PROJECTION OF GREENHOUSE GASES 2023-2040

Scientific Report from DCE – Danish Centre for Environment and Energy No. 610 2024

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DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Data sheet

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

List of abbreviations

ARD	Afforestation, Reforestation & Deforestation
BOD	Biological Oxygen Demand
C	Carbon
CH_4	Methane
CHP	Combined Heat and Power
CHR	Central Husbandry Register
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand
COPERT	COmputer Programme to calculate Emissions from Road Transport
CORINAIR	CORe INventory on AIR emissions
CRF	Common Reporting Format
CL	Cropland
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
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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.

Danish Agricultural Agency (DAA), 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 2022. The emissions are projected to 2040 using a scenario, which includes the estimated effects of policies and measures implemented in Denmark's greenhouse gas (GHG) emissions based on 'frozen policy' (or 'with existing measures' projection) – meaning that the policies and measures are implemented or decided by December 2023. The official Danish energy projection, e.g. the latest official projection from the Danish Energy Agency (DEA), is used to provide activity rates (2023-2040) in the models for those sectors for which these projections are available. The emission factors refer to international guidelines or are country-specific and refer to Danish legislation, Danish research reports or calculations based on emission data from a considerable number of industrial plants in Denmark. The projection models are generally based on the same structure and methodology as the Danish emission inventories in order to ensure consistency.

The main emitting sectors in 2022 are Energy industries (20 %), Transport (29 %), Agriculture (28 %) and Other sectors (8 %). For the latter sector, the most important sources are fuel combustion in the residential sector. GHG emissions show a decreasing trend in the projection period. The total emissions in 2022 are estimated to be 41.7 million tonnes CO_2 equivalents including LULUCF and indirect CO_2 and the corresponding total in 2040 is projected to be 20.7 million tonnes CO_2 equivalents. From 1990 to 2022 the emissions decreased by 46.8 %. From 2022 to 2040, the emission is projected to decrease by approximately 50 %.

The total greenhouse gas emissions in 1990 including LULUCF and indirect CO_2 is estimated at 78.3 million tonnes of CO_2 equivalents and the emission in 2030 is projected to be 28.8 million tonnes of CO_2 equivalents including LULUCF and indirect CO_2. This corresponds to a reduction of 63.3 % 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.

For the first time in 2022, the LULUCF sector became a net sink, i.e. the removals exceeded the emissions. This is shown as negative numbers in Figure S.1.

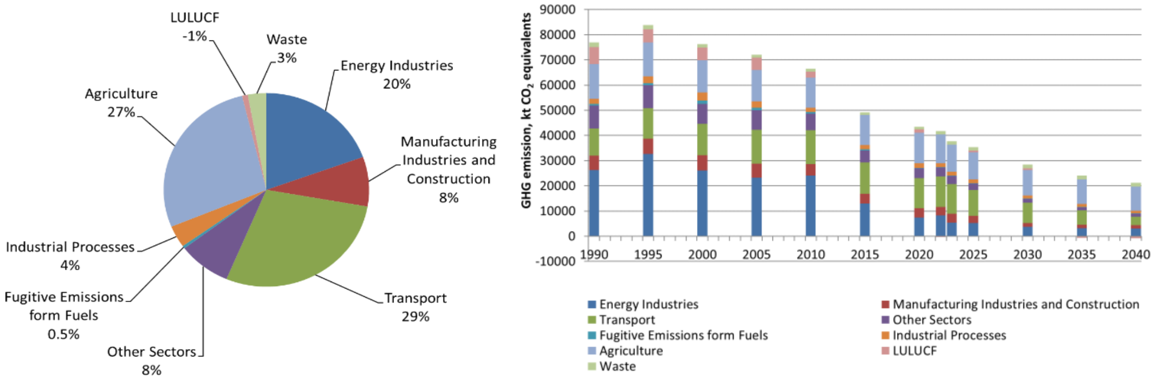


Figure S.1 Total GHG emissions in CO_2 equivalents. Distribution according to main sectors (2022) and time series for 1990 to 2040.

Stationary combustion

Stationary combustion includes Energy industries, Manufacturing industries and construction and Other sectors. Other sectors include combustion in commercial/institutional, residential and agricultural plants. The GHG emissions in 2022 from the main source, which is public power and heat production (49 %), are estimated to decrease in the period from 2022 to 2040 (75 %) 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 92 % from 2022 to 2040, due to a lower consumption of fossil fuels. Emissions from manufacturing industries decreases by 75 %, 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 1990-2022, 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 2022-2040 by 13 %. 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 so that the emission in 2040 are slightly lower than the emission in 2022. 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 2022 are mineral industry (mainly cement production) with 70 % and use of substitutes (F-gases) for ozone depleting substances (ODS) (17 %). The corresponding shares in 2040 are expected to be 74 % and 7 %, respectively. Consumption of limestone and the emission of CO_2 from flue gas cleaning are assumed to follow the consumption of coal and waste for generation of heat and power. The GHG 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 2022 (80 %) and emissions from this source are expected to decrease in the projection period 2022 to 2040, but with the largest reduction happening after 2030. The emission shares for the remaining mobile sources (e.g. domestic aviation, national navigation, railways and non-road machinery in industry, households and agriculture) are small compared with road transport. Non-road machinery in agriculture, forestry and fishing contributes 8 % of the sectoral GHG emission in 2022.

Agriculture

The main sources in 2022 are agricultural soils (32 %), enteric fermentation (36 %) and manure management (30 %). The corresponding shares in 2040 are expected to be 35 %, 39 % and 25 %, respectively. From 1990 to 2022, the emission of GHGs in the agricultural sector decreased by 17 %. From 2022 to 2040, the emissions are expected to decline slightly by about 18 %. The reduction in the historical years can mainly be explained by improved utilisation of nitrogen in manure, a significant reduction in the use of fertiliser and a reduced emission from N-leaching. Measures in the form of technologies to reduce ammonia emissions in stables and expansion of biogas production are considered in the projections and emissions from enteric fermentation are estimated to increase due to an expected increase in the number of animals.

Waste

The total GHG emission from the waste sector has been decreasing in the years 1990 to 2022 by 38 %. From 2022 to 2040, the emissions are projected to increase by 26 % driven by a significant increase in emissions from anaerobic digestion. In 2022, the GHG emission from solid waste disposal contributed with 34 % of the emission from the sector as a whole. A decrease of 10 % is expected for this source in the years 2022 to 2040, 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 2022 contribute with 17 %. Emissions from biological treatment of solid waste (composting and biogas production) contribute with 47 % in 2022 and 60 % in 2040.

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 2030 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 6 694 kt CO_2 equivalents in 1990 and reduced to a sink of 381 kt CO_2 equivalents in 2022. A net average emission of 145 kt CO_2 equivalents is estimated for 2023-2030. 2031-2040 represents a small decrease from that with a net average sink of 79 kt CO_2 equivalents.

Sammenfatning

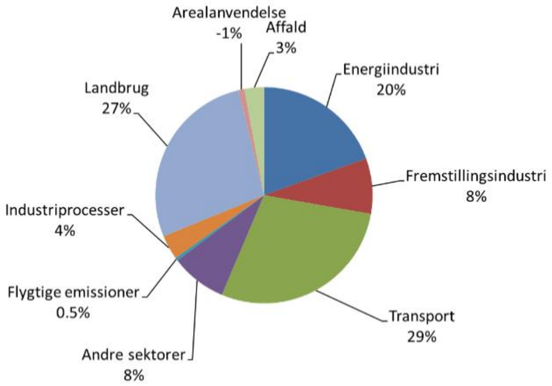
Denne rapport indeholder en beskrivelse af modeller, baggrundsdata og fremskrivninger af de danske emissioner af drivhusgasserne kuldioxid (CO_2), metan (CH_4), lattergas (N_2O), de fluorerede drivhusgasser HFC'ere, PFC'ere, svovlhexafluorid (SF_6). Det seneste historiske år ved udarbejdelsen af fremskrivningen var 2022. Emissionerne er fremskrevet til 2040 på baggrund af et scenarie, som medtager de estimerede effekter på Danmarks drivhusgasudledninger af virkemidler iværksat eller besluttet indtil december 2023 (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 (2023-2040) anvendt. Emissionsfaktorerne refererer enten til internationale vejledninger, dansk lovgivning, danske rapporter eller er baseret på målinger på danske anlæg. Fremskrivningsmodellerne bygger på samme struktur og metoder, som er anvendt for de danske emissionsopgørelser, hvilket sikrer, at historiske og fremskrevne emissionsopgørelser er konsistente.

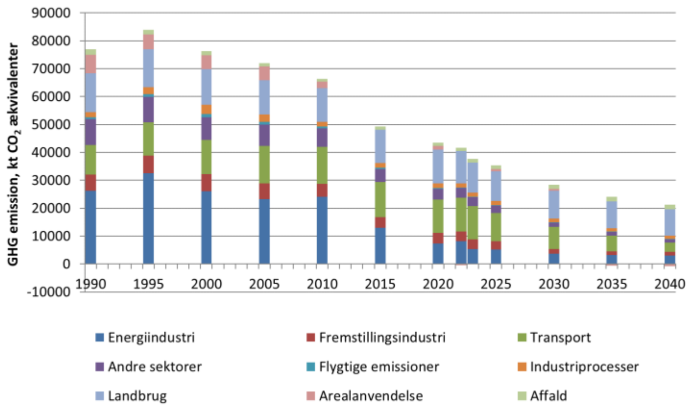
De vigtigste sektorer i forhold til emission af drivhusgas i 2022 forventes at være energiproduktion og -konvertering (20 %), transport (29 %), landbrug (28 %), og andre sektorer (8 %). For "andre sektorer", er den vigtigste kilde forbrænding i husholdninger (Figur R.1). Drivhusgasemissionerne viser et fald gennem fremskrivningsperioden. De totale emissioner er beregnet til 41,7 millioner tons CO_2-ækvivalenter i 2022 inklusiv LULUCF og indirekte CO_2 og er fremskrevet til 20,7 millioner tons i 2040 inklusiv LULUCF og indirekte CO_2. Fra 1990 til 2022 er emissionerne faldet med 46,8 %. Fra 2022 til 2040 er den fremskrevne reduktion ca. 50 %.

Den samlede drivhusgasemission i 1990 inklusiv LULUCF og indirekte CO_2 er beregnet til 78,3 millioner tons CO_2-ækvivalenter og emissionen i 2030 er fremskrevet til 28,8 million tons CO_2-ækvivalenter. Dette svarer til en reduktion på 63,3 % mellem 1990 og 2030. Effekten af CO_2 fangst og lagring (carbon capture and storage - CCS) er ikke muligt at tildele til enkelte sektorer og er derfor ikke medtaget i dette tal.

I 2005 er emissionen med LULUCF og indirekte CO_2 beregnet til 72,9 millioner tons CO_2-ækvivalenter. Emissionen var i 2022 faldet 48,0 % i forhold til 2005 og forventes reduceret med 60,6 % fra 2005 til 2030.

2022 er første år i tidsserien, hvor LULUCF-sektoren var et netto optag, dvs. det samlede CO_2-optag var større end de samlede emissioner. Dette er illustreret med negative værdier i Figur S.1.





Figur R.1 Totale drivhusgasemissioner i CO_2-ækvivalenter fordelt på hovedsektorer for 2022 og tidsserier fra 1990 til 2040.

Stationær forbrænding

Stationær forbrænding omfatter Energiindustri (konvertering og olie/gas produktion), Fremstillingsindustri og Andre sektorer. Andre sektorer dækker over handel/service, husholdninger samt landbrug/gartneri. Drivhusgasemissionen fra kraft- og kraftvarmeværker, som er den største kilde i 2022 (49 %), er estimeret til at falde i perioden 2022 til 2040 (75 %) 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 2022 til 2040 med hele 92 % pga. lavere forbrug af de fossile brændstoffer. Emissioner fra fremstillingsindustrien falder tilsvarende med 75 % i samme periode pga. et fald i anvendelsen af fossile brændstoffer.

Flygtige emissioner

Emissionen af drivhusgasser fra sektoren Emissioner af flygtige forbindelser fra brændsler udviser store fluktuationer i de historiske år 1990-2022 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 13 % i perioden 2022-2040. Emissionen fra flaring stiger i den første del af fremskrivningsperioden pga. opstart af produktion på Tyrafeltet efter renoveringen, men falder igen, så niveauet i 2040 ventes at være lidt lavere end niveauet i 2022. 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 2022 er mineralsk industri (især cementproduktion), som bidrager med 70 % af drivhusgasemissionen i 2022, samt anvendelse af erstatningsgasser (F-gasser) for ozonnedbrydende stoffer (ODS), der bidrager med 17 %. De tilsvarende andele i 2040 forventes at ligge på hhv. 74 % og 7 %. Forbrug af kalk og derved emission af CO_2 fra røggasrensning antages at følge forbruget af kul og affald i kraftvarmeanlæg. Drivhusgasemissionen fra 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 2022 (80 %), og emissionerne fra denne kilde forventes at falde i fremskrivningsperioden 2022 til 2040 med det største fald i perioden efter 2030. Den samlede emission for andre mobile kilder (indenrigsluftfart, jernbane, indenrigssøfart, ikke-vejgående industrimaskiner, maskiner i have/hushold, landbrugsmaskiner) er lave sammenlignet med vejtransport. Ikke-vejgående maskiner inden for landbrug, skovbrug og fiskeri bidrager med 8 % af sektorens drivhusgasser i 2021.

Landbrug

De største kilder i 2022 er emissioner fra landbrugsjorder (32 %), dyrenes fordøjelse (36 %) og gødningshåndtering (30 %). De tilsvarende andele i 2040 forventes at være hhv. 35 %, 39 % og 25 %. Fra 1990 til 2022 er emissionen fra landbrugssektoren faldet med 17 %. I fremskrivningsperioden forventes emissionerne at falde med ca. 18 %. Årsagen til faldet i de historiske år er en forbedring i udnyttelsen af kvælstof i husdyrgødningen, og hermed et markant fald i anvendelsen af handelsgødning samt lavere emission fra kvælstofudvaskning. I fremskrivningen er der taget højde for teknologiske tiltag i form af ammoniakreducerende teknologi og en øget vækst i biogasanlæg, og emissionerne fra dyrenes fordøjelse er estimeret til at stige pga. en forventet stigning i antallet af dyr.

Affald

Affaldssektorens samlede drivhusgasemissioner er faldet med 38 % i perioden 1990 til 2022. Fra 2022 til 2040 er emissionerne fremskrevet til at stige med 26 %, hvilket kan tilskrives en markant stigning i emissionen fra biogasbehandling. I 2022 udgør drivhusgasemissionen fra lossepladser 34 % af den totale emission fra affaldssektoren. Et fald på 10 % er forventet for denne kilde i perioden 2022 til 2040. Dette skyldes, at mindre organisk nedbrydeligt affald bliver deponeret. Emissioner fra spildevand forventes at forblive nogenlunde konstant frem mod 2040. I 2022 udgør spildevandshåndteringen 17 % (211 kt CO_2e) af sektorens samlede emission. Emissionerne fra biologisk behandling af affald (kompostering og biogasbehandling) udgør 47 % i 2022 og 60 % i 2040.

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 afbrænding af biomasse 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 2023-2030 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. I 1990 udgjorde sektoren en emission på 6694 kt CO_2-ækvivalenter, hvilket var reduceret til et optag på 381 kt CO_2-ækvivalenter i 2022. For perioden 2023-2030 er emissionen fremskrevet til at være 145 kt CO_2-ækvivalenter i gennemsnit. Gennemsnittet for 2031-2040 repræsenterer et lille fald ned til et optag på 79 kt CO_2-ækvivalenter.

1 Introduction

In the Danish Environmental Protection Agency's project "Projection models 2010" a range of sector-related partial models were developed to enable projection of the emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x,) non-methane volatile organic compounds (NMVOC) and ammonia (NH_3) forward to 2010 (Illerup et al., 2002). Subsequently, the project "Projection of GHG emissions 2005 to 2030" was carried out in order to extend the projection models to include the GHGs CO_2, CH_4, N_2O as well as HFCs, PFCs and SF_6, and project the emissions for these gases to 2030 (Illerup et al., 2007). This was further updated in later projects (Nielsen et al., 2008, 2010, 2011, 2013, 2014, 2016, 2017, 2018, 2019, 2020, 2021, 2022 and 2023). The purpose of the present project, "Projection of greenhouse gas emissions 2023 to 2040" has been to update the emission projections for all sectors based on the latest national energy projections, other relevant activity data and emission factors.

1.1 Obligations

The European Union (EU) has committed itself to reduce emissions of GHGs by 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 2023 are included in the projections and the projection of total GHG emissions is therefore a so-called 'with existing measures' projection.

1.2 Greenhouse gases

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

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

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

The main greenhouse gas responsible for the anthropogenic influence on the heat balance is CO_2. The atmospheric concentration of CO_2 has increased from a pre-industrial value of about 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 time frame chosen is typically 100 years. The effect of the various greenhouse gases can, then, be converted into the equivalent quantity of CO_2, i.e. the quantity of CO_2 giving the same effect in absorbing solar radiation. According to the IPCC and their 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. (2023).

1.3 Historical emission data

The greenhouse gas emissions are estimated according to the IPCC guidelines and are aggregated into six main sectors. The greenhouse gases include CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3, although NF_3 is not occurring in Denmark. Figure 1.1 shows the estimated total greenhouse gas emissions in CO_2 equivalents from 1990 to 2022. The emissions are not corrected for electricity trade or temperature variations in accordance with the reporting guidelines.

CO_2 is the most important greenhouse gas contributing in 2022 to the national total in CO_2 equivalents excluding LULUCF (Land Use and Land Use Change and Forestry) and excluding indirect CO_2 emissions with 68.0%, followed by CH_4 with 20.2 %, N_2O with 11.2 %, and f-gases (HFCs, PFCs, SF_6 and NF_3) with 0.7 %. If including LULUCF and indirect CO_2, the CO_2 emissions account for 67.0%, followed by CH_4 with 21.0 %, N_2O with 11.3 %, 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 total national greenhouse gas emission in CO_2 equivalents excluding LULUCF has decreased by 41.3 % from 1990 to 2022 when considering indirect CO_2, if excluding indirect CO_2 the emissions have decreased by 40.7 %. The emissions including LULUCF and indirect CO_2 have decreased by 46.8 % from 1990 to 2022. Comments on the overall trends etc. seen in Figure 1.1 are given in the sections below on the individual greenhouse gases.

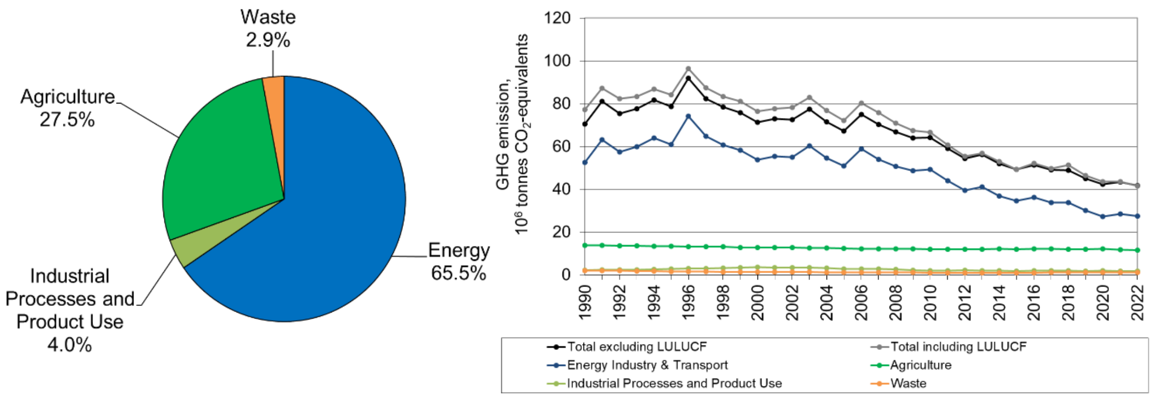


Figure 1.1 Greenhouse gas emissions in CO_2 equivalents distributed on main sectors for 2022 (excluding LULUCF and indirect CO_2) and time series for 1990 to 2022.

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 2022 and contributes with 42 %, followed by energy industries with 28 %. The CO_2 emission (excl. LULUCF) decreased by 3.9 % from 2021 to 2022. The main reason for this decrease is decreased used of fossil fuels particularly in non-industrial combustion and manufacturing industries In general, CO_2 emissions fluctuate significantly as a result of the electricity trade with neighbouring countries.

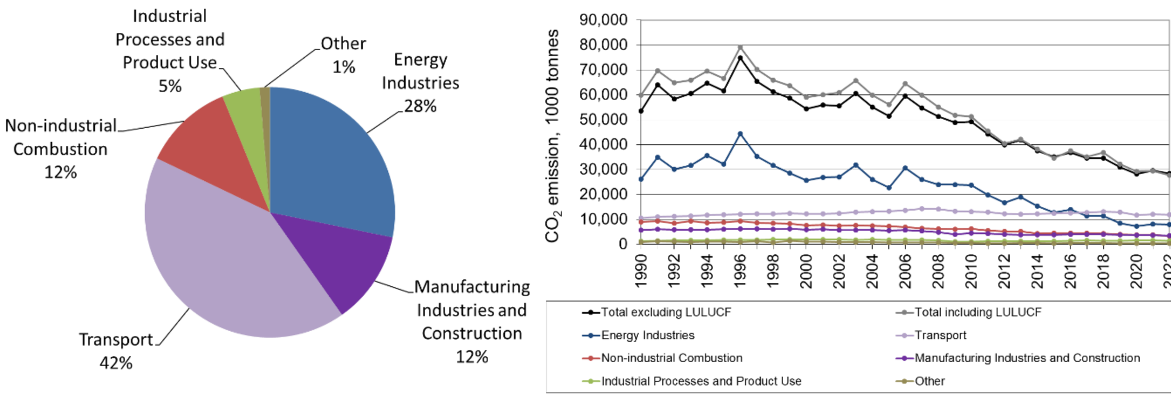


Figure 1.2 CO_2 emissions. Distribution according to the main sectors for 2022 and time series for 1990 to 2022.

1.3.2 Methane

The largest sources of anthropogenic CH_4 emissions are agricultural activities contributing with 83.5 % in 2022, waste (12.3 %) and the remaining emission sources covers 4.2 % - see Figure 1.3. The emission from agriculture derives from enteric fermentation (48.4 %) and management of animal manure (35.1 %).

Since 1990, the emission of CH_4 from enteric fermentation has decreased by 8.1 % mainly due to the decrease in the number of cattle. However, this reduction is countered by an increase of 19.5 % 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 (72.4 %) from 1990 to 2022 due to an increase in the incineration of waste and extensive recycling thereby causing a decrease in the waste disposal on land. The CH_4 emission from the energy sector increases from mid 1990s from public power and district heating plants increases due to the increasing use of gas engines in the decentralised cogeneration plant sector. Due to the liberalisation of the electricity market the use of gas engines declined from 2005 onwards. The high emission from gas engines is caused by the fact that up to 3 % of the natural gas in the gas engines is not combusted.

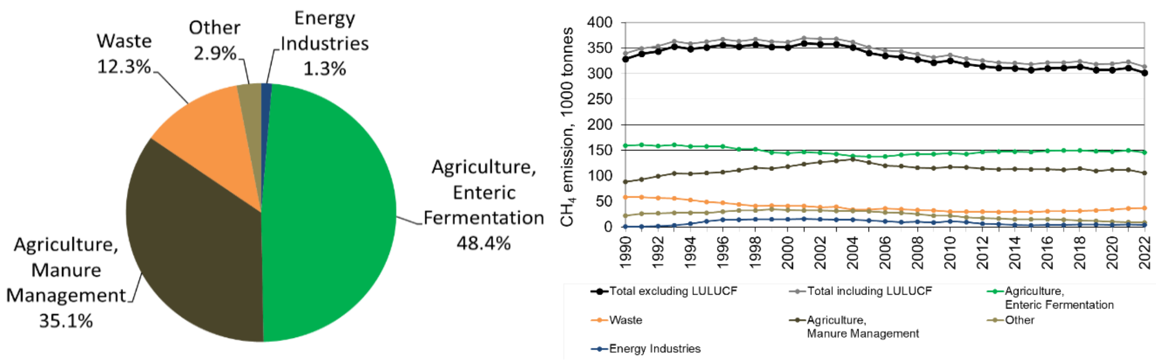


Figure 1.3 CH_4 emissions. Distribution according to the main sectors for 2022 and time series for 1990 to 2022.

1.3.3 Nitrous oxide

Agriculture is the most important N_2O emission source in 2022 contributing with 89.8 % (Figure 1.4) of which N_2O from soils dominates (78.5 % 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 33.2 % since 1990 caused by legislation to improve the utilisation of nitrogen in manure. Combustion of fuels contributes 6.1 % to the total whereof the N_2O emission from transport contributes with 2.5 % to the national total in 2022. Emission from industrial processes decreased significantly in 2004 due to the closure of the only nitric acid plant operating in Denmark and the emission from this emission source is therefore close to zero since then.

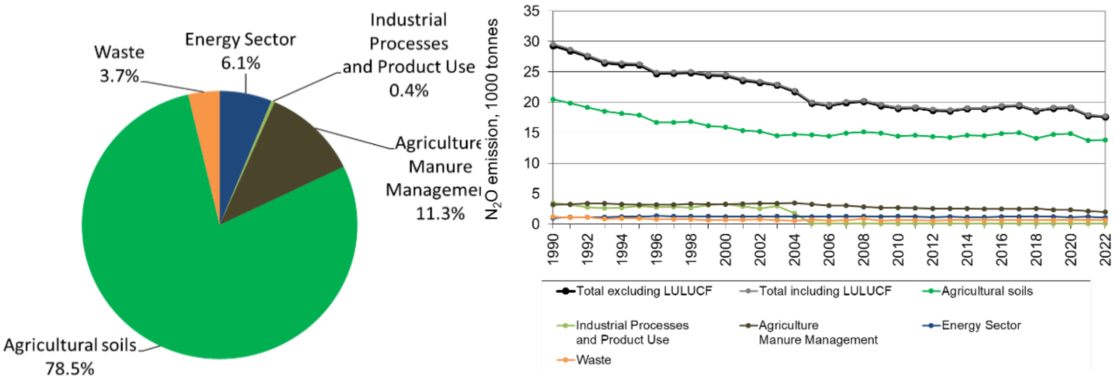


Figure 1.4 N_2O emissions. Distribution according to the main sectors for 2022 and time series for 1990 to 2022.

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 2.5. 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 2022. 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 4.8 % in 2022. 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.

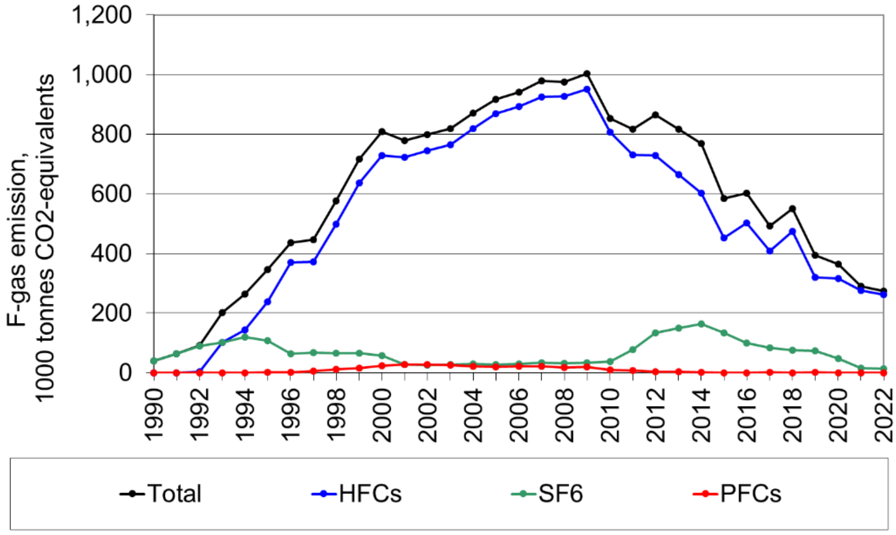


Figure 1.5 F-gas emissions. Time series for 1990 to 2022.

1.4 Projection models

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

(1.1) $$E = \sum_{s} A_s(t) \cdot \overline{EF_s}(t)$$

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

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

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

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

Official Danish projections of activity rates are used in the models for those sectors for which the projections are available. For other sectors, projected activity rates are estimated in co-operation with relevant research institutes and other organisations. The emission factors are based on recommendations from the IPCC Guidelines (IPCC, 2006 and the EMEP/EEA Guidebook (EMEP/EEA, 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 in order 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 2040 (Danish Energy Agency, 2024).

