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Emission inventories from the base year of the protocols to year 2023. Submitted to the UNECE and the European Commission

Scientific Report from DCE – Danish Centre for Environment and Energy No. 651 2025

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Abstract: This report is a documentation report on the emission inventories for Denmark as reported to the UNECE Secretariat under the Convention on Long Range Transboundary Air Pollution and the European Commission under the National Emission Ceilings Directive due by 15 March 2025. The report contains information on Denmark's emission inventories regarding emissions of (1) SO_X for the years 1980-2023, (2) NO_X, CO, NMVOC and NH_3 for the years 1985-2023, (3) Particulate matter: TSP, PM_{10}, $PM_{2.5}$ for the years 1990-2023, (4) Heavy Metals: Pb, Cd, Hg, As, Cr, Cu, Ni, Se and Zn for the years 1990-2023 (5) Polyaromatic hydrocarbons (PAH): Benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene and indeno(1,2,3-cd)pyrene, PCDD/F and HCB for the years 1990-2023. Further, the report contains information on background data for emissions inventory.

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

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List of abbreviations

BC	Black Carbon
CO	Carbon Monoxide
CORINAIR	CORe INventory on AIR emissions
CRF	Common Reporting Format
DAAS	Danish Agricultural Advisory Service
DAA	Danish Agricultural Agency
DCA	Danish Centre for food and Agriculture
DCE	Danish Centre for Environment and energy
DEA	Danish Energy Agency
DEPA	Danish Environmental Protection Agency
DST	Statistics Denmark
EEA	European Environment Agency
EF	Emission Factor
EIONET	European Environment Information and Observation Network
EMEP	European Monitoring and Evaluation Programme
ENVS	Department of ENVironmental Science, Aarhus University
HCB	Hexachlorobenzene
HM	Heavy Metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn)
IDA	Integrated Database model for Agricultural emissions
IPCC	Intergovernmental Panel on Climate Change
KCA	Key Category Analysis
LRTAP	Long-Range Transboundary Air Pollution LTO Landing and Take Off
NFR	Nomenclature For Reporting
NH_3	Ammonia
NIR	National Inventory Report
NMVOC	Non-Methane Volatile Organic Compounds
NOx	Nitrogen Oxides
PAH	Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated biphenyls
PCDD/F	Dioxins and Furanes
POP	Persistent Organic Pollutants
$PM_{2,5}$	Particulate matter of 2,5 µm
QA	Quality Assurance
QC	Quality Control
SCR	Selective Catalytic Reduction
SO2	Sulphur dioxide
TSP	Total Suspended Particles
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change

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Summary

I Background information on emission inventories

Annual report

This report is Denmark's Annual Informative Inventory Report (IIR) due March 15, 2025, under the UNECE-Convention on Long-Range Transboundary Air Pollution (LRTAP) and Directive (EU) 2016/2284 on the reduction of national emissions of certain atmospheric pollutants. The report contains information on Denmark's inventories for all years from the base years of the protocols to 2023.

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

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

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

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

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

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

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

Responsible institute

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

II Trends in emissions

Acidifying gases

In 1990, the relative contribution in acid equivalents was almost equal for the three gases SO_2, NO_x and NH_3. In 2023, the most important acidification factor in Denmark is ammonia nitrogen and the relative contributions for SO_2, NO_X and NH_3 were 4 %, 30 % and 66 %, respectively. However, with regard to long-range transport of air pollution, SO_2 and NO_X are still the most important pollutants.

Sulphur dioxide (SO_2)

The main part of the sulphur dioxide (SO_2) emission originates from combustion of fossil fuels, i.e. mainly coal and oil, in public power plant, district heating plants and manufacturing plants. Since 1990, the total emission has decreased by 95 %. The large reduction is mainly due to installation of desulphurisation and use of fuels with lower content of sulphur in public power and district heating plants. Despite the large reduction of the SO_2 emissions, these plants make up 30 % of the total emission. In addition, emissions from industrial combustion plants, non-industrial combustion plants and other mobile sources are important.

Nitrogen oxide (NO_x)

The largest sources of emissions of nitrogen oxides (NO_x) are road transport followed by other mobile sources and combustion in energy industries (mainly public power and district heating plants). The transport sector is the sector contributing the most to the emission of NO_x and, in 2023, 37 % of the Danish emissions of NO_x stems from road transport, national navigation, railways and civil aviation. In addition, emissions from national fishing and off-road vehicles contribute significantly to the NO_x emission. For non-industrial combustion plants, the main sources are combustion of gas oil, natural gas and wood in residential plants. The emissions from energy industries have decreased by 85 % from 1990 to 2023. In the same period, the total emission decreased by 73 %. The reduction is due to the increasing use of catalyst cars and installation of low-NO_x burners and denitrifying units in power plants and district heating plants.

