from swine housings, heat exchanger in broiler housing, frequent removal of mink manure from housing (2 x weekly) and slurry acidification in tank / during application of manure. Furthermore, reduction of emission due to slurry delivered to biogas production is taken into account.

6.5.1 Use of environmental technologies

The environmental technologies are closely related to the growth in the 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 (Nielsen et al., 2021b, Annex 3D Chapter 3D-1).

For cattle, the only available technology in housings are, for now, acidification - and the projection of this is made by SEGES (Freudendal, 2021). The projection is used for dairy cattle and heifers.

The projections of distribution of housings with acidification and cooling of manure are based on Hansen (2021) and distribution of housings with air cleaning is based on Wiborg (2022).

Distribution of housings with frequent removal of slurry from the housing is based on an estimation made by MED (2021). In Agreement to the Green Transition for Danish Agriculture (AGTDA, 2021) it is given that slurry from all housings with fattening pigs and all new buildings for sows and weaners from 2023 have to sluice out the slurry every seventh day. Some farmers can get a dispensation from this; hence it is assumed that 10 % of existing housings and 5 % of new build housings get a dispensation. Frequent removal of the slurry is not required if the slurry are acidified. An estimation of the share of newly build housings is estimated by MED (2021). Frequent removal of slurry from swine housing only reduce emission of CH_4.

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 newly built 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 the present level. 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 not greenhouse gasses.

Frequent removal of slurry is by legislation made mandatory from 2023 for housings with fattening pigs and it is expected to be performed in 87-89 % of the housings in the period 2023-2040. For sows and weaners, the frequent removal is made mandatory in newly built housings and the distribution is expected to increase to around 60 % in 2040.

Acidification in housings for cattle is expected to continue at the same level in the future as at the present level.

Table 6.5 Emission reducing technology included for swine and cattle production, %.

Cooling of manure	2020	2021	2023	2025	2030	2035	2040
Sows	7	11	17	24	40	55	70
Weaners	5	8	13	18	30	43	55
Fattening pigs	3	5	8	12	20	28	35
Acidification in housing							
Dairy cattle	3	3	4	4	4	4	4
Heifer	1	1	1	1	2	2	2
Sows	3	3	3	3	4	4	4
Weaners	1	1	2	2	2	2	2
Fattening pigs	2	2	3	3	5	5	5
Air cleaning							
Sows	0	1	2	3	5	3	0
Weaners	0	0	0	0	0	0	0
Fattening pigs	0	1	2	2	4	2	0
Frequent removal of slurry							
Sows	0	0	1	8	26	44	62
Weaners	0	0	2	9	27	46	64
Fattening pigs	0	0	88	87	87	88	89

In 2020, almost 90 % of broiler housings have heat exchangers installed and it is expected that this will increase to 100 % by 2030 (Jensen, 2021, Pers. Comm.). As mentioned, the mink production is non-existing in 2021-2022, but a small production is expected from 2023 and it is expected that 90 % of this will remove the manure twice a week.

The 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 6.6 Emission reducing technology included for poultry and mink production, percentage of production.

Heat exchanger	2020	2030	2040
Broilers	91	100	100
Removal of manure - 2 times weekly			
Mink	18	90	90
Acidification during application			
Cattle manure	8	12	16
Swine manure	1	2	4

6.5.2 Emission reduction effect – NH_3 and CH_4

The reduction factors for both ammonia emission and methane emission used in the projection are given in Table 6.7. The CH_4 reduction from cooling of manure in housing and acidification of manure is based on a report provided by AgroTech (Hansen et al., 2015). A national model has been developed to estimate national methane conversion factors (MCF) for untreated and biogas treated slurry (Mikkelsen et al., 2016). The model is updated in 2021 (Nielsen et al., 2021c). Frequent removal of slurry in swine housings is incorporated in the estimation of MCF.

NH_3 reduction due to the use of acidification, heat exchangers used in broiler housings and frequent removal of mink manure, is based on the List of Environmental Technologies (DEPA, 2021), which contains technologies that through tests have been documented to be environmentally efficient and operationally in practice.

Reduction of NH_3 emission as a result of air cleaning, is based on data from the analyzed environmental approvals. The approvals include information on NH_3 reduction factors for each farm depending on the volume of air exchange in housing. A weighted average of the NH_3 reduction factor is used, which take into account the distribution of the livestock production.

Table 6.7 Reducing factor of NH_3 and CH_4.

Technology	Location	Category	Compound	Reduction, %	Reference
Cooling of manure	Housing	Swine	NH_3	20	DEPA**
	Housing/storage	Swine	CH_4	20	Hansen et al., 2015
Acidification	Housing	Cattle	NH_3	50	DEPA**
	Housing	Swine	NH_3	64	DEPA**
	Storage	Cattle	NH_3	49	DEPA**
	Storage	Swine	NH_3	40	DEPA**
	Housing/storage	Cattle/swine	CH_4	60	Hansen et al., 2015
	Application	Cattle	NH_3	49	DEPA**
	Application	Swine	NH_3	40	DEPA**
Air cleaning	Housing	Sows	NH_3	61	Environmental approvals*
	Housing	Weaners	NH_3	54	Environmental approvals*
	Housing	Fattening pigs	NH_3	56	Environmental approvals*
Biogas treatment	Large-scale or farm-scale biogas plants	Cattle	CH_4	36-50	Based on results from the Danish biogas model (Nielsen et al., 2021c)
		Swine	CH_4	20-38	Do
Heat exchanger	Housing	Broilers	NH_3	30	DEPA**
Removal of slurry – twice weekly	Housing	Mink	NH_3	27	DEPA**

* Based on the review of the register of environmental approvals 2007-2016 (Nielsen et al., 2021b).

**List of Environmental Technologies (DEPA, 2021).

6.5.3 Biogas treatment of animal manure

Biogas treatment leads to a lower CH_4 and N_2O emission from animal manure. In 2020, approximately 8.3 million tonnes slurry were treated in biogas plants, which are equivalent to approximately 14 % of all slurry. Prognoses provided by DEA assume an increase of biogas production on manure based biogas plants from 19.9 PJ in 2020 to 48.7 PJ in 2030. The prognoses shows a decrease in the biogas production from 2030 to 2040 to 42.2 PJ due to uncertainties regarding the subsidy agreement in future.

Data reported from the biogas plants give an overview of the actual amount and different types of biomass used in biogas production in crop season 2015/2016 to 2019/2020 (register of Biomass Input to Biogas production (BIB)). The BIB register does not fully cover all biogas plants but includes the most important biogas producers. DEA estimates that the register covers 80-

90 % of the total biogas production in 2017/2018. However, data in this register can be used to estimate the relation between the biogas production and the amount of slurry delivered to biogas plants. Based on the average relation for 2016-2020 between biogas production and slurry input the amount of slurry, input for the years 2021-2040 is estimated.

It is assumed that cattle slurry accounts for 62 % and swine slurry for 38 %, based on data from the BIB register for 2020.

Table 6.8 Biogas production on manure based biogas plants.

Year	Total biogas production, PJ	Biogas production on manure based biogas plants, PJ	Slurry delivered to biogas plants, M tonnes
2020	21.4	19.9	8.3
2021	30.0	27.0	13.0
2030	51.7	48.7	23.4
2040	40.2	40.2	19.4

A Biogas Task Force set up by the DEA has initiated a number of projects in order to improve the Danish emission inventory regarding the reduction of GHG emissions as a consequence of biogas treated slurry. One of the outcomes of the projects was the estimation of the methane loss from manure management, which reflected the actual Danish agricultural conditions; temperature and livestock housing types (Mikkelsen et al., 2016). The model has been updated in 2021 (Nielsen et al., 2021c) and this national methane conversion factor (MCF) is now used in the Danish GHG emission inventory. The MCF changes from year to year depending on changes in housing type and change in the time that the slurry is in the housings. In the projection, it is assumed that cattle slurry delivered to biogas production reduces the CH_4 emission by approximately 36-50 %. It is assumed that pig slurry delivered to biogas production reduces the CH_4 emission by approximately 20-38 % with increasing effect from 2023 due to an increasing share of slurry, which is frequently removed from the housings.

6.6 Other agricultural emission sources

Besides the livestock production, some emission sources related to cultivation of the agricultural area has a relatively important impact, e.g. the consumption of inorganic nitrogen fertiliser, the area of cultivated organic soils and the nitrogen leaching to the aquatic environment.

6.6.1 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, 2021a), afforestation (Krogh, 2021) and areas 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.

Projection of the area of cultivated organic soils is estimated for 2021-2040 by the Danish Agricultural Agency and it is assumed that this area will decrease by 38 000 ha from 2020 to 2032. From 2033 to 2040, the area of organic soils are assumed to be at the same level as in 2032.

Table 6.9 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, 2021a).
[2] (Krogh, 2021).
[3] (Gyldenkærne, 2021).

6.6.2 Use of inorganic nitrogen fertilisers

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 an 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 a lower total N need.

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 tonnes 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) as 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 the legislation for § 3 areas, a general ban on spraying, fertilising and conversion of §3 protected areas is introduced (Law no. 1057 of 30 / 06 / 2020). In comments to this regulation, it is mentioned that a decrease of 5 800 tonnes N per year is expected and the law enters into force from July 1st 2022.

Due to 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. The 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 areas, areas for Christmas trees and vegetables and fruits. An 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. The increase in the area of perennial grass expects to impact a lower N-leaching from the coast zone by 11 kg per hectare based on estimates provided by the Danish Agricultural Agency.

Table 6.10 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 6.10 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.

6.6.3 Leaching and run off

The N_2O emission from N-leaching and run off is determined based on the amount of N applied to the agricultural soils and are, in the projection, based on the same method as used in the emission inventory. That is, N-leaching in groundwater is based on N applied from manure, grazing, inorganic fertiliser, sludge, other organic fertiliser, crop residue and mineralization multiplied with the average amount of N-leached in historic years (2015-2019). For N-leaching from rivers and estuaries, an average ratio of N in groundwater in 2018-2020 is estimated. The average ratio for rivers is 2.55 and for estuaries 2.21. The projected N-leaching from rivers and estuaries is based on N in groundwater divided with the ratios. N_2O is estimated as in the emission inventory, using the emission factor from IPCC 2006 of 0.0025 kg N_2O–N / kg N from groundwater, rivers and estuaries, respectively.

A reduction of N-leaching due to catch crop and an increased area with perennial grass and fallow is taken into account for the years 2021-2040 (Table 6.11). Estimation of the catch crop area and the expected reduction of N from groundwater is based on information from the Danish Agricultural Agency (DAA, 2021b). The increased area with perennial grass and fallow is based on AGMEMOD (Jensen, 2022) and this area is expected to reduce N in estuaries with 11 kg / ha (DAA, 2021c). Thus, there is projected a total catch crop area of 685 thousand hectare in 2021 increasing to 959 thousand hectare in 2030 / 2040 and a projected increase in the area with perennial grass and fallow of 55 200 ha in 2023, decreasing to 40 400 ha in 2040.

Table 6.11 N in groundwater used to estimate N_2O from leaching and run off.

	2021	2022	2023	2024	2025	2030	2035	2040
N-leaching in groundwater, t N	156 961	156 967	152 515	152 569	151 865	152 092	151 813	152 256
Area with catch crop, ha	685 000	685 000	653 000	653 000	653 000	959 000	959 000	959 000
N-reduction from catch crop, t N	-22 300	-22 300	-21 200	-21 200	-21 200	-30 000	-30 000	-30 000
Adjusted N-leaching in groundwater due to catch crops, t N	134 661	134 667	131 315	131 369	130 665	122 092	121 813	122 256
N-leaching in rivers, t N	52 771	52 774	51 460	51 481	51 205	47 846	47 736	47 910
N-leaching in estuaries, t N	60 991	60 994	59 476	59 500	59 181	55 298	55 172	55 372
Increased area with perennial grass and fallow, ha			55 221	54 644	58 235	57 200	49 556	40 361
N-reduction from perennial grass and fallow, t N			-607	-601	-641	-629	-545	-444
Adjusted N-leaching in estuaries due to perennial grass and fallow, t N	60 991	60 994	58 868	58 899	58 540	54 669	54 627	54 928

6.7 Results

In Table 6.12, the historical greenhouse gas emission 1990-2020 is listed, followed by the projected emissions for 2021-2040. The greenhouse gas emission is expected to decrease from 11.3 million tonnes CO_2 equivalents in 2020 to 9.8 million tonnes CO_2 equivalents in 2040. Thus, a 13 % decrease of GHG emission from the agricultural sector from 2020 to 2040 is expected. The decreased emission is driven by expansion of the biogas production, which leads to a decrease of both the N_2O and CH_4 emission from manure management and frequent removal of slurry from swine housings, which decrease the emission of CH_4.

Besides the biogas production and frequent removal of slurry, the decrease of the emission from 2020 to 2040 also can be explained by lower emission from use of inorganic fertiliser, reduction in the total area of organic soils and lower emission from N-leaching and run off.

Table 6.12 Total historical (1990-2020) and projected (2021-2040) emission, CO_2 e.

CO_{2e} , million tonnes	1990	2000	2020	2021	2025	2030	2035	2040
CH_4	5.90	6.01	5.88	5.90	5.58	5.52	5.36	5.17
N_2O	6.83	5.59	5.13	4.86	4.63	4.44	4.41	4.38
CO_2	0.62	0.27	0.25	0.22	0.22	0.21	0.21	0.21
Agriculture, total	13.34	11.87	11.27	10.98	10.43	10.17	9.98	9.77

6.7.1 CH_4 emission

The overall CH_4 emission has decreased slightly from 236 kt CH_4 in 1990 to 235 kt CH_4 in 2020 but are expected to decrease by 1 % to 207 kt CH_4 in 2040 (Table 6.13). The projection shows an increase in CH_4 emission from the enteric fermentation process, while the CH_4 emission from manure management decreases.

The historical emission related to the enteric fermentation shows a decrease up until 2015, which is due to a fixed EU milk quota. Because of higher milk yield per cow, a lower number of dairy cattle were needed to produce the amount of milk, corresponding to the EU milk quota. The fixed EU milk quota ended in 2015. The development from 2015-2020 shows an increase of CH_4 emission from enteric fermentation caused by a rise in the number of dairy cattle. The AGMEMOD model (Jensen, 2022) indicates that up until 2030, an increase is expected for the number of dairy cattle, but it is also expected to decrease again from 2030 to 2040. The milk production is expected to increase all years up until 2040 (Jensen, 2020). A growing number of dairy cattle, a continued increase in milk yield, followed by an increase of feed intake all leads to an increase of the CH_4 emission from enteric fermentation.

