PROJECTION OF GREENHOUSE GASES 2019-2040

Scientific Report from DCE – Danish Centre for Environment and Energy No. 408 2020

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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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.

Keywords: Greenhouse gases, projections, emissions, CO_2, CH_4, N_2O, HFCs, PFCs, SF_6

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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
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
MCF	Methane Conversion Factor
MSW	Municipal Solid Waste
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 May 2020.

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
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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.

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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 2018. The emissions are projected to 2040 using a scenario, which includes the estimated effects of policies and measures implemented on 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 May 2020. The official Danish energy projection, e.g. the latest official projection from the Danish Energy Agency (DEA), is used to provide activity rates (2019-2040) 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 main emitting sectors in 2019 are Energy industries (19 %), Transport (30 %), Agriculture (24 %) and Other sectors (10 %). 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 2019 are estimated to be 44.6 million tonnes CO_2 equivalents excluding LULUCF and indirect CO_2 and 34.5 million tonnes in 2040. From 1990 to 2018 the emissions decreased by 31 %.

The total GHG emission in 1990 including LULUCF and indirect CO_2 is estimated to 77.2 million tonnes of CO_2 equivalents, while the emission in 2018 is estimated to 54.8 million tonnes of CO_2 equivalents and the emission in 2030 is projected to 43.0 million tonnes of CO_2 equivalents. This corresponds to a reduction of 29.0 % between 1990 and 2018 and a projected reduction of 44.4 % between 1990 and 2030.

In 2005, the emissions including LULUCF and indirect CO_2 is calculated to 72.6 million tonnes of CO_2 equivalents. It decreased to 54.8 million tonnes CO_2 equivalents in 2018 (24.5 %), the projected emission in 2030 is 43.0 million tons of CO_2 equivalents corresponding to a decrease since 2005 of 40.8 %.

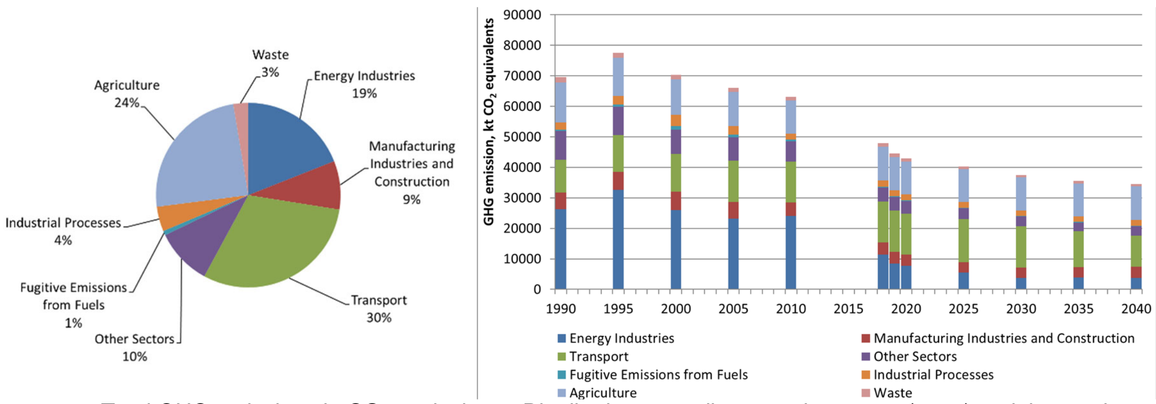


Figure 9.1 Total GHG emissions in CO_2 equivalents. Distribution according to main sectors (2019) and time series for 1990 to 2040.

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 2018 from the main source, which is public power and heat production (53 %), are estimated to decrease in the period from 2018 to 2040 (80 %) 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 projected; the emissions decrease by 48 % from 2018 to 2040, due to a lower consumption of fossil fuels. Emissions from manufacturing industries on the other hand only decreases by 3 %, 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 1990-2018, 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 2018-2040 by 42 %. 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 2018 are mineral industry (mainly cement production) with 64 % and use of substitutes (f-gases) for ozone depleting substances (ODS) (24 %). The corresponding shares in 2040 are expected to be 84 % and 5 %, 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 2018 (80 %) and emissions from this source are expected to decrease in the projection period 2018 to 2040, but only towards the very end, with no big changes in emissions until 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 9 % of the sectoral GHG emission in 2018.

Agriculture

The main sources in 2018 are agricultural soils (37 %), enteric fermentation (34 %) and manure management (27 %). The corresponding shares in 2040 are expected to be 36 %, 37 % and 25 %, respectively. From 1990 to 2018, the emission of GHGs in the agricultural sector decreased by 16 %. In the projection years 2018 to 2040, the emissions are expected to remain almost constant. 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 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 2018 by 35 %. The decreasing trend is expected to continue with a decrease of 41 % from 2018 to 2040. In 2018, the GHG emission from solid waste disposal contributed with 49 % of the emission from the sector as a whole. A decrease of 43 % is expected for this source in the years 2018 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 2018 contribute with 10 %. Emissions from biological treatment of solid waste contribute with 39 % in 2018 and 33 % 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 HWP is reported separately in Johannsen et al. (2019) although these emission estimates has been included here. The overall picture of the LULUCF sector excl. Forestry and HWP is a net source of 7 001 kt CO_2 equivalents in 1990. In 2018, the estimated emission has been reduced to a net source of 6 353 kt CO_2 and a net source of 4 828 kt CO_2 equivalents 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 slightly 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.

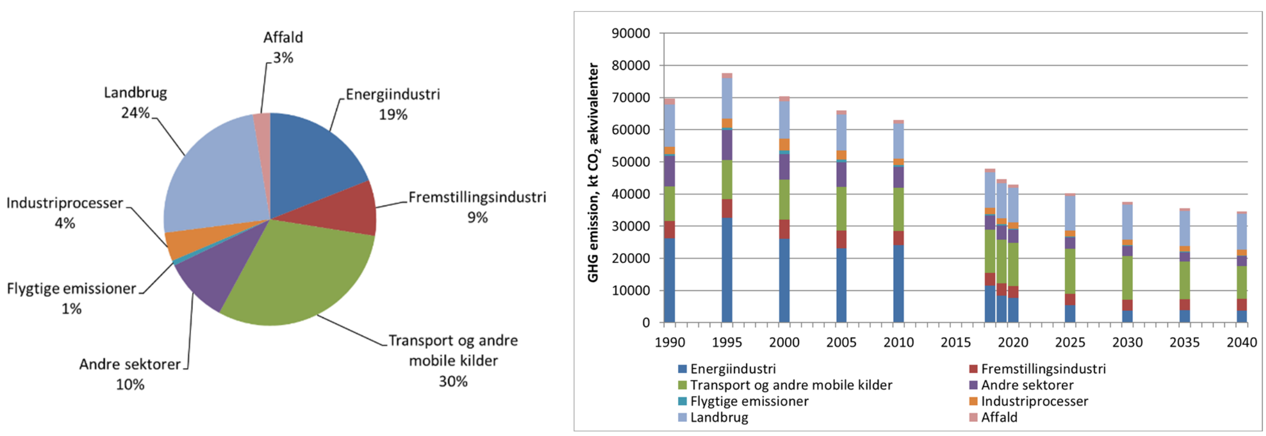
Sammenfatning

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 2018. Emissionerne er fremskrevet til 2040 på baggrund af et scenarie, som medtager de estimerede effekter på Danmarks drivhusgasudledninger af virkemidler iværksat eller besluttet indtil maj 2020 (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 (2019-2040) 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.

De vigtigste sektorer i forhold til emission af drivhusgas i 2019 forventes at være energiproduktion og -konvertering (19 %), transport (30%), landbrug (24 %), og andre sektorer (10 %). For "andre sektorer", er den vigtigste kilde forbrænding i husholdninger (Figur R.2). Drivhusgasemissionerne viser et fald gennem fremskrivningsperioden. De totale emissioner er beregnet til 44,6 millioner tons CO_2-ækvivalenter i 2018 eksklusiv LULUCF og indirekte CO_2 og til 34,5 millioner tons i 2040. Fra 1990 til 2018 er emissionerne faldet med 31 %.

Den samlede drivhusgasemission i 1990 inklusiv LULUCF og indirekte CO_2 er estimeret til 77,2 millioner tons CO_2-ækvivalenter, mens emissionen i 2018 er estimeret til 54,8 millioner tons CO_2-ækvivalenter og emissionen i 2030 er fremskrevet til 43,0 million tons CO_2-ækvivalenter. Dette svarer til en reduktion på 29,0 % mellem 1990 og 2018 og en fremskrevet reduktion på 44,4 % mellem 1990 og 2030.

I 2005 er emissionen med LULUCF og indirekte CO_2 beregnet til 72,6 millioner tons CO_2-ækvivalenter. Emissionen var i 2018 faldet til 54,8 millioner tons CO_2-ækvivalenter (24,5 %). Den fremskrevne emission i 2030 er 43,0 millioner tons CO_2-ækvivalenter svarende til en reduktion siden 2005 på 40,8 %.



Figur R.2 Totale drivhusgasemissioner i CO_2-ækvivalenter fordelt på hovedsektorer for 2019 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 kraftvarme-værker, som er den største kilde i 2018 (53 %), er beregnet til at falde i perioden 2018 til 2040 (80 %) 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 2017 til 2040 med hele 48 % pga. lavere forbrug af de fossile brændstoffer. Emissioner fra fremstillingsindustrien falder kun med 3 % 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 1990-2018 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 42 % i perioden 2018-2040. 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 nær-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 64 % af drivhusgasemissionen i 2018, samt anvendelse af erstatningsgasser (f-gasser) for ozonnedbrydende stoffer (ODS), der bidrager med 24 %. De tilsvarende andele i 2040 forventes at ligge på hhv. 84 % og 5 %. 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 2018 (80 %), og emissionerne fra denne kilde forventes at falde en smule i fremskrivningsperioden 2018 til 2040. 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 9 % af sektorens drivhusgasser i 2018.

Landbrug

De største kilder i 2018 er emissioner fra landbrugsjorde (37 %), dyrenes fordøjelse (34 %) og gødningshåndtering (23 %). De tilsvarende andele i 2040 forventes at være hhv. 36 %, 37 % og 25 %. Fra 1990 til 2018 er emissionen fra landbrugssektoren faldet med 16 %. I fremskrivningsperioden forventes emissionerne at være relativt konstante. 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 er estimeret til at stige pga. en forventet stigning i antallet af dyr.

Affald

Affaldssektorens samlede drivhusgasemissioner er faldet med 35 % i perioden 1990 til 2018. Den faldende trend forventes at fortsætte med et fald på 41 % fra 2018 til 2040. I 2018 udgør drivhusgasemissionen fra lossepladser 49 % af den totale emission fra affaldssektoren. Et fald på 43 % er forventet for denne kilde i perioden 2018 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 2018 udgør spildevandshåndteringen 10 % af sektorens samlede emission. Emissionerne fra biologisk behandling af affald (kompostering og biogasbehandling) udgør 39 % i 2018 og 33 % 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. (2019). 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 7 001 kt CO_2-ækvivalenter. I 2018 er emissionen beregnet til 6 353 kt CO_2-ækvivalenter og fremskrevet til 4 828 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 and 2019). The purpose of the present project, "Projection of greenhouse gas emissions 2019 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 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 March 2019 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

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 280 ppm to about 390 ppm in 2010 (an increase of about 38 %) (IPCC, 2013), and exceeds the natural range of 180-300 ppm over the last 650 000 years as determined by ice cores.

The main cause for the increase in CO_2 is the use of fossil fuels, but changing land use, including forest clearance, has also been a significant factor. The greenhouse gases CH_4 and N_2O are very much linked to agricultural production; CH_4 has increased from a pre-industrial atmospheric concentration of about 722 ppb to 1803 ppb in 2011 (an increase of about 150 %) and N_2O has increased from a pre-industrial atmospheric concentration of about 270 ppb to 324 ppb in 2011 (an increase of about 20 %) (IPCC, 2013).

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 atmospheric lifetimes for different substances differ greatly, e.g. for CH_4 and N_2O, approximately 12 and 120 years, respectively. So the time perspective clearly plays a decisive role. The lifetime chosen is typically 100 years. The effect of the various GHGs can then be converted into the equivalent quantity of CO_2, i.e. the quantity of CO_2 producing the same effect with regard to absorbing solar radiation. According to the IPCC and their Fourth Assessment Report, which UNFCCC has decided to use as reference, the global warming potentials (GWP) 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).

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 2018. The emissions are not corrected for electricity trade or temperature variations.

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

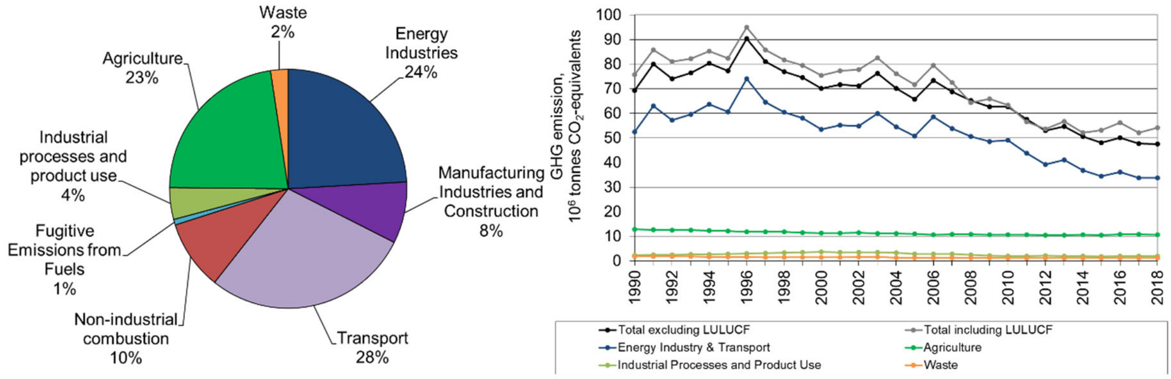


Figure 1.1 Greenhouse gas emissions in CO_2 equivalents distributed on main sectors for 2018 (excluding LULUCF and indirect CO_2) and time series for 1990 to 2018.

1.3.1 Carbon dioxide

The largest source of the emission of CO_2 is the energy sector, which includes the combustion of fossil fuels such as oil, coal and natural gas (Figure 1.2). Energy industries is a dominant source contributing 32.5 % of the total CO_2 emission, Figure 1.2. The transport sector contributes 38.3 %. The CO_2 emission (excl. LULUCF) decreased by 0.2 % from 2017 to 2018. The main reason for this small decrease is decreasing emissions from energy industries due to a decrease in the consumption of fossil fuels. Emissions from the transport sector increased mainly driven by increased activity in road transport. In general, CO_2 emissions fluctuate significantly as a result of the electricity trade with neighbouring countries. In 2018, the actual CO_2 emission (excl. LULUCF, incl. indirect CO_2) was 36.1 % less than the emission in 1990.

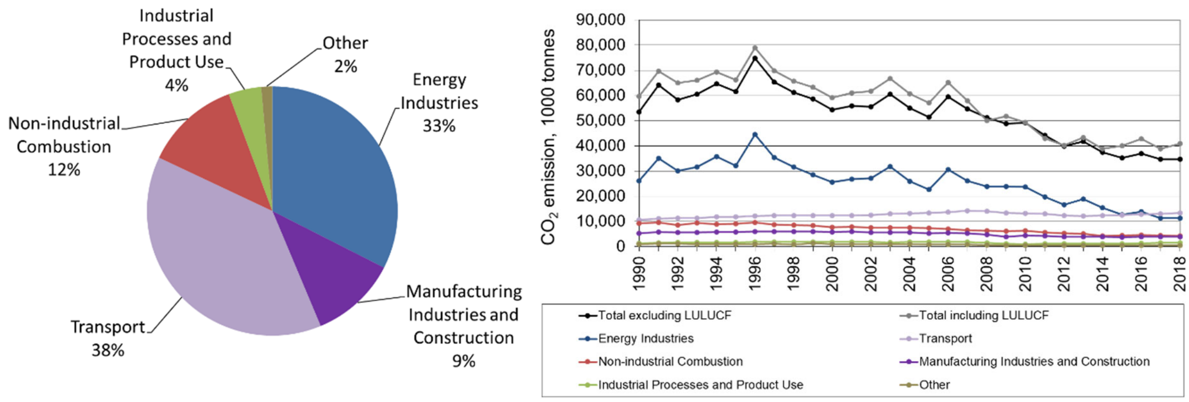


Figure 1.2 CO_2 emissions. Distribution according to the main sectors for 2018 and time series for 1990 to 2018.

1.3.2 Nitrous oxide

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

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

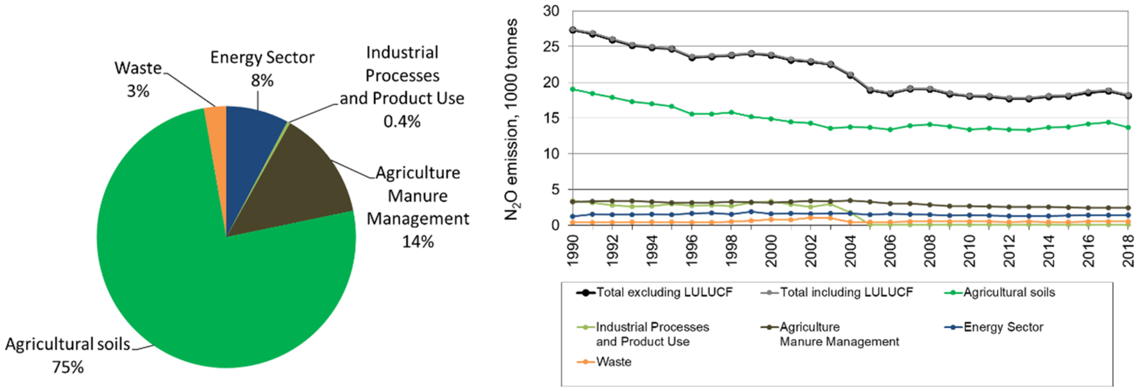


Figure 2.4 N_2O emissions. Distribution according to the main sectors for 2018 and time series for 1990 to 2018.

1.3.3 Methane

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

Since 1990, the emission of CH_4 from enteric fermentation has decreased 6.7 %, mainly due to the decrease in the number of cattle. However, this reduction is countered by an increase of 19.7 % in emissions from manure management caused by a change in housing type towards slurry-based systems. In later years, the emission from manure management has decreased due to changes in manure management, e.g. more biogas treatment and acidification of slurry. The emission of CH_4 from solid waste disposal has decreased significantly (63.5 %) from 1990 to 2018 due to an increase in the incineration of waste and extensive recycling thereby causing a decrease in the waste disposal on land. The CH_4 emission from the energy sector increases from mid 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.

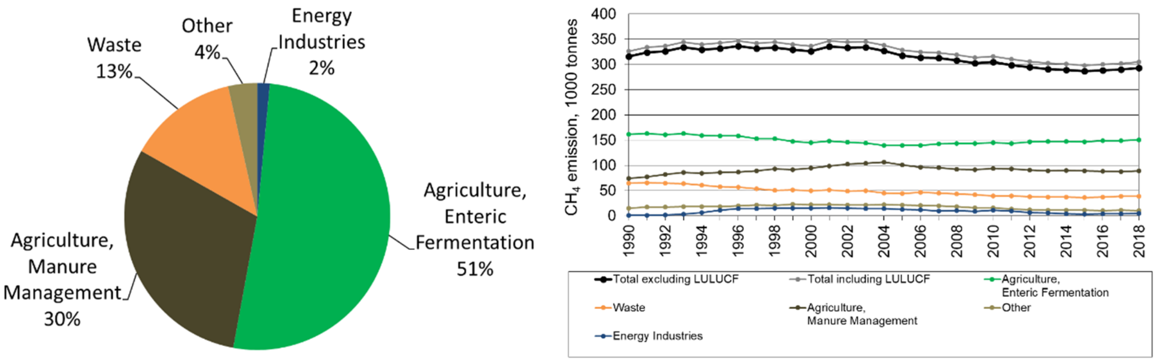


Figure 2.3 CH_4 emissions. Distribution according to the main sectors for 2018 and time series for 1990 to 2018.

1.3.4 Fluorinated gases

This part of the Danish inventory only comprises a full data set for all substances from 1995. From 1995 to 2000, there has been a continuous and substantial increase in the contribution from the range of F-gases as a whole, calculated as the sum of emissions in CO_2 equivalents, see Figure 2.5. This increase is simultaneous with the increase in the emission of HFCs. For the time series 2000-2009, the increase is lower than for the years 1995 to 2000 and after 2009 the emission has been decreasing. The overall increase from 1995 to 2018 for the total F-gas emission is 54.7 %, while emissions decreased from 2009 to 2018 by 46.3 % mainly due to decreasing emissions of HFCs. SF_6 contributed considerably to the F-gas sum in earlier years, with 28.6 % in 1995. Environmental awareness and regulation of this gas under Danish law has reduced its use in industry, see Figure 2.5. A further result is that the contribution of SF_6 to F-gases in 2018 was only 13.1 %. The use of HFCs has increased several folds. HFCs have, therefore, become even more dominant, comprising 71.2 % in 1995, but 86.9 % in 2017. HFCs are mainly used as a refrigerant. Danish legislation regulates the use of F-gases, e.g. since January 1, 2007, new HFC-based refrigerant stationary systems are forbidden. Refill of old systems is still allowed.

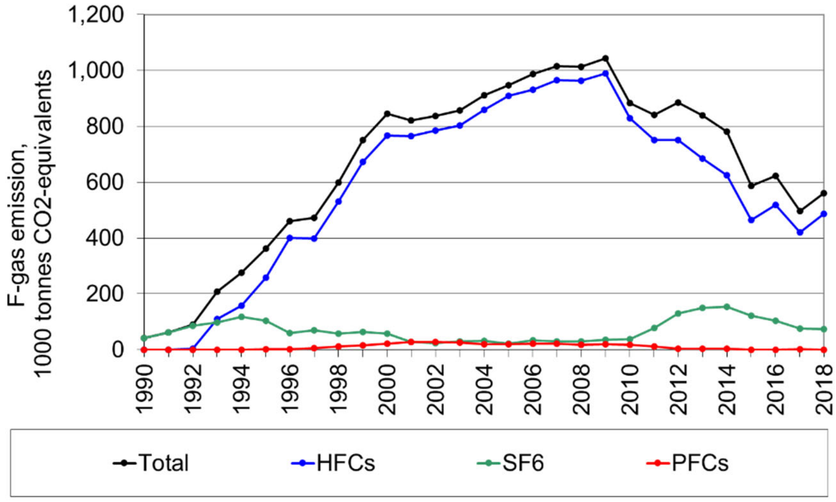


Figure 2.5 F-gas emissions. Time series for 1990 to 2018.

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

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, 2016) 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, 2016) 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, 2016). 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 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. It is important to stress that the overall fuel consumption as reported in the official energy statistics is maintained 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 plastic part of municipal waste is included in the projected emissions.

The fuel consumption in the energy projections have in the most recent energy outlook not been divided into ETS and non-ETS consumption. Therefore, the split between ETS and non-ETS is uncertain and has been done using historical data, assumptions from previous projections together with knowledge of the industrial process emissions that are covered by the EU ETS. The result of this is included in Chapter 14.