Ammonia (NH_3)

Almost all atmospheric emissions of ammonia (NH_3) result from agricultural activities. Only a minor part of the total emission originates from stationary combustion (1.5 %), road transport (1.0 %), industrial processes (0.5 %) and waste (1.0 %). The share for road transport was increasing during the 1990's and early 2000's due to increasing use of catalyst cars. In recent years, the share has been decreasing due to more advanced catalysts being implemented. The total ammonia emission has decreased by 57 % since 1990.

The major part of the emission from agriculture stems from livestock manure (37 %) and agricultural soils (58 %). The largest source for manure management is losses of ammonia occurring during the handling of the manure in animal housing systems. For agricultural soils, the emissions are mainly stemming from application of mineral fertiliser, application of animal manure, growing crops and crop residues.

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

Other air pollutants

Non-methane volatile organic compounds (NMVOC)

The emissions of Non-Methane Volatile Organic Compounds (NMVOC) originate from many different sources and can be divided into two main groups: incomplete combustion and evaporation. Small combustion plants (e.g. residential wood burning) is a big source of NMVOC originating from combustion. Other important sources are road vehicles and other transport sources such as national navigation. NMVOC from road transportation vehicles have been decreasing since 1990, due to the introduction of catalyst cars. The evaporative emissions mainly originate from the agricultural sector, use of solvents, and the extraction, handling and storage of oil and natural gas. The total anthropogenic emissions have decreased by 55 % since 1990, largely due to the increased use of catalyst cars and reduced emissions from use of solvents.

Particulate Matter (PM)

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

The largest $PM_{2.5}$ emission source is residential plants (51 %), road transport (10 %) and other mobile sources (8 %). Emissions from residential plants increased by 58 % from 1990 to 2007, followed by a decrease of 60 % from 2007 to 2023. The increase was caused by increasing wood consumption while the decrease has been caused by a slightly lower wood consumption (until 2016) combined with legislative demands on new wood stoves and boilers. From 2016, the wood consumption decreased significantly leading to a significant decrease in emissions with a small increase again from 2022 to 2023. For the road transport sector, exhaust emissions account for less than a sixth (13 %) of the emissions, while the remaining emissions come from tyre and brake wear and road abrasion. For other mobile sources, the most important sources are off-road vehicles and machinery in the industrial sector and in the agricultural/forestry sector (12 % and 20 %, respectively). The $PM_{2.5}$ emission decreased by 52 % from 1990 to 2023, but most of the reduction has occurred after 2008.

The largest TSP emission sources are agriculture and non-industrial combustion (77 % and 9 % of total TSP emission in 2023, respectively). Residential plants is the largest source in the non-industrial combustion sector, making up 7 % of the national total TSP emission in 2023.The TSP emissions from transport are also important and include both exhaust emissions and the non-exhaust emissions from brake and tyre wear and road abrasion. The non-exhaust emissions account for 95 % of the TSP emission from road transport in 2023.

Black carbon (BC)

The black carbon (BC) emission inventory is reported for the years 1990 onwards. The main sources are residential plants and road transport contributing 45 % and 16 % in 2023, respectively. From 1990 to 2023, the total BC emission decreased by 70 %. The trend for non-industrial combustion is mainly controlled by the trend for the wood consumption in the residential sector.

BC emissions from the transport sector decreased by 88 % from 1990 to 2023, mainly due to implementing of new EURO norms and improved technology. An important factor is the use of particle filters for heavy-duty vehicles and passenger cars, which reduce the BC emission effectively.

BC emissions from fugitive emissions from fuels, which is mainly due to storage of coal, decreased by 88 % from 1990 to 2023, in line with the decrease of the coal consumption in electricity and heat production.

Heavy metals

In general, the most important sources of heavy metal emissions are combustion of fuels and waste. The heavy metal emissions have decreased substantially in recent years, except for Cu. The reductions span from 23 % to 93 % for Zn and Hg, respectively. The reason for the reduced emissions is mainly increased use of gas cleaning devices at power and district heating plants (including waste incineration plants) as well as lower fuel consumption. The large reduction in the Pb emission is due to a shift towards unleaded gasoline, the latter being essential for catalyst cars. The major source of Cu is automobile tyre and break wear (90 % in 2023) and the 27 % increase in total emission from 1990 to 2023 owe to increasing mileage.

