PROJECTION OF GREENHOUSE GASES 2024-2050

Scientific Report from DCE – Danish Centre for Environment and Energy No. 666 2025

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Data sheet

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Abstract: This report contains a description of models, background data and projections of CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 for Denmark. The emissions are projected to 2050 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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Contents

List of abbreviations

ARD	Afforestation, Reforestation & Deforestation
BOD	Biological Oxygen Demand
C	Carbon
CH_4	Methane
CHP	Combined Heat and Power
CHR	Central Husbandry Register
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand
COPERT	COmputer Programme to calculate Emissions from Road Transport
CORINAIR	CORe INventory on AIR emissions
CRF	Common Reporting Format
CL	Cropland
CO_2e	Equivalents of carbon dioxide
DCA	Danish Centre for Food and Agriculture
DCE	Danish Centre for Environment and Energy
DEA	Danish Energy Agency
DEPA	Danish Environmental Protection Agency
DM	Dry Matter
DSt	Statistics Denmark
EEA	European Environment Agency
EIONET	European Environment Information and Observation Network
EMEP	European Monitoring and Evaluation Programme
ENVS	Department of Environmental Science, Aarhus University
EU ETS	European Union Emission Trading Scheme
FL	Forest land
FOD	First Order Decay
FSE	Full Scale Equivalent
GHG	Green House Gas
GL	Grassland
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 December 2022.

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

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

Table 0.1 List of authors and reviewers.

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

As to the summary and conclusions (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.

The Agency for Green Transition and Aquatic Environment (SGAV), for providing data on expected national agricultural policies and interpretation of the EU Common Agricultural Policy 2023-2027 and its impact on future land use.

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

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

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

Summary

This report contains a description of the models, background data and projections of the greenhouse gases (GHG) carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) for Denmark. The latest historic year that has formed the basis of the projection is 2023. The emissions are projected to 2050 using a scenario, which includes the estimated effects of policies and measures implemented in Denmark's greenhouse gas (GHG) emissions based on 'frozen policy' (or 'with existing measures' projection) – meaning that the policies and measures are implemented or decided by December 2024. The official Danish energy projection, e.g. the latest official projection from the Danish Energy Agency (DEA), is used to provide activity rates (2024-2050) 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 2023 are Energy industries (17 %), Transport (30 %), Agriculture (28 %) and Other sectors (9 %). 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 2023 are estimated to be 38.8 million tonnes CO_2 equivalents including LULUCF and indirect CO_2 and the corresponding total in 2050 is projected to be 11.4 million tonnes CO_2 equivalents. From 1990 to 2023 the emissions decreased by 51.0 %. From 2023 to 2050, the emission is projected to decrease by approximately 71 %.

The total greenhouse gas emissions in 1990 including LULUCF and indirect CO_2 are estimated at 79.2 million tonnes of CO_2 equivalents and the emission in 2030 is projected to be 25.6 million tonnes of CO_2 equivalents including LULUCF and indirect CO_2. corresponds to a reduction of 67.7 % between 1990 and 2030. The effect of carbon capture and storage (CCS) in the projection is not attributable to any sector and not included in this figure.

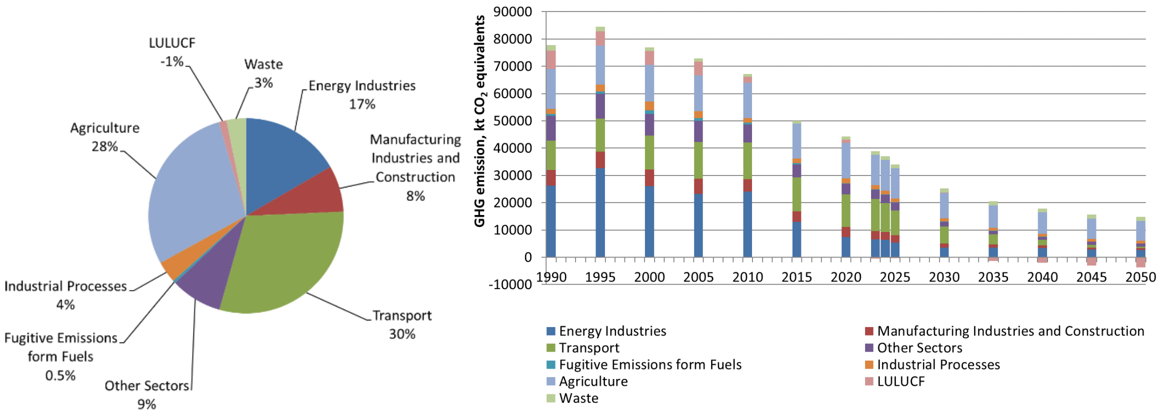


Figure S.1 Total GHG emissions in CO_2 equivalents. Distribution according to main sectors (2023) and time series for 1990 to 2050.

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 2023 from the main source, which is public power and heat production (45 %), are estimated to decrease in the period from 2023 to 2050 (57 %) due to a significant decrease in the fossil fuel consumption for electricity production in the later part of the time series. For residential combustion plants, a significant decrease in emissions is also projected; the emissions are expected to decrease by 96 % from 2023 to 2050, due to a lower consumption of fossil fuels. Emissions from manufacturing industries decrease by 83 %, also due to a 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 1990-2023, 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 2023-2050 by 88 %. The emissions from flaring are increasing in the first part of the projection period due to restart of production at the Tyra field after renovation. However, the emissions decrease again. 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 (IPPU) 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 2023 are mineral industry (mainly cement production) with 69 % and use of substitutes (F-gases) for ozone depleting substances (ODS) (18 %). The corresponding shares in 2050 are expected to be 84 % and 0 %, 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 emissions from the IPPU 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 2023 (79 %) and emissions from this source are expected to decrease in the projection period to 2050, but with the largest reduction happening after 2030. The emission shares for the remaining mobile sources (e.g. domestic aviation, national navigation, railways, fishing and non-road machinery in industry, households and agriculture) are small compared with road transport. Non-road machinery in agriculture, forestry and fishing contributes 8 % of the sectoral GHG emission in 2023.

Agriculture

The main sources in 2023 are agricultural soils (30 %), enteric fermentation (35 %) and manure management (33 %). The corresponding shares in 2050 are expected to be 36 %, 38 % and 23 %, respectively. From 1990 to 2023, the emission of GHGs in the agricultural sector decreased by 23 %. From 2023 to 2050, the emissions are expected to decline by about 35 %. The reduction in the historical years (1990-2023) 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 emissions in housing and manure storage and emission reducing feed additives are considered in the projections.

Waste

The total GHG emission from the waste sector has been decreasing in the years 1990 to 2023 by 38 %. From 2023 to 2050, the emissions are projected to increase by 11 % driven by a significant increase in emissions from anaerobic digestion. In 2023, the GHG emission from solid waste disposal contributed with 31 % of the emission from the sector. A decrease of 31 % is expected for this source in the years 2023 to 2050, due to less organic waste deposition on landfills. Emissions from wastewater are expected to be rather constant for the projection period. GHG emissions from wastewater handling in 2023 contribute with 17 %. Emissions from biological treatment of solid waste (composting and biogas production) contribute with 50 % in 2023 and 63 % in 2050.

LULUCF

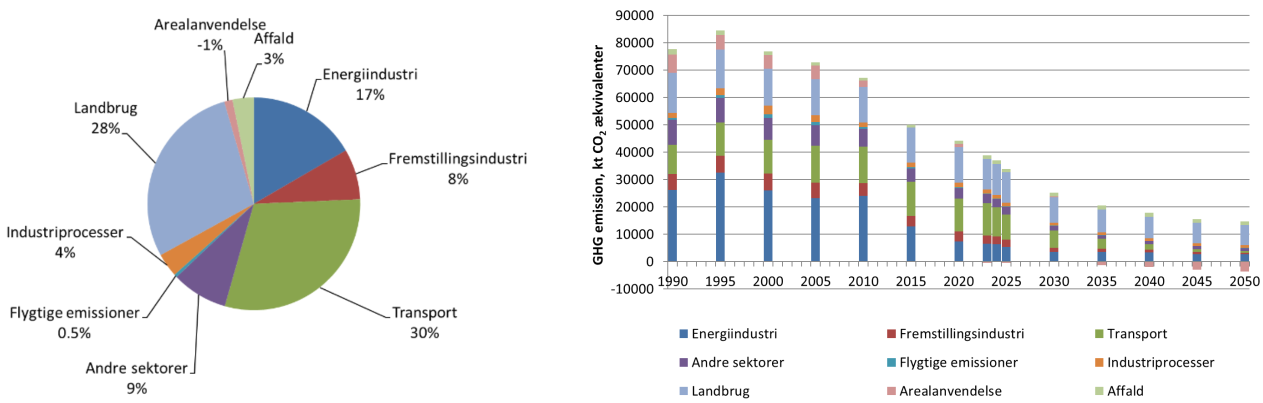
The LULUCF sector cover emissions and removals from land use, land use change and forestry. This includes conversions between Forest land (afforestation and deforestation), Cropland, Grassland, Wetlands, Settlement and Other land. The minor emission sources Harvested Wood Products (HWP) and burning of biomass in fires are also part of LULUCF. The work for this report includes the projection of Cropland, Grassland, Wetland, Settlement and Other land. Projection of Forestry and Harvested wood products (HWP) is conducted by Department of Geosciences and Natural Resource Management (IGN), Copenhagen University, and reported separately. The data included here are updated values for 2023 to 2050 received from IGN. The LULUCF sector excl. forestry and HWP is a net source of emissions in both the historical and projection period. Forestry and HWP are both net sinks and counter emissions lowering the net emissions from the entire LULUCF sector and even resulting in an overall sink. The combined emissions of the LULUCF sector were 6699 kt CO_2 equivalents in 1990 and reduced to a sink of 939 kt CO_2 equivalents in 2023. In 2030, a small net source of 300 kt CO_2 equivalents is estimated. From 2030 and up to 2050 is estimated a combined large sink of up to 3600 kt CO_2 equivalents due to less drained organic soils emitting CO_2 and a further increase in the amount of C stored in the Danish forest.

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 2023. Emissionerne er fremskrevet til 2050 på baggrund af et scenarie, som medtager de estimerede effekter på Danmarks drivhusgasudledninger af virkemidler iværksat eller besluttet indtil december 2024 (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 (2024-2050) 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 2023 er energisektoren (17 %), transport (30 %), landbrug (28 %), og andre sektorer (9 %). For "andre sektorer", er den vigtigste kilde forbrænding i husholdninger (Figur R.1). Drivhusgasemissionerne viser et fald gennem fremskrivningsperioden. De totale emissioner er beregnet til 38,8 millioner tons CO_2-ækvivalenter i 2023 inklusiv LULUCF og indirekte CO_2 og er fremskrevet til 11,4 millioner tons i 2050 inklusiv LULUCF og indirekte CO_2. Fra 1990 til 2023 er emissionerne faldet med 51,0 %. Fra 2023 til 2050 er den fremskrevne reduktion ca. 71 %.

Den samlede drivhusgasemission i 1990 inklusiv LULUCF og indirekte CO_2 er beregnet til 79,2 millioner tons CO_2-ækvivalenter og emissionen i 2030 er fremskrevet til 25,6 million tons CO_2-ækvivalenter. Dette svarer til en reduktion på 67,7 % mellem 1990 og 2030. Effekten af CO_2 fangst og lagring (carbon capture and storage - CCS) er ikke muligt at tildele til enkelte sektorer og er derfor ikke medtaget i dette tal.



Figur R.1 Totale drivhusgasemissioner i CO_2-ækvivalenter fordelt på hovedsektorer for 2023 og tidsserier fra 1990 til 2050.

Stationær forbrænding

Stationær forbrænding omfatter Energiindustri (konvertering og olie/gas produktion), Fremstillingsvirksomhed og Andre sektorer. Andre sektorer dækker over handel/service, husholdninger samt landbrug/gartneri. Drivhusgasemissionen fra kraft- og kraftvarmeværker, som er den største kilde i 2023 (45 %), er estimeret til at falde i perioden 2023 til 2050 (57 %) 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 2023 til 2050 med hele 96 % pga. lavere forbrug af de fossile brændstoffer. Emissioner fra fremstillingsindustrien falder tilsvarende med 83 % i samme periode pga. et fald i anvendelsen af fossile brændstoffer.

Flygtige emissioner

Emissionen af drivhusgasser fra sektoren udviser store fluktuationer i de historiske år 1990-2023, bl.a. 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 88 % i perioden 2023-2050. Emissionen fra flaring stiger i den første del af fremskrivningsperioden pga. opstart af produktion på Tyrafeltet efter renoveringen, men falder igen. Emissioner fra udvinding af olie og naturgas forventes at falde gennem fremskrivningsperioden pga. forventet mindre udvinding. Emissionerne af drivhusgasser fra de øvrige kilder forventes at være konstante eller næsten konstante i fremskrivningsperioden.

Industriprocesser og anvendelse af produkter

Emissionen af drivhusgasser fra industrielle processer og anvendelse af produkter (IPPU) 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 i 2023 er mineralsk industri (især cementproduktion), som bidrager med 69 % af drivhusgasemissionen, samt anvendelse af erstatningsgasser (F-gasser) for ozonnedbrydende stoffer (ODS), der bidrager med 18 %. De tilsvarende andele i 2050 forventes at ligge på hhv. 84 % og 0 %. Forbrug af kalk og medfølgende emission af CO_2 fra røggasrensning antages at følge forbruget af kul og affald i kraftvarmeanlæg. Drivhusgasemissionen fra IPPU-sektoren 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 2023 (79 %), og emissionerne fra denne kilde forventes at falde i fremskrivningsperioden 2023 til 2050 med det største fald i perioden efter 2030. Den samlede emission for andre mobile kilder (indenrigsluftfart, jernbane, indenrigssøfart, ikke-vejgående industrimaskiner, maskiner i have/hushold, landbrugsmaskiner, fiskeri) er lave sammenlignet med vejtransport. Ikke-vejgående maskiner inden for landbrug, skovbrug og fiskeri bidrager med 8 % af sektorens drivhusgasser i 2023.

Landbrug

De største kilder i 2023 er emissioner fra landbrugsjorder (30 %), dyrenes fordøjelse (35 %) og gødningshåndtering (33 %). De tilsvarende andele i 2050 forventes at være hhv. 36 %, 38 % og 23 %. Fra 1990 til 2023 er emissionen fra landbrugssektoren faldet med 17 %. I fremskrivningsperioden forventes emissionerne at falde med ca. 23 %. Fra 2023 til 2050 forventes emissionerne at falde med ca. 35 %. Årsagen til faldet i de historiske år (1990-2023) 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 stald og lager samt emissionsreducerende fodertiltag.

Affald

Affaldssektorens samlede drivhusgasemissioner er faldet med 38 % i perioden 1990 til 2023. Fra 2023 til 2050 er emissionerne fremskrevet til at stige med 11 %, hvilket kan tilskrives en markant stigning i emissionen fra biogasbehandling. I 2023 udgør drivhusgasemissionen fra lossepladser 31 % af den totale emission fra affaldssektoren. Et fald på 31 % er forventet for denne kilde i perioden 2023 til 2050. Dette skyldes, at mindre organisk nedbrydeligt affald bliver deponeret. Emissioner fra spildevand forventes at forblive nogenlunde konstant frem mod 2050. I 2023 udgør spildevandshåndteringen 17 % af sektorens samlede emission. Emissionerne fra biologisk behandling af affald (kompostering og biogasbehandling) udgør 50 % i 2023 og 63 % i 2050.

LULUCF

LULUCF (Land Use, Land Use Change and Forestry)-sektoren inkluderer emissioner fra og optag ved arealanvendelse og ændringer i arealanvendelsen for arealanvendelseskategorierne skove (skovrejsning, afskovning, skovdyrkning), dyrkede landbrugsarealer, permanente græsarealer, vådområder og søer, bebyggede arealer (by og infrastruktur) og øvrigt land. Emissioner og optag fra de to mindre kilder høstede træprodukter (HWP) og naturbrande er også en del af LULUCF. Arbejdet til denne fremskrivning dækker de dyrkede landbrugsarealer, permanente græsarealer, vådområder og søer, bebyggede arealer og øvrigt land. Fremskrivningen af emissioner og optag fra skov og høstede træprodukter udarbejdes af Institut for Geovidenskab og Naturforvaltning (IGN) ved Københavns Universitet, og er opgjort særskilt. Resultaterne herfra er opdateret for årene 2023-2050 på baggrund af nye data fra IGN. Overordnet set er LULUCF-sektoren historisk en kilde til CO_2-udledning i Danmark, men samlet har der i de senere år været et netto optag. Skovbrug og høstede træprodukter giver et netto optag af CO_2 og opvejer derved delvist eller helt de øvrige udledninger, hvilket giver en lavere samlet udledning for hele LULUCF-sektoren eller i nogle år et samlet netto optag. De samlede emissioner fra LULUCF-sektoren var 6699 kt CO_2-ækvivalenter i 1990 og reduceret til et optag på 939 kt CO_2-ækvivalenter i 2023. I 2030 anslås en lille nettokilde på 300 kt CO_2-ækvivalenter. Fra 2030 og frem til 2050 skønnes et samlet stort nettooptag på op til 3600 kt CO_2-ækvivalenter på grund af mindre areal med drænet organisk jord, der udleder CO_2 og en yderligere stigning i mængden af kulstof lagret i de danske skove.

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 to extend the projection models to include the GHGs CO_2, CH_4, N_2O as well as HFCs, PFCs and SF_6, and project the emissions for these gases to 2030 (Illerup et al., 2007). This was further updated in later projects (Nielsen et al., 2008, 2010, 2011, 2013, 2014, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023 and 2024). The purpose of the present project, "Projection of greenhouse gas emissions 2024 to 2050" has been to update the emission projections for all sectors based on the latest national energy projections, other relevant activity data and emission factors and extend the projection period to 2050.

1.1 Obligations

The European Union (EU) has committed itself to reduce emissions of GHGs by 55 % 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 50 % in 2030 compared to 2005. A part of that obligation can be fulfilled by making use of so-called LULUCF-credits under the EU LULUCF-regulation as well as emission allowances from the EU Emission Trading Scheme.

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

In this report, the estimated effects of policies and measures implemented or decided as of December 2024 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 not considered relevant for the projections.

The main greenhouse gas responsible for the anthropogenic influence on the heat balance is CO_2. The atmospheric concentration of CO_2 has increased from a pre-industrial value of about 278 ppm to about 410 ppm in 2019 (an increase of about 47 %) (IPCC, 2021) and exceeds the natural range of 180- 300 ppm over the last 650 000 years as determined by ice cores. The main cause for the increase in CO_2 is the use of fossil fuels, but changing land use, including forest clearance, has also been a significant factor. The greenhouse gases CH_4 and N_2O are very much linked to agricultural production; CH_4 has increased from a pre-industrial atmospheric concentration of about 729 ppb to 1866 ppb in 2019 (an increase of about 156 %) and N_2O has increased from a pre-industrial atmospheric concentration of about 270 ppb to 332 ppb in 2019 (an increase of about 23 %) (IPCC, 2021). Changes in the concentrations of greenhouse gases are not related in simple terms to the effect on the heat balance, however. The various gases absorb radiation at different wavelengths and with different efficiency. This must be considered in assessing the effects of changes in the concentrations of various gases. Furthermore, the lifetime of the gases in the atmosphere needs to be taken into account – the longer they remain in the atmosphere, the greater the overall effect. The global warming potential (GWP) for various gases has been defined as the warming effect over a given time of a given weight of a specific substance relative to the same weight of CO_2. The purpose of this measure is to be able to compare and integrate the effects of individual substances on the global climate. Typical lifetimes in the atmosphere of substances are very different, e.g. 12 and 109 years approximately for CH_4 and N_2O, respectively (Myhre et al., 2013). Therefore, the time perspective clearly plays a decisive role. The timeframe chosen is typically 100 years. The effect of the various greenhouse gases can then be converted into the equivalent quantity of CO_2, i.e. the quantity of CO_2 giving the same effect in absorbing solar radiation. According to the IPCC and their Fifth Assessment Report (Myhre et al., 2013), which UNFCCC (UNFCCC, 2018) has decided to use as reference for reporting under the Paris Agreement, the global warming potentials for a 100-year time horizon are

- CO_2 1
- CH_4 28
- N_2O 265

Based on weight and a 100-year period, CH_4 is thus 28 times more powerful a GHG than CO_2, and N_2O is 265 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 23 500 (Myhre et al., 2013).

Denmark includes reporting of indirect CO_2 in the emission inventory and projection. Indirect CO_2 is the atmospheric oxidation of CO, NMVOC and CH_4. For more information, please see Nielsen et al. (2024).

1.3 Historical emission data

The greenhouse gas emissions are estimated according to the IPCC guidelines and are aggregated into five main sectors. The greenhouse gases include CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3. Figure 1.1 shows the estimated total greenhouse gas emissions in CO_2 equivalents from 1990 to 2023. The emissions are not corrected for electricity trade or temperature variations.

CO_2 is the most important greenhouse gas contributing in 2023 to the national total in CO_2 equivalents including LULUCF (Land Use and Land Use Change and Forestry) and including indirect CO_2 emissions with 64.8%, followed by CH_4 with 23.1 %, N_2O with 11.4 %, and f-gases (HFCs, PFCs, SF_6 and NF_3) with 0.7 %.

The energy sector and agricultural sector represent the largest sources, followed by industrial processes and product use and waste, see Figure 1.1. The LULUCF sector was a net sink in 2023. The total national greenhouse gas emission in CO_2 equivalents excluding LULUCF has decreased by 45.8 % from 1990 to 2023 when considering indirect CO_2, if excluding indirect CO_2 the emissions have decreased by 45.2 %. The emissions including LULUCF and indirect CO_2 have decreased by 51.0 % from 1990 to 2023.

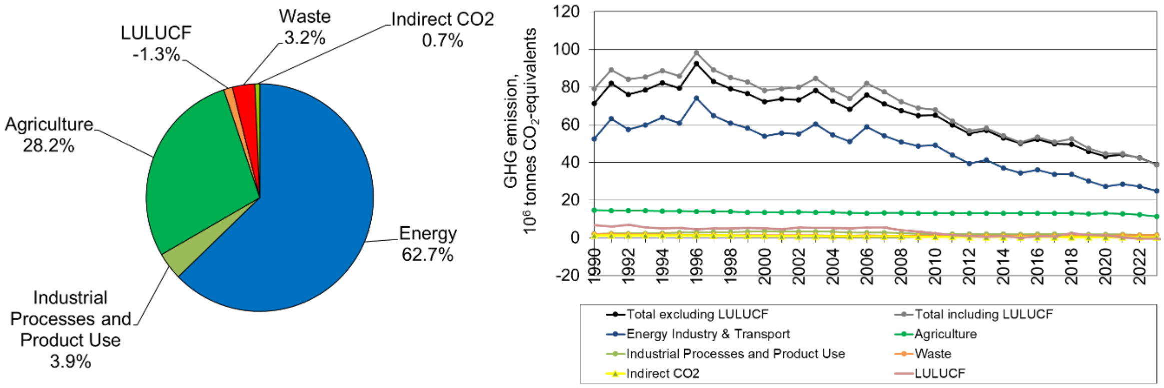


Figure 1.1 Greenhouse gas emissions in CO_2 equivalents distributed on main sectors for 2023 (excluding LULUCF and indirect CO_2) and time series for 1990 to 2023.

1.3.1 Carbon dioxide

The largest source to the emission of CO_2 is the energy sector, which includes combustion of fossil fuels like oil, coal and natural gas (Figure 1.2). The transport sector (dominated by road transport) is the largest sector in 2023 and contributes with 47 %, followed by energy industries with 25 %. The CO_2 emission decreased by 9.4 % from 2022 to 2023. The main reason for the decrease in emissions is decreased use of fossil fuels particularly in energy industries. In general, CO_2 emissions fluctuate significantly as a result of the electricity trade with neighbouring countries.

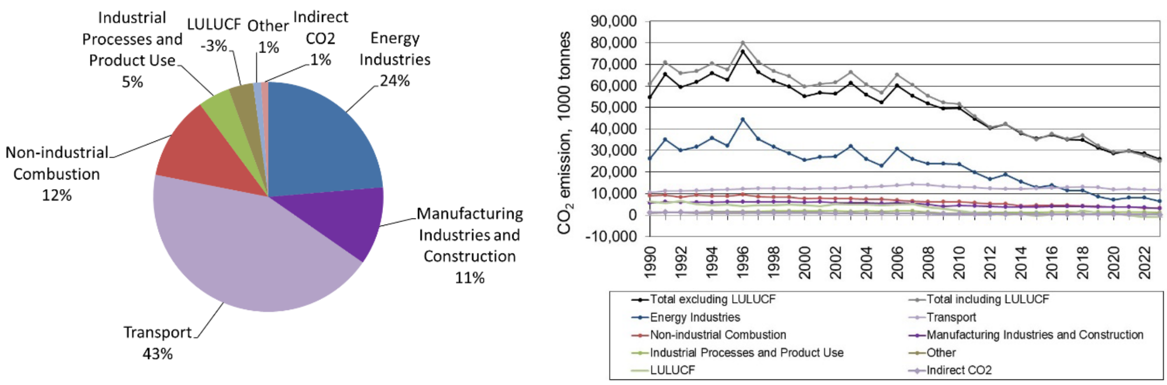


Figure 1.2 CO_2 emissions. Distribution according to the main sectors for 2023 and time series for 1990 to 2023.

1.3.2 Methane

The largest sources of anthropogenic CH_4 emissions are agricultural activities contributing with 79.8 % in 2023, waste (12.2 %) and the remaining emission sources cover 8.1 % - see Figure 1.3. The emission from agriculture derives from enteric fermentation (44.4 %) and management of animal manure (35.4 %).

Since 1990, the emission of CH_4 from enteric fermentation has decreased 10.8 % mainly due to the decrease in the number of cattle. However, this reduction is countered by an increase of 4.6 % 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 (73.8 %) from 1990 to 2023 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-1990's from public power and district heating plants increases due to the increasing use of gas engines in the decentralised cogeneration plant sector. Due to the liberalisation of the electricity market the use of gas engines declined from 2005 onwards. The high emission from gas engines is caused by the fact that up to 3 % of the natural gas in the gas engines is not combusted.

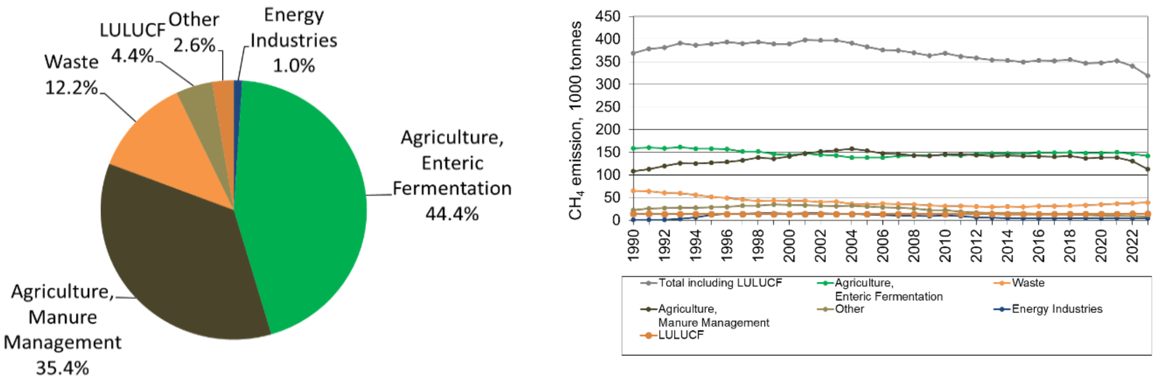


Figure 1.3 CH_4 emissions. Distribution according to the main sectors for 2023 and time series for 1990 to 2023.

1.3.3 Nitrous oxide

Agriculture is the most important N_2O emission source in 2023 contributing with 87.5 % (Figure 1.4) of which N_2O from soils dominates (76.1 % of total N_2O). Substantial emissions come from drainage water and coastal waters where nitrogen is converted to N_2O through bacterial processes. However, the nitrogen converted in these processes originates mainly from the agricultural use of manure and fertilisers.

The main reason for the decrease of N_2O emission is due to the agricultural sector, which has decreased with 40.3 % since 1990 caused by legislation to improve the utilisation of nitrogen in manure. Combustion of fuels contributes 6.3 % to the total whereof the N_2O emission from transport contributes with 2.6 % to the national total in 2023. Emission from industrial processes decreased significantly in 2004 due to the closure of the only nitric acid plant operating in Denmark and the emission from this emission source is therefore close to zero since then.

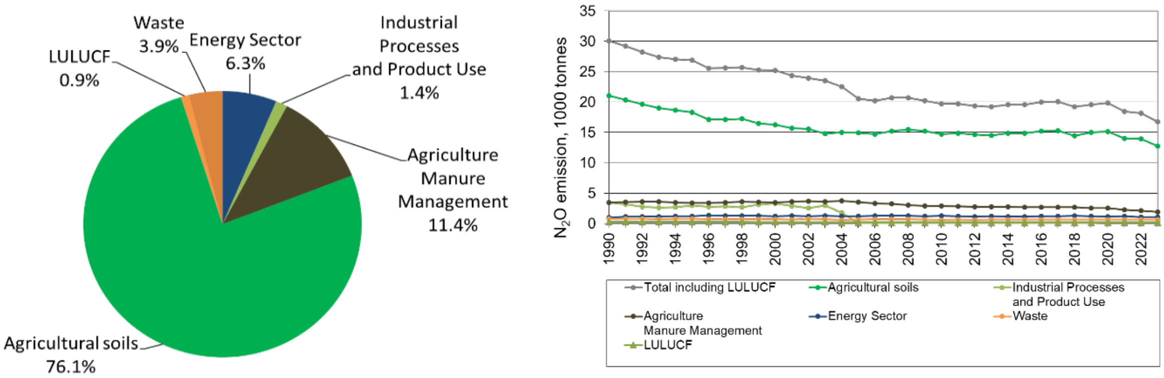


Figure 1.4 N$_2$O emissions. Distribution according to the main sectors for 2023 and time series for 1990 to 2023.

1.3.4 HFCs, PFCs, SF$_6$ and NF$_3$

This part of the Danish inventory only comprises a full data set for all substances from 1995 - see Figure 1.5. From 1995 to 2000, there was a continuous and substantial increase in the contribution from the range of f-gases as a whole (133.6 %) calculated as the sum of emissions in CO_2 equivalents. In 2000-2009, the increase of f-gas emissions continues with a lower increasing rate than for the years 1995 to 2000. Hereafter, the f-gas emission decreases.

The use of HFCs has increased several folds and HFCs have become the dominant f-gases, comprising 68.6 % in 1995 but 95.2 % in 2023. HFCs are mainly used as a refrigerant. SF$_6$ contributed considerably to the f-gas sum in earlier years, with 31.2 % in 1995 and reduced to 4.6 % in 2023. Due to environmental awareness the Danish legislation regulates the use of f-gases, e.g. since 1 January 2007, new HFC-based refrigerant stationary systems are forbidden. Refill of old systems are still allowed and the use of air conditioning in mobile systems increases.

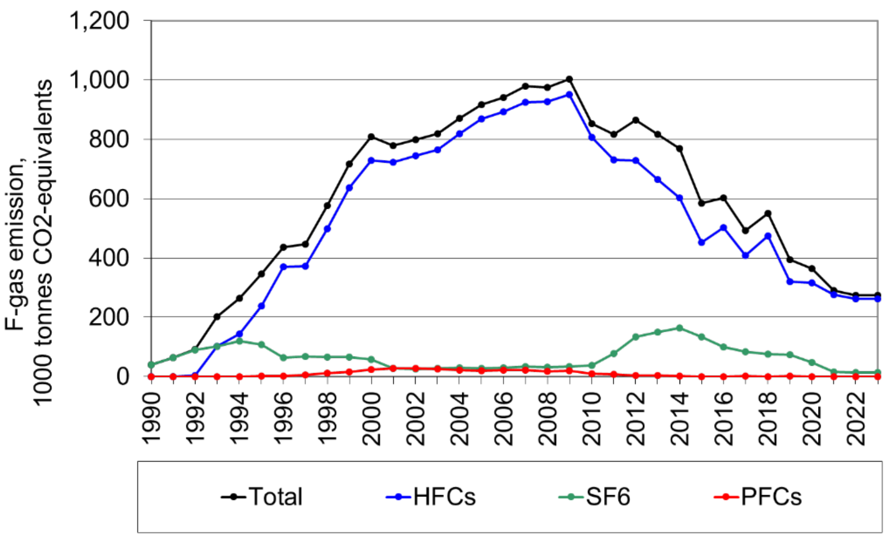


Figure 1.5 F-gas emissions. Time series for 1990 to 2023.

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.

Error! Bookmark not defined.Error! Bookmark not defined. 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, 2023) 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 to ensure consistency. In Denmark the emissions are estimated according to the EMEP/EEA Guidebook (EMEP/EEA, 2023) 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, 2023). The emission projections are based on the official activity rates projection from the Danish Energy Agency and on emission factors for different fuels, plants and sectors. For each of the fuels and categories (sector and e.g. type of plant), a set of general emission factors has been determined. Some emission factors refer to the IPPC Guidelines (IPCC, 2006) and some are country-specific and refer to Danish legislation, EU ETS (Emission Trading System) reports from Danish plants, Danish research reports or calculations based on emission data from a considerable number of plants.

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

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

2.2 Sources

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

Table 2.1 Sectors included in stationary combustion.

Sector	IPCC	SNAP
Public power	1A1a	0101
District heating plants	1A1a	0102
Petroleum refining plants	1A1b	0103
Oil/gas extraction	1A1c	0105
Commercial and institutional plants	1A4a	0201
Residential plants	1A4b	0202
Plants in agriculture, forestry and aquaculture	1A4c	0203
Combustion in industrial plants	1A2	03

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

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

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

2.3 Fuel consumption

Energy consumption in the model is based on the Danish Energy Agency's energy consumption projections to 2050 (Danish Energy Agency, 2025).

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

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

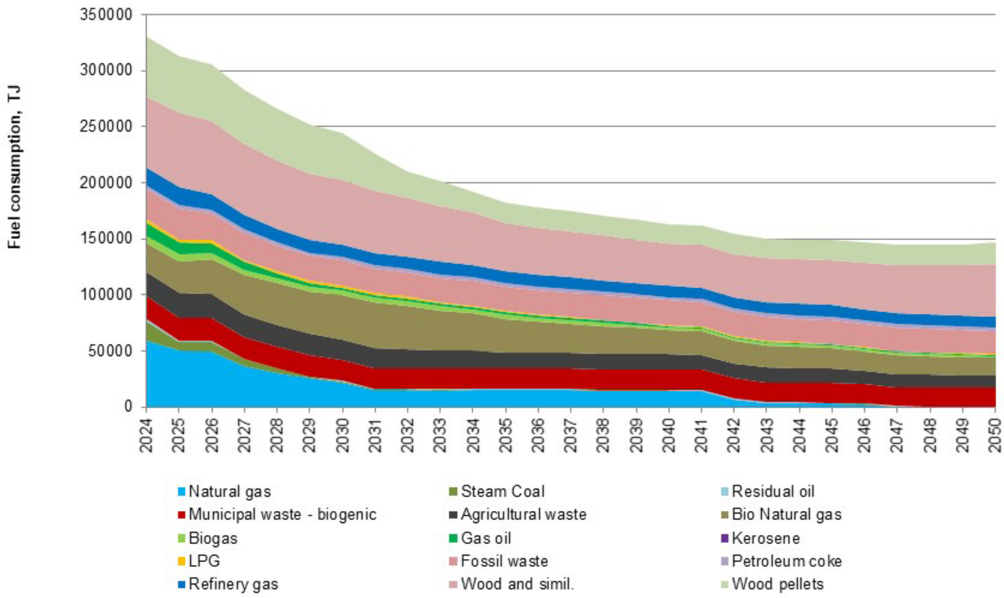

Figure 2.1 Projected energy consumption by fuel type.