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

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

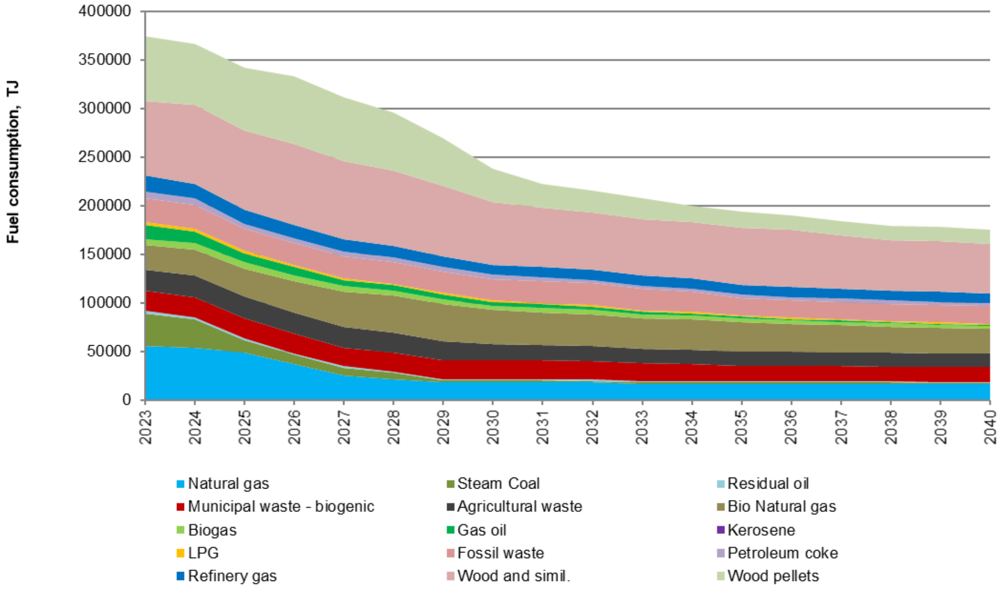

Figure 2.1 Projected energy consumption by fuel type.

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

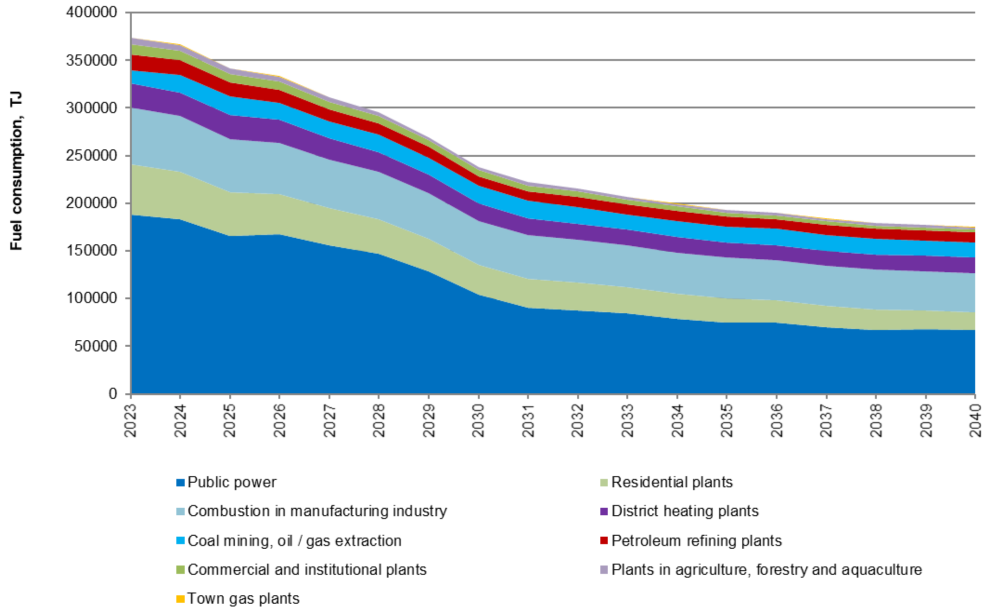

Figure 2.2 Energy use by sector.

2.4 Emission factors

In general, emission factors for area sources refer to the emission factors for 2022 applied in the 2024 emission inventory (Nielsen et al., 2024).

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 2017-2022 emission factors have been applied rather than including only the 2022 data.

The offshore Tyra gas field in the North Sea is shut down from September 2019 to spring 2024. During this period, consumers in Denmark will primarily get their gas supply from Germany (Energinet, 2021). The CO_2 emission factor applied for natural gas[1] in 2023 is based on gas quality data from Energinet for 2023 (Energinet, 2024). The CO_2 emission factor applied for 2024-2040 is the average value for the years 2014-2018.

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

2.5 Emissions

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

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

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	2015	2020	2022	2023	2025	2030	2035	2040
Public electricity and heat production	24804	23597	20617	21680	10455	5530	7491	3668	3276	2047	1598	1572
Petroleum refining plants	909	1003	940	855	980	912	973	916	831	599	598	595
Oil/gas extraction	536	1510	1664	1582	1468	907	716	814	1111	1057	971	931
Commercial and institutional plants	1423	928	974	873	649	524	433	358	251	38	38	42
Residential plants	5150	4193	3863	3379	2166	1664	1277	1153	808	215	140	88
Plants in agriculture, forestry and aquaculture	1005	1118	943	692	401	267	305	287	195	34	26	24
Combustion in industrial plants	5193	5485	4932	3819	3273	3111	3137	2826	2240	955	770	693
Total	39020	37834	33934	32880	19392	12914	14333	10024	8711	4945	4142	3946

From 1990 to 2040, the total emission decreases by approximately 35 100 kt CO_2 equivalents or 90 % 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, 2015, 2020 and 2022 (Nielsen et al., 2024).

[1] Except offshore gas turbines.

2.5.2 Carbon dioxide

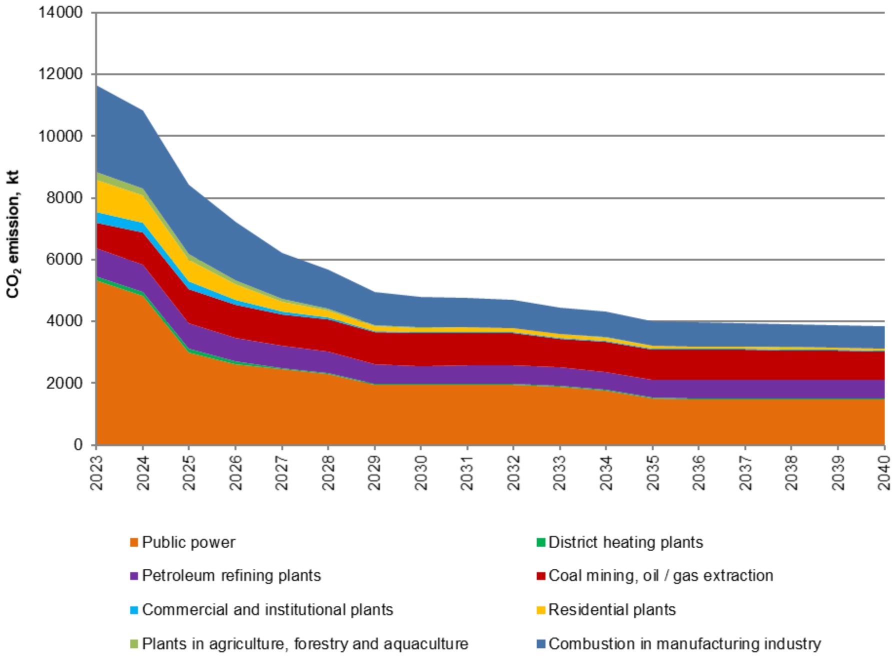

Figure 2.4 CO_2 emissions by sector.

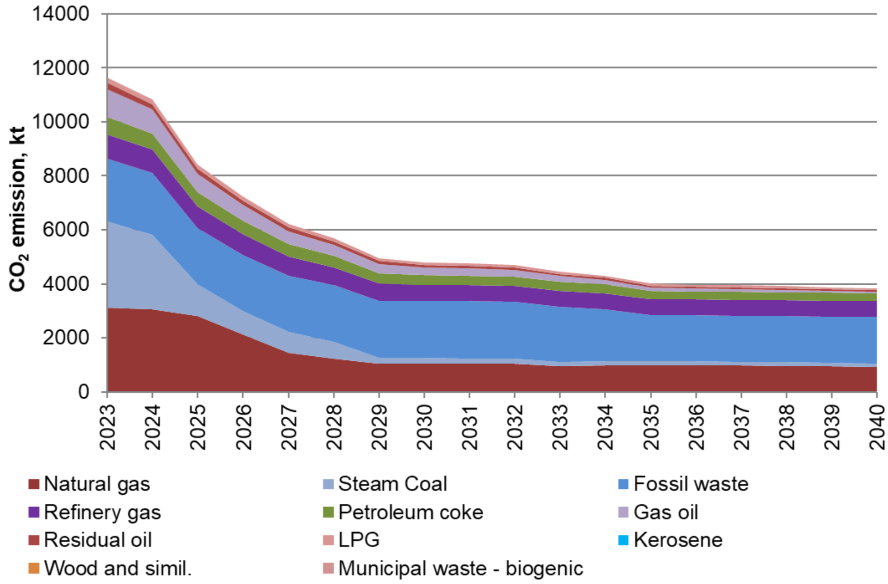

Figure 2.5 CO_2 emissions by fuel.

Table 2.3 CO_2 emissions by sector.

Sector	1990	2000	2005	2010	2015	2020	2022	2023	2025	2030	2035	2040
Public electricity and heat production	24717	23099	20196	21269	10293	5369	6229	5465	3103	1963	1522	1508
Petroleum refining plants	908	1000	938	854	978	910	912	915	830	598	597	595
Oil/gas extraction	530	1494	1653	1574	1460	902	879	810	1105	1052	966	926
Commercial and institutional plants	1415	904	940	864	635	508	449	355	251	34	34	39
Residential plants	4971	3992	3626	3125	1971	1526	1034	1046	720	145	87	52
Plants in agriculture, forestry and aquaculture	969	1045	877	591	373	238	400	263	171	10	5	2
Combustion in industrial plants	5136	5398	4861	3816	3222	3042	2772	2803	2248	981	792	719
Total	38647	36931	33091	32092	18931	12495	12676	11657	8428	4783	4003	3841

CO_2 is the dominant GHG for stationary combustion and comprises in 2022 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 49 % in 2022 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 70 % from 2022 to 2040 due to decreasing fossil fuel consumption.

2.5.3 Methane

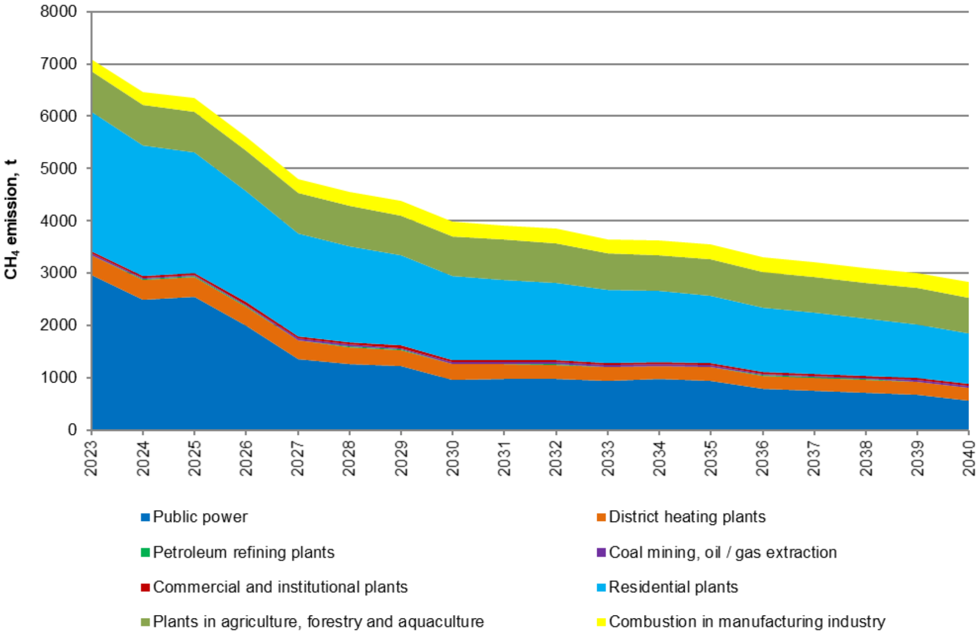

Figure 2.6 CH_4 emissions by sector.

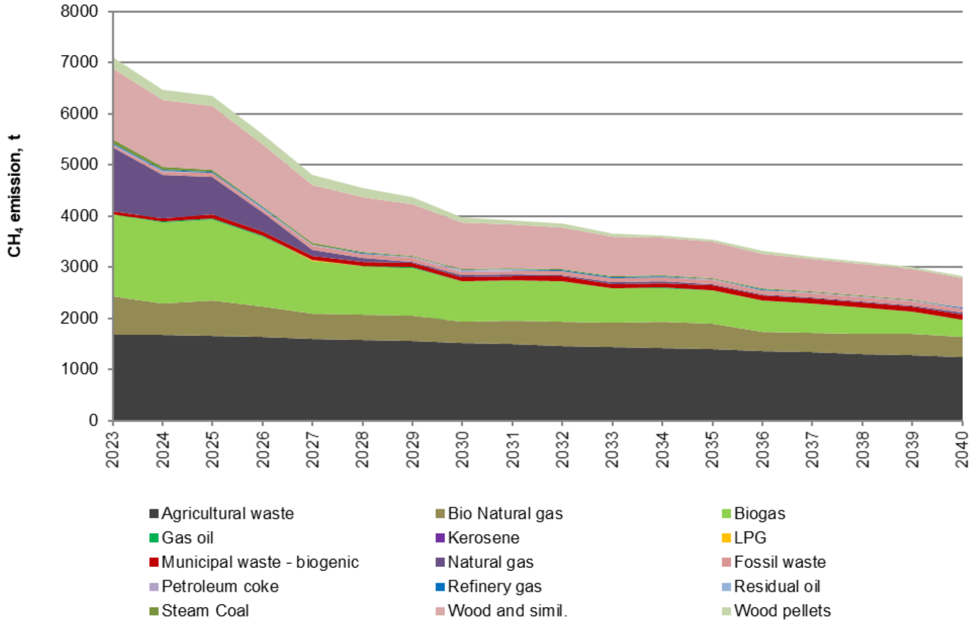

Figure 2.7 CH_4 emissions by fuel.

Table 2.4 CH_4 emissions by sector, t.

Sector	1990	2000	2005	2010	2015	2020	2021	2022	2025	2030	2035	2040
Public electricity and heat production	585	14620	12359	10922	3434	3617	3854	3335	2923	1260	1200	811
Petroleum refining plants	18	21	19	17	19	18	19	16	15	11	11	11
Oil/gas extraction	16	39	48	46	43	26	26	24	33	31	29	28
Commercial and institutional plants	130	900	798	683	378	386	350	42	41	40	39	37
Residential plants	5383	6064	6911	7141	5157	3391	2883	2675	2303	1603	1297	969
Plants in agriculture, forestry and aquaculture	1089	2465	2186	1375	897	898	857	771	769	766	687	685
Combustion in industrial plants	275	1020	818	546	473	947	661	232	265	268	284	287
Total	7496	25130	23139	20731	10401	9283	8650	7096	6349	3980	3547	2826

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

2.5.4 Nitrous oxide

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

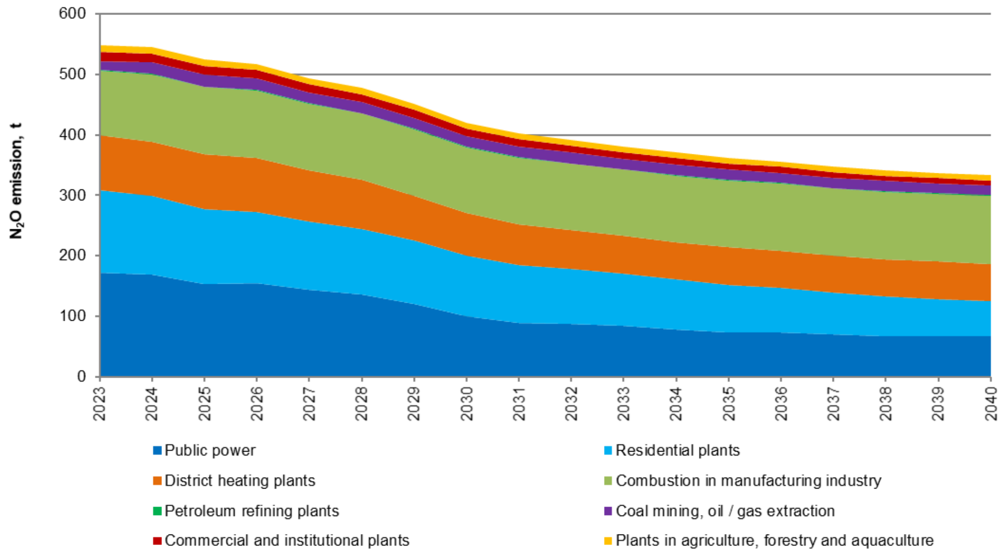

Figure 2.8 N_2O emissions by sector.

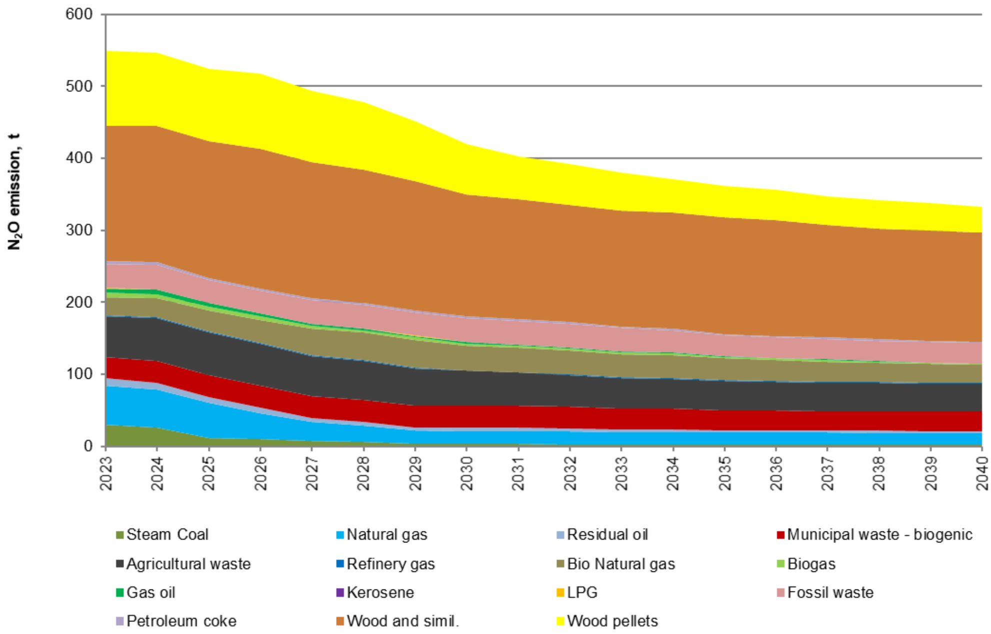

Figure 2.9 N_2O emissions by fuel.

Table 2.5 N_2O emissions by sector, t.

Sector	1990	2000	2005	2010	2015	2020	2021	2022	2025	2030	2035	2040
Public electricity and heat production	265	317	311	345	249	229	238	264	244	171	137	129
Petroleum refining plants	2	7	5	3	4	4	4	2	2	1	1	1
Oil/gas extraction	20	56	40	27	25	15	15	14	19	18	17	16
Commercial and institutional plants	17	15	17	18	15	17	16	16	15	12	10	8
Residential plants	106	118	162	202	192	160	132	136	124	100	77	57
Plants in agriculture, forestry and aquaculture	23	18	18	15	13	12	12	11	11	9	9	9
Combustion in industrial plants	186	221	182	175	140	162	137	107	111	109	111	113
Total	619	752	735	785	637	600	554	548	524	420	362	333

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, 2024). 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., 2024).

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 2017-2022 emission factors.

The offshore Tyra gas field in the North Sea is shut down from September 2019 to spring 2024. During this period, consumers in Denmark will primarily get their gas supply from Germany (Energinet.dk, 2021). Thus, the CO_2

emission factor applied for natural gas[2] in 2023 have been updated based on gas quality data for 2023 whereas the CO_2 emission factor applied for 2024-2040 have been updated to the average value for the years 2014-2018.

The implied emission factors for CH_4 from residential wood combustion have been updated according to the latest technology specific emission factors (Nielsen et al., 2024) and the updated energy projections.

2.7 References

Danish Energy Agency, 2024: Denmark's Energy and Climate Outlook. Available at:
https://ens.dk/en/our-services/projections-and-models/denmarks-energy-and-climate-outlook

EMEP/EEA, 2023: EMEP/EEA air pollutant emission inventory guidebook 2023. Technical report No 06/2023. Available at:
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Energinet, 2021: Faktablad for gaskvaliteter under Tyra genopbygningen med Baltic Pipe.

Energinet, 2024: e-mail from Jesper Bruun Munkegaard Hvid, Energinet, 17-01-2024

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:
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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. 2023. Denmark's National Inventory Report 2024. Emission Inventories 1990-2022 - Submitted under the United Nations Framework Convention on Climate Change. Aarhus University, DCE – Danish Centre for Environment and Energy (In prep.).

[2] Except offshore gas turbines.

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. (2024).

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 – DECO24) on production of oil and gas, and on flaring in upstream oil and gas production and on fuel consumption (DEA, 2024).

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

3.2 Activity data

The projection for the production of oil and gas (DEA, 2024) is shown in Figure 3.1. The production of both oil and gas is assumed to increase significantly from 2023 to 2025, mainly due to the restart of production from the Tyra field, which has been shut down since September 2019 for redevelopment. After some fluctuations, a levelling out to a decreasing trend is expected.

The projection includes production from existing fields and new fields based on existing technology, technological resources (estimated additional production due to new technological initiatives) and prospective resources (estimated production from new discoveries). Further, the projected production includes flaring in upstream oil and gas production. According to Denmark's Energy and Climate Outlook (DEA, 2024), the flaring amounts are expected to increase from 2023 to 2024, a significant decrease 2024 to 2025, followed by a levelled out trend until 2040. The overall trend for the projection years shows a decrease. Flaring related to exploration of oil and gas is not included in the oil and gas projection, and therefore this activity is not included in the projection.

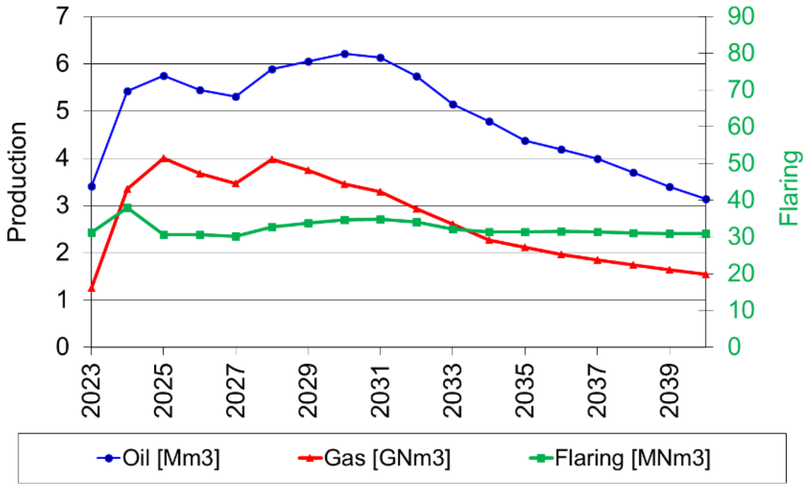

Figure 3.1 Projection for the production of oil and gas (DEA, 2024).

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

Data from Denmark's Energy and Climate Outlook by the DEA (2024) are applied in the projection of fugitive emissions from fuels for the sources transmission of natural gas, and distribution of natural gas and town gas. Consumption of natural gas is used as proxy to project transmission of natural gas and the consumption of town gas is used as a proxy for the fugitive losses from town gas distribution.

The fuel consumption and flaring rates for refineries are assumed to be constant for the projection period according to the Energy and Climate Outlook (DEA, 2024).

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) is used with the assumption equal amount of loading with and without VRU (Vapour Recovery Unit). 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 activity and flaring rates for refineries are kept constant for the projection period, at the level for the latest historical year. Emissions from processing in refineries are kept constant for the projection years at the average level for the latest five historical years.

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

3.4 Emissions

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

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

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

Figure 3.2 includes CH_4 emission on sub-sector level in selected historical years and projection years. The total fugitive CH_4 emission is expected to show a decrease from 2022 to 2023 followed by an increase from 2023 to 2024. A decreasing trend is expected for the remaining years in the projection period. The trend is mainly caused by a variation in emissions from gas (production, transmission and distribution). The low emissions in 2020-2023 are due to a decrease in oil and especially gas production, mainly due to the shutdown of the Tyra platform for redevelopment.

The fuel consumption and flaring amounts for refineries are assumed to be constant for the projection period according to the Energy and Climate Outlook (DEA, 2024), and correspondingly the emissions from fugitive emissions and flaring in refineries for the latest historical year are applied for the projection years.

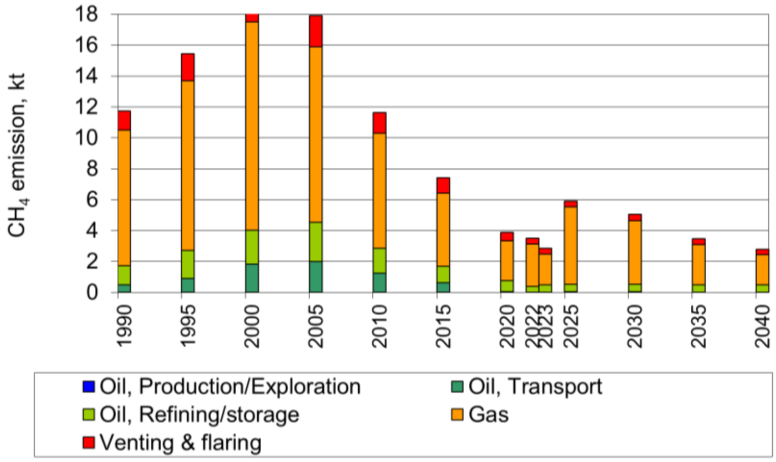

Figure 3.2 CH_4 emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2015, 2020 and 2022, including exploration of oil and gas) and projection years (2023, 2025, 2030, 2035, 2040, excluding exploration of oil and gas).

By far the largest source of fugitive emissions of CO_2 is flaring in upstream oil and gas production (Figure 3.3). CO_2 emissions peaked in 1999 and have shown a decreasing trend over the following historical years. In the projection years, the annual emission from flaring in upstream oil and gas production is more constant. The CO_2 emission from offshore flaring is estimated from the projected flaring rates (DEA, 2024) and an average emission factor for the latest five historical years. The average CO_2 emission factor applied in the projection years is 2.472 kg per Nm^3.

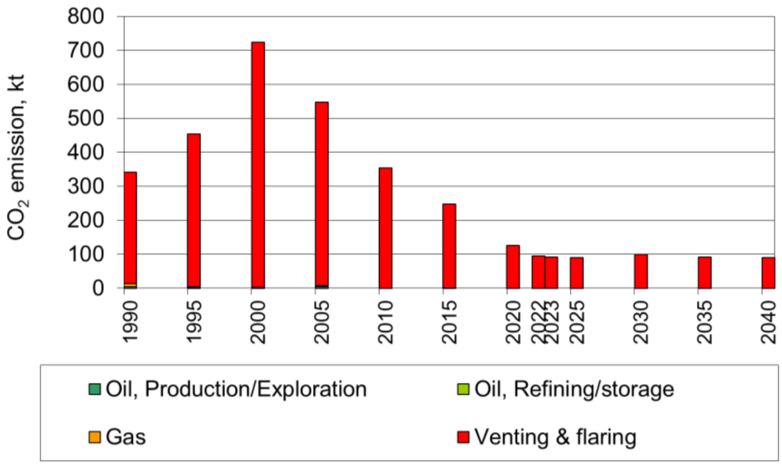

Figure 3.3 CO_2 emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2015, 2020 and 2022, including exploration of oil and gas) and projection years (2023, 2025, 2030, 2035, 2040, excluding exploration of oil and gas).