III Recalculations and Improvements

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

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

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

Sammenfatning

I Baggrund for emissionsopgørelser

Årlig rapport

Denne rapport er Danmarks årlige rapport om emissionsopgørelser rapporteret d. 15. marts 2025 til UNECE-konventionen om langtransporteret grænseoverskridende luftforurening (LRTAP) og Direktiv (EU) 2016/2284 om nedbringelse af nationale emissioner af visse luftforurenende stoffer. Rapporten indeholder oplysninger om Danmarks opgørelser for alle år fra basisårene for protokollerne til 2023.

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

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

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

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

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

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

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

Ansvarlig institution

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

II Udviklingen i emissioner

Forsurende gasser

I 1990 var det relative bidrag af syreækvivalenter næsten ens for de tre gasarter. I 2023 var ammoniak den vigtigste forsurende faktor i Danmark og de relative bidrag for SO_2, NO_x og NH_3 var på henholdsvis 4 %, 30 % og 66 %. Med hensyn til langtransporteret luftforurening, er det dog stadig SO_2 og NO_x, der er de vigtigste forureningskomponenter.

Svovldioxid (SO_2)

Hovedparten af SO_2-emissionerne stammer fra forbrænding af fossile brændsler, dvs. primært kul og olie, på kraftværker, kraftvarmeværker, fjernvarmeværker og industrielle værker. Siden 1990 er den totale udledning reduceret med 95 %. Den store reduktion er primært opnået gennem installation af afsvovlingsanlæg på kraftværker og fjernvarmeværker og brug af brændsler med lavere svovlindhold. Trods den store reduktion er disse værker kilde til 30 % af den samlede udledning. Også emissioner fra industrielle forbrændingsanlæg, ikke-industrielle forbrændingsanlæg, andre mobile kilder samt teglværker og produktion af ekspanderede lerprodukter er væsentlige bidragsydere til emissionen.

Kvælstofilter (NO_x)

Den største kilde til emissioner af NO_x er transportsektoren efterfulgt af andre mobile kilder og forbrænding i energisektoren (hovedsageligt kraftværker og fjernvarmeværker). Transportsektoren er den sektor, der bidrager mest til udledningen af NO_x, og i 2023 stammede 37 % af de danske NO_x-emissioner fra vejtransport, national søfart, jernbaner og civil luftfart. Også emissioner fra nationalt fiskeri og off-road køretøjer (entreprenør-, landbrugsmaskiner, m.m.) bidrager betydeligt til NO_x-emissionen. For ikke-industrielle forbrændingsanlæg er de primære kilder forbrænding af gasolie, naturgas og træ i husholdninger. Emissionerne fra kraftværker og fjernvarmeværker er faldet med 85 % fra 1990 til 2023. I samme periode er den totale emission faldet med 73 %. Reduktionen skyldes øget brug af katalysatorer i biler og installation af lav-NO_x-brændere og de-NO_x-anlæg på kraftværker og fjernvarmeværker.

Ammoniak (NH_3)

Hovedparten af emissioner af NH_3 stammer fra aktiviteter i landbruget. Kun en mindre del skyldes stationær forbrænding (1.5 %), vejtransport (1.0 %), industrielle processer (0.5 %) og affald (1.0 %). Andelen fra transporten var stigende gennem 1990'erne og i starten af 2000'erne pga. den øgede brug af biler med katalysator. I de senere år er andelen igen faldet på grund af implementeringen af mere effektive katalysatorer.

Hovedparten af emissionen fra landbruget stammer fra husdyrgødning (37 %) og landbrugsjorde (58 %). For husdyrgødning, er det største tab af ammoniak under håndtering af gødningen i stalden. For landbrugsjorde stammer emissionen hovedsageligt fra anvendelse af handelsgødning, udbringning af husdyrgødning samt emissioner fra voksende afgrøder.

Den totale ammoniakemission er faldet 57 % fra 1990-2023. Dette skyldes implementeringen af vandmiljøplaner og ammoniakhandlingsplanen som introducerede en række tiltag for at mindske kvælstoftabet i landbruget. Tiltagene har inkluderet krav om forbedret udnyttelse af kvælstof i husdyrgødning, et forbud mod udbringning af husdyrgødning om vinteren, forbud mod bredspredning af gødning, regler for plantning af efterafgrøder, regulering af antallet af tilladte dyr per hektar og et loft for gødningsanvendelsen for afgrøder. På trods af en stigning i produktionen af svin og fjerkræ, så er emissionen faldet betydeligt.