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

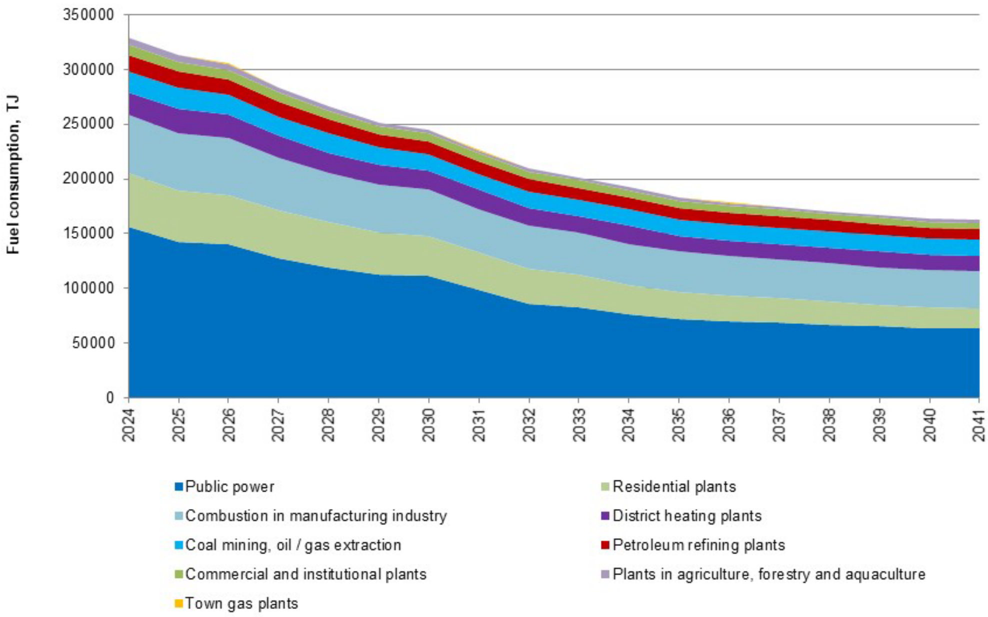

Figure 2.2 Energy use by sector.

2.4 Emission factors

In general, emission factors for area sources refer to the emission factors for 2023 applied in the 2025 emission inventory (Nielsen et al., 2025).

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

The CO_2 emission factors for coal, residual oil, refinery gas and offshore combustion of natural gas (offshore gas turbines) are all based on EU ETS data and updated annually in the historic emission inventories. In the projection, the average 2018-2023 emission factors have been applied rather than including only the 2023 data.

The offshore gas field in the North Sea, Tyra, was shut down for redevelopment in September 2019. Part load operation started in spring 2024, full load operation in spring 2025. During this period, consumers in Denmark primarily got their gas supply from Germany (Energinet, 2021). The CO_2 emission factor applied for natural gas[1] in 2024 is based on gas quality data from Energinet for 2024 (Energinet, 2025). The CO_2 emission factor applied for 2025-2050 is the average value for the years 2023-2024[2].

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

A time series has been estimated for the CH_4 emission factor for residential/agricultural combustion of straw. The time series is based on new legislation and assumptions concerning replacement rates for the boiler units.

2.5 Emissions

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

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

2.5.1 The total emission in CO_2 equivalents for stationary combustion is shown in Table 2.2

Table 2.2 Total emission in CO_2 equivalents for stationary combustion.

Sector	1990	2000	2005	2010	2020	2023	2024	2025	2030	2035	2040	2045	2050
Public electricity and heat production	24804	23592	20625	21666	5525	4812	4384	3334	2098	2020	2006	2022	2063
Petroleum refining plants	909	1003	940	855	912	900	880	861	639	619	591	589	588
Oil/gas extraction	536	1510	1664	1582	907	836	1110	1138	876	855	826	177	0
Commercial and institutional plants	1423	933	967	888	522	436	280	231	76	28	27	26	25
Residential plants	5150	4193	3863	3379	1664	1036	1076	938	338	76	52	42	37
Plants in agriculture, forestry and aquaculture	1005	1119	943	634	266	360	280	233	28	20	14	9	7
Combustion in industrial plants	5193	5485	4932	3877	3109	2348	2261	2006	896	668	619	506	401
Total	39021	37835	33934	32880	12904	10727	10272	8740	4952	4287	4136	3371	3120

[1] Except offshore gas turbines.
[2] The CO_2 emission factor for 2019-2022 is lower due to a large fraction of Russian gas with a lower CO_2 emission factor. The applied emission factor (average for 2023-2024) is close to the average emission factor for 2013-2018 and also close to the emission factor for the first months of 2025.

From 1990 to 2050, the total emission decreases by approximately 35 900 kt CO_2 equivalents or 92 % due to fossil fuels (mainly coal and natural gas) being 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, 2020 and 2023 (Nielsen et al., 2024).

2.5.2 Carbon dioxide

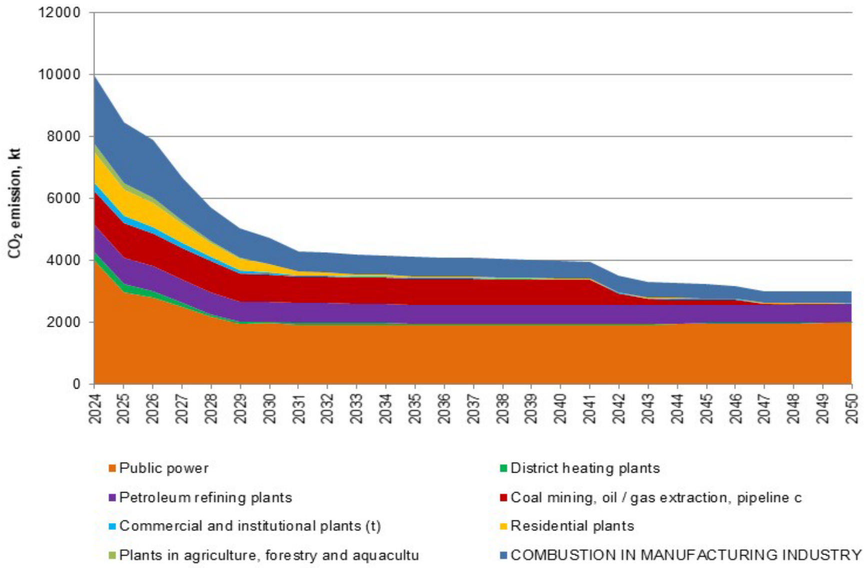

Figure 2.4 CO_2 emissions by sector.

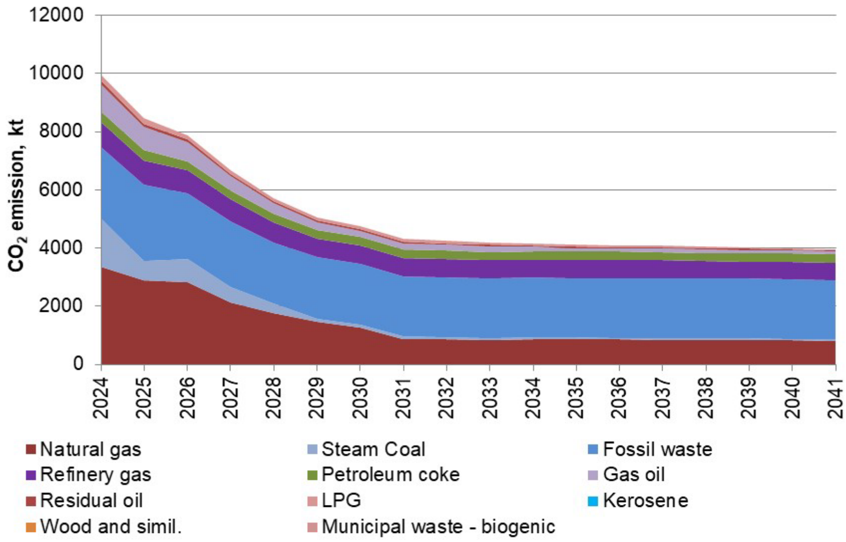

Figure 2.5 CO_2 emissions by fuel.

Table 2.3 CO_2 emissions by sector.

Sector	1990	2000	2005	2010	2020	2023	2024	2025	2030	2035	2040	2045	2050
Public electricity and heat production	24717	23099	20196	21269	5369	3527	4251	3226	2024	1957	1958	1973	2011
Petroleum refining plants	908	1000	938	854	910	915	879	860	639	618	590	588	588
Oil/gas extraction	530	1494	1653	1574	902	810	1104	1131	871	851	822	176	0
Commercial and institutional plants	1415	904	940	864	508	353	276	226	72	25	23	23	22
Residential plants	4971	3992	3626	3125	1526	1043	973	841	267	29	20	19	17
Plants in agriculture, forestry and aquaculture	969	1045	877	591	238	263	260	213	12	9	6	5	4
Combustion in industrial plants	5136	5398	4861	3816	3042	2791	2221	1965	856	630	581	466	359
Total	38647	36931	33091	32092	12495	9703	9964	8463	4741	4118	4001	3250	3000

CO_2 is the dominant GHG for stationary combustion and comprises in 2023 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 45 % in 2023 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 is projected to decrease by 71 % from 2023 to 2050 due to decreasing fossil fuel consumption.

2.5.3 Methane

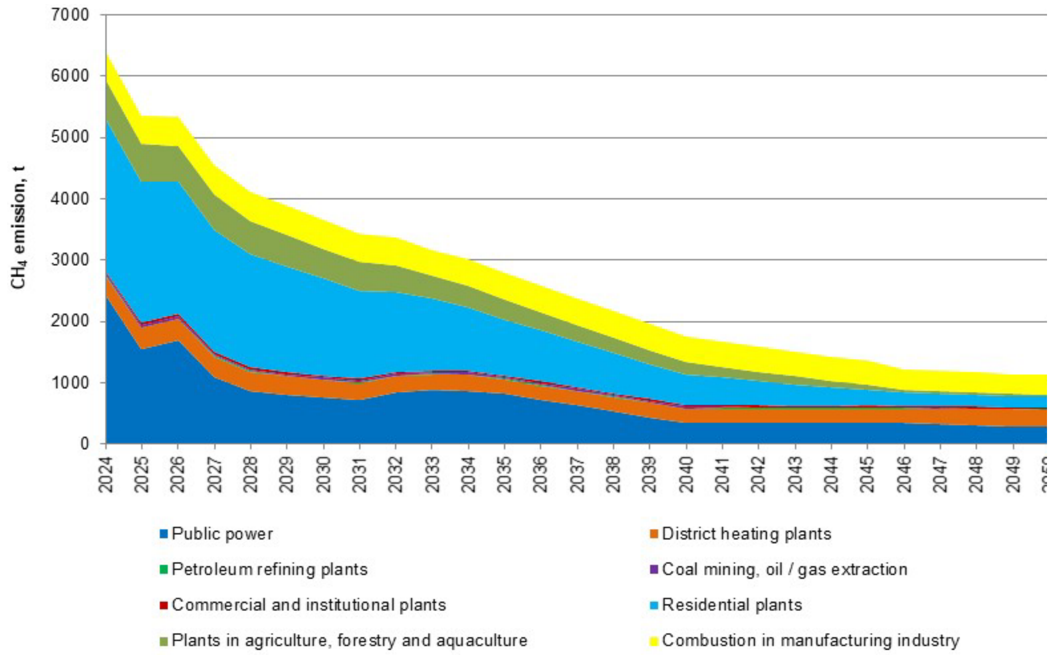

Figure 2.6 CH_4 emissions by sector.

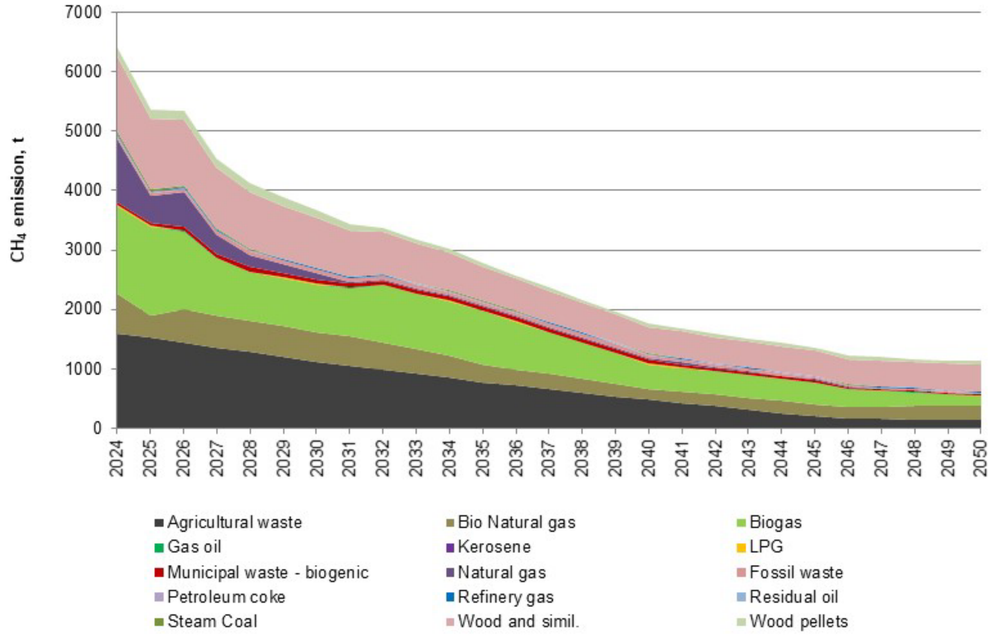

Figure 2.7 CH_4 emissions by fuel.

Table 2.4 CH_4 emissions by sector, t.

Sector	1990	2000	2005	2010	2020	2023	2024	2025	2030	2035	2040	2045	2050
Public electricity and heat production	585	14620	12359	10922	3405	3249	2753	1891	1047	1055	576	587	564
Petroleum refining plants	18	21	19	17	18	18	16	15	11	11	11	11	11
Oil/gas extraction	16	39	48	46	26	24	33	34	26	25	24	5	0
Commercial and institutional plants	130	900	798	683	335	287	37	36	34	32	30	29	27
Residential plants	5383	6064	6911	7141	3391	2888	2475	2305	1582	910	497	258	175
Plants in agriculture, forestry and aquaculture	1089	2465	2186	1375	868	772	638	614	491	325	202	79	39
Combustion in industrial plants	275	1020	818	546	872	535	458	468	472	427	423	392	320
Total	7496	25130	23139	20731	8915	7772	6410	5363	3665	2785	1762	1361	1135

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. However, in the later part of the projection period, manufacturing industries become the second largest source due to reductions in emissions from the residential sector. There is a significant increase in emissions from 1990 to 2000 due to the increased use of gas engines during the 1990s. Beginning around 2004, the natural gas consumption has begun to show a decreasing trend due to structural changes in the Danish electricity market.

2.5.4 Nitrous oxide

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

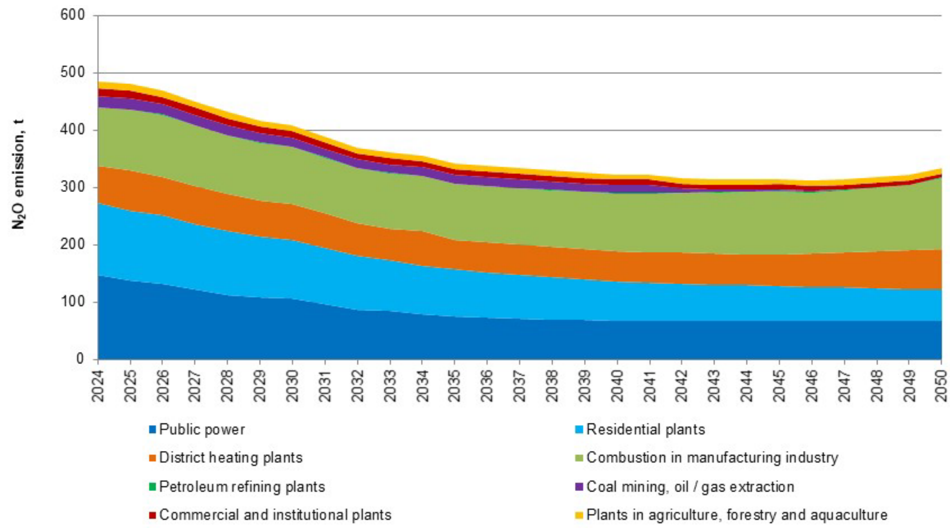

Figure 2.8 N_2O emissions by sector.

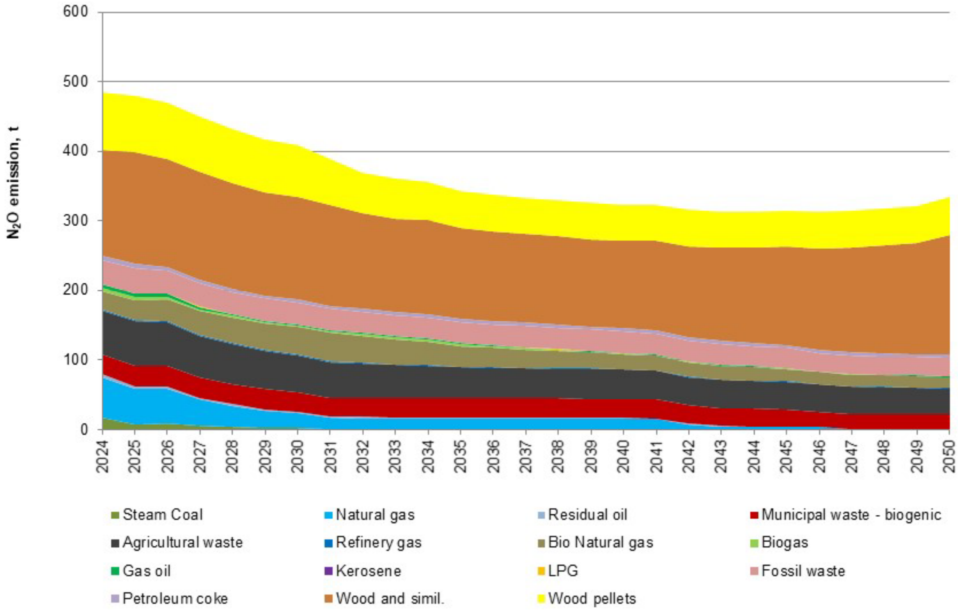

Figure 2.9 N_2O emissions by fuel.

Table 2.5 N_2O emissions by sector, t.

Sector	1990	2000	2005	2010	2020	2023	2024	2025	2030	2035	2040	2045	2050
Public electricity and heat production	265	317	311	345	229	230	212	208	168	126	119	122	139
Petroleum refining plants	2	7	5	3	4	4	2	2	1	1	1	1	1
Oil/gas extraction	20	56	40	27	15	14	19	20	15	15	14	3	0
Commercial and institutional plants	17	15	17	18	17	16	13	13	12	10	9	8	8
Residential plants	106	118	162	202	160	138	126	122	103	82	69	60	55
Plants in agriculture, forestry and aquaculture	23	18	18	15	12	12	11	11	10	10	9	9	9
Combustion in industrial plants	186	221	182	175	162	116	101	105	100	98	101	110	123
Total	619	752	735	785	599	531	484	480	408	342	323	314	334

2.6 Recalculations

2.6.1 Recalculations in fuel consumptions

Energy consumption in the model is based on the Danish Energy Agency's energy projections and energy projections for individual plants (Danish Energy Agency, 2025). All recalculations made in these projections are directly observable in the present emission projections.

2.6.2 Recalculations for emission factors

Emission factors have been updated according to the latest emission inventory (Nielsen et al., 2025).

The CO_2 emission factors for coal, residual oil, refinery gas and offshore combustion of natural gas (offshore gas turbines) are all based on EU ETS data and have been updated to the average 2018-2023 emission factors.

The offshore gas field in the North Sea, Tyra, has been shut down from September 2019 to spring 2024. During this period, consumers in Denmark primarily got their gas supply from Germany (Energinet.dk, 2021). The CO_2 emission factor applied for natural gas[3] in 2024 has been updated based on gas quality data for 2024 whereas the CO_2 emission factor applied for 2025-2050 has been updated to the average value for the years 2023-2024.

The implied emission factors for CH_4 from residential wood combustion have been updated according to the latest technology specific emission factors (Nielsen et al., 2025) and the updated energy projections. The CH_4 emission factor for residential / agricultural combustion of straw has been updated according to legislation for new plants.

2.7 References

Danish Energy Agency, 2025: Denmark's Energy and Climate Outlook.

EMEP/EEA, 2023: EMEP/EEA air pollutant emission inventory guidebook 2023. Technical report No 06/2023. Available at: https://www.eea.europa.eu//publications/emep-eea-guidebook-2023

Energinet, 2021: Faktablad for gaskvaliteter under Tyra genopbygningen med Baltic Pipe.

Energinet, 2025: e-mail from Jesper Bruun Munkegaard Hvid, Energinet, 02-01-2025.

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

[3] Except offshore gas turbines.

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Nielsen, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Hjelgaard, K., Fauser, P., Bruun, H.G., Levin, L., Callisen, L.W., Andersen, T.A., Johannsen, V.K., Nord-Larsen, T., Vesterdal, L., Stupak, I., Scott-Bentsen, N., Rasmussen, E., Petersen, S.B., Baunbæk, L., & Hansen, M.G. 2025. Denmark's National Inventory Document 2025. Emission Inventories 1990-2023 - Submitted under the United Nations Framework Convention on Climate Change and the Paris Agreement. Aarhus University, DCE – Danish Centre for Environment and Energy, 929 pp. Scientific Report No. 655. Available at: https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Videnskabelige_rapporter_600-699/SR655.pdf

3 Oil and gas extraction (Fugitive emissions from fuels)

This chapter includes fugitive emissions from fuels in the CRF sector 1B. The sources included in the Danish emission inventory and in this projection are listed in Table 3.1. The following chapters describe the methodology, activity data, emission factors and emissions in the projection. Detailed descriptions of the emission inventory for the historical years are included in Plejdrup et al. (2021) and Nielsen et al. (2025).

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.3	050206	Offshore loading of oil	Oil
1.B.2.a.3	050207	Onshore loading of oil	Oil
1.B.2.a.4	040101	Petroleum products processing	Oil
1.B.2.a.4	040103	Other processes in petroleum industries	Oil
1.B.2.a.4	040104	Storage and handling of petroleum products in refinery	Oil
1.B.2.a.4	040105	Other (catalytic regeneration)	Oil
1.B.2.a.4	050208	Storage of crude oil	Oil
1.B.2.a.5	050503	Service stations (including refuelling of cars)	Oil
1.B.2.a.6	050210	Abandoned wells	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.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.b.5	050606	Post-meter - industrial and power plants	Natural gas
1.B.2.b.5	050607	Post-meter - commercial and residential	Natural gas
1.B.2.b.5	050608	Post-meter - natural gas fired vehicles	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, 2019) 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 – DECO25) on production of oil and gas, and on flaring in upstream oil and gas production and on fuel consumption (DEA, 2025).

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

3.2 Activity data

Oil and gas production in the Energy and Climate Outlook (DEA, 2025) is shown in Figure 3.1. The production of both oil and gas is assumed to increase significantly from 2024 to 2025, mainly due to the restart of production from the Tyra field, which was shut down in September 2019 for redevelopment. Tyra II resumed production in March 2024 and reached full capacity in November 2024. After some years with fluctuations, the production of oil and gas phase-out in 2050. This is in line with the deal agreed by the Danish Parliament in 2020 to phase-out fossil fuel extraction in the North Sea by 2050.

The Energy and Climate Outlook 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, 2025), the flaring amounts are expected to decrease from 2024 to 2031, followed by a levelled-out trend until 2041, then a drop till 2043 followed by a phase-out in 2050. Flaring related to exploration of oil and gas is not included in the Energy and Climate Outlook, and therefore this activity is not included in the projection.

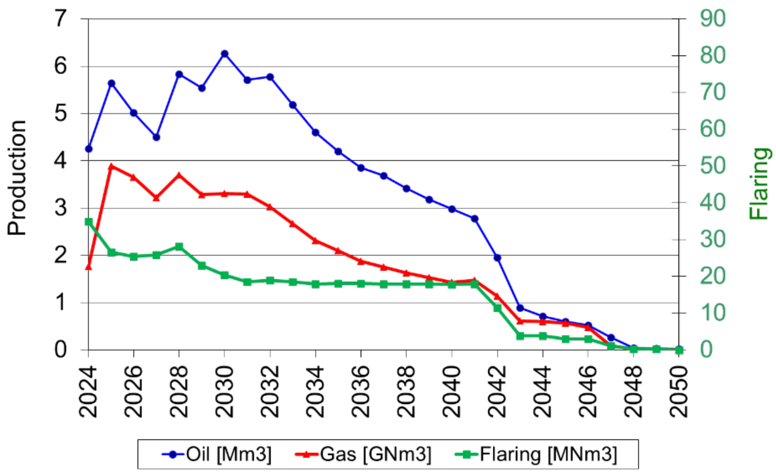

Figure 3.1 Projection of oil and gas production (DEA, 2025).

The DEA Energy and Climate Outlook of the production of oil and gas is used in the projection of emissions from several 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 DEA Energy and Climate Outlook are applied in the projection of fugitive emissions from fuels for the sources: transmission of natural gas, distribution of natural gas, and distribution of 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.

3.3 Emission factors

For some sources, the emission factors are based on the IPCC Guidelines (IPCC, 2006, 2019) and the EMEP/EEA Guidebook (EMEP/EEA, 2019). This is the case for offshore loading of oil to ships and flaring in upstream oil and gas production. For offshore loading of ships, the emission factors in the IPCC Guidelines (IPCC, 2019) are used with the assumption of equal amount of loading with and without VRU. The CH_4 emission factors for onshore loading in historical years are based on data from the harbour terminal. The emission factor for the latest historical year is used in the projection. The 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 (2019) for CO_2 from transport of oil in pipelines is applied.

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

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

The N_2O emission factor is taken from the 2019 IPCC Guidelines for flaring in upstream oil and gas production and at refineries.

In the projection of emissions from flaring in refineries the emission factors for the latest historical year are applied, in correspondence with the approach in the Energy and Climate Outlook, where the flaring rates for refineries are kept constant, 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, refinery processes, and for venting and flaring in gas storage and treatment plants.

3.4 Emissions

Most 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 an increase from 2023 to 2025, and a decreasing trend is expected for the projection years 2025-2050. The trend is mainly caused by a variation in emissions from oil and gas production. The low emissions in 2020-2023 are due to a decrease in oil and especially gas production, mainly due to the shutdown of the Tyra platform for redevelopment. Production on Tyra II was resumed in 2024.

The flaring amounts for refineries are assumed to be constant for the projection period according to the Energy and Climate Outlook (DEA, 2025), and correspondingly the emissions from flaring in refineries for the latest historical year are applied for the projection years.

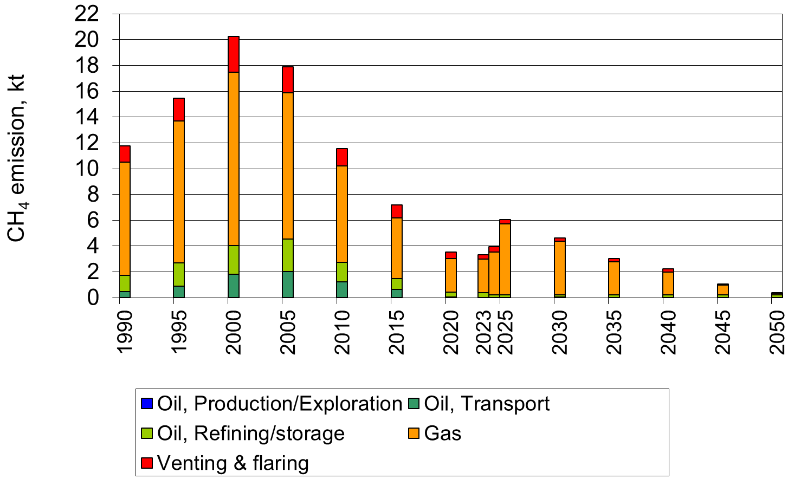

Figure 3.2 CH_4 emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2015, 2020 and 2023, including exploration of oil and gas) and projection years (2024, 2025, 2030, 2035, 2040, 2045, 2050, excluding exploration of oil and gas).

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, 2025) and an average emission factor for the latest five historical years. The average CO_2 emission factor applied in the projection years is 2.470 kg per Nm^3.

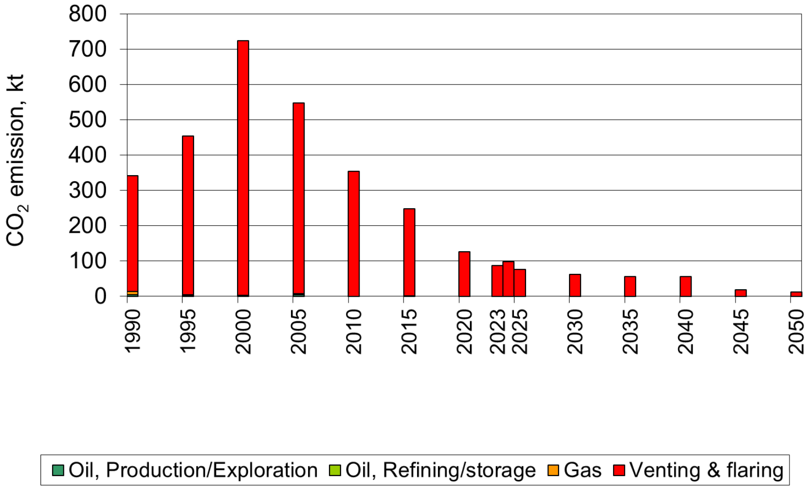

Figure 3.3 CO_2 emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2015, 2020 and 2023, including exploration of oil and gas) and projection years (2024, 2025, 2030, 2035, 2040, 2045, 2050, excluding exploration of oil and gas).

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 significantly. Emissions from onshore activities (storage of oil and loading of ships) have shown a large decrease from 2005 to 2016 due to new technology at the oil terminal and at the harbour terminal. The only source of N_2O emissions in the fugitive emission sector is flaring in upstream oil and gas production, at refineries and in gas storage and treatment plants. The fugitive N_2O emission is very limited.

The GHG emissions 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 owes to decreasing production 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 2.5 % of the total fugitive GHG emission (second and third highest emission occurred in 1990 and 1998 and contributed 2.1 % and 0.7 %, respectively).

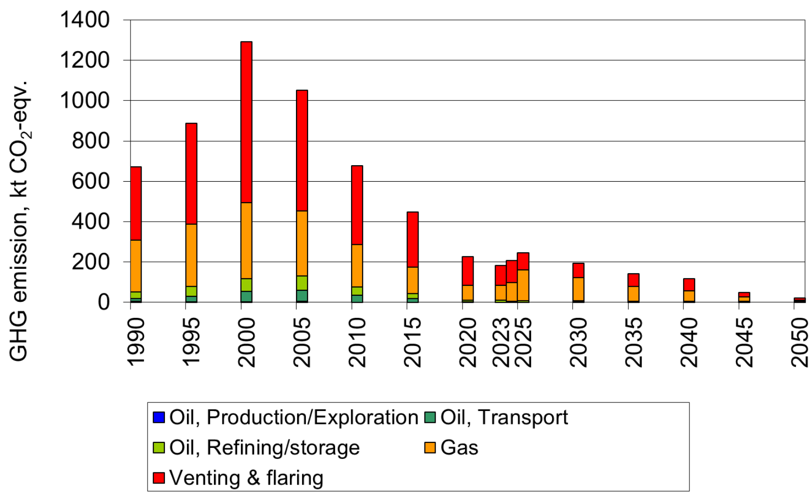

Figure 3.4 GHG emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2015, 2020 and 2023, including exploration of oil and gas) and projection years (2024, 2025, 2030, 2035, 2040, 2045, 2050, excluding exploration of oil and gas).

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 "GasTransport"). The names and content of the models for the fugitive sector are listed in Table 3.2.

Table 3.2 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.
GasTransport	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, 2025: 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 (07-03-2024).

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (07-03-2024).

IPCC, 2019: 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html (07-03-2024).

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Plejdrup, M.S., Nielsen, O.-K. & Nielsen, M. 2021. The Danish emission inventory for fugitive emissions from fuels. Aarhus University, DCE – Danish Centre for Environment and Energy, 61 pp. Scientific Report No. 463. Available at: http://dce2.au.dk/pub/SR463.pdf (07-03-2024).

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 CRT 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 Brickworks	04 06 91
		-	2A4a Expanded clay	04 06 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 from fuels and solvent use	2D1	Lubricant use	06 06 04
		2D2	Paraffin wax use	06 06 04
		2D3	Other	
		-	Use of urea in catalysts	06 06 07
		-	Road paving with asphalt	04 06 11
2E	Electronics industry	2E5	Fibre optics	06 05 08
2F	Product use as substitutes for ozone depleting substances	2F1	Refrigeration and air conditioning	06 05 02
		2F2	Foam blowing agents	06 05 04
		2F4	Aerosols	06 05 06
		2F5	Solvents	06 05 08
2G	Other product manufacture and use	2G1	Electrical equipment	
		-	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., 2025).

4.2 Methodology

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

For HFCs, PFCs and SF_6, also known as F-gases, emission projections are based on an F-gas projection done by Poulsen (2025a and 2025b).

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

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

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

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

4.2.1 F-gases

An account of the annual consumption and emission of F-gases is prepared by a consultant on behalf of the Danish Environmental Protection Agency (DEPA) (Poulsen, 2025a and 2025b). In this work, projections until 2050 are also prepared. Annual reports that contain both consumption and emission data are publicly available.

F-gases are powerful GHGs with global warming potentials (GWPs) between 138 (HFC-152a) and 23 500 (SF_6). Therefore, F-gases 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.

Emissions are calculated with a model for the individual substances life cycle over the time series, 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. (2025). 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, 2025a).

The report and the data collected in Poulsen (2025a, b) provide emission projections generally based on steady state consumption with 2023 as the reference year. In connection with Danish regulation concerning the phasing out of powerful GHGs, cut-off dates in relation to the phasing out of individual substances are taken into account.

For all medium/large commercial refrigeration and stationary air-conditioning categories with high GWP refrigerants, the trend is projected as steady state until 2025, whereafter the consumption will decrease 20 % per year. Consumption is phased out from 2032 where the service ban for these installations is enforced.

For mobile air-conditioning (MAC), the consumption decreases with 20 % per year from 2026. The assumption is made with reference to a graduated increased effect of the MAC Directive require only HFOs in new person cars introduced to the EU market.

For heat pumps, the projection of HFCs in monoblock units is steady state using most recent year as reference. The projection of consumption is based on a relative deduction of stock per year until 2026, where R290 is expected fully phased in as substitute for HFC-32. The consumption of HFC-410 in other air-water units is steady state until 2030 where the service ban for these installations is introduced.

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 2.A Mineral Industry; production of cement, lime, glass, glass wool, bricks/tiles, expanded clay and stone 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
		Stone 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 2023 is based on the company reporting to EU ETS (Aalborg Portland, 2024). The emission from cement production for 2024-2050 is estimated by the DEA (2025), see Table 4.3.

Table 4.3 Projected emission from cement production, kt CO_2. (DEA, 2025)

	2024	2030	2035	2040	2045	2050
Cement production	1002	889	917	957	1000	1049

Lime is used for a number of different applications. There are no projected production values available for lime production and the emission for 2024-2050 is therefore estimated to be the constant average value for 2019-2023. 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 2019-2023. The same projection method is also applied for glass production and production of expanded clay products.

The production of building materials, i.e. stone wool, glass wool and bricks/tiles, for 2024-2050 is estimated by extrapolating the 2023 emission for each category with the projected production value for the construction sector (DEA, 2025).

Consumption of lime for flue gas cleaning depends primarily on the consumption of coal at central heating plants (CHPs) and waste at waste incineration plants (WIPs). The emissions from flue gas desulphurisation for 2024-2050 are estimated as a sum of the two sources by extrapolating using the trend of the projected consumption of coal and waste from the energy projections (DEA).

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

4.2.3 Chemical Industry

There is only one source of GHG emissions within the emission projection of CRT category 2.B Chemical Industry; production of catalysts/fertilisers categorised under 2.B.10 Other.

There are no projected production values available for the production of catalysts/fertilisers; the emission for 2024-2050 is therefore estimated using the average of the five latest historical years.

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

Calculated emission projections are shown in Table 4.9.

4.2.4 Metal Industry

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

There is a small emission of CO_2 from lead production. Production ceased during 2021 and reopened in 2022. Emissions from this source are projected to slowly increase in 2024 before reaching the 2017-2021 average level from 2025 to 2050.

4.2.5 Non-Energy Products from Fuels and Solvent Use

This category includes CO_2, CH_4 and N_2O emissions from the source categories 2.D.1 Lubricant use, 2.D.2 Paraffin wax use and 2.D.3 Other (Road paving with asphalt and use of urea in catalysts).