The summarised greenhouse gas emissions for selected historical years and projection years are shown in Figure 3.4 on sub-sector level. The main source of fugitive GHG emissions is CO_2 from offshore flaring, but also upstream oil and gas production, oil storage at the crude oil terminal, and fugitive emissions from refineries contribute. Emissions from onshore activities (storage of oil and loading of ships) have shown a large decrease from 2005 to 2016 due to new technology at the oil terminal and 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 owe to decreasing production amounts of oil and natural gas, and to better technologies leading to less flaring on the offshore installations.

Emissions from exploration of oil and gas are not included in the projected emissions, but only in historical years. The maximum GHG emission from exploration occurred in 2002, where this source contributed 3.0 % of the total fugitive GHG emission (second and third highest emission occurred in 1990 and 1998 and contributed 2.8 % and 0.9 %, respectively).

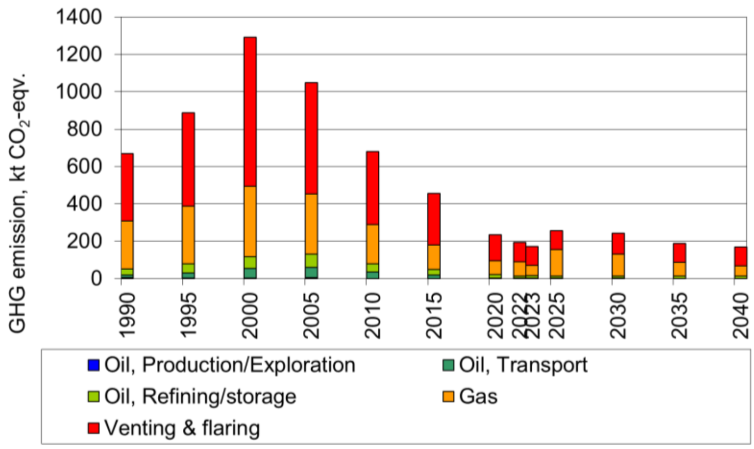

Figure 3.4 GHG emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2015, 2020 and 2022, including exploration of oil and gas) and projection years (2023, 2025, 2030, 2035, 2040, excluding exploration of oil and gas).

3.5 Model description

The model for projecting fugitive emissions from fuels, the "Fugitive emissions projection model", is created in Microsoft Excel. The projection model is built in accordance with the model used in the national emission inventory system; the "Fugitive emission model". For sources where data for the historical years are used to estimate emissions in the projection years, the "Fugitive emissions projection model" links to the "Fugitive emission model". Historical emission from Refineries and transmission/distribution of gas are treated in separate workbook models ("Refineries" and "Gas-Transport"). 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, 2024: 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).

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. 2024. Denmark's National Inventory Report 2024. Emission Inventories 1990-2022 - Submitted under the United Nations Framework Convention on Climate Change. Aarhus University, DCE – Danish Centre for Environment and Energy, 768 pp. (in prep.)

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

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

IPCC code			Sources/processes	SNAP code
2A	Mineral industry	2A1	Cement production	04 06 12
		2A2	Lime production	04 06 14
		2A3	Glass production	04 06 13
		2A4	Other process uses of carbonates	
		-	2A4a 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	
		-	Solvent use	06 04 00
		-	Use of urea in catalysts	06 06 07
		-	Asphalt roofing	04 06 10
		-	Road paving with asphalt	04 06 11
2E	Electronics industry	2E5	Fibre optics	06 05 08
2F	Product use as 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., 2024).

4.2 Methodology

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

For HFCs, PFCs and SF_6, also known as F-gases, emission projections are based on an F-gas projection done by Poulsen (2024a and 2024b).

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, please 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, 2024a and 2024b). In this work, projections to 2040 are also prepared. Annual reports that contain both consumption and emission data are 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. Exemptions from the Danish bans on e.g. refrigeration equipment have been taken into account in the projections.

Emissions are calculated with a model for the individual substance's lifecycle over the years, taking the emissions associated with the actual processes into consideration. The processes for refrigeration and high voltage equipment are filling up/topping up, operation and destruction. For foam, the processes are production of the products in which the substances are used as well as use and destruction of the product. The model has been developed and used in connection with the annual historic emission inventories for the Climate Convention; see Nielsen et al. (2024). 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, 2024a).

The report and the data collected in Poulsen (2024a, b) provide emission projections generally based on 'steady state' consumption with 2022 as the reference year. Cut-off dates in relation to the phasing out of individual substances, in connection with Danish regulation concerning the phasing out of powerful GHGs, are taken into account. For all commercial refrigeration categories with high GWP refrigerants, the trend is projected as steady state until 2025, whereafter the consumption will reduce 20 % per year.

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 mineral wool along with other uses of soda ash and flue gas cleaning (desulphurisation), see Table 4.2.

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

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

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

Cement production is the major CO_2 source within industrial processes. Information on the emission of CO_2 until 2022 is based on the company reporting to EU ETS (Aalborg Portland, 2023). The emission from cement production for 2023-2040 is estimated by the DEA (2024), see Table 4.3.

Table 4.3 Projected emission from cement production, kt CO_2. (DEA, 2024)

	2023	2025	2030	2035	2040
Cement production	1002	960	772	798	815

Lime is used for a number of different applications. There are no projected production values available for lime production and the emission for 2023-2040 is therefore estimated to be the constant average value for 2018-2022. 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 2018-2022. 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 2023-2040 is estimated by extrapolating the 2022 emission for each category with the projected production value for the construction sector (DEA, 2024).

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 2023-2040 are estimated as a sum of the two sources by extrapolating using the trend of the projected consumption of coal and waste.

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

4.2.3 Chemical Industry

There is only one source of GHG emissions within the emission projection of CRF category 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 2023-2040 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. The production ceased during 2021, and reopened in 2022. Emissions from this source are projected to slowly increase in 2023-2024 before reaching the 2016-2020 average level from 2025 to 2040.

4.2.5 Non-Energy Products from Fuels and Solvent Use

This category includes CO_2, CH_4, N_2O and NMVOC emissions from the source categories 2.D.1 Lubricant use, 2.D.2 Paraffin wax use, 2.D.3 Other solvent use (Paint application, Degreasing and dry cleaning, Chemical products, manufacture and processing and Other solvent and product use), Road paving with asphalt and Asphalt roofing.

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

Substance	Typical use	GWP CO_2e
CO_2	Lubricants, Paraffin wax use	1
CH_4	Paraffin wax use	28
N_2O	Paraffin wax use	265

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

The projections 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 CRF category 2E Electronic Industry. Fibre optics can lead to emissions of both HFC (HFC-23) and PFCs (PFC-14 and PFC-318). No emissions from fibre optics occurred in 2020-2022, and no emissions are expected for 2023-2040 (Poulsen, 2024b).

4.2.7 Product Uses as Substitutes for Ozone Depleting Substances

There are three sources of GHG emissions within the projection of the CRF category 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 2023-2025 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; 2023-2040. Emissions from heat pumps are modelled separately for air-air heat pumps
(steady state), monoblock units (phase out of HFC-32 complete in 2026) 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 2F and approved for inventory under the Climate Convention and KP with stated and approved GWP values. The GWP value for PFC-14 is 6 630. PFC-14 is used as cleaning fluid. The use of PFCs in Denmark is limited.

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

4.2.8 Other Product Manufacture and Use

There are four sources of GHG emissions within the CRF category 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 (2024a) contains both SF_6 consumption and emission data for both historic years and projected years until 2040. 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 (2024a and 2024b). Emissions from the Use of electrical equipment cover SF_6 from high voltage equipment. The emissions from SF_6 from other product uses cover SF_6 from double glazed windows and use of SF_6 in laboratories/research. The use of SF_6 in connection with double-glazing was banned in 2002, and according to the F-gas model, the last remaining double-glazing panes where SF_6 has been used will be disposed of in 2021 where the last emissions therefore will 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 2022, 73 % of GHG emissions from IPPU originate from Mineral Industry. By 2040, the number will have increased to 77 % because emissions from Product uses as ODS (ozone depleting substances) substitutes and Other Product Manufacture and Use decrease more than those from Mineral Industry.

The second largest source category is Product uses as substitutes for ODS with up to 18 % of IPPU GHG emissions early in the projection period (2025-2027).

Table 4.9 Projection of CO_2 process emissions, kt CO_2e.

Source Categories		1990	2005	2015	2020	2022	2023	2025	2030	2035	2040
2A	Mineral industry	973	1567	1049	1353	1217	1131	1087	899	926	945
	Hereof cement production	775	1363	932	1227	1073	1002	960	772	798	815
2B	Chemical industry	892	1.1	1.5	1.4	1.3	1.4	1.4	1.4	1.4	1.4
2C	Metal industry	61	16	0.20	0.09	0.05	0.06	0.13	0.13	0.13	0.13
2D	Non-energy products from fuels and solvent use	166	216	175	171	164	168	168	168	168	168
2E	Electronic industry	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2F	Product uses as ODS substitutes	-	889	452	317	261	261	288	206	126	76
2G	Other product manufacture and use	27	48	154	67	34	33	33	33	33	33
	Total	2119	2737	1831	1909	1678	1596	1578	1309	1255	1225

NO: Not occuring.

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

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

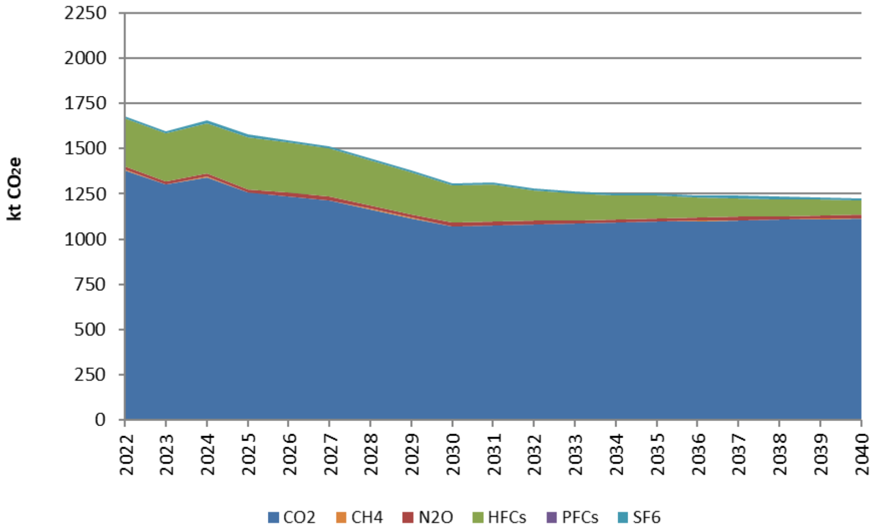

Figure 4.1 Time series for emissions, divided into individual pollutants.

4.3.1 Mineral Industry

Emission projections for mineral industries are shown in Table 4.10.

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

		1990	2005	2015	2020	2022	2023	2025	2030	2035	2040
2A1	Cement production	775	1363	932	1227	1073	1002	960	772	798	815
2A2	Lime production	105	60	51	43	59	44	44	44	44	44
2A3	Glass production	14	11	8	8	9	8	8	8	8	8
2A3	Glass wool production	2	2	1	2	2	2	2	2	2	3
2A4a	Bricks/tiles production	26	35	20	27	23	22	23	24	26	27
2A4a	Expanded clay production	20	19	9	16	18	19	19	19	19	19
2A4b	Other uses of soda ash	14	18	7	16	16	17	17	17	17	17
2A4d	Flue gas cleaning	10	51	16	8	11	11	8	6	5	5
2A4d	Stone wool production	7	8	6	5	5	5	5	6	6	6
	Total	973	1567	1049	1353	1217	1131	1087	899	926	945

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 slight increasing trend, the development is due to the projected cement production presented in Table 4.3. The second largest emission source for all projected years is lime production; 4-5 %.

In 2022, the contribution from category 2A was 2.8 % of the Danish total greenhouse gas emission excluding LULUCF and indirect sources. In 2040, this contribution is estimated to have increased to 4.4 %.

4.3.2 Chemical Industry

There is only one source of GHG emissions within this category; 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. 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 10-14 % of IPPU CO_2 equivalent emissions in 2023-2040.

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

		Pollutant	Unit	1990	2005	2015	2020	2022	2025	2030	2035	2040
2D1	Lubricant use	CO_2	kt	50	38	32	32	32	32	32	32	32
2D2	Paraffin wax use	CO_2	kt	22	100	71	59	62	63	63	63	63
2D3	Other (urea, asphalt, solvent use)	CO_2	kt	94	77	71	79	70	73	73	73	73
2D	Total CO_2	CO_2	kt	166	215	174	170	164	168	168	168	168
2D2	Paraffin wax use	CH_4	t	0.9	4.2	3.0	2.5	2.6	2.6	2.6	2.6	2.6
2D3	Other	CH_4	t	11	17	15	17	19	17	17	17	17
2D	Total CH_4	CH_4	t	12	21	18	19	22	20	20	20	20
2D2	Paraffin wax use	N_2O	t	0.2	0.8	0.6	0.5	0.5	0.5	0.5	0.5	0.5
2D	Total N_2O	N_2O	t	0.2	0.8	0.6	0.5	0.5	0.5	0.5	0.5	0.5
2D	Total CO_2e	CO_2e	kt	166	216	175	171	164	168	168	168	168

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 2023-2040 (Poulsen, 2024b).

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 (CFR category 2.F.1).

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

		1995	2005	2015	2020	2022	2025	2030	2035	2040
2F1a	Commercial refrigeration	31	571	295	164	102	115	66	13	6.2
2F1b	Domestic Refrigeration	9	17	-	-	-	-	-	-	-
2F1d	Transport Refrigeration	0.01	23	22	12	10	11	7.1	6.9	6.5
2F1e	Mobile Air-Conditioning	5	57	54	56	52	52	17	5.6	1.8
2F1f	Stationary air-conditioning	0.6	83	54	74	86	98	105	88	50
2F2a	Closed Cells	50	103	13	0.7	0.6	0.4	0.04	0.02	-
2F2b	Open Cells	142	15	-	-	-	-	-	-	-
2F4a	Metered Dose Inhalers	-	6.8	7.3	10	11	12	12	12	12
2F4b	Other aerosols	-	14	7.3	-	-	-	-	-	-
2F5	Solvents*	-	-	-	-	-	-	-	-	-
	Total	238	889	452	317	261	288	206	126	76

* Occured in 2000-2003.

4.3.7 Other Product Manufacture and Use

Emission projections for other product manufacture and use are not shown at a more disaggregated level due to the low emissions from this source. 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, 2024) and updates in the F-gas projection done by Poulsen (2024a and 2024b).

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

4.5 References

DEA, 2024: Danish Energy Agency. Denmark's Energy and Climate Outlook.

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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)[3] 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 2024" (DECO24) 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, 2023). 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, 2023). In COPERT, fuel consumption and emission simulations can be made for operationally hot engines, taking into account gradually stricter emission standards and emission degradation due to catalyst wear. Furthermore, the emission effects of cold-start and evaporation are simulated.

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

5.1.1 Vehicle fleet and mileage data

Corresponding to the COPERT 5 fleet classification, DEMOS-Road groups all present and future vehicles in the Danish fleet into vehicle classes, subclasses and layers. The layer classification is a further division of vehicle subclasses into groups of vehicles with the same average fuel consumption and emission behaviour, according to EU emission legislation levels. Table 5.2 gives an overview of the different model classes and sub-classes.

[3] 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 Car (PC)	Gasoline	< 0.8 l.
Passenger Car (PC)	Gasoline	0.8 - 1.4 l.
Passenger Car (PC)	Gasoline	1.4 – 2 l.
Passenger Car (PC)	Gasoline	> 2 l.
Passenger Car (PC)	Diesel	< 0.8 l.
Passenger Car (PC)	Diesel	0.8 - 1.4 l.
Passenger Car (PC)	Diesel	< 1.4 - 2 l.
Passenger Car (PC)	Diesel	> 2 l.
Passenger Car (PC)	2-stroke	
Passenger Car (PC)	LPG	
Passenger Car (PC)	CNG	
Passenger Car (PC)	Plug-in hybrid	
Light commercial vehicel (LCV)	Gasoline	<1305 kg
Light commercial vehicel (LCV)	Gasoline	1305-1760 kg
Light commercial vehicel (LCV)	Gasoline	>1760 kg
Light commercial vehicel (LCV)	Diesel	<1305 kg
Light commercial vehicel (LCV)	Diesel	1305-1760 kg
Light commercial vehicel (LCV)	Diesel	>1760 kg
Light commercial vehicel (LCV)	LPG	<1305 kg
Light commercial vehicel (LCV)	LPG	1305-1760 kg
Light commercial vehicel (LCV)	LPG	>1760 kg
Trucks	Gasoline	
Trucks	Diesel/CNG	Rigid 3,5 - 7,5t
Trucks	Diesel/CNG	Rigid 7,5 - 12t
Trucks	Diesel/CNG	Rigid 12 - 14 t
Trucks	Diesel/CNG	Rigid 14 - 20t
Trucks	Diesel/CNG	Rigid 20 - 26t
Trucks	Diesel/CNG	Rigid 26 - 28t
Trucks	Diesel/CNG	Rigid 28 - 32t
Trucks	Diesel/CNG	Rigid >32t
Trucks	Diesel/CNG	TT/AT 14 - 20t
Trucks	Diesel/CNG	TT/AT 20 - 28t
Trucks	Diesel/CNG	TT/AT 28 - 34t
Trucks	Diesel/CNG	TT/AT 34 - 40t
Trucks	Diesel/CNG	TT/AT 40 - 50t
Trucks	Diesel/CNG	TT/AT 50 - 60t
Trucks	Diesel/CNG	TT/AT >60t
Urban buses	Gasoline	
Urban buses	Diesel/CNG	< 15 tonnes
Urban buses	Diesel/CNG	15-18 tonnes
Urban buses	Diesel/CNG	> 18 tonnes
Coaches	Gasoline	
Coaches	Diesel/CNG	< 15 tonnes
Coaches	Diesel/CNG	15-18 tonnes
Coaches	Diesel/CNG	> 18 tonnes
Mopeds	Gasoline	
Motorcycles	Gasoline	2 stroke
Motorcycles	Gasoline	< 250 cc.
Motorcycles	Gasoline	250 – 750 cc.
Motorcycles	Gasoline	> 750 cc.

To support the emission projections fleet and annual mileage data are provided by DTU Transport for the vehicle categories present in COPERT 5

(Jensen, 2023). 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. (2023).

In addition, data from a survey made by the Danish Road Directorate (Hansen, 2010) has given information of the total mileage driven by foreign cars, vans, coaches and trucks on Danish roads in 2009 and a follow-up survey in 2014 has given additional information. This mileage contribution has been added to the total mileage for Danish trucks on Danish roads, for trucks > 16 tonnes of gross vehicle weight. The data has been further processed by DTU Transport; by using appropriate assumptions, the mileage have been backcasted to 1985 and projected to 2040.

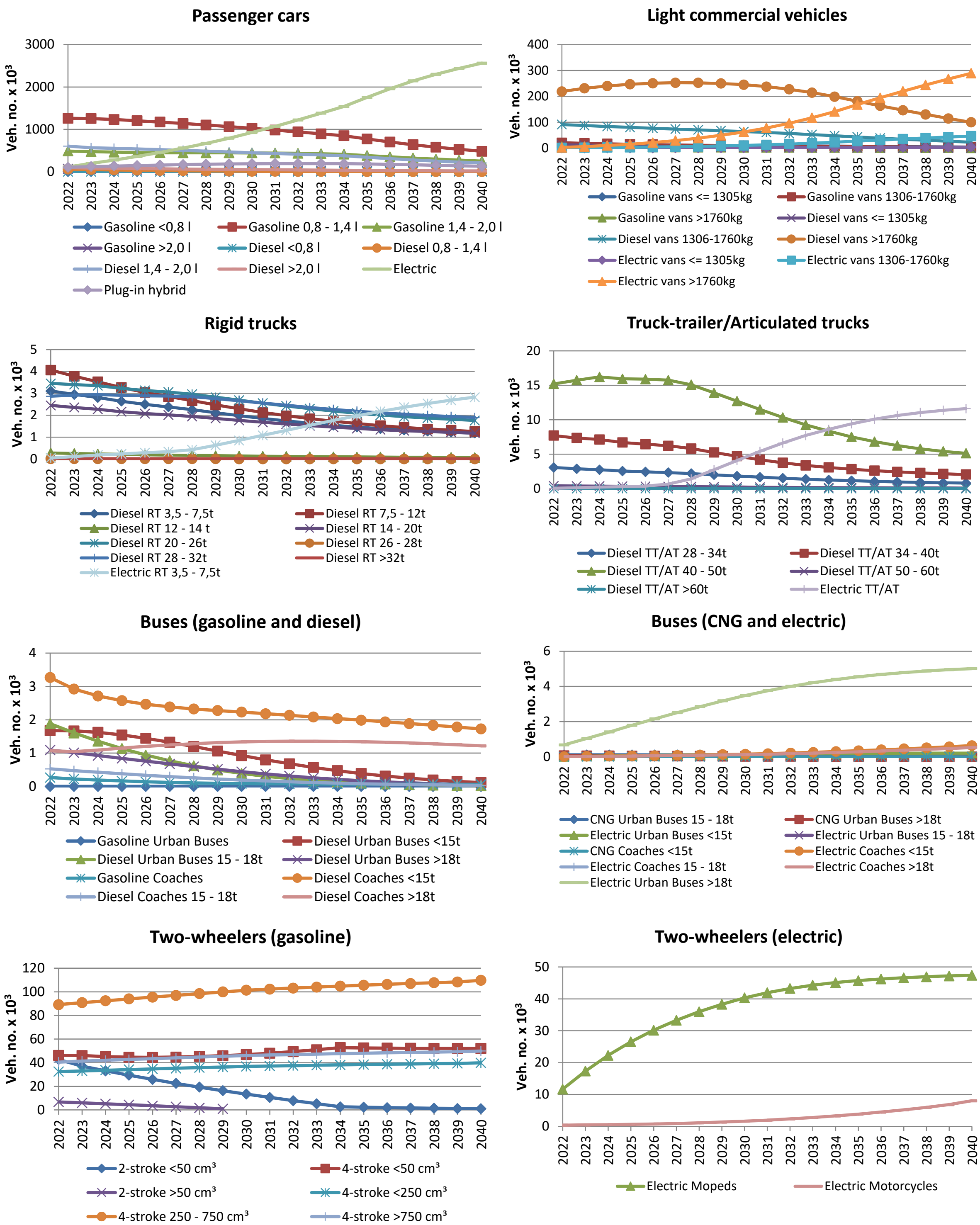

Figure 5.1 Number of vehicles in sub-classes from 2022-2040. PHEV = Plugin Hybrid Electric Vehicles.

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

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

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

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 2022-2040 periods. The latter figure clearly shows how vehicles complying with the gradually stricter EU emission levels (EURO 5/V, Euro 6/VI and Euro 6d) are introduced into the Danish motor fleet in the projection period.

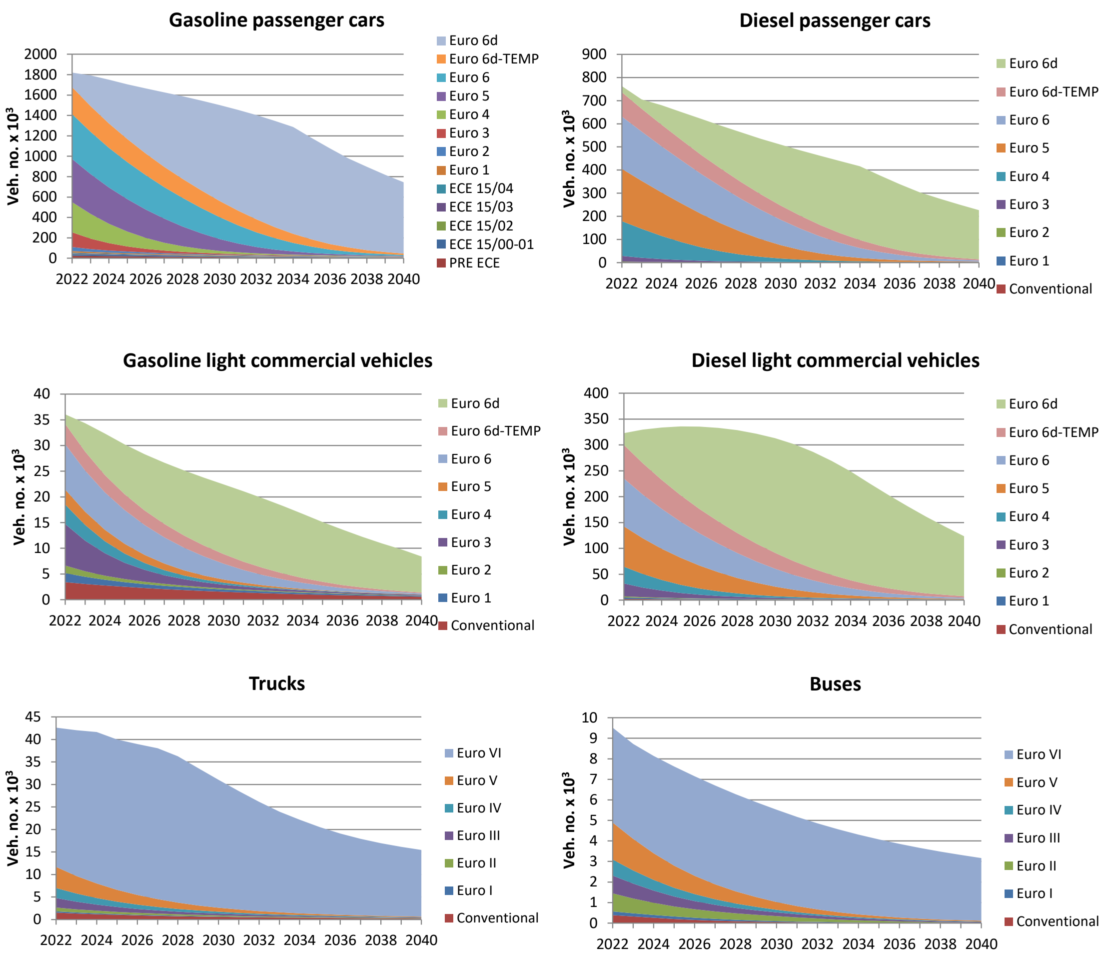

Figure 5.2 Layer distribution of vehicle numbers per vehicle type in 2022-2040.

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 3.5t (vans and car-derived vans, known as N1) and which weigh less than 2610 kg when empty.
- **Long-term target:** a target of 147g CO_2 per km is specified for the year 2020.
- **Excess emissions premium for small excess emissions until 2018:** if the average CO_2 emissions of a manufacturer's fleet exceed its limit value in any year from 2014, the manufacturer has to pay an excess emissions premium for each van registered. This premium amounts to €5 for the first g per km of exceedance, €15 for the second g per km, €25 for the third g per km, and €95 for each subsequent g per km. From 2019, the first g per

km of exceedance will cost €95. This value is equivalent to the premium for passenger cars.

- **Super-credits:** vehicles with extremely low emissions (below 50g per km) will be given additional incentives whereby each low-emitting van will be counted as 3.5 vehicles in 2014 and 2015, 2.5 in 2016 and 1.5 vehicles in 2017.
- **Eco-innovations:** Manufacturers can be granted a maximum of 7g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.
- **Other flexibilities:** manufacturers may group together to form a pool and act jointly in meeting the specific emissions targets. Independent manufacturers who sell fewer than 22,000 vehicles per year can also apply to the Commission for an individual target instead.

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, and bring 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_2target (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 1 000 new cars or fewer than 1 000 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 April 10, 2024 and ratified by the Council of the European Union on May 13, 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[4] (average speed: 19 km per h). The second part of the test is the run-through of the EUDC (Extra Urban Driving Cycle) test driving segment, simulating the fuel consumption under rural and highway driving conditions. The driving length of EUDC is 7 km at an average speed of 63 km per h. More information regarding the fuel measurement procedure can be found in the EU directive 80/1268/EØF.