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 50 % 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, 2020).

In the projection model, the sources are separated into area sources and large point sources, where the latter cover all plants larger than 25 MW_e. The projected fuel consumption of area sources is calculated as total fuel consumption minus the fuel consumption of large point sources and mobile sources.

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. For plants larger than 25 MW_e, fuel consumption is specified in addition to emission factors. 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.

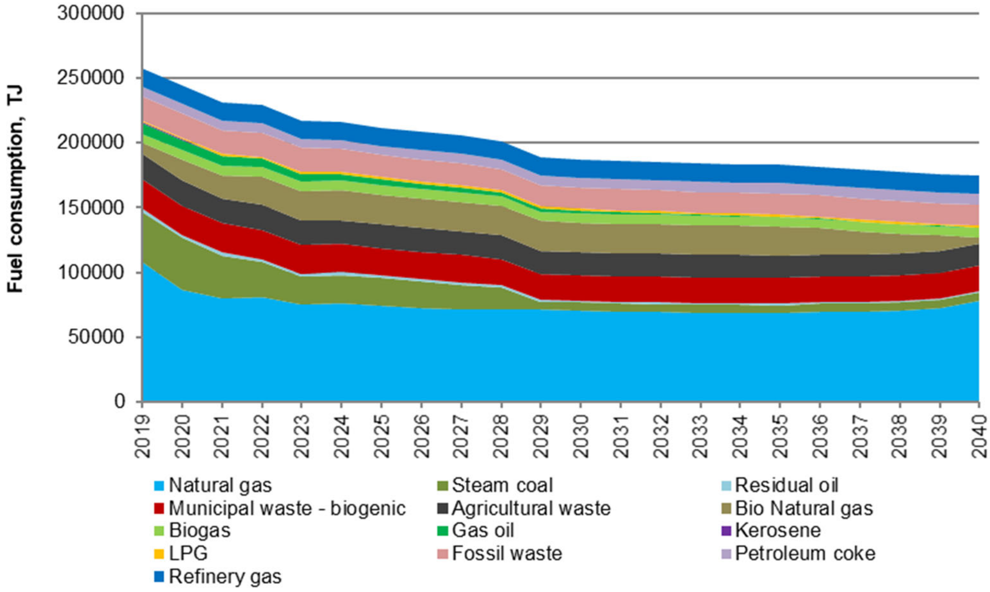

Figure 2.1 Projected energy consumption by fuel type.

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.

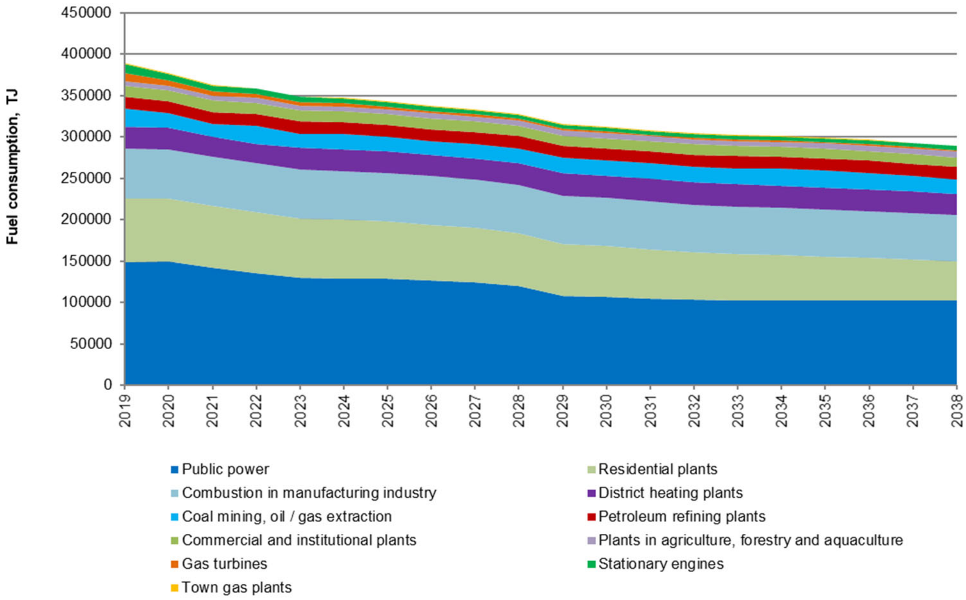

Figure 2.2 Energy use by sector.

2.4 Emission factors

2.4.1 Area sources

In general, emission factors for area sources refer to the emission factors for 2018 applied in the 2020 emission inventory (Nielsen et al., 2020).

In general, emission factors for area sources refer to the emission factors for 2018 applied in the 2020 emission inventory (Nielsen et al., 2020).

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 2013-2018 emission factors have been applied rather than including only the 2018 data. For natural gas the average CO_2 emission factor for 2013-2018 have been applied.

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.

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 same technology distribution has been assumed for 2035-2040. 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 aggregate emission factor for sector *s*.

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

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

Table 2.3 Greenhouse gas emissions, kt CO_2 equivalents.

Sector	1990	2000	2005	2010	2015	2018	2019	2020	2025	2030	2035	2040
Public electricity and heat production	24791	23584	20592	21686	10457	9301	6375	5884	3625	1838	1772	1882
Petroleum refining plants	909	1003	940	855	980	893	838	838	838	838	838	838
Oil/gas extraction	552	1465	1619	1563	1444	1267	1257	1016	1010	1065	1236	1014
Commercial and institutional plants	1423	926	990	872	648	630	633	579	470	399	326	377
Residential plants	5120	4151	3818	3350	2139	2004	1967	1759	1367	1155	917	1044
Plants in agriculture, forestry and aquaculture	701	911	767	519	202	187	178	159	160	172	189	260
Combustion in industrial plants	4789	5280	4715	3624	3182	3352	3174	2990	2836	2870	2828	3245
Total	38285	37320	33442	32468	19052	17634	14422	13225	10306	8337	8105	8662

From 1990 to 2040, the total emission falls by approximately 29 500 kt (CO_2 equivalents) or 77 % 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 2018 (Nielsen et al., 2020).

2.5.1 Carbon dioxide

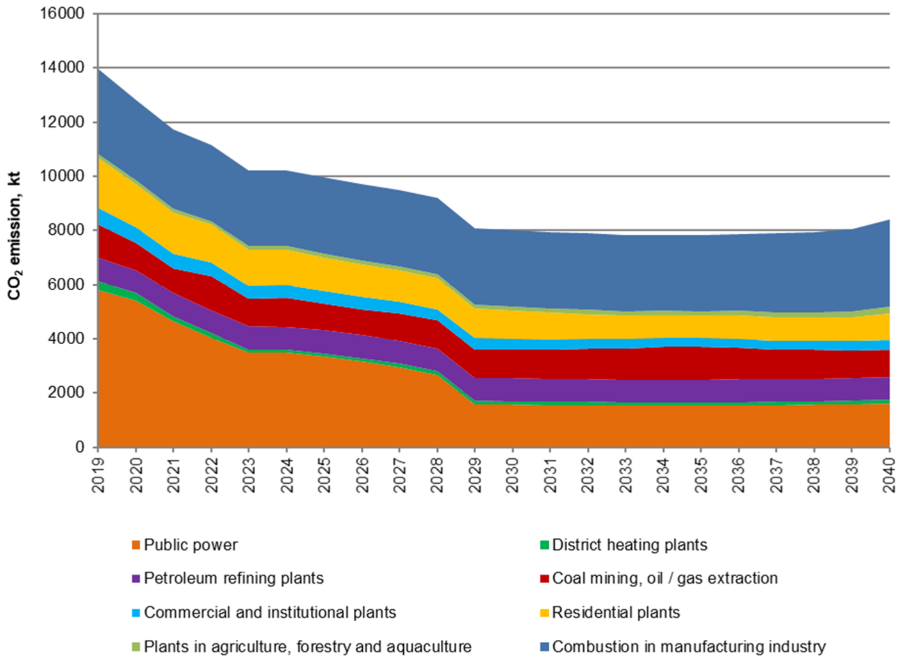

Figure 2.4 CO_2 emissions by sector.

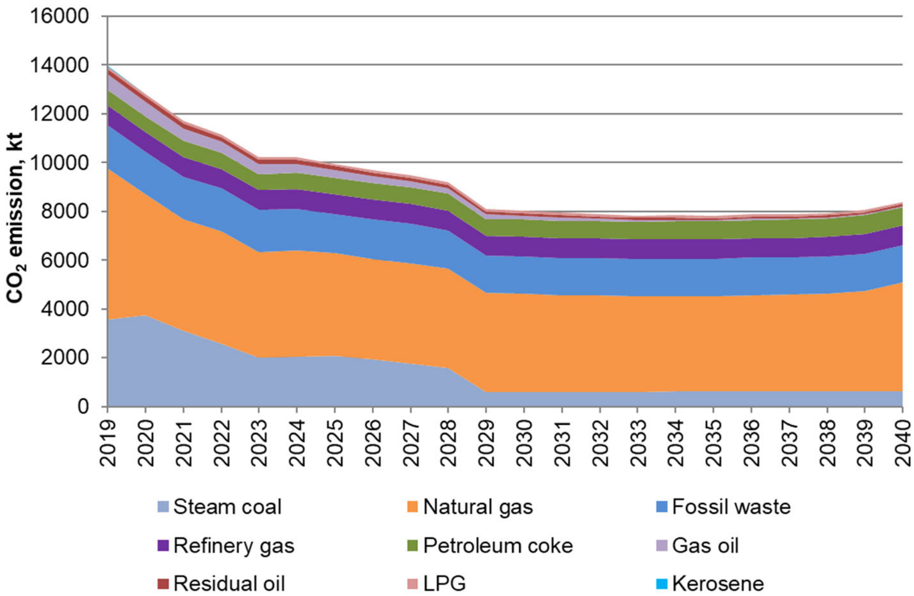

Figure 2.5 CO_2 emissions by fuel.

Table 2.4 CO_2 emissions, Gg.

Sector	1990	2000	2005	2010	2015	2018	2019	2020	2025	2030	2035	2040
Public electricity and heat production	24697	23123	20190	21309	10298	9113	6143	5691	3467	1699	1639	1749
Petroleum refining plants	908	1000	938	854	978	891	838	838	838	838	838	838
Oil/gas extraction	545	1448	1607	1554	1436	1260	1249	1010	1004	1058	1229	1008
Commercial and institutional plants	1415	899	964	850	633	615	625	572	462	391	317	368
Residential plants	4969	3990	3624	3140	1976	1849	1813	1611	1241	1050	829	974
Plants in agriculture, forestry and aquaculture	667	845	708	480	175	156	159	140	140	153	169	240
Combustion in industrial plants	4733	5193	4643	3565	3126	3275	3139	2955	2803	2838	2797	3215
Total	37935	36497	32673	31751	18623	17159	13966	12816	9955	8027	7817	8392

CO_2 is the dominant GHG for stationary combustion and comprises, in 2018, 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 53 % in 2018 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 51 % from 2018 to 2040 due to decreasing fossil fuel consumption.

2.5.2 Methane

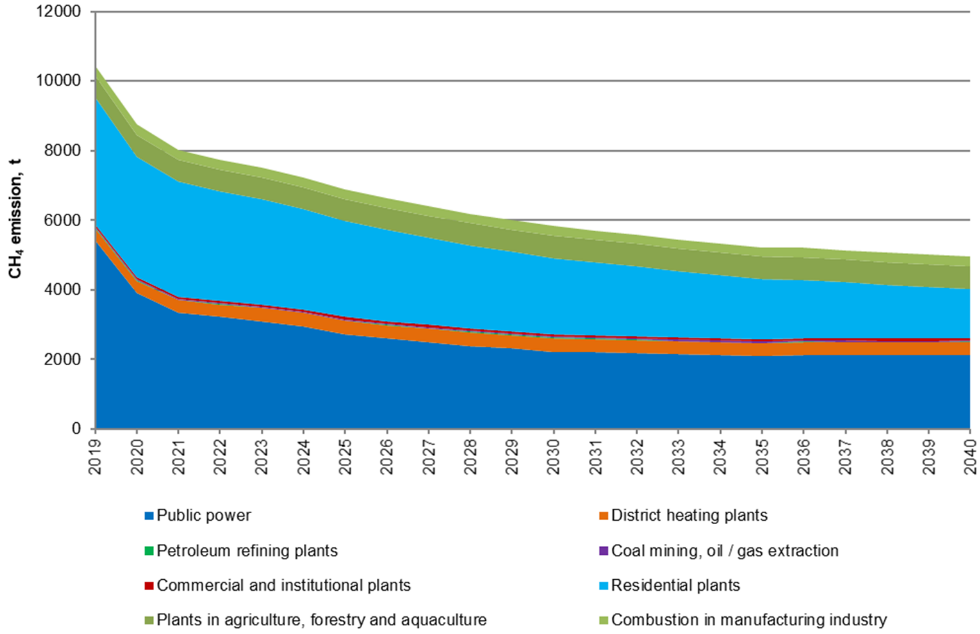

Figure 2.6 CH_4 emissions by sector.

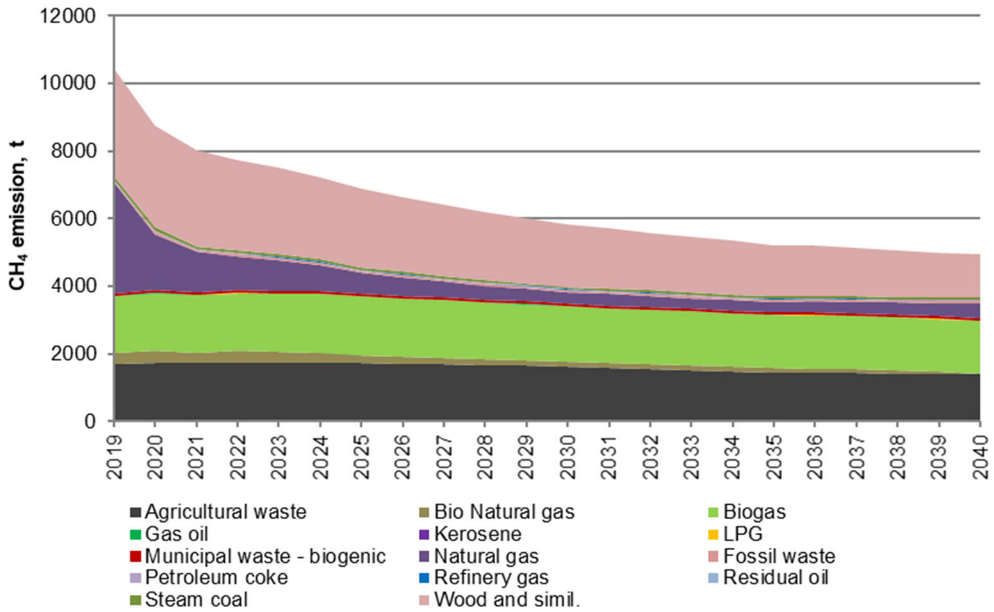

Figure 2.7 CH_4 emissions by fuel.

Table 2.5 CH_4 emissions, tonne.

Sector	1990	2000	2005	2010	2015	2018	2018	2020	2025	2030	2035	2040
Public electricity and heat production	596	14636	12375	10945	3376	4406	5759	4259	3113	2611	2457	2493
Petroleum refining plants	18	21	19	17	19	18	15	15	15	15	15	15
Oil/gas extraction	16	38	47	46	42	37	37	30	30	31	36	30
Commercial and institutional plants	131	902	824	679	403	376	56	57	60	64	70	78
Residential plants	4749	5055	5832	5989	4235	3769	3651	3469	2758	2193	1730	1406
Plants in agriculture, forestry and aquaculture	1086	2464	2184	1382	936	1072	623	625	633	641	650	660
Combustion in industrial plants	274	1024	827	535	521	878	293	293	276	272	268	270
Total	6870	24139	22108	19593	9533	10556	10435	8748	6885	5827	5226	4952

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. The very significant increase in CH_4 emission from biogas is due to the increasing use of biogas, combined with high emission factors when biogas is combusted in gas engines.

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.

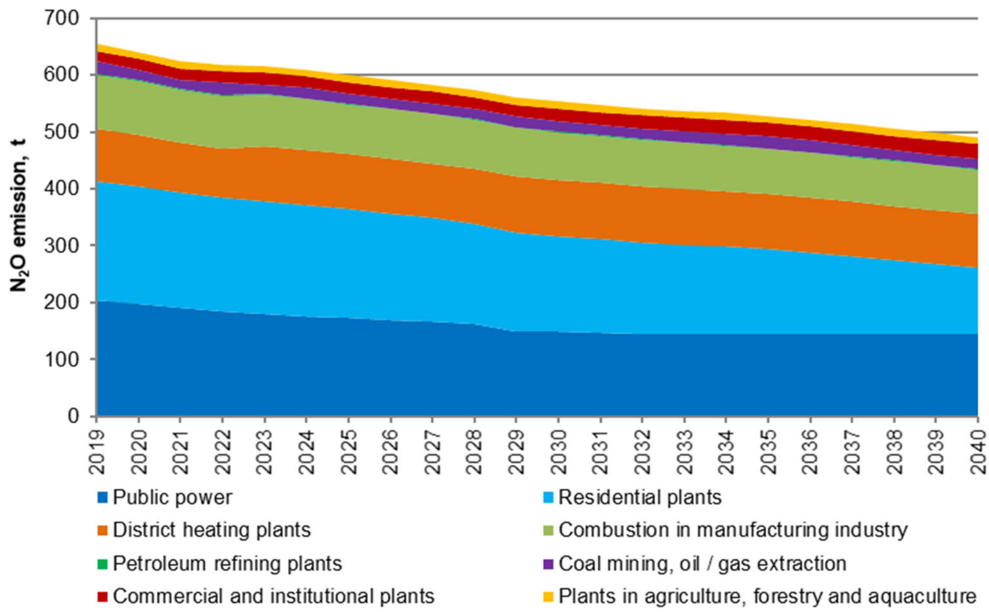

Figure 2.8 N_2O emissions by sector.

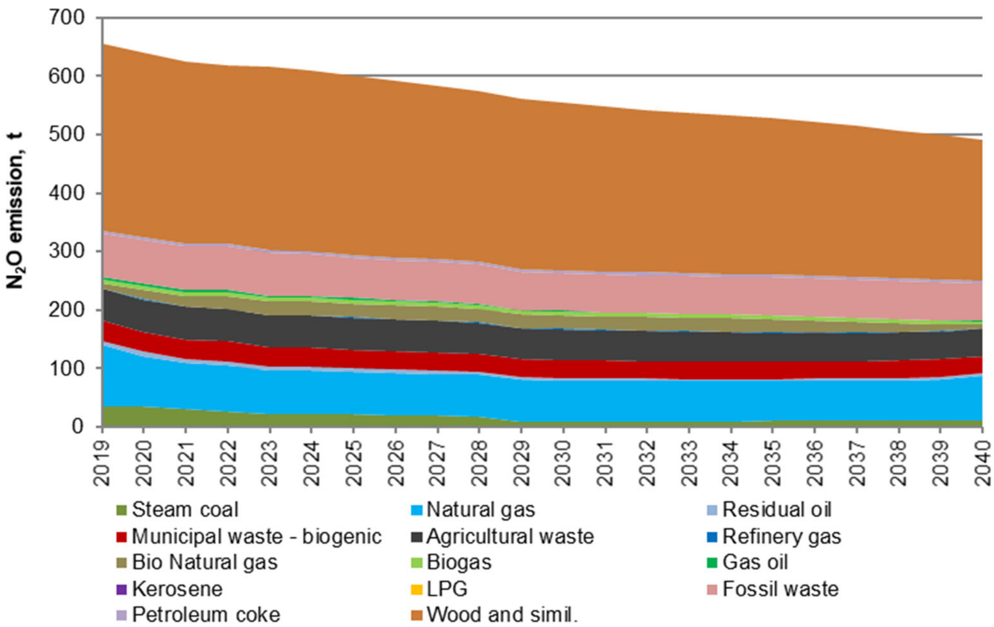

Figure 2.9 N_2O emissions by fuel.

Table 2.6 N_2O emissions, tonne.

Sector	1990	2000	2005	2010	2015	2017	2018	2020	2025	2030	2035	2040
Public electricity and heat production	264	318	311	346	249	263	295	288	269	248	241	237
Petroleum refining plants	2	7	5	3	4	4	2	2	2	2	2	2
Oil/gas extraction	21	55	39	27	25	22	21	17	17	18	21	17
Commercial and institutional plants	17	15	20	17	15	17	19	20	21	22	24	26
Residential plants	106	118	162	202	192	205	210	207	192	167	150	118
Plants in agriculture, forestry and aquaculture	21	17	17	15	12	12	12	12	12	12	12	13
Combustion in industrial plants	166	206	172	152	144	185	96	95	88	84	79	78
Total	598	737	726	761	640	708	654	640	600	553	528	491

2.6 Model description

The software used for the energy model is Microsoft Access 2010, which is a Relational Database Management System (RDBMS) for creating databases. The database is called the 'Fremskrivning 2019-2040' and the overall construction of the database is shown in Figure 2.10.

The model consists of input data collected in tables containing data for fuel consumption and emission factors for combustion plants larger than 25 MW_e and combustion plants smaller than 25 MW_e. 'Area' and 'Point' in the model refer to small and large combustion plants, respectively. However, gas engines as a group is also treated as a point source due to the different emission profile for this type of plant compared to other combustion technologies. The names and the content of the tables are listed in Table 2.7.

Table 2.7 Tables in the 'Fremskrivning 2019-2040'.

Name	Content
tblEmfArea	Emission factors for small combustion plants
tblActArea	Fuel consumption for small combustion plants
tblEmfPoint	Emission factors for large combustion plants
tblActPoint	Fuel consumption for large combustion plants

From the data in these tables a number of calculations and unions are created by means of queries. The names and the functions of the queries used for calculating the total emissions are shown in Table 2.8.

Table 2.8 Queries for calculating the total emissions.

Name	Function
qEmission_Area	Calculation of the emissions from small combustion plants. Input: tbArea_act and tblEmfArea
qEmission_Point	Calculation of the emissions from large combustion plants. Input: tblPoint_act and tblEmfPoint
qEmission_All	Union of qEmission_Area and qEmission_Point

Based on some of the queries a large number of summation queries are available in the 'Fremskrivning 2019-2040' (Figure 2.11). The outputs from the summation queries are Excel tables, see Table 2.9.

Table 2.9 Summation queries.

Name	Output
qxls_Emission_All	Table containing emissions for SNAP groups, Years and Pollutants
qxls_Emission_Area	Table containing emissions for small combustion plants for SNAP groups, Years and Pollutants
qxls_Emission_Point	Table containing emissions for large combustion plants for SNAP groups, Years and Pollutants
qxlsActivityAll	Table containing fuel consumption for SNAP groups, Years and Pollutants
qxlsActivityPoint	Table containing fuel consumption for large combustion plants for SNAP groups, Years and Pollutants

All the tables and queries are connected and changes of one or some of the parameters in the tables result in changes in the output tables.