Anden luftforurening

Flygtige organiske forbindelser (NMVOC)

Emissionen af flygtige organiske forbindelser ekskl. metan (NMVOC) stammer fra mange forskellige kilder og kan opdeles i to hovedgrupper: Ufuldstændig forbrænding og fordampning. Hovedkilderne til NMVOC-emissioner fra ufuldstændige forbrændingsprocesser er brændeovne, vejtrafik og andre mobile kilder, som national sejlads og ikke vejgående maskiner. Køretøjer til vejtransport er fortsat den største bidragsyder, selvom emissionerne er faldet siden introduktionen af biler med katalysator i 1990. Emissionerne fra fordampning stammer hovedsageligt fra landbrug, anvendelse af opløsningsmidler og udvinding, lagring og transport af olie og gas. De totale menneskeskabte emissioner er faldet med 55 % siden 1990, primært som følge af øget brug af biler med katalysator, reducerede emissioner fra anvendelse af opløsningsmidler og reducerede emissioner fra træfyring i husholdninger.

Partikler (PM)

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

De største kilder til $PM_{2,5}$-emission er husholdninger (51 %), vejtrafik (10 %) og andre mobile kilder (8 %). Emissionen fra husholdninger steg med 58 % fra 1990 til 2007 efterfulgt af et fald på 60 % fra 2007 til 2023. Stigningen skyldtes et stigende træforbrug, mens reduktionen efter 2007 skyldtes et svagt fald i træforbruget (indtil 2016) kombineret med emissionsgrænseværdier for nye ovne og kedler. Fra 2016 faldt træforbruget væsentligt, hvilket medførte betydelige fald i emissionerne, men der var en stigning i træforbruget mellem 2022 og 2023. For andre mobile kilder er offroad-køretøjer i industrien samt landbrugs- og skovbrugsmaskiner de vigtigste kilder (hhv. 12 % og 20 %). I transportsektoren tegner udstødningsemissioner sig for under en sjettedel (13 %), mens resten udgøres af partikler fra slid på dæk, bremser og vej. $PM_{2.5}$-emissionen er faldet med 52 % fra 1990 til 2023, hovedparten af reduktionen er fundet sted efter 2007.

De største kilder til TSP-emission er landbrugssektoren og husholdningerne med henholdsvis 77 % og 9 %. TSP-emissionen fra transport er også vigtig og inkluderer både udstødningsemissioner og ikke-udstødningsrelaterede emissioner fra slid af bremser, dæk og vej. De ikke-udstødningsrelaterede emissioner udgør 95 % af TSP-emissionen fra transport.

Sod (BC)

Emissionsopgørelsen for sod (Black Carbon – BC) er rapporteret fra år 1990 og fremefter. De vigtigste kilder er husholdninger og vejtransport, der bidrager med henholdsvis 45 % og 16 % i 2023. Fra 1990 til 2023 er den samlede BC-emission faldet med 70 %. Udviklingen indenfor ikke-industriel forbrænding er domineret af udviklingen i træforbruget i husholdninger.

BC-emissionen fra transportsektoren er faldet med 88 % fra 1990 til 2023, hvilket skyldes implementeringen af nye EURO-normer og forbedret teknologi. En vigtig faktor er anvendelsen af partikelfiltre for lastbiler og personbiler, som effektivt begrænser udledningen af partikler og også BC.

BC-emissioner fra udvinding/lagring/transport af kul, olie og gas kommer hovedsageligt fra lagring af kul. Emissionen er faldet med 88 % fra 1990 til 2023 på grund af det faldende kulforbrug til produktion af el og varme.

Tungmetaller

Generelt er de vigtigste kilder til emissioner af tungmetaller forbrænding af fossile brændsler og affald. Emissionerne af tungmetaller er med undtagelse af kobber, faldet betydeligt de seneste år. Reduktionerne spænder fra 23 % til 93 % for henholdsvis Zn og Hg. Årsagen til de reducerede emissioner er hovedsageligt den øgede brug af røggasrensning på kraftværker og fjernvarmeværker (inklusive affaldsforbrændingsanlæg). Den store reduktion i emissionen af Pb skyldes et løbende skift til fordel for blyfri benzin, som er nødvendigt for biler med katalysator. Den største kilde til emission af kobber er slid af køretøjers dæk og bremser (90 % i 2023). Emissionen herfra er steget 27 % fra 1990 til 2023 pga. en stigning i antal kørte kilometer.