The CH_4 emission from manure management has increased from 1990 to 2020, which is a result of change in housing systems towards more slurry based systems. In the future, the emission from manure management is expected to decrease due to more housing systems with acidification of manure and manure cooling and for swine frequent removal of slurry; further also because of more manure delivered to biogas production. A reduction in the CH_4 emission due to acidification and cooling of manure is not taken into account in the historic emission calculations and legislation on frequent removal of swine slurry will become effective from 2023.

Table 6.13 Historical (1990-2020) and projected (2021-2040) CH_4 emission.

CH_4 emission, kt	1990	2000	2020	2021	2025	2030	2035	2040
Enteric fermentation	161.6	145.2	147.2	149.7	152.1	157.7	155.0	151.9
Manure management	74.2	95.1	87.9	86.0	71.1	62.8	59.2	54.9
Field burning	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Total CH_4, kt	235.9	240.5	235.2	235.8	223.3	220.6	214.3	206.9

Note. The numbers in this table should be multiplied with a GWP value of 25 to calculate the CO_{2e} presented in Table 6.12.

6.7.2 N_2O emission

The historical emission inventory shows a decrease of N_2O emission from 22.9 kt N_2O in 1990 to 17.2 kt N_2O in 2020, corresponding to a 25 % reduction (Table 6.14). The reduction is primarily driven by a decrease in the use of inorganic nitrogen fertilisers as a consequence of improved utilization of nitrogen in manure, forced by environmental requirements. For the projected emission, it is expected to decrease by 15 % until 2040, which leads to a total N_2O emission at 14.7 kt N_2O. The most important reasons for this decreasing emission is first of all a result of the expansion of the biogas production. Furthermore, the decrease is also supported by a lower use of inorganics fertiliser, which is due to a requirement of a higher utilisation rate for the nitrogen content in animal manure, a higher N content in manure because of increasing cattle production and regulation regarding lower N supply for organic soil areas which are vulnerable to high inputs of nitrogen (§3 areas) and increased areas with perennial grass and fallow. Furthermore, a reduction of the area of cultivated organic soils and a lower emission from N-leaching caused by the catch crop area, also has an impact on the lower N_2O emission towards 2040.

Table 6.14 Historical (1990-2020) and projected (2021-2040) N_2O emission.

N_2O emission, kt	1990	2000	2020	2021	2025	2030	2035	2040
Manure management	2.58	2.55	1.83	1.65	1.46	1.24	1.21	1.13
Indirect N_2O emission	0.66	0.61	0.43	0.39	0.37	0.34	0.30	0.27
Inorganic fertilisers	6.29	3.95	3.96	3.48	3.19	3.10	3.21	3.31
Animal manure applied to soils	3.33	3.06	3.31	3.26	3.22	3.19	3.04	2.89
Sludge and other organic fertilisers applied to soils	0.07	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Urine and dung deposited by grazing animals	1.00	1.01	0.60	0.59	0.60	0.61	0.61	0.60
Crop residues	2.46	2.48	2.99	3.06	2.99	3.17	3.22	3.28
Mineralization	0.68	0.35	0.21	0.14	0.19	0.11	0.09	0.12
Organic soils	2.74	2.49	2.01	2.01	1.88	1.55	1.53	1.53
Atmospheric deposition	1.26	0.76	0.61	0.60	0.58	0.57	0.56	0.55
Nitrogen leaching and run-off	1.83	1.37	1.12	0.98	0.94	0.88	0.88	0.88
Field burning	0.002	0.003	0.004	0.003	0.003	0.003	0.003	0.003
Total N_2O, kt	22.91	18.76	17.22	16.31	15.55	14.91	14.80	14.71

- The numbers in this table should be multiplied with a GWP value of 298 to calculate the CO_{2e} presented in Table 6.12.

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7 Waste

7.1 Solid waste disposal on land

The CRF source category *5.A Solid waste disposal,* gives rise to CH_4 emissions.

The CH_4 emission is calculated by means of a First Order Decay (FOD) model equivalent to the IPCC Tier 2 methodology (Nielsen et al., 2022). The model calculations are performed using national statistics on landfill waste categories reported in the national waste statistics. Waste amount reported according to the European waste codes are grouped into 18 waste types with individual content of degradable organic matter and degradation kinetics expressed as half-lives (Nielsen et al., 2022).

7.1.1 Emissions model

The model has been developed and used in connection with the historic emission inventories prepared for the United Nation Climate Convention. As a result, the model has been developed in accordance with the guidelines found in the IPCC Guidelines (2006). Based on the recommendations in these guidelines, a so-called Tier 2 method, a decay model, has been selected. The model is described in the National Inventory Report, which is prepared for the Climate Convention, the latest being the 2022 NIR report (Nielsen et al., 2022). In short, the degradation and release of methane is modelled according to waste type specific content of degradable organic matter and degradation rates assuming FOD kinetics. For a detailed description of the model and input parameters, the reader is referred to Nielsen et al. (2022).

7.1.2 Activity data

Deposited amounts of waste

The total amount of waste deposited at landfills are fluctuating, while a continuous decrease in the amount of organic degradable waste reaches a constant level in the period 2003 to 2020 (109-253 kt), as shown in Figure 7.1. The high value for total waste in 2010-2020 is caused by changes to the data system and registration of more inert waste, i.e. soil and stone, than in preceding or following years.

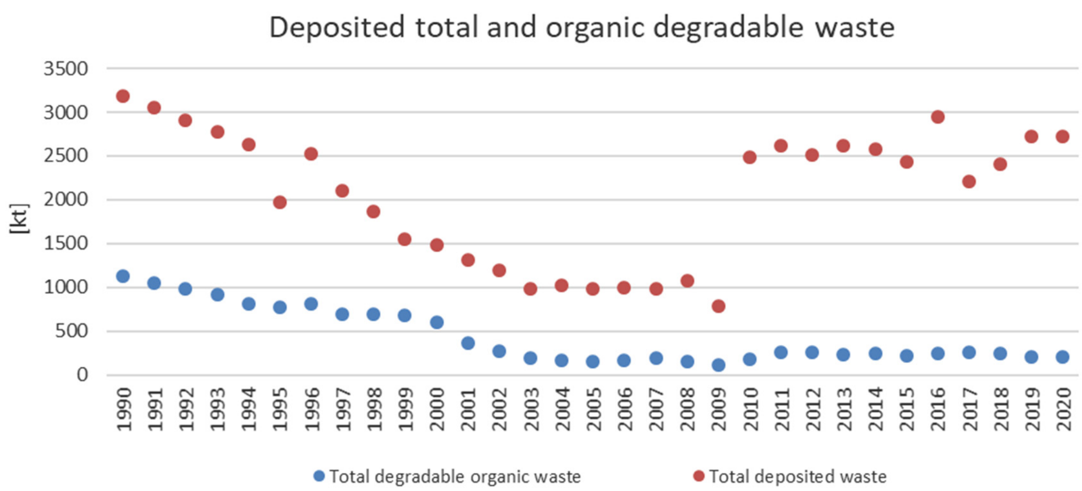

Figure 7.1 Historical data on the total amount of waste, i.e. organic/degradable and inert/non-degradable waste, and total organic waste disposed of at solid waste disposal sites.

Amounts of waste being disposed of at Danish landfills, excluding soil and stones, are projected by the Danish EPA (DEPA, 2020a).

The projected methane emissions from solid waste disposal sites (SWDSs), assumes waste type distributions equal to the composition for 2020 throughout the projection period 2021-2040. This implies that 32 % of the deposited amount are categorised as inert, while 68 % of the deposited waste are comprised by waste types with a content of organic degradable carbon (DOC_i>1). This fraction consists mainly of construction waste, i.e. 92 %, which is assumed to contain 40% wooden waste, 5.4 % sludge, 2.3 % paper and cardboard, wood and textile waste and 0.25 % biowaste (Nielsen et al., 2022).

Amount of recovered methane

The amount of recovered methane was estimated based on information from the Danish Energy Agency stating that the amount of recovered methane is projected to be 0.13 PJ per year in the period 2021-2032, 0.05 PJ in 2033 and 0.003 PJ in 2034-2036 after which the recovery of methane is estimated to be zero (Figure 7.2).

7.1.3 Historical and projected activity data and emissions

Table 7.1. Historical and projected amounts of deposited waste, generated methane, recovered methane collected for biogas production, oxidised methane in the top layer and resulting net emission for the Danish SWDS

Year	Landfilled waste	Gross methane emission	Recovered methane	Methane oxidised in the top layers	Net methane emission	
	kt	kt CH_4	kt CH_4	kt CH_4	kt CH_4	kt CO_2e
1990	3190	68.8	0.5	6.8	61.5	1536
1995	1969	66.8	7.6	5.9	53.2	1331
2000	1489	58.9	11.3	4.8	42.9	1073
2005	983	50.4	9.9	4.0	36.4	909
2010	2487	40.0	5.7	3.4	30.9	772
2015	2437	32.4	3.4	2.9	26.1	653
2020	2718	26.5	2.5	2.4	21.6	540
2021	475	25.4	2.4	2.3	20.7	518
2025	513	22.1	2.4	2.0	17.7	444
2030	541	18.7	2.4	1.6	14.7	368
2035	566	16.4	0.0	1.6	14.7	367
2040	595	14.6	0.0	1.5	13.1	328

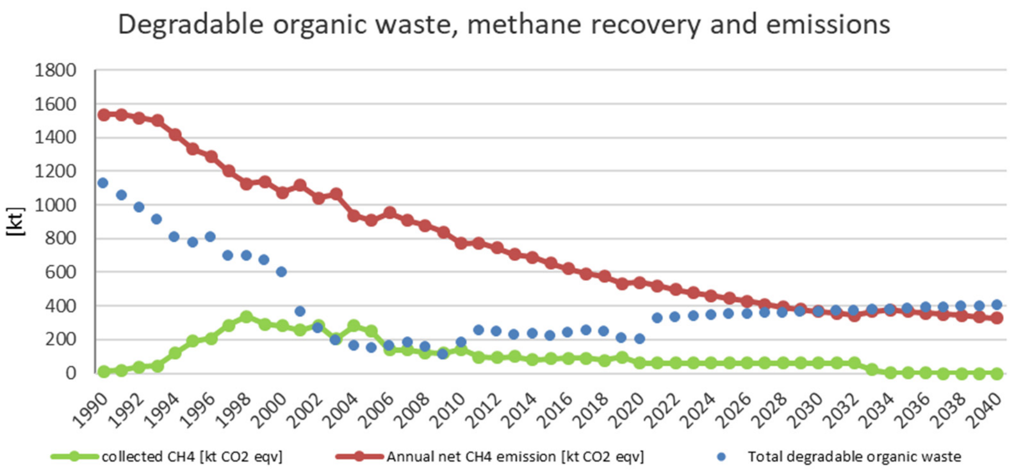

Figure 7.2 Historical and projected amounts of degradable organic waste deposited at landfill, amount of recovered and net CH_4 emissions. Historic data: 1990-2020. Projections: 2021-2040, kt.

The reason for the sharp decrease in historical data on deposited amounts of organic waste in the period 1990-2009 is to be found in a combination of the Danish waste strategies and action plans, including goals for a continued minimising of the amount of deposited waste in favour of an increased reuse and combustion for energy production. From 2009 to 2015 the amount of waste being landfilled in Denmark has decreased from 6 to 3 % staying at a constant level in the period 2015-2020. From the last historical year to 2040, the total amount of waste being landfilled increases by 29 % (DEPA, 2021). In the period 2020-2040, the annual net methane emission reduces from 537 to 328 kt CO_2e corresponding to a reduction of 39 %.

It should be mentioned that the impact of implementing the Biocover instrument has not been included in the projected methane emissions (BEK nr. 752 af 21/06/2016). Work is ongoing to document the effect with the aim of including this in future projections.

7.2 Biological Treatment of Solid Waste

The Danish greenhouse gas emission from the CRF source category 5.B Biological treatment of solid waste, consists of sub-category 5.B.1 Composting, and 5.B.2 Anaerobic digestion of organic waste.

7.2.1 Composting

Emissions from composting are calculated according to a country specific Tier 1 method. In Denmark, composting of solid biological waste includes composting of:

- Garden and park waste
- Organic waste from households and other sources
- Sludge
- Home composting of garden and vegetable food waste

The future activity of each category has been held constant in this projection as average values of the last three historical years and the emission factors are kept constant throughout the time series.

Emission factors

By assuming that the process of compost production will not significantly change over the next 20 years, the updated emission factors are used for this projection (Nielsen et al., 2022).

Table 7.2 Emission factors for compost production, t per kt wet weight.

	Garden and park waste	Organic waste	Sludge	Home composting
CH_4	3.19	4.00	0.22	4.20
N_2O	0.23	0.24	0.09	0.20

Historical and projected activity data and emissions

The projection of composting was performed as an average for the last three historical years.

Table 7.3 Historical and projected amounts of composted waste and emissions of CH_4, N_2O and CO_2e, kt.

Year	Garden and park waste	Organic waste	Sludge	Home composting	CH_4	N_2O	CO_2e
1990	288	16	5	20	1.07	0.07	48.9
1995	376	40	7	21	1.45	0.10	66.3
2000	677	47	218	21	2.48	0.19	119.0
2005	737	45	50	22	2.63	0.19	122.3
2010	811	65	75	23	2.96	0.21	137.6
2015	884	29	30	23	3.04	0.22	140.8
2020	964	56	54	23	3.41	0.24	158.0
2021	959	58	49	23	3.39	0.24	157.3
2025	959	58	49	23	3.39	0.24	157.3
2030	959	58	49	23	3.39	0.24	157.3
2035	959	58	49	23	3.39	0.24	157.3
2040	959	58	49	23	3.39	0.24	157.3

7.2.2 Anaerobic Digestion at manure-based biogas plants

Biogas production in this sector covers emissions from the handling of biological waste including biowaste and manure digested at biogas plants.

The energy production at biogas plants within the agricultural sectoral sector are projected by the Danish Energy Agency to increase from 28.4 PJ in 2021 reaching a maximum level of 50.1 PJ in 2030 after which a gradual decrease to 40.2 PJ in 2040. The CH_4 emission is calculated using an emission factor of 4.2% of the CH_4 content in the produced biogas in the period 1990-2016 and 2.9 % for 2020 onwards. Emission factors for 2017-2019 are interpolated. Historical and projected emission are provided in Table 7.4 and visualised in Figure 7.3.