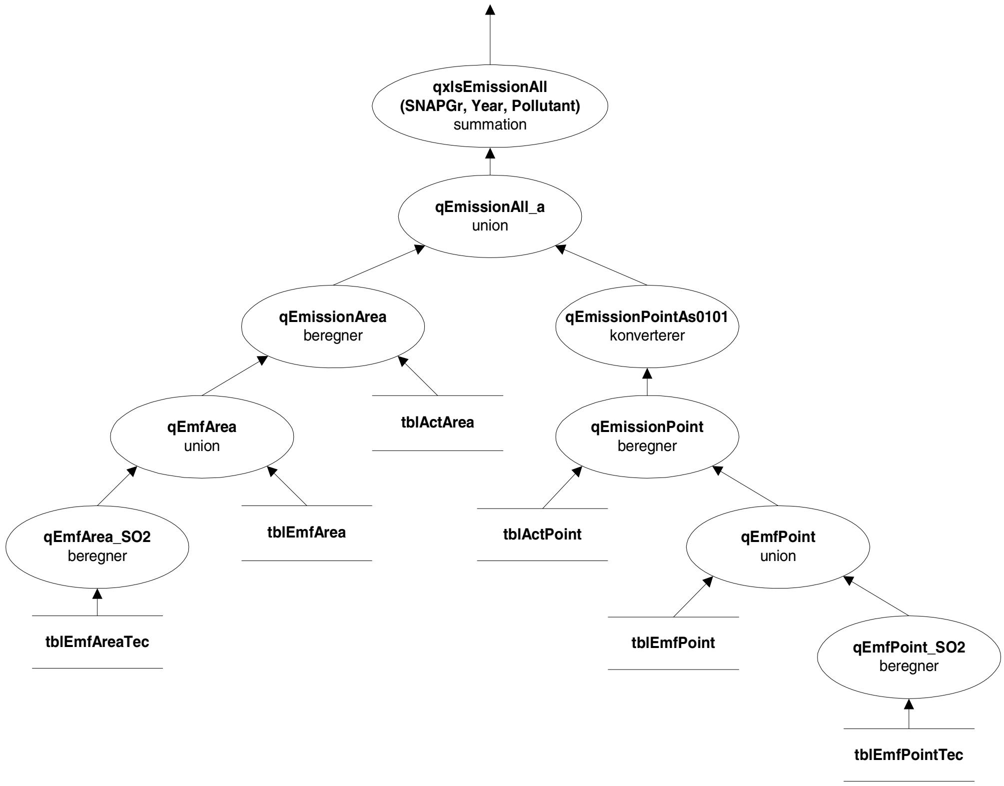

Figure 2.10 The overall construction of the database.

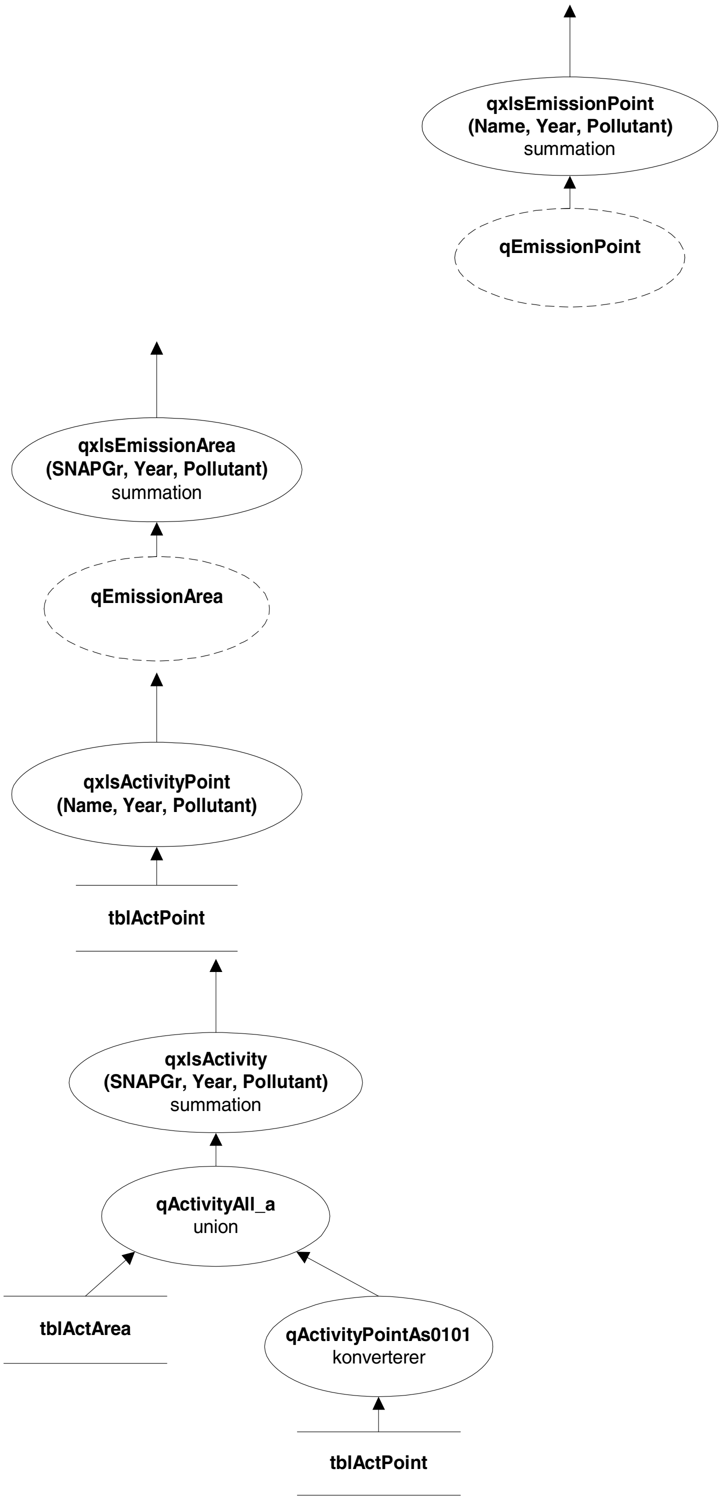

Figure 2.11 Summation queries.

2.7 Recalculations

2.7.1 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, 2020). All recalculations made in these projections are directly observable in the present submission.

2.7.2 Recalculations for emission factors

Emission factors have been updated according to the latest emission inventory.

The CO_2 emission factor for natural gas has been updated to the average 2013-2018 value and the CO_2 emission factors based on EU ETS data have been updated to the average value for 2013-2018.

2.8 References

Astrup, T., Larsen, A.W., Fuglsang, K. & Pedersen, N.H. 2012: PSO-0213, Biogenic Carbon in Danish Combustable Waste. DTU 2012.

Danish Energy Agency, 2020: Denmark's Energy and Climate Outlook. https://ens.dk/en/our-services/projections-and-models/denmarks-energy-and-climate-outlook

EMEP/EEA, 2016: EMEP/EEA air pollutant emission inventory guidebook 2016. Technical report No 21/2016. Available at:
https://www.eea.europa.eu/publications/emep-eea-guidebook-2016

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., Callesen, I., Caspersen, O.H., Scott-Bentsen, N., Rasmussen, E., Petersen, S.B., Olsen, T. M. & Hansen, M.G. 2020. Denmark's National Inventory Report 2020. Emission Inventories 1990-2018 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Aarhus University, DCE – Danish Centre for Environment and Energy, 900 pp. Scientific Report No. 372. Available at: http://dce2.au.dk/pub/SR372.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. (2015) and Nielsen et al. (2020).

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 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 – DECO20) on production of oil and gas, and on flaring in upstream oil and gas production and on fuel consumption (DEA, 2020).

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, 2020) is shown in Figure 3.1. The production of both oil and gas is assumed to decrease from 2019 to 2021, followed by an increase and then levelling out to a decreasing trend.

The overall trend for the projection years 2019-2040 is decreasing for both oil and gas production. 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, 2020), the flaring amounts are expected to show a decreasing trend from 2019 to 2025, followed by a slightly increasing trend for the years 2026 to 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.

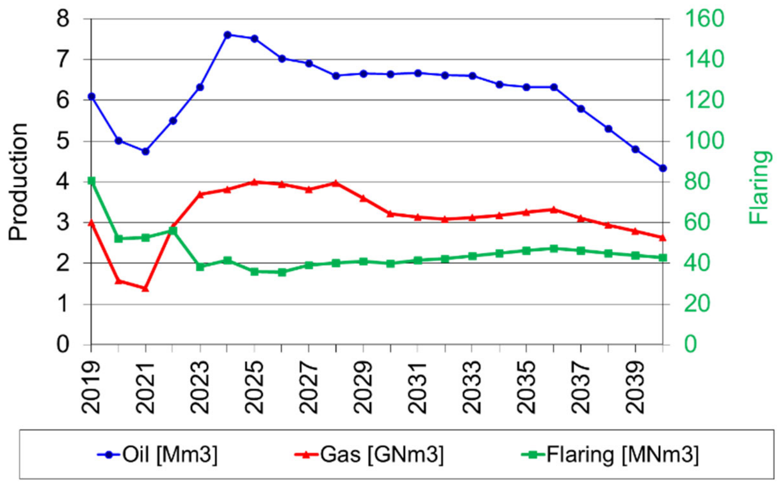

Figure 3.1 Projection for the production of oil and gas (DEA, 2020).

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 (2020) 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, 2020).

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 onshore and 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 factor for onshore loading given in the guidebook has been reduced by 21 % in the projection period due to introduction of new vapour recovery unit (VRU) at the Danish oil terminal in 2010 (Spectrasyne Ltd, 2010). Further, a new degassing system has been built and taken into use medio 2009, which reduced the CH_4 emissions from raw oil terminal by 53 % (Spectrasyne Ltd, 2010). 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.

Table 3.2 Emission factors for 2019-2040.

Source	CH_4	Unit	Ref.
Ships offshore	0.00005	Fraction of loaded	EMEP/EEA, 2019
Ships onshore	0.0000079	Fraction of loaded	EMEP/EEA, 2019; Spectrasyne Ltd, 2010

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 2014-2018 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 projection, 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 small decrease in the projection period. The decrease is mainly caused by a decrease in flaring and in production of gas, which contributes to lower CH_4 emissions from offshore extraction and offshore loading of ships. The low emissions in 2020 are due to the expected decrease in oil and gas production.

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, 2020), and correspondingly the emissions from fugitive emissions and flaring in refineries for the latest historical year are applied for the projection years.

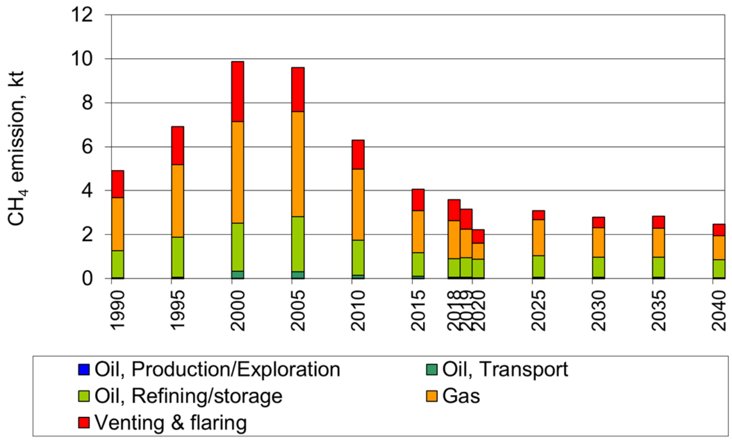

Figure 3.2 CH_4 emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2015 and 2018, including exploration of oil and gas) and projection years (2019, 2020, 2025, 2030, 2035, 2040, excluding exploration of oil and gas).

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, 2020) and an average emission factor for the latest five historical years. The average CO_2 emission factor applied in the projection years is 2.574 kg per Nm^3.

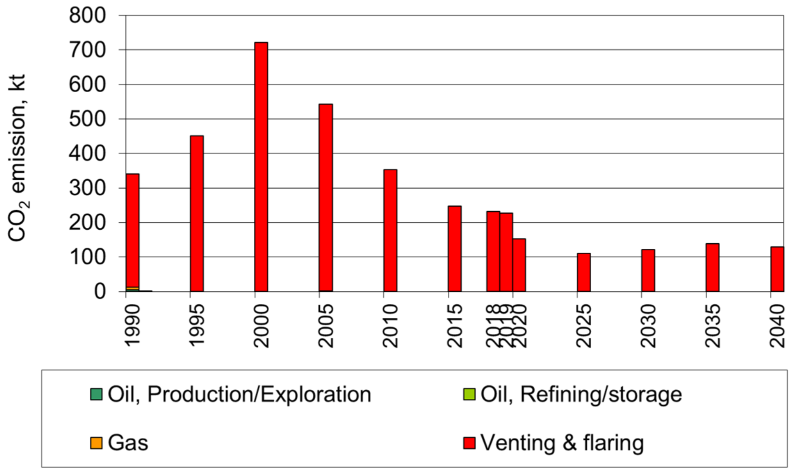

Figure 3.3 CO_2 emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2015 and 2018, including exploration of oil and gas) and projection years (2019, 2020, 2025, 2030, 2035, 2040, excluding exploration of oil and gas).

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 2010 due to new technology. 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 3.3 % of the total fugitive GHG emission (second and third highest emission occurred in 1990 and 1999 and contributed 2.9 % and 0.8 %, respectively).

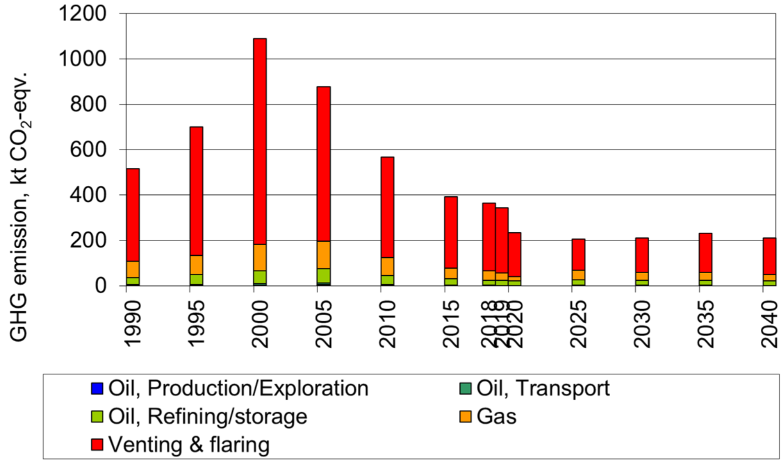

Figure 3.4 GHG emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2015 and 2018, including exploration of oil and gas) and projection years (2019, 2020, 2025, 2030, 2035, 2040, excluding exploration of oil and gas).

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 3.3.

Table 3.3 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, 2020: 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 (27-05-2020).

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (06-03-2018).

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Nielsen, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Thomsen, M., Hjelgaard, K., Fauser, P., Bruun, H.G., Johannsen, V.K., Nord-Larsen, T., Vesterdal, L., Callesen, I., Caspersen, O.H., Scott-Bentsen, N., Rasmussen, E., Petersen, S.B., Olsen, T. M. & Hansen, M.G. 2020. Denmark's National Inventory Report 2020. Emission Inventories 1990-2018 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Aarhus University, DCE – Danish Centre for Environment and Energy, 900 pp. Scientific Report No. 372. Available at: http://dce2.au.dk/pub/SR372.pdf (27-05-2020).

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Spectrasyne Ltd (2009): Fugitive Hydrocarbon Emission Survey of 8 Crude Oil Storage Tanks at DONG, Frederica. Spectrasyne, Environmental Surveying, Sep/Oct 2009.

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 Sub-	2F1	Refrigeration and air conditioning	06 05 02
	stitutes for Ozone De-	2F2	Foam blowing agents	06 05 04
	pleting 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., 2020).

4.2 Methodology

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

The emission projections are for some of the industrial sources based on projected production values for the energy and production industries. These production value projections are available for steel-, glass- and cement industry; see Table 4.3 (DEA, 2020).

For HFCs, PFCs and SF_6, also known as F-gases, emission projections are based on an F-gas projection done by Poulsen (2020).

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

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.

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, 2020). 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 emissions have been kept constant.

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. (2020). 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, 2020).

The report and the data collected in Poulsen (2020) provide emission projections based on 'steady state' consumption with 2018 as the reference year and compared to 2001. 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 2018 is based on the company report to EU ETS (Aalborg Portland, 2019). The emission for 2019-2040 is estimated by extrapolating the 2018 emission with a factor based on projected production values for the cement industry presented in Table 4.3 (Danish Energy Agency, 2020).

Table 4.3 Extrapolation factors for estimation of CO_2 emissions from industrial processes based on production value projections by Danish Energy Agency (2019).

	Construction	Cement and non-metallic mineral industry
2018	1.00	1.00
2019	1.03	1.03
2020	1.07	1.06
2021	1.09	1.07
2022	1.10	1.08
2023	1.12	1.09
2024	1.14	1.10
2025	1.16	1.11
2026	1.17	1.12
2027	1.18	1.12
2028	1.18	1.13
2029	1.19	1.14
2030	1.20	1.15
2031	1.21	1.15
2032	1.22	1.16
2033	1.22	1.17
2034	1.23	1.17
2035	1.24	1.18
2036	1.25	1.19
2037	1.26	1.19
2038	1.27	1.20
2039	1.28	1.21
2040	1.29	1.22

Lime is used for a number of different applications. There are no projected production values available for lime production and the emission for 2019-2040 is therefore estimated to be the constant average value for 2014-2018. 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 2014-2018.

Glass is mainly produced for packaging. The emission for 2019-2040 is estimated by extrapolating the 2018 emission with a factor based on projected production values for the cement and non-metallic mineral industry (Danish Energy Agency, 2020); see Table 4.3.

The production of building materials i.e. stone wool, glass wool, bricks / tiles and expanded clay products for 2019-2040 is estimated by extrapolating the 2018 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 2019-2040 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 4.10 and Table 4.11.

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 2019-2040 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 4.10.

4.2.4 Metal Industry

There has been no production at Danish steelworks since 2006. There is also no planned reopening. There is however a small emission of CO_2 from lead production that is projected as the average of the years 2014-2018.

Calculated emission projection is shown in Table 4.10.

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 2014-2018. Calculated emission projections are shown in Table 4.10.

4.2.6 Electronic Industry

Fibre optics is the only source in CRF category 2E. Fibre optics leads to emissions of both HFC (HFC-23) and PFCs (PFC-14 and PFC-318) and is projected by Poulsen (2020).

Table 4.5 Global Warming Potentials (GWPs) for substances in category 2E.

Substance:	Typical use	GWP CO_{2e}
HFC-23	Fibre optics	14 800
PFC-14	Fibre optics	7 390
PFC-318	Fibre optics	10 300

Calculated emission projections are shown in Table 4.10.

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 six HFCs (HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-152a and unspecified HFCs) and two PFCs (PFC-14 and PFC-218).

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 4.6 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
Other HFCs	Refrigerants (K2)	2 088

However, HFCs in Denmark are estimated in accordance with the trade names for HFC mixtures, Table 4.7 provides the “pure” HFC content of the mixtures.

Table 4.7 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.

Emissions from the use of HFC-23 are covered by category 2E Electronic Industry.

PFCs

PFCs comprise a range of substances, of which only PFC-218 (C_3F_8) and PFC-14 (CF_4) are relevant for source category 2F and approved for inventory under the Climate Convention and KP with stated and approved GWP values. The GWP value for PFC-218 is 8,830 and for PFC-14 7,390. PCF-218 is used as a refrigerant and PFC-14 as cleaning fluid. The use of PFCs in Denmark is limited.

Emissions of PFC-14 and PFC-318 are covered by category 2E Electronic Industry.

Calculated emission projections from 2F Product uses as substitutes for ODS are shown in Table 4.10 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 4.8 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

The different substances reported within category 2G are shown in Table 4.9 along with the source categories responsible for their release and their respective GWPs.

Table 4.9 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 (2020) 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 and PFCs from other product use are available from Poulsen (2020). Emissions from the Use of electrical equipment cover SF_6 from high voltage equipment. The emissions from SF_6 and PFCs from other product use cover SF_6 from double glazed windows, running shoes and use of SF_6 in laboratories / research. The use of SF_6 in connection with double-glazing was banned in 2002, but throughout the projection period there will be emission of SF_6 in connection with the disposal of double-glazing panes where SF_6 has been used.

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 2018 level and the average of the five latest historical years, 2012-2016, respectively.

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, 2014-2018 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 4.10 and Table 4.13.

4.3 Emissions

The results of the GHG emission projections for the entire industrial sector are presented in Table 4.10.

In 2018, 64 % of GHG emissions from Industrial Processes and Product Use originate from Mineral Industry; in 2040, the number will have increased to 84 % due to an increase in emissions from this source category but also due to a decrease in other F-gas emissions (Product uses as substitutes for ODS and Other product manufacture and use).

The second largest source category is Product uses as substitutes for ODS with up to 18 % of GHG emissions early in the projection period.

Table 4.10 Projection of CO_2 process emissions, Gg CO_{2e}

Source Categories		1990	2005	2015	2018	2019	2020	2025	2030	2035	2040
2A	Mineral Industry	1082	1567	1049	1298	1331	1365	1429	1474	1514	1559
	Herof cement production	882	1363	932	1160	1192	1224	1285	1330	1368	1410
2B	Chemical Industry	1003	1	2	1	1	1	1	1	1	1
2C	Metal Industry	60	16	0	0	0.2	0.2	0.2	0.2	0.2	0.2
2D	Non-energy products from fuels and solvent use	166	215	173	161	171	171	171	171	171	171
2E	Electronic industry	0	0	0	0	0	0	0	0	0	0
2F	Product uses as ODS substitutes	0	927	465	487	341	315	186	92	92	92
2G	Other product manufacture and use	33	43	144	95	93	69	37	38	38	38
	Total	3226	4132	2765	3202	3129	3145	3109	3106	3184	3271

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 industrial sector are dominated by CO_2 and that of the F-gases HFCs contributes the most to GHG emissions.

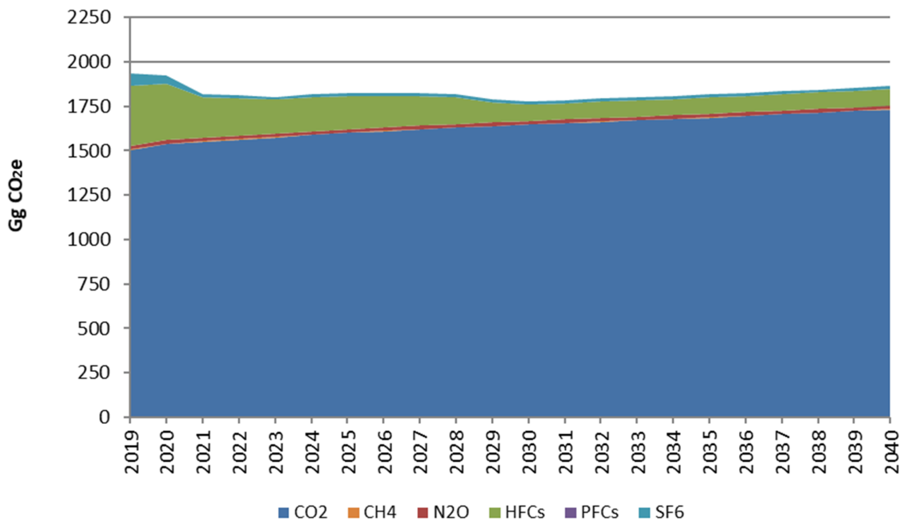

Figure 4.1 Time series for emissions, divided into individual pollutants.