III Genberegninger og forbedringer

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

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

1 Introduction

1.1 Background information on emission inventories

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

1.1.1 Annual report

This report is Denmark's Annual Informative Inventory Report due March 15, 2025. The report contains information on Denmark's inventories for all years from the base years of the protocols to 2023.

According to the guidelines for reporting emission data under the Convention on Long-Range Transboundary Air Pollution (ECE/EB.AIR/150/Add.1) prepared by the Task Force on Emission Inventories and Projections and approved by the Executive Body, countries that are parties to the UNECE-Convention on Long-Range Transboundary Air Pollution should annually submit an informative inventory report to the Secretariat. The current reporting Guidelines (ECE/EB.AIR/150/Add.1) were accepted at the meeting of the Executive Body in December 2022.

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

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

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

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

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

1.2 A description of the institutional arrangement for inventory preparation

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

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

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

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

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

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

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

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

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

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

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

1.3 Brief description of the process of inventory preparation - Data collection and processing, data storage and archiving

The background data (activity data and emission factors) for estimation of the Danish emission inventories is collected and stored in central databases located at DCE. The databases are in Access format and handled with software developed by the European Environmental Agency (EEA) and DCE. As input to the databases, various sub-models are used to estimate and aggregate the background data in order to fit the format and level in the central databases. The methodologies and data sources used for the different sectors are described in Chapter 1.4 and Chapters 3 to 6. As part of the QA/QC plan (Chapter 1.5), the data structure for data processing support the pathway from collection of raw data, data compilation, modelling and final reporting.

For each submission, databases and additional tools and submodels are archived together with the resulting NFR reporting format. This material is placed on central institutional servers, which are subject to routine back-up services. Material, which has been backed up is archived safely. A further documentation and archiving system is the official journal for DCE, for which obligations apply to DCE, as a governmental institute. In this journal system, correspondence, both in-going and out-going, is registered, which in this case involves the registration of submissions and communication on inventories with the UNECE-LRTAP Secretariat, the European Commission, review teams, etc.

Figure 1.1 shows a schematic overview of the process of inventory preparation. The figure illustrates the process of inventory preparation from the first step of collecting external data to the last step, where the reporting schemes are generated for the UNFCCC and EU (in the CRF format (Common Reporting Format)) and to the United Nations Economic Commission for Europe/Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (UNECE/EMEP) (in the NFR format (Nomenclature For Reporting)). For data handling, the software tool is CollectER II and for reporting the software tool is developed by DCE. Data files and programme files used in the inventory preparation process are listed in Table 1.1.

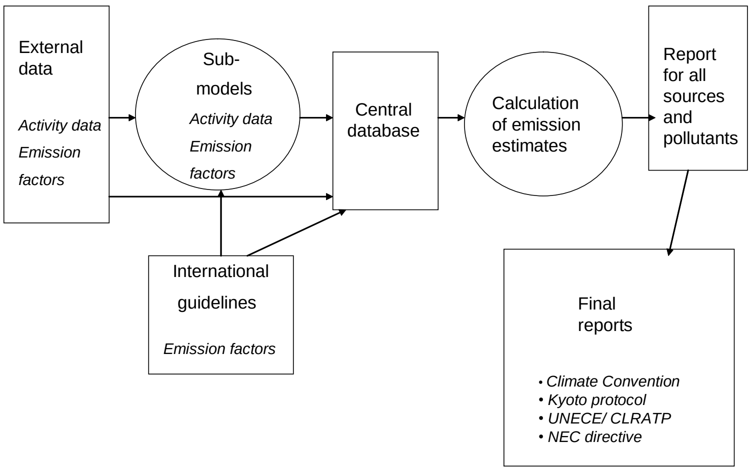

Figure 1.1 Schematic diagram of the process of inventory preparation.

Table 1.1 List of current data structure; data files and programme files in use.