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	28
N_2O	Paraffin wax use	265

The projections for all included sources in this category, are based on the average emission of the five latest historical years. Calculated emission projections are shown in Table 4.9 and Table 4.11.

4.2.6 Electronic Industry

Fibre optics is the only source in CRT category 2E Electronic Industry. Fibre optics can lead to emissions of both HFC (HFC-23) and PFCs (PFC-14 and PFC-318). No emissions from fibre optics occurred in 2020-2022, and no emissions are expected for 2024-2050 (Poulsen, 2025b).

4.2.7 Product Uses as Substitutes for Ozone Depleting Substances

There are three sources of GHG emissions within the projection of the CRT category 2.F Product Uses as Substitutes for Ozone Depleting Substances (ODS); refrigeration and air conditioning (2.F.1), foam blowing agents (2.F.2) and aerosols (2.F.4).

Emission projections from this source category include six HFCs (HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-152a and HFC-227ea) and one PFC (PFC-14).

Emissions from mobile air-conditioning (MAC) (2.F.1.e), high GWP gasses from medium-large commercial refrigeration (2.F.1.a) and high GWP gasses from stationary air-conditioning (2.F.1.f), are projected for 2024-2025 using steady state, followed by an expected reduction of 20 % per year. Stand-alone domestic refrigeration (2.F.1.b), transport refrigeration (2.F.1.d), low GWP gasses from medium-large commercial refrigeration (2.F.1.a), low GWP gasses from stationary air-conditioning and medical dose inhalers (MDIs) (2.F.4.a) are projected using steady state for all projected years; 2024-2050. Emissions from heat pumps are modelled separately for air-air heat pumps (steady state), monoblock units (phase out of HFC-32 complete in 2031) and other air-water units (steady state).

HFCs

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

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

Substance	Typical use	GWP CO_2e
HFC-32	Refrigeration (K2)	677
HFC-125	Refrigerants (K1-4)	3 170
HFC-134a	Refrigerants (K1-4), foam blowing and aerosols	1 300
HFC-143a	Refrigerants (K1-4)	4 800
HFC-152a	Refrigerants (K2) and foam blowing	138

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

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

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

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

PFCs

PFCs comprise a range of substances, of which only PFC-14 (CF_4) is relevant for the projection of source category 2.F and approved for inventory under the Climate Convention and KP with stated and approved GWP values. The GWP value for PFC-14 is 6630. PFC-14 is used as cleaning fluid. The use of PFCs in Denmark is minor.

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

4.2.8 Other Product Manufacture and Use

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

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

	Sources/processes
2.G.1 Electrical equipment	Use of electrical equipment
2.G.2 SF_6 and PFCs from other product use	SF_6 from other product uses: - Double glazed windows* - Laboratories/research - Running shoes*
2.G.3 N_2O from product uses	N_2O from medical applications Propellant for pressure and aerosol products
2.G.4 Other	Other product uses - Fireworks - Tobacco - Charcoal for barbeques

* Only for historic years

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

Table 4.8 Global Warming Potentials (GWPs) for substances in category 2.G Other Product Manufacture and Use.

Substance	Typical use	GWP CO_2e
CO_2	Fireworks	1
CH_4	Fireworks, tobacco, charcoal for BBQs	28
N_2O	Anaesthetics, propellant, fireworks, tobacco, charcoal for BBQs	265
SF_6	High voltage electrical equipment, double glazing, laboratories/research, running shoes	23 500

The annual F-gas report from Poulsen (2025a) contains both SF_6 consumption and emission data for both historic years and projected years until 2050. For more details on this report and the model it is based on, see the section 4.2.1 F-gases.

The emission projections for the sources Use of electrical equipment and SF_6 from other product uses are available from Poulsen (2025a and 2025b). Emissions from the Use of electrical equipment cover SF_6 from high voltage equipment. The emissions from SF_6 from other product uses cover SF_6 from double glazed windows and use of SF_6 in laboratories/research. The use of SF_6 in connection with double-glazing was banned in 2002, and according to the F-gas model, the last remaining double-glazing panes where SF_6 has been used will have been disposed of in 2021 where the last emissions therefore will have occurred.

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

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

The calculated emission projections are shown in Table 4.9.

4.3 Emissions

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

In 2023, 72 % of GHG emissions from IPPU originate from Mineral Industry. By 2050, the number will have increased to 87 % because emissions from Product uses as ODS substitutes decrease more than those from Mineral Industry.

The second largest source category is Product uses as substitutes for ODS with up to 19 % of IPPU GHG emissions early in the projection period (2024-2027).

Table 4.9 Projection of CO_2 process emissions, kt CO_2e.

Source Categories		1990	2005	2015	2020	2023	2024	2025	2030	2035	2040	2045	2050
2A	Mineral Industry	973	1567	**1049**	1353	1112	1002	1030	889	917	957	1000	1049
	Hereof cement production	775	1363	**932**	1227	982	879	907	765	791	830	871	918
2B	Chemical Industry	892	1.1	**1.5**	40.8	43.4	37.6	37.6	37.6	37.6	37.6	37.6	37.6
2C	Metal Industry	61	16	**0.20**	0.09	0.07	0.09	0.11	0.11	0.11	0.11	0.11	0.11
2D	Non-energy products from fuels and solvent use	72	139	**111**	101	102	104	104	104	104	104	104	104
2E	Electronic industry	NO	NO	**NO**	NO	0.5	NO	NO	NO	NO	NO	NO	NO
2F	Product uses as ODS substitutes	-	889	**452**	317	261	273	274	149	60	13	2	1
2G	Other product manufacture and use	27	48	**154**	67	33	20	20	20	20	20	20	20
	Total	2025	2660	**1768**	1879	1553	1437	1466	1200	1139	1133	1163	1212

NO: Not occurring

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

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

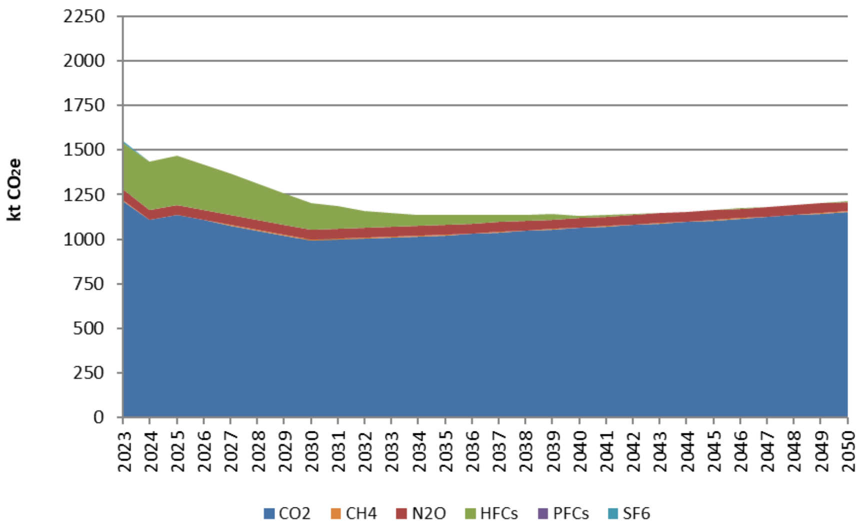

Figure 4.1 Time series for emissions, divided into individual pollutants.

4.3.1 Mineral Industry

Emission projections for mineral industries are shown in Table 4.10.

Table 4.10 Some historical emissions and emission projections for mineral industries (2.A), kt CO_2e.

		1990	2005	2015	2020	2023	2024	2025	2030	2035	2040	2045	2050
2A1	Cement production	775	1363	932	1227	982	879	907	765	791	830	871	918
2A2	Lime production	105	60	51	43	60	49	49	49	49	49	49	49
2A3	Glass production	14	11	8	8	9	9	9	9	9	9	9	9
2A3	Glass wool production	2	2	1	2	2	2	2	2	2	2	2	2
2A4a	Bricks/tiles production	26	35	20	27	20	20	20	22	23	25	26	28
2A4a	Expanded clay production	20	19	9	16	14	19	19	19	19	19	19	19
2A4b	Other uses of soda ash	14	18	7	16	16	16	16	16	16	16	16	16
2A4d	Flue gas cleaning	10	51	16	8	7	6	5	4	4	4	4	4
2A4d	Stone wool production	7	8	6	5	3	3	3	4	4	4	4	5
	Total	973	1567	1049	1353	1112	1002	1030	889	917	957	1000	1049

The largest source of emissions in Mineral Industry is cement production; 80-91 %. Cement production has a decreasing trend in the projected years until 2030 followed by a slow increasing trend for 2030-2050, the development is due to the projected cement production presented in Table 4.3. The second largest emission source for all projected years is lime production; 5 % of the mineral industry.

The mineral industry in turn amounts to 70-87 % of the IPPU sector GHG emissions for the projected years.

In 2023, the contribution from category 2A was 2.8 % of the Danish total greenhouse gas emission excluding LULUCF and indirect sources. In 2050, this contribution is estimated to have increased to 7.1 %.

4.3.2 Chemical Industry

There is only one source of GHG emissions within this category after 2023; production of catalysts/fertilisers categorised under 2.B.10 Other. There is therefore no additional disaggregation available to the data presented in Table 4.9.

Emissions from catalyst production are projected as the constant average of the latest five historical years.

4.3.3 Metal Industry

Lead production is the only source of GHG emissions from metal industries after 2023. There is therefore no additional disaggregation available to the data presented in Table 4.9. Projected emissions are based on historic years.

4.3.4 Non-Energy Products from Fuels and Solvent Use

All sources within this category were projected as the constant average of the five latest historical years. Category 2.D makes up 7-9 % of IPPU CO_2 equivalent emissions in 2024-2050.

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

	Pollutant	Unit	1990	2005	2015	2020	2023	2024	2025	2030	2035	2040	2045	2050
2D1 Lubricant use	CO_2	kt	50	38	32	32	32	32	32	32	32	32	32	32
2D2 Paraffin wax use	CO_2	kt	22	100	71	59	61	62	62	62	62	62	62	62
2D3 Other (urea, road paving)	CO_2	kt	NO	0.01	8	9	9	9	9	9	9	9	9	9
2D Total CO_2	CO_2	kt	71	138	111	100	101	103	103	103	103	103	103	103
2D2 Paraffin wax use	CH_4	t	0.9	4.2	3.0	2.5	2.5	2.6	2.6	2.6	2.6	2.6	2.6	2.6
2D3 Other	CH_4	t	11	17	15	17	23	18	18	18	18	18	18	18
2D Total CH_4	CH_4	t	12	21	18	19	26	21	21	21	21	21	21	21
2D2 Paraffin wax use	N_2O	t	0.2	0.8	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
2D Total N_2O	N_2O	t	0.2	0.8	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
2D Total CO_2e	CO_2e	kt	72	139	111	101	102	104	104	104	104	104	104	104

4.3.5 Electronic Industry

There is only one source in category 2.E; i.e. Fibre optics. There is therefore no additional disaggregation available to the data presented in Table 4.9. No emissions occurred in 2020-2022, and no emissions are expected for 2024-2050 (Poulsen, 2025b).

4.3.6 Product Uses as Substitutes for Ozone Depleting Substances

The category 2.F Product Uses as Substitutes for ODS is dominated by emissions from refrigeration and air conditioning (CFT category 2.F.1).

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

	1995	2005	2015	2020	2023	2024	2025	2030	2040	2045	2050
2F1a Commercial refrigeration	33	575	290	163	106	101	105	34	0.01	0.001	0.0003
2F1b Domestic Refrigeration	7	12	5	1	0	0	0 -		-	-	-
2F1d Transport Refrigeration	0.01	23	22	12	10	9	10	4.3	0.2	0.1	0.03
2F1e Mobile Air-Conditioning	5	57	54	56	54	54	54	18	-	-	-
2F1f Stationary air-conditioning	0.6	83	54	74	80	97	94	86	11	0.03	0.001
2F2a Closed Cells	50	103	13	0.7	0.5	0.4	0.3	0.03	-	-	-
2F2b Open Cells	142	15	-	-	-	-	-	-	-	-	-
2F4a Metered Dose Inhalers	-	7	7	10	12	12	11	7	2	1.4	0.8
2F4b Other aerosols	-	14	7	-	-	-	-	-	-	-	-
2F5 Solvents*	-	-	-	-	-	-	-	-	-	-	-
Total	238	889	452	317	261	273	274	149	13	1.5	0.9

* Occurred in 2000-2003.

4.3.7 Other Product Manufacture and Use

Emission projections for other product manufacture and use are not shown at a more disaggregated level due to the low emissions from this source. CH_4 from barbeques and N_2O emissions from medical applications contribute the most to the projection time series. Overall emissions from this category are presented in Table 4.9.

4.4 Recalculations

Recalculations compared to the previous projection are caused by the update of the historical years, updates in the activity/energy projections from the Danish Energy Agency (DEA, 2025) and updates in the F-gas projection done by Poulsen (2025a and 2025b).

The largest changes in historical data that also affect the projections are the exclusion of indirect CO_2 emissions (from solvent use and asphalt products) and the introduction of N_2O emissions from the catalyst production.

There are no updates to the methodology of the emission projection calculations.

4.5 References

DEA, 2025: Danish Energy Agency. Denmark's Energy and Climate Outlook.

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Poulsen, 2025a: Tomas Sander Poulsen, Provice ApS. Danish consumption and emission of F-gases - 2023. The Danish Environmental Protection Agency, Environmental Project no. 2285, January 2025. Available at: https://mst.dk/publikationer/2025/januar/danish-consumption-and-emission-of-f-gases-2023 (24/04-2025)

Poulsen, 2025b: Excel spreadsheet containing projection assumptions for F-gasses for 2024-2050. Prepared by Tomas S. Poulsen, Provice ApS. (Not publicly available)

Aalborg Portland, 2024: EU-ETS data for 2006-2023, CO_2-opgørelse og afrapportering 2023. Aalborg Portland A/S. Fremstilling af klinker (cement). (Confidential)

5 Transport and other mobile sources

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

In the emission inventories, all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution), according to the CollectER system.

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 motorcycles	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
080204 Train contact wire wear	1A3c Railways
080205 Wheel and rail wear	1A3c Railways
080206 Brake wear	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)
080505 Dom. airport traffic (tyre and brake wear)	1A3aii (i) Civil aviation (Domestic, LTO
080506 Int. airport traffic (tyre and brake wear)	1A3ai (i) Civil aviation (International, LTO)
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

Road traffic evaporation, brake and tire wear, and road abrasion (SNAP codes 0706, 0707 and 0708), train contact wire wear, wheel and rail wear and brake wear (SNAP codes 080204, 080205 and 080206) and domestic and international aviation tyre and brake wear (SNAP codes 080505 and 080506) are not a part of the CRF list since no greenhouse gases are emitted from these sources.

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

Agricultural and forestry non-road machinery (SNAP codes 0806 and 0807) is accounted for in the Agriculture/forestry (1A4cii) sector. Fishing activities (SNAP code 080403) regardless of vessel flag is reported under 1A4ciii.

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

The fuel consumption used in the emission projections follow the sector split as the official energy statistics elaborated by the Danish Energy Agency (DEA). However, based on bottom-up calculations within sectors, DCE in a few cases make different splits of non-road mobile and stationary consumption compared to the fuel splits in the latest official Danish energy forecast "Danish Energy and Climate Outlook 2025" (DECO25) provided by DEA (2024).

5.1 Methodology and references for road transport

For road transport, the detailed methodology (Tier 3) is used to make annual estimates of the Danish emissions, as described in the EMEP/EEA Air Pollutant Emission Inventory Guidebook (EMEP/EEA, 2024). The calculations are made with the DEMOS-Road (Danish Emission model system for Mobile Sources) model developed at DCE, Aarhus University, using the European COPERT 5 model methodology (EMEP/EEA, 2024). In COPERT, fuel consumption and emission simulations can be made for operationally hot engines, considering 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 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 5 fleet classification, DEMOS-Road groups all present and future vehicles in the Danish fleet 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.

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

Table 5.2 Model vehicle classes and sub-classes.

Vehicle classes	Fuel type	Engine size/weight
Passenger cars	Gasoline/Diesel/Plug-in hybrid	< 0.8 l.
Passenger cars	Gasoline/Diesel/Plug-in hybrid	0.8 - 1.4 l.
Passenger cars	Gasoline/Diesel/Plug-in hybrid	1.4 – 2 l.
Passenger cars	Gasoline/Diesel/Plug-in hybrid	> 2 l.
Passenger cars	2-stroke	
Passenger cars	LPG	
Passenger cars	CNG	
Light commercial vehicles (LCV)	Gasoline/Diesel/LP/CNG/Plug-in hybrid	<1305 kg
Light commercial vehicles (LCV)	Gasoline/Diesel/LP/CNG/Plug-in hybrid	1305-1760 kg
Light commercial vehicles (LCV)	Gasoline/Diesel/LP/CNG/Plug-in hybrid	>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, 2024). 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. (2024).

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 back-casted to 1985 and projected to 2050.

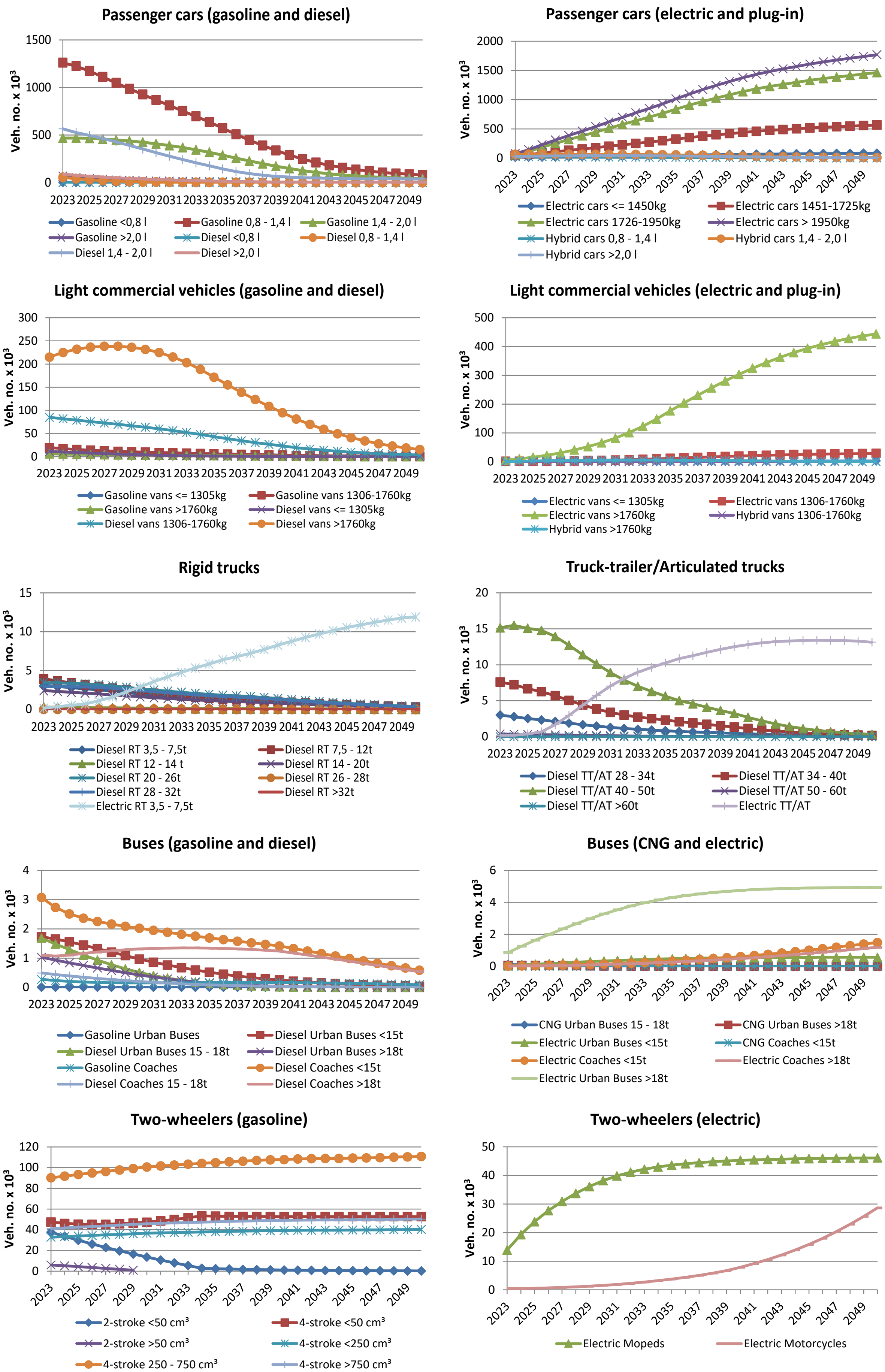

Figure 5.1 Number of vehicles in sub-classes from 2023-2050.

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 2023-2050 periods. The latter figure clearly shows how vehicles complying with the gradually stricter EU emission levels (Euro 6/VI and Euro 7/VII) are introduced into the Danish motor fleet in the projection period.

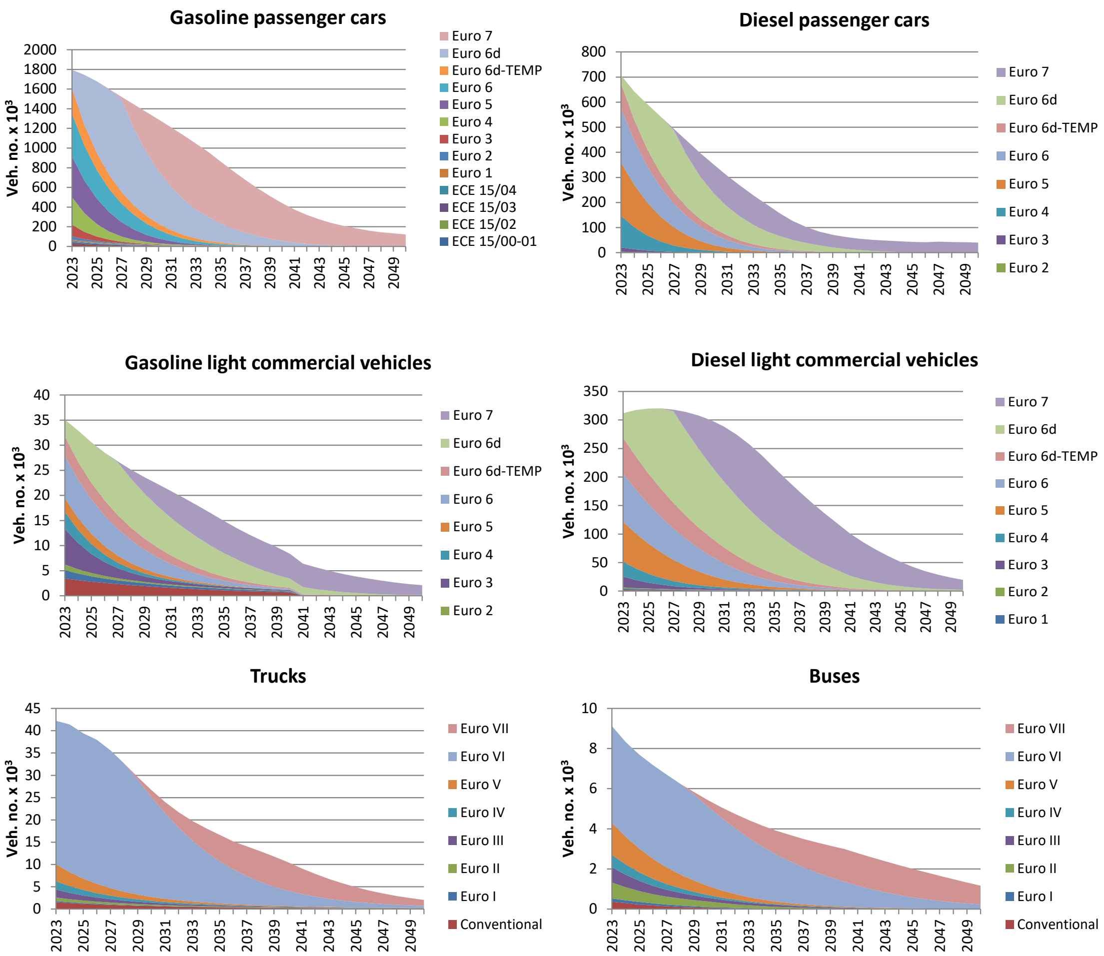

Figure 5.2 Layer distribution of vehicle numbers per vehicle type in 2023-2050.

5.1.2 Emission legislation

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

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

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

- **Target dates:** the EU fleet average of 175 g CO_2 per km will be phased in between 2014 and 2017. In 2014, an average of 70 %of each manufacturer's newly registered vans must comply with the limit value curve set by the legislation. This proportion will rise to 75 % in 2015, 80 % in 2016, and 100 % from 2017 onwards.
- **Limit value curve:** emissions limits are set according to the mass of vehicle, using a limit value curve. The curve is set in such a way that a fleet average of 175 grams of CO_2 per kilometre is achieved. A so-called limit value curve of 100 % implies that heavier vans are allowed higher emissions than lighter vans while preserving the overall fleet average. Only the fleet average is regulated, so manufacturers will still be able to make vehicles with emissions above the limit value curve provided these are balanced by other vehicles, which are below the curve.
- **Vehicles affected:** the vehicles affected by the legislation are vans, which account for around 12 % of the market for light-duty vehicles. This includes vehicles used to carry goods weighing up to 3.5 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 will cost €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 will be counted as 3.5 vehicles in 2014 and 2015, 2.5 in 2016 and 1.5 vehicles in 2017.
- **Eco-innovations:** manufacturers can be granted a maximum of 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).

On 19 April 2023, the European Parliament and the Council amended the Regulation 2019/631 to strengthen the CO_2 emission performance standards for new passenger cars and vans, bringing them in line with the EU's ambition to reach climate neutrality by 2050. This amendment strengthened the emission targets applying from 2030 and set a 100 % emission reduction target for both cars and vans from 2035 onwards.

The following description of the amendment of the regulation (EU) 2019/631 is given on the EU Commission Climate Action web page (https://climate.ec.europa.eu/eu-action/transport/road-transport-reducing-co2-emissions-vehicles/co2-emission-performance-standards-cars-and-vans_en). The main elements of the amended regulation are:

Target levels

Below are the EU fleet-wide CO_2 emission targets set in the regulation:

2020 to 2024

Cars: 95 g CO_2/km

Vans: 147 g CO_2/km

These target levels refer to the NEDC emission test procedure.

2025 to 2034

The targets that will apply from 2025 onwards are based on the WLTP (Worldwide harmonized Light vehicles Test Procedure) and were set out in Commission Implementing Decision (EU) 2023/1623:

Cars: 93,6 g CO_2/km (2025-2029) and 49,5 g CO_2/km (2030-2034)

Vans: 153,9 g CO_2/km (2025-2029) and 90,6 g CO_2/km (2030-2034)

From **2035 onwards**, the EU fleet-wide CO_2 emission target for both cars and vans is 0 g CO_2/km, corresponding to a 100 % reduction.

The **annual specific emission targets** of each manufacturer are based on these EU fleet-wide targets, taking into account the average mass of its registered new vehicles. Since 2021, those specific emission targets are based on the WLTP.

The manufacturer targets for the **years 2021-2024** are calculated in accordance with point 4 of Annex I (parts A and B) to Regulation (EU) 2019/631, using the values set out in Annex II to [Commission Implementing Decision (EU) 2022/2087].

The manufacturer targets **from 2025 onwards** are calculated in accordance with point 6 of Annex I (parts A and B) to Regulation (EU) 2019/631, using the values set out in Annex II to Commission Implementing Decision (EU) 2023/1623.

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

From 2025 to 2029, a ZLEV **crediting system** will apply both for car and van manufacturers. The system will alleviate a manufacturer's specific emission target if its share of new ZLEV (vehicles with emissions between 0 and 50 g CO_2/km) registered in a given year exceeds the following benchmarks:

Cars: 25% ZLEV

Vans: 17% ZLEV

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 alleviation of the emission target will be capped at maximum 5 % to safeguard the environmental integrity of the Regulation.

To calculate the ZLEV share in a manufacturer's fleet, an accounting rule give a greater weight to ZLEVs with lower CO_2 emissions. An additional multiplier may apply for cars registered in Member States with a low share and number of ZLEVs registered in 2017.

Penalties for excess emissions:
If the average CO_2 emissions of a manufacturer's fleet exceed its specific emission target in a given year, the manufacturer must pay – for each of its new vehicles registered in that year – an **excess emissions premium** of €95 per g/km of target exceedance.

Pooling:
Different manufacturers can act jointly to meet their emissions target. When forming a pool, manufacturers must respect the rules of competition law. Pooling between car and van manufacturers is not possible.

Exemptions and derogations:
Manufacturers responsible for fewer than 1000 new cars or fewer than 1000 new vans registered in the EU per year are **exempt** from meeting a specific emission target in the following year, unless they voluntarily apply for a derogation.

Manufacturers may apply for a **derogation** from their specific emission target with the following conditions:

A "small-volume" manufacturer (responsible for less than 10 000 new cars or less than 22 000 new vans registered per year) can propose its own derogation target, based on the criteria set in Article 10 of the regulation.

A "niche" car manufacturer (responsible for between 10 000 and 300 000 new cars registered per year) can apply for a derogation for the years until 2028, included. The derogation targets are calculated as set out in Article 10(4) of the Regulation and in point 5 of Part A of its Annex I. Feel free to access the values used to calculate the "niche" derogation target from 2025 onwards.

Eco-innovations:
To promote the development of new and advanced technologies reducing CO_2 emissions from vehicles, manufacturers may obtain emission credits for cars and vans which are equipped with innovative technologies (eco-innovations) whose full CO_2 savings are impossible to demonstrate during their type-approval.

The manufacturer must demonstrate these savings based on independently verified data. The maximum emission credits for these eco-innovations per manufacturer are 7 g CO_2/km per year until 2024, 6 g CO_2/km from 2025 to 2029, and 4 g CO_2/km from 2030 to 2034. As of 2025, the efficiency improvements for air conditioning systems will become eligible as eco-innovations.

In-service verification:
Manufacturers must ensure that the CO_2 emissions recorded in the certificates of conformity of their vehicles and the in-service CO_2 emissions of such vehicles correspond. Type-approval authorities must verify this correspondence in selected vehicles, as well as the presence of any strategies to artificially improve the vehicle's performance during type-approval tests.

In case deviations or artificial strategies are detected, type-approval authorities must report those to the Commission, who will take them into account when calculating the average specific emissions of a manufacturer. Authorities must also ensure the correction of the certificates of conformity and may take additional measures as set out in the Type Approval regulation.

Real-world emissions:
To assess the real-world representativeness of the CO_2 emissions and the fuel or energy consumption values determined during type-approval, as well as to prevent the growing of the gap between emissions tested in the laboratory and real-world emissions, the Commission is collecting real-world data from cars and vans using on-board fuel consumption monitoring (OBFCM) devices, starting with vehicles first registered in 2021.

On 14 February 2023, the European Commission tabled a legislative proposal to revise Regulation (EU) 2019/1242 setting CO_2 emission standards for new

HDVs in the EU, see https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2023)747880. The revision was approved by the European Parliament on 10 April 2024 and ratified by the Council of the European Union on 13 May 2024.

The revision expands the scope of the regulation to include urban buses, coaches, trailers and additional types of lorries. The average CO_2 emissions of trucks and coaches, compared with 2019 levels, would have to fall by 45 % from 2030, by 65 % from 2035, and by 90 % from 2040 onwards.

The revision introduced a 2035 100 % zero emissions target for urban buses, with an intermediate 90 % 2030 goal.

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

The NEDC test cycle is not adequately describing real world driving behaviour, and consequently, for diesel cars and vans, there is an increasing mismatch between the step wise lowered EU emission limits the vehicles comply with during the NEDC test cycle, and the more or less constant emissions from the same vehicles experienced during real world driving. In order to bridge this emission inconsistency gap, a new test procedure, the "World-Harmonized Light-Duty Vehicles Test Procedure" (WLTP), has been developed which simulates much more closely real-world driving behaviour. The WLTP test procedure gradually take effect from 2017.

For newer Euro 6 vehicles and Euro 7 vehicles emission measurements must also be made with portable emission measurement systems (PEMS) during real traffic driving conditions with random acceleration and deceleration patterns. During the new Real Driving Emission (RDE) test procedure in a temporary phase, the emissions of NO_x are not allowed to exceed the NEDC based Euro 6 emission limits by more than 110 % by 1 September 2017 for all new car models and by 1 September 2019 for all new cars (Euro 6d-TEMP). From 1 January 2020 in the final phase, the NO_x emission not-to-exceed levels are adjusted downwards to 50 % for all new car models and by 1 January 2021 for all new cars (Euro 6d). Implementation dates for vans are one year later.

In the road transport emission model, compromise dates for enter into service of the Euro 6d-TEMP technology are set to 1 September 2018 and 1 September 2019, for diesel cars and vans, respectively. For Euro 6d, the enter into service dates are 1 January 2021 and 1 January 2022 for cars and vans, respectively.

[5] For Euro 3 and on, the emission approval test procedure was slightly changed. The 40 s engine warm up phase before start of the urban driving cycle was removed.

For NOx, VOC (NMVOC + CH_4), CO and PM, the emissions from road transport vehicles must comply with the different EU directives listed in Table 5.3. For cars and vans, the emission directives distinguish between three vehicle classes according to vehicle reference mass[6]: passenger cars and light-duty trucks (< 1305 kg), light-duty trucks (1305-1760 kg) and light-duty trucks (> 1760 kg). The specific emission limits are shown in Nielsen et al. (2023).

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 and Euro VII 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.

For Euro VII engines emissions measured during a Real Driving Emission (RDE) test procedure with random acceleration and deceleration patterns, must comply with specific emission limits given in EU directive 2024/1257.

[6] Reference mass: net vehicle weight + mass of fuel and other liquids + 100 kg.

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

Vehicle category	Emission layer	EU directive	Type approval	First registration date
Passenger cars (gasoline)	PRE ECE	-	-	<1970-
	ECE 15/00-01	70/220 - 74/290	1972[a]	1970[a]
	ECE 15/02	77/102	1981[b]	1979[b]
	ECE 15/03	78/665	1982[c]	1981[c]
	ECE 15/04	83/351	1987[d]	1986[d]
Passenger cars (diesel)	Conventional	-	-	<1991-
Passenger cars	Euro 1	91/441	1.7.1992[e]	1.1.1991[e]
	Euro 2	94/12	1.1.1996	1.1.1997
	Euro 3	98/69	1.1.2000	1.1.2001
	Euro 4	98/69	1.1.2005	1.1.2006
	Euro 5	715/2007(692/2008)	1.9.2009	1.1.2011
	Euro 6	715/2007(692/2008)	1.9.2014	1.9.2015
	Euro 6d-TEMP	2016/646	1.9.2017	1.9.2018
	Euro 6d	2016/646	1.1.2020	1.1.2021
	Euro 7	2024/1257	29.11.2026	29.11.2027
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
	Euro 7	2024/1257	29.11.2026	29.11.2027
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
	Euro 7	2024/1257	29.11.2026	29.11.2027
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
	Euro VII	2024/1257	29.5.2028	29.5.2029
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
Motorcycles	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

Continued				
	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, 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 enough test vehicles. It is similarly important to have separate fuel consumption and emission data for cold-start emission calculations and gasoline evaporation (hydrocarbons).

The fuel consumption and emission factors used in DEMOS-Road come from the COPERT 5 model[7], using trip speeds representative for urban, rural and highway driving. The factors can be seen in Nielsen et al. (2024). The scientific basis for COPERT 5 is fuel consumption figures and emission information from various European measurement programmes, transformed into trip speed dependent fuel consumption and emission factors for all vehicle categories and layers.

It should be noted that for PHEV (plug-in hybrid electric vehicles) cars and vans, the utility factor is set to 0.3, i.e. 30 % of total mileage is assumed to be battery driven, according to assumptions made by DEA (2024)[8]. The fuel consumption and emission factors for plug-in vehicles used in the Danish national emission inventories for road transport, and shown in the present report, only contain the part of fuel consumption and emissions related to the combustion of fossil fuel (gasoline) in the vehicles. The emissions related to the generation of the electricity used by battery electric vehicles and plug-in vehicles are included under stationary sources in the Danish emission inventories as prescribed by the UNFCCC reporting guidelines.