Table 7.4 Historical and projected energy production, amounts of emissions of CH_4, N_2O and CO_2e.

Year	Biogas production, TJ	CH_4 production, kt	CH_4 emission, kt	CO_2e, kt
1990	266	5.3	0.2	5.6
1995	746	14.9	0.6	15.7
2000	1442	28.8	1.2	30.3
2005	2375	47.5	2.0	49.9
2010	3184	63.7	2.7	66.9
2015	5164	103.3	4.3	108.4
2020	19937	398.7	11.6	289.1
2021	28410	568.2	16.5	411.9
2025	38928	778.6	22.6	564.5
2030	50062	1001.2	29.0	725.9
2035	43035	860.7	25.0	624.0
2040	40198	804.0	23.3	582.9

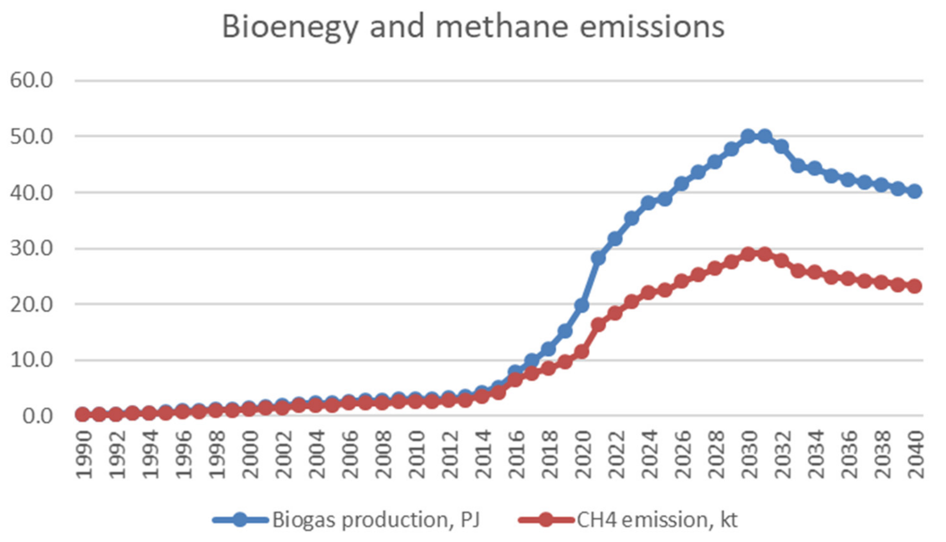

Figure 7.3 Historical and projected amounts of bioenergy and CH_4 emissions. Historic data: 1990-2020. Projections: 2021-2040.

7.3 Waste Incineration

The CRF source category 5.C Waste Incineration, includes cremation of human bodies and cremation of animal carcasses that gives rise to CH_4 emissions.

Incineration of municipal, industrial, clinical and hazardous waste takes place with energy recovery; the emissions are therefore included in the relevant subsectors under CRF sector 1A. For documentation, please refer to Chapter 2. Flaring off-shore and in refineries are included under CRF sector 1B2c, for documentation please refer to Chapter 3. No flaring in chemical industry occurs in Denmark.

7.3.1 Human cremation

It is assumed that no drastic changes are made in the subject of human cremation that will influence greenhouse gas emissions.

Figure 7.4 presents the trend of the number of deceased persons together with the activity data for human cremation.

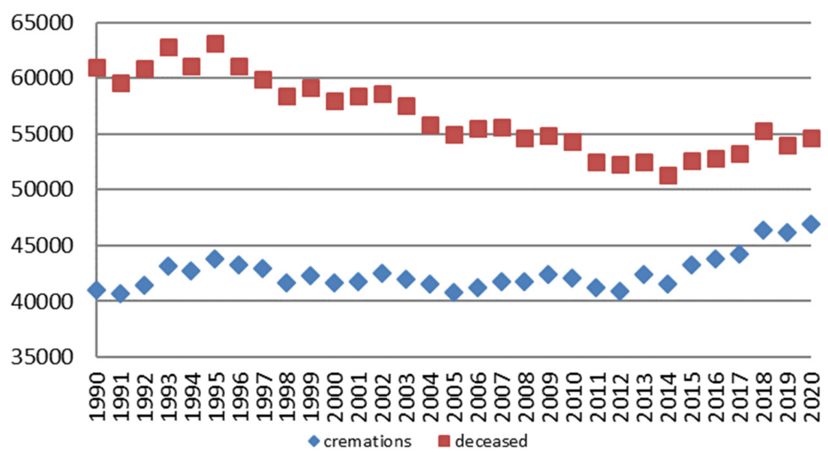

Figure 7.4 Trends of the activity data for cremation of human corpses and the national number of deceased persons.

As shown in Figure 7.4, the number of deceased annually has decreased from 1990 to 2014 after which a smaller increase in the number of deceased is observed as is expected to continue to increase corresponding to 1 % of the population per year. In this year's emission projection for human cremations, a constant level is chosen, corresponding to the average value of the last three historical years as shown in Table 7.5.

Table 7.5 CH_4 and N_2O emission from human cremations, t.

Year	1990	1995	2000	2005	2010	2015	2020	2021-2040
CH_4	0.48	0.52	0.49	0.48	0.49	0.51	0.55	0.55
N_2O	0.60	0.64	0.61	0.60	0.62	0.64	0.69	0.68
Total, CO_2e	191.6	205.0	194.7	190.5	196.6	202.1	219.3	217.2

7.3.2 Animal cremation

Historically, the development in the amount of cremated animal carcasses is difficult to explain. It is therefore also difficult to predict the future development. Figure 7.5 shows historical data.

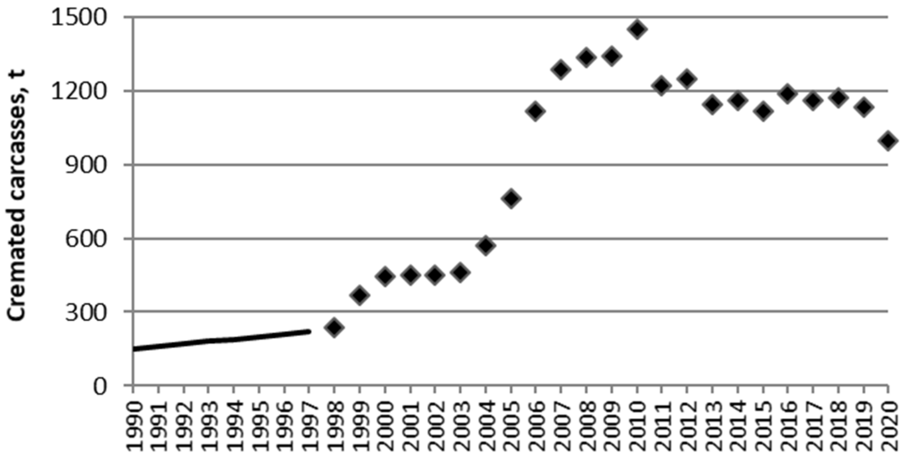

Figure 7.5 The amount of animal carcasses cremated (tonnes). Data from 1998-2020 are delivered by the crematoria and is considered to be exact; these data are marked as points. Data from 1990-1997 are estimated and are shown as the thick line in the figure.

A constant value corresponding to the average of the three latest historical years emissions were adopted throughout the projection period 2021-2040.

Table 7.6 CH_4 and N_2O emission from animal cremations, t.

Year	1990	1995	2000	2005	2010	2015	2020	2021 - 2040
CH_4	0.03	0.04	0.08	0.14	0.26	0.20	0.18	0.20
N_2O	0.03	0.05	0.10	0.17	0.33	0.25	0.23	0.25
Total, CO_2e	10.8	14.4	31.9	54.8	104.2	80.5	71.6	79.0

7.4 Wastewater handling

The CRF source category 5.D Waste water handling, constitutes emission of CH_4 and N_2O from wastewater collection and treatment.

7.4.1 Emission models and Activity Data

Methane emission

Methane emissions from the municipal and private wastewater treatment plants (WWTP) are divided into contributions from 1) the sewer system, primary settling tank and biological N and P removal processes, 2) from anaerobic treatment processes in closed systems with biogas extraction and combustion for energy production and 3) septic tanks. For a detailed description of the model equations and input parameters (process-specific emissions factors and activity data) the reader is referred to Nielsen et al. (2022) and Thomsen (2016).

Emission from the sewer system, primary settling tank and biological N and P removal processes:
The fugitive emissions from the sewer system, primary (and secondary) settler tanks (clarifiers) and aerobic biological treatment processes, $CH_{4,sewer+MB}$, are estimated as:

$$CH_{4,sewer+MB} = EF_{sewer+MB} \cdot TOW_{inlet}$$

$$\Downarrow$$

$$CH_{4,sewer+MB} = B_o \cdot MCF_{sewer+MB} \cdot TOW_{inlet}$$

where TOW_{inlet} equals the influent organic degradable matter measured as the chemical oxygen demand (COD) in the influent wastewater flow, B_o is the default maximum CH_4 producing capacity, i.e. 0.25 kg CH_4 per kg COD (IPCC, 2006).

The fraction of TOW that is unintentionally converted to CH_4 in sewers, primary clarifiers and aerobic biological treatment processes, $MCF_{sewer+MB}$, is set equal to 0.003 based on an expert judgement . The emission factor, $EF_{sewer+MB}$, for these processes equals 0.00075 kg CH_4 per kg COD in the inlet wastewater (Nielsen et al., 2022). An overview of the historical and projected amount of COD in the influent wastewater is provided in Table 7.7.

Table 7.7 Total degradable organic waste (TOW) in the influent wastewater, kt.

Year	1990	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
COD	295	365	364	372	385	391	396	402	409	416	421

Note: Historical data: 1990-2020, projected data: 2021-2040.

“TOW, National Unit PE BOD value” are the national BOD value of 21.9 kg BOD per year multiplied by a national COD/BOD conversion factor of 2.7 and multiplied by the population number of Denmark (Thomsen, 2016).

Methane emissions from anaerobic treatment processes:
The net methane emission from anaerobic digestion in biogas tanks are estimated according to the below equation for the whole time series:

$$CH_{4,AD} = EF_{AD} \cdot CH_{4,AD,recovered}$$

where the emission factor, EF_{AD}, has been set equal to 1.3 %, i.e. 0.013, of the CH_4 content in the gross energy production at national level reported by the Danish Energy Agency. Table 7.8 shows the historical and projected gross energy production reported by the Danish Energy Agency.

Tabel 7.8 Gross Energy production and the corresponding methane content.

	1990	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
Energy production, TJ	458	857	913	840	901	1307	1486	1486	1486	152	0
CH_4 content, kt	9.3	17.4	18.6	17.1	18.3	26.6	30.2	30.2	30.2	3.1	0

Note: Historical data: 1990-2020, projected data: 2021-2040.

The CH_4 content in the biogas is calculated from the calorific value 23 GJ / 1 000 m^3 biogas provided by the Danish Energy Agency, a percent volume content of methane of 65 % and a density of 0.68 kg CH_4 / Nm^3.

Methane emissions from septic tanks:

Methane emission from septic tanks is calculated as:

$$CH_{4,st} = EF_{st} \cdot f_{nc} \cdot P \cdot DOC_{st}$$

where the emission factor is calculated from the default IPCC value quantifying the maximum methane producing capacity B_o of 0.25 kg CH_4 per kg COD (chemical oxygen demand) multiplied by the methane conversion factor for septic tanks, corresponding to the amount of suspended organic material that settles in the septic tank, equal to 0.19 (Nielsen et al., 2022). Hence, an EF_{st} value of 0.047 kg CH_4 per kg COD is obtained.

The fraction of the population, P, not connected to the collective sewer system, f_{nc}, is set equal to 10 % for the entire time series estimated from National statistics of scattered houses in percent of the total number of households in Denmark (DME, 2014; Statistics Denmark).

Lastly, the default IPCC value of the per capita produced degradable organic matter, DOC_{st}, i.e. 22.63 kg BOD per person corresponding to 56.6 kg COD per person (IPCC, 2006), were used.

The projection of methane emissions from septic tanks are estimated from the population statistics and the assumption of ten per cent of the population not being connected to the sewerage system (Nielsen et al., 2022). The population numbers used for deriving historical and projected emissions from septic tanks is provided in Table 7.9.

Table 7.9 Population numbers and projections for Denmark.

Year	1990	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
Population estimates (1000)	5135	5330	5411	5535	5660	5823	5845	5930	6043	6137	6207

Note: Historical data: 1990-2020, projected data: 2021-2040.

Methane emission projections are provided in Chapter 7.4.2, Table 7.11. For details regarding the methodology for estimating the methane emissions from the Danish WWTPs, the reader is referred to Nielsen et al. (2022) and Thomsen (2016).

Nitrous oxide

The direct and indirect N_2O emission from wastewater treatment processes is calculated based on country specific and process specific emission factors (Nielsen et al., 2022) and the amount of nitrogen in the influent and effluent wastewater, respectively.

The N content in influent and effluent wastewater was projected based on the average influent N per person for 2016-2020 and projected according to population statistics (Table 7.9), while the effluents from separate industries, rainwater conditioned effluents, scattered houses and aquaculture was held constant at the average level of the last five historical years from 2021-2040. Total N in the influent and effluent wastewater is presented in Table 7.10 and total N_2O emissions from wastewater treatment and discharge in Table 7.11.

Table 7.10 Total N in the influent and effluent wastewaters, t.

Year	1990	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
Influent N, municipal WWTPs	14679	26952	32288	27357	30509	30288	30506	30951	31542	32031	32395
Effluent N, municipal WWTPs	16884	4653	3831	4025	3705	3245	3424	3474	3540	3595	3636
Influent N, industrial WWTPs	32175	11213	5688	4225	4141	3533	2978	3770	3770	3770	3770
Effluent N, separate industries	2574	897	441	338	331	283	302	302	302	302	302
Rainwater conditioned effluents	921	762	622	762	1476	914	1053	1053	1053	1053	1053
Effluents from scattered houses	1280	979	919	902	747	471	551	551	551	551	551
Effluents from aquaculture	1737	2714	1225	933	1029	966	1023	1023	1023	1023	1023
Total effluent N	19458	10005	7038	6960	7288	5879	6353	6403	6469	6524	6565

Note: Historical data: 1990-2020, projected data: 2021-2040.