QA/QC Level	Name	Application type	Path	Type	Input sources
4 store	CFR Submissions (UNFCCC and EU) NFR Submissions (UNECE and EU)	External report	U:\ST_ENVS-LUFT-EMI\Inventory\AllYears\8_AllSectors\Level_4a_Storage\	MS Excel, xml	CRF Reporter
3 process	CRF Reporter	Management tool	Working path: local machine Archive path: U:\ST_ENVS-LUFT-EMI\Inventory\AllYears\8_AllSectors\Level_3b_Processes	(exe + mdb)	manual input and Importer2CRF
3 process	Importer2CRF	Help tool	U:\ST_ENVS-LUFT-EMI\Inventory\AllYears\8_AllSectors\Level_3b_Processes	MS Access	CRF Reporter, CollectEr2CRFand excel files
3 process	CollectER2CRF	Help tool	U:\ST_ENVS-LUFT-EMI\Inventory\AllYears\8_AllSectors\Level_3b_Processes	MS Access	NERIRep
2 process 3 store	NERIRep	Help tool	Working path: U:\ST_ENVS-LUFT-EMI\Inventory\AllYears\8_AllSectors\Level_3a_Storage	MS Access	CollectER databases; dk1972.mdb..dkxxxx.mdb
2 process	CollectER	Management tool	Working path: local machine Archive path: U:\ST_ENVS-LUFT-EMI\Inventory\AllYears\8_AllSectors\Level_2b_Processes	(exe +mdb)	manual input
2 store	dk1980.mdb.dkxxxx.mdb	Datastore	U:\ST_ENVS-LUFT-EMI\Inventory\AllYears\8_AllSectors\Level_2a_Storage	MS Access	CollectER

1.4 Brief description of methodologies and data sources used

Denmark's air emission inventories are based on the EMEP/EEA Guidebook, the CORINAIR methodology as well as the 2006 IPCC Guidelines (IPCC, 2006). CORINAIR (COoRdination of INformation on AIR emissions) is a European air emission inventory programme for national sector-wise emission estimations, harmonised with the IPCC guidelines. In 2023, the latest edition of the EMEP/EEA Guidebook (EEA, 2023) was adopted for use by the EMEP Executive Body. In 2009, the EMEP/CORINAIR Guidebook changed name to the EMEP/EEA Guidebook (EEA, 2009). In this change, the Guidebook switched nomenclature from SNAP to NFR.

The Danish inventory is prepared at the more detailed SNAP level rather than at the NFR level that is only suitable for reporting. To ensure estimates are as timely, consistent, transparent, accurate and comparable as possible, the inventory programme has developed calculation methodologies for most subsectors and software for storage and further data processing.

A thorough description of the CORINAIR inventory programme used for Danish emission estimations is given in Illerup et al. (2000). The CORINAIR calculation principle is to calculate the emissions as activities multiplied by emission factors. Activities are numbers referring to a specific process generating emissions, while an emission factor is the mass of emissions per unit activity. Information on activities to carry out the CORINAIR inventory is largely based on official statistics. The most consistent emission factors have been used, either as national values or default factors proposed by international guidelines.

A list of all subsectors at the most detailed level is given in Illerup et al. (2000) together with a translation between CORINAIR and IPCC codes for sector classifications.

1.4.1 The specific methodologies regarding stationary combustion

Stationary combustion plants are part of the CRF emission sources 1A1 Energy Industries, 1A2 Manufacturing Industries and 1A4 Other sectors.

The Danish emission inventory for stationary combustion plants is based on the former CORINAIR system. The emission inventory for stationary combustion is based on activity rates from the Danish energy statistics. General emission factors for various fuels, plants and sectors have been determined. Some large plants, such as power plants, are registered individually as large point sources and plant-specific emission data are used.

The fuel consumption rates are based on the official Danish energy statistics prepared by the Danish Energy Agency (DEA). DCE aggregates fuel consumption rates to SNAP categories. The fuel consumption of the NFR category 1A2 Manufacturing industries and construction is disaggregated to subsectors according to the DEA data prepared and reported to Eurostat.

For each of the fuel and SNAP categories (sector and e.g. type of plant), a set of general emission factors has been determined. Some emission factors refer to the EMEP/EEA Guidebook and some are country specific and refer to Danish legislation, Danish research reports or calculations based on emission data from a considerable number of plants.

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

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

1.4.2 Specific methodologies regarding transport

The emissions from transport referring to SNAP category 07 (Road transport) and the sub-categories in 08 (Other mobile sources) are made up in the NFR categories; 1A3b (Road transport), 1A2f (Industry-other), 1A3a (Civil aviation), 1A3c (Railways), 1A3d (Navigation), 1A4c (Agriculture/forestry/-fisheries), 1A4a (Commercial/institutional), 1A4b (Residential) and 1A5 (Other).