Adjustment for fuel efficient vehicles

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

[7] For hydrogen fuel cell passenger cars and light commercial vehicles, hydrogen fuel cell and battery electric buses and trucks, and battery electric mopeds and motorcycles fuel consumption factor data are obtained from the HBEFA (Handbook of Emission Factors) model version 4.1 (e.g. Matzer et al., 2019).

[8] The electric driven mileage shares for Danish urban, rural and highway driving conditions are derived by weighing in electric driven mileage shares for urban, rural and highway driving conditions obtained from HBEFA.

The 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. In the fleet and mileage database, type approval fuel efficiency values based on the WLTP driving cycle is converted into TA_{NEDC} values by using conversion factors from NEDC to WLTP established by JRC (2017).

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 FC_{inuse} function uses TA_{NEDC}, vehicle weight, engine size and regression coefficients by first registration year, as input parameters (EMEP/EEA, 2023). 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 2015-2022, the $\overline{FC_{inuse}}(i,f,k)$ values for 2014 are adjusted for the years 2015-2022[9] with an index function (indexed from 2014), C_{ICCT} (i, f), based on the reported ICCT fuel gap figures by fuel type for the new registration years 2014-2022.

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

In a final step the ratio between the layer specific fuel factors for the Danish fleet ($\overline{FC_{inuse}}(layer)$) and the COPERT Euro 4 vehicles ($FC_{COPERT,\ sample}$) are

[9] The ICCT monitoring report include new cars up to 2017. For new cars from 2018-2022, fuel gap figures are used for cars from 2017.
[10] The factors are derived from the Common Artemis Driving Cycle (CADC), with a 1/3 weight for each of the urban, rural and highway parts of CADC.

used to scale the trip speed dependent COPERT 5 fuel consumption factors for Euro 4 layers onwards.

For years beyond 2023 annual fuel efficiency, improvement rates are used for new cars depending on fuel type as suggested by DEA (2024).

For vans, trucks, urban buses and coaches, annual fuel efficiency improvement rates are used for new vehicles depending on fuel type as suggested by DEA (2024).

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. (2024).

5.2 Other mobile sources

The emission inventories for other mobile sources are divided into several sub-sectors: Civil aviation, national navigation, national fishing, railways, military, and non-road mobile machinery in agriculture, forestry, industry, commercial/institutional and residential.

The emission calculations are made for each sub-sector in the DEMOS model using the detailed method as described in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2024)[11].

5.2.1 Activity data

Air traffic

For air traffic, DEMOS-Aviation uses air traffic statistics for the latest historical year 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 an LTO/cruise split of the fuel consumption projections for domestic and international aviation from DECO25 due to lack of a projection of air traffic movements.

In more details the historical activity data used in the DEMOS-Aviation consists of records per flight (city-pairs) provided by the Danish Civil Aviation and Railway Authority. Each flight record contains 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.

[11] For military and other sea vessels than ferries, the simple fuel-based method is used.

In DEMOS-Aviation, each aircraft type is paired with a representative aircraft type, for which fuel consumption and emission data exist in the EMEP/EEA databank. As a basis, the type relation table is taken from the Eurocontrol AEM model, which is the primary source for the present EMEP/EEA fuel consumption and emission data. Supplementary aircraft types are assigned to representative aircraft types based on the type relation table already established in the previous version of DEMOS-Aviation (e.g. Winther, 2024).

Non road mobile machinery

Non road mobile machinery is used in agriculture, forestry and industry, for household/gardening purposes and inland waterways (recreational craft). The specific machinery types comprised in the DEMOS-NRMM 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, forklifts, building and construction, other	Forklifts (LPG), building and construction, other
Residential and Commercial/ institutional	Port and airport ground service equipment	Riders, lawn mowers, 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 (2023) 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 DECO25 for the sectors "National sea transport" and "Greenland/Faroe Islands maritime" are used as activity data input for the subsequent emission calculations in DEMOS-Navigation. 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, 2024; Nielsen et al., 2024).

Table 5.5 lists the most important domestic ferry routes in Denmark in 2023. The complete list of ferries is shown in e.g. Winther (2024). 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. Winther (2024) for more details regarding traffic and technical data.

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+

Fisheries

For fishing vessels, the activity data consist of projected total energy use for fishing activities in DECO25, and electronic log data for the latest historical year 2023 provided by Aarhus University for each fishing trip made by Danish registered fishing vessels.

The log data register the following: Vessel registration number, build year, type, overall length (OAL), brutto tonnes (BT), total installed engine power (kW) and hours at sea. Please refer to Winther (2024) for more details regarding log register data.

Railways

The activity data for railways used in the DEMOS-Rail model consists of the projected total energy use for Danish railways activities in DECO25, historical train km statistics per train Litra type provided by Danish State Railways and train km statistics for private railway lines provided by Danish Civil Aviation and Railway Authority.

For several private railway companies, the following technical and operational data has been collected for each railway line operated by the companies: Train litra type, litra new sales year, Euro emission level, fuel type, fuel consumption factors, number of seats/standing rooms, and percentage distribution of annual litra km driven per litra type. For railway lines not able to provide data, supplementary data has been gathered from relevant web pages.

Military

The activity data for military activities consists of fuel consumption information from DECO25.

International navigation

For international sea transport, the activity data used in DEMOS-Navigation is the fuel sold in Danish ports for vessels with a foreign destination, as defined in the IPCC guidelines. The fuel consumption activity data is taken from DECO25.

5.2.2 Emission legislation

For other modes of transport and non-road machinery, the engines must 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 impact the emissions of CH_4, the latter emission component forming a part of total VOC. 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 relates 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 relates to Stage V agricultural and forestry tractors (Table 5.6).

Table 5.6 Overview of EU emission directives and emission limit values relevant for diesel fuelled non-road mobile machinery other than agricultural and forestry tractors and for agricultural and forestry tractors.

Stage	Engine size	CO	VOC	NO_x	$VOC+NO_x$	PM	Other machinery than agricultural and forestry tractors			Agricultural and forestry tractors	
								Implement. date		EU	Implement.
	[kW]			[g/kWh]			EU Directive	Transient	Constant	Directive	Date
Stage I											
A	130<=P<560	5	1.3	9.2	-	0.54	97/68	1/1 1999	-	2000/25	1/7 2001
B	75<=P<130	5	1.3	9.2	-	0.7		1/1 1999	-		1/7 2001
C	37<=P<75	6.5	1.3	9.2	-	0.85		1/4 1999	-		1/7 2001
Stage II											
E	130<=P<560	3.5	1	6	-	0.2	97/68	1/1 2002	1/1 2007	2000/25	1/7 2002
F	75<=P<130	5	1	6	-	0.3		1/1 2003	1/1 2007		1/7 2003
G	37<=P<75	5	1.3	7	-	0.4		1/1 2004	1/1 2007		1/1 2004
D	18<=P<37	5.5	1.5	8	-	0.8		1/1 2001	1/1 2007		1/1 2002
Stage IIIA											
H	130<=P<560	3.5	-	-	4	0.2	2004/26	1/1 2006	1/1 2011	2005/13	1/1 2006
I	75<=P<130	5	-	-	4	0.3		1/1 2007	1/1 2011		1/1 2007
J	37<=P<75	5	-	-	4.7	0.4		1/1 2008	1/1 2012		1/1 2008
K	19<=P<37	5.5	-	-	7.5	0.6		1/1 2007	1/1 2011		1/1 2007
Stage IIIB											
L	130<=P<560	3.5	0.19	2	-	0.025	2004/26	1/1 2011	-	2005/13	1/1 2011
M	75<=P<130	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
N	56<=P<75	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
P	37<=P<56	5	-	-	4.7	0.025		1/1 2013	-		1/1 2013
Stage IV											
Q	130<=P<560	3.5	0.19	0.4	-	0.025	2004/26	1/1 2014	1/1 2014	2005/13	1/1 2014
R	56<=P<130	5	0.19	0.4	-	0.025		1/10 2014	1/10 2014		1/10 2014
Stage V[A]											
NRE-v/c-7	P>560	3.5	0.19	3.5		0.045	2016/1628		2019	167/2013[B]	2019
NRE-v/c-6	130≤P≤560	3.5	0.19	0.4		0.015			2019		2019
NRE-v/c-5	56≤P<130	5.0	0.19	0.4		0.015			2020		2020
NRE-v/c-4	37≤P<56	5.0			4.7	0.015			2019		2019
NRE-v/c-3	19≤P<37	5.0			4.7	0.015			2019		2019
NRE-v/c-2	8≤P<19	6.6			7.5	0.4			2019		2019
NRE-v/c-1	P<8	8.0			7.5	0.4			2019		2019
Generators	P>560	3.5	0.19	0.67		0.035			2019		2019

A = For selected machinery types, Stage V includes emission limit values for particle number.
B = Article 63 in 2016/1628 revise Article 19 in 167/2013 to include Stage V limits as described in 2016/1628.

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

	Category	Engine size [ccm]	CO [g pr kWh]	HC [g pr kWh]	NO_X [g pr kWh]	$HC+NO_X$ [g pr kWh]	Implement. date
EU Directive 2002/88	Stage I						
Handheld	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 handheld	SN3	100≤S<225	519	-	-	16.1	1/2 2005
	SN4	225≤S	519	-	-	13.4	1/2 2005
	Stage II						
Handheld	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 handheld	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						
Handheld (<19 kW)	NRSh-v-1a	S<50	805	-	-	50	2019
	NRSh-v-1b	50≤S	805	-	-	72	2019
Not handheld (P<19 kW)	NRS-vr/vi-1a	80≤S<225	610	-	-	10	2019
	NRS-vr/vi-1b	S≥225	610	-	-	8	2019
Not handheld (19=<P<30 kW)	NRS-v-2a	S≤1000	610	-	-	8	2019
	NRS-v-2b	S>1000	4.40*	-	-	2.70*	2019
Not handheld (30=<P<56 kW)	NRS-v-3	any	4.40*	-	-	2.70*	2019

* Or any combination of values satisfying the equation $(HC+NO_x) \times CO^{0.784} \leq 8.57$ and the conditions $CO \leq 20.6$ g/kWh and $(HC+NO_x) \leq 2.7$ g/kWh.

For recreational craft, Directive 2003/44 comprises the Stage 1 emission legislation limits for diesel engines, and for 2-stroke and 4-stroke gasoline engines, respectively. The CO and VOC emission limits depend on engine size (kW) and the inserted parameters presented in the calculation formulas in Table 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 inboard engines	P_N ≤ 373	18/1 2017	75	5	-
	373 ≤ P_N ≤ 485	18/1 2017	350	16	-
	P_N > 485	18/1 2017	350	22	-
Outboard engines and PWC engines (**)	P_N ≤ 4.3	18/1 2017	500 – (5.0 x P_N)	15.7 + ($50/PN^{0.9}$)	-
	4.3 ≤ P_N ≤ 40	18/1 2017	500 – (5.0 x P_N)	15.7 + ($50/PN^{0.9}$)	-
	P_N > 40	18/1 2017	300		-

(*) Alternatively, this engine segment shall not exceed a PM limit of 0.2 g/kWh and a combined HC + NO_x limit of 5.8 g/kWh.
(**) Small and medium size manufacturers making outboard engines <= 15 kW have until 18/1 2020 to comply.

Table 5.10 Overview of the EU emission directive 2004/26 for railway locomotives and motor cars[12].

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

Aircraft engine emissions of NO_x, CO, VOC and smoke are regulated by ICAO (International Civil Aviation Organization). The engine emission certification standards are contained in Annex 16 — Environmental Protection, Volume II — Aircraft Engine Emissions to the Convention on International Civil Aviation (ICAO Annex 16, 2008, plus amendments). The emission standards relate to the total emissions (in grams) from the so-called LTO (Landing and Take

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

Off) cycle divided by the rated engine thrust (kN). The ICAO LTO cycle contains the idealised aircraft movements below 3000 ft (915 m) during approach, landing, airport taxiing, take off and climb out.

For smoke all aircraft engines manufactured from 1 January 1983 must 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 5700 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 5700 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 8618 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 5700 kg maximum certificated take-off mass for which the application for certification of the change in type design is submitted on or after 1 January 2023.
- **Derived versions of non-CO_2 certified propeller-driven aeroplanes** of greater than 8618 kg maximum certificated take-off mass for which the application for certification of the change in type design is submitted on or after 1 January 2023.
- **Individual non-CO_2-certified subsonic jet aeroplanes** of greater than 5700 kg maximum certificated take-off mass for which a certificate of airworthiness is first issued on or after 1 January 2028; and
- **Individual non-CO_2-certified propeller-driven aeroplanes** of greater than 8618 kg maximum certificated take-off mass for which a certificate of airworthiness is first issued on or after 1 January 2028.

Marpol 73/78 Annex VI agreed by IMO (International Maritime Organisation) concerns the control of NO_x emissions (Regulation 13 plus amendments) and SO_x and particulate emissions (Regulation 14 plus amendments) from ships (DNV, 2009). The so-called Energy Efficiency Design Index (EEDI) fuel efficiency regulations for new built ships were 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 soon.

5.2.3 Emission factors

The CO_2 emission factors for other fuels than diesel, LNG, LPG and GTL are country-specific and come from Fenhann and Kilde (1994).

For diesel, the CO_2 emission factor is taken from IPCC (2006). For LNG, the CO_2 emission factor is estimated by the Danish gas transmission company, Energinet.dk, based on gas analysis data (Energinet.dk, 2022). For LPG, the emission factor source is EMEP/EEA (2024).

A country-specific emission factor for diesel used in road transportation is not available from Danish refineries, instead, the diesel EF for stationary combustion is used, which is from EU ETS. The average CO_2 EF of diesel burned in stationary sources during 2008-2016 is 74.1 kg/GJ, identical EF to the IPCC default data.

The N_2O emission factors are taken from the EMEP/EEA guidebook; EMEP/EEA (2024) for road transport and non-road mobile machinery, and IPCC (2006) for national sea transport and fisheries as well as aviation.

In the case of military ground equipment, due to lack of fleet/activity and emission data, aggregated CH_4 emission factors for gasoline and diesel are derived from total road traffic emission results. For piston engine aircraft using aviation gasoline, the CH_4 emission factors are derived from VOC factors from EMEP/EEA (2023) and a NMVOC/CH_4 split, based on the NMVOC/CH_4 split for conventional gasoline engines used in Danish road transport.

For railways, VOC emission factors are derived from specific Danish VOC measurements from the Danish State Railways (Mølgård, 2024). For private railway lines, VOC emission factors are estimated for the different train type technologies using diesel or GTL. The CH_4 emission factors for railways are derived from the VOC emission factors using 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, 2009), Notter and Schmied (2015) and Winther (2023). The NMVOC/CH_4 split is taken from IFEU (2009).

For national sea transport and fisheries, the VOC emission factors come from the Danish TEMA2015 emission model (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 used by Mols Linjen is provided by Kristensen (2013) and engine load specific VOC emission data is provided by Nielsen (2022).

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 marine engines using diesel or residual oil, VOC/CH_4 splits are taken from EMEP/EEA (2023).

The source for CH_4 emission factors for aircraft main engines (jet fuel) is the EMEP/EEA guidebook (EMEP/EEA, 2024). For aircraft auxiliary power units (APU), ICAO (2020) is the data source for VOC emission factors and VOC/CH_4 splits for aviation are taken from EMEP/EEA (2024).

5.2.4 Calculation method

Air traffic

For aviation, the emissions are calculated in DEMOS-Aviation 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 Winther (2024).

Non-road working machinery and recreational craft

The fuel consumption and emissions are calculated in DEMOS-NRMM 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, lifetimes 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 Winther (2024).

National sea transport and international sea transport

The fuel consumption and emissions for domestic ferries are bottom up calculated in DEMOS-Navigation 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 residual fuel consumption (the difference between DECO25 fuel consumption for national sea transport and bottom-up fuel consumption for domestic ferries) as explained in Winther (2024). For international sea transport, fuel-based calculations are made in DEMOS-Navigation using fuel-related emission factors and fuel consumption from DECO25 as explained in Winther (2024).

Fisheries

The fuel consumption and emissions for fisheries are bottom up calculated in DEMOS-Navigation for each fishing trip as the product of vessel engine size, load factor, sailing time per fishing trip, and fuel consumption/emission factors.

The calculated fuel consumption and emissions for fishing vessels are adjusted in a fuel balance to account for all fuel projected for fisheries in DECO25.

Railways

In DEMOS-Railways, the fuel consumption and emissions are calculated for Danish State Railways and private railway lines as the product of total train set km split into train litra types, and km-based fuel consumption/emission factors per train litra type.

The calculated fuel consumption and emissions for the train activities are adjusted in a fuel balance to account for all fuel projected for railways in DECO25.

Military

For military, the emissions are calculated as the product of fuel consumption from DECO25 and fuel-related emission factors.

Subsectoral fuel transferals between DECO25 and the emission projections

The DECO25 fuel totals for the CRF sectors 1A2 (manufacturing industries), 1A4a (commercial/institutional), 1A4b (residential) and 1A4c (agriculture/forestry/aquaculture/fisheries) are used in the emission projections as totals for these sectors to obtain a fuel balance. However, based on bottom-up calculations for non-road mobile machinery in DEMOS-NRMM, a different split of non-road mobile and stationary fuel consumption is made, compared to the sub-sectoral fuel splits also provided by DEA in DECO25.

5.3 Fuel consumption and emission results

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

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

		1990	2005	2015	2020	2022	2023	2025	2030	2035	2040	2045	2050
CO_2, kt	Industry - Other (1A2g)	7,3	8,7	8,2	8,3	9,1	8,9	8,9	8,0	6,9	5,6	4,3	3,7
	Civil Aviation nat. (1A3a)	3,0	2,2	1,8	1,1	1,7	1,7	1,6	1,7	1,6	1,6	1,6	1,4
	Road - Cars (1A3bi)	69,0	88,9	91,4	85,7	83,8	86,8	80,4	51,5	27,5	10,5	3,8	1,6
	Road - Light duty trucks (1A3bii)	18,4	27,9	24,1	21,6	23,2	25,2	25,0	21,7	14,4	6,8	2,5	0,7
	Road - Heavy duty vehicles (1A3biii)	39,0	49,0	48,9	51,7	49,6	25,0	17,6	11,7	6,1	3,8	2,6	2,3
	Road - Motorcycles and mopeds (1A3biv)	0,6	1,0	1,0	1,0	0,9	0,8	0,8	0,8	0,7	0,7	0,7	0,6
	Railways (1A3c)	4,0	3,1	3,4	2,7	2,4	2,4	2,3	1,0	0,2	0,0	0,0	0,0
	Navigation (1A3d)	9,4	9,3	5,8	6,4	6,2	6,2	6,1	4,8	4,7	4,6	4,3	4,2
	Comm./Inst. (1A4a)	2,1	2,8	2,9	2,5	2,4	0,8	0,7	0,2	0,2	0,2	0,3	0,3
	Residential (1A4b)	0,4	0,5	0,5	0,4	0,4	0,5	0,5	0,5	0,5	0,5	0,5	0,5
	Agriculture/forestry/fisheries (1A4c)	16,7	16,8	14,6	13,7	14,2	13,7	13,5	12,4	10,6	10,1	9,9	9,8
	Other (1A5b, military mobile)	1,6	3,7	1,3	2,0	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4
	Other (1A5b, recreational craft)	0,7	1,4	1,3	1,3	1,3	1,3	1,3	1,2	1,2	1,3	1,3	1,3
	Navigation int. (1A3d)	39,1	30,7	30,3	21,5	21,1	21,2	20,9	20,2	18,9	16,3	11,3	8,5
	Civil Aviation int. (1A3a)	24,5	35,5	36,4	13,6	34,5	37,7	37,3	37,9	37,0	36,2	35,5	32,7

		1990	2005	2015	2020	2023	2024	2025	2030	2035	2040	2045	2050
CH_4, t	Industry - Other (1A2g)	532	637	605	609	673	655	649	565	482	396	294	248
	Civil Aviation nat. (1A3a)	215	156	131	76	122	121	112	51	94	76	65	30
	Road - Cars (1A3bi)	5043	6505	6415	5904	5792	6071	5485	3483	1863	714	262	108
	Road - Light duty trucks (1A3bii)	1357	2061	1680	1501	1631	1814	1711	1447	964	473	175	52
	Road - Heavy duty vehicles (1A3biii)	2891	3632	3405	3586	3477	1794	1192	766	396	258	176	157
	Road - Motorcycles and mopeds (1A3biv)	46	70	70	67	65	53	53	54	51	48	44	40
	Railways (1A3c)	297	232	249	196	175	171	156	67	15	0	0	0
	Navigation (1A3d)	715	699	431	479	463	467	450	353	330	287	205	158
	Comm./Inst. (1A4a)	152	205	213	176	170	62	49	18	16	16	20	21
	Residential (1A4b)	26	34	32	28	25	32	32	32	32	32	32	32
	Agriculture/forestry/fisheries (1A4c)	1235	1246	1084	1017	1050	1018	992	896	769	752	733	724
	Other (1A5b, military mobile)	119	271	98	146	170	170	170	170	170	170	170	170
	Other (1A5b, recreational craft)	48	103	92	92	93	95	91	89	89	92	92	92
	Navigation int. (1A3d)	3006	2352	2293	1620	1598	1606	1582	1534	1431	1233	859	642
	Civil Aviation int. (1A3a)	1764	2553	2622	979	2487	2714	2633	2562	2132	1719	1481	707

		1990	2005	2015	2020	2023	2024	2025	2030	2035	2040	2045	2050
N_2O, t	Industry - Other (1A2g)	48	35	25	21	20	7	7	6	5	4	3	3
	Civil Aviation nat. (1A3a)	4	4	1	1	1	1	1	1	1	1	1	1
	Road - Cars (1A3bi)	2571	909	279	185	174	164	149	95	56	23	8	3
	Road - Light duty trucks (1A3bii)	200	102	16	6	5	5	4	3	2	1	0	0
	Road - Heavy duty vehicles (1A3biii)	294	332	65	40	41	27	21	13	8	5	4	4
	Road - Motorcycles and mopeds (1A3biv)	89	115	83	71	63	51	50	47	42	38	34	30
	Railways (1A3c)	12	9	5	3	2	2	2	1	0	0	0	0
	Navigation (1A3d)	10	11	26	28	13	13	13	11	11	10	10	10
	Comm./Inst. (1A4a)	33	73	36	30	28	1	0	0	0	0	0	0
	Residential (1A4b)	47	60	24	21	18	23	22	20	20	20	20	20
	Agriculture/forestry/fisheries (1A4c)	214	86	62	49	47	20	20	17	15	14	13	13
	Other (1A5b, military mobile)	5	12	2	4	6	6	6	6	6	6	6	6
	Other (1A5b, recreational craft)	77	62	7	6	6	5	5	5	5	5	5	5
	Navigation int. (1A3d)	44	38	39	28	28	29	28	28	26	23	16	12
	Civil Aviation int. (1A3a)	10	10	9	3	7	8	8	8	8	8	8	7

		1990	2005	2015	2020	2023	2024	2025	2030	2035	2040	2045	2050
CO_2-eq., kt	Industry - Other (1A2g)	20	26	27	28	31	31	32	28	25	20	15	13
	Civil Aviation nat. (1A3a)	10	8	7	4	6	6	6	6	6	5	5	5
	Road - Cars (1A3bi)	181	228	173	136	124	133	115	61	28	9	3	1
	Road - Light duty trucks (1A3bii)	10	61	54	44	45	49	48	42	29	14	5	2
	Road - Heavy duty vehicles (1A3biii)	104	46	194	239	241	118	81	57	23	13	8	8
	Road - Motorcycles and mopeds (1A3biv)	1	1	1	1	1	1	1	1	1	1	1	1
	Railways (1A3c)	9	7	8	6	5	5	5	2	0	0	0	0
	Navigation (1A3d)	18	18	11	12	12	12	11	9	9	9	8	8
	Comm./Inst. (1A4a)	6	7	8	7	7	3	2	1	1	1	1	1
	Residential (1A4b)	0	1	1	0	0	1	1	1	1	1	1	1
	Agriculture/forestry/fisheries (1A4c)	38	43	42	41	42	41	41	39	33	32	31	31
	Other (1A5b, military mobile)	4	7	4	5	6	6	6	6	6	6	6	6
	Other (1A5b, recreational craft)	1	3	4	4	4	3	3	3	3	3	3	3
	Navigation int. (1A3d)	76	59	58	41	40	40	40	39	36	31	22	16
	Civil Aviation int. (1A3a)	59	87	89	33	84	92	91	92	90	88	86	80

5.3.1 Road transport

The total CO_2 emissions decrease is expected to be 99 % from 2023-2050. 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.

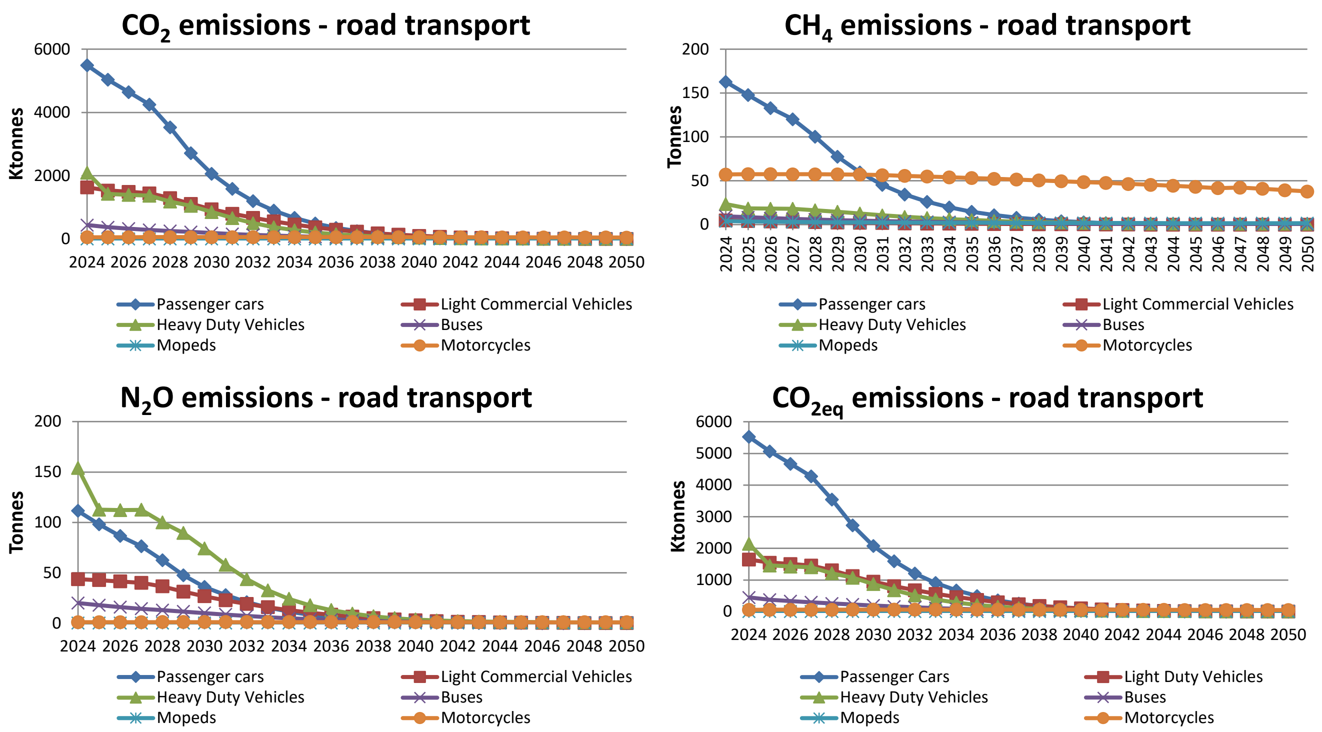

Figure 5.3 CO_2, CH_4, N_2O and CO_{2e} emissions from 2024-2050 for road traffic.

The majority of the CH_4 emissions from road transport come from gasoline passenger cars, and for N_2O heavy duty vehicles are the largest emission source (Figure 5.3). The CH_4 and N_2O emissions decrease by 86 % and 99 %, respectively, from 2023 to 2050.

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 Industry (1A2g) and Navigation (1A3d). 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 Residential (1A4b) and Agriculture/forestry/fisheries (1A4c). Navigation (1A3d) and Other (1A5) also have notable CH_4 emission contributions. Only small emission contributions are noted for the remaining other mobile sectors.

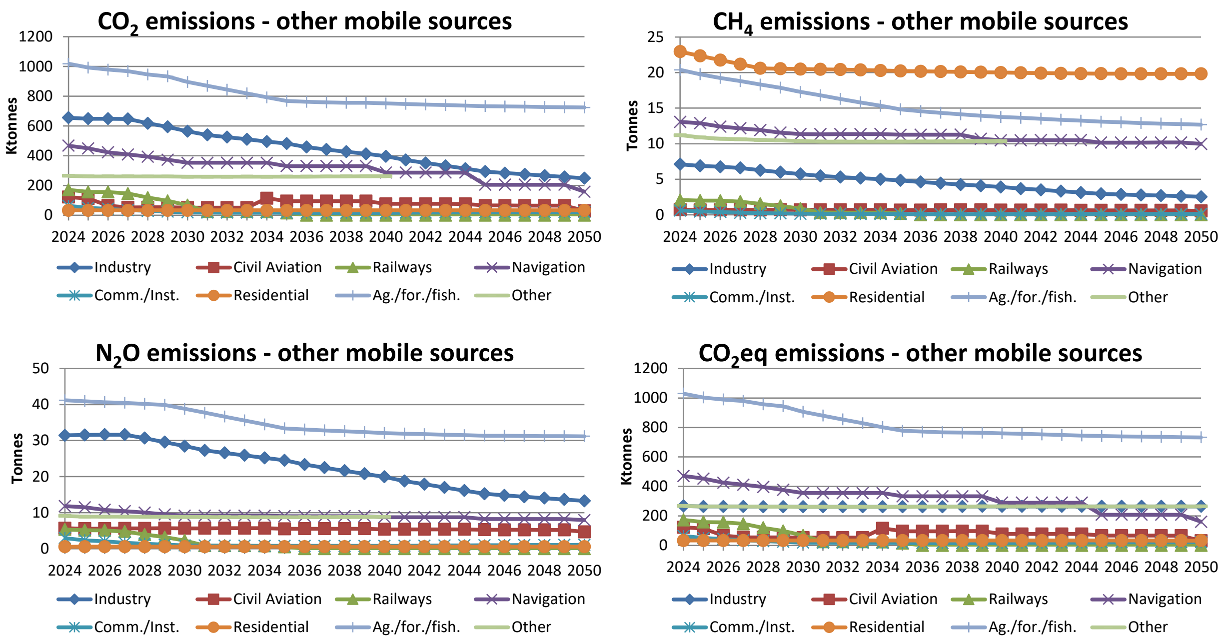

Figure 5.4 CO_2, CH_4, N_2O and CO_{2e} emissions from 2024-2050 for other mobile sources.

5.4 Model structure for the DEMOS mobile emission models

The DEMOS (Danish Emission model system for Mobile Sources) model developed at DCE, Aarhus University, is used to calculate the historical emission inventories and projections for mobile sources. The DEMOS model system comprises database models for road transport (DEMOS-Road), aviation (DEMOS-Aviation), navigation (DEMOS-Navigation), railways (DEMOS-Rail) and non-road mobile machinery (DEMOS-NRMM). The input data are organised in tables for fleet/stock and operational data as well as fuel sale figures. Output fuel consumption and emission results are obtained through linked database queries.

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6 Agriculture

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

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

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

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

The current projection considers the elements included in the Political agreements and regulation initiated or decided until 1 January 2025 (so called "frozen policy" or projection "with existing instruments"). For this projection, measures in relation to Agreement on a Green Denmark (AGD, 2024) is considered as frozen policy. This means that following measures are considered; tax on CO_2 (equivalents) from animal production, subsidy for use of CH_4 reducing feeding of dairy cattle, lower agricultural soils due to expansion of forest area, wetlands and area for infrastructure (rails and cities). Furthermore, subsidy for decreased use of fertiliser, increased area with cover crops and organic cultivated area and inclusion of schemes that results in change from intensive to more extensive farming (more grass and crop-free edges). The initiatives mentioned have an impact, which lead to lowering the total nitrogen supply of the agricultural land and furthermore to a decrease in the nitrogen leaching.

Another agreement "Agreement on the Green Transition for Danish Agriculture" (AGTDA, 2021) has influence for the livestock production, which also is considered in the projection. This agreement requires more frequently removal of slurry from swine barns and increased content of fatty acids in fodder for dairy cattle. Fatty acids can be replaced by use of Bovaer.

The future biogas production is based on a projection provided by the Danish Energy Agency (DEA, 2025).

6.1 Projected agricultural emission 2024 - 2050

The latest official reporting of emissions includes time series until 2023 for all emission sources. The development of agricultural greenhouse gases from 1990 to 2023 (Table 6.1) shows a decrease from 14.6 million tonnes CO_2 equivalents to 11.2 million tonnes CO_2 equivalents, which correspond to a 23 % reduction. In the current projection, based on the assumptions provided, the emission decreases by 35 % from 2023 to 2050, and thus the total emission is estimated to 7.2 million tonnes CO_2 equivalents by 2050. The development towards lower total greenhouse gas emissions is particularly driven by an expected decrease of CH_4 and N_2O emission from manure management due to expansion of the biogas production and frequent removal of slurry from swine barns. Furthermore, the decrease is also affected by lower emission from enteric fermentation due to changes in feeding strategy for cattle and decrease in number of animals. The decrease of N_2O from cultivation of agricultural soils is due to a lower nitrogen supply, caused by fall in the agricultural land, subsidy for decreased use of fertiliser and schemes which promote more extensive cultivation where fertilizer is not allowed and thus result in lower emission from N-leaching.

Table 6.1 Historic and projected emission from the agricultural sector, kt CO_2 equivalents.

	1990	2000	2005	2010	2015	2020	2023	2025	2030	2035	2040	2045	2050
Enteric fermentation	4 455	4 034	3 873	4 048	4 106	4 137	3 974	3 804	3 221	3 010	2 852	2 789	2 779
Manure management	3 944	4 866	5 224	4 844	4 683	4 554	3 670	3 478	2 653	2 212	1 974	1 764	1 633
Agricultural soils	5 580	4 307	3 954	3 907	3 934	4 016	3 375	3 533	3 097	2 860	2 762	2 656	2 634
Field burning of agricultural residue	2	3	3	2	2	3	3	3	3	3	3	3	3
Liming	565	261	220	153	166	250	183	223	211	201	195	189	189
Urea application (CO_2 emission)	15	2	0	1	1	1	13	6	6	6	6	5	5
Other carbon-containing fertilisers	33	5	1	2	9	4	5	4	4	4	4	4	3
Total	14 594	13 477	13 276	12 957	12 901	12 964	11 223	11 051	9 195	8 296	7 795	7 409	7 246

6.2 Comparison with previous projection

By comparing the current projection with the latest provided greenhouse gas projection (Nielsen et al., 2024a), the emission given in CO_2 equivalents has decreased up to 18 % in the years 2024-2040. Figure 6.1 shows the emission trend for CH_4 and N_2O for the current projection compared with last year's projection. For CH_4, an update of the calculation for CH_4 from manure management have been made, which increases the emission in the historic years (1990-2023). For the projected years the emission of CH_4 is increased for the years 2024-2027 with up to 6 % compared to the latest projection, but for the years 2028- 2040 the emission is decreased with up to 19 % compared to the latest projection. The changes are due to a combination of change in the model for CH_4 from manure management and change in number of animals which affect both emission from enteric fermentation and manure management.

The N_2O emission is almost unchanged in 2024 but decreased for all years 2025-2040 in the current projection compared to the latest projection and this is due to decrease in emission from manure management, inorganic N fertiliser, animal manure applied to soil, organic soils and crop residue. Decrease in emission from manure management and manure applied to soils are mainly due to decrease in the number of animals. Changes in emission from inorganic N fertiliser, organic soils and crop residue is due to changes in the agricultural area and amount of fertiliser applied.

Figure 6.1 shows changes for CH_4 emission in the historical years 1990-2023 of up to 11 % increase, which is mainly due to change in the calculation of CH_4 from manure management. For the emission of N_2O the emission from 1990 to 2022 increase with up to 3 %, while a decrease of 5 % is seen in 2023. The increase in 1990-2022 is mainly due to increase in the emission from atmospheric deposition due to update of the emission factor, which were updated to EF given in IPCC 2019 for wet climate. The decrease in 2023 is mainly due decrease in emission from inorganic N fertiliser and crop residue.