4.3.1 Mineral Industry

Emission projections for mineral industries are shown in Table 4.11.

Table 4.11 Some historical emissions and emission projections for mineral industries, Gg CO_{2e}

		1990	2005	2015	2018	2019	2020	2025	2030	2035	2040
2A1	Cement production	882	1 363	932	1 160	1 192	1 224	1 285	1 330	1 368	1 410
2A2	Lime production	105	60	51	37	50	50	50	50	50	50
2A3	Glass production	14	11	8	8	7	7	7	8	8	8
2A3	Glass wool production	2	2	1	2	2	2	2	2	2	2
2A4a	Bricks/tiles production	26	35	20	29	29	30	32	33	35	36
2A4a	Expanded clay production	20	19	9	17	15	15	16	17	17	18
2A4b	Other uses of soda ash	14	18	7	19	13	13	13	13	13	13
2A4d	Flue gas cleaning	10	51	16	15	12	12	9	7	7	7
2A4d	Stone wool production	8	8	6	11	11	12	13	13	14	14
	Total	1 082	1 567	1 049	1 298	1 331	1 365	1 429	1 474	1 514	1 559

The largest source of emissions in Mineral Industry is cement production; 82-90 %. Cement production has an increasing trend in the projected years due to the extrapolation factors presented in Table 4.3. The second largest emission source for all projected years is lime production; 3-10 %.

In 2018, the contribution from category 2A was 2.7 % of the Danish total greenhouse gas emission without LULUCF. In 2040, this contribution is estimated to have increased to 4.5 %.

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 aggregation available to the data presented in Table 4.10.

4.3.3 Metal Industry

There is only one source of GHG emissions within this category; 2C5 Lead Production. There is therefore no additional aggregation available to the data presented in Table 4.10.

4.3.4 Non-Energy Products from Fuels and Solvent Use

All sources within this category were projected as the constant average of the historical years 2014-2018. Category 2D makes up 9-10 % of CO_2 equivalent emissions in 2019-2040.

The sources within this category have not been projected individually and are therefore not available in this report. The total emission from category 2D is presented in Table 4.10.

4.3.5 Electronic Industry

There is only one source in category 2E, Fibre optics. There is therefore no additional aggregation available to the data presented in Table 4.10. 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 Ozone Depleting Substances is dominated by emissions from refrigeration and air conditioning. No subdividing is presented. For further information, see Poulsen (2020).

4.3.7 Other Product Manufacture and Use

Emission projections for other product manufacture and not shown at a more disaggregated level due to the low emissions from this source.

4.4 Recalculations

Recalculations compared to the previous projection are caused by the update of the historical years as well as updates to the extrapolation factors shown in Table 4.3.

4.5 References

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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 Dom. airport traffic (LTO < 1000 m)	1A3aii (i) Civil aviation (Domestic, LTO)
080502 Int. airport traffic (LTO < 1000 m)	1A3ai (i) Civil aviation (International, LTO)
080503 Dom. cruise traffic (> 1000 m)	1A3aii (ii) Civil aviation (Domestic,Cruise)
080504 Int. cruise traffic (> 1000 m)	1A3ai (ii) Civil aviation (International, Cruise)
0806 Agriculture	1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry
0807 Forestry	1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry
0808 Industry	1A2gvii Manufacturing industries/construction (mobile)
0809 Household and gardening	1A4bii Residential: Household and gardening (mobile)
0811 Commercial and institutional	1A4aii Commercial/institutional: Mobile

Military transport activities (land and air) refer to the CRF / NFR sector Other (1A5), the latter sector also 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)[1] 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

[1] A LTO cycle consists of the flying modes approach / descent, taxiing, take off and climb out. In principle, the actual times-in-modes rely on the actual traffic circumstances, the airport configuration, and the aircraft type in question.

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 / fisheries (1A4c) sector together with fishing activities (SNAP code 080403).

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 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. This bottom-up calculation does not match the data in the energy projection. Therefore, fuel amounts can be transferred between 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. It is important to stress that the overall fuel consumption as reported in the official energy statistics and projection is maintained by DCE, only the sectoral allocation is impacted.

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. (2020).

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.

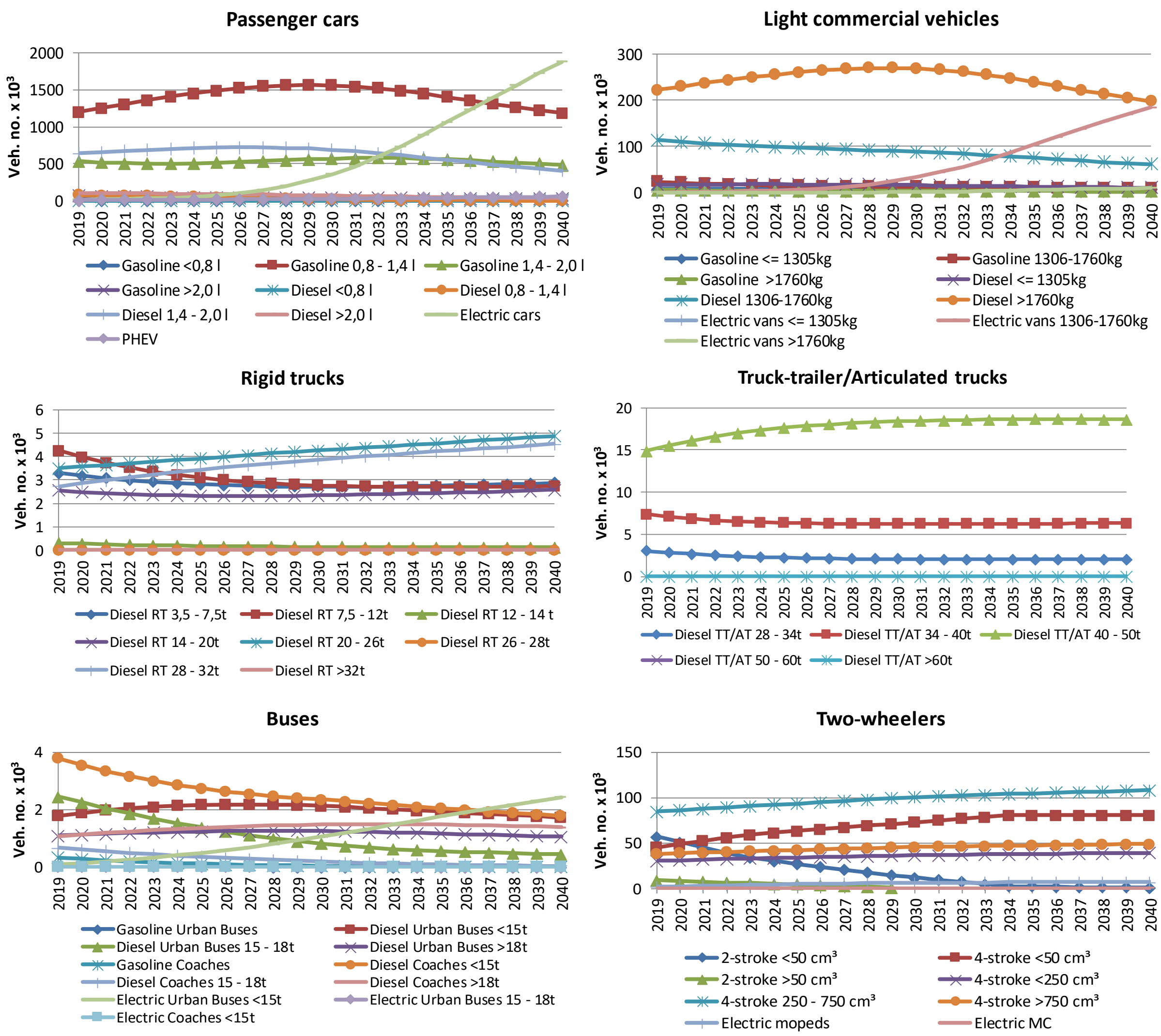

Figure 5.1 Number of vehicles in sub-classes from 2019-2040. PHEV = Plug In Hybrid Electric Vehicles.

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:

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

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.

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

The trends in vehicle numbers per EU layer are also shown in Figure 5.2 for the 2019-2040 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.

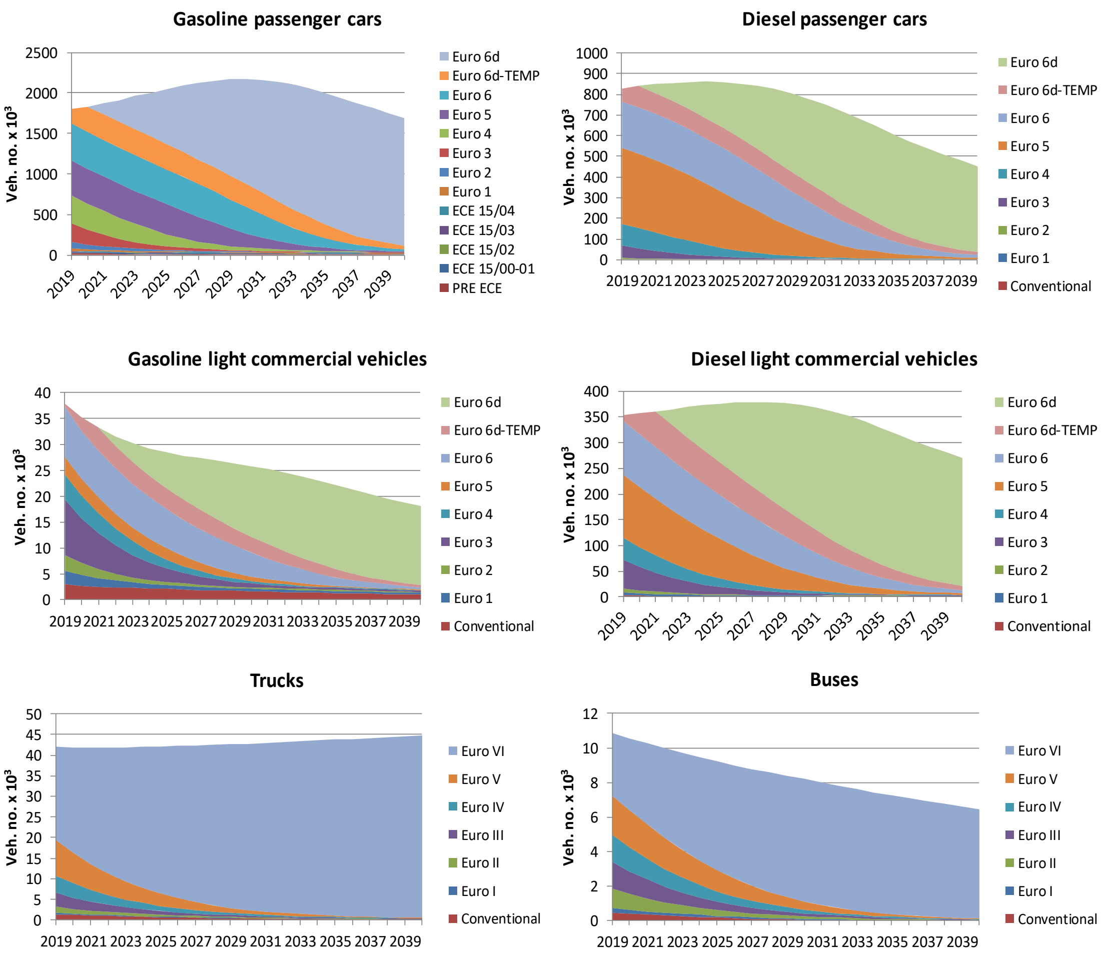

Figure 5.2 Layer distribution of vehicle numbers per vehicle type in 2019-2040.

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 95g CO_2 per km is specified for the year 2021.
- **Eco-innovations:** manufacturers can be granted a maximum of 7g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.

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

- **Target dates:** the EU fleet average of 175 g CO_2 per km 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[2] (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[3]: 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. (2020).

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.

[2] 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.
[3] 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[4], using trip speeds representative for urban, rural and highway driving. The factors can be seen in Nielsen et al. (2020). 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.

Adjustment for fuel efficient vehicles

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

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

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

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

The latter function uses TA_{NEDC}, vehicle weight, engine size and regression coefficients by first registration year, as input parameters (EMEP / EEA, 2019).

[4] 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).

For each new registration year, i, fuel type, f, and engine size, k, number based average values of TA_{NEDC} and FC_{inuse} are summed up and referred to as $\overline{TA_{NEDC}}(i, f, k)$ and $\overline{TA_{inuse}}(i, f, k)$. For vehicle new registrations after 2014, regression coefficients are used for 2014.

The FC_{inuse} function has been developed from a vehicle database consisting of new registered cars from 2006-2014 (Tietge et al. 2017). Hence, as previously mentioned, The FC_{inuse} function is not able to account for the fuel gaps after 2014, between type approval and real world fuel consumption as monitored by ICCT (Tietge et al., 2019).

To obtain $\overline{FC_{inuse}}(i, f, k)$ values for vehicle new registrations 2015-2018, the $\overline{FC_{inuse}}(i, f, k)$ values for 2014 are adjusted for the years 2015-2018[5] with an index function (indexed from 2014), C_{ICCT} (i, f), based on the reported ICCT fuel gap figures by fuel type for the new registration years 2014-2018.

The most recent emission projections use the assumption from The Danish Energy Agency that Danish vehicle sales meet a slightly softer national target of 99,74 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 99,74 g CO2/km target, the following approach is used to forecast the average TA_{NEDC} values ($\overline{TA_{NEDC}}(i)$) until 2021. As a starting point, the average CO_2 emission factor (average from all new registrations) is calculated for the last historical year (2018) based on the registered average TA_{NEDC} values from DTU Transport. Next, the average CO_2 emission factor (and $\overline{TA_{NEDC}}(i)$) for each future year's new sold cars is reduced with a linear function, C_{2021} (i), until the emission factor reaches 99,74 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 ($\overline{FC_{inuse}}(layer)$).

At the same time, COPERT provides fuel consumption factors for Euro 4 vehicles for a specific driving pattern composition[6] 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.

[5] The ICCT monitoring report include new cars up to 2017. For new cars from 2018, fuel gap figures are used for cars from 2017.
[6] 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.

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. (2019).

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 – DECO20 (DEA, 2020b) 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 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 previous version of the DCE model (e.g. Nielsen et al., 2020).

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 (2018) 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 DECO20 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, 2018; Nielsen et al., 2020).

Table 5.5 lists the most important domestic ferry routes in Denmark in 2018. The complete list of ferries is shown in e.g. Nielsen et al. (2020). 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. (2020) 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 DECO20. 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 hand-held (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 $(HC+NOx) \times CO^{0.784} \leq 8.57$ and the conditions $CO \leq 20.6$ g/kWh and $(HC+NOx) \leq 2.7$ g/kWh.

For recreational craft, Directive 2003/44 comprises the Stage 1 emission legislation limits for diesel engines, and for 2-stroke and 4-stroke gasoline engines, respectively. The CO and VOC emission limits depend on engine size (kW) and the inserted parameters presented in the calculation formulas in Table 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.

	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 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 was submitted on or after 1 January 2023;
- **Derived versions of non-CO_2 certified propeller-driven aeroplanes** of greater than 8 618 kg maximum certificated take-off mass for which the application for certification of the change in type design was submitted on or after 1 January 2023;

- **Individual non-CO_2-certified subsonic jet aeroplanes** of greater than 5 700 kg maximum certificated take-off mass for which a certificate of airworthiness was first issued on or after 1 January 2028; and
- **Individual non-CO_2-certified propeller-driven aeroplanes** of greater than 8 618 kg maximum certificated take-off mass for which a certificate of airworthiness was first issued on or after 1 January 2028.

Marpol 73/78 Annex VI agreed by IMO (International Maritime Organisation) concerns the control of NO_x emissions (Regulation 13 plus amendments) and SO_x and particulate emissions (Regulation 14 plus amendments) from ships (DNV, 2009). 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, aggregated CH_4 emission factors for conventional cars are used.

The CH_4 emission factors for railways are derived from specific Danish VOC measurements from the Danish State Railways (Mølgård, 2019) and a NMVOC / CH_4 split, based on expert judgement.

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

For national sea transport and fisheries, the VOC emission factors come from 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. (2020).

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. (2020).

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. (2020).

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 – DECO20 (DEA, 2020b).

Fuel transferals between DECO20 and inventory sectors

In some cases for mobile sources, DECO20 for specific sectors do not fully match the DCE projected fuel consumption. In the following, the transferal of fuel consumption data from DECO20 sectors into DCE categories is explained for national sea transport and fisheries, non-road machinery and recreational craft, and road transport. Please refer to Nielsen et al. (2020) for more details.

National sea transport and fisheries

Bottom up estimates for heavy fuel oil (ferry to the Faroe Island) is taken from DECO20 international sea transport and added to DCE national sea transport. Also the reported fuel sold (examined by DCE) for freight transport between Denmark and Greenland are taken from DECO20 international sea transport and added to DCE national sea transport.

In national sea transport, LNG fuel has been used by Danish ferries since 2015. However, in DECO20, the consumption of LNG for national sea transport is included under diesel instead of being reported as LNG. In the DCE projection, the bottom up estimated consumption of LNG is reported under national sea transport, and the DCE diesel total for national sea transport is subsequently being reduced by the same number.

The DCE bottom up diesel estimates for recreational craft is subtracted from DECO20 fisheries, and grouped in the DCE "Other" inventory category together with military activities.

The small amount of gasoline from DECO20 fisheries is transferred to DCE road transport.

The small amount of LPG from DECO20 fisheries is transferred to the DCE category "Non-industrial combustion plants" (0203).

Non road machinery and recreational craft

For diesel and LPG, the non-road relevant DECO20 fuel sectors are agriculture / horticulture / forestry, construction and commodity production, and the residual part of diesel not being used for heating in households (single and multi family) as estimated by DCE. The amount of diesel and LPG not being used by non-road machinery in the DCE non road model, is transferred to the sectors "Combustion in manufacturing industry" (0301) and "Non-industrial combustion plants" (0203) in the DCE projection.

For gasoline, the DECO20 household (single family) sector, together with the DECO20 sectors mentioned for diesel and LPG (agriculture / horticulture / forestry, construction and commodity production), contribute to the non-road fuel consumption total. In addition, a certain amount of gasoline is transferred from DECO20 road transport in order to obtain a fuel balance.

The DCE bottom up gasoline estimates for recreational craft is subtracted from DECO20 road transport, and grouped in the DCE "Other" inventory category together with military activities.

Domestic aviation

The small amount of gasoline from DECO20 domestic aviation is transferred to DCE road transport.

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 Summary table of emissions for mobile sources in Denmark.

		1990	2005	2015	2018	2019	2020	2025	2030	2035	2040
CO_2, kt	Industry - Other (1A2g)	629	720	631	605	610	618	636	589	530	500
	Civil Aviation national (1A3a)	205	140	129	133	133	134	140	148	150	153
	Road - Cars (1A3bi)	5017	6527	6468	6798	6895	6818	7164	7008	5837	4530
	Road - Light duty trucks (1A3bii)	1460	2155	1695	1703	1729	1736	1779	1682	1418	1128
	Road - Heavy duty vehicles (1A3biii)	2833	3590	3417	3756	3754	3779	3914	3737	3564	3518
	Road - Motorcycles and mopeds (1A3biv)	46	70	55	49	69	66	65	65	65	65
	Railways (1A3c)	297	232	248	224	210	211	195	66	66	66
	Navigation (1A3d)	714	724	559	621	608	607	602	596	583	570
	Commercial/institutional (1A4a)	45	88	84	83	82	80	80	78	77	76
	Residential (1A4b)	19	25	24	23	23	22	22	22	22	22
	Agriculture/forestry/fisheries (1A4c)	1928	1587	1390	1326	1314	1302	1270	1156	1044	979
	Other (1A5b, military mobile)	119	271	98	118	118	118	118	118	118	118
	Other (1A5b, recreational craft)	48	103	97	97	97	97	97	97	97	97
	Navigation international (1A3d)	3005	2352	2293	1720	1739	1739	1739	1739	1739	1739
	Civil Aviation international (1A3a)	1774	2569	2624	3045	3014	3023	3090	3194	3213	3228
		1990	2005	2015	2018	2019	2020	2025	2030	2035	2040
CH_4, t	Industry - Other (1A2g)	59	41	25	21	19	18	15	14	13	13
	Civil Aviation national (1A3a)	3	2	1	1	2	2	2	2	2	2
	Road - Cars (1A3bi)	2557	906	275	226	218	211	208	215	194	160
	Road - Light duty trucks (1A3bii)	198	105	15	9	8	7	4	3	3	2
	Road - Heavy duty vehicles (1A3biii)	294	337	71	58	53	50	52	66	70	70
	Road - Motorcycles and mopeds (1A3biv)	89	115	83	77	72	70	64	60	57	54
	Railways (1A3c)	12	9	5	4	2	0	0	0	0	0
	Navigation (1A3d)	15	17	32	37	36	36	36	36	36	36
	Commercial/institutional (1A4a)	24	68	34	33	31	29	28	28	28	28
	Residential (1A4b)	37	45	17	17	16	15	13	13	13	13
	Agriculture/forestry/fisheries (1A4c)	265	122	99	81	78	75	72	69	68	67
	Other (1A5b, military mobile)	5	12	2	2	2	2	2	2	2	2
	Other (1A5b, recreational craft)	77	62	7	7	6	6	5	5	4	4
	Navigation international (1A3d)	64	55	57	44	45	45	46	46	47	47
	Civil Aviation international (1A3a)	6	8	9	12	12	12	12	12	12	12
		1990	2005	2015	2018	2019	2020	2025	2030	2035	2040
N_2O, t	Industry - Other (1A2g)	25	30	28	28	28	29	30	28	25	24
	Civil Aviation national (1A3a)	10	8	7	7	7	7	7	7	7	8
	Road - Cars (1A3bi)	180	227	172	159	158	155	150	137	107	79
	Road - Light duty trucks (1A3bii)	10	60	54	50	50	49	47	46	40	32
	Road - Heavy duty vehicles (1A3biii)	104	46	191	235	242	249	277	303	320	328
	Road - Motorcycles and mopeds (1A3biv)	1	1	1	1	1	1	1	1	1	1
	Railways (1A3c)	9	7	8	7	7	7	6	2	2	2
	Navigation (1A3d)	18	18	14	16	15	15	15	15	15	14
	Commercial/instutional (1A4a)	1	2	2	2	2	2	2	2	2	2
	Residential (1A4b)	0	0	0	0	0	0	0	0	0	0
	Agriculture/forestry/fisheries (1A4c)	65	59	58	57	56	56	55	50	45	42
	Other (1A5b, military mobile)	4	7	4	5	5	5	5	5	6	6
	Other (1A5b, recreational craft)	1	3	4	4	3	3	3	3	3	3
	Navigation international (1A3d)	76	59	58	43	44	44	44	44	44	44
	Civil Aviation international (1A3a)	60	88	89	102	101	101	103	107	107	108
		1990	2005	2015	2018	2019	2020	2025	2030	2035	2040
CO_2-eq., kt	Industry - Other (1A2g)	638	730	640	614	619	627	645	597	538	507
	Civil Aviation national (1A3a)	208	143	131	135	135	136	142	150	153	155
	Road - Cars (1A3bi)	5134	6618	6527	6851	6947	6870	7214	7054	5874	4557
	Road - Light duty trucks (1A3bii)	1468	2176	1712	1718	1744	1751	1793	1695	1430	1137
	Road - Heavy duty vehicles (1A3biii)	2871	3613	3475	3828	3828	3855	3998	3829	3661	3617
	Road - Motorcycles and mopeds (1A3biv)	49	73	57	52	71	68	67	67	67	67
	Railways (1A3c)	300	234	251	226	212	213	197	66	66	66
	Navigation (1A3d)	720	730	564	627	613	612	607	602	589	575
	Commercial/institutional (1A4a)	46	91	85	84	84	82	81	80	78	77
	Residential (1A4b)	20	27	24	24	23	22	22	22	22	22
	Agriculture/forestry/fisheries (1A4c)	1954	1607	1410	1345	1332	1321	1288	1173	1059	994
	Other (1A5b, military mobile)	120	273	100	119	119	119	119	119	119	119
	Other (1A5b, recreational craft)	50	105	99	99	99	98	98	98	98	98
	Navigation international (1A3d)	3029	2371	2312	1734	1753	1753	1753	1753	1753	1753
	Civil Aviation international (1A3a)	1792	2595	2651	3076	3044	3054	3122	3226	3246	3260

5.3.1 Road transport

The total CO_2 emissions decrease is expected to be 26 % from 2019-2040. 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.