For the total N in the effluents, the contribution from separate industries, rainwater conditioned effluents, scattered settlements and aquaculture, a decreasing trend followed by a close to constant level is observed and the effluent levels are kept constant at the average values for 2016-2020 throughout the projection period. The total N content in the influent and effluent from WWTPs is increasing according to population statistics for the period 2021-2040.

The emission projection for the total N_2O emission is provided in Table 7.11.

Remarks to the presented projection of nitrous oxide from wastewater handling

Direct emissions from wastewater treatment within industries are included. Historical N_2O emissions from wastewater treatment plants in Denmark were derived from reported effluent N from separate industries and information about N-removal efficiencies (Thomsen, 2016). From the influent N load data, emissions are calculated by use of the country-specific emission factor.

The default IPCC emission factor for N_2O emissions from domestic wastewater nitrogen effluent is 0.005 (0.0005 - 0.25) kg N_2O-N / kg N (IPCC, 2006).

For the direct N_2O emissions, an emission factor of 0.0084 kg N_2O-N / kg total N in the influent, or 13.2 kg N_2O / tonnes influent N are used in the estimated historical and projected direct N_2O emissions (DEPA, 2020b).

7.4.2 Historical emission data and projections

Historical and projected methane emissions are shown in Table 7.11.

Table 7.11 Methane and nitrous oxide emission from wastewater treatment and discharges, kt.

	1990	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
$CH_{4, \text{sewer system and MB}}$	0.22	0.27	0.27	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32
$CH_{4, \text{septic tanks}}$	1.30	1.35	1.37	1.40	1.44	1.48	1.48	1.50	1.53	1.56	1.57
$CH_{4, \text{AD}}$	0.12	0.23	0.24	0.22	0.24	0.35	0.39	0.39	0.39	0.04	0.00
$CH_{4, \text{total emission}}$	1.64	1.85	1.89	1.91	1.96	2.12	2.17	2.20	2.23	1.91	1.89
N_2O, direct	0.62	0.50	0.50	0.42	0.46	0.45	0.45	0.46	0.46	0.47	0.47
N_2O, indirect	0.18	0.08	0.06	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.05
N_2O, total	0.80	0.58	0.56	0.47	0.51	0.49	0.50	0.51	0.51	0.52	0.53
$CO_{2eqv, \text{total}}$	280.2	219.9	213.0	188.2	202.4	199.8	203.1	205.6	209.0	202.9	203.9

Note: Historical data: 1990-2020, Projected data: 2021-2040.

The total N_2O and net CH_4 emission figures converted to CO_2 equivalents and the sum up result for emissions from wastewater treatment and discharge are provided in the last row of Table 7.11.

7.5 Other

The sub-sector category 5.E Waste Other is a catch up for the waste sector. Emissions presently included in this category are accidental building and vehicle fires. Emissions from accidental building and vehicle fires was set equal the average value of the last three historical years.

7.5.1 Historical emission data and projections

Table 7.12 gives an overview of the Danish non-biogenic greenhouse gas emission from the CRF source category 5.E Waste Other.

Table 7.12 Historical and projection of overall emission of greenhouse gases from the accidental building and vehicle fires.

	Unit	1990	2000	2005	2010	2015	2020	2021-2040
CO_2e	kt	25	25	24	26	24	26	26

7.6 Emission overview

The total emissions from the waste sector are presented in Table 7.13 below.

Table 7.13 Emissions from the waste sector in kt CO_2 equivalents.

	1990	2000	2005	2010	2015	2020	2021	2025	2030	2035	2040
5A Solid waste disposal	1536	1073	909	772	653	537	518	444	368	367	328
5B Biological treatment of solid waste	55	149	172	204	249	447	569	722	883	781	740
5C Incineration and open burning of waste	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
5D Waste water treatment and discharge	280	220	213	188	202	200	203	206	209	203	204
5E Other	25	25	24	26	24	26	26	26	26	26	26
Total	1896	1467	1319	1191	1130	1210	1317	1398	1487	1378	1299

7.7 Source specific recalculations

For the solid waste disposal, there is no changes in the historical emissions, but the emissions for 2020 were 65 kt CO_2e (i.e. 14 %) higher than expected from last year's projection. Projected emissions for 2021-2032 for solid waste disposal have increased with 10-26 %. In the projection period 2033-2040 only minor recalculations of -4 % to +2 % occur. Recalculations are caused by changes in the projected methane recovery by the Danish Energy Agency (DEA, 2022) compared to the last projection.

For category 5B Biological treatment of solid waste, increases in projected emissions of 276 kt to 474 kt CO_2e (95 %-116 %) are caused by a significant increase in projected methane emission from bioenergy production at industrial and manure-based biogas plant production (DEA, 2022). The emission factor used in this projection has been updated due to new data for historical years (Nielsen et al., 2022). Recalculations from composting are miniscule.

For category 5C Incineration and open burning of waste we applied the average of the three last historical years in the emission projection resulting in a decrease of 0.04 % throughout the projections period 2021-2040.

For category 5D Wastewater treatment and discharge, an increase of 1-4 % is observed due to minor change in the activity data as well as the amount of bioenergy produced at sludge-based biogas plants.

For the category Other, activity data has been updated throughout the time series 1990-2020, and as the average of the three last historical year are used in the projection, emissions for 2021-2040 have decreased with 1 %.

7.8 References

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8 LULUCF

The emission and uptake of GHGs from the LULUCF sector (Land Use, Land Use Change and Forestry) primarily includes the emission of CO_2 from land use, small amounts of N_2O from disturbance of soils not included in the agricultural sector and CH_4 emission from Grassland, Wetlands and wild fires in the LULUCF sector.

The LULUCF sector is subdivided into six major categories:

- Forest (FL) subdivided into forest and Christmas-trees
- Cropland (CL)
- Grassland (GL)
- Wetlands (WE) subdivided into fully water covered and partly water covered
- Settlements (SE)
- Other Land (OL)

This projection includes emission estimates from Forest land and land converted to Forest land but not described in detail. The methodology for these emissions is published separately by the University of Copenhagen, Department of Geosciences and Natural Resource Management (Johannsen et al., 2022).

The projections are made based on the best available data of the past development in the land use in Denmark and expectations for the future. Regarding the methodology for estimation of the sources/sinks from the different sectors, see the latest available Danish National Inventory Report (NIR), Chapter 7 in Nielsen et al. (2022). There has been some major changes in methodology and updated data in the latest submission of LULUCF.

Approximately two thirds of the total Danish land area are cultivated and 14.9 % is forest, see Figure 8.1. Intensive cultivation and large numbers of animals exert a high pressure on the landscape and regulations have been adopted to reduce this pressure. The adopted policy aims at doubling the forested area within a forest generation (80-100 years), at restoring former wetlands and establishing protected national parks. In Denmark, almost all natural habitats and all forests are protected. Therefore, only limited conversions from forest or WE into CL or GL have occurred and are expected to occur in the future.

Figure 8.1 shows the land use in 1990 and towards 2040. A continuous increase in FL and SE is expected, at the expense of primarily the CL area. It should be noted that the definition of the LULUCF sectors differs slightly from the normal Danish land use definitions and the distribution shown will therefore differ from other national statistics.

Land use conversions (LUC) affect whether a category is a sink or a source. In the following, emissions by sources are provided as positive values (+) and removals by sinks as negative values (-).

The figures reflect the reporting under the UNFCCC (here the Convention). This implies that an area, which has undergone LUC, is kept in the corresponding land use change category for 30 years. The IPCC recommend a transition time of 20 years, but Denmark has chosen a 30 years transition time due to the rather cold climate, which slow down growth rates and soil biology and as a consequence it takes longer time to reach the equilibrium state in carbon stock. After this period, the area is moved to land remaining land.

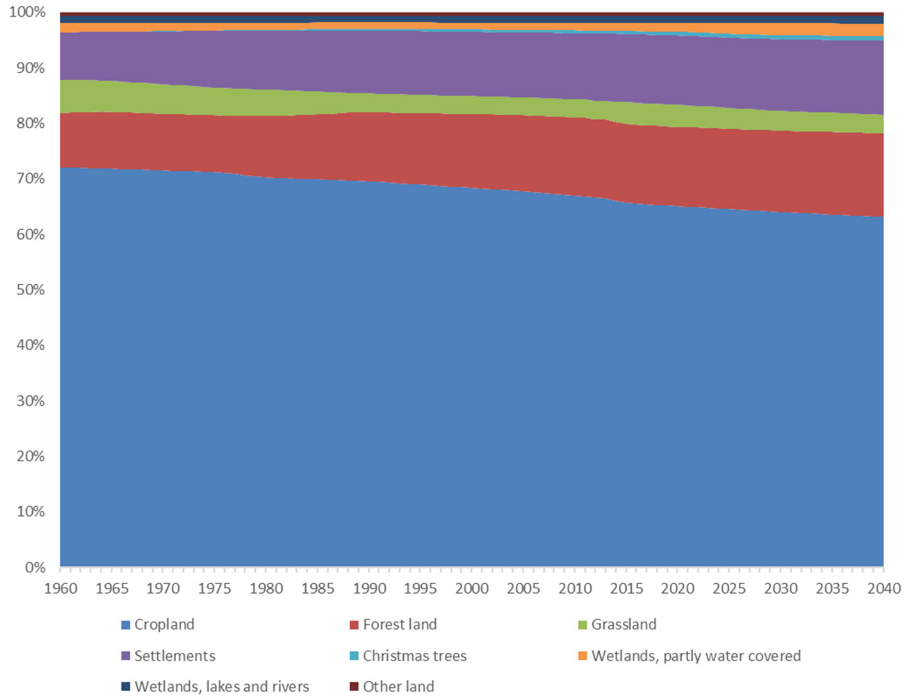

Figure 8.1 Land area use 1960-2040.

Table 8.1.a, b and c show the projected average land use changes between the different land use categories. Actually three distinct periods have been chosen: 2021, 2025 and 2030. This distinction is mainly due to the current funding scheme for converting agricultural land to wetlands. As this funding is allocated to different fiscal years and ceases at different times, the projected LUC is changed accordingly (Finance Act, 2022). As there is a delay between financing and establishment of WE, it is assumed that establishing will take place three years (n+3 years) after entering the governmental budget. No financial allocations for converting agricultural land to WE after 2032 is assumed, except for minor usual observed land use changes.

Conversion to Settlements and other infrastructures (SE) is expected to continue with the same pace as seen historically.

As the WE restoration plan is targeting agricultural organic soils, the area of organic agricultural soils will decrease too. Overall it is assumed that approximately 3 000-6 000 hectares per year in the Land Use Matrix (LUM) will undergo LUC when omitting LUC from CL to GL and back again. This LUC is not seen as direct land use change as this is often the same agricultural area mowing from one definition to the other. The direct LUC is primarily due to the continuous afforestation and the demand for SE and infrastructure purposes.

Table 8.1a Expected annual land use change in hectares per year in 2021, ha.

	Settlement	Lake	Forest	Christmas trees	Cropland	Grassland	Wetland	Other land	Total, ha per year
Settlement		0	0	0	0	0	0	0	0
Lake	1		0	0	0	0	0	0	1
Forest	50	0		1	101	54	0	0	206
Christmas trees	0	0	1		1	1	0	0	3
Cropland	2300	31	1119	1		3000	275	0	6726
Grassland	360	31	91	1	3000		275	0	3758
Wetland, partly water covered	6	0	0	0	0	0		0	6
Other land	0	0	0	0	0	0	0		0
Total, ha per year	2718	61	1211	3	3102	3055	550	0	10700

Table 8.1b Expected annual land use change in hectares per year in 2025, ha.

	Settlement	Lake	Forest	Christmas trees	Cropland	Grassland	Wetland	Other land	Total, ha per year
Settlement		0	0	0	0	0	0	0	0
Lake	1		0	0	0	0	0	0	1
Forest	50	0		1	101	54	0	0	206
Christmas trees	0	0	1		1	1	0	0	3
Cropland	2300	379	3233	1		3000	3412	0	12326
Grassland	360	379	262	1	3000		3412	0	7415
Wetland, partly water covered	6	0	0	0	0	0		0	6
Other land	0	0	0	0	0	0	0		0
Total, ha per year	2718	758	3496	3	3102	3055	6824	0	19957

Table 8.1c Expected annual land use change in hectares per year in 2030, ha.

	Settlement	Lake	Forest	Christmas trees	Cropland	Grassland	Wetland	Other land	Total, ha per year
Settlement		0	0	0	0	0	0	0	0
Lake	1		0	0	0	0	0	0	1
Forest	50	0		1	101	54	0	0	206
Christmas trees	0	0	1		1	1	0	0	3
Cropland	2300	493	1554	1		3000	4440	0	11789
Grassland	360	493	126	1	3000		4440	0	8421
Wetland, partly water covered	6	0	0	0	0	0		0	6
Other land	0	0	0	0	0	0	0		0
Total, ha per year	2718	987	1681	3	3102	3055	8880	0	20426

When LUC is taking place, fixed factors are used for the direct changes / losses. The most important emission factors are given in Table 8.2.

Table 8.2 Emission factors used in the projection until 2040.

		Carbon stock
Default amount of living biomass	Cropland	11.875 tonnes dry matter (dm)/ha
	Grassland	8.360 tonnes dm/ha
	Wetlands	13.680 tonnes dm/ha
	Settlement	4.400 tonnes dm/ha
Default amount of C in mineral soils	Forest	142 tonnes C/ha
	Cropland	121 tonnes C/ha
	Grassland	142 tonnes C/ha
	Wetlands	No changes assumed when converted to WE from other land uses
	Settlements	96.7 tonnes C/ha (80 % of CL)
		Emissions
Soil	Crop in rotation: Organic soils > 12 % OC	11.5 tonnes C/ha/yr 13 kg N_2O-N/ha/yr
	Crop in rotation: Organic soils 6-12 % OC	5.75 tonnes C/ha/yr 6.25 kg N_2O-N /ha/yr
	Abandoned areas in Cropland and Grassland: Organic soils > 12 %	3.6 tonnes C/ha/yr 39 kg CH_4/ha/yr
	Abandoned areas in Cropland and Grassland: Organic soils 6-12 % OC	1.8 tonnes C/ha/yr 19.5 kg CH_4/ha/yr
	Permanent Grassland: Organic soils > 12 % OC	8.4 tonnes C/ha/yr 16 kg CH_4/ha/yr 8.2 kg N_2O-N /ha/yr
	Permanent Grassland: Organic soils 6-12 % OC	4.2 tonnes C/ha/yr 8 kg CH_4/ha/yr 4.1 kg N_2O-N /ha/yr
	Forest land, drained: Organic soils > 12 % OC	2.6 tonnes C/ha/yr 2.5 kg CH_4/ha/yr 2.8 kg N_2O-N /ha/yr
	Wetlands: > 12 kg OC	0 kg C/ha/yr 0 kg N_2O-N/ha/yr 288 kg CH_4/ha/yr
	Peat extraction areas	Excavated peat + 2.8 tonnes C/ha/yr 6.1 kg CH_4/ha/yr 0.3 kg N_2O-N /ha/yr

Table 8.3 Overall emission estimates from the LULUCF sector from 1990 to 2040, kt CO_2 eqv per year. By convention are emissions reported as positive figures and sinks as negative figures.