Some of the changes of the emission trend for the current projection are related to update of the latest historical year, from 2022 to 2023. The yearly update can for some emission sources have a particular impact for the projected emission trend because the assumption is based on an interpolation between 2050 and the latest historical year.

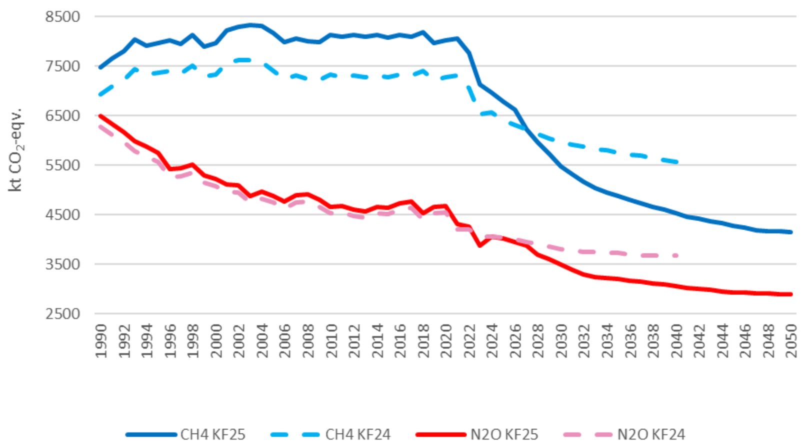

Figure 6.1 Projection 2025 (KF25) compared with projection 2024 (KF24).

As mentioned above the total CH_4 emission is up to 19 % lower in 2023-2040 compared to the previous projection. Emission of CH_4 from enteric fermentation are 1-22 % lower in the years 2023-2040 in the current projection mainly due to changes in number of animals due to updated projection from IFRO (Jensen, J.D., 2025) and inclusion of the effect of the feeding subsidy Bovaer fed to dairy cattle. The emission of CH_4 from manure management are 2-26 % higher in the years 2023-2031 and 1-12 % lower in the years 2032-2040 compared to the previous projection. Update of the calculation method increase the emission, while the decrease in number of animals decrease the emission. As the decrease in number of animals are higher in the later years the overall effect is a decrease in emissions.

Compared to previous projection (KF24), the current projected N_2O emission is up to 11 % lower for all years 2023-2040.

The change in emission of N_2O between current projection and the latest projection is due to a range of changes, some mentioned above. Projection of area with organic soils are lower compared to the previous projection due to the political agreement about extraction of organic soils from the agricultural production. Further will the political agreement also lead to a decrease in agricultural area and a lower supply of fertiliser which affect the emission from inorganic N fertiliser, other organic fertiliser, crop residue and nitrogen leaching. As for the historic years the emission from atmospheric deposition is higher in the current projection due to update of the emission factor, which were updated to EF given in IPCC 2019 for wet climate.

6.3 Methodology

The methodology used to estimate the projected emission is based on the same methodology as used in the annual emission inventories, which is described in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006, IPCC, 2019). Thus, the same database setup is used, as well as the same estimation approach and the same emission factors.

The main part of the emissions is related to the livestock production, and thus the expectations to the development in the number of livestock are a key element and have a substantial impact on the emission. The assumptions related to the expected development on the livestock production and the agricultural area are based on estimates provided by IFRO by using 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 to consider the influence of other member states on a given country market. For more information on description of the AGMEMOD model, please refer to Jensen (2017).

Increasing demands to reduce unwanted environmental effects of the livestock production has led to additional legislation regarding approvals and establishment of new animal barns 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 (barn, storage, and application), cooling of manure in barns, heat exchanger for poultry barns, manure removal in mink barns 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 estimations made by SEGES (2025). The expectations to expansion of the biogas production are based on assumptions provided by the DEA (DEA, 2025).

Measurements to reduce CH_4 emissions has also been taken into account; frequent removal of slurry from swine barns, higher ratio of fatty acids in fodder or use of the feeding subsidy Bovaer for dairy cattle. Frequent removal of slurry from barns influences the estimation of CH_4 from manure management, while higher ratio of fatty acids or use of Bovaer in the fodder influences the estimation of the methane conversion rate (Ym).

6.4 Livestock production

For cattle, swine, hens and broilers, the number of animals is based on the model AGMEMOD (Jensen, J.D., 2025). For non-dairy cattle, the number of bulls and heifers are projected based on AGMEMOD combined with estimates from DCA (Kristensen and Lund, 2016), to make it convertible with the cattle categories used in the national inventory setup.

The production of horses, sheep, goats, turkeys, ducks, and geese is less important, because the contribution for these categories is relatively small compared to production of cattle, swine, and fur animals. Therefore, the number of animals is kept at the same level as in 2023. When it comes to fur bearing animals (mink) the situation changes dramatically in 2020. Because of the risk for developing a COVID-19 variant, the government required to destroy all fur animals, which was done by the end of 2020. Therefore, no production of mink in 2021-2022. The mink production has started up again in 2023 in small scale and because it is difficult to estimate how it will develop the number of animals is kept at the same level as in 2023.

6.4.1 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, J.D., 2025).

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 (Lund, 2023; Lund et al., 2023). The average milk yield for large breed is expected to increase from 11 200 l/cow/year in 2023 to 13 800 l/cow/year in 2040, which correspond to a rise of 23 %. This development corresponds to an N-excretion in 2023 for large breed cattle at 160 kg N, increasing to 183 kg N in 2040. To extend the projection to 2050 N-excretion for cattle are projected by linear projection (KEFM, 2024a).

For the estimation of Ym, is considered higher ratio of fatty acids in fodder and use of the feeding supply Bovaer for dairy cattle from the year 2025 and forward. Given in Agreement on the Green Transition for Danish Agriculture (AGTDA, 2021) it is expected that the farmers will reduce the emissions of GHG by use of higher ratio of fatty acids. In 2024 the requirement for use of fatty acids was adjusted so reduction of GHG also could be achieved by use of Bovaer in 80 days per year. Due to subsidy for use of Bovaer all year, it is in the estimation of Ym incorporated that a share of the dairy cattle will be given Bovaer all year. This is not considered doable for organic farmers with the current availability of feedstuffs and Ym estimated including Bovaer or higher ratio of fatty acids is in the projection calculations therefore only used for conventional farmed dairy cattle.

Dairy cattle are in the projected calculations divided in conventional and organic farmed dairy cattle. In Lund (2023) and Lund et al. (2023) are given N-excretion and Ym divided for conventional and organic farmed dairy cattle. In SEGES (2025) are days on grass divided in conventional and organic farmed cattle so conventional farmed dairy cattle are on grass 11 days per year in average and organic farmed dairy cattle are on grass in 78 days per year in average.

For distribution of dairy cattle on barn types, are used the same distribution for organic farmed dairy cattle as used for conventional farmed because no divided projection of this is available. Higher ratio of fatty acids in fodder or use of Bovaer are not included for organic farmed dairy cattle.

Table 6.2 Number of dairy cattle and milk yield - figures used in the projection to 2050.

Dairy cattle	2023*	2025	2030	2035	2040	2045	2050
No. of dairy cattle, 1000 unit	547	544	488	455	430	414	407
Milk yield, kg milk per cow per year							
Large breed	11 171	11 651	12 355	13 063	13 775	14 482	15 189
Jersey	7 699	7 965	8 446	8 931	9 417	9 901	10 384
Large breed, organic	-	10 824	11 277	11 730	12 183	12 636	13 089
Jersey, organic	-	7 459	7 771	8 083	8 396	8 708	9 020
N-excretion, kg per year							
Large breed	160	165	171	177	183	189	195
Jersey	130	137	142	147	153	158	163
Large breed, organic	-	159	163	167	170	174	178
Jersey, organic	-	129	133	136	139	143	146
Feed intake, kg dm per year							
Large breed	8 488	8 720	9 092	9 466	9 842	10 215	10 588
Jersey	6 836	7 041	7 353	7 668	7 984	8 297	8 611
Large breed, organic	-	8 265	8 503	8 742	8 981	9 249	9 516
Jersey, organic	-	6 606	6 804	7 003	7 201	7 424	7 646
Ym, %							
Large breed	5.77	5.37	4.46	4.43	4.40	4.37	4.34
Jersey	5.81	5.41	4.50	4.47	4.45	4.43	4.40
Large breed, organic	-	5.90	5.88	5.85	5.83	5.80	5.78
Jersey, organic	-	5.93	5.91	5.89	5.87	5.85	5.83

* Weighted average for conventional and organic farmed dairy cattle.

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 are expected and therefore kept at the same level as in 2023. Non-dairy cattle are not divided in conventional and organic farmed animals, because no divided projected information for N-excretion, feed intake and other production information are available.

6.4.2 Swine

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

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

Swine	2023	2025	2030	2035	2040	2045	2050
Trend*							
Sows	100	98	88	83	78	72	70
Weaners	100	99	92	89	87	83	81
Fattening pigs	100	84	77	70	68	65	65
Numbers, millions produced							
Sows	0.91	0.89	0.80	0.76	0.71	0.66	0.64
Weaners	29.90	29.49	27.61	26.72	25.97	24.80	24.35
Fattening pigs	15.33	12.88	11.84	10.75	10.37	10.02	9.90

* Based on AGMEMOD (Jensen, J.D., 2025).

The projection of N-excretion for sows, weaners and fattening pigs is based on projection made by DCA (Nørgaard & Hellwing, 2023). To extend the projection to 2050 N-excretion for swine are projected by linear projection (KEFM, 2024a).

Table 6.4 N-excretion, kg N-excretion.

Swine	2023	2025	2030	2035	2040	2045	2050
Sows	22.96	23.57	23.26	22.97	22.63	22.33	22.02
Weaners	0.37	0.41	0.39	0.34	0.32	0.29	0.25
Fattening pigs	2.56	2.87	2.73	2.56	2.40	2.25	2.09

6.4.3 Barn systems

Projection of distribution for cattle in different types of barn systems is provided by SEGES (2025). The estimates are for 2030, 2040 and 2050 for dairy cattle and heifers. Distribution for the years 2024-2029, 2031-2039 and 2041-2049 are interpolated. The projection considers legislation about animal welfare (space requirement, straw etc.) and environment requirement. In 2023, 88 % of the dairy cattle were housed in systems with cubicles. It is assumed that 91 % of dairy cattle will be housed in systems with cubicles in 2050, and tethering are phased out before 2030. For heifers, the tethering barns is also assumed to be phased out before 2030. Around 21 % expects to be housed in deep litter systems in 2050 and the remaining part is assumed to be placed in barn systems with cubicles.

For bulls and suckling cattle, the distribution on different barn systems for 2024-2050 is set at the same level as 2023, except for the barn type slatted floor-boxes, which is phased out in 2024 due to a ban of this barn type.

For swine, SEGES (2025) estimates the distribution of animals on different barn systems. The estimates are made for 2030, 2040 and 2050 and for the years 2024-2029, 2031-2039 and 2041-2049 the distribution is interpolated. Approximately 99 % of the fattening pigs and weaners are housed in systems with drained or partly slatted floor in 2023 and this is assumed to be the same in 2050. For sows, a decrease in systems where the sow is housed individually is assumed.

Jensen, H.B. (2025) projects distribution of hens and broilers on different barn systems. The estimates are made for 2030 and 2035 for the years 2023-2029 and 2031-2034, the distribution is interpolated and 2036-2050 is set at the same level as 2035. For broilers, it is assumed that the share of slowly growing and organic broilers increases, while the share of 32 and 35 days broilers decrease in the years up to 2035.

For mink, there are two types of barn systems in the projection; barns where the manure is removed once a week and barns where manure is removed two times a week. In 2020, 11 % of mink was in systems where manure is removed two times a week. No production of mink is expected for 2021-2022 due to legislation brought on by COVID-19. For the years 2023-2050, the same distribution of barn systems as for 2020 are used.

6.5 Emission reducing measures

In the historic emission inventory is included reduction of NH_3 from the emission reducing technologies, acidification of slurry, cooling of manure, frequent removal of slurry in barns with fattening pigs, heat exchanger in broiler barns and frequent removal of manure in mink barns. The inventory also considers the reduced emission of CH_4 and N_2O because 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 (LOV nr. 1057 af 30/06/2020), and therefore also reductions from other emission reducing technologies are included in the projection.

The following technologies are included in the projection; reduction of CH_4 due to cooling of manure in pig barns, acidification of cattle- and swine manure (barn) and frequent removal of slurry from swine barns. Reduction of NH_3 due to heat exchanger in broiler barns, frequent removal of mink manure from barns (2 x weekly) and slurry acidification in tank/during application of manure. Furthermore, reduction of emission due to slurry delivered to biogas production is considered. For reduction of CH_4 from enteric fermentation from dairy cattle higher ratio of fatty acids in fodder or use of Bovaer are included.

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 and acidification systems sold (Nielsen et al., 2024b, Annex 3D Chapter 3D-1).

For cattle the only available technology in barns is, for now, acidification and projection of this is made by SEGES (2025). The projection is used for dairy cattle and heifers.

Projection of distribution of barns with acidification and cooling of manure for swine are based on information from SEGES (2025).

Distribution of barns with frequent removal of slurry from the barn for swine is based on estimation made by Danish Ministry of Environment (MIM, 2024). In Agreement on the Green Transition for Danish Agriculture (AGTDA, 2021) it is given that slurry from all barns with fattening pigs and all new buildings for sows and weaners from 2023 must sluice out the slurry when the height of the slurry reach 10 cm or at the most every seventh day. Some farmers can get a dispensation from this, so it is assumed that 1 % of existing barns and new build barns get a dispensation. Frequent removal of the slurry is not required if the slurry is acidified. Frequent removal of slurry from swine barns only reduce emission of CH_4.

Manure cooling is the most frequently used technology for overall swine production, particularly in barns for sows and weaners and this trend is expected to continue. For new build barns, cooling of manure is expected to be installed extensively. Acidification of manure in barns for swine is expected to slightly increase in the future.

Frequent removal of slurry is by legislation made mandatory from 2023 for barns with fattening pigs and it is expected to be done in 99 % of the barns in the period 2024-2050. For sows and weaners, the frequent removal is made mandatory in new build barns, and the distribution is expected to increase to around 89 % in 2050.

Acidification in barns for cattle is expected to stay at the same level in the future.

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

Cooling of manure	2023	2025	2030	2035	2040	2045	2050
Sows	10	17	35	48	60*	61	61*
Weaners	5	12	30	35	40*	41	42*
Fattening pigs	4	9	20	21	21*	21	21*
Acidification in barn							
Dairy cattle, large breed	2	2	2	2	2	2	2
Dairy cattle, jersey	3	3	2	2	2	2	2
Heifer, large breed	0	1	1	1	2	2	2
Heifer, jersey	0	0	1	1	2	2	2
Sows	2	3	3	4	4	4	5
Weaners	1	2	2	2	3	3	3
Fattening pigs	3	3	5	5	6	7	7
Frequent removal of slurry							
Sows	0	8	28	45	60	74	89
Weaners	0	8	28	45	60	74	89
Fattening pigs	99	99	99	99	99	99	99

* In SEGES (2025) share of cooling is estimated to 60 % in 2040 and 80 % in 2050 for sows, 50 % in 2040 and 70 % in 2050 for weaners and to 30 % in 2040 and 40 % in 2050 for fattening pigs, but these shares are reduced in the emission calculations, because combinations of emission reducing technics are difficult to handle in the calculation model, and thus avoid more than 100 % technics.

In 2023, almost 90 % of broiler barns have heat exchangers installed, and it is expected that the share increases to 100 % by 2030 (Jensen, 2021, Pers. Comm.). As mentioned, the mink production is not existing in 2021-2022, but a small production is started from 2023, and it is expected that 90 % of the production will remove the manure two times a week.

Use of high ratio of fatty acid in fodder or use of Bovaer are only included for conventional dairy cattle and are included in the estimation of Ym, see Table 6.2. Projection of the distribution of use of high ratio of fatty acid and Bovaer are based on projection estimations made by Danish Ministry of Climate, Energy and Utilities (KEFM, 2024b).

Projection of acidification during application of manure is based on SEGES (2025). The acidification during application is estimated to increase due to increasing demands for utilisation of N in manure and reduction of emission, which will increase the need for acidification (SEGES, 2025).

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

Heat exchanger	2023	2025	2030	2035	2040	2045	2050
Broilers	90	93	100	100	100	100	100

Removal of manure - 2 times weekly							
Mink	11	34	90	90	90	90	90
Acidification during application							
Cattle manure	8	9	12	14	16	16	16
Swine manure	1	1	2	3	4	4	4

6.5.1 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 barn and acidification of manure is based on Andersen et al. (2024). A national model has been developed to estimate methane from untreated and biogas treated slurry (Nielsen et al., 2025). Frequent removal of slurry in swine barns is incorporated in the model for estimation of CH_4 emission.

Reduction of CH_4 from enteric fermentation by use of Bovaer are based on Lund et al. (2024).

NH_3 reduction due to the use of acidification, heat exchangers used in broiler barns and frequent removal of mink manure, is based on the List of Environmental Technologies (SGAV, 2025), which contains technologies that through tests have been documented to be environmentally efficient and operationally in practice.

Table 6.7 Reducing factor of NH_3 and CH_4.

Technology	Location	Category	Compound	Reduction, %	Reference
Cooling of manure	Barn	Swine	NH_3	20	ConTerra (2022)
	Barn/storage	Swine	CH_4	2	Andersen et al. (2024)
Acidification	Barn	Cattle	NH_3	33	SGAV (2024)
	Barn	Swine	NH_3	64	SGAV (2024)
	Storage	Cattle	NH_3	18-36	Hafner et al. (2021)
	Storage	Swine	NH_3	20-43	Hafner et al. (2021)
	Barn/storage	Cattle/swine	CH_4	70	Andersen et al. (2024)
	Application	Cattle	NH_3	18-36	Hafner et al. (2021)
	Application	Swine	NH_3	20-43	Hafner et al. (2021)
Biogas treatment	Storage	Cattle	CH_4	96	Nielsen et al. (2025)
		Swine	CH_4	97	Nielsen et al. (2025)
		Cattle	N_2O	88	IPCC (2019)
		Swine	N_2O	87	IPCC (2019)
Heat exchanger	Barn	Broilers	NH_3	30	SGAV (2024)
Removal of slurry – 2 x weekly	Barn	Mink	NH_3	27	SGAV (2024)
Bovaer		Dairy cattle	CH_4	27%	Lund et al. (2024)

6.5.2 Biogas treatment of animal manure

Biogas treatment leads to a lower CH_4 and N_2O emission from animal manure. In 2023, approximately 12.3 million tonnes slurry were treated in biogas plants, which are equivalent to approximately 36 % of all slurry. Prognoses provided by DEA assume an increase of biogas production on manure-based biogas plants from 30.3 PJ in 2023 to 46.0 PJ in 2035. The prognoses show a decrease in the biogas production from 2035 to 2050 to 44.8 PJ due to uncertainties regarding the subsidy agreement in future.

Data reported from the biogas plants give an overview of the actual amount and different types of biomasses used in biogas production in crop season 2015/2016 to 2022/2023 (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 2021-2023 between biogas production and slurry input the amount of slurry input for the years 2024-2050 is estimated.

It is assumed that cattle slurry accounts for 63 % and swine slurry for 37 %, based on data from the BIB register for 2023.

Table 6.8 Biogas production on manure-based biogas plants.

Year	Total biogas production, PJ	Biogas production on manure-based biogas plants, PJ	Slurry delivered to biogas plants, M tonnes
2023	31.7	30.3	12.3
2025	34.8	32.4	12.5
2030	44.2	41.7	16.1
2035	48.6	46.0	17.7
2040	47.4	44.8	17.3
2045	47.4	44.8	17.2
2050	47.4	44.8	17.2

A Biogas Task Force set up by the DEA initiated several projects to improve the Danish emission inventory documenting the reduction in GHG emissions resulting from biogas treatment of 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 barn types (Mikkelsen et al., 2016). The model has been updated in 2024 (Nielsen et al., 2025). The emission depends on excretion of volatile solids, changes in barn type and change in time the slurry is in the barns. In the projection, it is assumed that cattle slurry delivered to biogas production reduces the CH_4 emission from storage by approximately 96 %. It is assumed that swine slurry delivered to biogas production reduces the CH_4 emission from storage by approximately 97 %.

6.6 Other agricultural emission sources

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

6.6.1 Agricultural area

The projection of the agricultural area is based on the area estimated by AGMEMOD (Jensen, 2025). In 2023, the agricultural land is estimated to 2621 thousand hectares, which is expected to decrease to 2214 thousand hectares in 2040 and furthermore to 2205 thousand hectares in 2050. This corresponds to a 16 % reduction in the agricultural land for 2023 to 2050 due to extraction of organic soils, wetlands, forest or areas for infrastructure (cities and roads).

Regarding emission calculation due to the agricultural are, measures in relation to Agreement on a Green Denmark is considered (AGD, 2024). Based on information from Agency for Green Transition and Aquatic Environment (KEFM, 2024c and KEFM, 2024d), the following schemes affect changes towards more extensive cultivation of the fields, with increased areas of grass and cultivation-free edges where fertilization is not permitted. Three schemes are included: Eco-scheme for biodiversity and sustainability, Eco-scheme extensification with cut and Permanent extensification, which all accounts for 47 892 ha in 2050.

Table 6.9 Based on Agreement on a Green Denmark expects an increase of area with perennial grass by, 1 000 ha.

	2024	2025	2030	2035	2040	2045	2050
Eco-scheme for biodiversity and sustainability	31582	31695	30778	30778	30778	30778	30778
Eco-scheme extensification	3597	-6291	-6291	-6291	-6291	-6291	-6291
Permanent extensification		6667	23405	23405	23405	23405	23405
Total area expected to be converted to perennial grass	35179	32071	47892	47892	47892	47892	47892

The production of different crops dependents on the development in prices and yields and are estimated by AGMEMOD (Jensen, 2024). The crop types included in AGMEMOD are used in the projection. Only production crops are included in AGMEMOD. For other agricultural crops for example feed beets and seeds for sowing, the areas are kept at the same level as the latest historical year.

6.6.2 Use of inorganic nitrogen fertilisers

Use of inorganic fertiliser depends on the agricultural area and the amount of available nitrogen in animal manure and sewage sludge (amount of N in the farmers nitrogen fertiliser account). The use of inorganic fertiliser is also affected by the policy decision regarding Agreement on a Green Denmark is considered (AGD, 2024) (Table 6.9).

The Eco-scheme for biodiversity and sustainability, Eco-scheme extensification with cut and Permanent extensification lower the N-supply. The 35 179 ha more extensive cultivated area in 2024 (Table 6.9) expected to lower the N-supply with 139 kg N/ha (average N-supply 2021-2023), which means that the total N-supply decreases by 4.9 kt. Other measures also affect the calculation of the total N requirement and thus the need for the use of inorganic fertilisers.

An increased area with catch crops contributes to a retention of N in the soil, which means that the N need is lower in the following growing season. This effect is included in the calculation of the commercial fertilizer reserve, where it is assumed, based on data from DAA, that the effect is 21.7 kg N/ha (KEFM, 2024c).

Due to developments given in AGMEMOD, organic farmed area will increase by 22 400 hectares from 2023 to 2050. An increase is expected until 2030 and hereafter a drop until 2040, while 2040-2050 is nearly no change. It is assumed that organic farmed land will reduce the N need by 71 kg N per hectare compared with conventional production, which is based on estimate received by Danish Ministry of Climate, Energy and Utilities (KEFM, 2024c).

In relation to the agreement on a green Denmark, a scheme is being established where it is possible for the farmers to receive subsidies for reduced use of nitrogen applied to the soil. Based on estimates from Ministry of the Implementation of the Green Three-Partite Agreement (MGTP, 2025) it is assumed that this scheme will reduce the total N-supply between 4.4%-5.6% for years 2028-2050.

In Table 6.10 is shown the calculation of the N used for inorganic fertiliser 2024-2050. The total N quota is estimated as an average for the years 2021-2023, which is calculated to 139 kg N/ha. Based on the average N-fertilisation, the total N need in 2024 is estimated to be 363.5 kt N. The subtraction due to the policy decisions and the assumptions for these mentioned above, the adjusted N quota is estimated to be 357.6 kt N for 2024. A part of the N need is achieved by applying livestock manure and sewage sludge to the soil and the reaming N need is assumed to be achieved by use of inorganic fertiliser, which for 2024 is calculated to 197.3 kt N.

A decrease in the total cultivated area leads to lower total N quota, while the decrease in livestock production lower the amount of N from manure applied to soils. The consumption of inorganic fertiliser is assumed to decrease from 197.3 kt N in 2023 to 185.0 kt N in 2050.

Table 6.10 Consumption of inorganic nitrogen fertilisers.

	2023	2024	2025	2030	2035	2040	2045	2050
Agricultural area, ha	2620947	2615300	2600470	2471310	2351310	2281930	2213900	2205272
Total N quota. kt N		363.5	361.5	343.5	326.8	317.2	307.7	306.5
Reduced N quota:								
Extensive cultivation, kt N		4.9	4.5	6.7	6.7	6.7	6.7	6.7
Reduced N due to catch crops, kt N		0.8	0.8	3.4	3.4	3.4	3.4	3.4
Expansion of organic cultivated area, kt N		0.31	0.13	0.06	-0.45	0.09	0.01	0
Reduced fertilisation, kt N		0	0	18.9	16.7	14.6	13.5	13.5
Adjusted total N quota, kt N	364.3	357.6	356.1	314.5	300.6	292.5	284.1	283.0
N fulfilled by manure + sewage, kt N*	132.9	131.7	133.7	122.2	112.1	105.1	100.1	97.9
N fulfilled by inorganic fertiliser, kt N	197.3	225.8	222.4	192.3	188.5	187.4	184.0	185.1
Kg N fertilised per ha**	139	137	137	127	128	128	128	128

* Amount of N, which must be counted for in the farmers nitrogen fertiliser account.
** 2023 estimate reflects the average for 2021-2023.

6.6.3 Leaching and run off

The N_2O emission from N-leaching and run off is determined based on the amount of N applied to the agricultural soils. The N-leaching into the groundwater is based on N applied from animal manure, grassing animals, inorganic fertiliser, sludge, other organic fertiliser, crop residue and mineralization multiplied with the average amount of N-leached in historic years (2021-2023). The projected N-leaching from rivers and estuaries is based on ratio compared with the N into groundwater as an average for years 2021-20231. The N_2O emission factor is based on the default values given in IPCC 2019 Refinement of 0.006 kg N_2O–N/kg N for groundwater and 0.0026 N_2O–N/kg N for rivers and estuaries.

A reduction of N leached due to catch crop is taken into account for the years 2024-2050 (Table 6.11). Based on estimate from Agency for Green Transition and Aquatic Environment (SGAV) (KEFM, 2024c), there is assumed a catch crop area of 451 000 hectares in 2023 increasing to 606 300 hectares in 2027, which are maintained at same level until 2050. The establishment of catch crops assumed to reduce the N leaching to the groundwater with 33 kg N/ha, which is based on information from SGAV (KEFM, 2024c).

In Table 6.11 is shown the background data used for calculation of the estimated N-leaching to groundwater, rivers, and estuaries.

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

	2023	2025	2030	2035	2040	2045	2050
N-leaching into groundwater (based on N applied), t N	136 000	139 893	127 728	122 242	118 898	114 994	114 634
Area with catch crops, ha	451 062	486 500	606 270	606 270	606 270	606 270	606 270
N-reduction from catch crops, t N		-1 169	-5 122	-5 122	-5 122	-5 122	-5 122
Adjusted N-leaching into groundwater, t N		138 723	122 606	117 121	113 776	109 872	109 512
N-leaching in rivers, t N		60 333	53 324	50 938	49 483	47 785	47 629
N-leaching in estuaries, t N		50 796	44 895	42 886	41 661	40 232	40 100

6.7 Deviation from AGMEMOD

The projection of emissions from the agricultural sector is based on projections from the model AGMEMOD, but for some sources deviations are made because the projection of emissions must be in line with historic reported emissions.

6.7.1 Number of animals

In historic years number of swine are defined differently in AGMEMOD and the national emission inventory. AGMEMOD includes animals realised for export or for slaughter, but the national emission inventory includes discarded animals because these also have had an emission while living. Therefore, the trend for sows, weaners, and fattening pigs from AGMEMOD are used to estimate the number of swine in the projection, see Table 6.3.

In AGMEMOD, projections for the number of sheep are included, but these are not used in the projection of emissions. The number of sheep in the historic years differ significantly between AGMEMOD and the national emission inventory and since the contribution from sheep to the total emissions are minor, the number of sheep are kept at the same level as the last historic year in the emission projection.

6.8 Results

In Table 6.12, the historical greenhouse gas emission 1990-2023 is listed, followed by the projected emissions for 2024-2050. The greenhouse gas emission is expected to decrease from 11.2 million tonnes CO_2 equivalents in 2023 to 7.3 million tonnes CO_2 equivalents in 2050. Thus, a 41 % decrease of GHG emission from the agricultural sector from 2023 to 2050 is expected. The decreased emission is driven by lower number of animals, expansion of the biogas production, which lead to a decrease of both the N_2O and CH_4 emission from manure management and frequent removal of slurry from swine barns, which decrease emission of CH_4.

Besides the biogas production and frequent removal of slurry, the decrease of the emission from 2023 to 2050 also can be explained by lower emission from enteric fermentation, use of inorganic fertiliser, reduction in the total area of organic soils and lower emission from N-leaching and run off.

Table 6.12 Total historical (1990-2023) and projected (2024-2050) emission, CO_2 equivalents.

million tonnes	1990	2000	2020	2023	2025	2030	2035	2040	2045	2050
CH_4	7.48	7.98	8.03	7.14	6.79	5.48	4.88	4.52	4.28	4.15
N_2O	6.50	5.23	4.68	3.88	4.03	3.50	3.20	3.07	2.94	2.90
CO_2	0.61	0.27	0.25	0.20	0.23	0.22	0.21	0.20	0.20	0.20
Agriculture, total	14.59	13.48	12.96	11.22	11.05	9.20	8.30	7.79	7.41	7.25

6.8.1 CH_4 emission

The overall CH_4 emission has decreased slightly from 267 kt CH_4 in 1990 to 255 kt CH_4 in 2023 but are expected to decrease by 42 % to 148 kt CH_4 in 2050 (Table 6.13). The projection shows a decrease in CH_4 emission from both the enteric fermentation and manure management.

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 development from 2015-2023 shows an almost unaltered CH_4 emission from enteric fermentation. The AGMEMOD model (Jensen, 2025) indicates that a decrease is expected for the number of dairy cattle from 2023 to 2050. The milk production is expected to increase all years up until 2050 (Jensen, 2025). The decrease in number of dairy cattle and changes in feeding strategy with higher ratio of fatty acids in fodder and supplementation of Bovaer for dairy cattle from the year 2025 and forward, is the main reason for decrease in the CH_4 emission from enteric fermentation.

The CH_4 emission from manure management has increased from 1990 to 2022, which is a result of change in barn systems towards more slurry-based systems. From 2023 frequent removal of slurry in barn for fattening pigs are mandatory and this decreases the overall emission of CH_4 from manure management. In the future, the emission from manure management is expected to decrease due to more barn systems with acidification of manure and manure cooling, for swine also frequent removal of slurry barns for sows and weaners and further also because of more manure delivered to biogas production. Reduction in CH_4 emission due to acidification and cooling of manure is not considered in the historic emission calculations.

Table 6.13 Historical and projected CH_4 emission.

kt	1990	2000	2020	2023	2025	2030	2035	2040	2045	2050
Enteric fermentation	159.1	144.1	147.7	141.9	135.9	115.0	107.5	101.9	99.6	99.2
Manure management	108.0	140.8	138.8	113.0	106.5	80.5	66.9	59.6	53.0	48.9
Field burning	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total CH_4, kt	267.2	284.9	286.6	255.0	242.5	195.7	174.5	161.6	152.7	148.2

- The numbers in this table should be multiplied with a GWP value of 28 to calculate the CO_2 eqv. presented in Table 6.12.

6.8.2 N_2O emission

The historical emission inventory shows a decrease of N_2O emission from 24.5 kt N_2O in 1990 to 14.6 kt N_2O in 2023, corresponding to 40 % reduction (Table 6.14). The reduction is primarily driven by a decrease in use of inorganic nitrogen fertilisers because of improved utilization of nitrogen in manure, forced by environmental requirements. For the projected emission, it is expected to decrease by 25 % until 2050, which leads to a total N_2O emission at

10.9 kt N_2O. The most important reasons for the decreasing projected emission are a decrease in the area with cultivated organic soils, a decrease in manure management and manure applied to soil due to a decrease in the number of animals. Additionally, there is also a lower N_2O emission from cultivation of agricultural soils is due to a lower nitrogen supply, caused by fall in the agricultural land, schemes which promote more extensive cultivation where fertilizer is not allowed and thus result in lower emission from N-leaching.

Table 6.14 Historical and projected N_2O emission.

kt	1990	2000	2020	2023	2025	2030	2035	2040	2045	2050
Manure management	2.55	2.63	1.90	1.46	1.42	1.11	0.92	0.83	0.77	0.73
Indirect N_2O emission	0.92	0.86	0.62	0.45	0.45	0.39	0.36	0.32	0.29	0.27
Inorganic fertilisers	6.29	3.95	3.96	3.10	3.49	3.02	2.96	2.95	2.89	2.91
Animal manure applied to soils	3.28	3.07	3.37	2.81	2.84	2.58	2.37	2.22	2.12	2.07
Sludge and other organic fertilisers applied to soils	0.07	0.14	0.18	0.17	0.17	0.16	0.16	0.15	0.15	0.15
Urine and dung deposited by grazing animals	0.23	0.20	0.10	0.10	0.09	0.09	0.08	0.07	0.07	0.07
Crop residues	2.45	2.48	3.04	2.39	2.82	2.74	2.66	2.61	2.57	2.59
Mineralization	0.67	0.35	0.21	0.28	0.19	0.16	0.16	0.16	0.10	0.08
Organic soils	2.71	2.47	1.38	1.20	1.12	0.59	0.18	0.11	0.05	0.01
Atmospheric deposition	2.04	1.23	0.96	0.80	0.85	0.78	0.74	0.70	0.68	0.67
Nitrogen leaching and run-off	3.31	2.37	1.95	1.88	1.76	1.56	1.49	1.45	1.40	1.39
Field burning	0.001	0.001	0.002	0.001	0.002	0.001	0.001	0.001	0.001	0.001
Total N_2O, kt	24.53	19.74	17.67	14.65	15.20	13.19	12.08	11.57	11.08	10.94

- The numbers in this table should be multiplied with a GWP value of 265 to calculate the CO_2 equivalents presented in Table 6.12.

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7 Waste

In the Danish emission inventories, emissions from waste are divided into five main groups of sources: 5.A Solid waste disposal, 5.B Biological treatment of solid waste, 5.C Incineration and open burning, 5.D Wastewater treatment and discharge and 5.E Other.

7.1 Emission overview

Table 7.1 gives an overview of historic and projected emissions from the waste sector. 5.B Biological treatment of solid waste has been divided in the two sources 5.B.1 Composting and 5.B.2 Anaerobic digestion at biogas facilities and 5.D Wastewater, has been divided into treatment and discharge.

Table 7.1 Greenhouse gas emissions from the waste sector for chosen years in the time series, kt CO_2 equivalents.

	1990	2000	2010	2020	2023	2024	2025	2030	2035	2040	2045	2050
5.A Solid waste disposal	1525	977	611	447	400	404	391	350	320	298	283	275
5.B.1 Composting	37	93	106	140	138	132	134	138	137	138	138	140
5.B.2 Anaerobic digestion at biogas facilities	6	34	75	320	494	519	551	703	773	753	753	753
5.C Incineration and open burning	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
5.D Wastewater treatment	217	212	181	202	191	180	181	185	189	190	191	191
5.D Wastewater discharge	225	57	39	28	29	28	28	28	29	29	29	29
5.E Other	24	152	118	128	123	114	114	115	116	117	117	118
Total	2034	1525	1130	1264	1375	1377	1399	1520	1564	1524	1511	1506
Share of national emissions excl. LULUCF	3%	2%	2%	3%	4%	4%	4%	6%	8%	8%	10%	10%

More information is available for each subsector in the following sections.

7.2 Solid waste disposal on land

The source category *5.A Solid waste disposal,* only gives rise to emissions of one greenhouse gas; i.e. 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., 2025). The model calculations are performed using national statistics on landfill waste categories reported in the national waste statistics. The waste amount reported or estimated for the historical time series since 1940, are grouped into 20 waste types (10 degradable and 10 inert) with individual content of degradable organic matter and degradation kinetics expressed as half-lives (Nielsen et al., 2025).