An internal DCE model with a structure similar to the European COPERT IV emission model (EEA, 2023) is used to calculate the Danish annual emissions for road traffic. The emissions are calculated for operationally hot engines, during cold start and fuel evaporation. The model also includes the emission effect of catalyst wear. Input data for vehicle stock and mileage is obtained from DTU Transport and Statistics Denmark, and is grouped according to average fuel consumption and emission behaviour. For each group, the emissions are estimated by combining vehicle type and annual mileage figures with hot emission factors, cold:hot ratios and evaporation factors.

For air traffic, from 2001 onwards estimates are made on a city-pair level, using flight data provided by the Danish Civil Aviation Agency (CAA-DK) for flights between Danish airports and flights between Denmark and Greenland/Faroe Islands, and LTO and distance-related emission factors from the CORINAIR guidelines (Tier 2 approach). For previous years, the background data consists of LTO/aircraft type statistics from Copenhagen Airport and total LTO numbers from CAA-DK. With appropriate assumptions, consistent time series of emissions are produced back to 1990 and include the findings from a Danish city-pair emission inventory in 1998.

Off-road working machines and equipment are grouped in the following sectors: inland waterways (pleasure craft), agriculture, forestry, industry, and household and gardening. The sources for stock and operational data are various branch organisations and key experts. In general, the emissions are calculated by combining information on the number of different machine types and their respective load factors, engine sizes, annual working hours and emission factors.

The inventory for navigation consists of regional ferries, local ferries and other national sea transport (sea transport between Danish ports and between Denmark and Greenland/Faroe Islands). For regional ferries, the fuel consumption and emissions are calculated as a product of number of round trips per ferry route (Statistics Denmark), sailing time per round trip, share of round trips per ferry, engine size, engine load factor and fuel consumption/emission factor. The estimates take into account the changes in emission factors and ferry specific data during the inventory period.

For the remaining navigation categories, the emissions are calculated simply as a product of total fuel consumption and average emission factors. For each inventory year, this emission factor average comprises the emission factors for all present engine production years, according to engine life times.

Please refer to Chapter 3.3 and Annex 3B for further information on emissions from transport.

1.4.3 The specific methodologies regarding fugitive emissions

Fugitive emissions from oil (1.B.2.a)

Fugitive emissions from oil are estimated according to the methodology described in the Emission Inventory Guidebook (EEA, 2023). The sources include offshore extraction of oil and gas, onshore oil tanks, onshore and offshore loading of ships, and gasoline distribution. Activity data are given in the Danish Energy Statistics by the Danish Energy Agency. The emission factors are based on the figures given in the guidebook except in the case of oil and gas production, onshore oil tanks and gasoline distribution where national values are included.

The VOC emissions from petroleum refinery processes cover non-combustion emissions from feed stock handling/storage, petroleum products processing, and product storage/handling. SO_2 is also emitted from non-combustion processes and includes emissions from product processing and sulphur-recovery plants. The emission calculations are based on information from the Danish refineries.

Fugitive emissions from natural gas (1.B.2.b)

Inventories of NMVOC emission from transmission and distribution of natural gas and town gas are based on annual environmental reports from the Danish gas transmission company and annual reports for the gas distribution companies. The annual gas composition is based on from the national transmission company.

Fugitive emissions from flaring (1.B.2.c)

Emissions from flaring offshore, in gas treatment and storage plants, and in refineries are included in the inventory. Emissions calculations are based on annual reports from the Danish Energy Agency and environmental reports from gas storage and treatment plants and the refineries. Calorific values are based on the reports for the EU ETS for offshore flaring, on annual gas quality data from Energinet.dk, and on additional data from the refineries. Emission factors are based on national studies and the EMEP/EEA Guidebook (EEA, 2023).

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

1.4.4 Specific methodologies regarding industrial processes and product use

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

Mineral industry

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

Chemical industry

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

Metal industry

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

Other production

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

Solvent and other product use

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

The detailed approach in EMEP/EEA Guidebook is used. Here all relevant consumption data on all relevant solvents must be inventoried or at least those together representing more than 90 % of the total NMVOC emission. Simple mass balances for calculating the use and emissions of chemicals are set up 1) use = production + import – export, 2) emission = use emission factor. Production, import and export figures are extracted from Statistics

Denmark, from which a list of more than 400 single chemicals, a few groups and products is generated. For each of these, a "use" amount in tonnes per year is calculated. For some chemicals and/or products, e.g. propellants used in aerosol cans and ethanol used in windscreen washing agents, use amounts are obtained from the industry as the information from Statistics Denmark does not comply with required specificity. It is found that approximately 40 different NMVOCs comprise over 95 % of the total use and these 40 chemicals are thus investigated further. The "use" amounts are distributed across industrial activities according to the Nordic SPIN (Substances in Preparations in Nordic Countries) database, where information on industrial use categories is available in a NACE coding system. The chemicals are also related to specific products according to the Use Category (UCN) system. Emission factors are obtained from regulators, literature or the industry.