UNFCCC category	1990	2010	2017	2018	2019	2020	2025	2030	2035	2040
4. LULUCF	6873.6	2457.5	1820.4	3737.7	2893.0	3107.1	4783.5	3672.9	3347.8	3635.6
A. Forest Land*	-1228.7	-2269.4	-2570.3	-2124.9	-2490.2	-2172.5	265.0	-26.9	-177.2	20.1
1. Forest Land remaining Forest Land*	-192.1	-1040.9	-1442.3	-1154.7	-1203.0	-985.8	907.1	748.8	416.3	563.2
2. Land converted to Forest Land*	-1036.6	-1228.5	-1128.1	-970.2	-1287.2	-1186.7	-642.1	-775.7	-593.5	-543.1
B. Cropland	5297.9	2549.1	2225.7	3381.8	3051.2	2851.0	2376.3	1642.9	1466.8	1521.1
1. Cropland remaining Cropland	5209.3	2507.5	2223.2	3327.7	3042.2	2757.7	2364.9	1630.8	1457.3	1517.8
2. Land converted to Cropland	88.6	41.6	2.5	54.0	9.0	93.3	11.4	12.1	9.5	3.3
C. Grassland	2229.7	1880.7	2055.9	2218.5	2132.0	2231.9	2065.8	1747.3	1612.8	1613.9
1. Grassland remaining Grassland	2173.6	1809.8	2011.8	2153.8	2088.2	2186.8	2035.1	1714.2	1577.6	1577.1
2. Land converted to Grassland	56.1	70.8	44.1	64.7	43.9	45.0	30.7	33.0	35.2	36.8
D. Wetlands	104.8	80.4	47.1	75.7	71.0	72.3	113.1	248.7	299.1	293.4
1. Wetlands remaining Wetlands	101.6	67.3	55.8	78.6	56.7	36.9	40.9	0.0	0.0	0.0
2. Land converted to Wetlands	3.2	13.1	-8.7	-3.0	14.3	35.4	72.2	248.7	299.1	293.4
E. Settlements	472.2	241.9	224.2	232.9	213.5	242.1	262.0	295.7	326.3	344.3
1. Settlements remaining Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2. Land converted to Settlements	472.2	241.9	224.2	232.9	213.5	242.1	262.0	295.7	326.3	344.3
F. Other Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
G. Harvested Wood Products*	-2.4	-25.1	-162.2	-46.2	-84.6	-117.6	-298.7	-234.8	-179.8	-157.2

*The methodology for estimation of emission and projections for all Forest and HWP data are reported in Johannsen et al., (2022).

In total from 1990 to 2040, an afforestation of 124 783 hectares is expected (excl. Christmas trees), while the deforestation is only expected to include 13 892 hectares (excl. Christmas trees). The total area with Christmas trees is around 35 000 hectares of which 10 000 are inside the forest and the remaining planted in agricultural fields. This area is assumed to be fairly constant. The deforestation area is due to conversion to SE and new roads, or more open areas in the forests. FL remaining FL is expected to be a source in the near future and afforestation is expected to be net sink. For further details on the forest projection, see Johannsen et al., 2022.

CL and GL are major sources, primarily due to the large area with cultivated organic soils in Denmark. The steady extensification of the CL area on organic soils towards permanent GL and conversion to WE, leads to a decrease in emissions until 2040. Currently, the agricultural mineral soils have been storing carbon at a rate of 200-300 kt CO_2 per year. This is expected to slightly increase to around 500 kt CO_2 per year until 2040 due to an increased area with catch crops and more grass. The expected increasing temperature will increase the annual losses from the mineral soils but this is partly counteracted by the expected increase in harvest yields. In the projection of emissions from mineral soils, a dynamic temperature modelling tool (C-TOOL ver. 2.3.) is used. The overall emission from CL also depends on the cultivated agricultural area on organic soils. Due to major subsidies to rewet these soils, the emission from drained organic soils in CL will be reduced in the future, adding to the expected lower emission from CL. CL will still be a major source due to large emissions from the organic soils.

The area reported under GL is assumed to decrease slightly due to the rewetting program for drained organic soils. But as for CL, it will still be a large source due to its large area with organic soils.

For WE, only emissions from managed WE are reported and not naturally occurring moors and other wetlands. The overall trend for WE is a decreasing emission from WE remaining WE, caused by a decreasing peat excavation in Denmark. Peat excavation is expected to cease completely by 2029. Land converted to WE is expected to increase due to the current ongoing program running from 2016 to 2030 for conversion of agricultural organic soil to WE. The reported emission is only CH_4.

SE is expected to have decreasing emissions. The emission from SE is basically loss of organic matter from soils converted to SE until it reaches a new equilibrium state after 30 years. The actual estimated emission is therefore caused by new housing and infrastructures introduced up to 30 years before the actual inventory year. As there were large building activities in the 1960s and 1970s and hereafter a decreased activity, the emission in land converted to SE was high in 1990 and has now decreased to a steady emission estimate of 300 kt CO_{2e} per year in the coming years.

8.1 Forest

The Department of Geosciences and Natural Resource Management at the University of Copenhagen (IGN), is responsible for the reporting of GHG emissions from the Danish forests. IGN has made a separate report on the Danish forest projection to 2050 (Johannsen et al., 2022). The Land Use Matrix for LUC in this report, is the same as in the forest projection.

Since 1990, the forested area has increased. This is expected to continue in the future, caused by a Danish policy aim to increase the forest area. Afforestation is expected to take place on 3 500 hectares per year until 2030 and then to cease. This cease is defined because the projection is based on existing funding scedules and therefore no plans exist to go beyond 2030. Christmas trees, also those grown on agricultural soils, are included in FL. The Danish forests are well protected and only limited deforestation is expected to occur. The deforestation is mainly due to development of infrastructure and to a limited extent also due to an opening of the state forest where small forest areas are turned into open spaces. These spaces are converted into GL. Only limited deforestation on land for SE and infrastructure is assumed. Deforestation is normally low in Denmark - around 150-200 hectares per year.

For projected sinks and sources for Afforestation, Deforestation, Forest land remaining Forest land and HWP (Harvested Wood Products), please see Johannsen et al., 2022.

8.2 Cropland

Agriculture occupies the major part of the Danish territory. In total, approximately 2.7 million hectares are utilised for agricultural activities of which crops in rotation covers the far majority.

CL is subdivided into four types: Agricultural CL, which is the agricultural area defined by Statistics Denmark, Wooden agricultural crops, which are fruit trees, willow, Christmas trees on CL etc., Hedgerows and small biotopes and “Other agricultural land”. The latter is defined as the difference between the area in the national statistics and the CL area defined by satellite monitoring and cadastral information. This area varies slightly between years, due to annual differences in the agricultural area reported by Statistics Denmark.

In CL, three different C pools are accounted for: above ground living biomass, below ground living biomass and SOC. The major part of the CL area is annual crops. Approximately 100 000 hectares are hedgerows or small biotopes that do not meet the definition of forest. Area, C stock and C stock changes in hedges and small biotopes are LiDAR based measurements in 2006 and 2014/2015 combined with a growth model for newly planted hedges (Nielsen et al., 2022).

8.2.1 Agricultural cropland

The area with CL has decreased over the last many years, primarily due to urbanisation and afforestation. This is expected to continue in the future. According to Statistics Denmark, the area with agricultural crops has declined with 141 000 hectares from 1990 to 2000, or 14 100 hectares per year. From 2000 to 2010, the reduction in the area with agricultural crops was only 600 hectares. This variation is, beside the declining area, due to differences in the reporting to Statistics Denmark. However, and even more important is the EU subsidiary system, which has changed and thus resulted in more agricultural CL reported to Statistics Denmark than previously. The LUM shows more conservative figures, as land, which is not reported in other Land Use sectors, will remain in the CL sector. From 1990 to 2010, 60 000 hectares have left CL with higher rates in the 1990s than in the following decade. The reduced conversion of agricultural land to other land uses can be attributed to less need of land for SE and other infrastructure. For the projected change in the agricultural area, the AGMEMOD model is used, see Chapter 7 for more details. In most recent years, the LUM shows that approximately 4 800 ha per year are leaving to other land use categories and the remaining is reported in CL and GL. An inter-annual conversion between CL and GL and vice versa is estimated to 3 000 ha per year for technical reasons. This conversion has no impact on the overall emission estimates.

8.2.2 Methodology

By default, the amount/change of living biomass in CL is estimated as the amount of living biomass at its peak, i.e. just before harvest. This peak is estimated as the average barley yield for the 10-year period 1999 to 2008.

Due to a reduced area with agricultural CL, an average loss of biomass of approximately 70-200 kt CO_{2e} per year is expected. This is partly counteracted by an increase in the amount of living biomass in the land class to which it is converted.

The change in SOC in mineral agricultural soils is estimated with C-TOOL (Ver 2.3) (Taghizadeh-Toosi, 2015). C-TOOL is used for all mineral soils in both CL and GL with area data from the Danish Agricultural Agency (Land parcel information data, LPIS) and harvest data from Statistics Denmark. Changes in SOC stocks in areas, which should refer to GL (Section 4C) is therefore reported under 4B. C-TOOL is a dynamic 3-pooled soil C model, which uses annual C input and C stock in soil as driving parameters. C-TOOL is run on eight separate regions, and further subdivided into two or three soil types depending on the soil types within the region. The input to C-TOOL is the amount of straw and roots returned to soil based on actual crop yield, areas with different crop types and applied animal manure (amount of volatile substance) as reported in the agricultural sector. Based on this, C-TOOL estimates the degradation of Soil Organic Matter and returns the net annual change in C. C-TOOL Ver. 2.3 has been used for this projection. The average crop yield for the years 2006-2021 is used as input to estimate a reference yield level in 2020. For the last 18 years, there has been a restriction on the farmer's N use in Denmark. This was partly abandoned in 2016. In the projection, an annual increase in crop yield for all cash crops of 0.4-0.7 Hkg kernel per ha per year is assumed, which is the average nitrogen corrected increase for all cereal crops in the period 2006 to 2021.

Presently, a re-evaluation of the Danish agricultural regulation is ongoing, aiming to move from a general regulation to an individual targeted regulation on farm level. This change will affect the future area with especially catch crops. Catch crops account for approximately 212 000 hectares in 2010. In 2030, the expected area is 770 000 hectares, adding biomass to the SOC stock. Minor changes in the distribution of the currently grown crops is assumed as the current EU policy include prescribed set-a-side from 2023. No further removal of straw and other crop residues are foreseen in this projection.

Future temperatures have been estimated for each region by the Danish Meteorological Institute (Courtesy of senior researcher Marianne Sloth, Danish Meteorological Institute). For each region, a linear increasing temperature regime has been estimated based on IPCCs 5th Assessment Report, AR5 for Danish conditions for the RCP 4.5 scenario with an average increase in the temperature of 1.6°C per 60 years from the mean period 1986-2005 to the mean period 2046-2065 (Olesen et al., 2014). To this has been added the natural observed variation in the monthly temperature data from 1998 to 2021 to include the effect of variation in the climate between years. The outcome is therefore not a linear change in the model outcome but a merely likely natural variation as shown in Figure 8.2 and 8.3. For the purpose of this projection, C-TOOL has been run with 10 different randomly selected temperature projections up to year 2040.

Presently, the clay agricultural soils are estimated to be in a near steady state. The sandy soils, primarily located in Jutland, is expected to increase the carbon stock further. In total the agricultural mineral soils is expected to be a net sink of approximately 500 kt CO_2 per year. The blue line in Figure 8.2 indicates the total amount of C as SOC including fresh not degraded crop residues and the red line indicates the total reported C stock in soils. Only C in the humified organic matter (HUM) and resilient organic matter (ROM) pool (red line) are as reported, belonging to the carbon stock in mineral soils. The overall trend will be an increased carbon stock in the agricultural mineral soils until a new equilibrium state is reached. With the current expectation to crop yields and temperature development, this is not foreseen to take place until past 2080.

Figure 8.3 shows the reported and expected annual emissions from mineral soils in kt C per year. Due to high yields in most recent years, a sink has been estimated from 1995 and forward. This sink will increase further in the near future due to an expected yield increase. Year 2018 was extremely dry with low yields. Hence the estimated C stock decreased (large emission).

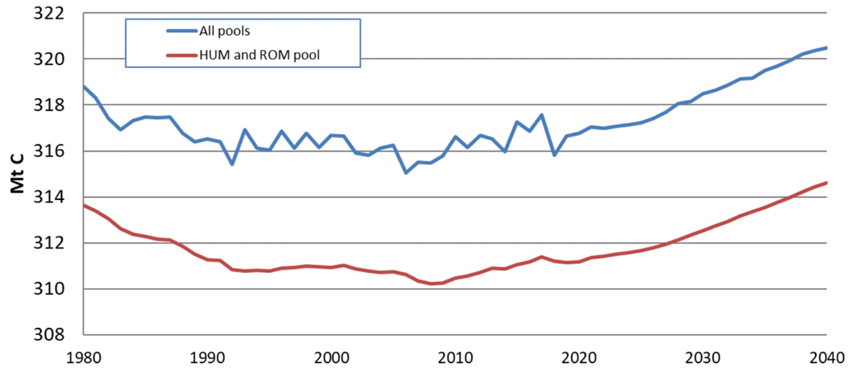

Figure 8.2 Total estimated carbon stock in mineral soils in Cropland and Grassland, kt C per year. HUM = Humified organic matter, ROM = Resilient organic matter.