7.2.1 Emissions model

The model has been developed and used in connection with the historic emission inventories prepared for the United Nation Climate Convention. As a result, the model has been developed in accordance with the guidelines found in the IPCC Guidelines (2006). Based on the recommendations in these guidelines, a so-called Tier 2 method, a decay model, has been selected. The model is described in the National Inventory Document, which is prepared for the Climate Convention, the latest being the 2025 NID report (Nielsen et al., 2025). 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. (2025).

CH_4 emissions for the projected years 2024-2050 are calculated using the same FOD model as used for calculation of historical emissions. The same DOCs, half-lives and historical waste amounts (since 1940) are also applied for historical and projected years, for more information on these factors, the reader is referred to Nielsen et al. (2025).

7.2.2 Activity data, input

Deposited amounts of waste

It is relevant in this context to distinguish between organic and inert waste types, as only organic waste is degradable and thereby a source of CH_4 emissions. Of the 20 waste types prepared for the FOD model, only 10 are degradable. For more information in the deposited amounts of inert waste, the reader is referred to Nielsen et al. (2025).

Historically, the total amount of organic waste deposited at landfills increased from 1940 to the mid 1980's followed by a rather steep decrease. Since 2003, deposited organic waste amounts have reached a more constant level at 102-232 kt (45-114 kt excl. demolition waste).

Deposited total waste amounts for 2024-2050 excl. soil, sand and stone are projected by DEPA (2025). The deposited amounts of the individual organic waste fractions are estimated from DEPA (2025) and the waste composition of the latest historic data year, i.e. 2023. This implies that 31 % of the deposited amounts estimated by DEPA (2025) is categorised as organic, i.e. comprised by waste types with a content of organic degradable carbon (DOC_i>0). This fraction consists mainly of demolition waste (53 %), food waste (14 %) and paper & cardboard (7 %).

Figure 7.1 presents the deposited organic waste for 1990-2050. The FOD model calculations also includes waste amounts deposited in 1940-1989.

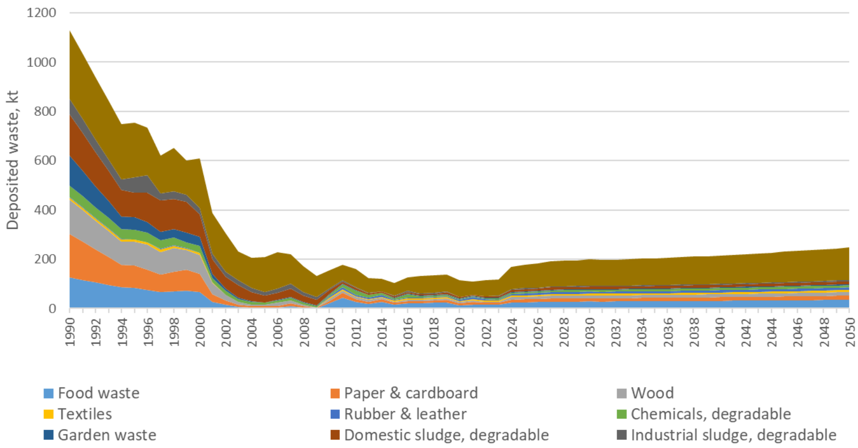

Figure 7.1 Deposited amounts of organic waste divided into 10 organic waste fractions.

The reason for the sharp decrease in historical data on deposited amounts of organic waste is to be found in a combination of the Danish waste strategies and action plans, including goals for a continued minimising of the amount of deposited waste in favour of an increased reuse and combustion for energy production. From the last historical year (2023) to the first projected year

(2024), the total amount of waste being landfilled increases by 55 % and is projected to further increase from 2024-2050 by 46 % (DEPA, 2025).

Amount of recovered methane

The amount of recovered methane was estimated based on information from the Danish Energy Agency (2025) stating that the amount of recovered methane is projected to be 0.07-0.08 PJ per year in the period 2024-2050 (Table 7.2 and Figure 7.2).

7.2.3 Activity data and emissions, output

Table 7.2 and Figure 7.2 show the results of the FOD model calculations for 1990-2050.

Table 7.2 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.

	Deposited organic waste	Annual deposited generation potential	Gross methane emission	Recovered methane	Methane oxidised in the top layers	Net methane emission	
	kt	kt CH_4	kt CH_4	kt CH_4	kt CH_4	kt CH_4	kt CO_2e
1990	1128	68.8	61.0	0.5	6.1	54.5	1525
1995	753	42.1	56.8	7.6	4.9	44.3	1240
2000	608	33.5	50.0	11.3	3.9	34.9	977
2005	208	5.0	39.2	9.9	2.9	26.3	736
2010	154	5.6	30.0	5.7	2.4	21.8	611
2015	102	4.6	24.4	3.4	2.1	18.9	530
2020	114	4.7	20.2	2.5	1.8	16.0	447
2023	116	4.6	18.0	2.1	1.6	14.3	400
2024	170	7.4	17.4	1.3	1.6	14.4	404
2025	176	7.7	16.9	1.4	1.6	14.0	391
2030	199	8.6	15.3	1.4	1.4	12.5	350
2035	203	8.8	14.1	1.4	1.3	11.4	320
2040	215	9.3	13.2	1.4	1.2	10.6	298
2045	230	10.0	12.7	1.4	1.1	10.1	283
2050	247	10.7	12.3	1.4	1.1	9.8	275

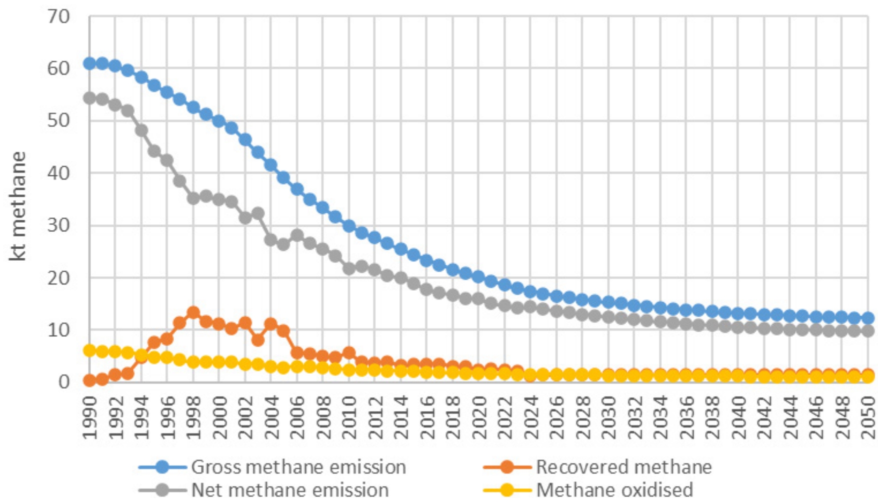

Figure 7.2 Historical and projected methane emissions. Historic data: 1990-2023. Projections: 2024-2050, kt.

In the period 2023-2050, the annual net methane emission reduces from 400 to 275 kt CO_2 equivalents, corresponding to a reduction of 31 %.

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.

Due to the nature of the decay model, each annual emission is the sum of partial degradation of waste deposited in all prior years, back to 1940. To illustrate the impact on today's emissions from waste deposited decades ago, the model calculations were split into four periods as presented in Table 7.3.

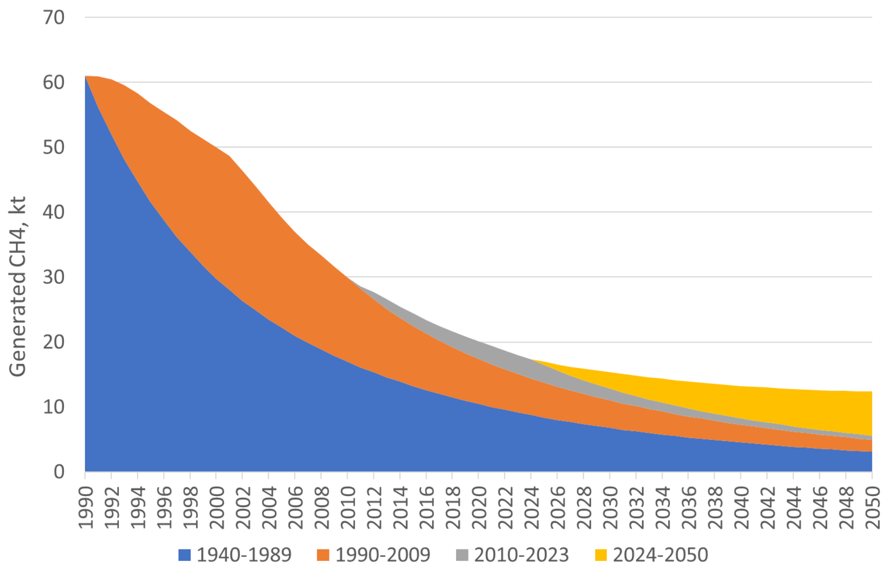

Figure 7.3 Methane generated from waste deposited in different periods.

In 2023, 51 % of the generated methane was caused by waste deposited before 1990. In 2050, this same waste (i.e. deposited in 1940-1989) still contributes with 25 % of the total generated methane.

7.3 Biological Treatment of Solid Waste

The Danish greenhouse gas emission from 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.

7.3.1 Composting

In Denmark, composting of solid biological waste includes composting of:

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

Emissions from composting are calculated according to a country specific Tier 2 method for garden waste, organic waste and sludge and Tier 1 for home composting. Applied emission factors are a combination of country specific and default values.

Methodology

The future activity of organic waste and home composting has been held constant in this projection as average values of the last three historical years. The activities of garden waste and sludge for composting have been projected using the trend from DEPA (2025). The activity data from DEPA (2025) differs significantly from the historical activity received from DEPA - and applied in the national emission inventories (Nielsen et al., 2025). It is therefore not possible to apply activity data projected by DEPA (2025) directly, but only as surrogate data. All emission factors are kept constant throughout the time series 1990-2050.

Emission factors

By assuming that the process of compost production will not significantly change over the next 25 years, the emission factors applied for this projection are the same as is used for historic years in Nielsen et al. (2025).

Table 7.3 Emission factors for compost production, t per kt wet weight.

	Garden waste	Organic waste	Sludge	Home composting
CH_4	2.57	4.00	0.29	2.78
N_2O	0.15	0.24	0.09	0.09

Activity data and emissions

The projection of composting was performed individually for the four waste types. Table 7.4 presents activity data and calculated emissions for selected years in the time series 1990-2050.

Table 7.4 Historical and projected amounts of composted waste and emissions of CH_4, N_2O and CO_2e, kt.

Year	Garden waste	Organic waste	Sludge	Home composting	CH_4	N_2O	CO_2e
1990	288	16	5	20	0.86	0.05	37.2
1995	376	40	7	21	1.19	0.07	51.4
2000	677	47	218	21	2.05	0.13	92.9
2005	737	45	50	22	2.15	0.13	94.0
2010	810	64	65	23	2.42	0.14	106.0
2015	883	60	49	23	2.59	0.15	113.0
2020	992	129	118	24	3.17	0.19	139.6
2023	954	158	29	24	3.16	0.19	137.8
2024	2345	131	13	24	2.95	0.19	131.8
2025	2387	131	13	24	2.99	0.19	133.7
2030	2482	131	14	24	3.09	0.19	138.1
2035	2458	131	16	24	3.06	0.19	137.1
2040	2468	131	17	24	3.08	0.19	137.7
2045	2483	131	19	24	3.09	0.20	138.5
2050	2516	131	20	24	3.13	0.20	140.1

7.3.2 Anaerobic Digestion at manure-based biogas plants

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

The energy production at biogas plants within the agricultural sector accounts for 95-97 % of the biogas production included here. The biogas production is projected by the Danish Energy Agency (2025) and is estimated to increase from 31.9 PJ in 2024 reaching a maximum level of 47.6 PJ in 2034 after which a gradual decrease to 46.3 PJ in 2050. The CH_4 emission is calculated using an emission factor of 4.2% of the CH_4 content in the produced biogas in the period 1990-2016 and 2.9 % for 2020-2050. Emission factors for 2017-2019 are interpolated. For more information, please refer to Nielsen et al. (2025).

Historical and projected emissions are provided in Table 7.5 and visualised in Figure 7.4.

Table 7.5 Historical and projected energy production, and emissions of CH_4 and CO_2e.

Year	Biogas production, TJ	CH_4 production, kt	CH_4 emission, kt	CO_2e, kt
1990	266	5.3	0.2	6.3
1995	746	14.9	0.6	17.5
2000	1442	28.8	1.2	33.9
2005	2375	47.5	2.0	55.9
2010	3184	63.7	2.7	74.9
2015	5199	104.0	4.4	122.3
2020	19725	394.5	11.4	320.3
2023	30425	608.5	17.6	494.1
2024	31929	638.6	18.5	518.5
2025	33919	678.4	19.7	550.8
2030	43270	865.4	25.1	702.7
2035	47589	951.8	27.6	772.8
2040	46356	927.1	26.9	752.8
2045	46339	926.8	26.9	752.6
2050	46339	926.8	26.9	752.6

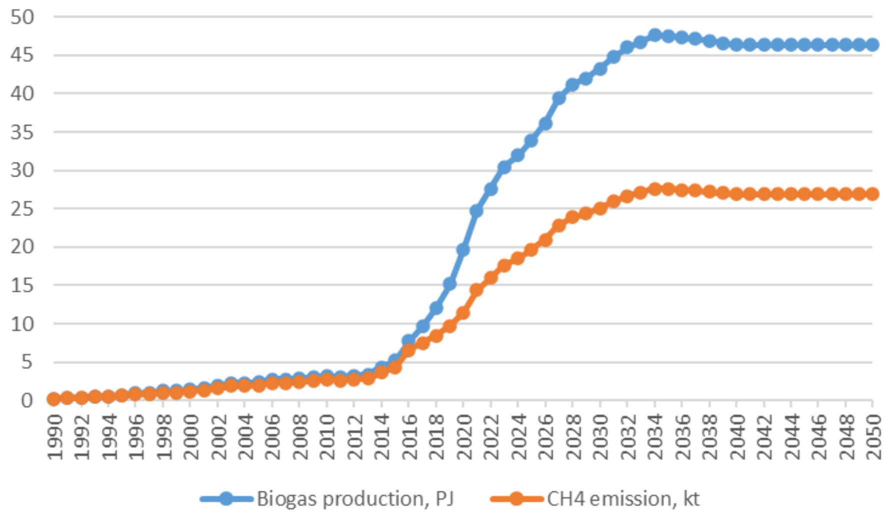

Figure 7.4 Historical and projected amounts of bioenergy and CH_4 emissions. Historic data: 1990-2023. Projections: 2024-2050.

7.4 Waste Incineration

The source category *5.C Waste Incineration* includes cremation of human bodies and cremation of animal carcasses and gives rise to CH_4 and N_2O emissions.

Incineration of municipal, industrial, clinical and hazardous waste takes place with energy recovery; the emissions are therefore included in the relevant subsectors under the Energy sector (*1.A Stationary combustion*). For documentation, please refer to Chapter 2 of this report. Flaring offshore and in refineries are included under sub-sector 1.B.2c, for documentation please refer to Chapter 3 of this report. No flaring in chemical industry occurs in Denmark.

As presented in Table 7.1, greenhouse gas emissions from the Waste Incineration sub-sector are miniscule.

7.4.1 Activity data

It is assumed that no drastic changes are made in the subject of human- and animal cremation that will influence greenhouse gas emissions in the years until 2050.

Table 7.6 presents the number of deceased persons and number of human cremations together with the amount of cremated carcasses.

In this year's emission projection, a constant level of cremations is chosen for both human and animal cremations, corresponding to the respective average value of the last three historical years.

Table 7.6 Activity data for waste incineration.

	Deceased humans	Human cremations	Animal cremations
	no.	no.	tonnes
1990	60926	40991	150
1995	63127	43847	200
2000	57998	41651	443
2005	54962	40758	762
2010	54368	42050	1449
2015	52555	43238	1119
2020	54645	46910	995
2023	58384	50493	786
2024		50293	897
2025		50293	897
2030		50293	897
2035		50293	897
2040		50293	897
2045		50293	897
2050		50293	897

7.4.2 Emission factors

The applied emission factors for cremations are the same for all years in the time series 1990-2050, for more information please refer to Nielsen et al. (2025).

Table 7.7 Emission factors for waste incineration.

	Human cremation		Animal cremation	
	Value	Unit	Value	Unit
CH_4	11.8	g/body	0.18	kg/t
N_2O	14.7	g/body	0.23	kg/t

7.4.3 Emissions

Figure 7.5 presents greenhouse gas emission from the waste incineration sub-sector, divided in contributions from the two sources and two pollutants.

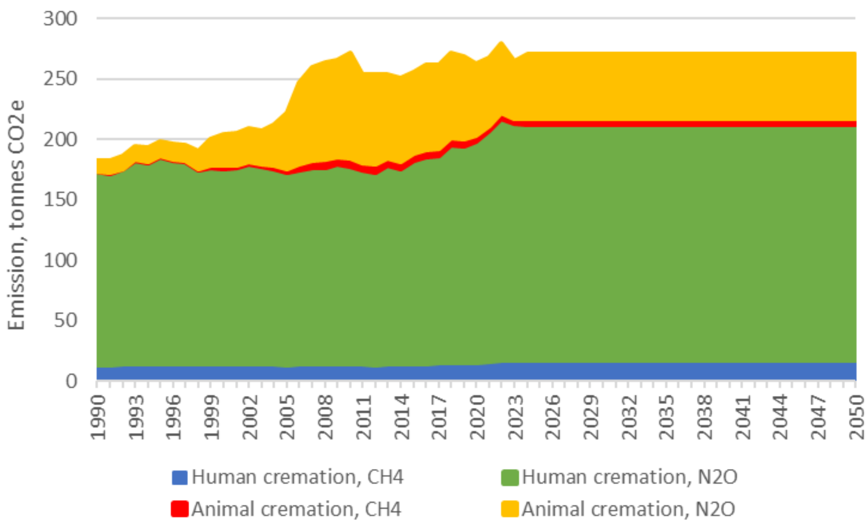

Figure 7.5 Emissions from waste incineration.

7.5 Wastewater handling

The source category 5.D Wastewater handling constitutes emissions of CH_4 and N_2O from wastewater treatment and from discharge in both the residential/commercial and industrial sectors. Emissions from the part of the Danish population not connected to the sewer system is also included.

7.5.1 Methodology

The following contributions to the wastewater sub-sector are included in the Danish greenhouse gas inventories and projections:

- CH_4 from anaerobic treatment plants (5D1a)
- CH_4 from sewer systems and municipal wastewater treatment (5D1b)
- CH_4 from septic tanks (5D1c)
- CH_4 from discharge (5D1d+5D2d)
- N_2O from wastewater treatment (5D1b+5D2b)
- N_2O from discharge (5D1d+5D2d)

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. (2025).

All activity and emission data are presented in Table 7.8

Methane emission from anaerobic digestion

The net methane emission from anaerobic treatment processes of sludge in closed systems with biogas extraction for energy production is estimated from the gross energy production leakage rate (6.9 %), based on measured data at biogas facilities at wastewater treatment plants (Nielsen et al., 2025) and the biogas production (available from DEA, 2025). The energy production at biogas facilities is measured for historic years (available from the national Energy Statistics) and projected for 2024-2050 (available from the Energy and Climate Outlook), both datasets are produced by the Danish Energy Agency (DEA).

Methane emission from sewers and municipal wastewater treatment

The fugitive emissions from the sewer system, primary (and secondary) settling tanks (clarifiers) and aerobic biological N and P removal processes, are estimated from the influent organic degradable matter measured as the chemical oxygen demand (COD) in the influent wastewater flow and the default maximum CH_4 producing capacity, i.e. 0.25 kg CH_4 per kg COD (IPCC, 2006).

The fraction of total organically degradable carbon in wastewater (COD) that is unintentionally converted to CH_4 in sewers and treatment processes, is set equal to 0.003 based on a country specific expert judgement (Nielsen et al., 2025). The resulting emission factor for these processes therefore equals 0.75 g CH_4 per kg COD in the inlet wastewater.

The projection calculations are made from the average COD (t per inhabitant) for the three latest historic years (2021-2023) and the projected population from Statistics Denmark (2025).

Methane emission from septic tanks

For the part of the population not connected to the collective sewer system, simple decentralised wastewater handling is assumed and modelled as septic tanks. The methane emission is calculated from the population number, an emission factor for septic tanks and the fraction of the population that is not connected to the sewer system, i.e. scattered houses.

Data on historic and projected population numbers and historic data on housing types are available from Statistics Denmark (2025). The population fraction outside the sewer system is a time series that steadily decreases from 11.5 % in 1990 to 7.0 % in 2023, this fraction is kept constant at 7.0 % for the projection calculations; 2024-2050. The country specific emission factor of 2.54 kg CH_4 per person per year and is kept constant for the entire time series 1990-2050.

Methane emissions from discharge

The fugitive CH_4 emission from effluent wastewater includes discharge from both:

- Domestic wastewaters, including effluents from municipal wastewater treatment plants, rainwater conditioned effluents and effluents from scattered houses not connected to the sewage system.
- Industrial wastewater, including effluents from wastewater treatment plants at separate industries and effluents from aquaculture.

Emissions are based on the effluent organic degradable matter measured as the chemical oxygen demand (COD) in the effluent wastewater flow. Applied emission factors are the default maximum CH_4 producing capacity, i.e. 0.25 kg CH_4 per kg COD (IPCC, 2019) and the fraction of DOC that is released at discharge in waterbodies. Since it is not possible to categorise wastewater discharge by the type of waterbody in Denmark, the default Tier 1 value of 0.11 from IPCC (2019) is applied.

The effluent COD is available for each of the five contributions mentioned above, these are summed into domestic- and industrial wastewater streams and emissions are calculated separately for the two streams. The emission factor for discharge regardless of whether the effluent wastewater is from domestic or industrial sources, equals 27.5 g CH_4 per kg COD. (Nielsen et al., 2025)

For domestic wastewater discharge, projections are calculated from the average COD per inhabitant from the latest three historic years and population projections from Statistics Denmark (2025).

For industrial wastewater discharge, projections are estimated as the constant average of the latest three historic years.

Nitrous oxide emission from wastewater treatment

The N_2O emission from wastewater treatment processes is calculated from the annually reported influent N load flow of either domestic or industrial wastewater and an emission factor of 13.2 kg N_2O per tonne N load in the influent wastewater (Nielsen et al., 2025).

For separate industrial wastewater treatment plants, influent N load is not available from the monitoring programme but only the effluent total-N load. The influent N load is therefore estimated from the effluent time series, by assuming that the industrial treatment plants have the same average N-removal efficiency as municipal treatment plants.

Projections for municipal wastewater treatment are estimated from population projections and the average N load per capita for the latest three historical years. For industrial sources, the N_2O emission is projected as the constant average of the latest three historical years.

Nitrous oxide emission from discharge

The fugitive N_2O emission from effluent wastewater includes discharge from both:

- Domestic wastewaters, including effluents from municipal wastewater treatment plants, rainwater conditioned effluents and effluents from scattered houses not connected to the sewage system
- Industrial wastewater, including effluents from wastewater treatment plants at separate industries and effluents from aquaculture

Emissions are calculated from the effluent sewage nitrogen load and an emission factor of 7.9 kg N_2O per tonne N load in the effluent wastewater. This emission factor value is calculated from the IPCC Tier 1 default emission factor of 0.005 kg N_2O-N per kg sewage-N produced (IPCC, 2019, V5C6, Table 6.8A) and the stochiometric relation between N and nitrous oxide (44/28).

The effluent nitrogen load is available for each of the five contributions mentioned above, these are summed into domestic- and industrial wastewater streams and emissions are calculated separately for the two streams.

Projections of effluent emissions from domestic wastewater treatment are calculated from population projections and the average N per capita for the latest three years.

Projections of effluent emissions from rainwater conditioned outlets, from scattered houses not connected to the sewage system, from aquaculture and from wastewater treatment plants at separate industries are all estimated as the constant average emissions from the latest three historic years.

7.5.2 Emissions

Activity data are presented in the following Table 7.8, along with historical and projected greenhouse gas emissions from wastewater treatment and discharge. Emissions are also presented graphically in Figure 7.6.

Table 7.8 Activity data and emissions from wastewater treatment and discharge

	Unit	1990	2000	2005	2010	2015	2020	2023	2025	2030	2035	2040	2050
Population	1000s	5135	5330	5411	5535	5660	5823	5933	5984	6024	6085	6129	6168
Biogas prod. from WWTP	TJ	458	857	913	840	901	1293	1198	788	872	940	940	940
5D1a Emission, anaerobic TPs	kt CH_4	0.61	1.14	1.21	1.11	1.20	1.71	1.59	1.05	1.16	1.25	1.25	1.25
Influent TOW at municipal TPs	kt COD	349	390	353	370	387	388	375	389	391	395	398	401
5D1b Emission, sewers and municipal WWT	kt CH_4	0.26	0.29	0.26	0.28	0.29	0.29	0.28	0.29	0.29	0.30	0.30	0.30
Population not connected to sewage system	-	12%	11%	10%	9%	9%	7%	7%	7%	7%	7%	7%	7%
5D1c Emission, septic tanks	kt CH_4	1.50	1.45	1.41	1.32	1.22	1.09	1.06	1.06	1.07	1.08	1.09	1.10
Effluent TOW from domestic sources	kt COD	72.2	22.5	19.2	20.5	24.7	15.5	14.5	15.4	15.6	15.7	15.8	15.9
5D1d Emission, domestic effluent	kt CH_4	1.99	0.62	0.53	0.56	0.68	0.43	0.40	0.42	0.43	0.43	0.44	0.44
Effluent TOW from industry	kt COD	154.0	24.4	13.3	12.6	7.3	4.8	5.2	5.1	5.1	5.1	5.1	5.1
5D2d Emission, industrial effluent	kt CH_4	4.24	0.67	0.37	0.35	0.20	0.13	0.14	0.14	0.14	0.14	0.14	0.14
Total CH_4 emission	kt CH_4	8.59	4.17	3.78	3.62	3.59	3.65	3.47	2.97	3.09	3.20	3.21	3.22
Influent N load at municipal TP	kt	33.2	31.7	32.4	27.4	30.5	30.3	29.3	30.3	30.5	30.8	31.0	31.2
5D1b Emission, sewers and municipal WWT	t N_2O	438.7	418.0	428.2	361.1	402.7	400.3	386.6	399.9	402.6	406.6	409.5	412.2
Influent N load at industries	kt	9.7	5.8	3.2	2.6	2.7	2.6	1.9	2.2	2.2	2.2	2.2	2.2
5D2b Emission, industrial WWT	t N_2O	128.0	76.6	41.6	34.1	36.0	34.8	25.1	28.6	28.6	28.6	28.6	28.6
Effluent N load from municipal WWT	kt	15.4	4.7	3.8	3.6	3.7	3.2	3.8	3.4	3.4	3.4	3.5	3.5
other domestic sources	kt	2.9	1.7	1.5	1.7	2.3	1.4	1.8	1.5	1.5	1.5	1.5	1.5
Emission, municipal WWT eff.	t N_2O	120.8	36.6	30.1	28.1	29.1	25.5	29.7	26.6	26.7	27.0	27.2	27.4
Emission, other domestic eff.	t N_2O	22.8	13.7	12.1	13.1	18.0	10.9	14.2	11.9	11.9	11.9	11.9	11.9
5D1d Emission, domestic effluent	t N_2O	143.6	50.3	42.2	41.2	47.1	36.4	43.9	38.4	38.6	38.9	39.1	39.3
Effluent N load from industry	kt	6.0	3.6	1.7	1.3	1.4	1.2	1.0	1.1	1.1	1.1	1.1	1.1
5D2d Emissions, industrial effluent	t N_2O	47.5	28.4	13.1	10.0	10.7	9.8	8.1	8.4	8.4	8.4	8.4	8.4
Total N_2O emission	kt N_2O	0.76	0.57	0.53	0.45	0.50	0.48	0.46	0.48	0.48	0.48	0.49	0.49
Total CO_2 eq. emission	kt CO_2e	441.3	268.7	245.0	219.7	232.1	229.8	219.9	209.1	213.3	217.4	218.6	219.7

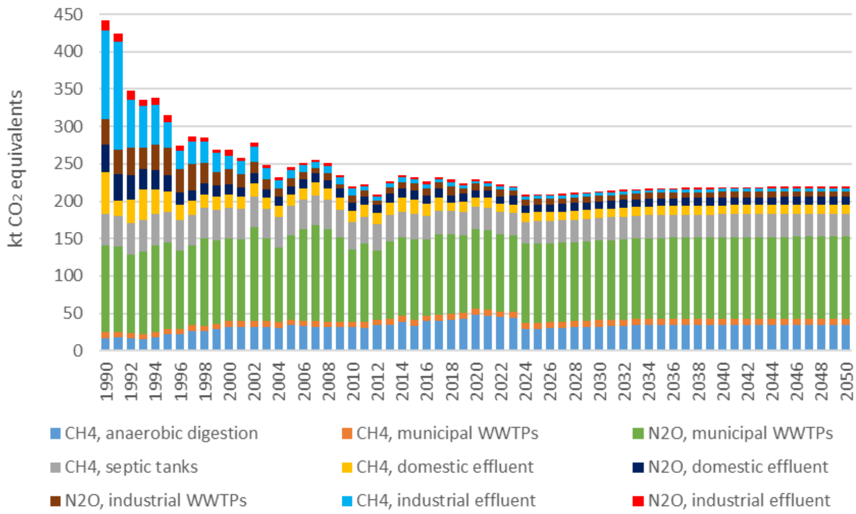

Figure 7.6 CO_2 equivalent emissions from wastewater handling, kt CO_2e.

Greenhouse gas emissions from effluents are slightly higher than all wastewater treatments combined in 1990, for all other years (1991-2050), emissions are higher for treatment than for effluent. Effluent emissions quickly decrease in the 1990s due to improvements in the wastewater treatment efficiencies and are below 20 % of the total greenhouse gas emission from the wastewater sector since 2001.

The projected total emissions from the wastewater sector shows a slight increase that is driven primarily by the general increase in population.

7.6 Other

The source category 5.E Waste Other is a catch up for the waste sector. Emissions presently included in this category are CO_2 and CH_4 emissions from accidental building and accidental vehicle fires.

Activity data for accidental fires are calculated from the registered number of fires available from The Danish Emergency Management Agency. Registered fires are categorised in five building types and 13 vehicle types and also in four sizes (small-, medium-, large- and full-scale fires). By using average building floor area and average vehicle weight data from Statistics Denmark along with average building mass per floor area factors, the total amount of combusted mass is calculated for all historical years. Emission factors for building fires and vehicle fires are known from international literature.

Emissions from accidental fires were projected as the average emission of the last three historical years.

Historical and projected non-biogenic greenhouse gas emissions are presented in Figure 7.7.

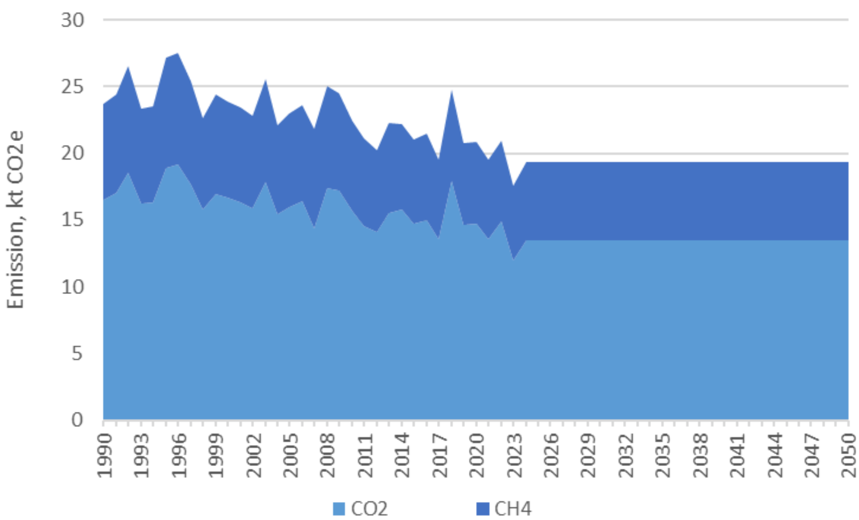

Figure 7.7 Greenhouse gas emissions from accidental fires.

7.7 Source specific recalculations

Projected emissions in this report are not the same as last year's projections, as the calculations of both historic and projected emissions are ongoing and continuously altered to match current available knowledge.

For the 5A Solid waste disposal, new waste data from the DEPA for 2011-2022 results in decreased emissions for these years. The decrease in emissions is between 7.3 and 16.3 kt CO_2 eq. in 2012-2022. Since projections are based on historic data for disposal, this correction affects the projected emissions with decreases. Projected emissions for solid waste disposal have decreased between 21 kt CO_2 eq. (-5 %) in 2024 and 83 kt CO_2 eq. (-22 %) in 2050.

For category 5B Biological treatment of solid waste, recalculations were made for both source categories. Recalculations in the historic years 2011-2022 were made for composting due to new data becoming available from DEPA. The resulting change in expected emissions from composting have decreased because of this; between 4 kt CO_2 eq. (-3 %) in 2024 and 6 kt CO_2 eq. (-4 %) in 2040. For anaerobic digestion of organic waste at biogas facilities, the projected biogas production prepared by the DEA (2025), has decreased compared to last year's projection. As a result, the methane emission from this activity has decreased between 10 kt CO_2 eq. (-2 %) in 2024 and 56 kt CO_2 eq. (-7 %) in 2030.

For category 5C Incineration and open burning of waste, there are no changes in the historic emission inventory. The average of the three latest historical years is applied in the emission projection, resulting in a slight increase in emissions of 0.001 kt CO_2e (+0.1%) per year in the projections period 2024-2040.

Since last year, category 5D Wastewater treatment and discharge has gone through a thorough review of the methodologies and calculation factors resulting in several recalculations. The most significant changes are:

- CH_4 emission calculations from both industrial effluent and domestic effluent are new in this year's submission. The calculations follow the new guidance provided by the 2019 refinement of the IPCC Guidelines. The CH_4 contribution from these new sources are 6.2 kt CH_4 in 1990, decreasing to 0.5 kt CH_4 in 2023 and slightly increasing to 0.6 kt CH_4 in 2050;
- The CH_4 content in biogas was adjusted from the rounded number 50 to 52.04 MJ per kg CH_4 (decrease in CH_4 from residential/commercial plants);
- The N-removal for separate industries is not available. The removal was previously kept constant at 92 %, but it is now assumed to be the same as for residential/commercial plants, i.e. an increasing trend. This results in the calculated amount of influent N to decrease significantly for the early years in the time series and hence also the removed amount of N (and the resulting N_2O emissions). The resulting decrease in N_2O emission is between -0.6 kt in 1990 (-83% from separate industries) to -0.01 kt in 2022 (-17%).

The overall recalculation in historic greenhouse gas emissions from wastewater treatment and discharge are highest for 1990, 1991 and 1993 with increases of 69-81 kt CO_2 eq. The overall change in projected emissions is an increase between 5.6-7.5 kt CO_2 eq. per year (3-4%).

For the category Other, the historic emission inventory has changes slightly due to the correction of an error. As emissions are projected as the average of the three last historical years, emissions for 2024-2040 have also changed. The recalculation amounts to a decrease of 1 kt CO_2e (-5 %) for each projected year.

7.8 References

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8 LULUCF

The emission and uptake of GHGs from the LULUCF sector (Land Use, Land Use Change and Forestry) primarily includes carbon dioxide (CO_2) from C stock changes in land use and cultivation of organic soils, small amounts of nitrous oxide (N_2O) from disturbance of soils and methane (CH_4) from Cropland, Grassland and Wetlands.