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

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

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

For NOx, VOC (NMVOC + CH_4), CO and PM, the emissions from road transport vehicles have to comply with the different EU directives listed in Table 5.3. For cars and vans, the emission directives distinguish between

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

three vehicle classes according to vehicle reference mass[5]: 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 engines the WHSC (World Harmonized Stationary Cycle) and WHTC (World Harmonized Transient Cycle) test cycles are used. For a description of the test cycles, see e.g. www.dieselnet.com.

[5] 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
Passenger cars (gasoline)	PRE ECE	-	-	< 1970-
	ECE 15/00-01	70/220 - 74/290	1972[a]	1970[a]
	ECE 15/02	77/102	1981[b]	1979[b]
	ECE 15/03	78/665	1982[c]	1981[c]
	ECE 15/04	83/351	1987[d]	1986[d]
Passenger cars (diesel)	Conventional	-	-	< 1991-
Passenger cars	Euro 1	91/441	1.7.1992[e]	1.1.1991[e]
	Euro 2	94/12	1.1.1996	1.1.1997
	Euro 3	98/69	1.1.2000	1.1.2001
	Euro 4	98/69	1.1.2005	1.1.2006
	Euro 5	715/2007(692/2008)	1.9.2009	1.1.2011
	Euro 6	715/2007(692/2008)	1.9.2014	1.9.2015
	Euro 6d-TEMP	2016/646	1.9.2017	1.9.2018
	Euro 6d	2016/646	1.1.2020	1.1.2021
LCV < 1305 kg	Conventional	-	-	< 1995
	Euro 1	91/441	1.10.1994	1.1.1995
	Euro 2	94/12	1.1.1998	1.1.1999
	Euro 3	98/69	1.1.2001	1.1.2002
	Euro 4	98/69	1.1.2006	1.1.2007
	Euro 5	715/2007(692/2008)	1.9.2010	1.1.2012
	Euro 6	715/2007(692/2008)	1.9.2015	1.9.2016
	Euro 6d-TEMP	2016/646	1.9.2018	1.9.2019
	Euro 6d	2016/646	1.1.2021	1.1.2022
LCV 1305-1760 kg & > 1760 kg	Conventional	-	-	< 1995
	Euro 1	93/59	1.10.1994	1.1.1995
	Euro 2	96/69	1.1.1998	1.1.1999
	Euro 3	98/69	1.1.2001	1.1.2002
	Euro 4	98/69	1.1.2006	1.1.2007
	Euro 5	715/2007	1.9.2010	1.1.2012
	Euro 6	715/2007	1.9.2015	1.9.2016
	Euro 6d-TEMP	2016/646	1.9.2018	1.9.2019
	Euro 6d	2016/646	1.1.2021	1.1.2022
Heavy duty vehicles	Euro 0	88/77	1.10.1990	1.10.1990
	Euro I	91/542	1.10.1993	1.10.1993
	Euro II	91/542	1.10.1996	1.10.1996
	Euro III	1999/96	1.10.2000	1.10.2001
	Euro IV	1999/96	1.10.2005	1.10.2006
	Euro V	1999/96	1.10.2008	1.10.2009
	Euro VI	595/2009	1.1.2013	1.1.2014
Mopeds	Conventional	-	-	-
	Euro I	97/24	2000	2000
	Euro II	2002/51	2004	2004
	Euro III	2002/51	2014[f]	2014[f]
	Euro IV	168/2013	2017	2017
	Euro V	168/2013	2021	2021
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
	Euro V	168/2013	2021	2021

a,b,c,d: Expert judgement suggests that Danish vehicles enter into the traffic before EU directive first registration dates. The effective inventory starting years are a: 1970; b: 1979; c: 1981; d: 1986; e: The directive came into force in Denmark 1.10.1990.

5.1.3 Fuel consumption and emission factors

In practice, the emissions from vehicles in traffic are different from the legislation limit values and, therefore, the latter figures are not suited for total emission calculations. Besides difference in test versus real world driving behaviour, as discussed in the previous section, the emission limit values do not reflect the emission impact of cumulated mileage driven, and engine and exhaust after treatment maintenance levels for a vehicle fleet as such.

Therefore, in order to represent the Danish fleet and to support average national emission estimates, the selected emission factors must be derived from numerous emission measurements, using a broad range of real world driving patterns and a sufficient number of test vehicles. It is similarly important to have separate fuel consumption and emission data for cold-start emission calculations and gasoline evaporation (hydrocarbons).

The fuel consumption and emission factors used in DEMOS-Road come from the COPERT 5 model[6], using trip speeds representative for urban, rural and highway driving. The factors can be seen in Nielsen et al. (2023). 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 battery driven, according to assumptions made by DEA (2023)[7]. The fuel consumption and emission factors for plug-in vehicles used in the Danish national emission inventories for road transport, and shown in the present 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 compensate for the increasing fuel gap between fuel consumption measured during vehicle type approval and real world fuel consumption.

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

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

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

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[8] with an index function (indexed from 2014), C_{ICCT} (i, f), based on the reported ICCT fuel gap figures by fuel type for the new registration years 2014-2022.

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

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

For years beyond 2022 annual fuel efficiency, improvement rates are used for new cars depending on fuel type as suggested by DEA (2023).

[8] 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.
[9] The factors are derived from the Common Artemis Driving Cycle (CADC), with a 1/3 weight for each of the urban, rural and highway parts of CADC.

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 (2023).

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. (2023).

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, 2023)[10].

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 a LTO/cruise split of the fuel consumption projections for domestic and international aviation from DECO24 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.

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

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

table already established in the previous version of DEMOS-Aviation (e.g. Winther, 2022).

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, airport ground service equipment, other	Forklifts (LPG), building and construction, other
Residential and Commercial/ institutional	-	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 DECO24 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, 2022; Nielsen et al., 2023).

Table 5.5 lists the most important domestic ferry routes in Denmark in 2022. The complete list of ferries is shown in e.g. Winther (2022). 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 (2022) 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 DECO24, and electronic log data for the latest historical year 2022 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 (2022) 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 DECO24, 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 DECO24.

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 DECO24.

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

Table 5.6 Overview of EU emission directives 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						
Hand held	SH1	S<20	805	295	5.36	-	1/2 2005
	SH2	20≤S<50	805	241	5.36	-	1/2 2005
	SH3	50≤S	603	161	5.36	-	1/2 2005
Not hand held	SN3	100≤S<225	519	-	-	16.1	1/2 2005
	SN4	225≤S	519	-	-	13.4	1/2 2005
	Stage II						
Hand held	SH1	S<20	805	-	-	50	1/2 2008
	SH2	20≤S<50	805	-	-	50	1/2 2008
	SH3	50≤S	603	-	-	72	1/2 2009
Not hand held	SN1	S<66	610	-	-	50	1/2 2005
	SN2	66≤S<100	610	-	-	40	1/2 2005
	SN3	100≤S<225	610	-	-	16.1	1/2 2008
	SN4	225≤S	610	-	-	12.1	1/2 2007
EU Directive 2016/1628	Stage V						
Hand held (<19 kW)	NRSh-v-1a	S<50	805	-	-	50	2019
	NRSh-v-1b	50≤S	805	-	-	72	2019
Not hand held (P<19 kW)	NRS-vr/vi-1a	80≤S<225	610	-	-	10	2019
	NRS-vr/vi-1b	S≥225	610	-	-	8	2019
Not hand held (19=<P<30 kW)	NRS-v-2a	S≤1000	610	-	-	8	2019
	NRS-v-2b	S>1000	4.40*	-	-	2.70*	2019
Not hand held (30=<P<56 kW)	NRS-v-3	any	4.40*	-	-	2.70*	2019

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

For recreational craft, Directive 2003/44 comprises the Stage 1 emission legislation limits for diesel engines, and for 2-stroke and 4-stroke gasoline engines, respectively. The CO and VOC emission limits depend on engine size (kW) and the inserted parameters presented in the calculation formulas in Table 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[11].

				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 Off) cycle divided by the rated engine thrust (kN). The

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

ICAO LTO cycle contains the idealised aircraft movements below 3000 ft (915 m) during approach, landing, airport taxiing, take off and climb out.

For smoke all aircraft engines manufactured from 1 January 1983 have to meet the emission limits agreed by ICAO. For NO_x, CO, VOC the emission legislation is relevant for aircraft engines with a rated engine thrust larger than 26.7 kN. In the case of CO and VOC, the ICAO regulations apply for engines manufactured from 1 January 1983.

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

The regulations published by ICAO are given in the form of the total quantity of pollutants (D_p) emitted in the LTO cycle divided by the maximum sea level thrust (F_{oo}) and plotted against engine pressure ratio at maximum sea level thrust.

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

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

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

Embedded applicability dates are:

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

- **All propeller-driven aeroplanes**, including their derived versions, of greater than 8 618 kg maximum take-off mass, for which the application for a type certificate was submitted on or after 1 January 2020;
- **Derived versions of non-CO_2 certified subsonic jet aeroplanes** of greater than 5 700 kg maximum certificated take-off mass for which the application for certification of the change in type design is submitted on or after 1 January 2023;
- **Derived versions of non-CO_2 certified propeller-driven aeroplanes** of greater than 8 618 kg maximum certificated take-off mass for which the application for certification of the change in type design is submitted on or after 1 January 2023;
- **Individual non-CO_2 certified subsonic jet aeroplanes** of greater than 5 700 kg maximum certificated take-off mass for which a certificate of airworthiness is first issued on or after 1 January 2028; and
- **Individual non-CO_2 certified propeller-driven aeroplanes** of greater than 8 618 kg maximum certificated take-off mass for which a certificate of airworthiness is first issued on or after 1 January 2028.

Marpol 73/78 Annex VI agreed by IMO (International Maritime Organisation) concerns the control of NO_x emissions (Regulation 13 plus amendments) and SO_x and particulate emissions (Regulation 14 plus amendments) from ships (DNV, 2009). The so called Energy Efficiency Design Index (EEDI) fuel efficiency regulations for new built ships was included in Chapter 4 of Annex VI in the Marpol convention for the purpose of controlling the CO_2 emissions from new built ships larger than 400 GT (Lloyd's Register, 2012).

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

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

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

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

It is envisaged that also ro-ro (roll on – roll off) cargo, ro-ro passenger and cruise passenger ships will be included in the EEDI scheme 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 (2023).

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 (2023) 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, 2023). 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 Ministry of Transport (2015). Specifically for the ferries used by Mols Linjen, VOC emission factors are provided by Kristensen (2008), originating from engine measurements (Hansen et al., 2004; Wismann, 1999; PHP, 1996). Complimentary VOC emission factor data for new ferries is provided by Kristensen (2013) and engine load specific VOC emission data is provided by Nielsen (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, 2023). 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 (2023).

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 (2022).

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 (2022).

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 DECO24 fuel consumption for national sea transport and bottom up fuel consumption for domestic ferries) as explained in Winther (2022). For international sea transport, fuel based calculations are made in DEMOS-Navigation using fuel-related emission factors and fuel consumption from DECO24 as explained in Winther (2022).

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 in order to account for all fuel projected for fisheries in DECO24.

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 in order to account for all fuel projected for railways in DECO24.

Military

For military, the emissions are calculated as the product of fuel consumption from DECO24 and fuel-related emission factors.

Subsectoral fuel transferals between DECO24 and the emission projections

The DECO24 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 DECO24.

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
CO_2, kt	Industry - Other (1A2g)	532	637	605	610	648	634	638	604	563	503
	Civil Aviation nat. (1A3a)	216	155	131	76	118	99	103	39	32	26
	Road - Cars (1A3bi)	5018	6503	6442	5921	5873	6230	5844	4775	3617	2192
	Road - Light duty trucks (1A3bii)	1446	2136	1646	1473	1527	1814	1738	1419	927	435
	Road - Heavy duty vehicles (1A3biii)	2826	3559	3411	3596	3668	2900	1778	1344	740	504
	Road - Motorcycles and mopeds (1A3biv)	46	71	71	68	68	55	54	53	53	55
	Railways (1A3c)	297	232	249	196	154	174	166	67	15	0
	Navigation (1A3d)	715	699	431	479	495	501	450	309	272	200
	Comm./Inst. (1A4a)	152	205	213	176	175	55	46	26	15	11
	Residential (1A4b)	26	34	32	28	26	36	36	36	36	36
	Agriculture/forestry/fisheries (1A4c)	1235	1246	1084	1017	1059	1032	1000	904	800	758
	Other (1A5b, military mobile)	119	271	98	146	93	93	93	93	93	93
	Other (1A5b, recreational craft)	48	103	92	92	92	92	91	89	88	88
	Navigation int. (1A3d)	3006	2352	2293	1620	1547	1554	1554	1554	1554	1554
	Civil Aviation int. (1A3a)	1763	2554	2622	979	2169	2133	2020	1884	1549	1262
		1990	2005	2015	2020	2022	2023	2025	2030	2035	2040
CH_4, t	Industry - Other (1A2g)	48	35	25	21	20	7	7	6	5	5
	Civil Aviation nat. (1A3a)	3	4	1	1	1	1	1	1	1	0
	Road - Cars (1A3bi)	2559	914	280	188	180	176	156	122	90	56
	Road - Light duty trucks (1A3bii)	198	101	16	6	6	7	5	3	2	1
	Road - Heavy duty vehicles (1A3biii)	289	326	66	41	43	36	26	18	11	8
	Road - Motorcycles and mopeds (1A3biv)	89	116	84	71	67	53	51	47	44	43
	Railways (1A3c)	12	9	5	3	2	2	2	1	0	0
	Navigation (1A3d)	10	11	26	28	9	9	8	6	6	5
	Comm./Inst. (1A4a)	33	73	36	30	31	1	0	0	0	0
	Residential (1A4b)	47	60	24	21	19	26	24	22	22	22
	Agriculture/forestry/fisheries (1A4c)	214	86	62	49	47	20	19	17	15	14
	Other (1A5b, military mobile)	5	12	2	4	3	3	3	3	3	3
	Other (1A5b, recreational craft)	77	62	7	6	6	6	5	5	5	5
	Navigation int. (1A3d)	44	38	39	28	27	28	28	28	28	28
	Civil Aviation int. (1A3a)	7	10	9	3	6	6	6	6	6	6
		1990	2005	2015	2020	2022	2023	2025	2030	2035	2040
N_2O, t	Industry - Other (1A2g)	20	26	27	28	30	30	31	30	29	26
	Civil Aviation nat. (1A3a)	10	8	7	4	6	5	5	5	5	2
	Road - Cars (1A3bi)	180	228	172	136	126	139	124	91	67	40
	Road - Light duty trucks (1A3bii)	10	60	53	44	45	52	51	45	31	15
	Road - Heavy duty vehicles (1A3biii)	101	45	193	237	248	198	127	112	67	49
	Road - Motorcycles and mopeds (1A3biv)	1	1	1	1	1	1	1	1	1	1
	Railways (1A3c)	9	7	8	6	5	6	5	2	0	0
	Navigation (1A3d)	18	18	11	12	12	13	11	8	8	7
	Comm./Inst. (1A4a)	6	7	8	7	7	3	2	1	1	1
	Residential (1A4b)	0	1	1	0	0	1	1	1	1	1
	Agriculture/forestry/fisheries (1A4c)	38	43	42	41	42	41	41	39	35	33
	Other (1A5b, military mobile)	4	7	4	5	3	3	3	4	4	4
	Other (1A5b, recreational craft)	1	3	4	4	4	3	3	3	3	3
	Navigation int. (1A3d)	76	59	58	41	39	39	39	39	39	39
	Civil Aviation int. (1A3a)	60	87	89	33	73	72	69	68	65	64
		1990	2005	2015	2020	2022	2023	2025	2030	2035	2040
CO_2-eq., kt	Industry - Other (1A2g)	539	644	613	618	657	642	647	613	571	510
	Civil Aviation nat. (1A3a)	219	158	133	77	119	100	104	40	33	26
	Road - Cars (1A3bi)	5138	6589	6496	5962	5911	6272	5881	4802	3637	2205
	Road - Light duty trucks (1A3bii)	1454	2155	1661	1485	1539	1828	1751	1431	935	439
	Road - Heavy duty vehicles (1A3biii)	2861	3580	3464	3660	3735	2953	1812	1375	758	517
	Road - Motorcycles and mopeds (1A3biv)	49	74	73	71	70	57	56	55	55	56
	Railways (1A3c)	300	235	251	198	155	175	168	68	15	0
	Navigation (1A3d)	720	704	435	483	499	505	453	311	274	202
	Comm./Inst. (1A4a)	154	209	216	179	177	56	46	26	16	11
	Residential (1A4b)	27	36	33	28	27	36	36	36	36	36
	Agriculture/forestry/fisheries (1A4c)	1251	1260	1097	1029	1072	1044	1011	915	810	767
	Other (1A5b, military mobile)	120	273	100	148	94	94	94	94	94	95
	Other (1A5b, recreational craft)	50	106	94	93	93	94	92	89	89	89
	Navigation int. (1A3d)	3027	2369	2310	1631	1558	1566	1566	1566	1566	1566
	Civil Aviation int. (1A3a)	1779	2577	2646	988	2188	2152	2039	1902	1567	1280

5.3.1 Road transport

The total CO_2 emissions decrease is expected to be 71 % from 2022-2040. Passenger cars have the largest fuel consumption share followed by heavy duty vehicles, light commercial vehicles, buses and 2-wheelers in decreasing order, see Figure 5.3.

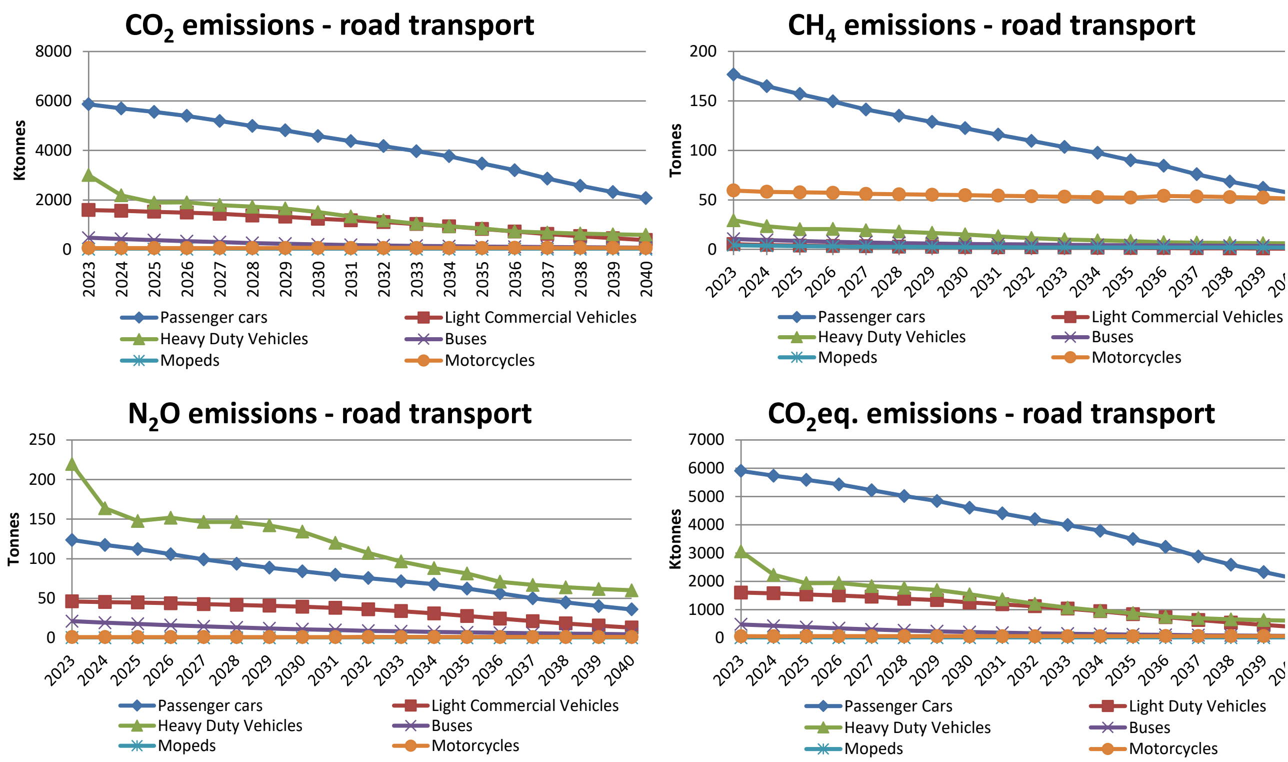

Figure 5.3 CO_2, CH_4, N_2O and CO_{2e} emissions from 2023-2040 for road traffic.

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 60 % and 73 %, respectively, from 2022 to 2040.

5.3.2 Other mobile sources

The development in CO_2 emissions for other mobile sources, see Figure 5.4, corresponds with the development in fuel consumption. Agriculture/forestry/fisheries (1A4c) is by far the largest source of CO_2 emissions followed by 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.

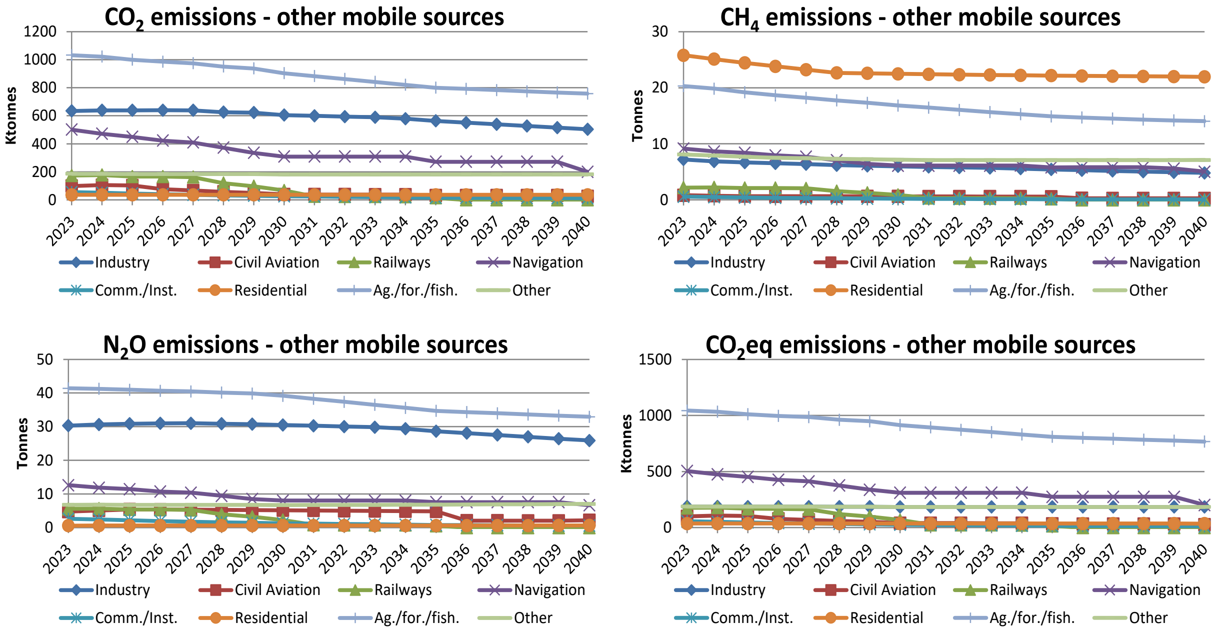

Figure 5.4 CO_2, CH_4, N_2O and CO_{2e} emissions from 2023-2040 for other mobile sources.

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 housing types and the enlargement of the biogas production, influences the management of animal manure and thus also affect the methane emission.

The expectations to the livestock production and the agricultural area 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 (agricultural advisory company).

The current projection considers the elements included in the Political agreements and regulation initiated or decided until December 2023 (so called “frozen policy” or projection “with existing instruments”). For this projection, the Agreement on the Green Transition for Danish Agriculture (AGTDA, 2021) is considered, for measures, which can be considered as frozen policy. This means that following measures are considered; removal of organic soils as cultivated area, lower nitrogen quota for cultivated organic soils, no fertilisation for §3 areas, increased areas with perennial grass, extension of the organic cultivated area with lower nitrogen fertilisation and extended hectare with catch crops. The initiatives mentioned have an impact, which lead to lowering the total nitrogen supply of the agricultural land and furthermore to a decrease in the nitrogen leaching. For farmers with animal production agreements on frequent removal of slurry from swine housings and decrease of emission from cattle, here as increased content of fatty acids in fodder for dairy cattle, is considered.

The future biogas production is based on a projection provided by the Danish Energy Agency (DEA, 2023).

6.1 Projected agricultural emission 2023 - 2040

The latest official reporting of emissions includes time series until 2022 for all emission sources. The development of agricultural greenhouse gases from 1990 to 2022 (Table 6.1) shows a decrease from 13.8 million tonnes CO_2 equivalents to 11.5 million tonnes CO_2 equivalents, which correspond to a 17 % reduction. In the current projection, based on the assumptions provided, the emission decreases by 18 % from 2022 to 2040, and thus the total emission is estimated to 9.5 million tonnes CO_2 equivalents by 2040. 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 housings. 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 is also due to a lower consumption of inorganic fertiliser, caused by requirement to higher utilisation of nitrogen content in animal manure, regulation regarding lower nitrogen supply for organic soils, areas which are vulnerable to high inputs of nitrogen (§3 areas), increase in organic farmed areas and increased in area with perennial grass outside rotation. The last explanation for the emission decrease, which must be mentioned, is a reduction of the cultivation of organic soils and a lower emission from N-leaching caused by the catch crop area.

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

	1990	2000	2005	2010	2015	2020	2022	2023	2025	2030	2035	2040
Enteric fermentation	4 455	4 034	3 873	4 048	4 106	4 136	4 092	4 028	3 898	3 827	3 748	3 680
Manure management	3 330	4 163	4 389	3 993	3 829	3 760	3 492	3 002	2 985	2 556	2 396	2 251
Agricultural soils	5 431	4 214	3 882	3 825	3 852	3 935	3 668	3 573	3 561	3 389	3 339	3 322
Field burning of agricultural residue	2	3	3	2	2	3	4	3	3	3	3	3
Liming	565	261	220	153	166	250	246	235	234	228	226	226
Urea application (CO_2 emission)	15	2	0	1	1	1	16	4	4	4	4	4
Other carbon-containing fertilisers	33	5	1	2	9	4	6	4	4	4	4	4
Total	13 831	12 682	12 369	12 024	11 965	12 089	11 523	10 849	10 688	10 010	9 719	9 488

6.2 Comparison with previous projection

By comparing the current projection with the latest provided greenhouse gas projection (Nielsen et al., 2023a), the emission given in CO_2 equivalents has decreased up to 5 % in the years 2023-2040. 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, the emission is decreased for the years 2023-2040 with up to 3 % compared to the latest projection, due to lower emission from both enteric fermentation and manure management, which is mainly due changes in the number of dairy cattle and swine. The N_2O emission is decreased for all years 2023-2040 in the current projection compared to the latest projection and this is mainly due to decrease in emission from organic soils and crop residue. Emission from organic soils is changed because new data for the area with organic soils have been applied and for crop residue an error in dry matter content for maize have been corrected. Figure 6.1 shows small changes for CH_4 emission in the historical years 1990-2022 of 1 % decrease (1990-1991) to up to 2 % increase (1992-2022), mainly due to changes in number of days on grass and changes in number of weaners and fattening pigs. For the emission of N_2O the emission from 1990 to 2000 is almost unaltered, while a decrease of 1-8 % is seen for the years 2001-2022, which is mainly due to updating of area with organic soils and updated emission from crop residue.

Some of the changes of the emission trend for the current projection are related to update of the latest historical year, from 2021 to 2022. 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 2040 and the latest historical year.

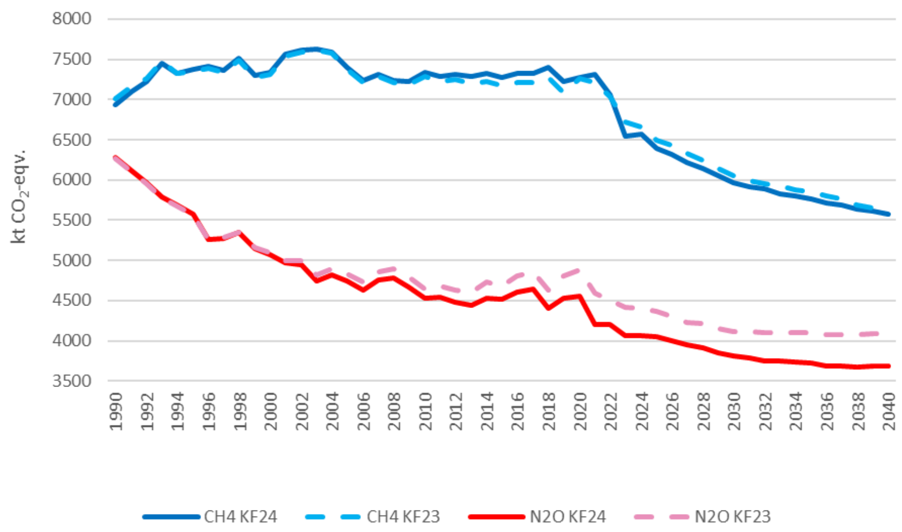

Figure 6.1 Projection 2024 (KF24) compared with projection 2023 (KF23).