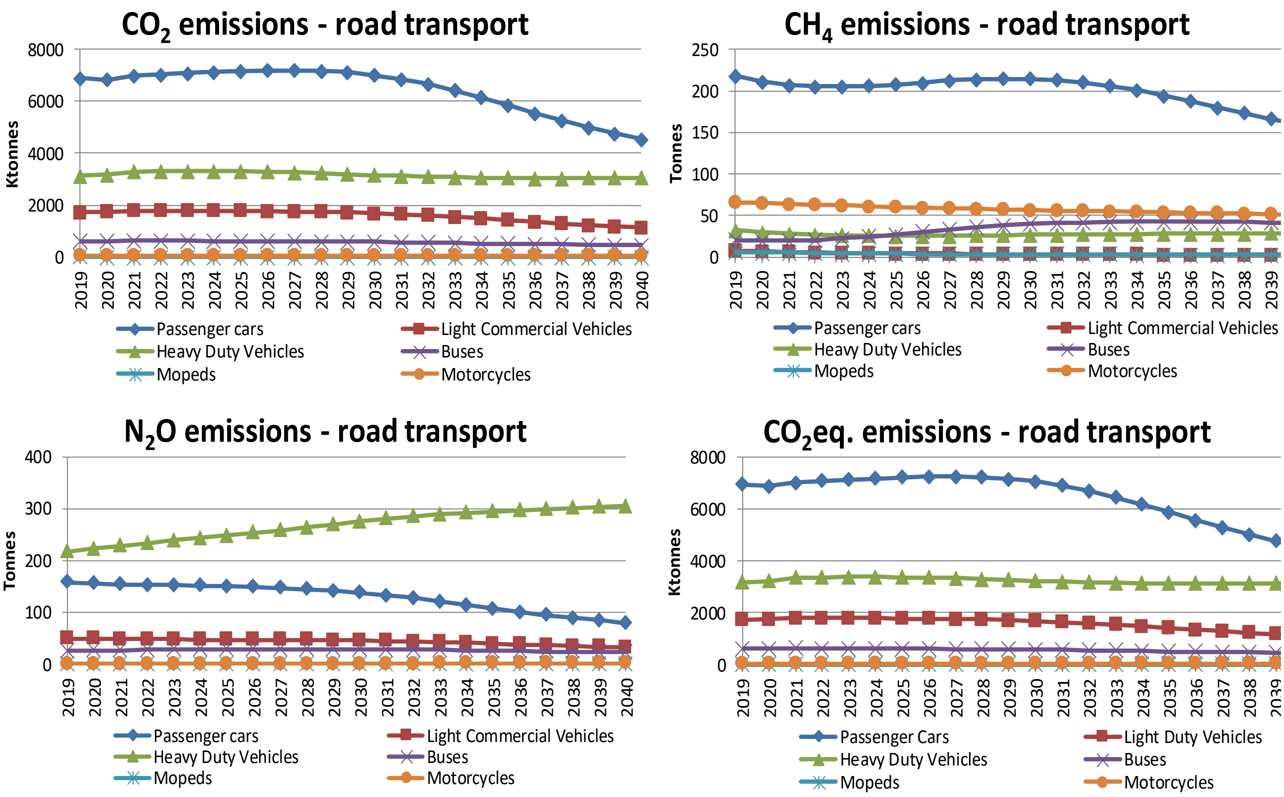

Figure 5.3 CO_2, CH_4, N_2O and CO_{2e} emissions from 2019-2040 for road traffic.

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 18 % and 2 %, respectively, from 2019 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 Agriculture / forestry / fisheries (1A4c) followed by Navigation (1A3d) and Commercial / institutional (1A4a), whereas for Railways (1A3c) and Domestic aviation (1A3a) only small emission contributions are noted.

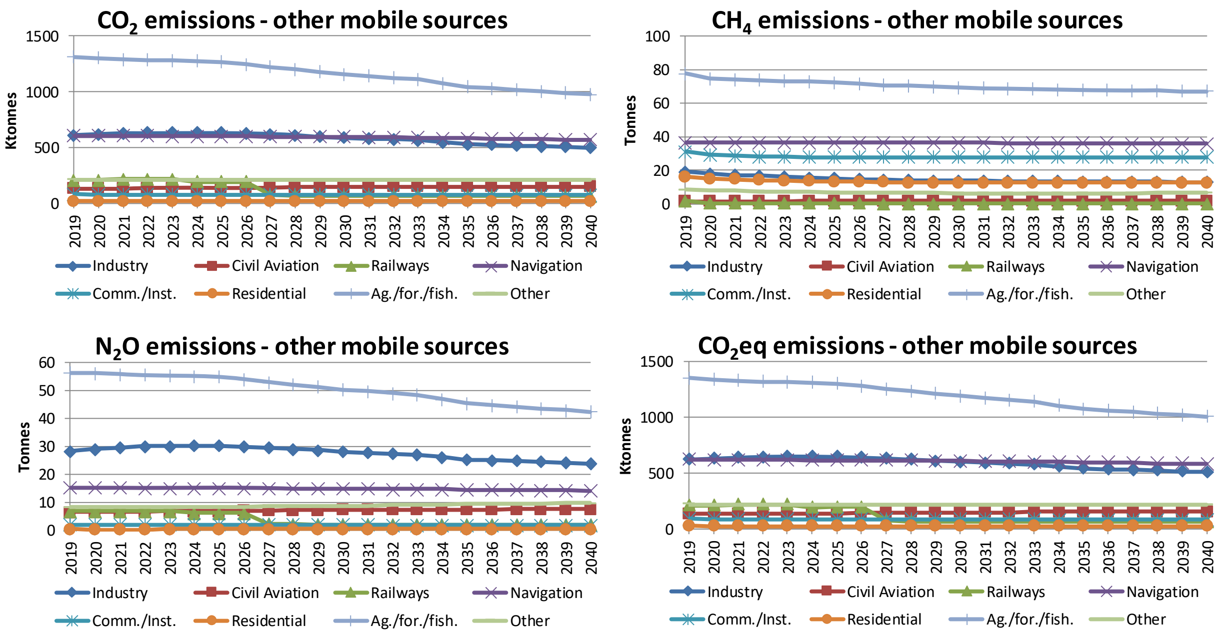

Figure 5.4 CO_2, CH_4, N_2O and CO_{2e} emissions from 2019-2040 for other mobile sources.

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.

6.1 Introduction

Projection of greenhouse gas emissions is regularly updated based on new scientific knowledge as a consequence of updating of the historical emission inventory, eventually new emission sources introduced, changes of emission factors or changes in agricultural production conditions due to e.g. legislation and regulation. Some of the changes may lead to revision and this projection may therefore show some deviations compared to previously published projections. The present projection of greenhouse gases replaces the latest projection published in Scientific Report from DCE – Danish Centre for Environment and Energy No. 345, 2019 (Nielsen et al., 2019).

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. 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 current projection takes into account the elements included in the Political Agreement on a Food and Agricultural package adopted in December 2015 (MEFD, 2017). The purpose of the agreement was to establish better framework conditions for the agricultural production, to ensure opportunities for economic growth, increased exports and increased employment, in interaction with nature and the environment. The key points for the assessment of the projected greenhouse gas emissions is the development of the livestock production, the biogas plants possibilities to use the animal manure and the extent of the use of emission reducing technologies. 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. The environmental approvals register is used as the underlying basis for the assumption of the extension of emission reducing technologies. The future biogas production is based on a projection provided by the Danish Energy Agency (DEA).

6.2 Projected agricultural emission 2019 - 2040

The latest official reporting of emissions includes time series until 2018 for all emission sources. The development of agricultural greenhouse gases from 1990 to 2018 (Table 6.1) shows a decrease from 13.2 million tonnes CO_2 equivalents to 11.0 million tonnes CO_2 equivalents, which correspond to a 16 % reduction. In the current projection, based on the assumptions provided, the emission increases to 11.1 million tonnes CO_2 equivalents in 2040. The higher emission in 2040 is driven by an expected growth in the number of dairy cattle, which leads to an increase of CH_4 emission from enteric fermentation.

From 2030 to 2040 only few changes in total emission occur and these are caused by changes in biogas treatment of manure. The remaining emissions sources only includes projected estimate until year 2030 corresponding to the data presented in the model AGMEMOD (See Chapter 6.4 for a description), and thus the agricultural conditions from 2031 to 2040 is kept at the same level.

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	2018	2019	2020	2025	2030	2035	2040
Enteric fermentation	4 039	3 631	3 483	3 631	3 667	3 767	3 775	3 809	3 952	4 093	4 093	4 093
Manure management	2 832	3 321	3 487	3 133	2 969	2 952	2 826	2 752	2 556	2 461	2 536	2 821
Agricultural soils	5 668	4 443	4 072	3 988	4 096	4 073	4 025	4 017	4 015	4 044	4 010	4 015
Field burning of agricultural residue	3	4	5	3	3	4	4	4	4	4	4	4
Liming	565	261	220	153	166	240	240	212	207	202	202	202
Urea application (CO_2 emission)	15	2	0	1	1	1	1	1	1	1	1	1
Other carbon-containing fertilisers	38	5	2	3	10	3	4	4	4	4	4	4
Total	13 161	11 667	11 270	10 911	10 913	11 041	10 875	10 799	10 739	10 808	10 849	11 139

6.3 Comparison with previous projection

By comparing the current projection with the latest provided greenhouse gas projection (Nielsen et al., 2019), the emission given in CO_2 equivalents has increased up to 3 % for 2019-2040, (Figure 6.1). Changes in the projected emission is not only a result of changes in assumptions, e.g. number of animal and agricultural area, but also a consequence of changes in the historical emission.

The N_2O emission is 1-3 % lower in 2019-2025 and around ± 1 % in 2026-2040 compared to the previous projection. Emission from inorganic fertiliser is changed from 2019 due to new assumptions for the level of fertiliser based on the historic trend for 2016-2018. Furthermore is the projection of amount of manure treated in biogas facilities changed based on projections from DEA.

The CH_4 emission is 5-9 % higher in all years 2019-2040 compared to the previous projection. Emission from enteric fermentation is lower in 2019-2040 compared to the previous projection mainly due to changes in number of cattle. The projected emission from manure management is higher in 2019-2040 mainly due to recalculation of the emission factor MCF. The model estimating the national MCF has been updated and this changes both the historic and the projected emission of CH_4 from manure management.

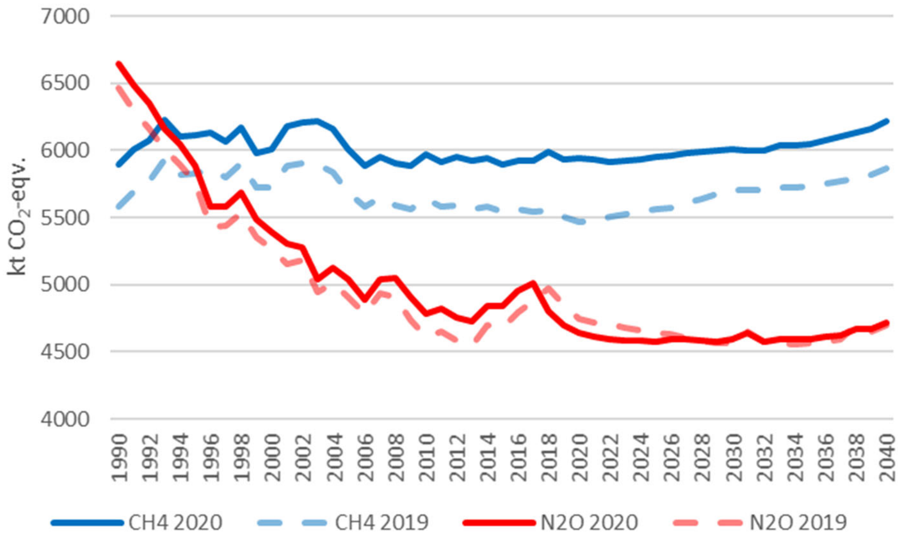

Figure 6.1 GHG projection 2020 compared to GHG projection 2019.

6.4 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 University of Copenhagen, Department of Food and Resource Economics by using the 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 on description of the AGMEMOD model, please refer to Jensen et al. (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 plant.

The assumptions regarding the expansion and development of emission reducing technologies in livestock production is based on data from the environmental approvals register 2007-2016 (Nielsen et al., 2020a, Annex 3D Chapter 3D-1). The expectations to expansion of the biogas production are based on assumptions provided by DEA - the Danish Energy Agency.

6.5 Livestock production

For cattle, swine, hens and broilers, the number of animals is based on the model AGMEMOD (Jensen, 2020) until 2030. For 2031-2040, the numbers have been assumed constant. 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 projection of number of fur bearing animals (mink) is based on estimates made by Bramsen & Hansen (2020). Number of horses, sheep, goats, turkeys, ducks and geese is kept at the same level as in 2020.

6.5.1 Cattle

In AGMEMOD, the projection of the number of dairy cattle is based on projection of milk production, which in AGMEMOD is based on projection of milk yield, milk prices and production costs (Jensen, 2020).

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, 2020; Lund et al., 2020). The average milk yield is expected to increase from 10 700 l/cow/year in 2018 to 12 200 l/cow/year in 2030, which correspond to a rise of 14 %. This development corresponds to an N-excretion in 2018 for large breed cattle at 159 kg N, increasing to 172 kg N in 2030.

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

Dairy cattle	2018	2019	2020	2025	2030	2035	2040
No. of dairy cattle, 1000 unit	575	566	572	582	603	603	603
Milk yield, kg milk per cow per year	10 674	10 776	10 877	11 537	12 197	12 197	12 197
Large breed, kg N-excretion per year	159	160	160	166	172	172	172
Large breed, feed intake, kg dm per year	8 082	8 132	8 184	8 526	8 868	8 868	8 868
Ym, %	6.00	5.97	5.93	5.90	5.86	5.86	5.86

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 2018.

6.5.2 Swine

AGMEMOD estimates the number of sows, weaners and fattening pigs based on projections of prices for pig meat and production costs (Jensen, 2020). 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 for future production, the projection trend estimated in AGMEMOD is applied.

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

Swine	2018	2019	2020	2025	2030	2035	2040
Trend*							
Sows		99	98	90	82	82	82
Weaners		101	101	102	102	102	102
Fattening pigs		93	99	98	96	96	96
Numbers, millions produced							
Sows	1.05	1.04	1.02	0.94	0.86	0.86	0.86
Weaners	33.18	33.40	33.60	33.88	33.83	33.83	33.83
Fattening pigs	19.20	17.82	18.96	18.75	18.34	18.34	18.34

* Based on AGMEMOD (Jensen, 2020).

The projection of N-excretion for sows, weaners and fattening pigs is based on the trend in the estimations made by DCA (Poulsen, 2016) and improvement of feed efficiency is excepted to be continued until 2030 by 3 % for sows and 4 % for fattening pigs and 10 % for weaners.

Table 6.4 N-excretion, kg N-excretion.

Swine	2018	2020	2025	2030	2035	2040
Sows	23.79	23.48	23.23	23.08	23.08	23.08
Weaners	0.48	0.44	0.44	0.43	0.43	0.43
Fattening pigs	2.99	2.92	2.91	2.88	2.88	2.88

6.5.3 Housing system

Projection of distribution for cattle in different types of housing systems is provided by SEGES (2019). The estimates are for 2020 and 2030 for dairy cattle and heifers. Distribution for the years 2019 and 2021-2029 are interpolated and 2031-2040 is set at the same level as 2030. In 2018, 87 % of the dairy cattle were housed in systems with cubicles. It is assumed that 93 % dairy cattle will be housed in systems with cubicles in 2020, increasing to 99 % in 2030 and thus most of the tethering and housing systems with deep litter are phased out. The result is that almost all manure from dairy cattle in 2030 are handled as slurry. For heifers, the tethering housing is assumed to be phased out in 2030. Around 25 % expects to be housed in deep litter systems 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 are made for 2020. For 2019, the distribution are interpolated and for 2021-2040, it is set at the same level as 2020.

For swine, SEGES (2019) estimates the distribution of animals on different housing systems. The estimates are made for 2020 and 2030 and for the years 2019 and 2021-2029 the distribution are interpolated and 2031-2040 is set at the same level as 2030. Over 95 % of the fattening pigs and weaners are housed in systems with drained or partly slatted floor in 2018 and this is assumed to be the same in 2030. For sows, a decrease in systems where the sow is housed individually is assumed.

Jensen (2019, Pers. Comm.) projects distribution of hens and broilers on different housing systems. The estimates are made for 2020 and 2030 and for the years 2019 and 2021-2029, the distribution are interpolated and 2031-2040 is set at the same level as 2030. For hens, it is assumed that battery hens are phased out in 2020 and all free-range, barn and organic hens are housed in aviary-systems in 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.

SEGES (2019) projects the distribution of housing systems for mink. The estimates for 2030 are used and for the years 2019-2029, the distribution are interpolated and 2031-2040 is set at the same level as 2030. For mink, there are two types of housing systems in the projection; housings where the manure is removed once a week and housings where manure is removed two times a week. In 2018, 11 % of mink were in systems where manure is removed two times a week, it is assumed this will increase to 90 % in 2030.

6.6 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. Other emission reducing technologies as air cleaning etc. are not included in the historical emission inventory. The inventory also take into account the reduced emission as a result of slurry delivered to the biogas production.

It is expected that the reduction of emission from use of technology will be expanded in the future, which is mainly caused by the requirements in the Environmental Approval Act for Livestock Holdings (BEK nr. 1380, 30/11/2017), and therefore also reduction from other emission reducing technologies is included in the projection.

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, 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.

6.6.1 Use of environmental technologies

The environmental technologies are closely related to the growth in livestock production. An expansion of existing or new farms will be met by environmental requirements and the emission reducing technology will, for some farmers, be chosen as an opportunity to reduce the ammonia emission. The economic conditions can make it difficult for farmers to expand the livestock production, but animal housing systems will be outdated over time, and thus need to be replaced.

The assumptions regarding the expansion and development of emission reducing technologies in livestock production used in the historic emission inventory is based on data from the environmental approvals register 2007-2016 (Nielsen et al., 2020a, Annex 3D Chapter 3D-1).

For good reasons no information on which technologies the farmers will prefer in future is available, and therefore the allocation pattern for emission reducing technology from the register of environmental approvals 2007-2016 is used as a distribution key for the future approvals. Said in another way; no significant change in allocation of technology is assumed compared with allocation taken place in 2007-2016. It means, for example for the swine production, that manure cooling also in the future expects to be the most common chosen environmental technology to reduce the ammonia emission.

Regarding the number of expected new approvals in the future, it is based on the average of new approvals in the years 2011-2016, because the development in this period has been stable. This gives 136 new approvals per year until 2030. No changes is assumed from year 2030 to 2040. In Table 6.5 is listed the expectations of implementation of emission reducing technology in animal housing 2020 and 2030.

Regarding the swine production, the environmental technology is mainly implemented in sow housing, where 33 % of the production in 2030 is expected to take place in housing with environmental technology. For weaners, it is 18 % of the production in 2030, and for fattening pigs it is 20 %. Manure cooling is the most frequently used technology for the overall swine production.

Acidification of manure in housing is expected to be implemented for 8 % of the total dairy cattle production in 2030. For heifers, the acidification of manure in housing account for 2 % of the total production in 2030. Review of the environmental approval 2007-2016 indicate a very small part of the cattle production (less than 0.5 %) with manure cooling, but is in the case of projection considered as not important in context of the uncertainties of the data set.

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

Technology	Percentage of total production with technology	
Cooling of manure	2020	2030
Sows	6	17
Weaners	7	12
Fattening pigs	8	8
Acidification in housing	2020	2030
Dairy cattle	4	8
Heifer	1	2
Sows	2	6
Weaners	2	3
Fattening pigs	4	5
Air cleaning	2020	2030
Sows	2	9
Weaners	0	3
Fattening pigs	1	7

In 2018, almost 90 % of broiler housings have heat exchanger installed and it is expected that this increase to 100 % by 2030. Assessment of housing systems for mink production, including housing with practice on twice a week manure removal, is based on information from SEGES (2019).

Regarding the acidification during application of manure, it is estimated that around 8 % of the cattle slurry is acid treated in 2018 and for swine slurry it is estimated to 1 %. The same level as in 2018 is used for the following years.

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

Heat exchanger	2020	2030
Broilers	92	100
Removal of slurry - 2 times weekly	2020	2030
Mink	24	90
Acidification during application	2020	2030
Cattle manure	8	8
Swine manure	1	1

6.6.2 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 for untreated and biogas treated slurry (Mikkelsen et al., 2016). The model is updated in 2020 (Nielsen et al., 2020b).

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, 2020), 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	38-43	Based on results from the Danish biogas model (Nielsen et al., 2020b)
		Swine	CH_4	15-18	Do
Heat exchanger	Housing	Broilers	NH_3	30	DEPA**
Removal of slurry – 2 x weekly	Housing	Mink	NH_3	27	DEPA**

* Based on the review of the register of environmental approvals 2007-2016 (Nielsen et al., 2020a).

**List of Environmental Technologies (DEPA, 2020).

6.6.3 Biogas treatment of animal manure

Biogas treatment leads to a lower CH_4 emission from animal manure. In 2018, approximately 5.7 million tonnes slurry were treated in biogas plants, which are equivalent to approximately 15 % of all slurry. Prognoses provided by DEA assume an increase of biogas production from 12.2 PJ in 2018 to 20.8 PJ in 2020 and 28.7 PJ in 2030. The prognoses shows a decrease in the biogas production from 2033 to 2040 to 6.0 PJ and this is due to DEA´s approach on “frozen policy”. For now, no agreement have been made on incentives for the biogas production and therefor are no new biogas plants included in the prognoses to replace biogas plants working now, since it is not plausible that new biogas plants will be built without subsidy.