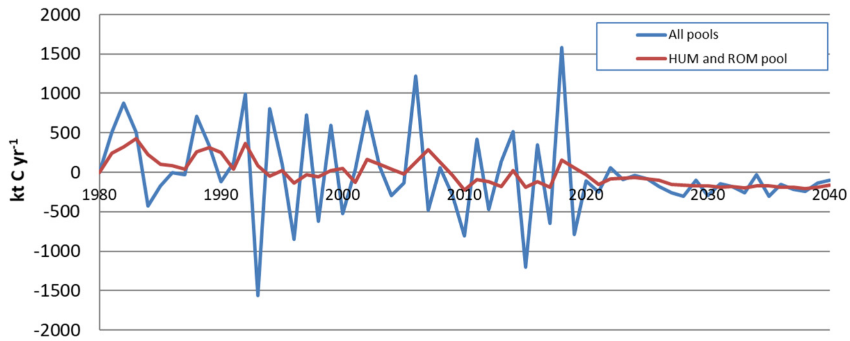

Figure 8.3 Annual emissions from mineral soils in Cropland and Grassland, kt CO_2 per year.

The emissions from organic soils from CL are based on high organic soils with an Organic Carbon (OC) content > 12 % OC and soils having a medium soil OC, 6-12 %. The 6 % limit is the traditional limit for organic soils in the Danish soil classification system from 1975. Soils having 6-12 % OC are given emission factors, which are half of what have been measured in soils having > 12 % OC. Very few measured values can be found for these soils. However, during drainage, a continuous degradation of the OC will take place until an equilibrium state is obtained between input and degradation, which is around 1.5-2.5 % OC in most cultivated mineral soils.

The area of organic soils with annual crops or grass in rotation is based on data from the EU subsidy register and a soil map for organic soils from 2010. The organic soil map has shown a decrease in the area with organic soils in Denmark. It is assumed to have a high accuracy. Soil maps were produced in 1975 and again in 2010. In 1975, 243 000 ha agricultural land was registered as having > 6 % OC. Of these has 118 000 ha been estimated to have >12 % OC. Using the 2010 boundary of agricultural land map on top of the soil map from 2010, these areas has been reduced in total to around 179 000 ha > 6%. This large decrease is attributed to the Danish organic soils being very shallow and thus "just disappear" because they are depleted for organic matter. In the projection is only taken into account conversion of organic soils to WE. No "disappearance" or reclassification of organic soils to mineral soils is included in the projection so the development can be seen as a conservative approach.

The financial allocation for re-establishment of WE in the governmental budget (Finance Act, 2022) made by the Danish Agricultural Agency and the

Danish Environmental Agency based on historical data on wetland restoration experiences is used in the projection. The overall result is that approximately 64 % of an established WE will take place on organic soils (>6 % OC). The expected total converted organic agricultural land converted to WE from 2021 to 2032 is shown in Table 8.4. The projection assumes a three year delay from the financing to the establishment of the WE, so the 611 ha mentioned for 2021 in Table 8.4 is based on financial funding in 2018.

Table 8.4 Expected funded agricultural areas converted to WE in 2021-2032, ha (Finance Act 2022 and other sources) and its expected share on organic soils.

	% organic	2021	2023	2025	2027	2029	2030	2032	Total area 2021-2032
Lavbundsordning uk.29 kollektive (LDP ordning)	75%	130	756	376	376	376	376		4347
Lavbundsordning +22000 (CAP + national)	75%			2445	2163	6479	6479		22000
N-Vådområder uk.34	50%	481	817	1414	1414	1414	1414		13343
P-Vådområder uk.39	50%		0	98	105	98	98		620
FL20 lavbund	60%			2000	1500	1500	1500	1500	15000
FL21 lavbund (5000 ha)	60%			1250	1250				5000
Total funded WE conversion, ha		611	5082	17909	31918	47443	57310	60310	60310

The applied emission factor for CO_2 from organic soils is 11.5 tonnes C per ha for annual crops and for grass in rotation. Drained GL on organic soils outside annual rotation has a lower emission factor of 8.4 tonnes C per ha per year combined with a CH_4 emission factor of 16 kg per ha per year. N_2O emissions are reported in the agricultural chapter. For shallow-drained nutrient rich organic soils, a CH_4 emission factor of 39 kg per ha per year from the 2013 Wetland Supplement is used (IPCC, 2014). IPCC (2014) is also the source for the emission factor for leached carbon, i.e. off-site CO_2 emissions via waterborne carbon losses.

The total area with organic soils and their emissions reported in CL and GL is shown in Table 8.5.

Table 8.5 Areas and emission from organic soils in Cropland and Grassland.

	1990	2010	2018	2019	2020	2025	2030	2035	2040
Cropland, organic area, inside fields > 6 % OC, ha	133700	109877	94228	94444	92372	86955	73901	73001	73001
Grassland, organic area, > 6 % OC, ha	81590	70559	79063	78638	79922	74506	61451	60551	60551
Cropland, emission, > 6 % OC, kt CO_{2e}	3959	3175	2604	2614	2549	2378	1965	1936	1936
Grassland, emission, > 6 % OC, kt CO_{2e}	1975	1667	1864	1853	1882	1757	1455	1434	1434
Leached C from organic soils, kt CO_{2e}	180	147	141	141	140	131	109	107	107
CH_4 from Cropland and Grassland, kt CO_{2e}	256	210	207	207	206	193	160	158	158
Total emission, kt CO_{2e}	6370	5200	4815	4814	4777	4458	3689	3636	3636

The CO_2 emission from organic soils in CL was reduced from 3 959 kt CO_2 in 1990 to 2 549 kt CO_{2e} in 2020 (Table 8.5); it is expected to continue to decrease with an estimated emission in 2030 of 1 965 kt CO_{2e}. For Grassland, the same pattern is expected from 1 975 kt CO_{2e} in 1990 to 1 455 kt CO_{2e} in 2030.

From 2033, the annual emission is expected to be fairly constant as no further conversion of organic soils are included in the projection. Based on expert judgement from established WE, it can be concluded that a high share of the planned WE establishment is taking place on fairly wet soils and not on fully drained agricultural organic soils and hence the emission effect is smaller. Use of an emission factor for fully drained soils (11.5 tonnes C per ha per year) is likely an overestimation of the real effect. A further analysis on the real agricultural state of the planned projected WE is of outmost importance to get a better understanding of the real drainage status of the organic agricultural soils.

8.2.3 Perennial wooden crops

Perennial wooden crops in CL covers fruit trees, fruit plantations and energy crops grown on CL. Fruit trees are marginal in Denmark and cover only around 5 300 hectares in 2020. No changes in the area with fruit trees are expected. The area with willow as energy crop is expected to be stable with 4 837 hectares in 2020, as there are currently no incentives to increase the area. A possible increase in this area has only very marginal effect on the emission estimates, as the area is harvested every 2-3 year and thus no larger amounts of C in living biomass is present in the willow plantations.

8.2.4 Hedgerows and small biotopes

The area with hedgerows and small biotopes, which do not meet the definition of forest, is today around 100 000 hectares in the defined CL area. An analysis has shown that the area has not changed significantly over the past 20 years, although there is large dynamic in the landscape as old hedgerows are removed and replaced with new ones to facilitate new farming technologies. Establishing hedgerows and small biotopes are partly subsidised by the Danish government. No further establishment of new hedges with governmental funding is assumed as it has not been allocated in the financial budget.

8.3 Grassland

GL is defined as permanent grassland and areas without perennial vegetation meeting the forest definition. Grass in rotation is reported under CL.

A total of 169 000 hectares is reported in the GL sector in 2020. The area is expected to be fairly constant in the future. The Danish reporting is based on information from the EU subsidiary system for each land parcel. In this system, the actual crop grown on each field is known. As the farmers reporting for a given field often changes from annual crops to GL, this information adds ‘noise’ to the reporting system because a high share of the agricultural land, either CL or GL, is reported in the category “Land converted”. It should be mentioned here, that the GL definition differs from the one used by Statistics Denmark for permanent GL and includes heath land and other marginal areas, which are not reported in the other land use categories. Therefore, areas reported here for GL are not comparable to data from Statistics Denmark.

The amount of living biomass in GL is limited and only minor changes are foreseen.

For drained organic soils in GL > 12 % OC, which can be found inside geographically located fields in the field maps, an average emission of 8 400 kg C per ha per year (national figure) is assumed, combined with a CH_4 emission of 16 kg CH_4 per ha per year (IPCC 2014).

N_2O emissions from cultivated GL are reported in the agricultural sector.

Although no major changes in GL is assumed, GL will continuously be a net source which is slightly reduced from currently around 1 800 to 1 500 kt CO_{2e}

per year in 2030 (Table 8.5) due to the expected conversion of organic GL soils to wetlands.

8.4 Wetlands

Wetlands (WE) are defined as peat land where peat excavation takes place, and restored WE. Emissions from wetlands occurring before 1990 are not reported. Due to the intensive utilisation of the Danish area for farming purposes, WE restoration has taken place for many years for environmental reasons.

8.4.1 Peat land

Peat excavation is taking place at three locations in Denmark. The sites are managed by Pindstrup Mosebrug A/S (www.pindstrup.dk). In total, it is estimated that 800 hectares are under influence of peat excavation, although the current open area for peat excavation is around 400 hectares. Pindstrup Mosebrug A/S is operating under a 10-year licence. The license has recently been renewed (Pindstrup Mosebrug, pers. com) and it is not expected to be extended further. It is therefore not expected that any major changes will take place until the new licence expires in 2028. From 2029, no peat excavation is expected in Denmark.

The emission is estimated as a degradation of peat on the soil surface and an immediate oxidation of excavated peat, which is mainly used for horticultural purposes.

In 2020, 165 000 m^3 of peat were excavated. This was higher than in previous years and can possibly be attributed to more dry conditions for peat extraction. The total emission from this is estimated to 34 kt CO_2 and 0.0004 kt N_2O per year.

8.4.2 Re-established Wetlands

Only emissions from re-established WE are included in the WE category. Emissions from naturally occurring wetlands, have not been estimated. Some larger WE restoration projects were carried out in the 1990s. Until 2020, in total 27 500 ha has been converted WE of which 4 300 ha can be considered as organic soil. The low fraction of organic soils in the historical conversions is mainly due to the fact that previously a large share of wetlands construction was made to reduce nitrogen leaching on mineral soils and not targeted organic soils.

There has been a large variation in the area converted to restored WE within the past years. In the projection, up to 7 000 ha is expected to be converted to WE in a single year in the period up to 2032 (Table 8.4). From 2032, no conversion is projected as the projection is based on a frozen policy assumption where no further funding is available for wetland constructions.

The new WE are divided into fully covered water bodies (lakes) and partly water covered WE. In the projection is assumed that 90 % of the area is converted to partly water covered wetlands and 10 % into lakes.

The new partly water covered WE are assumed to be in zero balance with the environment in terms of the C stock. This means that no losses or gains are assumed in the soil. Only emissions of CH_4 occur. The 2013 Wetlands Supplement assumes a net emission of 288 kg CH_4 emission from the WE. This has been implemented in the projection for partly water covered WE, but not for lakes and other fully water covered areas.

The overall expected emission trend for WE remaining WE are shown in Table 8.3. In recent years, the emission from managed WE has been estimated to around 70 kt CO_{2e} per year in the most recent years. This is expected to increase to 250 kt CO_{2e} per year in 2030 after the peat excavation has ceased and the emerging of new WE - primarily due to the large CH_4 emission from the organic soils on re-established WE.

8.5 Settlements

The need for areas for housing and other infrastructure has resulted in an increase in the SE area from 1990 to 2020 of 52 488 hectare or 1 600 hectare per year. It is assumed that the historic increase in SE will continue in the future and mainly result from conversion of CL. The projection assumes an annual conversion of 2 718 ha per year, which is the average conversion to SE in the years 2012 to 2020.

The overall expected emission trend is shown in Table 8.3. Land converted to SE is considered a source of CO_2 because the C stock in land use categories other than SE is higher than in SE areas. In GL and CL, the C stock in mineral soils is 121-142 tonnes C per ha. In SE, it is assumed that a new equilibrium of 96.7 tonnes C per ha is reached after 30 years. The estimated new equilibrium stage is 80 % of the value in CL and in accordance with the IPCC 2006 Guidelines (IPCC, 2006), as no Danish data are available. Consequently, the emission from converted soils will continue for many years.

8.6 Other Land

Other Land (OL) is defined as sandy beaches and sand dunes without or with only sparse vegetation. The total area is 26 433 hectares in all years. No changes in the area are foreseen in the future. The C stock in these soils is very low and almost absent in terms of living biomass. No emissions are expected from these areas.

8.7 Fires

Forest fires are very seldom in Denmark and only as wild fires. As an average, between 0 and 2 hectares are burned per year. Controlled burning of heathland to maintain the heath is carried out by the Danish Nature Agency. Previously, around 300 hectares were burned every year. In some years, more areas have been burned, resulting in around 700-800 hectares burned area every year. These very small areas are not assumed to have any influence on the C stock of living biomass as regeneration takes place very fast. The emissions from these fires are included in Table 8.3 and shown in Table 8.6.

Table 8.6 Emission from forest wild fires and controlled burning of heath land.

	1990	2010	2015	2020	2025	2030	2035	2040
Forest area burned, ha	150	0	0	0	0	0	0	0
Heathland area burned, ha	47	359	714	29.7	300	300	300	300
Total burned area, ha	197	359	714	29.7	300	300	300	300
Emission, CH_4, kt	0.026	0.001	0.001	0.000	0.001	0.001	0.001	0.001
Emission, N_2O, kt	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total, kt CO_2 eqv.	1.086	0.031	0.062	0.003	0.026	0.026	0.026	0.026

8.8 Harvested Wood Products

The category Harvested Wood Products (HWP) is reported by IGN in Johannsen et al., 2022.

8.9 Emission

The total emission is shown in Table 8.3.

The overall picture of the LULUCF sector is a net source of 6 874 kt CO_{2e} in 1990. In 2020, the estimated emission has been reduced to a net source of 3 107 kt CO_{2e} increasing to be a net source of 3 891 kt CO_{2e} in 2021-2030 (average of 2021-2030). The major reason for the decrease in the source is that the forests is changing from a net sink to be in a steady state in the future due to a foreseen ageing of the forest that will incentive the forest owners to increase the harvesting in the near future. For further information, see Johannsen et al., 2022.