As mentioned above the total CH_4 emission is up to 3 % lower in 2022-2040 compared to the previous projection. Emission of CH_4 from enteric fermentation are up to 2 % lower in the years 2022-2039 and less than 1 % higher in 2040 in the current projection and emission of CH_4 from manure management is 1-4 % lower compared to the previous projection. The changes in emission of CH_4 from enteric fermentation is mainly due to changes in number of animals due to updated projection from IFRO (Jensen, 2023). The lower emission from manure management is mainly due to change in number of animals and updated projection of slurry treated in biogas plants (DEA, 2023).

Compared to previous projection (KF23), the current projected N_2O emission is 7-9 % 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. As mentioned above has new data for the area with organic soils and correction of an error in dry matter content for maize in crop residue decreased the emission. Further has changes in number of animals and updated projection of slurry treated in biogas plants (DEA, 2023) also decreased the emission. Emission from some subcategories have increased a bit compared to previous projection: Inorganic fertiliser due to lower number of animals which gives lower N applied to soil, mineralisation, and atmospheric deposition mainly due to increased NH_3 emission from inorganic fertiliser because emission factors in EMEP/EEA Guidebook 2023 are updated.

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 agricultural area reported in the agricultural sector differs slightly (a few thousands hectare out of 2.5 million hectares) from the agricultural area used in the LULUCF sector as DCE in February 2024 has received new data from the Danish Agricultural Agency on the future afforestation rate and wetland restoration rate. These are included in the LULUCF sector.

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 houses with focus on ammonia reducing technologies. The current projection includes an increase in the uptake of ammonia reducing technologies, which has an indirect impact on N_2O emissions, as well as on CH_4 emissions. In the current projection, ammonia reducing technology includes acidification of slurry (housing, storage, and application), cooling of manure in housing, air cleaning in housing, heat exchanger for poultry housing, manure removal in mink housing two times a week and slurry delivered to biogas plant.

The assumptions regarding the expansion and development of emission reducing technologies in livestock production is based on estimations made by SEGES (2023). The expectations to expansion of the biogas production are based on assumptions provided by the DEA.

Measurements to reduce CH_4 emissions has also been taken in to account; frequent removal of slurry from swine housings and higher ratio of fatty acids in fodder for dairy cattle. Frequent removal of slurry from housings influences the estimation of MCF, while higher ratio of fatty acids in the fodder influences the estimation of 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, 2023). 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 2022. 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 can be continued from 2023, but it will be very difficult and costly to restart the mink production especially because of the loss of breeding animals, so the production is projected to be only 10 % of the production in 2020.

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, 2023).

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 11 100 l/cow/year in 2022 to 13 800 l/cow/year in 2040, which correspond to a rise of 24 %. This development corresponds to an N-excretion in 2022 for large breed cattle at 161 kg N, increasing to 183 kg N in 2040.

For the estimation of Ym, is considered higher ratio of fatty acids in fodder 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 and one of the methods is by increasing the ratio of fatty acids in the fodder. This is not considered doable for organic farmers with the current availability of feedstuffs and Ym used in the projection calculations are 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 (2023) 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 housing 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 are not included for organic farmed dairy cattle.

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

Dairy cattle	2022*	2025	2030	2035	2040
No. of dairy cattle, 1000 unit	557	543	517	493	473
Milk yield, kg milk per cow per year					
Large breed	11 127	11 651	12 355	13 063	13 775
Jersey	7 637	7 965	8 446	8 931	9 417
Large breed, organic	-	10 824	11 277	11 730	12 183
Jersey, organic	-	7 459	7 771	8 083	8 396
N-excretion, kg per year					
Large breed	161	165	171	177	183
Jersey	131	137	142	147	153
Large breed, organic	-	159	163	167	170
Jersey, organic	-	129	133	136	139
Feed intake, kg dm per year					
Large breed	8 456	8 720	9 092	9 466	9 842
Jersey	6 814	7 041	7 353	7 668	7 984
Large breed, organic	-	8 265	8 503	8 742	8 981
Jersey, organic	-	6 606	6 804	7 003	7 201
Ym, %					
Large breed	5.76	5.38	5.35	5.31	5.28
Jersey	5.80	5.42	5.39	5.36	5.33
Large breed, organic	-	5.90	5.88	5.85	5.83
Jersey, organic	-	5.93	5.91	5.89	5.87

* Weighted average for conventional and organic farmed dairy cattle

For non-dairy cattle, historic normative data for N-excretion for all cattle sub-categories show few changes. In the projection, no significant changes in N-excretion are expected and therefore kept at the same level as in 2022. 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, 2023). 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	2022	2025	2030	2035	2040
Trend*					
Sows	100	94	91	88	84
Weaners	100	95	96	95	94
Fattening pigs	100	83	85	85	84
Numbers, millions produced					
Sows	0.97	0.92	0.89	0.86	0.82
Weaners	32.45	30.78	31.02	30.93	30.57
Fattening pigs	18.66	15.47	15.81	15.78	15.63

* Based on AGMEMOD (Jensen, 2023).

The projection of N-excretion for sows, weaners and fattening pigs is based on projection made by DCA (Nørgaard & Hellwing, 2023).

Table 6.4 N-excretion, kg N-excretion.

Swine	2022	2025	2030	2035	2040
Sows	23.20	23.57	23.26	22.97	22.63
Weaners	0.39	0.41	0.39	0.34	0.32
Fattening pigs	2.63	2.87	2.73	2.56	2.40

6.4.3 Housing system

Projection of distribution for cattle in different types of housing systems is provided by SEGES (2023). The estimates are for 2030 and 2040 for dairy cattle and heifers. Distribution for the years 2023-2029 and 2031-2039 are interpolated. The projection considers legislation about animal welfare (space requirement, straw etc.) and environment requirement. In 2022, 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 2040, and tethering are phased out before 2030. For heifers, the tethering housing is also assumed to be phased out before 2030. Around 25 % expects to be housed in deep litter systems in 2040 and the remaining part is assumed to be placed in housing systems with cubicles.

For bulls and suckling cattle, the distribution on different housing systems for 2023-2040 is set at the same level as 2022, except for the housing type slatted floor-boxes, which is phased out in 2024 due to a ban of this housing type.

For swine, SEGES (2023) estimates the distribution of animals on different housing systems. The estimates are made for 2030 and 2040 and for the years 2023-2029 and 2031-2039 the distribution is interpolated. Approximately 99 % of the fattening pigs and weaners are housed in systems with drained or partly slatted floor in 2022 and this is assumed to be the same in 2040. For sows, a decrease in systems where the sow is housed individually is assumed.

Jensen (2021, Pers. Comm.) projects distribution of hens and broilers on different housing systems. The estimates are made for 2030 and for the years 2023-2029, the distribution is interpolated and 2031-2040 is set at the same level as 2030. For broilers, it is assumed that the share of barn and organic broilers increase, while the share of 35 days broilers decrease in the years up to 2030.

For mink, there are two types of housing systems in the projection; housings where the manure is removed once a week and housings where manure is removed two times a week. In 2020, 11 % of mink were in systems where manure is removed two times a week. No production of mink is expected for 2021-2022 due to legislation brought on by COVID-19. For the years 2023-2040, the same distribution of housing systems as for 2020 are used.

6.5 Emission reducing technology

In the historic emission inventory is included reduction of NH_3 from the emission reducing technologies; acidification of slurry, cooling of manure, heat exchanger in broiler housing and frequent removal of manure in mink housings. The inventory also considers the reduced emission of CH_4 and N_2O because of slurry delivered to the biogas production.

Other emission reducing technologies as air cleaning and frequent removal of slurry from swine housings are not included in the historical emission inventory due to lack of data. It is expected that the reduction of emission from use of technology will 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.

Following technologies are included in the projection; reduction of CH_4 due to cooling of manure in pig housing, acidification of cattle- and swine manure (housing) and frequent removal of slurry from swine housings. Reduction of NH_3 due to air cleaning in swine housing, heat exchanger in broiler housing, frequent removal of mink manure from housing (2 x weekly) and slurry acidification in tank/during application of manure. Furthermore, reduction of emission due to slurry delivered to biogas production is considered.

6.5.1 Use of environmental technologies

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

The assumptions regarding the expansion and development of emission reducing technologies in livestock production used in the historic emission inventory is based on data from the environmental approvals register 2007-2016 and acidification systems sold (Nielsen et al., 2023b, Annex 3D Chapter 3D-1).

For cattle the only available technology in housings is, for now, acidification and projection of this is made by SEGES (2023). The projection is used for dairy cattle and heifers.

Projection of distribution of housings with acidification and cooling of manure are based on information from SEGES (2023) and distribution of housings with air cleaning is based on Wiborg (2022).

Distribution of housings with frequent removal of slurry from the housing is based on estimation made by the Ministry of Environment (MED, 2022). In Agreement on the Green Transition for Danish Agriculture (AGTDA, 2021) it is given that slurry from all housings with fattening pigs and all new buildings for sows and weaners from 2023 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 5 % of existing housings and up to 1 % of new build housings get a dispensation. Frequent removal of the slurry is not required if the slurry is acidified. An estimation of share of new build housings is estimated by MED (2022). Frequent removal of slurry from swine housing only reduce emission of CH_4.

Manure cooling is the most frequently used technology for the overall swine production, in particular in housings for sows and weaners and this trend is expected to continue. For new build housings, cooling of manure is expected to be installed extensively. Acidification of manure in housings for swine is expected to slightly increase in the future. Air cleaning is expected to be phased out in 2040 based on the low distribution at present and because air cleaning only reduces ammonia and no greenhouse gasses.

Frequent removal of slurry is by legislation made mandatory from 2023 for housings with fattening pigs and it is expected to be done in 92-93 % of the housings in the period 2023-2040. For sows and weaners, the frequent removal is made mandatory in new build housings and the distribution is expected to increase to around 65 % in 2040.

Acidification in housings for cattle is expected to slightly increase in the future.

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

Cooling of manure	2022	2023	2025	2030	2035	2040
Sows	10	14	21	40	53	65*
Weaners	5	8	14	30	39	48*
Fattening pigs	4	6	10	20	28	35
Acidification in housing						
Dairy cattle, large breed	2	3	4	8	8	8
Dairy cattle, jersey	3	4	5	8	8	8
Heifer, large breed	0	1	1	2	2	2
Heifer, jersey	0	0	1	2	2	2
Sows	2	3	3	4	4	5
Weaners	1	2	2	2	2	3
Fattening pigs	3	3	3	5	5	6
Air cleaning						
Sows	1	2	3	5	3	0
Weaners	0	0	0	0	0	0
Fattening pigs	1	2	2	4	2	0
Frequent removal of slurry						
Sows	0	1	9	27	46	64
Weaners	0	2	10	29	48	66
Fattening pigs	0	92	92	92	92	92

* In SEGES (2023) share of cooling is estimated to 70 % for sows and 55 % for weaners, 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 2022, almost 90 % of broiler housings 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 expected from 2023 and it is expected that 90 % of the production will remove the manure two times a week.

Projection of acidification during application of manure is based on SEGES (2023). 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, 2023).

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

Heat exchanger	2021	2030	2040
Broilers	90	100	100
Removal of manure - 2 times weekly			
Mink	11	90	90
Acidification during application			
Cattle manure	8	12	16
Swine manure	1	2	4

6.5.2 Emission reduction effect – NH_3 and CH_4

The reduction factors for both ammonia emission and methane emission used in the projection are given in Table 6.7. The CH_4 reduction from cooling of manure in housing and acidification of manure is based on a report provided by AgroTech (Hansen et al., 2015). A national model has been developed to estimate national methane conversion factors (MCF) for untreated and biogas treated slurry (Mikkelsen et al., 2016). The model is updated in 2023 (Nielsen et al., 2023c). Frequent removal of slurry in swine housings is incorporated in the estimation of the projected MCF.

NH_3 reduction due to the use of acidification, heat exchangers used in broiler housings and frequent removal of mink manure, is based on the List of Environmental Technologies (DEPA, 2023), which contains technologies that through tests have been documented to be environmentally efficient and operationally in practice.

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

Table 6.7 Reducing factor of NH_3 and CH_4.

Technology	Location	Category	Compound	Reduction, %	Reference
Cooling of manure	Housing	Swine	NH_3	20	DEPA**
	Housing/storage	Swine	CH_4	20	Hansen et al., 2015
Acidification	Housing	Cattle	NH_3	33	DEPA**
	Housing	Swine	NH_3	64	DEPA**
	Storage	Cattle	NH_3	49	DEPA**
	Storage	Swine	NH_3	40	DEPA**
	Housing/storage	Cattle/swine	CH_4	60	Hansen et al., 2015
	Application	Cattle	NH_3	49	DEPA**
	Application	Swine	NH_3	40	DEPA**
Air cleaning	Housing	Sows	NH_3	61	Environmental approvals*
	Housing	Weaners	NH_3	54	Environmental approvals*
	Housing	Fattening pigs	NH_3	56	Environmental approvals*
Biogas treatment	Large-scale or farm-scale biogas plants	Cattle	CH_4	48-58	Based on results from the Danish biogas model (Nielsen et al., 2023c)
		Swine	CH_4	38-59	Do
		Cattle	N_2O	88	IPCC 2019 Refinement
		Swine	N_2O	87	IPCC 2019 Refinement
Heat exchanger	Housing	Broilers	NH_3	30	DEPA**
Removal of slurry – 2 x weekly	Housing	Mink	NH_3	27	DEPA**

* Based on the review of the register of environmental approvals 2007-2016 (Nielsen et al., 2023b).
**List of Environmental Technologies (DEPA, 2023).

6.5.3 Biogas treatment of animal manure

Biogas treatment leads to a lower CH_4 and N_2O emission from animal manure. In 2022, approximately 10.0 million tonnes slurry were treated in biogas plants, which are equivalent to approximately 27 % of all slurry. Prognoses provided by DEA assume an increase of biogas production on manure-based biogas plants from 27.5 PJ in 2022 to 46.0 PJ in 2035. The prognoses show a decrease in the biogas production from 2035 to 2040 to 45.5 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 2021/2022 (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 2020-2022 between biogas production and slurry input the amount of slurry input for the years 2023-2040 is estimated.

It is assumed that cattle slurry accounts for 62 % and swine slurry for 38 %, based on data from the BIB register for 2022.

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
2022	28.8	27.5	10.0
2023	32.2	28.5	11.1
2030	47.8	44.0	17.1
2040	49.2	45.5	17.7

A Biogas Task Force set up by the DEA initiated several projects to improve the Danish emission inventory regarding the reduction of GHG emissions as a consequence of 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 housing types (Mikkelsen et al., 2016). The model has been updated in 2023 (Nielsen et al., 2023c) and this national methane conversion factor (MCF) is now used in the Danish GHG emission inventory. The MCF changes from year to year depending on changes in housing type and change in time the slurry is in the housings. In the projection, it is assumed that cattle slurry delivered to biogas production reduces the CH_4 emission by approximately 48-58 %. It is assumed that pig slurry delivered to biogas production reduces the CH_4 emission by approximately 38-59 % with increasing effect from 2023 due to increasing share of slurry, which is frequently removed from the housings.

6.6 Other agricultural emission sources

Besides the livestock production, some emission sources related to cultivation of the agricultural area has a relatively important impact, 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, 2023). In 2022 the agricultural land is estimated to 2 624 thousand hectares, which is expected to decrease to 2 542 thousand hectares in 2030 and furthermore to 2 511 thousand hectares in 2040. This corresponds to a 4 % reduction in the agricultural land for 2022 to 2040 due to extraction of organic soils, wetlands, forest or areas for infrastructure (cities and roads).

Regarding emission calculation due to the agricultural are, it is important to take into account the political Agreement on the Green Transition for Danish Agriculture, where three measures expect to increase the areas with perennial grass (KEFM, 2023). These measures are Eco-scheme for biodiversity and sustainability accounting for 50 000 ha and GLM8 (God Landbrugs- og Miljømæssig stand – Good Agricultural and Environmental State) accounting for 32 200 ha. Furthermore, Bio-scheme for extensification with grass is included and cover 38 000 ha, but only 33 100 hectare is implemented in the projection because 4 900 ha have already been implemented during 2022.

Table 6.9 Agreement on the Green Transition for Danish Agriculture expects to increase the area of perennial grass by, 1 000 ha.

	2022	2023	2025	2030	2035	2040
Eco-scheme for biodiversity and sustainability		50.0	50.0	50.0	50.0	50.0
GLM8		32.2	32.2	32.2	32.2	32.2
Eco-Scheme for scheme extensification with grass		33.1	33.1	33.1	33.1	33.1
Total area expected to be converted to perennial grass		115.3	115.3	115.3	115.3	115.3

The production of different crops dependents on the development in prices and yields and are estimated by AGMEMOD (Jensen, 2023). The crop types mention in AGMEMOD is used in the projection. Only production crops are mentioned in AGMEMOD and for other agricultural crops as for example feed beets and seeds for sowing is kept at the same level as the latest historical years.

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 no fertilisation of §3 areas and the three measure for increased area with perennial grass (Table 6.9), increase N in soil due to increased area with cover crops and more hectare cultivated as organic farming. These policy related decisions are expected to lower the total amount of N applied to the agricultural area. The assumption for each of these policy decisions is described below.

In legislation for § 3 areas are introduced a general ban on spraying, fertilising, and conversion of §3 protected areas (Law no. 1057 of 30/06/2020). In comments to this regulation is mentioned that a decrease of 5 800 tonnes N per year is expected and the law entered into force on 1/7-2022.

The increasing interest and demand for reduction of loss of N-surplus to the aquatic environment and reduction of the air emission as well as the emission of greenhouse gases, a political agreement has been reached; Agreement on the Green Transition for Danish Agriculture (AGTDA, 2021). This agreement includes subsidy schemes, and based on this, an increase in the area of perennial grass must be expected. The agreement on Eco-scheme for biodiversity and sustainability, Bio-scheme for extensification with grass and GLM8 expect to provide further 115 300 hectares with perennial grass (non-fertilisation), which assumed to reduce the nitrogen need by 148 kg N/ha, which correspond to the average N fertilization on agricultural land 2020-2022.

Due to development given in AGMEMOD organic farmed area will increase by 51 300 hectares from 2022 to 2040. However, a decrease in organic farmed area is expected to take place from 2031–2035. It is taken into account that organic farmed land will reduce the N need by 71 kg N per hectare, which is based on an estimate received by Danish Ministry of Climate, Energy and Utilities (KEFM 2024), but data are provided by the Danish Agricultural Agency (DAA).

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, 2024).

To estimate the consumption of inorganic fertiliser we first have to know the total N need for the overall agricultural area. Next the lower N need due to the policy decisions mentioned above must be subtracted and this is defined as the adjusted total N need. 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. The total N quota is estimated as an average for the years 2020-2022, which is calculated to 148 kg N/ha. Based on the average N-fertilisation, the total N need in 2023 is estimated to be 387.6 kt N. The subtraction due to the policy decisions and the assumptions for these mentioned above, the adjusted N quota is estimated to be 363.7 kt N for 2023. Table 6.10 shows background data for estimation of the amount of N consumption for use of inorganic fertiliser.

A decrease in the total cultivated area leads to lower total N quota, and the policy decision measures also confirm this trend, 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 238.8 kt N in 2022 to 222.0 kt N in 2040.

Table 6.10 Consumption of inorganic nitrogen fertilisers.

	2022	2023	2025	2030	2035	2040
Agricultural area, ha	2624245	2619140	2604430	2542250	2521480	2510700
Total N quota, kt N		387.6	385.5	376.3	373.2	371.6
Reduced N quota:						
§3 areas, kt N		-5.8	-5.8	-5.8	-5.8	-5.8
Reduced N due to catch crops, kt N		-0.7	-0.4	-3.4	-3.4	-3.4
Increased area with perennial grass, kt N		-17.1	-17.1	-17.1	-17.1	-17.1
Expansion of organic cultivated area		-0.4	-0.6	0.0	0.0	-0.1
Adjusted total N quota, kt N	388.4	363.7	361.6	349.9	347.0	344.2
N fulfilled by manure + sewage, kt N*	144.2	135.1	137.8	134.2	128.5	123.2
N fulfilled by inorganic fertiliser, kt N	238.8	228.6	223.8	215.7	218.4	222.0
Kg N fertilised per ha**	148	139	139	138	138	137

* Amount of N, which must be counted for in the farmers nitrogen fertiliser account.
** 2022 estimate reflect the average for 2020-2022.

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 (2019-2021). The projected N-leaching from rivers and estuaries is based on ratio compared with the N into groundwater as an average for years 2017-2021. 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 2023-2040 (Table 6.11). Based on estimate from the Danish Agricultural Agency (DAA) (KEFM, 2024) there is assumed a catch crop area of 508 000 hectares in 2022 increasing to 665 800 hectares in 2027, which are maintained at same level until 2040. Establishment of catch crops assumed to reduce the N leaching to the groundwater with 33 kg N/ha, which is based on information from DAA (KEFM, 2024).

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.

	2022	2023	2025	2030	2035	2040
N-leaching into groundwater (based on N applied), t N	144 273	139 505	139 804	137 089	136 499	136 559
Area with catch crop, ha	507 955	537 000	527 600	665 770	665 770	665 770
N-reduction from catch crop, t N		-958	-648	-5.208	-5.208	-5.208
Adjusted N-leaching into groundwater, t N		138 546	139 156	131 881	131 292	131 352
N-leaching in rivers, t N		61 962	62 235	58 981	58 718	58 745
N-leaching in estuaries, t N		51 467	51 693	48 991	48 772	48 794

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 1990-2022 is listed, followed by the projected emissions for 2023-2040. The greenhouse gas emission is expected to decrease from 11.5 million tonnes CO_2 equivalents in 2022 to 9.5 million tonnes CO_2 equivalents in 2040. Thus, a 18 % decrease of GHG emission from the agricultural sector from 2022 to 2040 is expected. The decreased emission is driven by 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 housings, which decrease emission of CH_4.

Besides the biogas production and frequent removal of slurry, the decrease of the emission from 2022 to 2040 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 (1990-2022) and projected (2023-2040) emission, CO_2 eqv.

CO_2 eqv. million tonnes	1990	2000	2020	2022	2023	2025	2030	2035	2040
CH_4	6.94	7.34	7.28	7.06	6.54	6.40	5.96	5.76	5.57
N_2O	6.28	5.07	4.56	4.20	4.07	4.05	3.81	3.73	3.68
CO_2	0.61	0.27	0.25	0.27	0.24	0.24	0.24	0.23	0.23
Agriculture, total	13.83	12.68	12.09	11.52	10.85	10.69	10.01	9.72	9.49

6.8.1 CH_4 emission

The overall CH_4 emission has increased slightly from 248 kt CH_4 in 1990 to 252 kt CH_4 in 2022 but are expected to decrease by 21 % to 199 kt CH_4 in 2040 (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 2015-2022 shows an almost unaltered CH_4 emission from enteric fermentation. The AGMEMOD model (Jensen, 2023) indicates that a decrease is expected for the number of dairy cattle from 2022 to 2040. The milk production is expected to increase all years up until 2040 (Jensen, 2023). The decrease in number of dairy cattle and changes in feeding strategy with higher ratio of fatty acids in fodder 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 housing systems towards more slurry-based systems. In the future, the emission from manure management is expected to decrease due to more housing systems with acidification of manure and manure cooling, for swine frequent removal of slurry 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 and legislation on frequent removal of swine slurry will become effective from 2023.

Table 6.13 Historical (1990-2022) and projected (2023-2040) CH_4 emission.

CH_4 emission, kt	1990	2000	2020	2022	2023	2025	2030	2035	2040
Enteric fermentation	159.1	144.1	147.7	146.2	143.8	139.2	136.7	133.9	131.4
Manure management	88.6	118.0	112.1	105.8	89.7	89.2	76.2	71.7	67.6
Field burning	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total CH_4, kt	247.7	262.1	259.9	252.1	233.6	228.5	213.0	205.6	199.1

- 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 23.7 kt N_2O in 1990 to 15.8 kt N_2O in 2022, corresponding to 33 % 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 12 % until 2040, which leads to a total N_2O emission at 13.9 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 applied to soil due to a decrease in the number of animals. Additionally, there is also a lower use of inorganic fertilisers, which is due to regulation regarding lower N supply for areas which are vulnerable to high inputs of nitrogen (§3 areas). In addition, a lower emission from N-leaching caused by the catch crop area also has an impact on lowering the N_2O emission towards 2040.

Table 6.14 Historical (1990-2022) and projected (2023-2040) N_2O emission.

N_2O emission, kt	1990	2000	2020	2022	2023	2025	2030	2035	2040
Manure management	2.55	2.63	1.90	1.64	1.52	1.50	1.27	1.17	1.09
Indirect N_2O emission	0.65	0.61	0.44	0.35	0.34	0.34	0.32	0.30	0.27
Inorganic fertilisers	6.29	3.95	3.96	3.75	3.59	3.52	3.39	3.43	3.49
Animal manure applied to soils	3.28	3.07	3.37	3.03	2.90	2.96	2.89	2.76	2.65
Sludge and other organic fertilisers applied to soils	0.07	0.14	0.16	0.17	0.16	0.16	0.16	0.16	0.16
Urine and dung deposited by grazing animals	0.23	0.20	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Crop residues	2.43	2.46	3.01	2.97	2.93	2.92	2.99	3.01	3.03
Mineralization	0.68	0.35	0.21	0.16	0.21	0.25	0.20	0.22	0.26
Organic soils	2.71	2.47	1.38	1.23	1.20	1.12	0.77	0.64	0.58
Atmospheric deposition	1.50	0.90	0.70	0.65	0.63	0.63	0.61	0.61	0.60
Nitrogen leaching and run-off	3.31	2.37	1.95	1.77	1.77	1.78	1.68	1.68	1.68
Field burning	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001	0.001
Total N_2O, kt	23.70	19.15	17.19	15.83	15.34	15.28	14.38	14.07	13.89

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

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7 Waste

In the Danish emission inventories system 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.

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

	1990	2000	2010	2015	2020	2022	2023	2025	2030	2035	2040
5.A Solid waste disposal	1525	977	611	546	458	421	433	419	399	387	381
5.B.1 Composting	37	93	106	107	126	122	132	138	143	142	143
5.B.2 Anaerobic digestion at biogas facilities	6	34	75	122	320	447	510	564	759	792	783
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
5.D Wastewater treatment and discharge	368	236	201	214	219	211	197	203	208	210	212
5.E Other	24	162	132	145	139	135	138	138	140	142	144
Total	1960	1503	1125	1134	1262	1336	1409	1461	1650	1674	1662
Share of national emissions excl. LULUCF	3 %	2 %	2 %	2 %	3 %	3 %	4 %	4 %	6 %	7 %	8 %

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., 2024). 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., 2024).

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 Report, which is prepared for the Climate Convention, the latest being the 2024 NIR report (Nielsen et al., 2024). 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. (2024).

CH_4 emissions for the projected years 2023-2040 are calculated using the same FOD model as used for calculation of historical emissions. The same DOCs, half-lifes 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. (2024).

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. (2024).

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 97-232 kt (37-162 kt excl. demolition waste).

Deposited total waste amounts for 2023-2040 excl. soil, sand and stone are projected by DEPA (2024). The deposited amounts of the individual organic waste fractions are estimated from DEPA (2024) and the waste composition of the latest historic data year, i.e. 2022. This implies that 37 % of the deposited amounts estimated by DEPA (2024) 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 (42 %), food waste (16 %) and paper & cardboard (10 %).

Figure 7.1 presents the deposited organic waste for 1990-2040. The FOD model calculations also includes waste amounts deposited in 1940-1989.