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, 2016/2017 and 2017/2018 (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 2014-2018 between biogas production and slurry input the amount of slurry input for the years 2019-2040 is estimated.

In 2020, 11.1 Mtonnes of slurry are expected to be delivered to biogas treatment, increasing to 15.3 Mtonnes in 2030. It is assumed that cattle slurry accounts for 62 % and swine slurry for 38 %, based on data from the BIB register.

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 [Mtonnes]
2018	13.4	12.2	5.7
2020	23.0	20.8	11.1
2030	31.0	28.7	15.3
2040	7.0	6.0	3.2

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 2020 (Nielsen et al., 2020b) 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. In the projection, it is assumed that cattle slurry delivered to biogas production reduces the CH_4 emission by approximately 33-41 %. It assumed that pig slurry reduces the CH_4 emission by approximately 22-24 %.

6.7 Other agricultural emission sources

Besides the livestock production, the most important variable regarding the emission of the greenhouse gases is the use of inorganic nitrogen fertiliser on agricultural soils.

6.7.1 Agricultural area

The projection of the agricultural area is based on the model AGMEMOD for 2019 to 2030. The years 2031-2040 are set at the level as 2030. The production of different crops dependents on the development in prices and yields. The area with wheat and mays is assumed to increase in the years up to 2030, while the areas with other cereals and grass is assumed to decrease (Jensen, 2020).

Projection of the area with organic soils is estimated for 2019-2040 (Gyldenkærne, 2020) and it is assumed that the area will decrease by 9 % from 2018 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.

	2018	2019	2020	2025	2030	2035	2040
Agricultural land area, 1 000 ha	2 632	2 620	2 608	2 547	2 488	2 488	2 488

6.7.2 Use of inorganic nitrogen fertilisers

The projection on the use of inorganic nitrogen fertiliser is based on assumptions for N applied per ha, including N from manure and sewage sludge.

The historic trend shows a use of inorganic fertiliser N of 200-210 M kg N in the period 2009-2015. In 2015, a political agreement (Agricultural agreement, 2015) was made which nullified the reduced fertiliser norms and in 2016 and 2017 the use of inorganic fertiliser increased to 243 and 254 M kg N, respectively. In 2018 and 2019 the use of inorganic fertiliser decreased again to around 225 M kg N. To take into account the variation in use of inorganic fertiliser an average N per ha for 2016-2019 is estimated based on amount of

N applied to soils from inorganic fertiliser, manure and sewage sludge divided with the area of agricultural land. The average N per ha 2016-2019 is estimated to 148 kg N per ha and this is used for the years 2020-2030. For the years 2031-2040 consumption of inorganic fertiliser is set to the same level as in 2030. The amount of inorganic fertiliser for 2021-2030 is estimated as:

148 kg N / ha * ha – N applied from manure and sewage sludge

Table 6.10 shows the projected amount of N applied from manure and sewage sludge, area of agricultural land and the estimated consumption of inorganic fertiliser.

Table 6.10 Consumption of inorganic nitrogen fertilisers.

	2019	2020	2025	2030
Manure, kt N	144	145	149	152
Sewage sludge, kt N	9	9	8	8
Agricultural land, ha	2 625 965	2 620 080	2 559 080	2 499 510
Kg N per ha*		148	148	148
Inorganic fertiliser, kt N	225	233	221	210

* Average for 2016-2019.

6.7.3 Leaching and run off

In the projection of N_2O from leaching and run off, reduction of N leached due to catch crop is taken into account for the years 2019-2021. Estimation of area with catch crop and reduction of N in groundwater is based on information from the Danish Agricultural Agency (DAA, 2019).

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

	2019	2020	2021
N in groundwater without reduction from catch crops, t	150 652	150 376	150 365
Reduction of N, t	345	2 066	3 140
N in groundwater, t	150 307	148 310	147 225

6.8 Results

In Table 6.12, the historical greenhouse gas emission 1990-2018 is listed, followed by the projected emissions for 2019-2040. The greenhouse gas emission is expected to decrease from 11.0 million tonnes CO_2 equivalents in 2018 to 10.8 million tonnes CO_2 equivalents in 2020 and then increase 11.1 million tonnes CO_2 equivalents in 2040. Thus, a 1 % increase of GHG emission from the agricultural sector from 2018 to 2040 is expected. The increased emission is driven by an increase in CH_4 emission.

Table 6.12 Total historical (1990-2018) and projected (2019-2040) emission, CO_2 eqv.

CO_{2e} , million tonnes	1990	2000	2018	2019	2020	2025	2030	2035	2040
CH_4	5.90	6.01	5.99	5.93	5.94	5.95	6.00	6.05	6.21
N_2O	6.65	5.39	4.81	4.70	4.64	4.58	4.60	4.60	4.72
CO_2	0.62	0.27	0.24	0.25	0.22	0.21	0.21	0.21	0.21
Agriculture, total	13.16	11.67	11.04	10.88	10.80	10.74	10.81	10.85	11.14

6.8.1 CH_4 emission

The overall CH_4 emission has increased slightly from 236 kt CH_4 in 1990 to 240 kt CH_4 in 2018. From 2018 to 2040, the CH_4 emission is expected to increase to 249 kt CH_4, corresponding to an increase of 4 % (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 decrease.

The historical emission related to the enteric fermentation shows a decrease up to 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 number of dairy cattle and the emission from enteric fermentation increase from 2015 to 2018. The AGMEMOD model indicates that Denmark, in the future, can be expected to increase both the milk production and the number of dairy cattle. 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 2018, 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 because of more manure delivered to biogas production. The increase in the emission from 2030 to 2040 is due to changes in the projection of amount of manure treated in biogas facilities.

Table 6.13 Historical (1990-2018) and projected (2019-2040) CH_4 emission.

CH_4 emission, kt	1990	2000	2018	2019	2020	2025	2030	2035	2040
Enteric fermentation	161.6	145.2	150.7	151.0	152.3	158.1	163.7	163.7	163.7
Manure management	74.1	94.9	88.8	86.1	85.3	79.7	76.3	78.0	84.7
Field burning	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total CH_4, kt	235.8	240.3	239.6	237.2	237.8	238.0	240.1	241.8	248.5

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

6.8.2 N_2O emission

The historical emission inventory shows a decrease of N_2O emission from 22.3 kt N_2O in 1990 to 16.1 kt N_2O in 2018, corresponding to 28 % reduction (Table 6.14). The reduction is primarily driven by a decrease in 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 2 % until 2040, which leads to a total N_2O emission at 15.8 kt N_2O. A range of the sources for N_2O emission is expected to decrease until 2040, while emission from animal manure applied to soil, crop residue, atmospheric deposition and nitrogen leaching increases. Emission from manure management is expected to decrease until 2030 but increases from 2030 to 2040 due to changes in the projection of amount of manure treated in biogas facilities.

Table 6.14 Historical (1990-2018) and projected (2019-2040) N_2O emission.

N_2O emission, kt	1990	2000	2018	2019	2020	2025	2030	2035	2040
Manure management	2.62	2.57	2.00	1.83	1.65	1.47	1.45	1.55	1.95
Indirect N_2O emission	0.66	0.61	0.46	0.43	0.43	0.42	0.41	0.41	0.41
Inorganic fertilisers	6.29	3.95	3.52	3.54	3.67	3.48	3.30	3.30	3.30
Animal manure applied to soils	3.33	3.06	3.41	3.33	3.35	3.43	3.49	3.49	3.49
Sludge applied to soils	0.07	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.13
Urine and dung deposited by grazing animals	1.00	1.01	0.59	0.54	0.53	0.54	0.55	0.55	0.55
Crop residues	1.91	1.83	1.59	1.71	1.76	1.97	2.17	2.17	2.17
Mineralization	0.50	0.13	0.45	0.27	0.05	0.02	0.09	0.02	0.03
Organic soils	2.87	2.60	2.19	2.18	2.17	2.08	2.00	1.97	1.97
Atmospheric deposition	1.21	0.79	0.67	0.67	0.69	0.69	0.69	0.69	0.69
Nitrogen leaching and run-off	1.84	1.39	1.11	1.13	1.11	1.14	1.16	1.15	1.15
Field burning	0.002	0.003	0.004	0.003	0.003	0.003	0.003	0.003	0.003
Total N_2O, kt	22.31	18.10	16.13	15.77	15.56	15.36	15.43	15.43	15.83

- 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., 2020). 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., 2020).

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) and IPCC Good Practice Guidance (2001). Based on the recommendation in these reports, a so-called Tier 2 method, a decay model, has been selected for the model. The model is described in the National Inventory Report, which is prepared for the Climate Convention, the latest being the 2020 NIR report (Nielsen et al., 2020). 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., 2020.

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 2005 to 2018, as shown in Figure 7.1. The high value for total waste in 2010-2012 is caused by changes to the data system and registration of more inert waste than in preceding or following years.

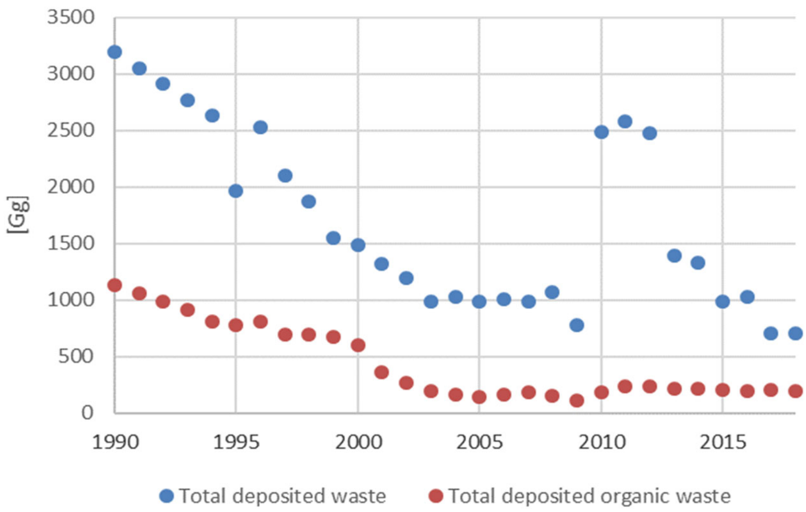

Figure 7.1 Historical data on the total amount of waste, i.e. organic/degradable and inert/non-degradable waste, and total organic waste disposed of at solid waste disposal sites.

Amounts of waste being disposed of at Danish landfills, excluding sludge and stones, are projected by the Danish EPA (DEPA, 2019).

The projected methane emissions from solid waste disposal sites (SWDSs), assumes waste type distributions equal to the composition for 2018 throughout the projection period 2019-2040.

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 I projected to be 0.16 PJ in 2019 and 0.15 PJ per year from 2020 to 2032 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, [kt].

Year	Landfilled waste	Gross methane emission	Recovered methane	Methane oxidised in the top layers		Net methane emission
Year	kt	kt CH_4	kt CH_4	kt CH_4	kt CH_4	kt CO_{2e}
1990	3 190	69	1	7	61	1 536
1995	1 969	67	8	6	53	1 331
2000	1 489	59	11	5	43	1 073
2005	983	50	10	4	36	909
2010	2 487	40	6	3	31	772
2015	987	32	3	3	26	651
2018	700	29	4	2	22	560
2020	421	26	3	2	21	530
2025	470	22	3	2	17	430
2030	497	19	3	2	14	355
2035	521	16	0	2	14	361
2040	550	14	0	1	13	318

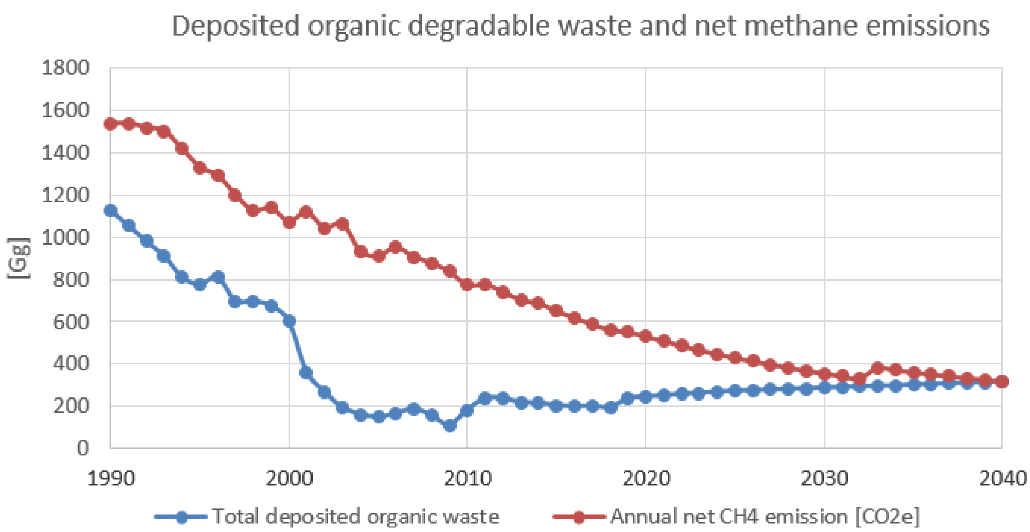

Figure 7.2 Historical and projected amounts of waste deposited at landfill and net CH_4 emissions. Historic data: 1990-2018. Projections: 2019-2040, [kt].

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. Even though the percentage of waste being deposited at landfills is decreasing slightly from 3.7 % in 2015 to 3.6 % in 2035, the total amount of waste is increasing from 10 891 kt in 2015 to 14 290 kt in 2035 (DEPA, 2019), which causes the absolute amount of waste being deposited at landfills to increase slightly.

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 23 years, the emission factors known from Nielsen et al. (2015) are used for this projection.

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

	Garden and park waste	Organic waste	Sludge	Home composting
CH_4	4.20	4.00	0.41	5.63
N_2O	0.12	0.24	1.92	0.11
Source	Boldrin et al., 2009	IPCC, 2006	MST, 2013	Boldrin et al.,2009

Activity data

Garden and park waste for 1995-2009 is determined based on the Danish waste statistics (DEPA, 2011) and on the two statistical reports Petersen (2001) and Petersen & Hansen (2003). Activity data for the waste categories Organic waste from households and other sources and Sludge are extracted from the Danish waste statistics 1995-2009. For 1990-2012, Home composting of garden and vegetable food waste is determined based on data from Statistics Denmark and on Petersen & Kielland (2003).

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

Table 7.3 Activity data for compost production, 2019-2040.

kt	Average (2016-2018)
Garden and park waste	938
Organic waste	27
Sludge	80
Home composting	23

Historical and projected emissions

Calculated historical and projected emissions is shown in Table 7.4.

Table 7.4 Historical and projected emissions from biological treatment of solid waste, kt.

	1990	1995	2000	2005	2010	2015	2018	2019-2040
CH_4	1.39	1.86	3.24	3.42	3.8	3.98	4.27	4.42
N_2O	0.04	0.07	0.51	0.20	0.29	0.22	0.28	0.29
CO_2 equivalents	46.8	67.5	234.0	144.4	181.8	164.4	190.3	187.1

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 13.25 PJ in 2019 reaching a constant level of 28.65 PJ from 2023 to 2032 after which a gradual decrease to 6 PJ in 2040 is projected. In addition to the agricultural section, the energy production within industrial sector is estimated to increase from 0.9 PJ in 2019 to a constant level of 1 PJ in in period 2022-2040. The CH_4 emission is calculated using an emission factor of 4.2 % of the CH_4 content in the produced biogas in 2018 and 2019 and 1 % for 2020 onwards. Historical and projected emission are provided in Table 7.5.

Table 7.5 Historical and projected emissions from biological treatment of solid waste, kt.

	1990	1995	2000	2005	2010	2015	2018	2020	2025	2030	2035	2040
CH_4	0.2	0.6	1.2	2.0	2.7	4.4	10.3	4.3	5.9	5.9	5.0	1.4
CO_2 equivalents	5.6	15.7	30.3	49.9	66.9	109.2	257.1	108.3	148.3	148.3	123.8	35.0

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

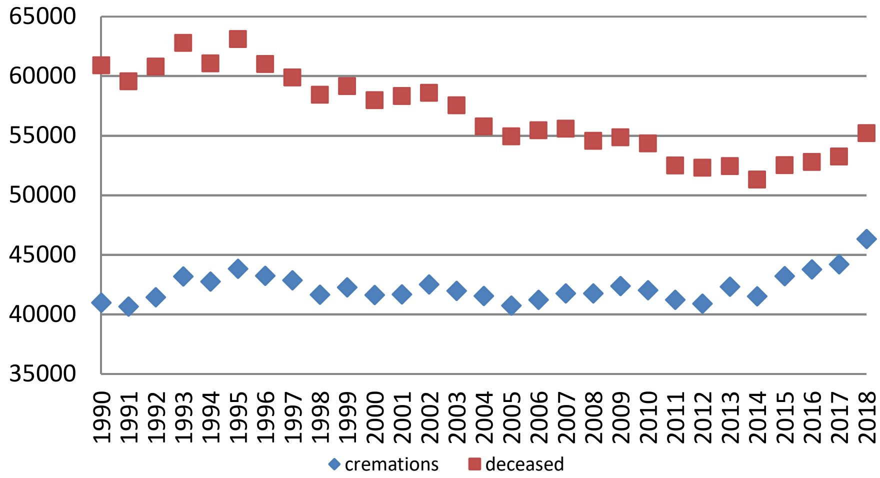

Figure 7.3 Trends of the activity data for cremation of human corpses and the national number of deceased persons.

As shown in Figure 7.3, 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 corresponding to the average value of the last five historical years as shown in Table 7.6.

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

Year	1990	1995	2000	2005	2010	2015	2018	2019 - 2040
CH_4	0.48	0.52	0.49	0.48	0.49	0.51	0.54	0.52
N_2O	0.60	0.64	0.61	0.60	0.62	0.64	0.68	0.64
Total, CO_{2e}	191.62	204.97	194.70	190.53	196.57	202.12	216.62	204.85

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 7.4 shows historical data.

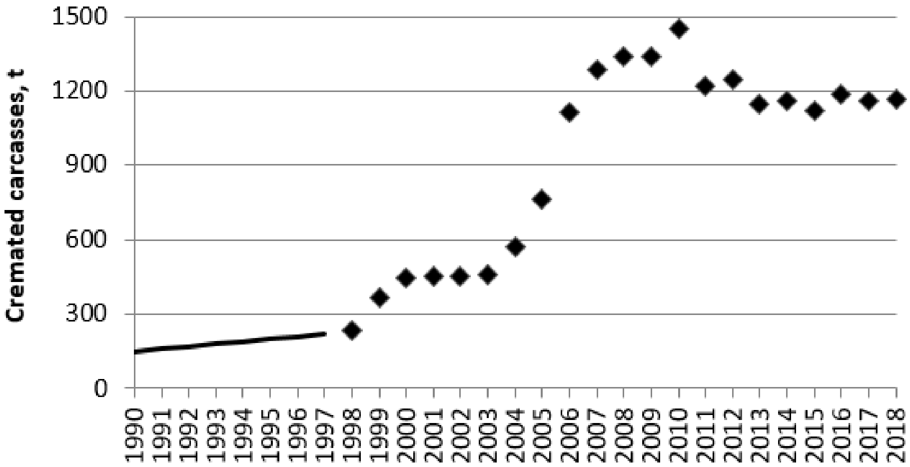

Figure 7.4 The amount of animal carcasses cremated (Mg). Data from 1998-2018 are delivered by the crematoria and is considered to be exact; these data are marked as points. Data from 1990-1997 are estimated and are shown as the thick line in the figure.

A constant value corresponding to the average of the five latest historical years emissions were adopted throughout the projection period 2019-2040.

Table 7.7 CH_4 and N_2O emission from animal cremations, t.

Year	1990	1995	2000	2005	2010	2015	2018	2019 - 2040
CH_4	0.03	0.04	0.08	0.14	0.26	0.20	0.21	0.21
N_2O	0.03	0.05	0.10	0.17	0.33	0.25	0.26	0.26
Total, CO_{2e}	10.8	14.4	31.9	54.8	104.2	80.5	84.1	83.4

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. (2020) 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., 2020; Thomsen, 2016). An overview of the historical and projected amount of COD in the influent wastewater is provided in Table 7.8.

Table 7.8 Total degradable organic waste (TOW) in the influent wastewater [kt COD per year].

Year	1990	2000	2005	2010	2015	2018	2020	2025	2030	2035	2040
COD, [kt]	295	365	364	372	385	398	396	405	413	420	425

Note: Historical data: 1990-2018, projected data: 2019-2040.

"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 7.9 shows the historical and projected gross energy production reported by the Danish Energy Agency.

Table 7.9 Gross Energy production [TJ] and the corresponding methane content [kt H_4].

	1990	2000	2005	2010	2015	2018	2020	2025	2030	2035	2040
Energy production	458	857	913	840	901	1002	1200	1200	1200	0	0
CH_4 content	9.3	17.4	18.6	17.1	18.3	20.4	24.4	24.4	24.4	0.0	0.0

Note: Historical data: 1990-2018, projected data: 2019-2040.

The CH_4 content in the biogas is calculated from the calorific value 23 GJ/1000 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., 2019). 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., 2020). The population numbers used for deriving historical and projected emissions from septic tanks is provided in Table 7.10.

Table 7.10 Population numbers and projections for Denmark.

Year	1990	2000	2005	2010	2015	2018	2020	2025	2030	2035	2040
Population estimates (1000)	5135	5330	5411	5535	5660	5781	5845	5982	6109	6214	6296

Note: Historical data: 1990-2018, projected data: 2019-2040.

Methane emission projections are provided in Chapter 7.4.2, Table 7.12. For details regarding the methodology for estimating the methane emissions from the Danish WWTPs, the reader is referred to Nielsen et al. (2020) 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., 2020) 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 influent N per person per year in 2017 and projected according to population statistics (Table 7.10), while the effluents from separate industries, rainwater conditioned effluents, scattered houses and aquaculture was held constant at the 2018 level form 2019-2040. Total N in the influent and effluent wastewater is presented in Table 7.11 and total N_2O emissions from wastewater treatment and discharge in Table 7.12.

Table 7.11 Total N in the influent and effluent wastewaters [Mg].

Year	1990	1995	2000	2005	2010	2015	2018	2020	2025	2030	2035	2040
Influent N, municipal WWTPs	14 679	22 340	26 952	32 288	27 357	30 509	30 288	30 548	31 182	31 820	32 337	32 726
Effluent N, municipal WWTPs	16 884	8 938	4 653	3 831	4 025	3 705	3 127	3 154	3 219	3 285	3 338	3 378
Influent N, industrial WWTPs	32 175	16 644	11 213	5 688	4 225	4 141	4 250	4 250	4 250	4 250	4 250	4 250
Effluent N, separate industries	2 471	2 471	897	441	338	331	371	337	337	337	337	337
Rainwater conditioned effluents	867	867	762	622	762	1 476	714	714	714	714	714	714
Effluents from scattered houses	1 141	1 141	979	919	902	747	493	493	493	493	493	493
Effluents from aquaculture	1 735	1 735	2 714	1 225	933	1 029	1 040	1 040	1 040	1 040	1 040	1 040
Total effluent N	19 355	15 152	10 005	7 038	6 960	7 288	5 745	5 738	5 804	5 870	5 923	5 963

Note: Historical data: 1990-2018, projected data: 2019-2040.