For Cropland, a decrease in the emission is expected from an average in 2016-2020 of 2 835 kt CO_{2e} per year to 2 146 kt CO_{2e} per year in 2021-2030 and to 1 447 kt CO_{2e} per year in 2031-2040. This decrease is partly due to increased carbon stock in mineral soils due to an increased crop yield and a larger organic matter input into the mineral soils from the area with catch crops and also due to less managed organic soils. The large area with managed organic soils is responsible for an annual emission from both CL and GL organic soils of 4 830 kt CO_{2e} per year, 4 342 kt and 3 638 kt CO_{2e} per year, respectively, in the above mentioned years. GL is projected to be a net emitter of 2 000 kt CO_{2e} per year - also in the future.

The emissions from WE are estimated to increase from 70 CO_{2e} (in 2020) to 250-300 CO_{2e} (2030-2040) per year due to the increased conversion of organic agricultural soils to re-established wetlands.

Emissions from SE are projected to increase in the future being around 250 kt CO_{2e} per year due to C losses from areas converted to SE, mainly from agricultural soils.

Because Denmark has a high share of agricultural land, most LUCs are from CL to other land use categories. CL has the highest C stock of living biomass, so conversions from CL to other categories will result in a loss of C in living biomass and as such an emission. The reason for the loss is that the current C stock for annual crops is defined as average cereal harvest yield over 10 years multiplied with allometric functions used by Statistics Denmark for straw combined with Shoot-Root-ratio from IPCC 2006 GL (IPCC, 2006). This gives a carbon stock in living biomass of 5.9 tonnes C per ha. How living biomass in Cropland shall be interpreted is vague in the 2006 IPCC Guidelines (IPCC, 2006, page 2.19-2.20, 5.27-5.28). E.g. “The area of land converted can be categorized based on management practices e.g., intensively managed plantations.” The 2006 IPCC Guidelines gives a global default of 5 tonnes C per ha. A further elaboration has been made on the term allometric functions in the 2019 IPCC Refinement page 2.19-2.20, giving an default C stock of 4.7 tonnes C $ha^{-1,}$ page 5.41 (IPCC, 2019). Conversion of CL having a high amount of C in living biomass into other categories with a lower amount of living biomass like urban areas, will therefore cause an overall loss of C.

Increasing the input of organic matter into the agricultural soils seems very difficult, because out of an increased carbon input from extra crop residues, only 10-15 % of the annual input will add to the SOC, while the remaining will degrade very rapidly and return to the air as CO_2. An increased organic matter input to the mineral soils is therefore most likely if extra crops can be grown such as catch crops or converting of the existing crop pattern into other crop types like spring cereals to winter cereals or more grass in the crop rotation.

Growing of energy crops will only have marginal effect on the emissions in the LULUCF sector, as only small amounts of C will be stored temporarily in the energy crops before it is harvested.

8.10 Recalculations

Several recalculations has been made since the latest projection which has affected both the historical and the projected data

- New expectations on Afforestation rates and on establishing wetlands on cropland and grassland.
- New temperature scenario for the projection.
- Changed expectation on future C stocks in forest land remaining forest land (Nielsen et al., 2022, Johannsen et al., 2022).
- Implementation of a new EU regulation from 2023 on mandatory set-a-side.
- Changed C stock factors when afforestation is made (Nielsen et al., 2022).
- A correction of an error in the C-TOOL set up where the allometric function for wheat has been corrected for the whole time series.
- Recalculation of Harvested Wood Products (Nielsen et al. 2022).

The correction of error in C-TOOL is towards a lower amount of straw per hectare. As a consequence, the annual C input decrease and consequently it is more difficult to maintain the current estimated C stock. The result is a higher reported emission.

8.11 Uncertainty

The emission uncertainty estimates are very high as the LULUCF sector is dealing with biological processes. If the emission factors are kept constant for the whole time series, the uncertainty estimates are low to medium. Generally, the conversion of one land use category to another (except for Forestry) has a low effect on the emission estimates.

The highest inter-annual uncertainty relates to the use of the dynamic model for estimating the degradation of Soil Organic Matter, C-TOOL. The input data depends on actual harvest yields and the degradation on future temperature regimes in combination with a low annual change compared to a very large C stock in the soil. The total C stock in the agricultural mineral soils has been estimated to approximately 312 Tg C, which is equivalent to 1 100 million tonnes of CO_2. Even small changes in the parameters may change the emission prediction substantially. The average temperature in Denmark was very high in 2006-2008 whereas the average temperature decreased in 2009 and 2010 (Figure 8.4). This difference in temperature has an impact on the modelled outcome from C-TOOL. The effect of the cold winter in 2009 could be seen directly in the reported inventory on the emission from agricultural soils. A high uncertainty should therefore be expected for the emission estimate from especially mineral agricultural soils. The uncertainty for the organic soils mainly relate to the uncertainty on the estimate of the absolute emission factor used for these soils. Changes between years are therefore due to actual changes in how the land is utilized.

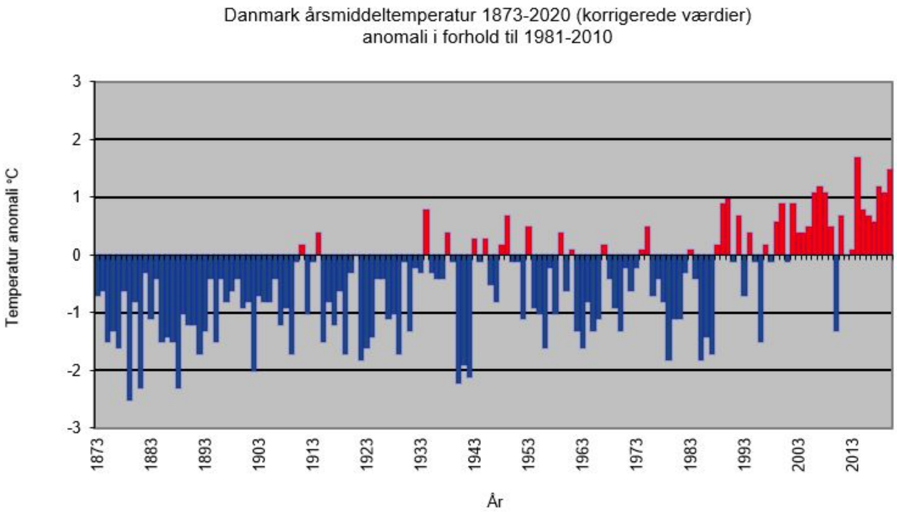

Figure 8.4 Annual change in temperature in Denmark 1873 to 2020 in relation to 1981-2010 (Cappelen, 2020).

8.12 The Danish commitment under the European Union 2021-2030

LULUCF is included in the Danish reduction commitment under the European Union. The EU regulation is laid down in Decision No 529/2013/EU. LULUCF emissions under this decision must follow the IPCC 2006 Guidelines and the 2013 Wetlands Supplement. Thus, there is no difference in the way the emission estimates are derived compared to the emission estimates submitted to UNFCCC. The accounting rules differ however, as Managed Cropland (MC) and Managed Grassland (MG) becomes obligatory with a base year for the emission being the average for the years 2005-2009. Accounting years are 2021-2030. Furthermore, Managed Wetlands (MW) has become obligatory, with the same base year but it must only be included in the accounting for year 2026-2030. For all three sectors net-net accounting must be used.

For accounting quantities in connection with forest, please refer to Johannsen et al., 2022.

Table 8.7 shows the average emissions for the base year (average 2005-2009) and projected emissions up to 2030. Table 8.8 shows the projected accounting for MC, MG and MW. The projection estimates that MG will contribute with is 17 128 kt CO_{2e}, MG with a debit of 1 315 kt CO_{2e} and MW with 517 kt CO_{2e}. In total, 15 296 kt CO_{2e} in the period 2021 to 2030.

Table 8.7 Projected emission estimates for Cropland Management, Grazing Land Management and Managed Wetlands under EU regulation 529, kt CO_{2e}. Not all years are shown.

	Average 2005-2009	2021	2023	2025	2027	2029	2030
MC	3918	2206	2528	2457	2060	1829	1702
MG	1865	2147	2099	2066	1940	1838	1747
MW	93	67	82	113	179	200	249

Table 8.8 Projected account estimates for Managed Cropland, Managed Grassland and Managed Wetlands under EU regulation 529, kt CO_{2e}. Not all years are shown.

	2021	2023	2025	2027	2029	2030	Total
MG	-1711	-1390	-1461	-1858	-2089	-2216	-17128
GM	282	234	201	75	-27	-117	1315
MW	NA	NA	NA	85	107	155	517
Total	-1429	-1156	-1260	-1697	-2009	-2178	-15296

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9 Conclusions

In assessing the projection, it is valuable to separate the emissions included in the EU ETS and hence the current projection provides a separate projection of the CO_2 emissions covered by the EU ETS. The CO_2 emissions covered by EU ETS are shown for selected years in Table 9.1. Detailed tables containing the projected emissions are available at:
http://envs.au.dk/videnudveksling/luft/emissioner/emissioninventory/

The historic and projected GHG emissions are shown in Figure 9.1. Projected GHG emissions include the estimated effects of policies and measures implemented or decided as of December 2021 and the projection of total GHG emissions is therefore a so-called ‘with existing measures’ projection also called ‘frozen policy’.

The main emitting sectors in 2020 are Energy industries (16 %), Transport (27 %), Agriculture (25 %) and Other sectors (8 %). For the latter sector, the most important sources are fuel combustion in the residential sector. GHG emissions show a decreasing trend in the projection period. The total emissions in 2020 are estimated to be 44.9 million tonnes CO_2 equivalents including LULUCF and indirect CO_2 and the corresponding total in 2040 is projected to be 28.2 million tonnes CO_2 equivalents. From 1990 to 2020 the emissions decreased by 42.5 %. From 2020 to 2040, the emission is projected to decrease by approximately 37 %.

The total greenhouse gas emissions in 1990 including LULUCF and indirect CO_2 is estimated at 78.0 million tonnes of CO_2 equivalents and the emission in 2030 is projected to be 34.7 million tonnes of CO_2 equivalents including LULUCF and indirect CO_2. This corresponds to a reduction of 55.5 % between 1990 and 2030. The effect of carbon capture and storage (CCS) in the projection is not attributable to any sector and not included in this figure.

In 2005, the emissions including LULUCF and indirect CO_2 is calculated to 72.1 million tonnes of CO_2 equivalents. It decreased by 37.8 % from 2005 to 2020 and estimated to be reduced by 51.9 % from 2005 to 2030.

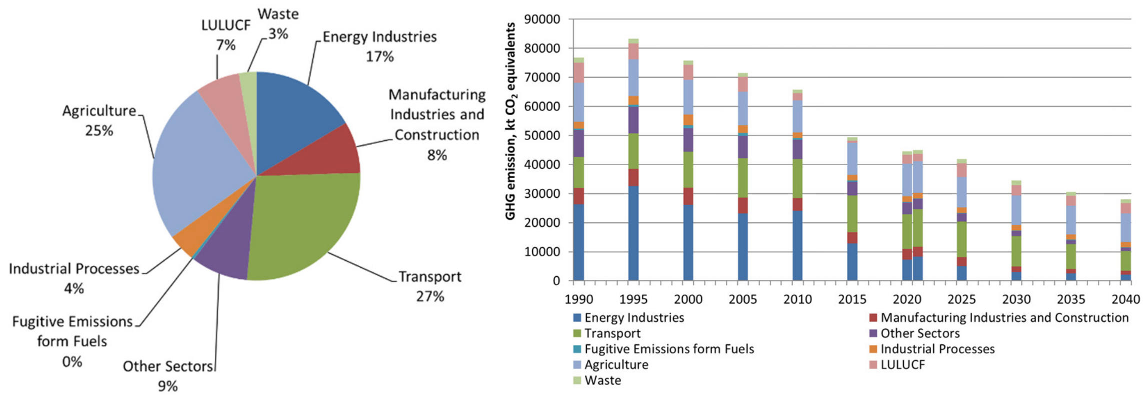

Figure 9.1 Total GHG emissions in CO_2 equivalents. Distribution according to main sectors (2020) and time series for 1990 to 2040.

9.1 Stationary combustion

Stationary combustion includes Energy industries, Manufacturing industries and construction and Other sectors. Other sectors include combustion in commercial / institutional, residential and agricultural plants. The GHG emissions in 2020 from the main source, which is public power and heat production (44 %), are estimated to decrease in the period from 2020 to 2040 (90 %) due to a significant decrease in the fossil fuel consumption for electricity production in the later part of the time series. For residential combustion plants, a significant decrease in emissions is also projected; the emissions are expected to decrease by 91 % from 2020 to 2040, due to a lower consumption of fossil fuels. Emissions from manufacturing industries on the other hand only decreases by 72 %, due to a much smaller decrease in fossil fuel combustion.

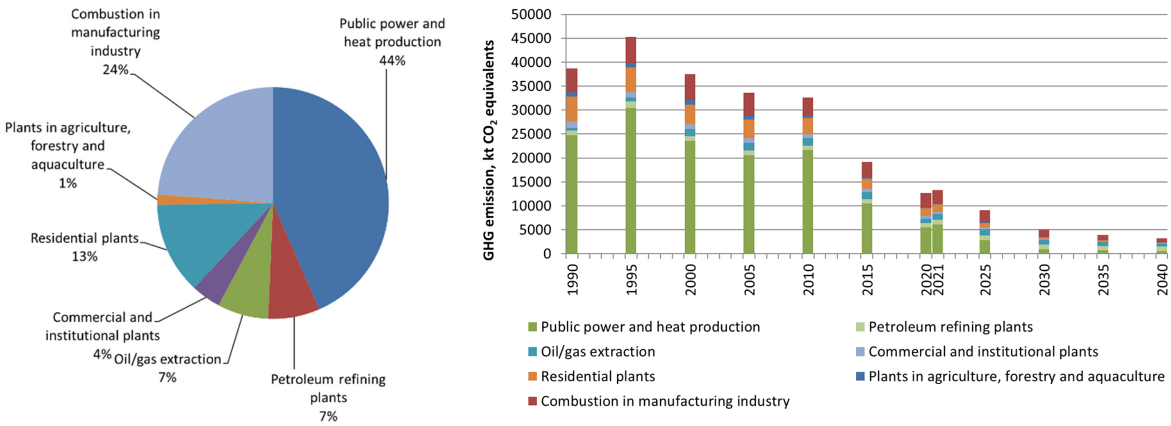

Figure 9.2 GHG emissions in CO_2 equivalents for stationary combustion. Distribution according to sources (2020) and time series for 1990 to 2040.