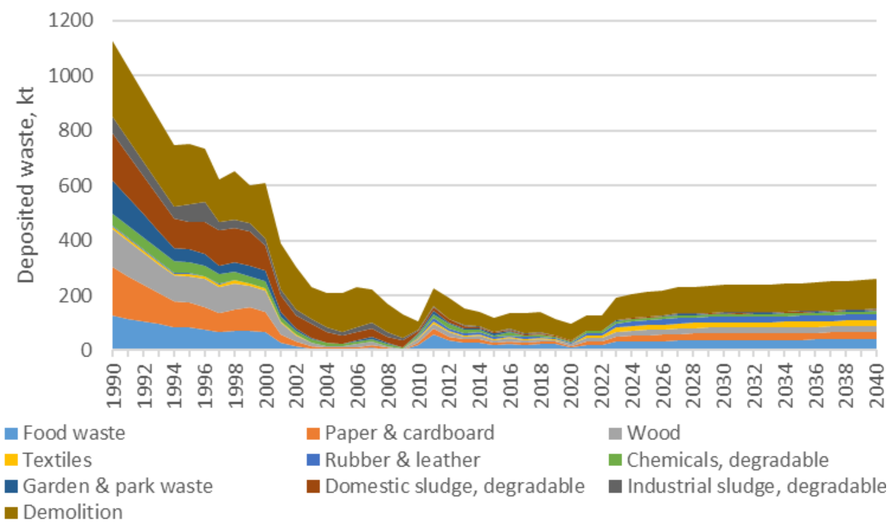

Figure 7.1 Deposited amounts of organic waste divided into 10 waste fractions.

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 2022 to 2023, the total amount of waste being landfilled increases by 54 % and is projected to further increase from 2023-2040 by 27 % (DEPA, 2024).

Amount of recovered methane

The amount of recovered methane was estimated based on information from the Danish Energy Agency (2024) stating that the amount of recovered methane is projected to be 0.074 PJ per year in the period 2023-2040 (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 1990-2040.

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	106	6.1	30.0	5.7	2.4	21.8	611
2015	118	6.2	25.1	3.4	2.2	19.5	546
2020	97	3.7	20.6	2.5	1.8	16.4	458
2022	125	7.5	19.1	2.4	1.7	15.0	421
2023	192	11.5	18.5	1.4	1.7	15.5	433
2025	212	12.7	18.0	1.4	1.7	15.0	419
2030	239	14.3	17.2	1.4	1.6	14.3	399
2035	244	14.6	16.7	1.4	1.5	13.8	387
2040	259	15.5	16.5	1.4	1.5	13.6	381

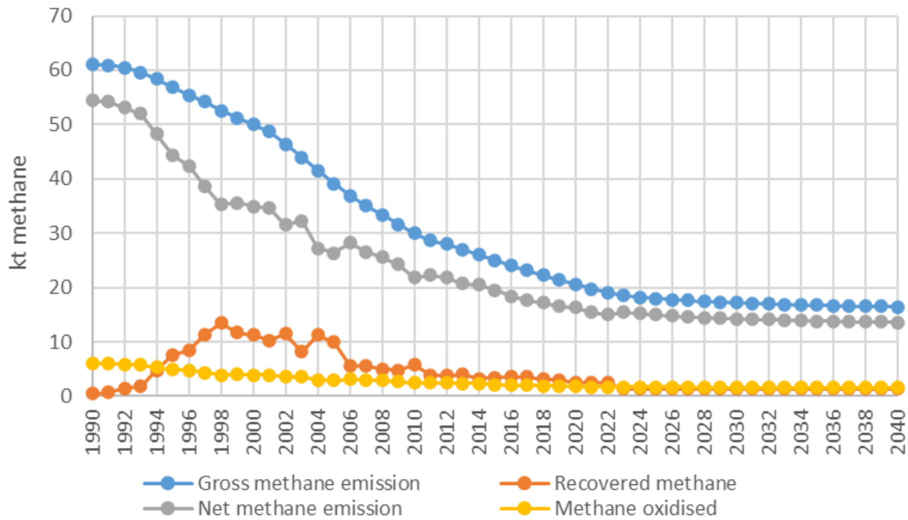

Figure 7.2 Historical and projected methane emissions. Historic data: 1990-2022. Projections: 2023-2040, kt.

In the period 2022-2040, the annual net methane emission reduces from 421 to 381 kt CO_2 equivalents, corresponding to a reduction of 10 %.

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.

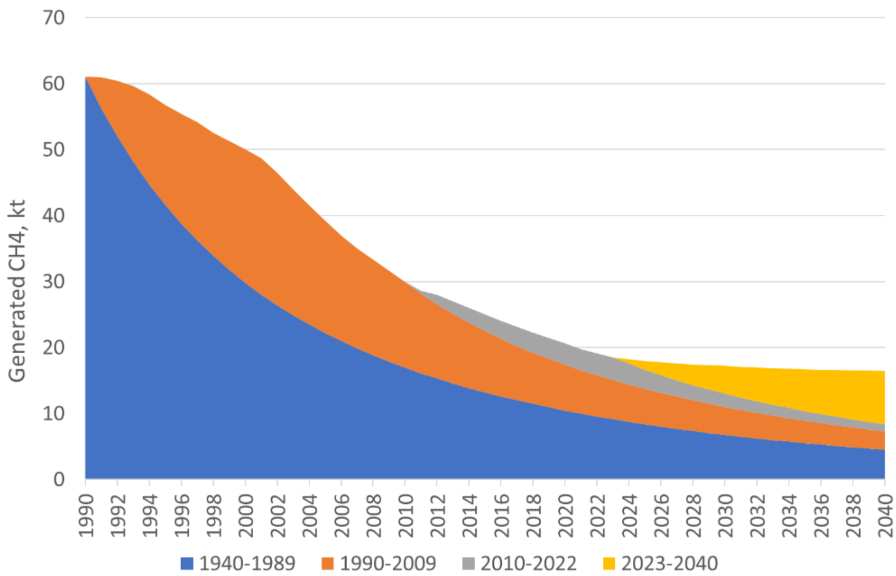

Figure 7.3 Methane generated from waste deposited in different periods.

In 2022, 50 % of the generated methane was caused by waste deposited before 1990. In 2040, this same waste (i.e. deposited in 1940-1989) still contributes with 27 % 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

Emissions from composting are calculated according to a country specific Tier 1 method. 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

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 activity of garden waste and sludge for composting has been projected using the trend from DEPA (2024). The activity data from DEPA (2024) differs significantly from the historical activity received from DEPA - and applied in the national emission inventories (Nielsen et al., 2024). It is therefore not possible to apply activity data projected by DEPA (2024) directly, but only as surrogate data. The emission factors are kept constant throughout the time series 1990-2040.

Emission factors

By assuming that the process of compost production will not significantly change over the next 20 years, the emission factors applied for this projection are the same as is used for historic years in Nielsen et al. (2024).

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 1990-2040.

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	65	65	23	2.42	0.14	106.2
2015	884	29	39	23	2.46	0.15	107.4
2020	996	41	160	24	2.84	0.18	125.9
2022	969	41	129	24	2.76	0.17	121.9
2023	1057	41	131	24	2.98	0.18	131.8
2025	1107	41	139	24	3.12	0.19	137.6
2030	1151	41	155	24	3.23	0.20	143.1
2035	1140	41	169	24	3.21	0.20	142.3
2040	1145	41	184	24	3.22	0.20	143.3

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 91-94 % of the biogas production included here. The biogas production is projected by the Danish Energy Agency (2024) and is estimated to increase from 31.4 PJ in 2023 reaching a maximum level of 48.8 PJ in 2033 after which a gradual decrease to 48.2 PJ in 2040. The CH_4 emission is calculated using an emission factor of 4.2% of the CH_4 content in the produced biogas in the period 1990-2016 and 2.9 % for 2020-2040. Emission factors for

2017-2019 are interpolated. For more information, please refer to Nielsen et al. (2024).

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
2022	27508	550.2	16.0	446.7
2023	31380	627.6	18.2	509.6
2025	34728	694.6	20.1	564.0
2030	46747	934.9	27.1	759.2
2035	48752	975.0	28.3	791.7
2040	48196	963.9	28.0	782.7

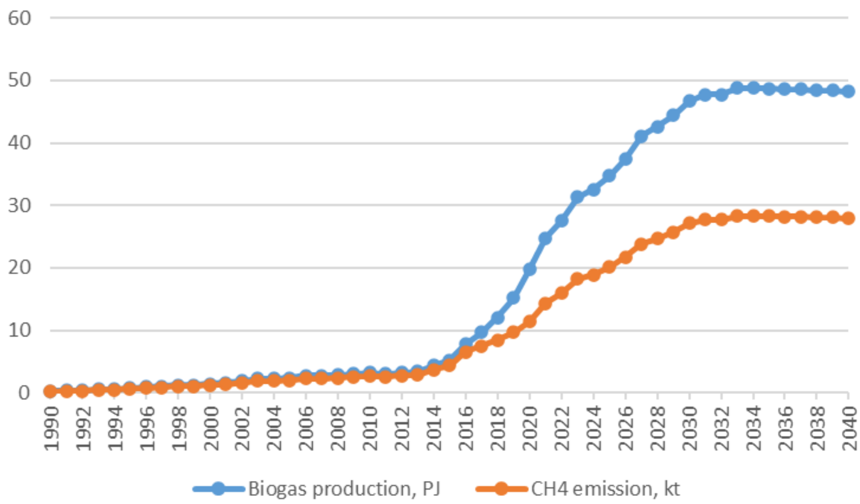

Figure 7.4 Historical and projected amounts of bioenergy and CH_4 emissions. Historic data: 1990-2022. Projections: 2023-2040.

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. Flaring off-shore and in refineries are included under sub-sector 1.B.2c, for documentation please refer to Chapter 3. 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.

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.	tons
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
2022	59435	51435	960
2023		49099	967
2025		49099	967
2030		49099	967
2035		49099	967
2040		49099	967

7.4.2 Emission factors

The applied emission factors for cremations are the same for all years in the time series 1990-2040, for more information please refer to Nielsen et al. (2024).

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.

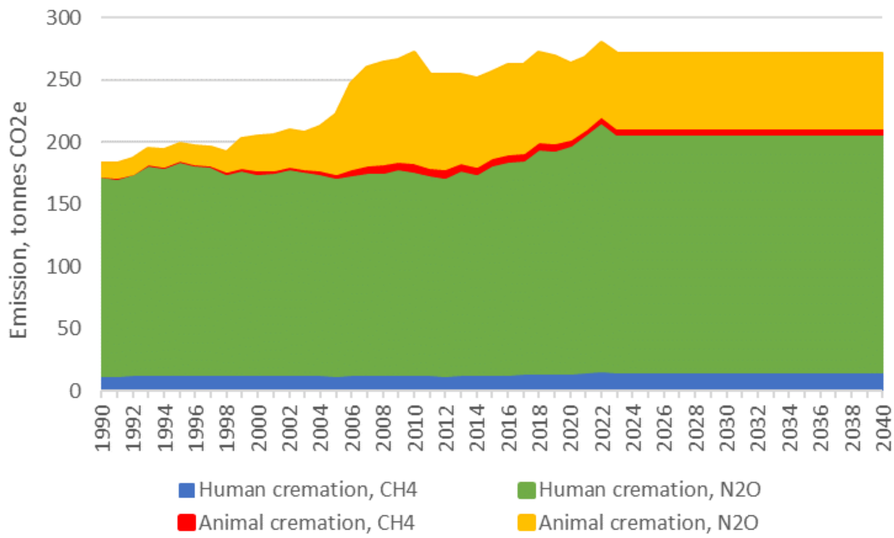

Figure 7.5 Emissions from waste incineration.

7.5 Wastewater handling

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

7.5.1 Methodology and input data

Methane emission

Methane emissions from the municipal and private wastewater treatment plants (WWTP) are divided into contributions from 1) the sewer system, primary settling tank and biological N and P removal processes ($CH_{4,\text{sewer system and MB}}$), 2) from anaerobic treatment processes in closed systems with biogas extraction and combustion for energy production ($CH_{4,AD}$) and 3) septic tanks ($CH_{4,\text{septic tanks}}$). For a detailed description of the model equations and input parameters (process-specific emissions factors and activity data) the reader is referred to Nielsen et al. (2024) and Thomsen (2016).

Emissions from the sewer systems

This source includes CH_4 emission from the sewer system as well as contributions from primary settling tank and biological N and P removal processes ($CH_{4,\text{sewer system and MB}}$).

The fugitive emissions from the sewer system, primary (and secondary) settler tanks (clarifiers) and aerobic biological treatment processes are estimated from the influent organic degradable matter measured as the chemical oxygen demand (COD) 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 (*TOW*) that is unintentionally converted to CH_4 in sewers, primary clarifiers and aerobic biological treatment processes, is set equal to 0.003 based on an expert judgement. The resulting emission factor for these processes therefore equals 0.75 g CH_4 per kg COD in the inlet wastewater (Nielsen et al., 2024).

The COD amount is projected based on the population projection from Statistics Denmark (2024) and the average COD per inhabitant ratio for the three latest historical years. An overview of the historical and projected amounts of COD in the influent wastewater (TOW_{inlet}) is provided in Table 7.8.

Table 7.8 Activity data for population and TOW_{inlet}.

	Population	COD
	1000s	kt
1990	5135	349
1995	5216	354
2000	5330	382
2005	5411	349
2010	5535	370
2015	5660	387
2020	5823	388
2022	5873	378
2023	5933	392
2025	5941	392
2030	6038	399
2035	6132	405
2040	6206	410

Note: Historical data: 1990-2022, projected data: 2023-2040.

Emissions from anaerobic treatment processes

The net methane emission from anaerobic digestion in biogas tanks ($CH_{4,AD}$) are estimated from the leakage rate from the biogas production and the methane content in the produced biogas. The applied emission factor is 6.9 % of the CH_4 content according to country specific measurements (Nielsen et al., 2024).

The energy production at biogas facilities is available from the national Energy Statistics for historical years and from the Energy and Climate Outlook for projection years, with both datasets produced by the Danish Energy Agency (DEA). The methane content in the biogas is calculated using the net calorific value of 0.02 kg CH_4 per MJ biogas. Table 7.9 shows the historical and projected gross energy production reported by DEA and the calculated methane content.

Table 7.9 Activity data for gross energy production and methane content.

	Energy production	CH_4 content
	TJ	kt
1990	458	9.2
1995	598	12.0
2000	857	17.1
2005	913	18.3
2010	840	16.8
2015	901	18.0
2020	1293	25.9
2022	1209	24.2
2023	741	14.8
2025	889	17.8
2030	956	19.1
2035	956	19.1
2040	956	19.1

Note: Historical data: 1990-2022, projected data: 2023-2040.

Emissions from septic tanks

Methane emission from septic tanks ($CH_{4,septic\ tanks}$) is calculated from the total population and an estimated time series of the fraction of the population not connected to the collective sewer system. The resulting activity data are multiplied with the degradable organic matter production per capita (IPCC default) and a country specific emission factor.

Data on historic and projected population numbers are available from Statistics Denmark (2024); see Table 7.8. Statistics Denmark also provides data on residences that is used to estimate the fraction of households outside the public sewer system for historic years. This fraction is kept constant on the 2022 level for all projected years. The fraction has historically seen a steady decrease from 12 % in 1990 to 7 % in 2022.

The emission factor of 0.112 kg CH_4 per kg BOD is based on country specific measurements. Lastly, the default IPCC value of 62 g BOD per capita per day was applied, i.e. 22.63 kg BOD per person per year (IPCC, 2006). Both factors are kept constant for all years 1990-2040.

Nitrous oxide

There are five individually calculated contributions to N_2O emission from wastewater handling, 1) direct N_2O from domestic WWTP, 2) indirect N_2O from domestic WWTP, 3) indirect N_2O from other, 4) direct N_2O from separate industrial WWTP and 5) indirect N_2O from separate industrial WWTP.

The direct and indirect N_2O emission from domestic wastewater treatment processes is calculated based on country specific and process specific emission factors (Nielsen et al., 2024) and the amount of nitrogen in the influent and effluent wastewater, respectively. The N content in influent and effluent wastewater at domestic WWTPs was projected based on the average influent N per person for the latest three historic years and population statistics from Statistics Denmark (Table 7.8).

Indirect N_2O emission from "other" includes rainwater dependent outlet and scattered settlements. These emissions are known for historic years and projected as the average value of the latest three historic years. The effluents for both direct and indirect emissions from separate industries (including aquaculture) was also held constant at the average level of the last three historical years for the projection years 2023-2040.

Total N in the influent and effluent wastewater is presented in Table 7.10.

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

	Influent N, municipal WWTPs	Effluent N, municipal WWTPs	Influent N, industrial WWTPs	Effluent N, industrial WWTPs[1]	Other effluents[2]	Total effluent N
1990	14679	16555	56100	6049	2900	25504
1995	22340	8938	30888	4206	2008	15152
2000	26952	4654	11225	3611	1743	10008
2005	32288	3831	5513	1666	1541	7038
2010	27357	3578	4225	1271	1664	6513
2015	30509	3705	4141	1360	2294	7359
2020	30301	3245	3533	1249	1385	5879
2022	29416	2849	3530	1104	1305	5258
2023	30257	3161	3122	1144	1369	5674
2025	30608	3198	3122	1144	1369	5711
2030	31103	3250	3122	1144	1369	5763
2035	31588	3300	3122	1144	1369	5813
2040	31973	3341	3122	1144	1369	5854

[1] Separate industries, including effluents from aquacultures.
[2] Other effluents comprise: effluents from rainwater conditioned outlets and scattered houses.
Note: Historical data: 1990-2022, projected data: 2023-2040.

The total N in influent and effluents from the contributions from industries and other, show decreasing trends for the historic years followed by constant values throughout the projection period. The total N content in the influent and effluent from municipal WWTPs is increasing according to population statistics for the period 2023-2040.

Direct N_2O emissions from wastewater treatment within industries are for historical years derived from reported effluent N from separate industries and information about N-removal efficiencies (Thomsen, 2016). From the influent N load data, emissions are calculated by use of the country-specific emission factor of 8.4 kg N_2O –N per ton N in influent (Nielsen et al., 2024).

Direct N_2O emissions from domestic WWTPs are calculated similarly to those from industries, i.e. from influent N load data and the country-specific emission factor of 8.4 kg N_2O–N per ton N in influent.

Indirect N_2O emissions from all contributions, i.e. municipal WWTPs, wastewater treatment within industries, rainwater conditioned outlets and scattered houses, are calculated from the respective N in the effluent and the default IPCC emission factor of 5.0 kg N_2O –N per ton N.

For more information on emission factors and methodology, please refer to Nielsen et al. (2024).

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

7.5.2 Emissions

Historical and projected greenhouse gas emissions from wastewater treatment are shown in Table 7.11 and Figure 7.6.

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

	1990	2000	2005	2010	2015	2020	2022	2023	2025	2030	2035	2040
$CH_{4, \text{sewer system and MB}}$	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
$CH_{4, \text{septic tanks}}$	1.5	1.5	1.4	1.3	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1
$CH_{4, \text{AD}}$	0.6	1.2	1.3	1.2	1.2	1.8	1.7	1.0	1.2	1.3	1.3	1.3
$CH_{4, \text{total emission}}$	2.4	2.9	2.9	2.8	2.8	3.2	3.0	2.4	2.6	2.7	2.7	2.8
N_2O, direct	0.9	0.5	0.5	0.4	0.5	0.4	0.4	0.4	0.4	0.5	0.5	0.5
N_2O, indirect	0.20	0.08	0.06	0.05	0.06	0.05	0.04	0.04	0.04	0.05	0.05	0.05
$N_2O_{\text{, total emission}}$	1.1	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
$CO_{2\text{eq, total emission}}$	368	236	229	201	214	219	211	197	203	208	210	212

Note: Historical data: 1990-2022, Projected data: 2023-2040.

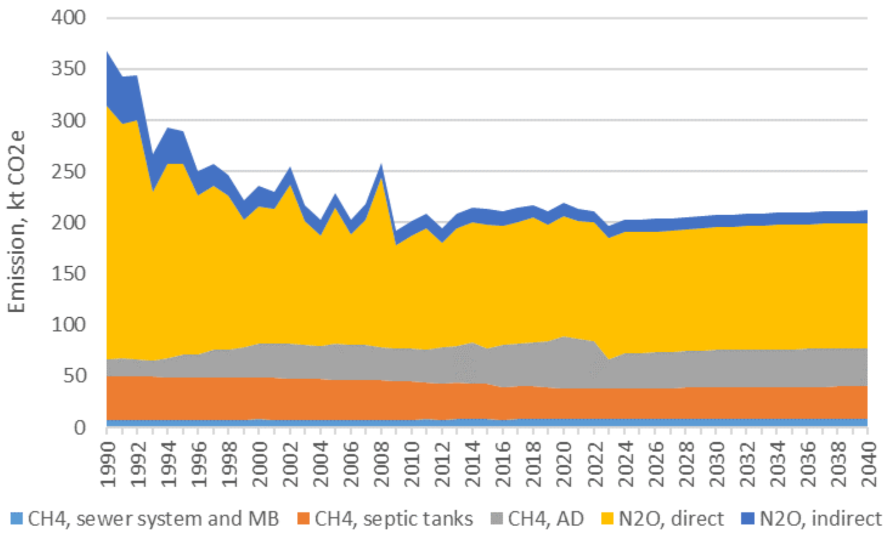

Figure 7.6 CO_2 equivalent emissions from wastewater handling, kt CO_2e.

Greenhouse gas emissions from domestic WWTPs comprise the majority of both direct and indirect emissions for 2023-2040; 91 % and 56-57 % respectively.

The historically decreasing emission trend is caused by reductions in N_2O emissions, mainly direct emissions from industrial WWTPs. While the contribution from N_2O to total greenhouse gas emission from WWT in 1990 was 82 %, this number has decreased to 66 % in 2023 and is expected to be 64 % in 2040.

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.

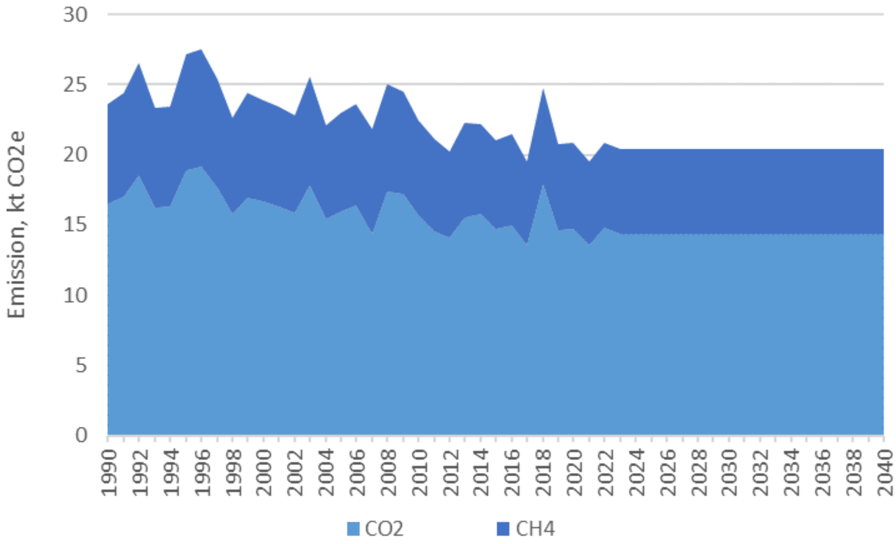

Figure 7.7 Greenhouse gas emissions from accidental fires.

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, a calculation error was corrected, influencing the historical emission calculations all the way back to 1940 (-15 to -44 t CH_4 per year). Since projections are based on historic emission levels, this correction affects the projected emissions with a small decrease. In addition, DEPA (2024) provides new projection data for deposition of waste. These predict significantly higher waste deposition numbers than the outcast applied in last year's emission projection. Overall, projected emissions for solid waste disposal have increased 0.5 kt CH_4 (+3 %) in 2023 and 1.9 kt CH_4 (+16 %) in 2040, and +4 % to +16 % in the intermediate years.

For category 5B Biological treatment of solid waste, recalculations in the historic years for composting are caused by the introduction of improved emission factors. These new emission factors are also applied for the projection years, leading to decreased emissions. The projection of composting activity data was kept constant in last year's projection, but this year, projected activity data are made available for two of the four waste types being composted. Overall, emissions from composting have decreased by 31.6 kt CO_2e in 2023 (-19%) and -19.5 kt CO_2e in 2040 (-12%). For Anaerobic digestion at biogas facilities, the only change in emissions in historic years, is for the year 2022, where the actual emission is 2.0 kt CH_4 lower than anticipated by last year's projection. The projected biogas production prepared by the Danish Energy Agency (2024), has decreases for 2023-2032 (with a max. of -15 % in 2024) and increases for 2033-2040 (with a max of +20% in 2040). As a result, the methane emission from this activity has decreased with up to 64.2 kt CO_2e (-10 %, in 2025) and increased up to 126.0 kt CO_2e (+19 %, in 2035).

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 decrease of 0.004 kt CO_2e (1.4%) per year in the projections period 2023-2040.

For category 5D Wastewater treatment and discharge, a number of minor updates since last year's projection includes updated population projection (Statistics Denmark, 2024), the N content in influent and effluent wastewater (average of latest three historic years), N_2O emissions from industries and other (average of latest three historic years). Resulting changes from wastewater treatment and discharge in the projected emissions since last year's projection report are decreases between 15.5 and 21.1 kt CO_2e per year (-7 to -9%).

For the category Other, this historic emission inventory has changes significantly due to an updated methodology. As emissions are projected as the average of the three last historical years, emissions for 2023-2040 have also changed. The recalculation amounts to a decreased of 0.1 kt CO_2e (-16 %) 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 (WL)
- 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. (2023). 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 (DAA), 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 (DAA, 2024ab). 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. (2023) and Johannsen et al. (2022). Updated projection data presented in the report is received directly from IGN in 2023.

8.1 Projected land use and land use changes

Approximately two thirds of the total Danish land area are cultivated with agricultural crops and 15 % 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 2040. 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, 2022). It is apparent from the figure that a continuous increase in FL, SE and WL is expected, at the expense of primarily the CL 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.

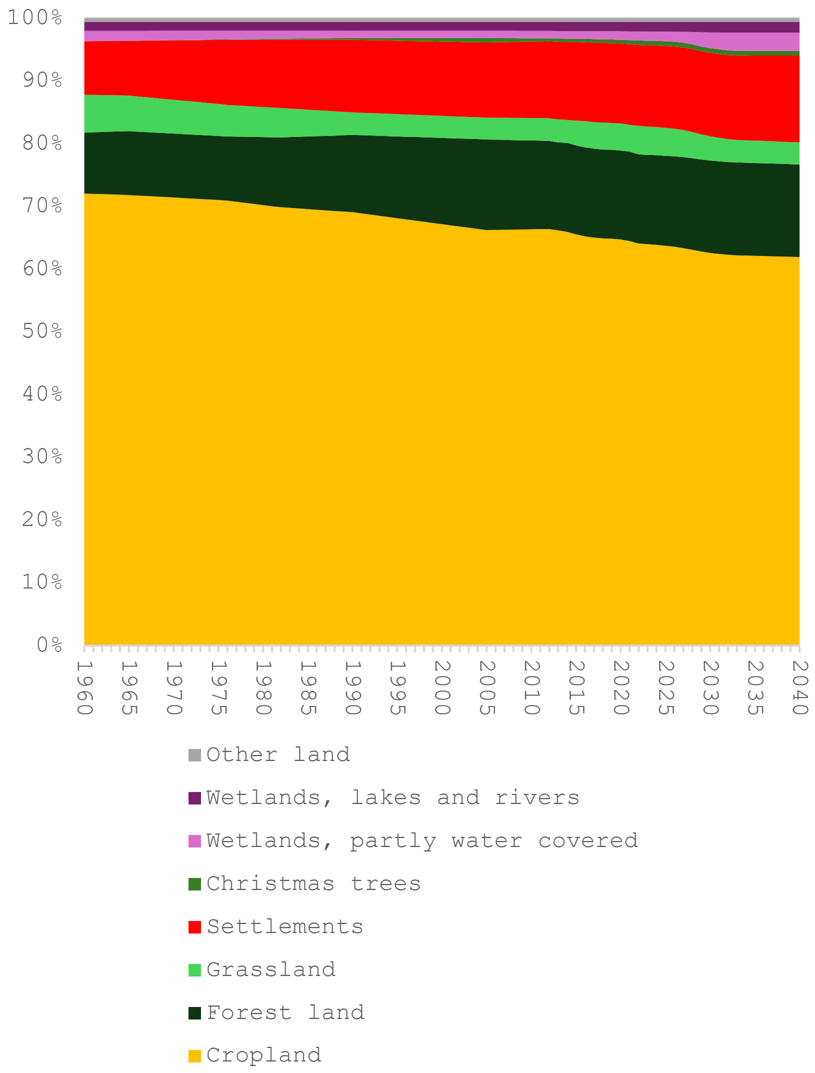

Figure 8.1 Land use from 1960-2040 distributed on land use categories.