The LULUCF sector is subdivided into six major land use categories:

- Forest land (FL)
- Cropland (CL)
- Grassland (GL)
- Wetlands (WE)
- Settlements (SE)
- Other land (OL)

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 and further detailed information on historical estimation of the sources and sinks, see the latest available Danish National Inventory Report (NIR), Chapter 6 in Nielsen et al. (2025). Projection of agricultural crop distribution and yield are prepared and delivered by University of Copenhagen, Department of Food and Resource Economics (IFRO). The Danish Energy Agency, as part of the Danish Ministry of Climate, Energy and Utilities deliver projections of straw removal for energy purposes. The Danish Agricultural Agency (SGAV), as part of the Ministry of Food, Agriculture and Fisheries of Denmark, delivers information on binding policy agreements and their respective expected effect on e.g. agricultural area with catch crops, grassland and organic farming, afforestation, and wetlands restoration on organic soils (SGAV, 2025ab). Emission estimates of Forest land and the minor source of harvested wood products are included but are prepared separately by the Department of Geosciences and Natural Resource Management (IGN), University of Copenhagen. The detailed methodology for the emission inventory and projections are described in the publications Nord-Larsen et al. (2025) and Johannsen et al. (2022). Updated projection data presented in the report is received directly from IGN in 2025.

8.1 Projected land use and land use changes

Approximately 68 % of the total Danish land area are reported under Cropland and Grassland in 2023, with 60 % with agricultural crops and 8 % is field boundaries etc. 15 % of the total land area is forest, see Figure 8.1. Intensive cultivation with a large number of animals exerts a high environmental pressure on the landscape and regulations have been adopted to reduce this. The adopted policy aims at doubling the forested area, restoring former wetlands, and establishing protected national parks. In Denmark, almost all natural habitats and all forests are protected, and the conversion of these areas therefore is limited.

Figure 8.1 shows the land use in 1990 and towards 2050. The land use and land use changes are based on a complex mapping of the entire terrestrial area of Denmark called the land use matrix (LUM) (Levin et al., 2014; Levin &

Gyldenkærne, 2024). It is apparent from the figure that a continuous increase in FL, SE and WE is expected, at the expense of primarily the CL area. The large increase in WE in 2025 to 2033 is due to a large rewetting program in Denmark (SGAV, 2024) primarily reducing the CL and the GL area. The definition of the LULUCF sectors applied here is based on the 2006 IPCC Guidelines. Numbers and distribution differ slightly from national statistics due to methodological differences.

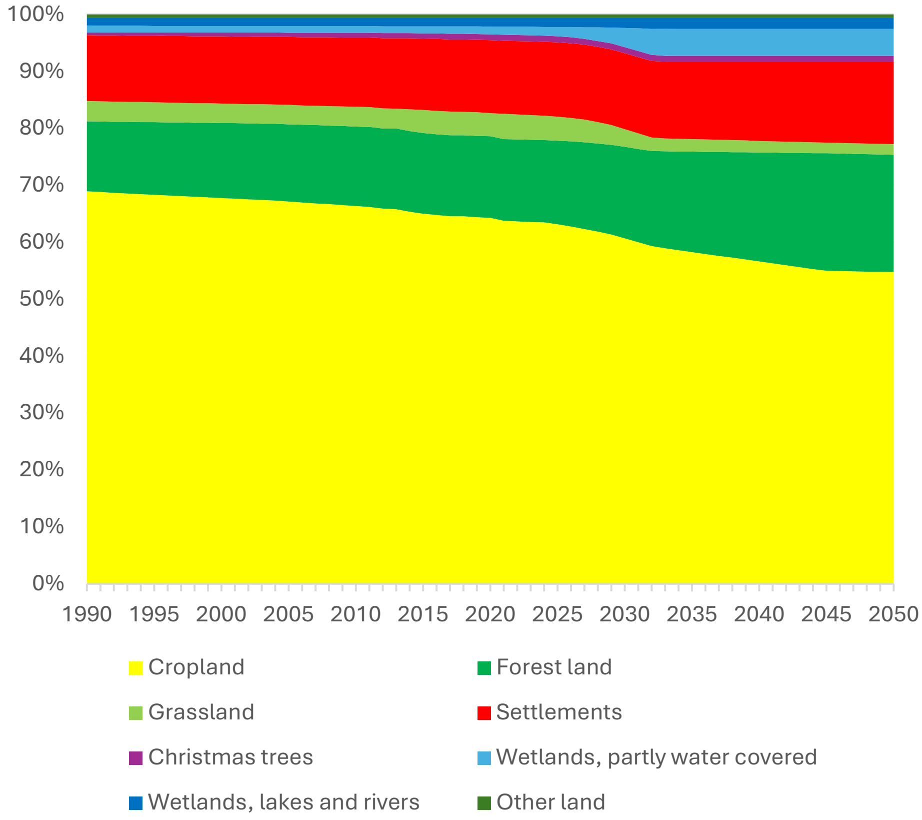

Figure 8.1 Land use from 1990-2050 distributed on land use categories.

Table 8.1 shows the distribution of land in number of hectares from 1990 to 2050 and the expected annual land use changes between the different categories in 2023, 2025, 2030 and up to 2050.

One of the important contributors to LUC is conversion of CL and GL to FL and WE. Afforestation and rewetting of drained organic soils is a mitigation measure with high political priority according to, for example, Agreement on a Green Denmark (GTP, 2024).

Aside from the afforestation and wetland restoration, the registered LUC is primarily due to the continuous the demand for new Settlements and infrastructure purposes. Conversion to Settlements and other infrastructures (SE) is expected to continue with the same pace as seen historically, based on the average of the past ten years. Additionally, land reclamation amounted to 520 ha from 1990 to 2023 resulting in an increasing total area. Of this 476 ha were added to SE, 44 ha to GL and 2 ha to WE permanent water covered.

In total from 1990 to 2050, an afforestation of 379 200 ha is expected (excl. Christmas trees). Deforestation is only expected to occur on 17 700 ha from

1990 to 2050 (incl. Christmas trees). In Table 8.1, Forest land includes Christmas trees. The deforestation is mainly due to conversion to SE and opening of the forest to grassland.

Table 8.1 Distribution of land area between the six land use categories.

Total area, ha	Forest land	Cropland	Grassland	Settlement	Wetlands	Other land	Total
1990	546267	2972001	153393	497829	109291	26575	4305356
2023	666631	2736825	187053	557259	131534	26575	4305877
2025	678945	2717851	181982	562203	138320	26575	4305877
2030	738374	2611346	133411	574531	221640	26575	4305877
2035	804133	2508641	94541	586859	285129	26575	4305877
2040	869891	2436987	88140	599186	285098	26575	4305877
2050	932409	2357917	80098	623841	285037	26575	4305877

8.2 Projected LULUCF emissions 2024 - 2050

LUC reflects conversions of land from one land use category to another, and the carbon (C) stocks of the living biomass and the soil C equilibrium states in each land use category affect, whether the result is a net sink or source of emissions. 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. This means that an area undergoing land use change (LUC) is kept in a conversion category of 'land converted to' for 30 years before it is redefined as 'land remaining' in the new land use category. The emissions from soil C stock change are distributed equally over the 30 years.

Table 8.2 Overall emission estimates from the LULUCF sector from 1990 to 2050, kt CO_2e per year.

Land Use Category	1990	2000	2010	2020	2025	2030	2035	2040	2045	2050
4. LULUCF Total	6699.3	5041.3	2291.7	1227.1	-405.4	322.1	-1308.4	-1990.2	-2999.3	-3631.1
A. Forest Land*	-1217.4	-1314.9	-2242.8	-2136.5	-2975.0	-1529.6	-2899.2	-3494.1	-4209.2	-4599.0
1. Forest Land remaining Forest Land*	-195.7	-978.6	-838.5	-958.4	-2116.1	153.0	-1112.6	-1791.9	-2673.9	-4405.4
2. Land converted to Forest Land*	-1021.7	-336.3	-1404.3	-1178.0	-858.9	-1682.6	-1786.6	-1702.3	-1535.3	-193.6
B. Cropland	6655.7	5264.7	3606.6	2389.6	1683.2	1180.0	566.7	507.0	231.6	61.6
1. Cropland remaining Cropland	6585.9	5214.2	3569.3	2360.8	1656.0	1149.9	533.2	470.0	190.9	17.1
2. Land converted to Cropland	69.8	50.5	37.3	28.8	27.1	30.1	33.5	37.1	40.7	44.5
C. Grassland	666.9	639.4	631.8	820.2	797.1	195.7	9.5	9.2	9.3	9.0
1. Grassland remaining Grassland	595.2	595.1	595.1	799.4	788.1	186.5	0.0	0.0	0.0	0.0
2. Land converted to Grassland	71.8	44.3	36.7	20.9	9.0	9.2	9.4	9.2	9.3	9.0
D. Wetlands	111.3	81.2	76.8	128.2	145.6	269.3	806.9	798.6	780.1	743.3
1. Wetlands remaining Wetlands	110.8	78.3	67.1	78.5	76.0	58.6	102.5	99.2	93.2	85.6
2. Land converted to Wetlands	0.5	2.9	9.6	49.7	69.6	210.6	704.4	699.5	686.9	657.7
E. Settlements	485.1	345.0	244.4	143.1	226.6	250.7	274.8	282.6	269.7	276.6
1. Settlements remaining Settlements	-4.7	-3.6	-2.2	-1.8	0.0	0.0	0.0	0.0	0.0	0.0
2. Land converted to Settlements	489.8	348.6	246.6	144.9	226.6	250.7	274.8	282.6	269.7	276.6
F. Other Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
G. Harvested Wood Products (HWP)*	-2.4	25.8	-25.1	-117.6	-282.8	-44.0	-67.1	-93.6	-80.9	-122.6

*The methodology for estimation of emission and projections for all Forest land and HWP data are reported in detail in Nord-Larsen et al. (2025).

Overall is it projected that the LULUCF-sector from being a large source in 1990 will turn into a net sink around 2030-2032. There are three major reasons for this development.

- Firstly, we see an effect of the afforestation which has taken place over many decades. It is now storing large amounts of CO_2;
- Secondly, the large emissions from drained organic soils are reduced and expected to cease by 2050. The reduction in the emission from the organic soils has two main reasons. Partly because many of the organic soils has only a thin organic profile. The loss of organic matter from a lot of these soils is now at a so low level that they classified as mineral soils and only release small amount of the remaining organic carbon until the carbon equilibrium state with the current agricultural practise is met. The other reason is due of restoration of drained agricultural cropland and grassland back into their former state as wetlands. This took place to smaller degree from 1990 to 2020 but is now accelerated up in the coming years so it is expected that in 2050 virtually no organic soils will be in a drained state.
- Thirdly, the input of organic matter in mineral soils is increasing, which increases the carbon store in the mineral soils. The increase in the carbon input is both the ban of straw burning in 1990, increased yield which increase the carbon input to the soils and the large import of feeding to the large Danish animal herd which produce large amounts of manure to be spread on the Danish fields.

FL remaining FL is expected to be a net sink through the whole period up to and including the last projected year 2050. For further details on the forest projection see Nord-Larsen et al. (2025a,b).

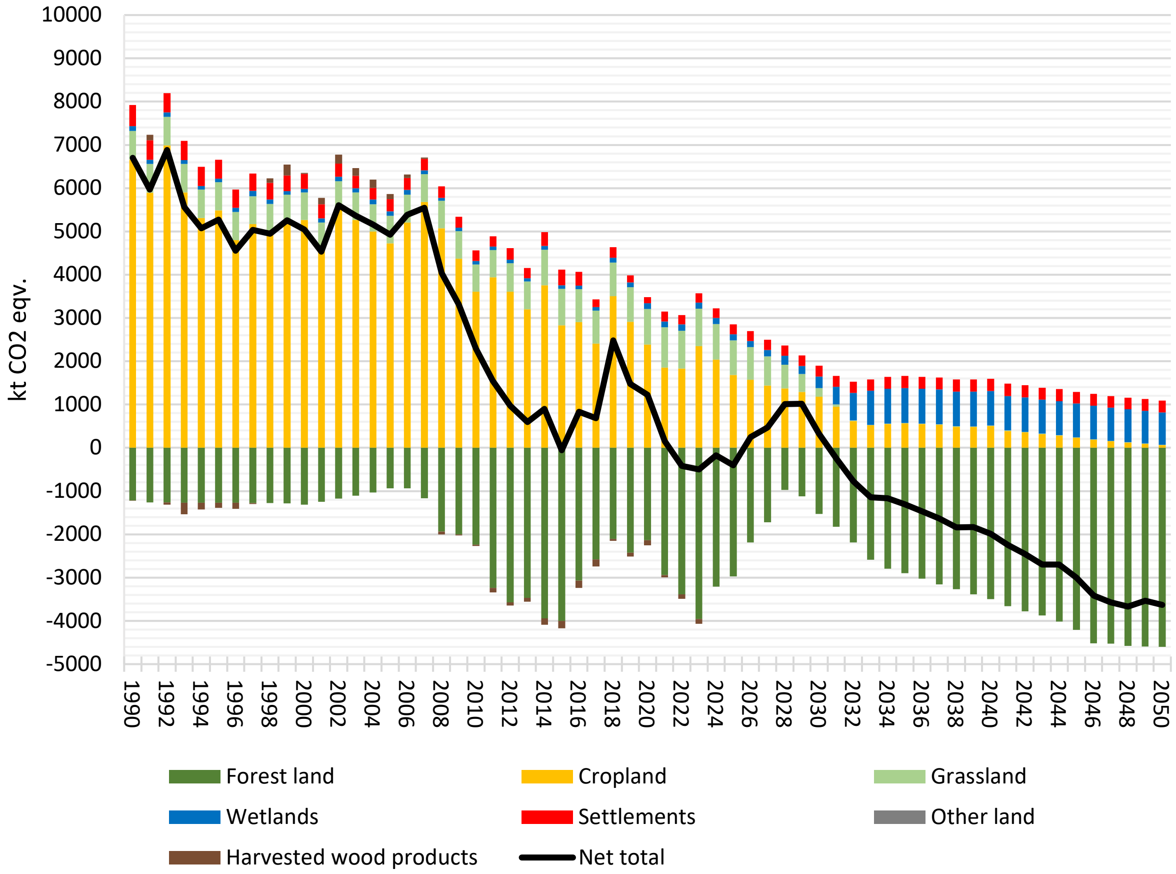

Figure 8.1 Emission estimates from the LULUCF sector from 1990 – 2050, distributed between land use categories and as net total (black line), kt CO_2e.

CL and GL are currently major sources, primarily due to the large area with cultivated organic soils in Denmark. However, drained organic soils loose carbon at a higher pace than earlier anticipated (Beucher et al., 2023), and consequently emissions from organic soils have ceased considerably over time. The steady extensification of the CL area on organic soils towards permanent GL and a large, expected conversion to WE leads to a decrease in emissions until 2050 where it is expected that almost none organic soils will be drained or cultivated. Currently, the agricultural mineral soils have been storing carbon at a rate of 200-300 kt CO_2 per year, this is expected to slightly decrease to an equilibrium state. This change is multifactorial and depends on crop grown, future yield expectations, increased temperature and C saturation in primarily the sandy clay soils where the equilibrium state is reached with the current carbon input and the degradation in the soil. In the projection of emissions from mineral soils, a dynamic temperature modelling tool (C-TOOL ver. 2.3.) is used. The overall emission from CL depends also on the cultivated agricultural area on organic soils. Due to major subsidies to rewet these soils the emission from drained organic soils in CL will be reduced in the future adding to the expected lower emission from CL. However, another important contributor to the decreasing emissions from organic soils is the loss of carbon through emissions, thus resulting in lower emissions as well as a decreasing area of organic soils.

Grassland is projected to be a declining source and cease to zero as the current emission is related to drained organic soils on permanent GL. The organic soils in GL will according to the expected WE restoration (SGAV, 2024) be water saturated before 2050 and converted to WE.

The overall trend for WE is an increase in CH_4 emissions from restored wetlands until 2035, also visible in Figure 8.1, because land converted to WE is expected to increase due to the current ongoing WE restoration program which has been running for several years and currently ongoing up until 2033 for conversion of agricultural organic soil. Simultaneously, there will be decreasing emissions from WE remaining WE, caused by an expected cease of the peat excavation in Denmark in near future.

SE is expected to have stable emission of around 250 kt CO_2 per year in the future. This is related to loss of organic matter from mineral soils. The major converted area is from agricultural land which have a relative high carbon content which will not be maintained under SE conditions. Denmark uses a linear model with 30-years transition period from when the SE is established to when the soil is in a new equilibrium state. As the conversion to SE was higher in 1970's there were a larger emission in 1990. The expected demand for SE is based on the historical demand for land over the last 10 years, which has been estimated to 2 466 hectares per year. Therefor will this source be stabilized around the loss from this average area.

The most important emission factors are given in Table 8.3. When LUC is taking place, fixed factors are used for the direct changes in biomass C. More detailed information on references, additional subcategories and emission factors can be found in the latest Danish National Inventory Report.

Table 8.3 Most important carbon stock and emission factors used in the emission inventory and projection for calculating emissions from land use conversions.

C pool	Land use category	C stock	Unit	C in t CO_2e.
Living biomass[a, b]	Cropland	5.9	t C per ha	21.8
	Grassland[c]	4.4	t C per ha	16
	Wetlands, established	6.8	t C per ha	25.1
	Settlement	2.2	t C per ha	8.1
Mineral soils	Forest land[d]	142	t C per ha	- (stock value)
	Cropland[e]	120.8	t C per ha	- (stock value)
	Grassland[f]	125.2	t C per ha	- (stock value)
	Wetlands	235	kg CH_4 per ha per yr	
	Settlements[g]	96.6	t C per ha	
Organic soils	**Land use subcategory**	**EF**		**EF in t CO_2e.**
Organic soils >6 % OC	Cropland CO_2 emission depends on Ground Water table.	7.3 NO 13	t C per ha kg CH_4 per ha per yr kg N_2O-N per ha per yr	26.9 NO 5.4
	Permanent CO_2 emission depends on Ground Water table.	4.5 16 8.2	t C per ha kg CH_4 per ha per yr kg N_2O-N per ha per yr	16.5 0.4 3.4
	Forest land, drained	2.6 2.5 2.8	t C per ha kg CH_4 per ha per yr kg N_2O-N per ha per yr	9.5 0.1 1.2
	Wetlands, periodically water covered	NO 235-288 NO	t C per ha kg CH_4 per ha per yr kg N_2O-N per ha per yr	NO 6.6-8.1 NO

NO = Not occurring.
[a] Living biomass = above ground biomass and below ground biomass. [b] The default conversion factor of 0.5 has been used to convert dry matter (DM) to carbon (C). [c] Average of grazing land and other grassland. [d] Average of all forest mineral soils (<6 % SOC, 262 plots in NFI and "Kvadratnet"). [e] Average of different Danish mineral soil types. [f] Same as for Forest land. [g] 80 % of Cropland. [j] Only for the drained area, the EF for ditches is higher (542 kg CH_4 per ha per yr).

8.2.1 Comparison with previous projection

Every year the new projection will show a slightly different picture of the projected emissions. As activity data for a new historical year is available, the projections that depend on previous averages of these activities are affected and improvements and adjustments to the calculations, models and data input also continuously affect the results.

The projection for the LULUCF sector made in 2025 differ very much to the previous projection made in 2024 due to the political agreement of a conversion of approximately 400 000 hectares of Cropland and Grassland into Forest land and Wetlands divided into an expected total afforestation of 275 000 hectares and conversion of 154 000 hectares to Wetlands within the next two decades (The Green Tripartite). The previous projection covered only to 2040.

The estimates on historical and projected net total LULUCF emissions from 1990 – 2050 from both this year's and last year's projections are presented in Figure 8.2 (whole LULUCF sector) and 8.3 (Forest sector) to visualise the difference. Especially the large expectation to wetland restoration from 2025 to 2033 gives a difference from the previous projection in 2024. For differences in the projection from the forets has only a minor effect on the carbon storage.

The total CH_4 emission for the LULUCF sector is expected to increase substantially because of the large conversion of drained organic soils – which do not or only emit CH_4 in small amounts compared to wetlands where large emission occurs.

For the whole period from 1990 to 2050, N_2O emissions are less than 1 % lower in this projection compared to that of last year.

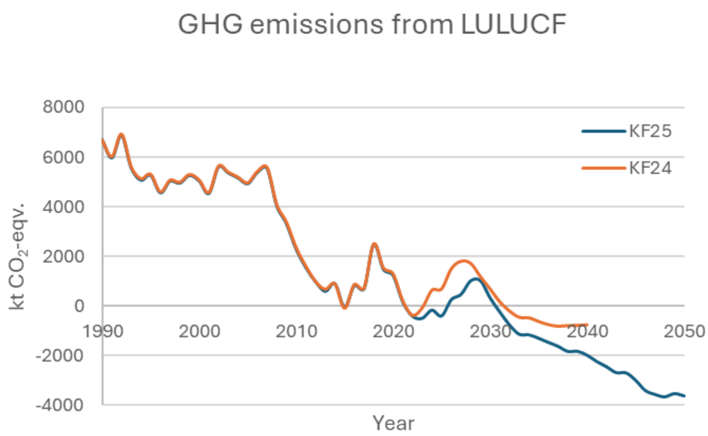

Figure 8.2 Net total emissions from the LULUCF sector from 1990 – 2050 in the 2025 projection (blue line) and last year's 2024 projection (red line).

8.3 Forest land

The Department of Geosciences and Natural Resource Management at the University of Copenhagen (IGN) is responsible for the reporting and projection of GHG emissions from the Danish forests and Harvested Wood Products (HWP, see section 8.10) (Nord-Larsen et al., 2025a). The Danish Forest projection to 2050 is reported in Nord-Larsen et al. (2025b) and also shown here in Figure 8.3. The Land Use Matrix developed by Institute of Environmental Science at Aarhus University to assess LUC is the same in this report as in the forest projection report. Christmas trees grown on agricultural soils are included in FL.

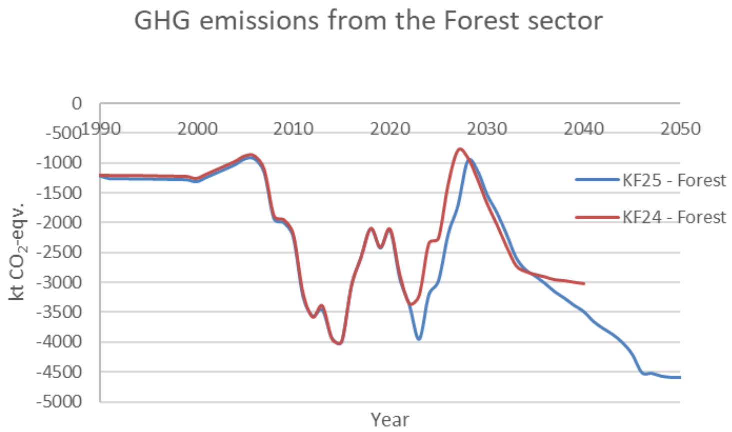

Figure 8.3 Net total emissions from the Forest sector from 1990 – 2050 in the 2025 projection (blue line) and last year's 2024 projection (red line).

Since 1990, the forested area has increased. This is expected to continue in the future, as an effect of Danish policy aims to increase the forest area. The afforestation rate is based on data received in February 2025 from the Agency for Green Transition and Aquatic Environment. Afforestation is expected to increase considerably since the last projection as a total afforestation of 275 000 ha before 2045 is projected, which gives an annual afforestation rate of 13 500 ha per year. From 2045 no further afforestation is included as the projection is based on existing funding schemes and no plans go beyond 2045. The Danish forests are well protected, and only limited deforestation is expected to occur – around 350 ha per year. The deforestation taking place 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 which are reclassified in the Land Use Matrix. These spaces are essentially converted into Grassland.

The forest projection is based on an individual tree-based approach, see Nord-Larsen et al., (2025b).

8.4 Cropland

Agriculture occupies a major part of the Danish territory. In total, approximately 2.7 million ha are utilised for agricultural activities.

CL is subdivided into four types of land use: Agricultural CL, Woody agricultural CL, which is fruit trees and willow on CL etc., hedgerows and small biotopes and "other agricultural land". In the inventory and in the projection, the latter is defined as the difference between the projected agricultural area and the CL area defined by the land use matrix. The majority of the CL area is the agricultural cropland, which is mainly cultivated with annual crops such as cereals, rape seed, fodder beets and grass in rotation.

8.4.1 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 (DSt, 2025) the area with agricultural crops has declined with 141 000 ha from 1990 to 2000, or 14 100 ha per year. From 2000 to 2010, the reduction in the area with agricultural crops was reduced with 600 ha. Likely, this development is mainly caused by a change and widening of the EU subsidiary system, which has resulted in more agricultural CL registered in the application schemes than previously, and hence reported in Statistics Denmark. From 2010-2023, the area with agricultural crops on average declined app. 1800 ha per year (DSt, 2025).

The figures from the LUM, which are applied in the projection, are more conservative as land will remain in the original category (here CL) until it is identified or registered as another land use category. From 1990 to 2023, 229 500 ha have left CL with higher rates in the 2000s than in the 1990s and again increasing in the 2010s. The increased conversion of agricultural land to other land uses is mainly due to a larger need for land to SE and other infrastructure, thus seeing rates of app. 1924 ha going from CL to SE in the period 2014-2023 and 395 ha from GL to SE These averaged yearly conversion to SE is continued in projected years 2024-2050.

For the projected distribution of the common cash crops and the total projected agricultural area, the AGMEMOD model is used, see Chapter 6 for more details. In most recent years, the LUM shows that approximately 4800 ha per year are converted from CL to other land use categories and the remaining is reported in CL or GL as the AGMEMOD projection includes the development in both CL and GL areas. An inter-annual conversion between CL and GL and vice versa is estimated at zero ha per year for technical reasons.

8.4.2 Methodology

In CL, three different C pools are accounted for: living biomass (above ground living biomass and below ground living biomass), dead organic matter, and soil organic carbon (SOC). Dead organic matter is only considered in conversions from Forest land (counted as a loss in CL).

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 of the C stock for living biomass in annual crops is defined based on the average cereal harvest yield over 10 years from 2000 to 2009, which gives a carbon stock in living biomass of 5.9 tonnes C per ha. This is the average used for land use conversions both to Cropland (as a gain in CL) and from Cropland (as a loss in the new land use category). As is apparent from Table 8.3, the living biomass is higher in CL than both GL and SE, which is why a reduced total area with agricultural CL, is expected to cause an average net loss of biomass even though the loss is partly counteracted by an increase in the amount of living biomass in the land class to which it is converted. Afforestation also causes an immediate loss of biomass instantly oxidised.

8.4.3 Mineral soils

The change in SOC in mineral agricultural soils is estimated with the model C-TOOL (Ver 2.3) (Taghizadeh-Toosi, 2015). C-TOOL is used for all mineral soils collectively for CL and GL with area input from the digital field maps and data (Land Parcel Information Data, LPIS), as delivered by the Danish Agricultural Agency, a part of the Ministry of Food, Agriculture and Fisheries of Denmark, and yield data from Statistics Denmark. Changes in SOC stocks in areas that are registered as CL or GL in the LUM are therefore included in the SOC stock change of CL. 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 amount of volatile substances (carbon compounds) applied to the soil with animal manure 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.

8.4.4 Crop yield

The projected crop yield is based on historical crop yields in the period 2006-2023, which have been converted to five-years average (e.g. 2006-2010, 2007-2011 etc.) to establish a linear trend. Based on this linear trend a reference yield is estimated for 2021 on which the projection is performed. This determines only the yield in the projected years.

In 1998 policy makers in Denmark introduced a restriction on the amount of nitrogen the farmers can apply to the soils. This policy was partly abandoned in 2016, meaning that farmers are now less restricted in their N fertilization. Hence, the historical yields from 2006 to 2015 were lower compared to now. A technical yield correction of the observed yields for 2006-2015 has been made to improve the projection. This results in an estimate for all cash crops of 0-0.4 Hkg kernel per ha per year, which is the average nitrogen corrected yield increase. Compared to last year's projection, the expected future yield increase is a bit lower in the new projection.

8.4.5 Catch crops

Presently, a re-evaluation of the Danish agricultural regulation is ongoing, aiming to move from a general more evenly distributed regulation to an emissions targeted regulation on farm level. This change will affect the future area with especially catch crops to reduce nitrogen leaching. Catch crops grown on approximately 212 000 ha in 2010, increased to 451 000 ha in 2023. In 2030, the expected area is 606 000 ha (SGAV, 2025a); each year adding biomass to the SOC stock. Compared to last year, the projected area with catch crops has been reduced.

8.4.6 Straw removal rate

Removal of straw from the fields is used as input in C-TOOL to estimate the amount of C added to the soil. Data from Statistics Denmark (DSt, HALM1), which covers straw for both energy, feed and bedding purposes, is used in the historical inventory. Removal of straw for energy purposes is currently very difficult to project. In the projection is used data from Danish Energy Agency on the energy yield from burned straw in PJ converted to amount of biomass. Removal for feed and bedding is still projected from the statistics in HALM1, as an average of the last three years now further adjusted according to the projection of cattle livestock (slight decrease).

8.4.7 ECO-schemes and projected crop distribution

A couple of the eco-schemes implemented in the CAP (common agricultural policy) system are reflected in the LULUCF projections if they influence crop distribution significantly. This year's projection is affected by the eco-scheme on biodiversity, the eco-scheme for extensification towards permanent grass, regulations in the gross national model, and the GLM8 requirements for farmers to leave a minimum of 4 % of their cultivated land as non-productive areas. These all lead to a reduction of the cultivated agricultural area. Not all areas regulated through the schemes are included directly, as it is assumed that most land is either already non-productive or peripheral areas or is already categorised as grass in the LUM. The LUM and its categorisation of land as either CL or GL is not affected by the eco-schemes.

Organic agriculture is reflected in its historical impact on the compiled yield and crop distribution, which are not at this point differentiated between organic and conventional agriculture.

8.4.8 Temperatures

In the projection, observed temperatures have been used including December 2024. 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). The natural observed variation in the monthly temperature data from 1998 to 2023 has been added to include the effect of annual variation. The outcome of the projected model therefore is not strictly linear in an attempt to include natural variation, as shown in Figure 8.4. C-TOOL is run with 10 different randomly selected temperature projections up to year 2050, and the output used in the projection presents the average values of these.

8.4.9 Results from C-TOOL on C stock in mineral soils

Presently, the clay agricultural soils are considered to be in a near steady state of soil carbon equilibrium. The sandy soils, primarily located in Jutland are expected to increase their carbon stock further. In total, the agricultural mineral soils are expected to constitute to be in a carbon neutral balance in the period up to 2050. Figure 8.4 shows the reported and expected annual emissions from mineral soils in kt C per year. Due to high yields in most recent years, a sink has been estimated in most years from 2010 and forward. The emissions from agricultural mineral soils are projected to stay relatively stable until 2050 with a slight tendency towards net removals. Year 2018 was extremely dry with low yields and hence an estimated decrease in C stock and a large emission.

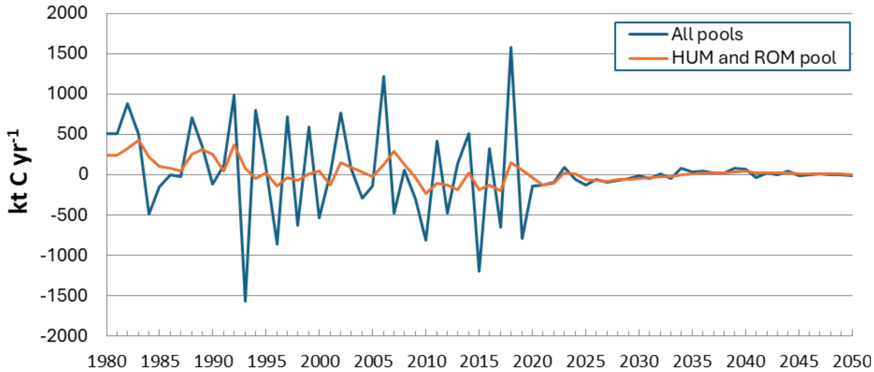

Figure 8.4 Annual emissions of C from mineral soils in Cropland and Grassland. Negative numbers indicate net storage and a CO_2 sink effect.

8.4.10 Organic soils

The emissions from organic soils in the land use categories CL and GL are based on a new developed emission model which takes into account the distance to the ground water table in the organic soils. For a further description see Gyldenkærne et al. (2025). The model is a pixel-based model with a 10*10 m resolution where the apparent emission in each pixel is estimated. The total annual emission is then the sum of the included pixels. The estimated emission in each pixel depends on the C content, the depth of the organic profile, the distance to the ground water table combined with a s-shaped emission function (often denounced as a Gompertz-function). The function has a minimum and a maximum emission. The maximum emission is estimated to 10 tonnes C per ha (Elsgaard, 2024). The minimum emission is set to 0 (zero). No differences can be found in the emission between land use, crop in rotation versus permanent grassland when taking the ground water table into account, so the model is used for all organic soils with > 6 % organic carbon (OC). For thin organic layers (<= 30 cm) is the maximum emission reduced to 75 % of the maximum.

The area of organic soils grown with annual crops or grass in rotation, defining a certain drainage level causing emissions, is based on data from the EU subsidy register used in a combination with the map of organic soils in 2022 (Beucher et al., 2024). Soil maps were produced representing 1975, 2010 (Adhikari et al., 2013; Greve et al., 2011), and again for 2022. Both the 2010 and 2022 maps showed a decrease in the area with organic soils in Denmark and are assumed to have a high accuracy. In 1975, 237 500 ha agricultural land was registered as having ≥ 6% OC. Using the 2010 boundary of agricultural land (thus including both CL and GL) in the LUM on top of the 2010 map, the number was reduced to around 180 000 ha, which for 2022 using the 2022 LUM was reduced further to 117 000 ha with > 6% OC in total. This large decrease is attributed to the fact that the Danish organic soils are very shallow and thus "disappear" because they are depleted for organic matter as cultivation and drainage initiates the C decomposition process. For the projection, it is assumed that the organic soils that are below 34 cm in thickness continue to lose carbon, thus the organic area is projected to decline to 73 000 ha organic soil in 2030 and to 54 000 ha in 2050 with wetland restoration. Organic soils with a depth of >34 cm are assumed to maintain the OC % content as these soils are assumed to have a deep horizon where the OC content does not change. However, as a very large effort on wetland restoration in the coming years is expected, the above-mentioned remaining hectares of drained agricultural organic soils without wetland restoration is expected to be reduced to only 681 hectares in cropland in 2050.

Conversion of organic soils into WE is accelerating the speed in the emission reduction from the drained agricultural organic soils. In the period 2024-2033, 70 542 ha agricultural soils (CL and GL) are expected to be converted to WE. Section 8.6.2 describes the conversion of CL and GL to WE.

For an overview of the most relevant emission factors related to organic soils, most of which are from the 2013 Wetland Supplement in IPCC (2014), see Table 8.3. For CO_2 from organic soils, a new approach was implemented in 2025 for the inventory years up to 2023 (Gyldenkærne et al., 2025) where the emission is estimated on a 10*10 m level where the % OC content, peat depth and ground water table is combined with an s-shaped emission model.

For CH_4 is used the previous used set-up with a default CH_4 emission factor of 16 kg per ha per year for soil having > 12 % OC and soils with 6-12% OC are given emission factors which are half of that of the soils with > 12% OC, as very few measured values can be found in the literature for the medium or low C organic soils. N_2O emissions from CL and GL are reported in the agricultural sector, Chapter 6, and therefore not reported here. IPCC (2014) is also the source for the emission factor for leached carbon, i.e. off-site CO_2 emissions via drainage related waterborne carbon losses. For more detailed information see the latest National Inventory Report on greenhouse gas emissions.

The total area with organic soils in CL and GL and their emissions reported is shown in Table 8.4.

Table 8.4 Areas and LULUCF emission from organic soils in Cropland and Grassland, 1990-2050.

	1990	2010	2020	2023	2025	2030	2035	2040	2050
Cropland, registered fields > 6% OC, ha	182312	149675	87618	72756	66418	45797	17219	10815	681
Grassland, > 6% OC, ha	30761	30761	39790	40935	38892	9900	0	0	0
Cropland and Grassland, total, ha	213073	180436	127408	113691	105310	55698	17219	10815	681
Emission, from agricultural land, kt C	1555.1	1285.7	821.5	711.8	656.5	373.7	126.4	80.0	5.5
Emission from leached C, kt C	61.9	61.4	35.3	36.0	19.6	15.1	4.7	3.0	0.2
CH_4, kt CH_4	13.6	11.7	9.0	8.2	7.7	3.6	1.0	0.6	0.0
Emission, total, kt CO_2-eqv.	6144.8	5103.5	3298.6	2876.1	2641.0	1487.0	496.3	313.9	21.5

The CO_2 emission from agricultural cultivated soils has been reduced by around 53 % from 6145 kt CO_2e in 1990 to 3327 kt CO_2e in 2023. It is expected to continue to decrease with an estimated emission in 2030 of 1487 kt CO_2e, equivalent of a total reduction since 1990 of nearly 76%.