9.2 Fugitive emissions from fuels

The greenhouse gas emissions from the sector "Fugitive emissions from fuels" show large fluctuations in the historical years 1990-2020, due to emissions from exploration, which occur only in some years with varying amounts of oil and gas flared. Emissions from exploration are not included in the projection, as no projected activity data are available. Emissions are estimated to decrease in the projection period 2020-2040 by 18 %. The decrease mainly owe to expected decrease of offshore flaring in the oil and natural gas extraction. Emissions from extraction of oil and natural gas are estimated to decline over the projection period due to the expectation of a decrease of extracted amounts of natural gas. Emissions of greenhouse gases from other sources are estimated to be constant or nearly constant over the projection period.

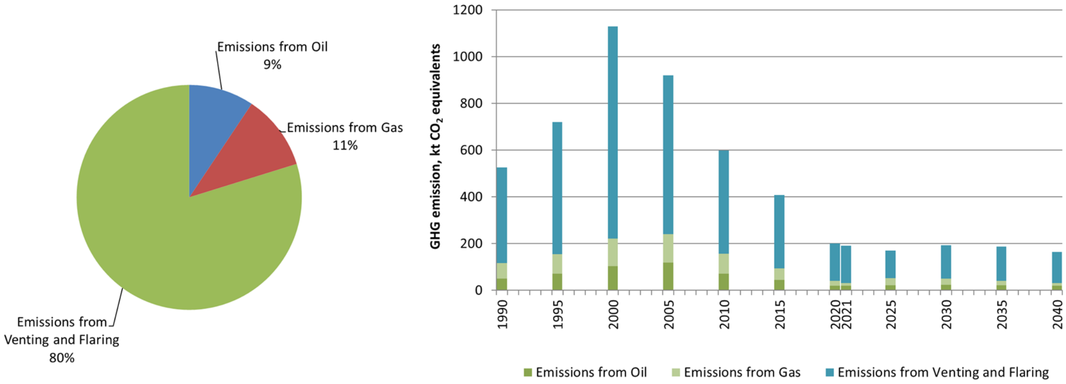

Figure 9.3 GHG emissions in CO_2 equivalents for fugitive emissions. Distribution according to sources for 2020 and time series for 1990 to 2040.

9.3 Industrial processes and product use

The GHG emission from industrial processes and product use increased during the nineties, reaching a maximum in 2000. Closure of a nitric acid / fertiliser plant in 2004 has resulted in a considerable decrease in the GHG emission. The most significant sources of GHG emission in 2020 are mineral industry (mainly cement production) with 70 % and use of substitutes (f-gases) for ozone depleting substances (ODS) (17 %). The corresponding shares in 2040 are expected to be 82 % and 7 %, respectively. Consumption of limestone and the emission of CO_2 from flue gas cleaning are assumed to follow the consumption of coal and waste for generation of heat and power. The GHG emission from this sector will continue to be strongly dependent on the cement production at Denmark's only cement plant.

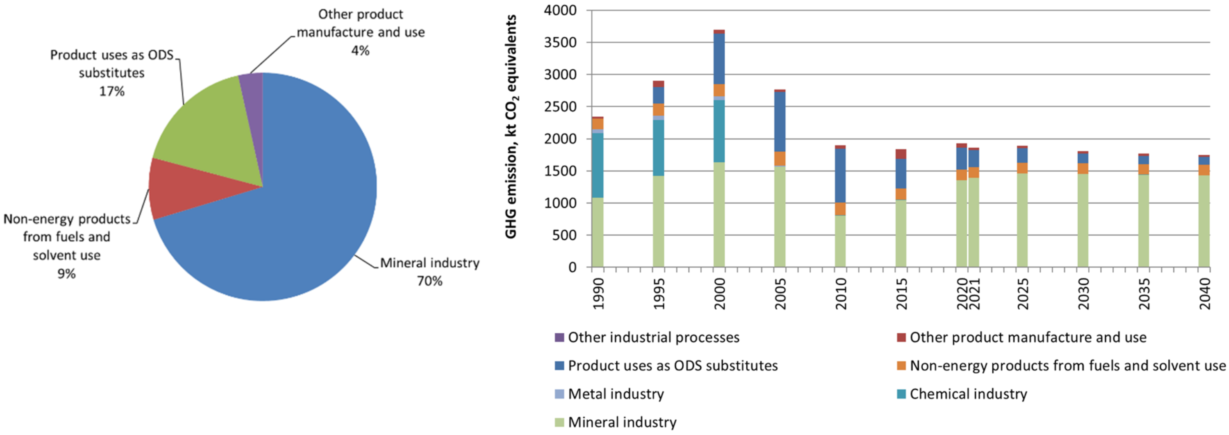

Figure 9.4 Total GHG emissions in CO_2 equivalents for industrial processes. Distribution according to main sectors (2020) and time series for 1990 to 2040.

9.4 Transport and other mobile sources

Road transport is the main source of GHG emissions from transport and other mobile sources in 2020 (80 %) and emissions from this source are expected to decrease in the projection period 2020 to 2040, but with the largest reduction happening after 2030. The emission shares for the remaining mobile sources (e.g. domestic aviation, national navigation, railways and non-road machinery in industry, households and agriculture) are small compared with road transport. Non-road machinery in agriculture, forestry and fishing contributes 8 % of the sectoral GHG emission in 2020.

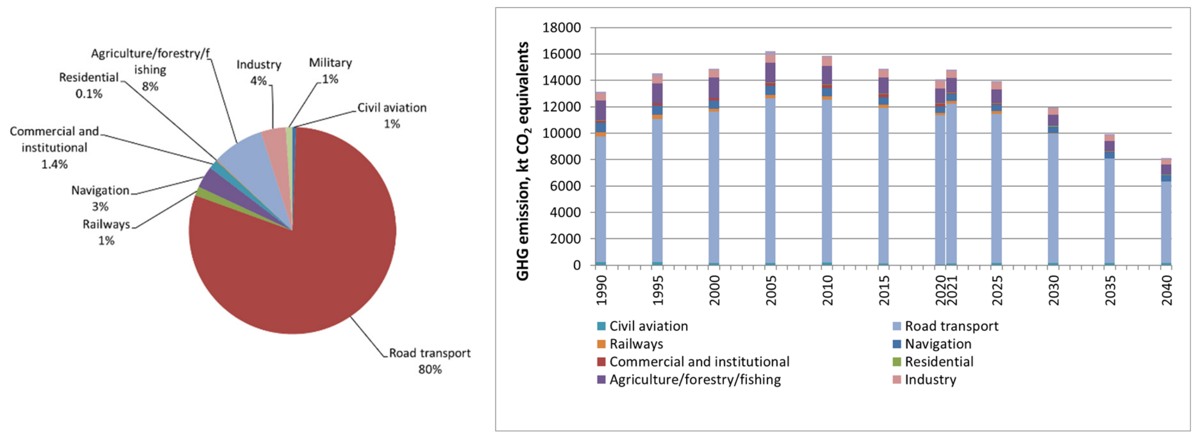

Figure 9.5 GHG emissions in CO_2 equivalents for mobile sources. Distribution according to main sources (2020) and time series for 1990 to 2040.

9.5 Agriculture

The main sources in 2020 are agricultural soils (40 %), enteric fermentation (33 %) and manure management (25 %). The corresponding shares in 2040 are expected to be 41 %, 39 % and 18 %, respectively. From 1990 to 2020, the emission of GHGs in the agricultural sector decreased by 16 %. In the projection years 2020 to 2040, the emissions are expected decline slightly by about 13 %. The reduction in the historical years can mainly be explained by improved utilisation of nitrogen in manure, a significant reduction in the use of fertiliser and a reduced emission from N-leaching. Measures in the form of technologies to reduce ammonia emissions in stables and expansion of biogas production are considered in the projections, but emissions from enteric fermentation are estimated to increase due to an expected increase in the number of animals.

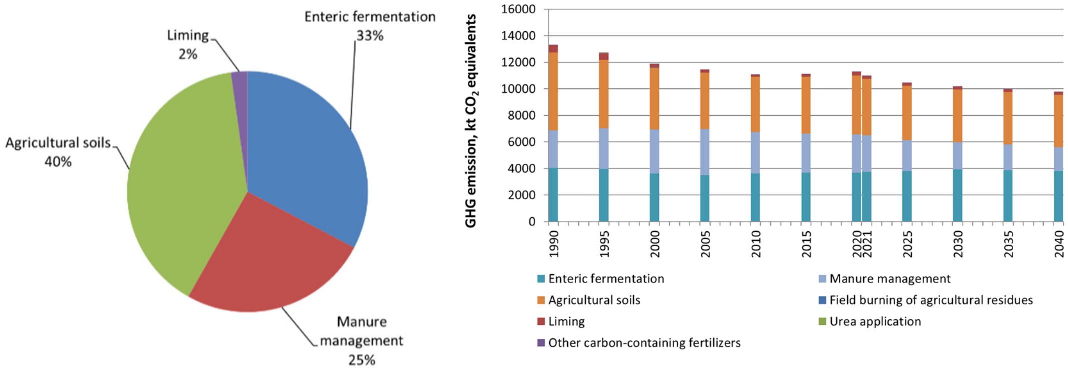

Figure 9.6 GHG emissions in CO_2 equivalents for agricultural sources. Distribution according to main sources (2020) and time series for 1990 to 2040.

9.6 Waste

The total GHG emission from the waste sector has been decreasing in the years 1990 to 2020 by 36 %. From 2020 to 2040, the emissions are projected to increase slightly by 7 % driven by a large increase in emissions from anaerobic digestion. In 2020, the GHG emission from solid waste disposal contributed with 44 % of the emission from the sector as a whole. A decrease of 39 % is expected for this source in the years 2020 to 2040, due to less waste deposition on landfills. An almost constant level for emissions from wastewater is expected for the projection period. GHG emissions from wastewater handling in 2020 contribute with 22 %. Emissions from biological treatment of solid waste contribute with 37 % in 2020 and 57 % in 2040.

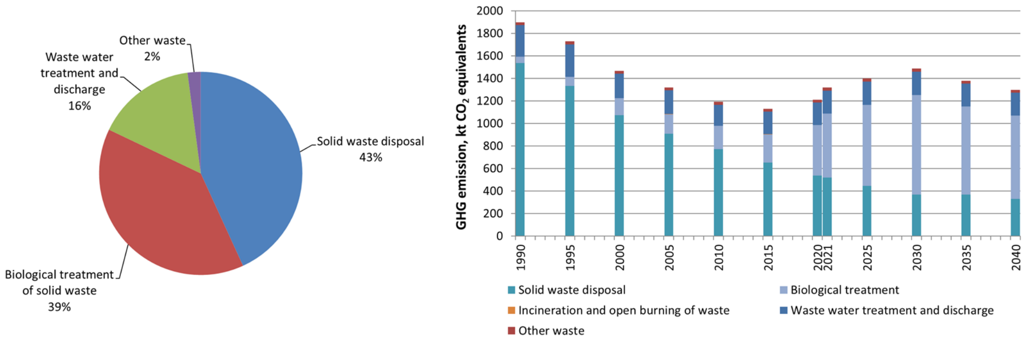

Figure 9.7 GHG emissions in CO_2 equivalents for Waste. Distribution according to main sources (2020) and the time series for 1990 to 2040.

9.7 LULUCF

The LULUCF sector includes emissions from Afforestation, Deforestation, Forest land remaining forest land, Cropland, Grassland, Wetlands, Settlement and Other land. This projection include only Cropland, Grassland, Wetland, Settlement and Other land. Forestry and Harvested wood products (HWP) is reported separately in Johannsen et al., 2022 although these emission estimates has been included here. The overall picture of the LULUCF sector excl. Forestry and HWP is a net source of 6 874 kt CO_{2e} in 1990. In 2020, the estimated emission has been reduced to a net source of 3 107 kt CO_{2e} and a net source of 3 891 kt CO_{2e} in 2021-2030 (average of 2021-2030). A small decrease is expected in year 2031-2040 compared to 2021-2030. This decrease can very likely be attributed to an expected increase in crop yield and a lower area with agricultural organic soils. However, it should be noted that the overall emission from this sector is very variable as it is very difficult to predict climate related emission/stock development in the agricultural soils. Agricultural mineral soils are expected to store more carbon in the near future. Agricultural regulations will reduce the area with cultivated agricultural organic soils further in the future, but there will still be a large net emission from these soils.

9.8 EU ETS

CO_2 emissions covered by EU ETS are from the energy sector and from industrial processes. From 2012 aviation is included in EU ETS, but otherwise only CO_2 emissions from stationary combustion plants are included under fuel combustion, hence the category Agriculture, forestry and aquaculture refers to stationary combustion within this sector. The major part of industrial process CO_2 emissions are covered by EU ETS. It is dominated by cement production and other mineral products. The results of the projection for EU ETS covered emissions are shown in Table 9.1.

Table 9.1 CO_2 emissions covered by EU ETS.

	20210	2025	2030	2035	2040
Public electricity and heat production	5461	2153	610	490	394
Petroleum refining	969	969	969	969	969
Other energy industries (oil/gas extraction)	1182	1256	1073	893	625
Combustion in manufacturing industry	2026	1833	1198	891	736
Domestic aviation	147	153	162	164	166
Agriculture, forestry and aquaculture	20	17	7	2	0
Fugitive emissions from flaring	126	94	113	115	106
Mineral industry	1379	1443	1439	1425	1416
Total	7918	7918	5570	4951	4412
Civil Aviation, international	1237	3125	3231	3241	3253

PROJECTION OF GREENHOUSE GASES 2021-2040

This report contains a description of models, background data and projections of CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 for Denmark. The emissions are projected to 2040 using a 'with measures' scenario. Official Danish projections of activity rates are used in the models for those sectors for which projections are available, e.g. the latest official projection from the Danish Energy Agency. The emission factors refer to international guidelines and some are country-specific and refer to Danish legislation, Danish research reports or calculations based on emission data from a considerable number of industrial plants. The projection models are based on the same structure and method as the Danish emission inventories in order to ensure consistency.

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