Table 8.1 shows the distribution of land in number of hectares from 1990 to 2040 and the expected annual land use changes between the different categories in 2023, 2025, 2030, and 2035.

One of the important contributors to LUC is conversion of CL and GL to WL. Rewetting of drained organic soils is a mitigation measure with high political priority according to, for example, the green transition agreement for Danish agriculture from 2021 (Danish Ministry of Finance, 2021).

Aside from the wetland restoration, the registered LUC is primarily due to the continuous afforestation and 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

59 ha from 1990 to 2021 resulting in an increasing total area. All 59 ha were added to SE.

In total from 1990 to 2040, an afforestation of 120 293 ha is expected (excl. Christmas trees), of which 27 130 ha are projected to take place based on public funding from 2023 to 2032. Deforestation is only expected to occur on 8 798 ha from 1990 to 2040 (excl. Christmas trees). In Table 8.1, Forest land includes Christmas trees. The deforestation is mainly due to conversion to SE.

Table 8.1 Distribution of land area between the six land use categories and future expected annual net change of 2023, 2025, 2030, and 2035, in ha.

Total area, ha	Forest land	Cropland	Grassland	Settlement	Wetlands	Other land	Total
1990	546 647	2 970 007	154 516	498 602	109 330	26 424	4 305 528
2022	645 984	2 758 908	195 528	552 394	126 349	26 424	4 305 587
2023	647 346	2 754 712	193 453	555 176	128 475	26 424	4 305 587
2025	649 521	2 750 342	192 600	557 562	129 137	26 424	4 305 587
2030	655 432	2 737 558	188 175	562 333	135 665	26 424	4 305 587
2035	671 078	2 687 192	159 449	574 260	187 184	26 424	4 305 587
2040	671 814	2 670 710	151 932	586 188	198 519	26 424	4 305 587
Annual net change							
2023	2 075	-4 270	-853	2 386	663	0	
2025	3 235	-6 693	-2 290	2 386	3 362	0	
2030	1 775	-7 617	-4 455	2 386	7 911	0	
2035	-305	-1 734	-340	2 386	-6	0	

Every year, a new historical year is added, and the projected matrix is adjusted to the new past average. The main difference in land use changes compared to last year's projection is a change in the assumed realisation time of Wetland restorations (now assumed 5 years after allocation of funding, whereas before it was assumed after 3 years) as well as an assumed lower cost per hectare and a slightly lower future increase in Settlements.

8.2 Projected LULUCF emissions 2022 - 2040

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 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 2040, in kt CO_2e per year.

Land Use Category	1990	2010	2020	2021	2022	2023	2025	2030	2035	2040
4. LULUCF Total	6 694.0	2 360.7	1 292.4	198.5	-381.0	-76.8	689.2	687.9	-629.8	-762.4
A. Forest Land*	-1 200.5	-2 184.9	-2 103.8	-2 866.9	-3 351.6	-3 212.1	-2 250.7	-1 668.8	-2 862.7	-3 014.9
1. Forest Land remaining Forest Land*	-195.7	-838.5	-958.4	-1 754.2	-1 785.0	-1 997.9	-1 119.0	-728.1	-2 248.0	-2 516.6
2. Land converted to Forest Land*	-1 004.8	-1 346.4	-1 145.3	-1 112.7	-1 566.6	-1 214.2	-1 131.7	-940.8	-614.7	-498.3
B. Cropland	5 008.9	2 336.1	1 187.2	626.4	615.8	750.5	794.4	500.3	511.1	641.3
1. Cropland remaining Cropland	4 938.3	2 312.8	1 195.0	635.9	640.4	748.1	791.5	490.0	504.9	627.0
2. Land converted to Cropland	70.6	23.4	-7.8	-9.5	-24.6	2.4	2.9	10.3	6.2	14.4
C. Grassland	2 334.9	1 884.8	1 994.6	2 067.9	1 966.3	1 911.5	1 802.5	1 223.6	1 029.5	961.8
1. Grassland remaining Grassland	2 267.3	1 841.6	1 958.9	1 940.5	1 916.6	1 880.9	1 771.5	1 188.2	996.3	923.9
2. Land converted to Grassland	67.6	43.1	35.7	127.4	49.7	30.6	31.0	35.4	33.2	37.9
D. Wetlands	101.9	80.6	124.5	135.0	141.8	153.6	170.5	341.9	421.0	412.8
1. Wetlands remaining Wetlands	101.2	54.1	43.4	43.4	36.6	41.5	40.8	0.0	0.0	0.0
2. Land converted to Wetlands	0.6	26.4	81.1	91.6	105.3	112.1	129.7	341.9	421.0	412.8
E. Settlements	451.2	269.2	207.4	291.9	344.7	232.0	241.6	268.9	286.4	294.1
1. Settlements remaining Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2. Land converted to Settlements	451.2	269.2	207.4	291.9	344.7	232.0	241.6	268.9	286.4	294.1
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	-25.1	-117.6	-55.9	-97.9	87.7	-69.0	22.1	-15.1	-57.5

*The methodology for estimation of emission and projections for all Forest land and HWP data are reported in detail in Nord-Larsen et al. (2024).

FL remaining FL is expected to be a net sink through the whole period up to and including the last projected year 2040. For further details on the forest projection see Nord-Larsen et al. (2024).

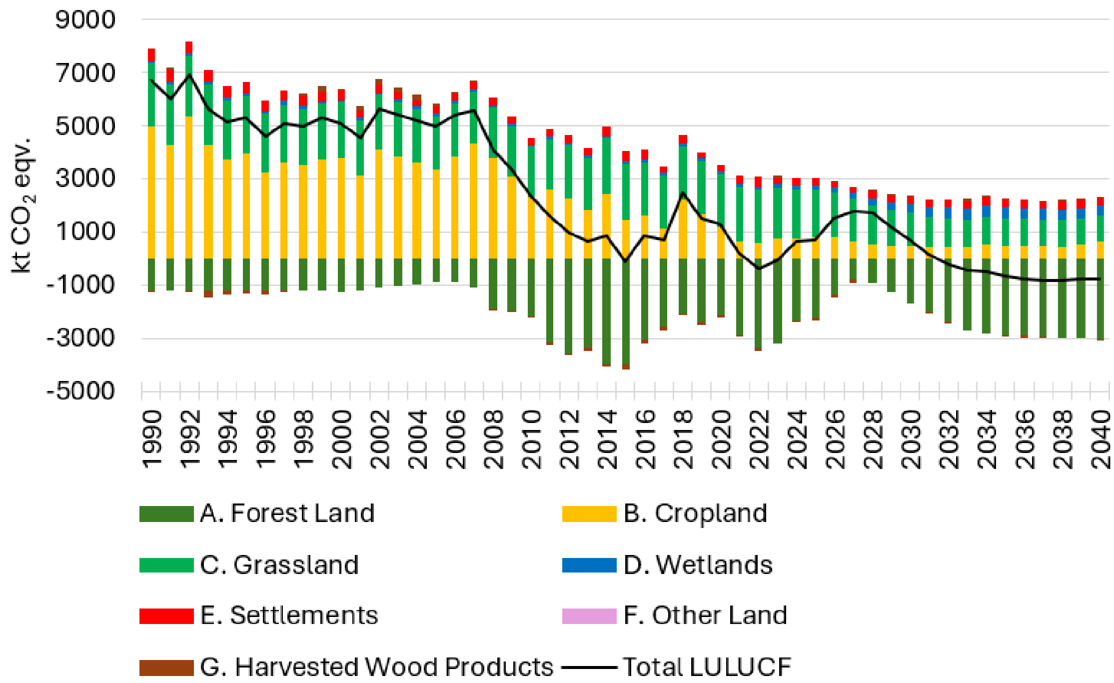

Figure 8.1 Emission estimates from the LULUCF sector from 1990 – 2040, distributed between land use categories and as net total (black line), in kt CO_2 eqv.

CL and GL are 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 conversion to WL also leads to a decrease in emissions until 2040. Currently, the agricultural mineral soils have been storing carbon at a rate of 200-300 kt CO_2 per year; this is expected to slightly increase to around 500 kt CO_2 per year until 2040 due to increased area with catch crops and more grass in rotation. The expected increasing temperature will increase the annual losses from the mineral soils, but this is partly counteracted by the expected increase in harvest yields. In the projection of emissions from mineral soils, a dynamic temperature modelling tool (C-TOOL ver. 2.3.) is used. The overall emission from CL 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. Consequently, emissions from CL have decreased considerably compared to last year's projection, but organic soils remain an important source of emissions.

Grassland is projected to continue to be a considerable source due to its large remaining area with organic soils, even though the area of organic soils has decreased and is projected to continue to decrease.

The overall trend for WL is an increase in CH_4 emissions from restored wetlands, also visible in Figure 8.1, because land converted to WL is expected to increase due to the current ongoing WL restoration program which has been running for several years and currently ongoing up until 2032 for conversion of agricultural organic soil. Simultaneously, there will be decreasing emissions from WL remaining WL, caused by an expected decreasing peat excavation in Denmark.

SE is expected to have slightly increasing emissions, however emissions from SE is still a minor share of total LULUCF.

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_2 eqv.
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_2 eqv.**
Organic soils >12 % OC	Crops in rotation (Cropland)	11.5 NO 13	t C per ha kg CH_4 per ha per yr kg N_2O-N per ha per yr	42.2 NO 5.4
	Abandoned land[h] (former Cropland and Grassland)	3.6 39 NO	t C per ha kg CH_4 per ha per yr kg N_2O-N per ha per yr	13.2 1.1 NO
	Permanent Grassland	8.4 16 8.2	t C per ha kg CH_4 per ha per yr kg N_2O-N per ha per yr	30.8 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 288 NO	t C per ha kg CH_4 per ha per yr kg N_2O-N per ha per yr	NO 8.1 NO
	Peat excavation	Peat[i] 2.8 6.1 0.3	t C per ha t C per ha kg CH_4 per ha per yr[j] kg N_2O-N per ha per yr	 10.3 0.2 0.1
Organic soils 6-12 % OC	Crops in rotation	5.75 NO 6.5	t C per ha kg CH_4 per ha per yr kg N_2O-N per ha per yr	21.1 NO 2.7
	Abandoned areas (former Cropland and Grassland)	1.8 19.5 NO	t C per ha kg CH_4 per ha per yr kg N_2O-N per ha per yr	6.6 0.5 NO
	Permanent Grassland	4.2 8 4.1	t C per ha kg CH_4 per ha per yr kg N_2O-N per ha per yr	15.4 0.2 1.7

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. [h] These areas are no longer being registered in the digital field maps used in the EU subsidy schemes and are assumed to have become too wet to cultivate. [i] The annual amount of excavated peat, instantly oxidised. [j] Only for the drained area, the EF for ditches is higher (542 kg CH_4 per ha per yr).

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 estimates on historical and projected net total LULUCF emissions from 1990 – 2040 from both this year's and last year's projections are presented in Figure 8.2, to visualise the difference. The estimates from the 2024 projection result in an average in the period 2022 – 2040 around 97 % lower than the average from the 2023 projection. Specifically for 2030, the 2024 projection estimates the total net emissions from LULUCF to be 3 356 kt CO_2 eqv. lower than last year, corresponding to a decrease in the projected total emissions in 2030 of 83 %.

Different projections on CO_2 emissions from Cropland, Grassland, and Forest land are the main causes of this considerable decrease in emissions. The primary factor impacting the new projections on CO_2 emissions from Cropland is an update of the area of organic soils (Beucher et al.,2023) leading to a continuous decrease in the area from 2011 and forward, thus resulting in decreased emissions as these soils are an important source of CO_2 emissions. These factors are elaborated in section 8.4 on Cropland. The same update has impacted emissions from Grassland, see section 8.5. For Forest land, the projection indicates that forests will contribute with considerable removals of CO_2. See also section 8.3.

CH_4 emissions are slightly lower (abt. 3 %) on average for the period 2022-2040 in the new projection. This is largely due to a reduced area of organic soils in the CL category, elaborated in the section on organic soils in 8.4.4. CH_4 emissions from WL have generally increased compared to last year's projection due to the introduction of a revised CH_4 emission factor, see section 8.6.2.

For the whole period from 1990 to 2040, N_2O emissions are less than 1 % lower in this projection compared to that of last year.

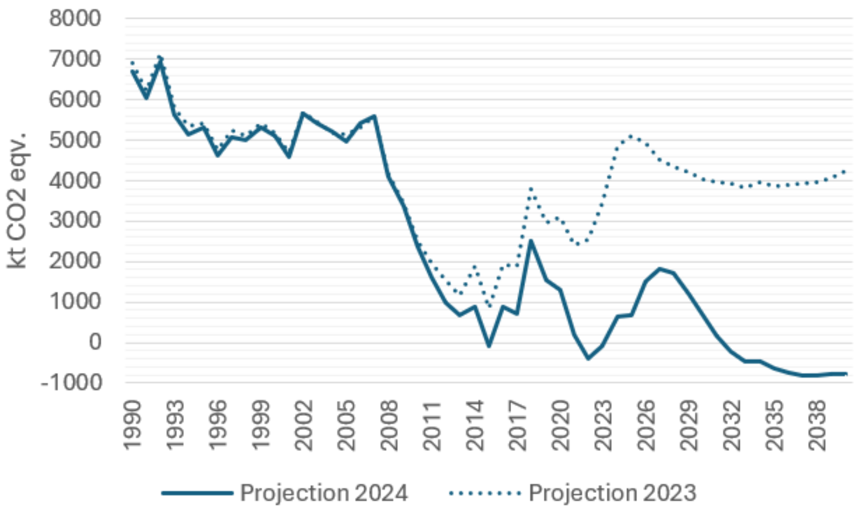

Figure 8.2 Net total emissions from the LULUCF sector from 1990 – 2040 in the 2024 projection (solid line) and last year's 2023 projection (dotted line).

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., 2024). The Danish Forest projection to 2050 is reported in Nord-Larsen et al. (2024). 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.

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 2024 from the Danish

Environmental Protection Agency. Afforestation is expected to take place on around 3 000 ha on average per year until 2030 and then to cease. This cease is defined as the projection is based on existing funding schemes and no plans go beyond 2030. The Danish forests are well protected and only limited deforestation is expected to occur – around 200 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. These spaces are essentially converted into Grassland.

The method applied in this year's projection of emissions and removals in FL differ significantly from the projection of last year resulting in FL exhibiting considerable carbon removals in future years, thus strongly counteracting the emissions from the LULUCF sector. The most important methodological change is the introduction of an individual tree-based approach contrary to the previous age-based approach, which resulted in a lower harvest rate in the current projection than in the previous projection Consequently, projected removals from living biomass increased significantly in the present projection compared to last year, see Nord-Larsen et al. (2024).

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, 2024) 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. This development is likely 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 2010-2022, the area with agricultural crops on average declined app. 1800 ha per year (DSt, 2004).

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 2022, 215 500 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. 1935 ha going from CL to SE in the period 2013-2022. This averaged yearly conversion of CL to SE is continued in projected years 2023-2040.

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 4 800 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 include the development in both CL and GL areas. An inter-annual conversion between CL and GL and vice versa is estimated at 3 000 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 ton 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 is 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.

Crop yield

The projected crop yield is based on historical crop yields in the period 2006-2021, which has 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 2020 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.

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 are grown on approximately 212 000 ha in 2010 increased to 508 000 ha in 2022. In 2030 the expected area is 665 770 ha (DAA, 2024a), each year adding biomass to the SOC stock. Compared to last year, the projected area with catch crops has been reduced. Therefore, it is no longer necessary with an adjustment of the area of winter crops to make room for an increased area of spring barley with catch crops.

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. On one hand the figures from the projection from the Danish Energy Agency project a decrease in straw consumption in power plants and on the other hand there is an unknown increasing demand for straw in biogas plants which counteracts. The amount of straw used for energy purposes is for simplicity assumed to be unaltered. 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).

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.

Temperatures

In the projection, observed temperatures have been used including December 2023. 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 8.2 and 8.3. C-TOOL is run with 10 different randomly selected temperature projections up to year 2040, and the output used in the projection presents the average values of these.

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 a net sink of approximately 400 kt CO_2 per year on average in the period 2023-2040. The blue line in Figure 8.2 indicates the total amount of C as soil organic carbon (SOC) including fresh organic matter (FOM, not degraded crop residues) and the red line indicates the total reported C stock, which only includes C in the humified organic matter (HUM) and resilient organic matter (ROM) pool. The overall trend will be an increased carbon stock in the agricultural mineral soils until a new equilibrium state is reached. With the current expectations to crop yields and temperature development, this is not foreseen to take place until past 2080.

Figure 8.3 shows the reported and expected annual emissions from mineral soils in kt C per year. Due to high yields in most recent years, a sink has been estimated in most years from 2010 and forward. The emissions from agricultural mineral soils are projected to stay relatively stable until 2040 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.

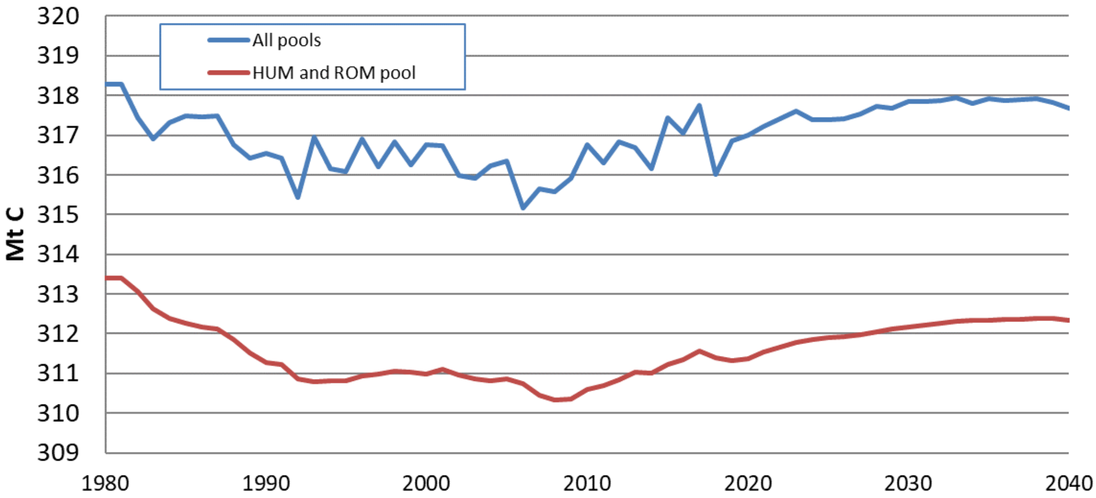

Figure 8.2 Development of total estimated carbon stock in mineral soils from 1980 – 2040 in Cropland and Grassland, in million tonnes carbon. HUM = Humified organic matter, ROM = Resilient organic matter.

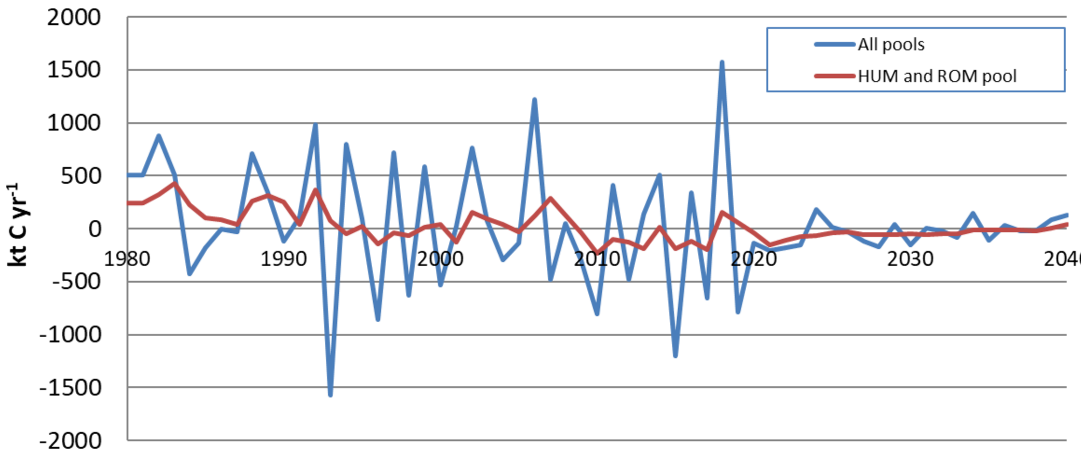

Figure 8.3 Annual emissions of C from mineral soils in Cropland and Grassland, in kt CO_2 per year. Negative numbers indicate net storage and a CO_2 sink effect.

8.4.4 Organic soils

The emissions from organic soils in the land use categories CL and GL (only drained GL areas) are based on emission factors for C high organic soils with an organic carbon (OC) content > 12 % OC and medium OC soils of 6-12 % OC. The 6 % limit is the traditional limit defining organic soils in the Danish soil classification system from 1975. Due to drainage, a continuous degradation of the OC takes place until the equilibrium state in soil organic carbon between annual input and annual degradation is obtained. The estimated equilibrium state is around 1.0-2.0 % OC in most cultivated mineral soils, which means that the drained medium soils of 6-12% OC must be assumed to loose carbon. Beucher et al. (2023) showed that the area of organic soils decreased considerably from 2010 to 2022, as soils transfer to the mineral category with SOC concentration < 6 %.

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 loose carbon, thus the organic area is projected to decline to 73 000 ha organic soil in 2030 and to 54 000 ha in 2040 (Gyldenkærne & Callisen, 2024). 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 do not change. Conversion of organic soils into WL is taken into account, thus also contributing to the decrease in the area of organic soils under agriculture. In the period 2023-2032, 54 742 ha agricultural soils (CL and GL) are expected to be converted to WL. Section 8.6.2 describes the conversion of CL and GL to WL.

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 8.2. The applied emission factor for CO_2 from organic soils >12% OC is 11.5 t C per ha per year for annual crops and for grass in rotation. Drained permanent GL on organic soils outside annual rotation has a lower emission factor of 8.4 t C per ha per year combined with a CH_4 emission factor of 16 kg per ha per year. These are the emission factors applied for soils with more than 12% OC. 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, 1990-2040.

	1990	2010	2019	2020	2021	2025	2030	2035	2040
Cropland, registered fields > 6% OC, ha	128 399	109 877	48 344	38 958	37 382	34 081	23 760	18 899	16 152
Grassland, > 6% OC, ha	84 674	70 559	79 064	77 844	76 094	71 361	49 261	41 100	37 441
Cropland, emission, > 6% OC, kt CO_2e	3 814	3 175	1 326	1 048	1 011	930	655	532	466
Grassland, emission, > 6% OC, kt CO_2e	2 053	1 667	1 774	1 735	1 703	1 604	1 076	902	837
Leached C from organic soils, kt CO_2e	179	147	101	92	90	84	57	48	43
CH_4 from organic soils (CL + GL), kt CO_2e	286	235	171	158	154	144	98	81	75
Total emission, kt CO_2e	6 332	5 225	3 372	3 033	2 958	2 763	1 886	1 564	1 421

The CO_2 emission from organic soils in CL has been reduced around 73 % from 3 959 kt CO_2e in 1990 to 1 117 kt CO_2e in 2022. It is expected to continue to decrease with an estimated emission in 2030 of 697 kt CO_2e, equivalent of a total reduction since 1990 of nearly 83 %. The same overall pattern is expected for GL, from 2 267 kt CO_2e in 1990 to 1 118 kt CO_2e in 2030, a reduction of around 48 %. The historical and the projected development in emissions are visualized in Figure 8.4. From 2017 and forward, emissions from organic soils on GL surpass those of CL, as permanent grass becomes more dominant on organic soil compared to crops in rotation, possibly due to the soils settling and making cultivation increasingly difficult. The emissions from organic soils in CL and GL are projected to continue to decrease, but slower from 2032 onwards with 2032 being the last year with decided WL restoration projects, see Section 8.6.2. From Figure 8.4, it is also evident that the annual decrease in the total area of organic soils is higher in 2010-2022 than the projected decrease in following years.

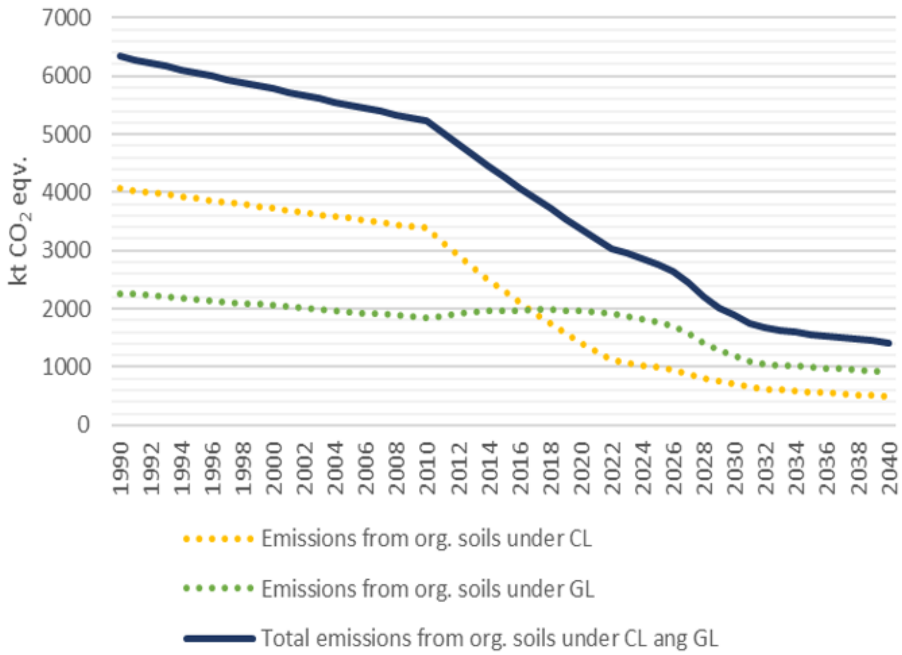

Figure 8.4 Estimated emissions from organic soils of ≥ 6 % OC in total and for Cropland and Grassland separately, C and CH_4, from 1990 - 2040 expressed in kt CO_2 eqv.

8.4.5 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 2022, 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 4 786 ha as in 2022, 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.

8.4.6 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. In the projection an annual increase of 50 ha new hedges is assumed.

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. Grass in frequent rotation is reported under CL as a part of the area with agricultural crops.

A total of 179 000 ha is reported in the GL category in 2022. The area is expected to decline slowly in the future to 143 000 ha in 2040. This reduction is primarily due to the expectation that a large part of the wetland restoration will take place on the more marginal GL areas. 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.

For drained organic soils >12 % OC, which has once been defined in the field maps and registered as a type of permanent grassland, an average emission of 8.4 t C per ha per year is assumed, combined with a CH_4 emission of 16 kg CH_4 per ha per year (IPCC, 2014).

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

GL will continuously be a net source of greenhouse gas emissions, reduced from currently around 1 850 to 1 150 kt CO_2e per year in 2030 (Table 8.2), due to the expected conversion of organic GL soils into wetlands (Table 8.5) as well as the projected decrease in emissions from soils as organic soils loose carbon and are transferred to the mineral soil category. The projected emissions in 2030 are equivalent to an emission reduction of nearly 48 % since 1990.

8.6 Wetlands

Wetlands (WL) 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 WL, WL 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 132 000 m^3 in 2022.The total emission from peatland is estimated to 35.7 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 2022.

8.6.2 Restored Wetlands

Only emissions from re-established WL are included in the WL category. Emissions from naturally occurring wetlands have not been estimated. Some larger WL restoration projects were carried out in the 1990s. Until 2022, a total of 27 653 ha were converted to WL. 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.

There has been a large variation in the area converted to restored WL within the past years. In the projection, up to 15 350 ha is expected to be converted to WL 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 WL are distributed between the existing subcategories of flooded WL (lakes) and periodically water covered WL. In the projection, it is assumed that 90% is converted to periodically water covered WL and 10% into flooded area. It is furthermore assumed that the WL restoration will take place on Grassland and Cropland in accordance with the latest distribution of restored land to WE. These data shows that a 76 % of the restored WE were on GL and the remaining 24 % on CL.

The new partly water covered WL 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 soils with 6-12 % OC. This has been implemented in the projection for partly water covered WL, but not for lakes and other fully water covered areas.