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 2018 effluent level are kept constant throughout the projection period. The total N content in the influent and effluent from WWTPs is increasing according to population statistics for the period 2019-2040.

The emission projection for the total N_2O emission is provided in Table 7.12.

Remarks to the presented projection of nitrous oxide from wastewater handling:

Direct emissions from wastewater treatment within industries are included for the first time. 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, a value of 4.99 kg N_2O / tonnes influent total N are used in the estimated historical and projected direct N_2O emissions; the value is within the range reported by Danish research in the area (e.g. Ni et al., 2011). However, very little has so far been available from the scientific literature about the size of the direct N_2O emissions (Nielsen et al., 2020; Thomsen, 2016) and novel data indicates that the N_2O emissions from secondary treatment processes may be underestimated for some plants (Andersen, 2012; Ni et al., 2011).

7.4.2 Historical emission data and projections

Historical and projected methane emissions are shown in Table 7.12.

Table 7.12 Methane and nitrous oxide emission from wastewater treatment and discharges, [kt].

Year	1990	1995	2000	2005	2010	2015	2018	2020	2025	2030	2035	2040
CH_4 sewer system and MB	0.22	0.25	0.27	0.27	0.28	0.29	0.30	0.30	0.30	0.31	0.31	0.32
CH_4 septic tanks	1.30	1.32	1.35	1.37	1.40	1.44	1.47	1.48	1.51	1.54	1.57	1.58
CH_4 AD	0.12	0.16	0.23	0.24	0.22	0.24	0.26	0.32	0.32	0.32	0.00	0.00
CH_4 total emission	1.64	1.73	1.85	1.89	1.91	1.96	2.03	2.09	2.13	2.17	1.88	1.90
N_2O direct	0.23	0.27	0.19	0.19	0.16	0.17	0.17	0.18	0.18	0.18	0.18	0.19
N_2O indirect	0.13	0.12	0.08	0.06	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.05
N_2O total	0.37	0.38	0.27	0.24	0.21	0.23	0.22	0.22	0.22	0.23	0.23	0.23
CO_{2e} total	150.3	157.8	126.5	120.1	110.9	117.7	116.1	118.2	120.2	122.2	115.9	117.2

Note: Historical data: 1990-2018, Projected data: 2019-2040.

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 7.12.

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 to the emission for 2016.

7.5.1 Historical emission data and projections

Table 7.13 gives an overview of the Danish non-biogenic greenhouse gas emission from the CRF source category 5.E Waste Other.

Table 7.13 Historical and projection of overall emission of greenhouse gases from the accidental building and vehicle fires.

	Unit	1990	1995	2000	2005	2010	2018	2019-2040
CO_2 equivalents	kt	23	23	21	20	17	17	16

7.6 Emission overview

The total emissions from the waste sector are presented in Table 7.14 below.

Table 7.14 Emissions from the waste sector in kt CO_2 equivalents.

	1990	2000	2005	2010	2015	2017	2018	2020	2025	2030	2035	2040
5A Solid waste disposal	1 536	1 331	1 073	909	772	651	560	530	430	355	361	318
5B Biological treatment of solid waste	52	83	264	194	249	274	442	295	335	335	311	222
5C Incineration and open burning of waste	0,2	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	150	158	126	120	111	118	116	118	120	122	116	117
5E Other	23	25	23	23	19	17	20	18	18	18	18	18
Total	1 762	1 598	1 487	1 246	1 151	1 059	1 139	961	904	831	806	675

7.7 Source specific recalculations

For the solid waste disposal, a decrease in the projected emissions in the period 2015 to 2032 of -1 to -6%, has occurred, which is due minor changes in the historical activity data as well as a correction in the projected amounts of water being landfilled. Opposite an increase in the emissions is observed from 2033 to 2040 which is due to a reduction in the amount of collected landfill gas by the Danish Energy Agency (DEA, 2020) compared to the last projection.

For category 5B Biological treatment of solid waste, the projected emissions have decreased between -1 and -7 %. This is due to a reduction in the historical emissions from 5B.1 composting due to correction of the methodology (Nielsen et al., 2019 and 2020).

For category 5C Incineration and open burning of waste we applied the average of the five last historical year in the emission projection instead of the last historical year.

For category 5D Wastewater treatment and discharge, there is a minor decrease which is due to a reduction in the estimated biogas production.

For the category Other, we applied the average of the five last historical year in the emission projection instead of the last historical year.

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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 include 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., 2019).

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 Chapter 7 in Nielsen et al. (2020). Furthermore, the 2006 IPCC Guidelines (IPCC, 2006) and the 2013 Wetlands Supplement (IPCC, 2014) have been taken into account.

Approximately two thirds of the total Danish land area are cultivated and 14.3 % 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 the next 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 that it takes longer time to reach the equilibrium state in carbon stock. After this period, the area is moved to land remaining land. The choice of implementing a longer transition time was done in the Danish National Forest Accounting Plan 2021-2030 (Johannsen et al., 2019).

Under the Kyoto Protocol, Denmark has elected Cropland Management (CM) and Grazing Land Management (GM) under article 3.4 to meet its reduction commitments besides the obligatory Afforestation, Reforestation and Deforestation (ARD) under article 3.3 and Forest Management (FM) under article 3.4. Since land, which is converted from one category to another (e.g. from CL to SE) cannot be omitted from the reporting obligation under the Kyoto Protocol, the actual estimates in each category reported under the Convention, may not be the same as accounted for under the Kyoto Protocol, see section 8.10. The reported values in section 8.11 have 1990 as base year.

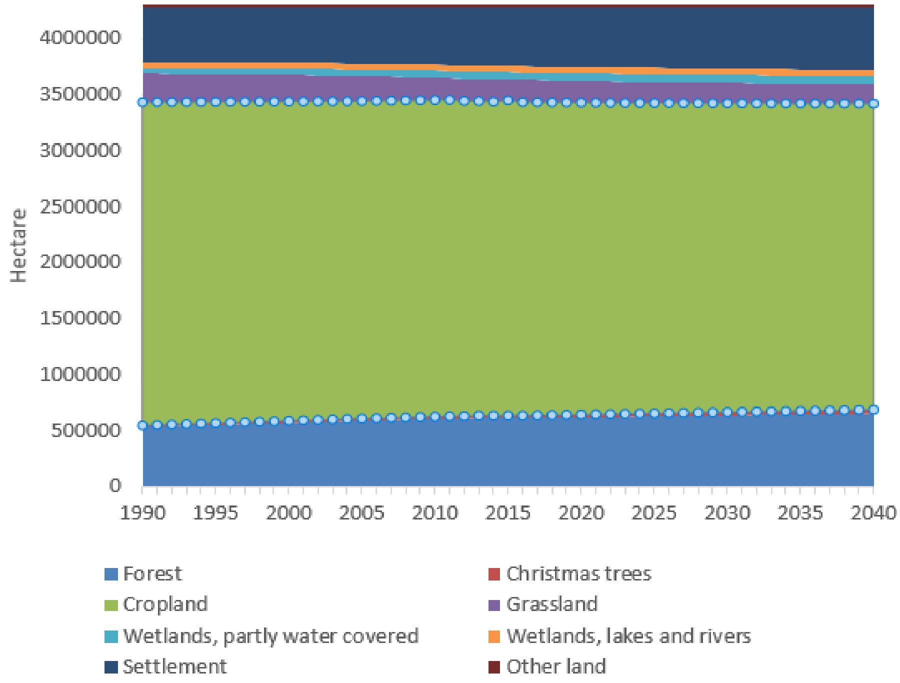

Figure 8.1 Land area use 1990-2040.

Table 8.1.a, b and c show the projected average land use changes between the different land use categories. Actually four distinct periods have been chosen: 2019-2020, 2021-2022, 2023-2024, 2025-2030 and 2030-2040. 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, 2020). 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. A special financing, which is not included in the Finance act is a funding of 270 million € from 2020 to 2029. This equivalents establishing of 1500 ha WE per year which is expected to be established in 2023 to 2032. No financial allocations for converting agricultural land to WE after 2032 is assumed except for minor usual observed land use changes. Conversion of FL to WE is expected to continue with 25 ha per year from 2021 and onwards due to clearcutting in the forests.

Conversion to Settlements and other infra structures (SE) is expected to continue with the same pace as seen historical.

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 4 000-6 000 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 from **2019-2020**, 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	0		0	0	0	0	0	0	0
Forest	47	9		57	34	34	0	0	180
Christmas trees	2	0	40		0	0	1	0	44
Cropland	1339	121	1405	592		3000	357	0	6813
Grassland	90	23	400	20	3000		161	0	3693
Wetland, partly water covered	3	1	55	1	25	0		0	85
Other land	0	0	0	0	0	0	0		0
Total, ha per year	1481	154	1900	669	3059	3034	519	0	10815

Table 8.1b Expected annual land use change in hectares per year from **2023-2024**, 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	0		0	0	0	0	0	0	0
Forest	47	9		57	34	34	25	0	205
Christmas trees	2	0	40		112	50	1	0	206
Cropland	1339	121	1405	592		3000	1192	0	7649
Grassland	90	23	400	20	3000		548	0	4080
Wetland, partly water covered	3	1	55	1	25	0		0	85
Other land	0	0	0	0	0	0	0		0
Total, ha per year	1480	154	1900	669	3171	3085	1765	0	12225

Table 8.1c Expected annual land use change in hectares per year from **2031-2040**, 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	0		0	0	0	0	0	0	0
Forest	47	9		57	34	34	25	0	205
Christmas trees	2	0	40		112	50	1	0	206
Cropland	1339	121	1405	592		3000	376	0	6833
Grassland	90	23	400	20	3000		167	0	3699
Wetland, partly water covered	3	1	55	1	25	0		0	85
Other land	0	0	0	0	0	0	0		0
Total, ha per year	1481	154	1900	669	3171	3085	569	0	11028

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 per year. By convention are emissions reported as positive figures and sinks as negative figures.

kt CO_{2e}	1990	2010	2016	2017	2018	2019	2020	2025	2030	2035	2040
4. LULUCF	544,6	-987,6	6165,7	4485,5	6593,6	4700,5	4544,1	4626,3	5286,5	4349,0	4471,5
A. Forest Land*	-3750,8	-5788,8	898,9	-82,4	402,2	-875,3	-131,1	424,5	252,2	-34,8	-285,3
1. Forest Land remaining Forest Land*	-3500,7	-6912,0	755,7	169,9	565,6	106,9	766,9	1059,8	889,2	586,3	281,7
2. Land converted to Forest Land*	-250,0	1123,2	143,2	-252,3	-163,4	-982,2	-898,0	-635,3	-637,0	-621,1	-567,0
B. Cropland	2794,7	3283,6	3737,0	3138,4	4586,0	4088,6	3145,6	2728,0	3610,5	2950,5	3298,2
1. Cropland remaining Cropland	2781,3	3269,4	3678,8	3143,9	4537,5	4090,1	3146,8	2728,9	3610,6	2953,0	3303,2
2. Land converted to Cropland	13,4	14,2	58,2	-5,4	48,5	-1,4	-1,2	-0,9	-0,2	-2,5	-5,0
C. Grassland	1277,3	1280,3	1371,9	1341,4	1463,5	1355,0	1392,3	1310,9	1266,1	1244,1	1243,3
1. Grassland remaining Grassland	1224,0	1225,2	1295,0	1291,7	1391,4	1320,2	1357,3	1274,0	1226,3	1198,5	1194,6
2. Land converted to Grassland	53,3	55,2	76,9	49,8	72,1	34,8	35,0	36,9	39,8	45,6	48,6
D. Wetlands	125,2	135,1	97,8	87,3	110,0	97,9	97,9	95,1	63,9	69,3	69,4
1. Wetlands remaining Wetlands	101,5	111,4	99,6	87,9	110,0	40,3	40,3	40,3	9,0	9,0	9,0
2. Land converted to Wetlands	23,7	23,8	-1,8	-0,6	0,0	57,7	57,7	54,8	54,9	60,3	60,4
E. Settlements	120,2	127,2	231,6	174,6	194,0	183,8	189,0	217,3	243,3	269,4	295,4
1. Settlements remaining Settlements	0,0	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	120,2	127,2	231,6	174,6	194,0	183,8	189,0	217,3	243,3	269,4	295,4
F. Other Land	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
G. Harvested Wood Products*	-22,0	-25,0	-171,5	-173,9	-162,1	-149,5	-149,5	-149,5	-149,5	-149,5	-149,5

*The methodology for estimation of emission and projections for all Forest and HWP data are reported in Johannsen et al., 2019.

In total from 1990 to 2040, an afforestation of 132 846 hectares is expected (excl. Christmas trees), while the deforestation is only expected to include 14 501 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 small source in the near future and Afforestation is expected to be net sink. For further details on the forest projection see Johannsen et al. (2019).

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 are near in a C-balance, this is expected to continue until 2040. The expected increasing temperature will increase the annual losses from the mineral soils but this is 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 projected temperature is based on an expected temperature increase combined with a natural temperature variability (observed data from 1994 to 2017) as recommended by the Danish Meteorological Institute (Marianne Sloth Madsen, pers. comm.). The temperature is a major driver for C-TOOL. A result of this variation in the temperature data combined with C-TOOL modelling can be seen in Table 8.3 for year 2025. By coincidence year 2025 is predicted to be cooler than average years giving a slower degradation of organic matter in the agricultural soils. The outcome can be seen in Table 8.3 for CL in 2025 which shows a pronounced less total emission from CL remaining CL than in the previous and the following years.

The overall emission from CL is expected to decrease over time but still be a major source due to large emissions from the organic soils.

The area reported under GL is assumed stable with only minor changes.

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 2020 for conversion of agricultural organic soil to WE.

SE is expected to have increasing emissions because of the steady LUC (Land Use Conversion) to SE and especially from CL. The increasing emissions are caused by loss of Soil Organic Carbon (SOC), because the default C stock in SE is lower than for the land, from which it is converted.

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 National Forest Accounting Plan 2021-2030, NFAP (Johannsen et al., 2019). The Land Use Matrix for LUC in this report, is the same as in the NFAP.

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 1900 hectares per year in the future. 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 130-150 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., 2019.

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 based LiDAR measurements in 2006 and 2014/2015 combined with a growth model for newly planted hedges (Nielsen et al., 2020).

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 kt CO_2 equivalents 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 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 2006-2015 is used as input to estimate a reference yield level in

2015. For the last 18 years, there has been a restriction on the farmer's N use in Denmark. This was partly abandoned in 2016. The higher N-quota is expected to increase the annual crop yield by 0.6 percent for all crops. The projection (carried out April 2020) uses observed crop data including year 2019.

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 2017 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.

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 240 000 hectares in 2015, increasing to 490 000 hectares in 2021, adding biomass to the SOC stock. No changes in the distribution of the currently grown crops are assumed. No further removal of straw and other crop residues are foreseen in this projection. At present, the use of catch crops is financed partly through a political agreement ending in 2021. From 2022 is assumed an area of 240 000 ha per year which is the mandatory area with catch crops.

Presently, the clayey 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 400 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. The overall trend will be an increased carbon stock in the agricultural soil 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 CO_2 per year. Due to high yields in most recent years, a sink has been estimated from 1995 up to 2016. This sink will increase further in the near future due to an expected yield increase. The large variation seen in Figure 8.3 between projected years is due to differences in temperature between years and crop yield. Year 2018 was extremely dry with low yields. Hence the estimated C stock decreased (large emission). In the temperature projection, the annual temperatures has been randomized to mimic natural temperature fluctuations. As mentioned, this can be seen for year 2025 (the drop in the red line for 2025 in figure 8.3 as well as a peak in the emission can be seen in 2031).

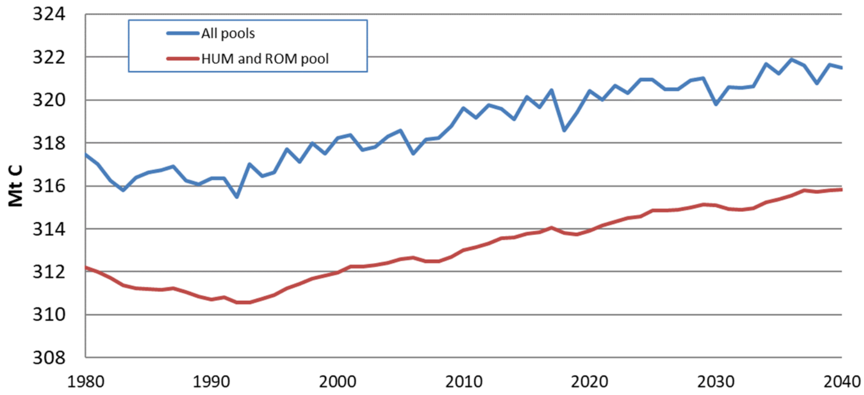

Figure 8.2 Total estimated carbon stock in mineral soils in Cropland and Grassland, kt C. HUM = humified organic matter, ROM = Resilient organic matter

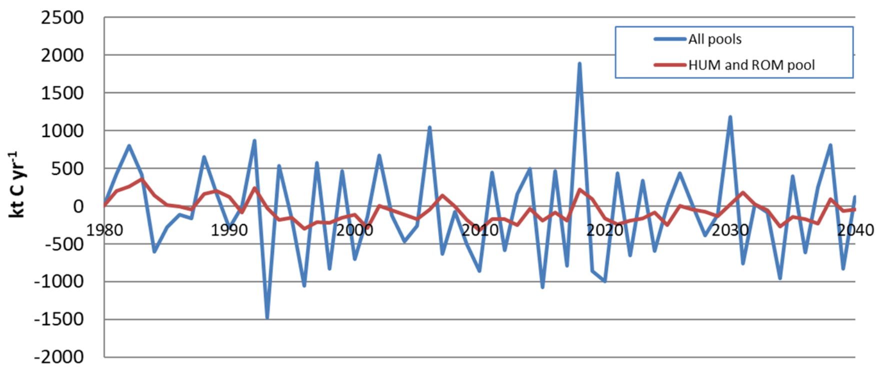

Figure 8.3 Annual emissions from mineral soils in Cropland and Grassland, kt CO_2 per year.

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 2-3 % 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 new soil map for organic soils from 2010. The new 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 118 162 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 to in total 177 135 ha > 6% OC of which 77 240 ha had an OC content of > 12 %. This large decrease is attributed to that the Danish organic soils are 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 conservative approach.

In the projection is used the financial allocation for re-establishment of WE in the governmental budget (Finance Act, 2020). Analysing data for 3000 ha recently established WE ("N-vådområder" and "Lavbundsprojekter")(unpublished) showed that approximately 84 % of the area inside the boundary of the re-established WE is on agricultural land. Of these were again 85 % on organic soils. The overall result is that approximately 70 % of an established WE will take place on organic soils (>6 % OC). The expected total converted organic agricultural land converted to WE from 2019 to 2030 is shown in Table 8.4. The projection assumes a three years delay from the financing to the establishment of the WE, so the 370 ha mentioned for 2019 in Table 8.4 is estimated to be implemented in the GHG emission estimate in 2022.

Table 8.4 Expected areas converted to WE in 2017-2030, ha (Finance Act 2020).

	Establishing of WE	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Financial allocation	§ 24.23.03.29	350	350	350	0	0	0	0	0	0	0	0	0
	§ 24.23.03.34	780	1150	1150	0	0	0	0	0	0	0	0	0
	Special allocation	0	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	0
	CL, organic soils	229	340	260	497	1453	1453	810	810	810	810	810	810
	GL, organic soils	114	199	148	272	707	707	345	345	345	345	345	345

The data from the EU subsidy register include information on areas where the farmers apply for subsidies as well as for other crops, which are mandatory to report. The register data from 2011 to 2018 show that the registered area has been reduced by 1 000-1 500 ha on organic soils per year (> 12% OC). The reason for this is not clear. The most plausible explanation is that these soils subside due to oxidation of the organic matter and combined with no possibilities for further drainage, makes the areas unsuitable for agricultural production. In the inventory, an emission factor of 3.6 tonnes C per ha per year is used from the 2013 Wetlands Supplement for these soils (IPCC 2014) equivalent to nutrient-rich shallow-drained organic soils.

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).

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	2017	2018	2019	2020	2025	2030	2040
Cropland, organic area, inside fields > 6 % OC, ha	156101	129403	119299	117363	117134	116793	112320	108270	106650
Cropland, organic area, outside fields > 6 % OC, ha	0	0	8104	10040	10040	10040	10040	10040	10040
Grassland, organic area, > 6 % OC, ha	58671	47733	50033	51331	51218	51018	48839	47114	46424
Cropland, emission, > 6 % OC, kt CO_{2e}	4704	3813	3567	3525	3516	3503	3351	3223	3171
Grassland, emission, > 6 % OC, kt CO_{2e}	1421	1132	1187	1219	1216	1210	1154	1114	1098
Leached C from organic soils, kt CO_{2e}	179	145	145	146	146	145	139	134	132
CH_4 from Grassland and leaching, kt CO_{2e}	248	200	207	210	210	209	201	194	191
Total emission, kt CO_{2e}	6553	5290	5106	5101	5087	5067	4844	4665	4593

The CO_2 emission from organic soils in CL was reduced from 4704 kt CO_2 in 1990 to 3525 kt CO_{2e} in 2018 (Table 8.5); it is expected to continue to decrease with an estimated emission in 2030 of 3223 kt CO_2. 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 5 200 hectares in 2018. No changes in the area with fruit trees are expected. The area with willow as energy crop is expected to be stable with 5062 hectares as in 2018, 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 very high 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 175 000 hectares is reported in the GL sector in 2018. 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 of around 1200 kt CO_2 equivalents per year (Table 8.5) due to the reported drained organic soils.

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 2018, 203 000 m^3 of peat were excavated. This was higher than in previous years and can possible be attributed to the very dry summer in 2018 making peat extraction more intense. The total emission from this is estimated to 44 kt CO_2 and 0.0004 kt N_2O per year (0.44 kt CO_2 equivalents).

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. Lately, only smaller areas have been converted. GIS analyses of 3000 ha restored WE (unpublished) have shown that 84 % of the re-established WE is located in areas where agricultural fields could be identified. If the WE is established on previous unmanaged GL, the impact on the emission estimates may be limited. This is also the case if the WE are established on mineral soils because large changes only occur if the WE are established on drained organic soils.

There has been a large variation in the area converted to restored WE within the past years. In the projection, an average conversion of 1 500-3 000 ha per year is used for 2018-2032 (Table 8.4) to WE. From 2032, a lower conversion rate to WE per year is projected (based on historical data).

The new WE are divided into fully covered water bodies (lakes) and partly water covered WE. In the projection is assumed that all area is converted to partly water covered wetlands and not 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 new 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 100 kt CO_2 equivalents per year. This is expected to decrease to 70 kt continue CO_2 equivalents per year after the peat excavation has ceased and emerging of new WE. From 2028, the CH_4 emission from the partly water saturated areas dominates the emission from managed WE, and corresponds to around 1.5 kt CH_4 per year equivalent to 70 kt CO_2 equivalents per year in 2040.