8.4.11 Perennial woody crops

Perennial woody crops cover fruit trees, fruit berry and nut plantations and energy crops such as willow, grown on CL. Fruit and nut trees are marginal in Denmark and cover only around 4000 ha in 2023, based on data from the land parcel information system and agricultural register. No changes in the area with fruit trees are expected and so projected based on the average of the last five years. The area with willow as energy crop is expected to be stable with 4 959 ha as in 2023, as there are currently no incentives to increase the area. The area has only minimal effect on the emission estimates, as it is harvested every 2-3 years and thus no larger amounts of C in living biomass is present in willow plantations.

8.4.12 Hedgerows and small biotopes

The area with hedgerows and small biotopes, which do not meet the definition of forest, is today around 100 000 ha within the defined CL area. An analysis has shown that the area has not changed significantly over the past 20 years, although there is a large dynamic in the landscape as old hedgerows are removed and replaced with new ones to facilitate new farming strategies. Establishing hedgerows and small biotopes are partly subsidised by the Danish government. An annual increase of 50 ha new hedges is assumed in the projection.

8.5 Grassland

GL is defined as permanent grassland and areas with perennial vegetation that do not meet the forest definition and includes areas such as heath and grazing land, which are not reported in any of the other land use categories. This GL definition differs from the one used by Statistics Denmark for permanent GL, which does not include heath land and other marginal areas. Therefore, areas reported here for GL are not comparable to data from Statistics Denmark. The Danish reporting is based on information from the land parcel information system and agricultural register as registered by the farmers for the EU subsidy schemes (LPIS). In this system, the actual crop grown on each field is known. Furthermore, a relatively large area, which should be considered as GL are included in the CL area of technical reasons. This allocation has no influence on the emissions as the emission from mineral soils are modelled as a whole based on LPIS information, emission from organic soils is only dependent on the ground water table regardless of the allocation in CL or GL and hedges and all other perennial wooden crops are reported in the CL sector.

A total of 187 000 ha is reported in the GL category in 2023. The area is expected to decline slowly in the future due to conversion into Wetlands.

N_2O emissions from cultivated GL are reported with the agricultural sector in Chapter 6.

Drained GL will continuously be a net source of greenhouse gas emissions but as the allocation has no impact on the emissions in the projection are they reported in the previous chapter 8.4 under Cropland.

8.6 Wetlands

Wetlands (WE) are subdivided into flooded wetlands, defined as lakes and other permanently water covered areas, periodically water covered areas, such as peat extraction areas, fens and bogs. The wetlands with the significant emissions are the peat extraction and the restored wetlands, which can be restored into both flooded and periodically water covered areas. Emissions from wetlands occurring before 1990 are not reported. Due to the intensive utilisation of the Danish area for farming purposes and thus intensive efforts historically to drain WE, WE restoration has taken place for many years for environmental reasons, to restore habitats, reduce nutrient leaching and more recently to reduce greenhouse gases as rewetting halts the C decomposition.

8.6.1 Peat land

Peat excavation is taking place at three locations in Denmark, and all sites are managed by Pindstrup Mosebrug A/S. In total, it is estimated that 800 ha are under influence of the drainage from the peat excavation, although the current open area for peat excavation is around 300 ha. Pindstrup Mosebrug A/S is operating under a 10-year licence, which has recently been renewed, and it is not expected to be extended further (Pindstrup Mosebrug, pers. com). It is therefore not expected that any major changes will take place until the new licence expires in 2028 and activity data therefore is projected based on the latest five years historical average from the three sites. 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. The total amount of peat excavated is decreasing and has been reduced almost 60 % from 399 000 m^3 in 1990 to 138 000 m^3 in 2023.The total emission from peatland is estimated to 32 kt CO_2, 0.0266 kt CH_4 (0.7 kt CO_2e) and 0.0004 kt N_2O (0.1 kt CO_2e) in 2023.

8.6.2 Restored Wetlands

Only emissions from re-established WE are included in the WE category. Emissions from naturally occurring wetlands have not been estimated. Some larger Restoration projects were carried out in the 1990s. Until 2023, a total of 23 232 ha was converted to WE. It is not possible to give a full picture of the area with organic soils, which were converted as there are two maps, one for 2010 and one for 2022. Based on an analysis of the maps, it is considered that 50 % as organic soil in the period 2011 to 2021. A low fraction of organic soils in the historical conversions is explained by the fact that a large share of former wetlands restoration projects were targeted reductions of nitrogen leaching on mineral soils and not targeted organic soils.

Agreement on a Green Denmark. (2024) lays out the detail for the projection. Until 2033 it is expected that 140 000 ha of wetlands will be restored on current CL and GL. areas. Of these, it is expected that 35 000 ha will be outside the actual field boundaries, 35 000 ha will be on mineral soils, and the remaining 70 000 ha will be on organic soils inside the field boundaries.

The combined extensification with existing plans sums up to 155 669 hectares of wetland restoration mainly on CL and GL areas from 2024 to 2033. Of these is expected are 70 542 ha on organic soils.

There has been a large variation in the area converted to restored WE within the past years. In the projection, up to 15 350 ha is expected to be converted to WE in a single year in the period up to 2032 (Table 8.5). Starting 2033, no further wetland restoration is projected to take place as no further funding has been decided upon.

The new areas of WE are distributed between the existing subcategories of flooded WE (lakes) and periodically water covered WE. In the projection, it is assumed that 90 % is converted to periodically water covered WE and 10 %

into flooded area. It is furthermore assumed that the WE restoration will take place on Grassland and Cropland in accordance with the latest distribution of restored land to WE. These data shows that 76 % of the restored WE were on GL and the remaining 24 % on CL.

The new partly water covered WE are assumed to be in a net zero balance in terms of the soil C stock. This means that no losses or gains are assumed in the soil, as the C decomposition is halted by the waterlogged conditions. Only emissions of CH_4 are reported, applying the emission factor from 2013 Wetlands Supplement with a net emission of 288 kg CH_4 per ha per year for soils >12 % OC, and 235 for mineral soils (0 – 12 % OC). This has been implemented in the projection for partly water covered WE, but not for lakes and other fully water covered areas.

The projection considers restoration of WE in the governmental budget of the Danish Finance Act (FA) as received from SGAV in December 2024. The exact numbers are estimated by the SGAV based on historical data on various wetland restoration projects and expenses. In the present projection effect is assumed implementation after 5 years. The expected total converted organic agricultural land converted to WE from 2022 to 2032 is shown in Table 8.5.

Table 8.5 Expected agricultural areas (CL+GL) converted to Wetlands (WE) in certain years and in total from 2024-2033 with public funding, ha (SGAV, 2025b). The expected share of organic soils is included in the presented numbers to reflect the effect on organic soils.

Wetland scheme and funding[a]	% Organic soil	2025	2027	2029	2030	2031	2032	2033	Total conversion to WE 2024-2033
Organic soil scheme (Rural Development Program)	60	828	3383	3793	24237	23083	27555	5462	90 100
Organic soil scheme +22000 (CAP + national)	60	0	0	10450	0	0	0		24 499
Nitrogen Removal Wetlands	40	894	1696	1624	1580	1580	1580		14 509
Phosphorus Removal Wetlands	60	0	117	121	109	109	109		701
Finance Act '20, organic soil	60	1905	2572	1412	4293	4042	0		17 805
Finance Act ’21, organic soil	60	0	3563	0	0	0	0		6 056
Accumulated Wetland restoration (incl. 2021)		6799	25359	59929	90149	118963	148207	153669	153 669

[a]In Danish: Lavbundsordning uk.29 kollektive (LDP-ordning), Lavbundsordning + 22000, Kvælstofvådområder uk.34, Fosforvådområder uk.39, Finanslov 2020 lavbund, Finanslov 2021 Lavbund (5000 ha).

The overall expected emission trend for Wetlands is shown in Table 8.2 and 8.6. In recent years, the emissions from WE have been increasing to 140 kt CO_2e in 2023 and are expected to increase to 369 kt CO_2e in 2030 and to 800 kt 369 kt CO_2e in 2035, primarily due to the increase in CH_4 emissions from the organic soils with restored WE. The negative emissions of CO_2 (sink effect) occur in years with large conversions of CL/GL into WE, as an instant effect of the higher C stock in living biomass for WE compared to CL/GL, see Table 8.2. N_2O emissions are minor and assumed not to occur on restored WE, so these are halted as peat extraction activities end by 2028.

Table 8.6 Expected emissions from WE from 1990 to 2050.

Wetlands	1990	2010	2020	2023	2025	2030	2035	2040	2050
Flooded area, lakes, 1000 ha	59.4	61.2	64.9	67.0	67.7	76.0	82.3	82.3	82.2
Periodically water covered, 1000 ha	48.2	49.2	58.6	63.7	70.7	145.7	202.8	202.8	202.8
Peat extraction area, 1000 ha	1.6	1.6	0.8	0.8	0.8	0.0	0.0	0.0	0.0
Wetlands, total, 1000 ha	109.3	112.0	124.3	131.5	139.1	221.6	285.1	285.1	285.0
Managed Wetlands, Living and dead biomass, kt C	0.0	2.2	3.8	-5.9	-8.5	-32.0	0.0	0.0	0.0
Peat extraction, soil organic matter, kt C	29.8	15.4	12.7	11.0	11.6	0.0	0.0	0.0	0.0
Total, kt C	29.8	17.6	16.5	5.0	3.1	-32.0	0.0	0.0	0.0
CH_4, kt CH_4	0.1	0.7	3.1	4.3	4.8	13.8	28.8	28.5	26.5
N_2O, kt N_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C, kt CO_2e	109.1	64.5	60.4	18.5	11.5	-117.4	0.0	0.0	0.0
CH4, kt CO_2e	1.5	19.7	85.6	120.9	134.0	386.6	806.9	798.6	743.3
N2O, kt CO_2e	0.2	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Total, kt CO_2e	110.8	84.5	146.1	139.5	145.6	269.3	806.9	798.6	743.3

When WE establishment is taking place on soils that are already fairly wet and not on fully drained agricultural organic soils, the emission reduction effect of restoring them as wetlands is lower, because the baseline emissions are also lower. Based on experience from established WE restoration projects, it can be concluded that this is the case for a high share of the planned conversions.

8.7 Settlements

The need for areas for housing and other infrastructure has resulted in an increase in the SE area of 58 954 ha or around 1700 hectare per year on average from 1990 to 2023. As there were large building activities in the 1960s and 1970s and hereafter a decreased activity, the emission in land converted to SE was high in 1990 and has now decreased to a steady emission estimate of just below 300 kt CO_2 equivalents per year in the projection up until 2050. It is assumed that the historical increase in SE will continue in the future and mainly result from conversion of CL. In the projection, an annual conversion is assumed of 2466 ha per year which is the average conversion to SE in the last ten years from 2014 to 2023 (aside from FL).

The overall expected emission trend is shown in Table 8.2. Land converted to SE is reported as a source of CO_2 because the C stock of both soil and living biomass in the other land use categories are higher than in SE areas. In GL and CL, the C stock of mineral soils is 125.2 and 120.8 t C per ha respectively. When converted to SE, it is assumed that a new equilibrium of 96.7 t C per ha is reached after 30 years. Consequently, the C loss and emissions from converted soils are distributed and will continue for many years after the original conversion.

8.8 Other Land

Other Land (OL) is defined as sandy beaches and sand dunes without or with only sparse vegetation and rocks. The total estimated area is 26 424 ha, kept constant in all years. No changes in the area are projected. The C stock in these soils is very low and almost absent in terms of living biomass and no emissions are reported or expected from these areas.

8.9 Fires

Forest fires are very seldom in Denmark and only occur as wildfires. An average between 0 and 2 ha is burned per year. Controlled burning of heathland to maintain the heath is carried out by the Danish Nature Agency, who also collect data on both wild and controlled fires. Around 400 ha have been burned annually over the last 20 years. 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 emission factors for CH_4 and N_2O are taken from the 2006 IPCC Guidelines. The emissions are negligible at 0.01 kt CO_2e in 2023 and 0.03 in 2030, projected based on the moving average number of ha from the previous five years. They are included in Forest land and for heath in Grassland in Table 8.2.

8.10 Harvested Wood Products

The category Harvested Wood Products (HWP) covers C stored in wood products in the categories sawn wood, wood-based panels and paper. Since 1990 the category has functioned as a small sink of C, equivalent in 2023 of 111.0 kt CO_2. The historical and projected emissions are reported by IGN in Nord-Larsen et al. (2025) and Johannsen et al. (2022) respectively.

8.11 Emission

The total emissions from all sources from 1990 to 2050 were shown in Table 8.2 and Figure 8.1.

The overall picture of the LULUCF sector was a net source of 6699 kt CO_2e in 1990. In 2023, the estimated emission had been reduced to a net sink of 500 kt CO_2e, increasing to be a net source 322 kt CO_2e in 2030 and then converted into a net sink due to the reduced emission from the drained organic soils and a net uptake of CO_2 in the Danish forest

Because Denmark has a high share of agricultural land, most LUCs are from CL to other land use categories. CL has higher C stock of living biomass compared to most land use categories, except for FL and conversion of CL into other categories with a lower amount of living biomass like urban areas, will therefore cause an overall loss of C in living biomass. These loss/gains are only occurring when land use changes occur and play only a limited role in the overall emission estimates.

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

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

8.12 Recalculations

Recalculations have been made in all sectors due to updated parameters and other settings. See the relevant sections.

8.13 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.

A further increase in the carbon stock in mineral agricultural soils will be difficult to obtain without a substantial change from annual crops to grass in rotation.

The highest inter-annual uncertainty relates to the use of the dynamic model for estimating the degradation of Soil Organic Matter, C-TOOL. The input data depends on actual harvest yields and the degradation on future temperature regimes in combination with a low annual change compared to a very large C stock in the soil. The total C stock in the agricultural mineral soils has been estimated to approximately 312 Tg C, which is equivalent to 1 100 million tonnes of CO_2. Even small changes in the parameters may change the emission prediction substantially. The average temperature in Denmark was very high in 2006-2008 whereas the average temperature decreased in 2009 and 2010 (Figure 8.5). 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. Similarly, the very high summer temperatures of 2018 caused relatively high emissions 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 relates 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.

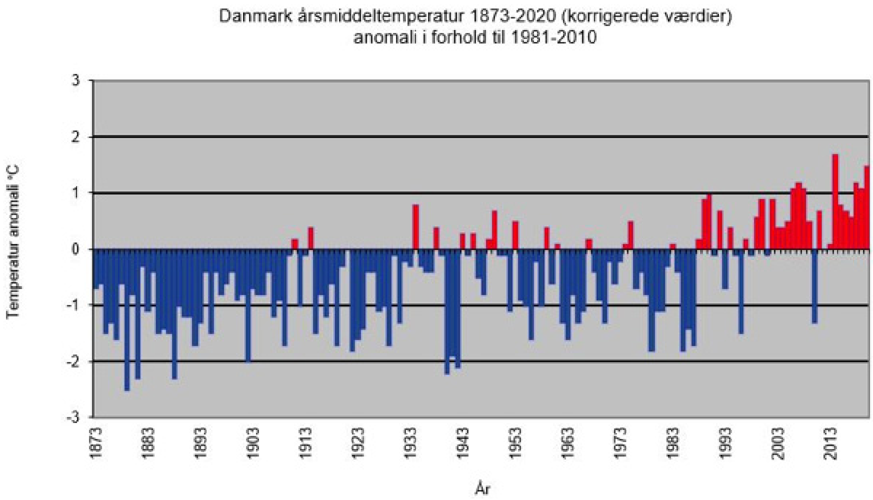

Figure 8.5 Annual change in temperature in Denmark 1873 to 2020 in relation to 1981-2010 (Cappelen, 2020).

8.14 The Danish commitment under the European Union in the second compliance period up until 2030

The Danish emission reduction commitment under the European Union for the LULUCF sector is laid down in EU regulation 2018/841 (European Union, 2018). This regulation has been updated in 2023 in EU regulation 2023/839 (European Union, 2023). The original reduction commitment in 2018/841 was based on the base year average emission of 2005-2009 covering the forest sector, cropland and grassland in 2021-2025 and inclusion of wetlands in 2026-2030. The updated 2023/839 regulation (European Union, 2023) is unchanged for the period 2021-2025 and substantially altered for the period 2026-2030. As this section is about the 2030 target, the first compliance period of 2021-2025 is not covered here.

The 2023/839 regulation has changed the base year to the average of years 2016-2018 and now includes all LULUCF sectors, instead of only FL, CL, GL, and WE. Furthermore, reduction targets have been set for all EU member states. The total EU reduction commitment of 310 million kt CO_2 eqv. is split between the member states in Annex III of the updated regulation (European Union, 2023). In Annex III Denmark has a reduction commitment of 441 kt CO_2e in the LULUCF sector from average 2016-2018 to 2030 following a linear trajectory path from 2022. This means that the average 2016-2018 emissions level of 1 362 kt CO_2e must decrease to 921 kt CO_2e in 2030, following a linear trajectory that determines a budget of allowed emissions between 2026-2029. If the accumulated budget is not met, the reduction commitment for 2030 is increased. The new regulation has included a multiplier for the target which will be calculated in the following way: "108 % of the gap between a Member State's budget for 2026 to 2029 and the corresponding net removals reported will be added to the figure reported for 2030 by that Member State" (European Union, 2023).

The total projected Danish emissions for the LULUCF sector are shown in Figure 8.6 and Table 8.7.

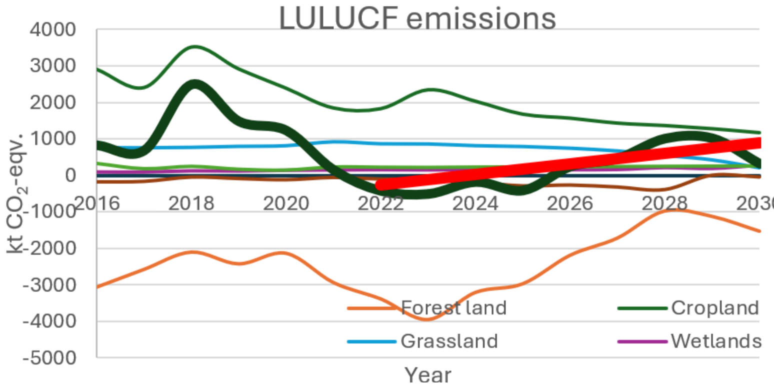

Figure 8.6 Reported and projected emissions from 2016 to 2030 for the LULUCF sector displayed along with the linear target (red line) necessary to meet EU commitments for the compliance period 2026 - 2030.

As can be seen from figure 8.6 and Table 8.7, Denmark will likely fulfil its EU reduction commitment with the current projection, as emissions are projected to follow the linear trajectory in 2026-2029.

Table 8.7 Historical average for 2016-2018 and emission for the LULUCF sector in 2023 and projected for 2026-2030 in kt CO_2e per year.

Land Accounting Categories	Base year average 2016-2018	2023	2026	2027	2028	2029	2030
Forest land	-2583	-3957	-2191	-1718	-973	-1123	-1530
Cropland	2939	2346	1575	1440	1374	1289	1180
Grassland	766	869	750	672	547	419	196
Wetlands	93	139	144	150	203	179	269
Settlements	246	213	231	236	241	246	251
Harvested Wood Products	-127	-111	-260	-315	-383	5	-44
Projected Net TOTAL	1333	-500	248	466	1009	1015	322
Linear target line		31	175	318	462	605	749
Projected target gap		532	-73	-148	-547	-410	427

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9 Conclusions

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

The historic and projected GHG emissions are shown in Figure 9.1. Projected GHG emissions include the estimated effects of policies and measures implemented or decided as of December 2024 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 2023 are Energy industries (17 %), Transport (30 %), Agriculture (28 %) and Other sectors (9 %). 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 2023 are estimated to be 38.8 million tonnes CO_2 equivalents including LULUCF and indirect CO_2 and the corresponding total in 2050 is projected to be 11.4 million tonnes CO_2 equivalents. From 1990 to 2023 the emissions decreased by 51.0 %. From 2023 to 2050, the emission is projected to decrease by approximately 71 %.

The total greenhouse gas emissions in 1990 including LULUCF and indirect CO_2 is estimated at 79.2 million tonnes of CO_2 equivalents and the emission in 2030 is projected to be 25.6 million tonnes of CO_2 equivalents including LULUCF and indirect CO_2. This corresponds to a reduction of 67.7 % between 1990 and 2030. The effect of carbon capture and storage (CCS) in the projection is not attributable to any sector and not included in this figure.

In 2005, the emissions including LULUCF and indirect CO_2 is calculated to 72.9 million tonnes of CO_2 equivalents. It decreased by 48.0 % from 2005 to 2022 and is estimated to be reduced by 60.6 % from 2005 to 2030.

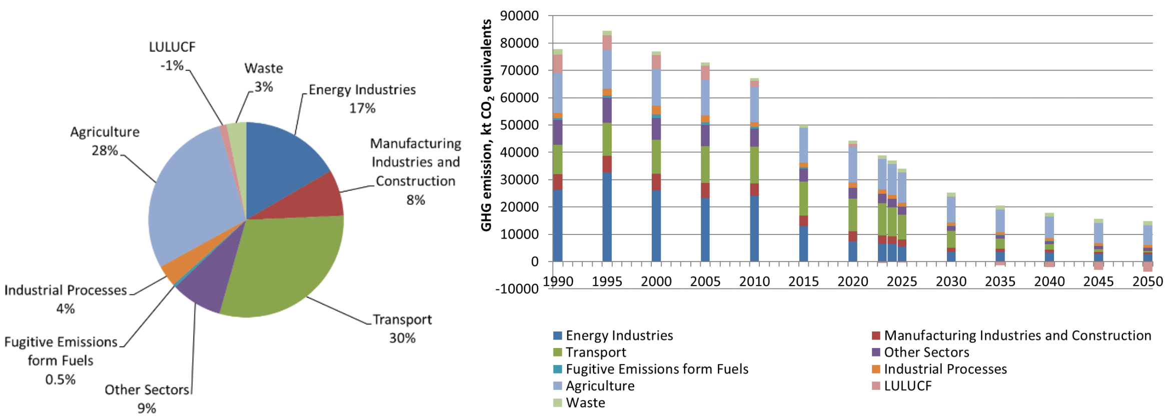

Figure 9.1 Total GHG emissions in CO_2 equivalents. Distribution according to main sectors (2023) and time series for 1990 to 2050.

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 2023 from the main source, which is public power and heat production (45 %), are estimated to decrease in the period from 2023 to 2050 (57 %) due to a significant decrease in the fossil fuel consumption for electricity production in the later part of the time series. For residential combustion plants, a significant decrease in emissions is also projected; the emissions are expected to decrease by 96 % from 2023 to 2050, due to a lower consumption of fossil fuels. Emissions from manufacturing industries decrease by 83 %, also due to a decrease in fossil fuel combustion.

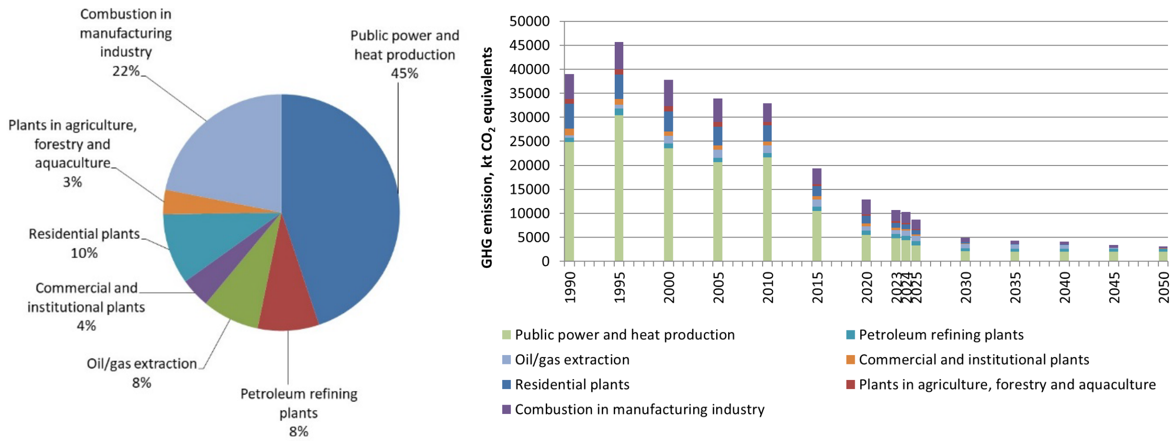

Figure 9.2 GHG emissions in CO_2 equivalents for stationary combustion. Distribution according to sources (2023) and time series for 1990 to 2050.

9.2 Fugitive emissions from fuels

The greenhouse gas emissions from the sector "Fugitive emissions from fuels" show large fluctuations in the historical years 1990-2023, 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 2023-2050 by 88 %. The emissions from flaring are increasing in the first part of the projection period due to restart of production at the Tyra field after renovation. However, the emissions decrease again. 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.

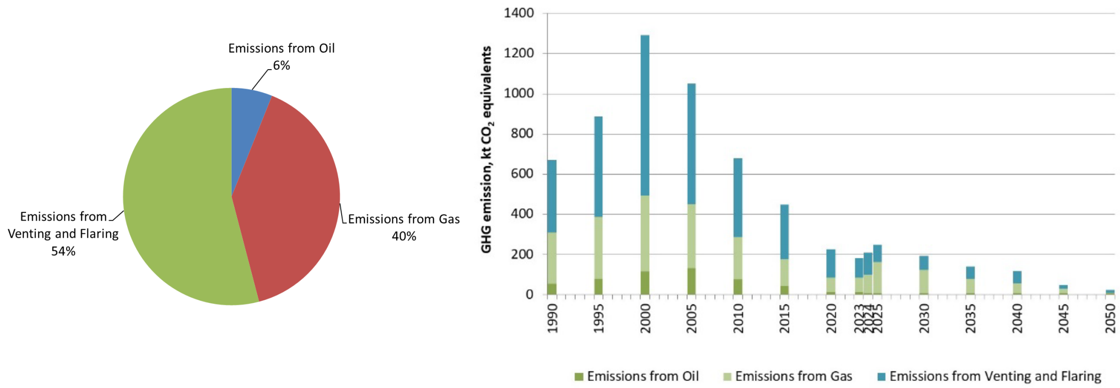

Figure 9.3 GHG emissions in CO_2 equivalents for fugitive emissions. Distribution according to sources for 2023 and time series for 1990 to 2050.

9.3 Industrial processes and product use

The GHG emission from industrial processes and product use (IPPU) 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 2023 are mineral industry (mainly cement production) with 69 % and use of substitutes (F-gases) for ozone depleting substances (ODS) (18 %). The corresponding shares in 2050 are expected to be 84 % and 0 %, 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 emissions from the IPPU sector will continue to be strongly dependent on the cement production at Denmark's only cement plant.

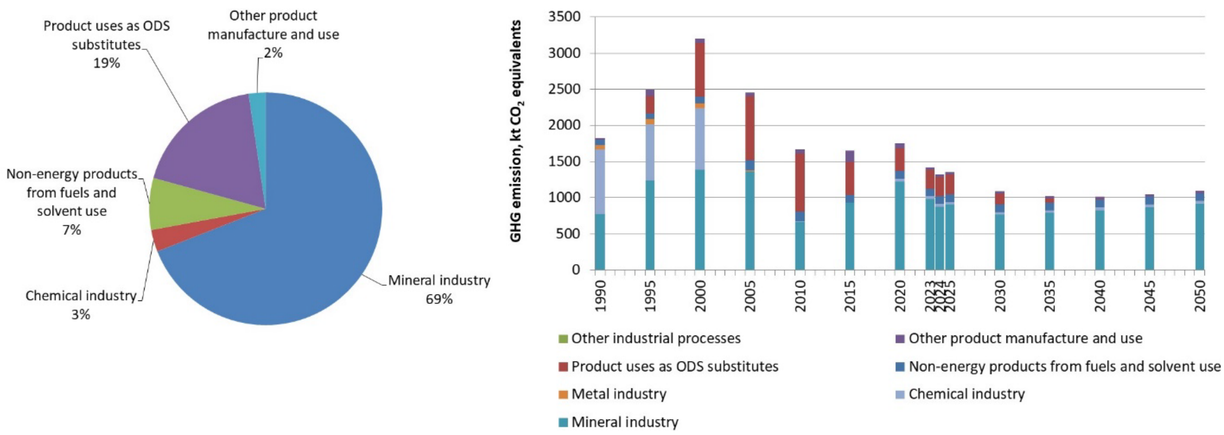

Figure 9.4 Total GHG emissions in CO_2 equivalents for industrial processes. Distribution according to main sectors (2023) and time series for 1990 to 2050.

9.4 Transport and other mobile sources

Road transport is the main source of GHG emissions from transport and other mobile sources in 2023 (79 %) and emissions from this source are expected to decrease in the projection period to 2050, but with the largest reduction happening after 2030. The emission shares for the remaining mobile sources (e.g. domestic aviation, national navigation, railways and non-road machinery in industry, households and agriculture) are small compared with road transport. Non-road machinery in agriculture, forestry and fishing contributes 8 % of the sectoral GHG emission in 2023.

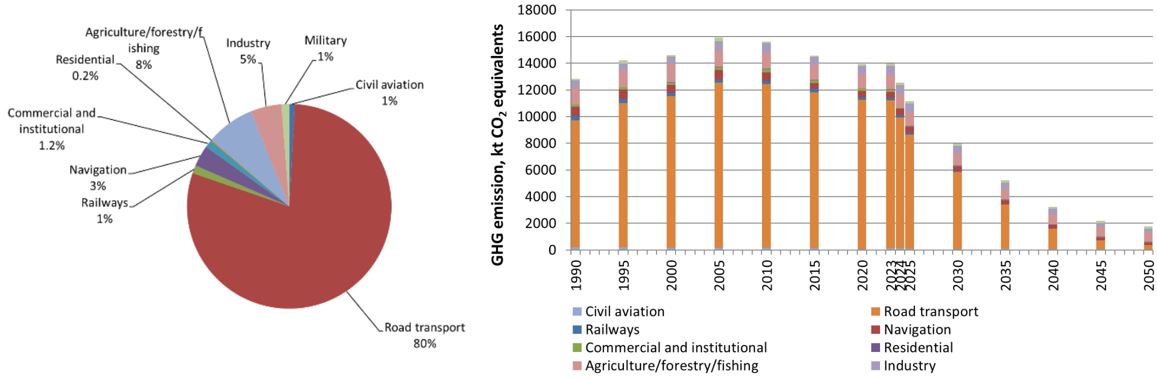

Figure 9.5 GHG emissions in CO_2 equivalents for mobile sources. Distribution according to main sources (2023) and time series for 1990 to 2050.

9.5 Agriculture

The main sources in 2023 are agricultural soils (30 %), enteric fermentation (35 %) and manure management (33 %). The corresponding shares in 2050 are expected to be 36 %, 38 % and 23 %, respectively. From 1990 to 2023, the emission of GHGs in the agricultural sector decreased by 23 %. From 2023 to 2050, the emissions are expected to decline by about 35 %. 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.

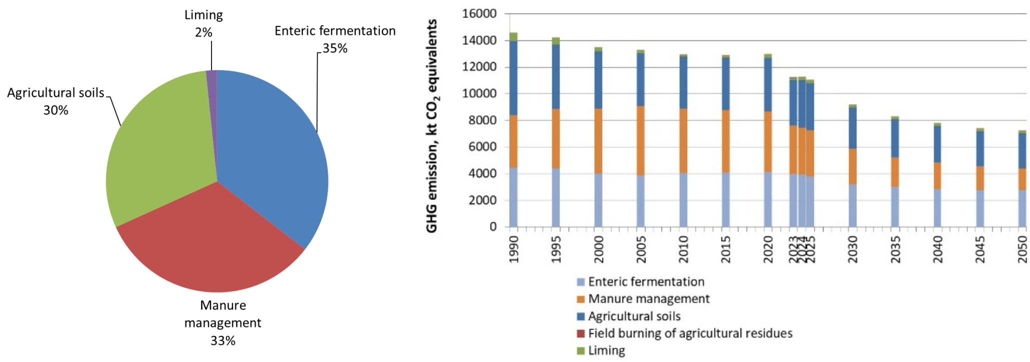

Figure 9.6 GHG emissions in CO_2 equivalents for agricultural sources. Distribution according to main sources (2023) and time series for 1990 to 2050.

9.6 Waste

The total GHG emission from the waste sector has been decreasing in the years 1990 to 2023 by 38 %. From 2023 to 2050, the emissions are projected to increase by 11 % driven by a significant increase in emissions from anaerobic digestion. In 2023, the GHG emission from solid waste disposal contributed with 31 % of the emission from the sector as a whole. A decrease of 31 % is expected for this source in the years 2023 to 2050, due to less organic waste deposition on landfills. Emissions from wastewater are expected to be rather constant for the projection period. GHG emissions from wastewater handling in 2023 contribute with 17 %. Emissions from biological treatment of solid waste (composting and biogas production) contribute with 50 % in 2023 and 63 % in 2050.

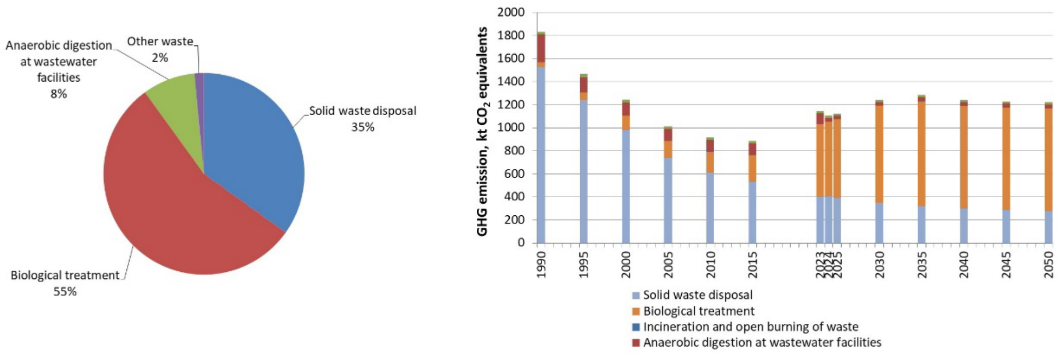

Figure 9.7 GHG emissions in CO_2 equivalents for Waste. Distribution according to main sources (2023) and the time series for 1990 to 2050.

9.7 LULUCF

The LULUCF sector covers emissions and removals from land use, land use change and forestry. This includes conversions between Forest land (afforestation and deforestation), Cropland, Grassland, Wetlands, Settlement and Other land. The minor emission sources Harvested Wood Products (HWP) and burning of biomass in fires are also part of LULUCF. The work for this report includes the projection of Cropland, Grassland, Wetland, Settlement and Other land. Projection of Forestry and Harvested wood products (HWP) is conducted by Department of Geosciences and Natural Resource Management (IGN), Copenhagen University, and reported separately. The data included here are updated values for 2023 to 2050 received from IGN. The LULUCF sector excl. forestry and HWP is a net source of emissions in both the historical and projection period. Forestry and HWP are both net sinks and counter emissions lowering the net emissions from the entire LULUCF sector and even resulting in an overall sink. The combined emissions of the LULUCF sector were 6 699 kt CO_2 equivalents in 1990 and reduced to a sink of 939 kt CO_2 equivalents in 2023. In 2030, a small net source of 300 kt CO_2 equivalents is estimated. From 2030 and up to 2050 is estimated a combined large sink of up to 3600 kt CO_2 equivalents due to less drained organic soils emitting CO_2 and a further increase in the amount of C stored in the Danish forest.

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 is 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.

	2024	2025	2030	2035	2040	2045	2050
Public electricity and heat production	3766	2867	1836	1790	1791	1818	1861
Petroleum refining	879	860	639	618	590	588	588
Other energy industries (oil/gas extraction)	1096	1124	870	851	822	176	0
Combustion in manufacturing industry	1396	1271	676	550	529	443	350
Domestic aviation	121	112	51	94	76	65	30
Agriculture, forestry and aquaculture	0	0	0	0	0	0	0
Fugitive emissions from flaring	97	77	62	56	55	18	11
Mineral industry	951	907	765	791	830	871	918
Total	8308	7218	4898	4750	4693	3980	3758
Civil Aviation, international	2714	2633	2562	2132	1719	1481	707

PROJECTION OF GREENHOUSE GASES 2024-2050

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 2050 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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