The projection considers restoration of WL in the governmental budget of the Danish Finance Act (FA) (Finance Act, 2024) as received from DAA in February 2024. The exact numbers are estimated by the DAA based on historical data on various wetland restoration projects and expenses. A recent analysis has resulted in a reassessment of the rate at which restoration takes place after funding. Thus, last year's projection assumed the restoration projects to have effect 3 years after funding, but in the present projection effect is assumed after 5 years, which consequently means that emissions are decreased later compared to the previous projection. Hence, if establishment of WL in 2025 is based on funding in 2020. Additionally, the DAA has reduced the assumption as to the proportion of the restoration area that is expected to take place on organic soils. Lastly, the DAA has adjusted the price for restoration (price per hectare) downwards. In summary, these adjustments result in an increase in the total area expected to be restored with current budgets, but a decrease in the expected number of restored hectares on organic soils. Based on the data from the DAA, it is assumed that 30 508 ha out of a total of 70 126 ha, approximately 44 %, of all established WL will take place and influence emissions on organic soils (≥6 % OC). The rest of the land included in the projects is mineral soil. The expected total converted organic agricultural land converted to WL from 2022 to 2032 is shown in Table 8.5.

Table 8.5 Expected agricultural areas (CL+GL) converted to Wetlands (WL) in certain years and in total from 2023-2032 with public funding, in ha (DAA, 2024b). 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	2023	2024	2025	2027	2029	2030	2032	Total conversion to WL 2022-2032
Organic soil scheme (Rural Development Program)	60	114	547	662	2 469	329	1 646	1 640	9 884
Organic soil scheme +22000 (CAP + national)	60	0	0	0	0	6 584	0	0	16 589
Nitrogen Removal Wetlands	40	422	1 926	715	1 238	1 238	1 238	1 238	11 685
Phosphorus Removal Wetlands	60	0	64	0	86	92	86	86	543
Finance Act '20, organic soil	60	0	0	1 235	1 667	895	3 154	0	12 239
Finance Act '21, organic soil	60	0	0	0	2 275	0	0	0	3 802
Accumulated Wetland restoration (incl. 2021)		535	3 073	5 685	18 349	39 724	45 847	54 742	54 742

[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 pictured in Figure 8.5. In recent years, the emissions from WL have been increasing to 142 kt CO_2e in 2022 and are expected to increase to 342 kt CO_2e in 2030, primarily due to the increase in CH_4 emissions from the organic soils with restored WL, as is evident from the figure below. The negative emissions of CO_2 (sink effect) occur in years with large conversions of CL/GL into WL, as an instant effect of the higher C stock in living biomass for WL compared to CL/GL, see Table 8.2. N_2O emissions are minor and assumed not to occur on restored WL, so these are halted as peat extraction activities end by 2028.

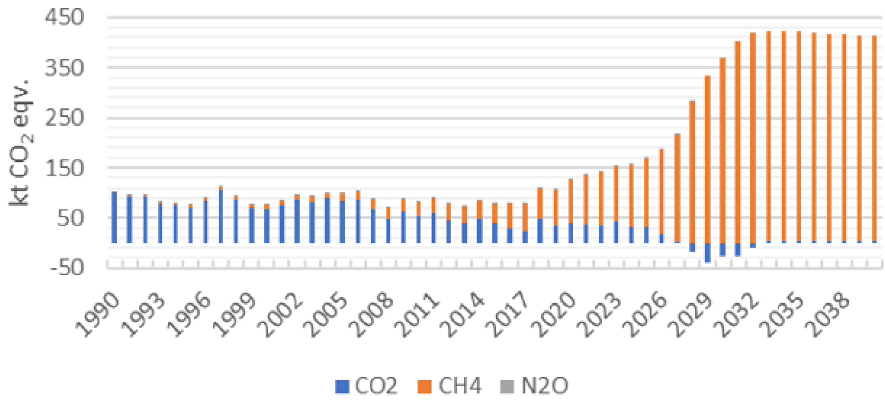

Figure 8.5 Estimated emissions from all Wetlands from 1990-2040 in kt CO_2 eqv. distributed between CO_2, CH_4 and N_2O.

When WL 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 WL restoration projects, it can be concluded that this is the case for a high share of the planned conversions. Use of an emission factor for fully drained soils at 11.5 t C per ha per year for CL and 8.4 t C per ha for GL, therefore, likely causes an overestimation of the real effect. A further analysis on the actual agricultural state of the land in the projected WL is of outmost importance to get a better understanding of the emission potentials. The methodology of the calculations is expected to be improved in 2025, implementing the results of ongoing projects on organic soils and water table depths on a national scale.

8.7 Settlements

The need for areas for housing and other infrastructure has resulted in an increase in the SE area of 54 642 ha or around 1 700 hectare per year on average from 1990 to 2022. 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 eqv. per year in the projection up until 2040. 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 2 386 ha per year which is the average conversion to SE in the last ten years from 2013 to 2022 (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 the 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 is 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 are 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 were 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 0.031 kt CO_2e in 2022 and 0.26 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 2022 of 97.9 kt CO_2. The historical and projected emissions are reported by IGN in Nord-Larsen et al. (2023) and Johannsen et al. (2022), respectively.

8.11 Emission

The total emissions from all sources from 1990 to 2040 are shown in Table 8.2 and Figure 8.1.

The projection estimates the following development of the emissions as averages in the projected period, presented in Table 8.6. The overall picture of the LULUCF sector was a net source of 6 694 kt CO_2e in 1990. In 2022, the estimated emission had been reduced to a net sink of 381 kt CO_2e, increasing to be a net source of 1 117 kt CO_2e in 2023-2030 (average of 2023-2030). Generally, emissions from all other land use categories than forest are projected to decrease towards 2040, and although Forest land is a sink throughout the period 1990-2040, the total LULUCF sector will only become a more consistent sink from 2032 onwards.

For Cropland, a decrease in the emission is expected from an average in 2017-2022 of 1 240 kt CO_2e per year to 663 kt CO_2e per year in 2023-2030 and to 489 kt CO_2e per year in 2031-2040. This decrease is partly due to increased carbon stock in mineral soils due to increased crop yield and a larger organic matter input into the mineral soils from the area with catch crops. Another important contributor to this decrease in emissions from CL is the decline in area of organic soils under cultivation as well as the gradual loss of carbon from these soils resulting in a reclassification of soils from organic to mineral and hence lower emission factors.

Grassland is a net emitter of 1 966 kt CO_2e in 2022 and projected to be the source of nearly 1611 kt CO_2e on average in the future from 2023-2030. The level of emissions from GL in 2030 of 1 224 kt CO_2e will be almost halved compared to 1990, see table 8.2 and figure 8.1. Again, grass on organic soils (including dissolved organic carbon) is a major contributor to emissions projected to make up more than 90% of emissions from GL in 2030.

The emissions from Wetlands are estimated to increase from 142 kt CO_2e (in 2022) to 413 kt CO_2e on average (2031-2040) per year due to the increased conversion of agricultural soils to re-established wetlands with CH_4 being the most important greenhouse gas.

Emissions from Settlements are projected to increase in the future to around 250 kt CO_2e per year (average from 2023 – 2030), due to C losses in biomass and soil from areas converted to SE, mainly from agricultural soils.

Table 8.6. Historical and projected average emissions from LULUCF, in kt CO_2e per year

	2017 – 2022	2023 – 2030	2031 – 2040
Total LULUCF	976	1 018	-553
Forest land	-2 566	-1 720	-2 761
Cropland	1 240	663	489
Grassland	2 015	1 611	1 030
Wetlands	116	223	413
Settlements	265	250	286
HWP	-94	-9	-11

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 WL. 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 has 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.

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 8.6). 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.

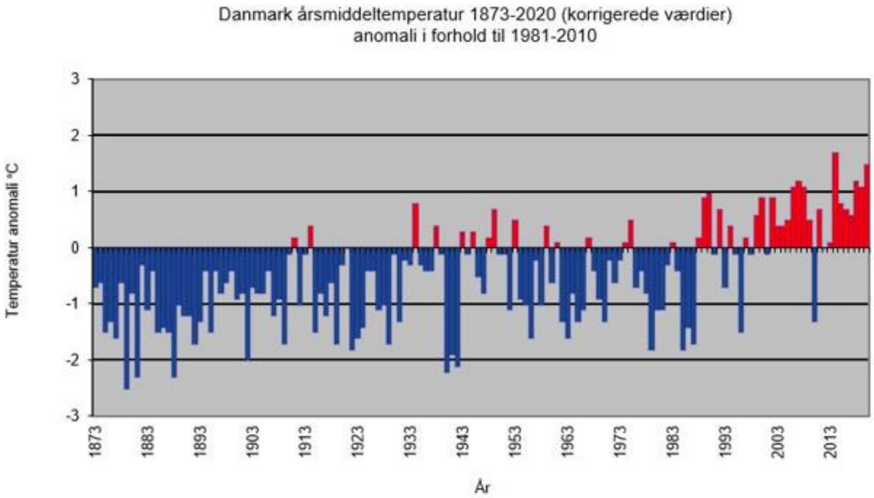

Figure 8.6 Annual change in temperature in Denmark 1873 to 2020 in relation to 1981-2010 (Cappelen, 2020).

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 WL. 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 8.7 and Table 8.7.

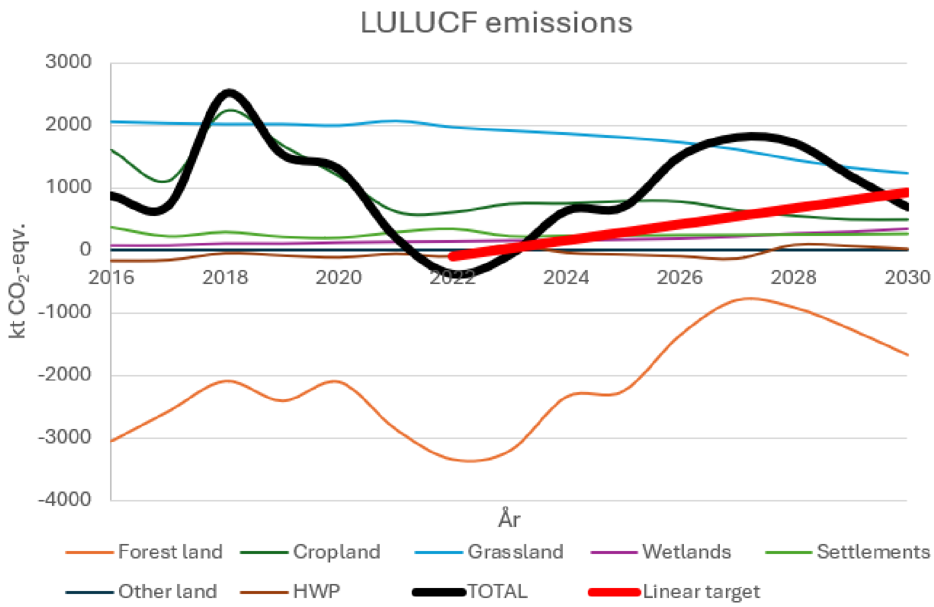

Figure 8.7 Reported and projected emissions from 2016 to 2030 for the LULUCF sector displayed along with the linear target necessary to meet EU commitments for the compliance period 2026 - 2030.

As can be seen from figure 8.7 and Table 8.7, Denmark will not fulfill its EU reduction commitment with the current projection, as emissions are projected to exceed the linear trajectory in 2026-2029.

Table 8.7 Historical average for 2016-2018 and emission for the LULUCF sector in 2022 and projected for 2026-2030 in kt CO_2e per year.

Land Accounting Categories	Base year average 2016-2018	2022	2026	2027	2028	2029	2030
Forest land	-2 573	-3 352	-1 348	-785	-902	-1 255	-1 669
Cropland	1 643	616	787	651	562	503	500
Grassland	2 033	1 966	1 724	1 607	1 443	1 311	1 224
Wetlands	89	142	186	217	266	292	342
Settlements	297	345	249	251	259	261	269
Harvested Wood Products	-127	-98	-97	-137	90	72	22
Projected Net TOTAL	1 362	-381	1 502	1 804	1 718	1 184	688
Linear target line		-86	417	543	669	795	921
Projected target gap		-295	1 085	1 261	1 048	389	-233

8.15 References

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9 Conclusions

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

The historic and projected GHG emissions are shown in Figure 9.1. Projected GHG emissions include the estimated effects of policies and measures implemented or decided as of December 2023 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 2022 are Energy industries (20 %), Transport (29 %), Agriculture (28 %) and Other sectors (8 %). For the latter sector, the most important sources are fuel combustion in the residential sector. GHG emissions show a decreasing trend in the projection period. The total emissions in 2022 are estimated to be 41.7 million tonnes CO_2 equivalents including LULUCF and indirect CO_2 and the corresponding total in 2040 is projected to be 20.7 million tonnes CO_2 equivalents. From 1990 to 2022 the emissions decreased by 46.8 %. From 2022 to 2040, the emission is projected to decrease by approximately 50 %.

The total greenhouse gas emissions in 1990 including LULUCF and indirect CO_2 is estimated at 78.3 million tonnes of CO_2 equivalents and the emission in 2030 is projected to be 28.8 million tonnes of CO_2 equivalents including LULUCF and indirect CO_2. This corresponds to a reduction of 63.3 % 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.

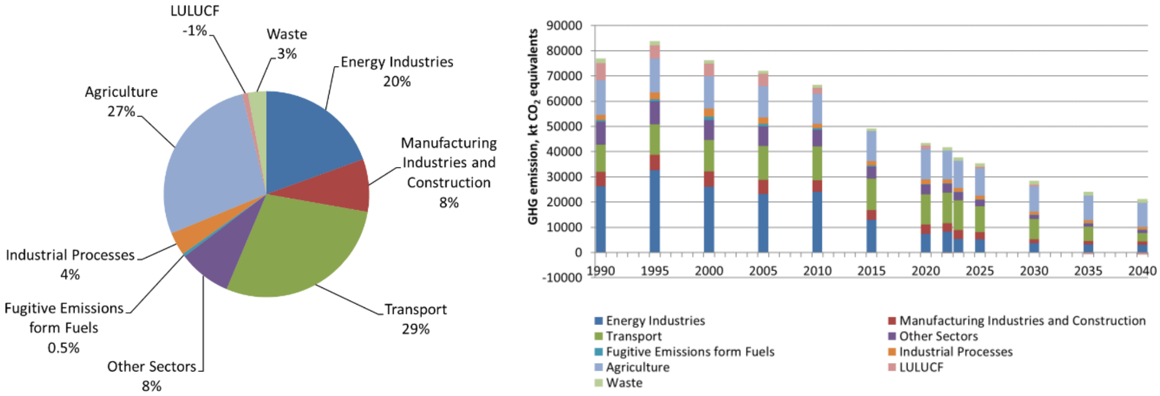

Figure 9.1 Total GHG emissions in CO_2 equivalents. Distribution according to main sectors (2022) and time series for 1990 to 2040.

9.1 Stationary combustion

Stationary combustion includes Energy industries, Manufacturing industries and construction and Other sectors. Other sectors include combustion in commercial/institutional, residential and agricultural plants. The GHG emissions in 2022 from the main source, which is public power and heat production (49 %), are estimated to decrease in the period from 2022 to 2040 (75 %) 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 92 % from 2022 to 2040, due to a lower consumption of fossil fuels. Emissions from manufacturing industries decreases by 75 %, also due to a decrease in fossil fuel combustion.

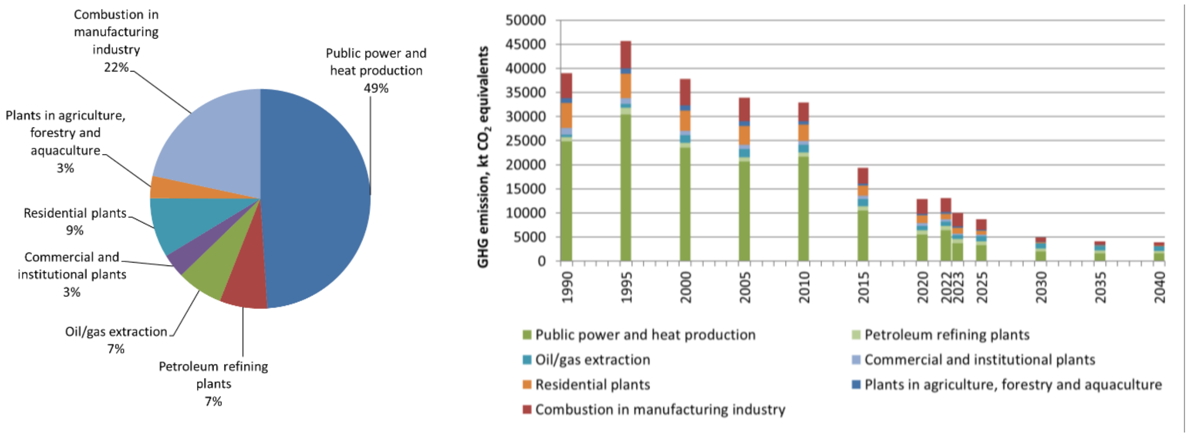

Figure 9.2 GHG emissions in CO_2 equivalents for stationary combustion. Distribution according to sources (2022) and time series for 1990 to 2040.

9.2 Fugitive emissions from fuels

The greenhouse gas emissions from the sector "Fugitive emissions from fuels" show large fluctuations in the historical years 1990-2022, 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 2022-2040 by 13 %. 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 so that the emission in 2040 are slightly lower than the emission in 2022. 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.

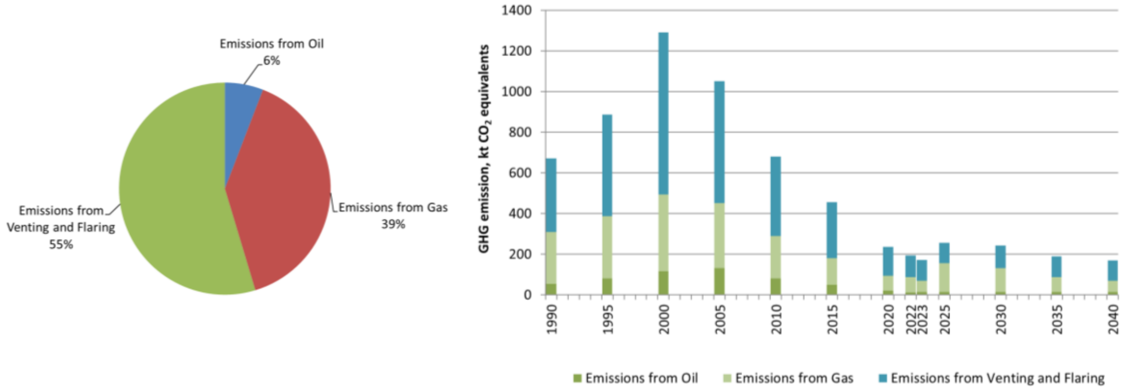

Figure 9.3 GHG emissions in CO_2 equivalents for fugitive emissions. Distribution according to sources for 2022 and time series for 1990 to 2040.

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 2022 are mineral industry (mainly cement production) with 70 % and use of substitutes (F-gases) for ozone depleting substances (ODS) (17 %). The corresponding shares in 2040 are expected to be 74 % and 7 %, respectively. Consumption of limestone and the emission of CO_2 from flue gas cleaning are assumed to follow the consumption of coal and waste for generation of heat and power. The GHG emissions from the IPPU sector will continue to be strongly dependent on the cement production at Denmark's only cement plant.

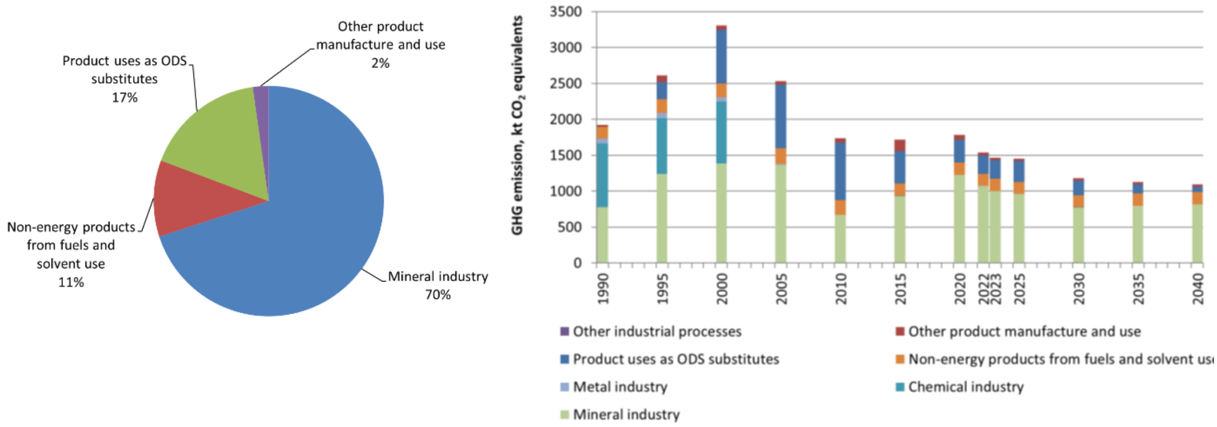

Figure 9.4 Total GHG emissions in CO_2 equivalents for industrial processes. Distribution according to main sectors (2022) and time series for 1990 to 2040.

9.4 Transport and other mobile sources

Road transport is the main source of GHG emissions from transport and other mobile sources in 2022 (80 %) and emissions from this source are expected to decrease in the projection period 2022 to 2040, but with the largest reduction happening after 2030. The emission shares for the remaining mobile sources (e.g. domestic aviation, national navigation, railways and non-road machinery in industry, households and agriculture) are small compared with road transport. Non-road machinery in agriculture, forestry and fishing contributes 8 % of the sectoral GHG emission in 2022.

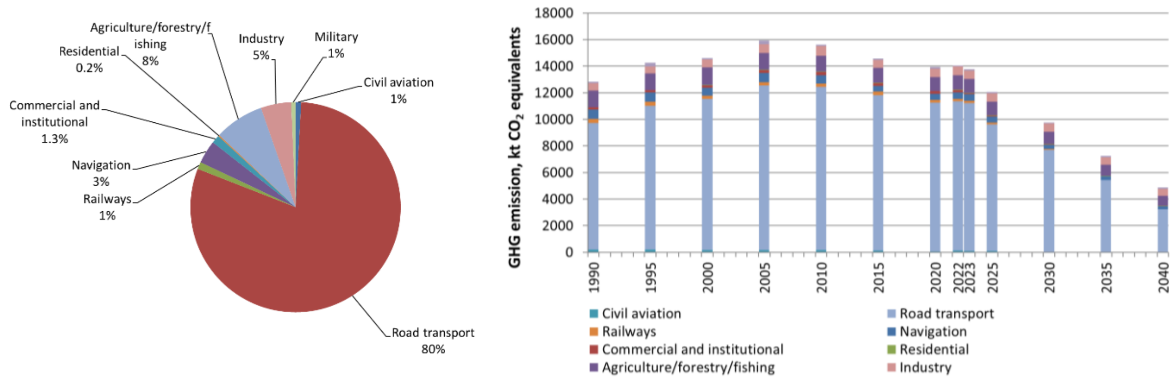

Figure 9.5 GHG emissions in CO_2 equivalents for mobile sources. Distribution according to main sources (2022) and time series for 1990 to 2040.

9.5 Agriculture

The main sources in 2022 are agricultural soils (32 %), enteric fermentation (36 %) and manure management (30 %). The corresponding shares in 2040 are expected to be 35 %, 39 % and 25 %, respectively. From 1990 to 2022, the emission of GHGs in the agricultural sector decreased by 17 %. From 2022 to 2040, the emissions are expected to decline slightly by about 18 %. The reduction in the historical years can mainly be explained by improved utilisation of nitrogen in manure, a significant reduction in the use of fertiliser and a reduced emission from N-leaching. Measures in the form of technologies to reduce ammonia emissions in stables and expansion of biogas production are considered in the projections and emissions from enteric fermentation are estimated to increase due to an expected increase in the number of animals.

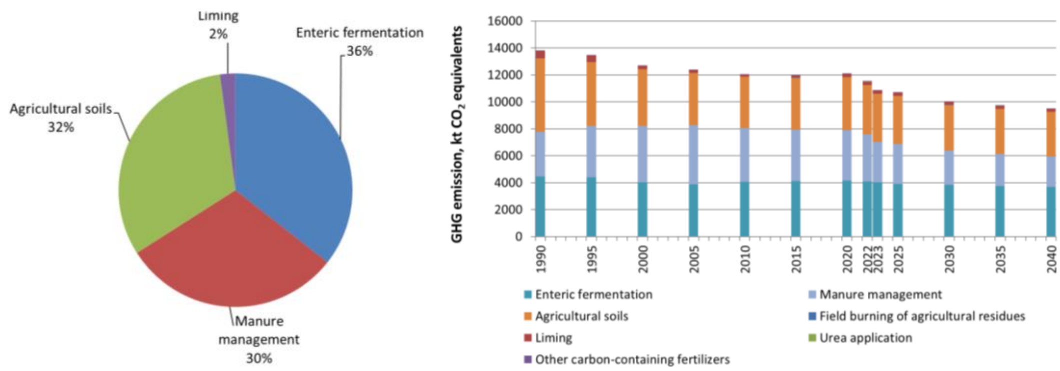

Figure 9.6 GHG emissions in CO_2 equivalents for agricultural sources. Distribution according to main sources (2022) and time series for 1990 to 2040.

9.6 Waste

The total GHG emission from the waste sector has been decreasing in the years 1990 to 2022 by 38 %. From 2022 to 2040, the emissions are projected to increase by 26 % driven by a significant increase in emissions from anaerobic digestion. In 2022, the GHG emission from solid waste disposal contributed with 34 % of the emission from the sector as a whole. A decrease of 10 % is expected for this source in the years 2022 to 2040, 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 2022 contribute with 17 %. Emissions from biological treatment of solid waste (composting and biogas production) contribute with 47 % in 2022 and 60 % in 2040.

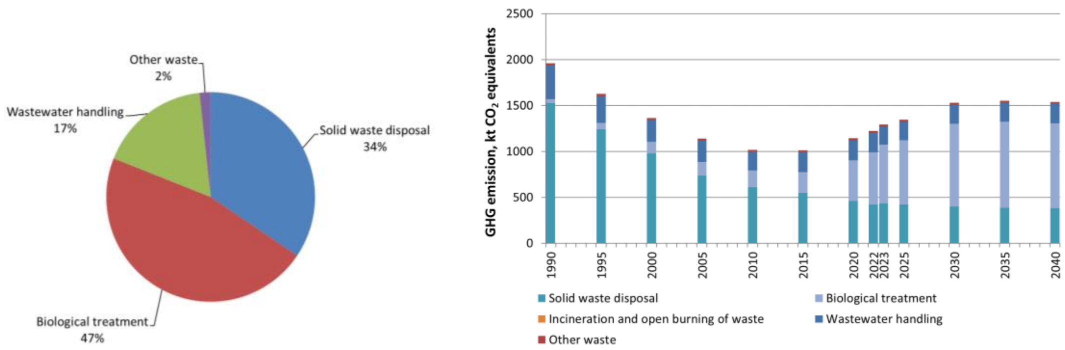

Figure 9.7 GHG emissions in CO_2 equivalents for Waste. Distribution according to main sources (2022) and the time series for 1990 to 2040.

9.7 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 2030 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 6 694 kt CO_2 equivalents in 1990 and reduced to a sink of 381 kt CO_2 equivalents in 2022. A net average emission of 145 kt CO_2 equivalents is estimated for 2023-2030. 2031-2040 represents a small decrease from that with a net average sink of 79 kt CO_2 equivalents.

9.8 EU ETS

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

Table 9.1 CO_2 emissions covered by EU ETS.

	2023	2025	2030	2035	2040
Public electricity and heat production	3181	2863	1810	1383	1371
Petroleum refining	915	830	598	597	595
Other energy industries (oil/gas extraction)	800	1098	1052	966	926
Combustion in manufacturing industry	1784	1408	695	608	551
Domestic aviation	99	103	39	32	26
Agriculture, forestry and aquaculture	1	1	0	0	0
Fugitive emissions from flaring	91	89	99	91	90
Mineral industry	1088	960	772	798	815
Total	7959	7352	5065	4475	4374
Civil Aviation, international	2133	2020	1884	1549	1262

PROJECTION OF GREENHOUSE GASES 2023-2040

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

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