8.5 Settlements

The need for areas for housing and other infrastructure has resulted in an increase in the SE area from 1990 to 2018 of 42 957 hectare or 1500 hectare per year. In 2011, the Danish Nature Agency estimated the need for SE areas in the vicinity of Copenhagen to 1 250 hectares per year for the period 2013 to 2025 (Danish Nature Agency, 2011). To this should be added the SE in the remaining parts of Denmark as well as areas for roads and other purposes. It is assumed that the historic increase in SE will continue in the future and mainly result from conversion of CL.

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 recent 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	2018	2020	2025	2030	2035	2040
Forest area burned, ha	150	0	0	0	0	0	0	0
Heathland area burned, ha	47	359	700	700	700	700	700	700
Total burned area, ha	197	359	700	700	700	700	700	700
Emission, CH_4, kt	0.026	0.001	0.001	0.001	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	0.061	0.061	0.061	0.061	0.061	0.061

8.8 Harvested Wood Products

The category Harvested Wood Products (HWP) is reported by IGN in Johannsen et al. (2019).

8.9 Total emission

The total emission is shown in Table 8.3. As Forest land and HWP is reported separately, only CL, GL, WE, SE and Other land are included here.

The overall picture of the LULUCF sector excl. Forestry and HWP is a net source of 7 001 kt CO_2 equivalents in 1990. In 2018, the estimated emission has been reduced to a net source of 6 353 kt CO_2 and a net source of 5 012 kt CO_2 equivalents in 2021-2030 (average of 2021-2030). A small decrease in the emission is expected in year 2031-2040 compared to 2021-2030. This decrease is partly due to increased carbon stock in mineral soils due to increased crop yield and a little less managed organic soils. However, the temperatures in the modelling is purely randomized.

CL is assumed to be a net emitter of 3 200 kt CO_2 equivalents in the future due to the stable high emission from the organic soils and an increasing but variable C stock in the mineral soils. The large drained and cultivated area with organic soils is responsible for an emission of 3 300 kt CO_2 per year and thus a major contributor of the total Danish emission from LULUCF. GL is projected to be a net emitter of 1 300 kt CO_2 equivalents per year - also in the future. The emissions from WE are estimated to 100 kt CO_2 equivalents per year and are fairly constant. Emissions from SE are projected to increase in the future being around 225 kt CO_2 equivalents per year due to C losses from areas converted to SE, mainly 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 ton 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 ton 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 ton 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.

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 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 313 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.

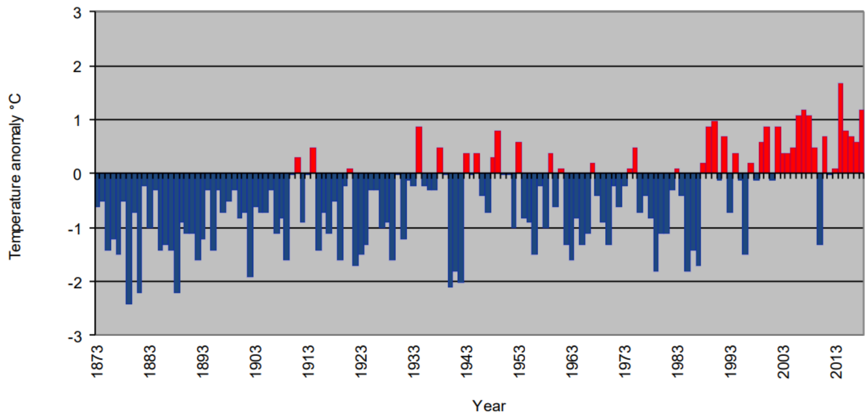

Figure 8.4 Annual change in temperature in Denmark 1873 to 2018 in relation to 1981-2010 (Cappelen, 2018).

8.11 The Danish Kyoto commitment

In addition to the obligatory inclusion of ARD (article 3.3) and FM in the second commitment period, Denmark has elected CM and GM under article 3.4 to meet its reduction commitment. Although the reduction commitment is based on the national inventory to UNFCCC, there are several differences. The major differences are CM and GM, where the reduction is estimated based on the net-net principle. Furthermore, a land area, which belongs to any of the elected land use activities in 1990, cannot leave the commitment and must therefore be accounted for in the future. This means that land converted from CL to e.g. SE must still be accounted for in the first and all subsequent commitment periods.

The projected emissions from CM and GM until 2020 are shown in Table 8.7. As land cannot leave an elected activity, these figures are slightly different from those given in Table 8.3 for CL and GL. The main driver for the decreased emission is the expected increase in C stock in mineral soils and conversion of organic CL and GL to WE. The projected effect of the election of CL and GL management on the Danish reduction commitment is illustrated in Table 8.8.

For CM, the expected increase in crop yield due to the increased N allocation to CL, leads to an increase of the C stock in the soil. This combined with a smaller emission from the organic soils CM is projected to add to the Danish reduction commitment (Table 8.8). GM is estimated to add slightly negatively to the Danish reduction commitment in the second commitment period. Because of the problems distinguishing CM and GM activities, CM and GM should be seen as a whole. In the second commitment period of the Kyoto Protocol, GM and GM is expected to add in total 15 070 kt CO_2 equivalents to the Danish reduction commitment.

Table 8.7 Projected emission estimates for CM and GM 1990 to 2020, kt CO_{2e}.

		1990	2013	2014	2015	2016	2017	2018	2019	2020
Art. 3.4	CM	5448.1	3029.0	4093.3	3588.5	3848.8	3281.3	4667.3	4078.9	3138.3
	GM	1573.9	1315.6	1417.2	1246.1	1390.5	1381.5	1470.8	1397.0	1434.5

Table 8.8 Projected accounting estimates Cropland Management and Grazing Land Management under the Kyoto Protocol until 2020, kt CO_{2e}.

	2013	2014	2015	2016	2017	2018	2019	2020	Total
CM	-2419.1	-1354.7	-1859.6	-1599.3	-2166.8	-780.8	-1206.7	-2147.4	-13534.4
GM	-258.3	-156.7	-327.8	-183.4	-192.4	-103.1	-175.5	-138.0	-1535.3

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 is derived compared to the emission estimates submitted to UNFCCC. The accounting rules differ however, as CM and GM becomes obligatory with a base year for the emission being the average for the years 2005-2009. Accounting years are 2021-2030. Furthermore, WE has become obligatory, with the same base year but it shall only be included in the accounting for year 2026-2030. For all three sectors net-net accounting shall be used.

Table 8.9 shows the average emissions for the base year (average 2005-2009) and projected emissions up to 2030. Table 8.10 shows the projected accounting for CM, GM and WDR (Wetlands, Drainage and Rewetting). The projection estimates that CM will contribute with 6269 kt CO_2 equivalents, GM with -249 kt CO_2 equivalents and WDR with 329 kt CO_2 equivalents. In total 6349 kt CO_2 equivalents in the period 2021 to 2030.

Table 8.9 Projected emissions estimates for Cropland Management, Grazing Land Management and Managed Wetlands under EU regulation 529, kt CO_{2e} Not all years are shown.

	2005-2009	2021	2023	2025	2027	2029	2030
CM	3876,9	2881,7	3137,9	2763,5	3482,8	3125,1	3669,0
GM	1321,2	1383,1	1374,4	1349,5	1330,2	1313,7	1305,4
WDR	91,0	43,0	36,6	37,6	37,6	6,3	6,3

Table 8.10 Projected account estimates for Cropland Management, Grazing Land Management and Managed Wetlands under EU regulation 529, kt CO_{2e} Not all years are shown.

	2021	2023	2025	2027	2029	2030	Total
CM	995,2	739,0	1113,4	394,1	751,8	207,9	6268,7
GM	-62,0	-53,2	-28,3	-9,0	7,5	15,8	-249,3
WDR	NA	NA	NA	53,4	84,6	84,6	329,5
Total							6348.9

8.13 References

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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 May 2020 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 2019 are Energy Industries (19 %), Transport (30 %), Agriculture (24 %) and Other Sectors (10 %). 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 2019 are estimated to be 44.6 million tonnes CO_2 equivalents excluding LULUCF and indirect CO_2 and 34.5 million tonnes in 2040. From 1990 to 2018, the emissions decreased by 31 %. In 2005, the emissions including LULUCF and indirect CO_2 is calculated to 72.6 million tonnes of CO_2 equivalents. It decreased to 54.8 million tonnes CO_2 equivalents in 2018 (24.5 %), the projected emission in 2030 is 43.0 million tons of CO_2 equivalents corresponding to a decrease since 2005 of 40.8 %.

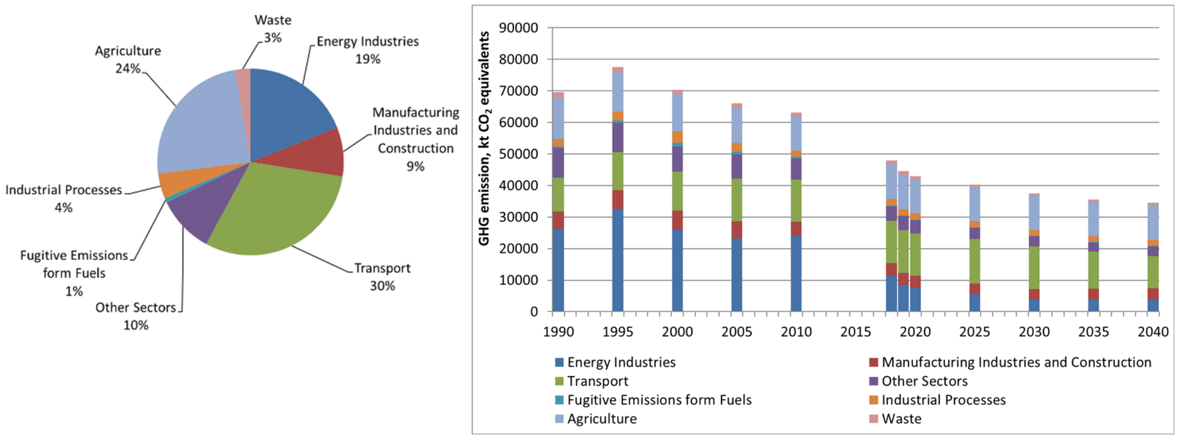

Figure 9.1 Total GHG emissions in CO_2 equivalents. Distribution according to main sectors (2019) and time series for 1990 to 2040.

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 2018 from the main source, which is public power and heat production (53 %), are estimated to decrease in the period from 2018 to 2040 (80 %) 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 projected; the emissions decrease by 48 % from

2018 to 2040, due to a lower consumption of fossil fuels. Emissions from manufacturing industries on the other hand only decreases by 3 %, due to a much smaller decrease in fossil fuel combustion.

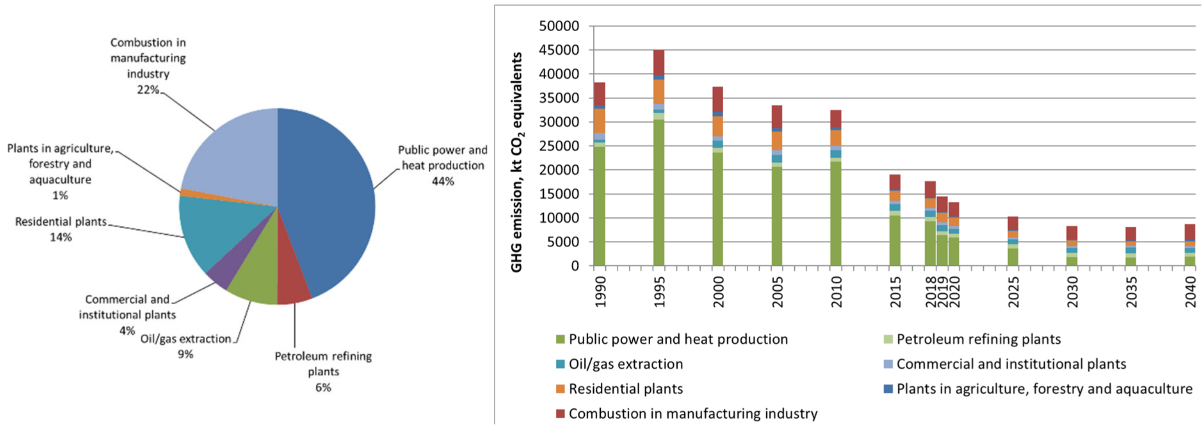

Figure 9.2 GHG emissions in CO_2 equivalents for stationary combustion. Distribution according to sources (2019) and time series for 1990 to 2040.

9.2 Fugitive emissions from fuels

The greenhouse gas emissions from the sector "Fugitive emissions from fuels" show large fluctuations in the historical years 1990-2018, 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 2018-2040 by 42 %. 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.

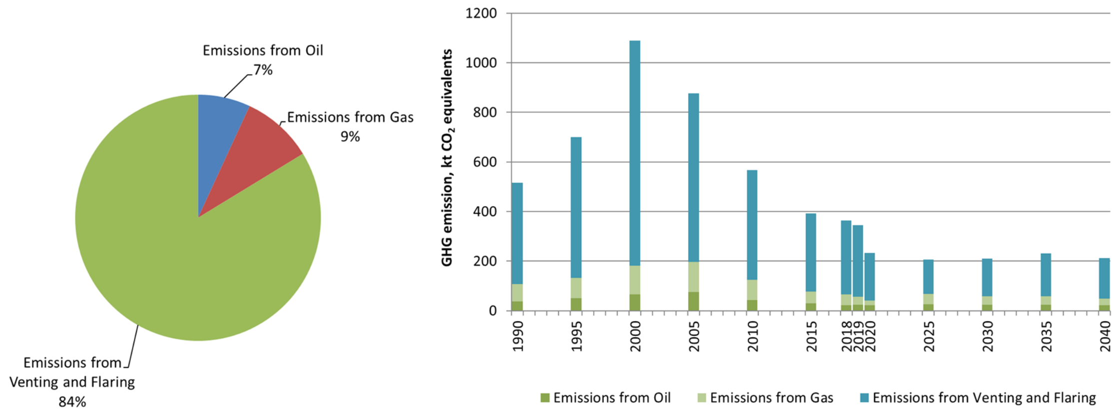

Figure 9.3 GHG emissions in CO_2 equivalents for fugitive emissions. Distribution according to sources for 2019 and time series for 1990 to 2040.

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 2018 are mineral industry (mainly cement production) with 64 % and use of substitutes (f-gases) for ozone depleting substances (ODS) (24 %). The corresponding shares in 2040 are expected to be 84 % and 5 %, 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.

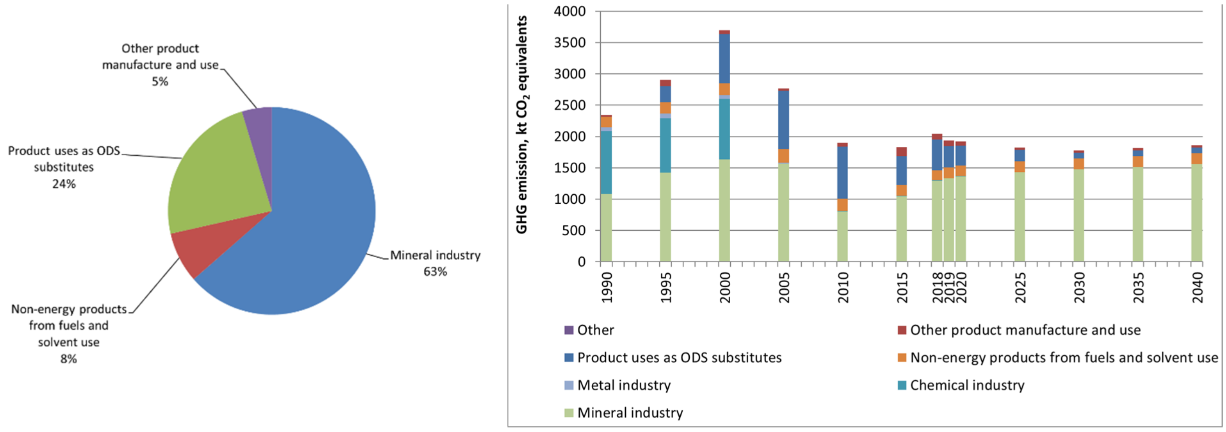

Figure 9.4 Total GHG emissions in CO_2 equivalents for industrial processes. Distribution according to main sectors (2019) and time series for 1990 to 2040.

9.4 Transport and other mobile sources

Road transport is the main source of GHG emissions from transport and other mobile sources in 2018 (80 %) and emissions from this source are expected to decrease in the projection period 2018 to 2040, but only towards the very end, with no big changes in emissions until 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 9 % of the sectoral GHG emission in 2018.

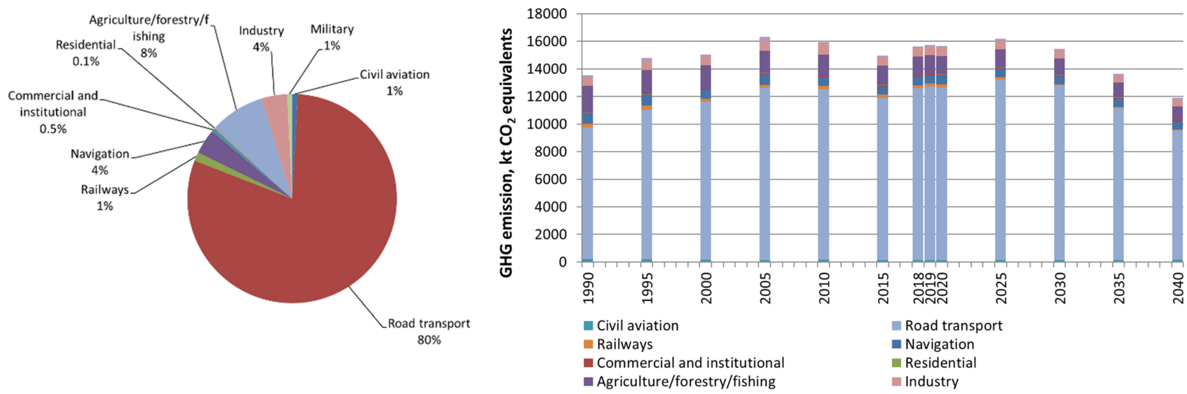

Figure 9.5 GHG emissions in CO_2 equivalents for mobile sources. Distribution according to main sources (2019) and time series for 1990 to 2040.

9.5 Agriculture

The main sources in 2018 are agricultural soils (37 %), enteric fermentation (34 %) and manure management (27 %). The corresponding shares in 2040 are expected to be 36 %, 37 % and 25 %, respectively. From 1990 to 2018, the emission of GHGs in the agricultural sector decreased by 16 %. In the projection years 2018 to 2040, the emissions are expected to remain almost constant. 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 are estimated to increase due to an expected increase in the number of animals.

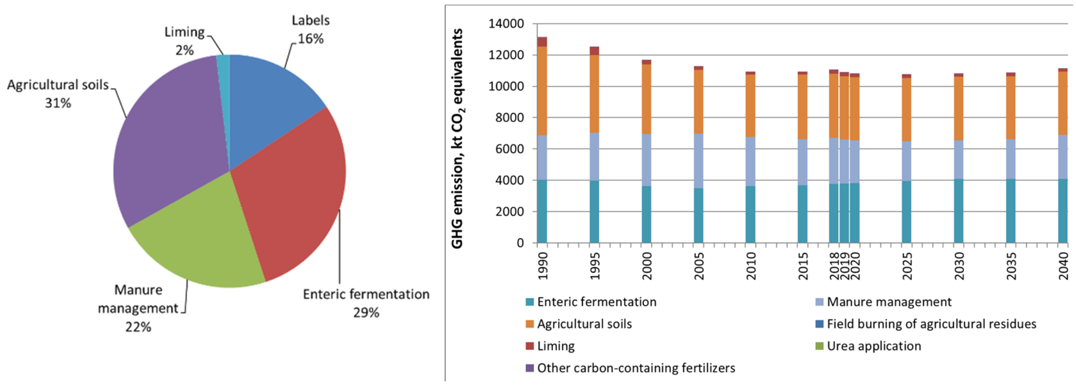

Figure 9.6 GHG emissions in CO_2 equivalents for agricultural sources. Distribution according to main sources (2019) and time series for 1990 to 2040.

9.6 Waste

The total GHG emission from the waste sector has been decreasing in the years 1990 to 2018 by 35 %. The decreasing trend is expected to continue with a decrease of 41 % from 2018 to 2040. In 2018, the GHG emission from solid waste disposal contributed with 49 % of the emission from the sector as a whole. A decrease of 43 % is expected for this source in the years 2018 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 2018 contribute with 10 %. Emissions from biological treatment of solid waste contribute 39 % in 2018 and 33 % in 2040.

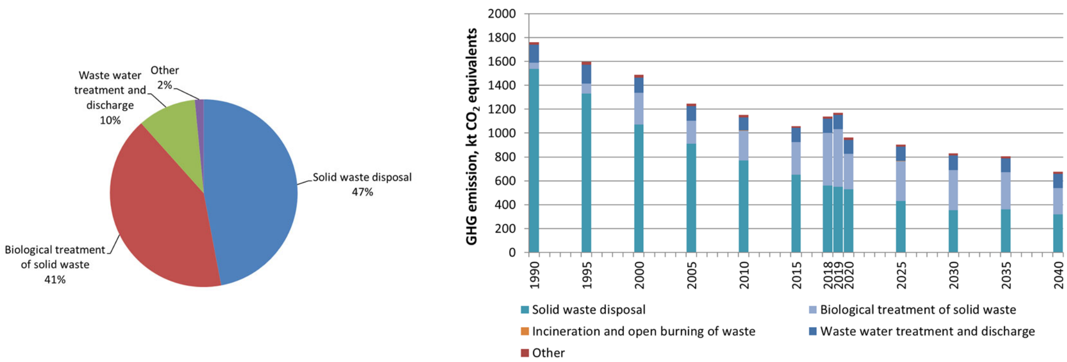

Figure 9.7 GHG emissions in CO_2 equivalents for Waste. Distribution according to main sources (2019) and the time series for 1990 to 2040.

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 HWP is reported separately in Johannsen et al., (2019) although these emission estimates has been included here. The overall picture of the LULUCF sector excl. Forestry and HWP is a net source of 7 001 kt CO_2 equivalents in 1990. In 2018, the estimated emission has been reduced to a net source of 6 353 kt CO_2 and a net source of 4 636 kt CO_2 equivalents in 2021-2030 (average of 2021-2030). A small increase is expected in year 2031-2040 compared to 2021-2030. This increase can very likely be attributed to differences in the climatic conditions when modelling the development in mineral agricultural soils as this is purely randomized. 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.

	2020	2025	2030	2035	2040
Public electricity and heat production	5102	3149	1450	1402	1493
Petroleum refining	838	838	838	838	838
Other energy industries (oil/gas extraction)	1010	1004	1058	1229	1008
Combustion in manufacturing industry	2233	2157	2188	2182	2515
Civil aviation	134	140	148	150	153
Commercial and institutional	4	3	3	3	3
Agriculture, forestry and aquaculture	35	36	40	44	62
Fugitive emissions from flaring	153	111	121	138	129
Mineral industry	1355	1418	1464	1504	1549
Total	10862	8856	7310	7489	7750
Civil Aviation, international	3023	3090	3194	3213	3228

PROJECTION OF GREENHOUSE GASES 2019-2040

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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