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

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

1.4.5 Specific methodologies regarding agriculture

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

Emissions from agricultural activities are estimated according to the methodology described in the EMEP/EEA air pollutant emission inventory guidebook (EEA, 2023). Activity data and national data regarding emission factors are collected, evaluated and discussed in cooperation with Statistics Denmark, DCA-Danish Centre for Food and Agriculture (Aarhus University), the Danish Agricultural Advisory Service, Danish Environmental Protection Agency and the Danish AgriFish Agency. It means that data are evaluated continuously according to the latest knowledge and information.

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

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

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

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

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

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

1.4.6 Specific methodologies regarding waste

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

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

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

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

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

1.5 Key categories

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

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

In the Danish National Inventory Report to UNFCCC (Nielsen et al., 2024) as well as in the QA/QC manual for the Danish Greenhouse gas inventory

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

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

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

The uncertainty estimates are based on emission data for the base year and year 2023, and on uncertainties for activity rates and emission factors for each of the main SNAP sectors. For all pollutants, 1990 is used as the base year.

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

Table 1.2 Danish uncertainty estimates, 2023.

Pollutant	Uncertainty Total emission [%]	Trend 1990-2023 [%]	Uncertainty Trend [%-age points]
SO_2	19	-95	0.8
NO_x	60	-73	9
NMVOC	117	-55	27
CO	43	-75	8
NH_3	17	-57	5
TSP	214	-22	20
PM_{10}	101	-39	19
$PM_{2.5}$	84	-52	14
BC	355	-70	72
Arsenic	210	-85	24
Cadmium	361	-51	146
Chromium	398	-71	49
Copper	908	27	83
Mercury	123	-93	9
Nickel	694	-82	65
Lead	612	-90	18
Selenium	156	-89	14
Zinc	534	-23	229
PCDD/F	385	-63	140
Benzo(b)fluoranthene	679	-53	55
Benzo(k)fluoranthene	678	-65	72
Benzo(a)pyrene	749	-62	40
Indeno(1,2,3-c,d)pyrene	661	-76	38
HCB	462	-84	55
PCBs	574	-87	65

1.8 General assessment of the completeness

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

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

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

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

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

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

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

1.9 Emission reduction commitments

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

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

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

Table 1.3 Emissions and achieved reduction under the UNECE.

Pollutant	2005	2020	2021	2022	2023	Reduction 2020, %	Reduction 2021, %	Reduction 2022, %	Reduction 2023, %	ERC, %
SO_2	26.29	8.77	7.95	8.12	8.14	66.6	69.8	69.1	69.1	35
NO_x	188.14	72.20	73.54	68.89	64.89	61.6	60.9	63.4	65.5	56
NH_3	98.48	82.78	75.36	72.68	66.26	15.9	23.5	26.2	32.7	24
NMVOC	160.59	106.93	106.62	100.69	97.94	33.4	33.6	37.3	39.0	35
NMVOC incl. adjustment	140.57	83.04	82.21	76.67	74.22	40.9	41.5	45.5	47.2	35
$PM_{2.5}$	21.47	12.17	12.15	11.22	11.22	43.3	43.4	47.8	47.7	33

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

Table 1.4 Emissions and achieved reduction under the NECD.

Pollutant	2005	2020	2021	2022	2023	Reduction 2020, %	Reduction 2021, %	Reduction 2022, %	Reduction 2023, %	ERC, %
SO_2	26.29	8.77	7.95	8.12	8.14	66.6	69.8	69.1	69.1	35
NO_x	187.39	71.49	72.83	68.16	64.17	61.8	61.1	63.6	65.8	56
NH_3	98.48	82.78	75.36	72.68	66.26	15.9	23.5	26.2	32.7	24
NMVOC	116.83	58.81	58.32	53.83	52.61	49.7	50.1	53.9	55.0	35
$PM_{2.5}$	21.47	12.17	12.15	11.22	11.22	43.3	43.4	47.8	47.7	33

Table 1.4 shows, that Denmark under the NECD has met the ERCs for all pollutants from 2022. There was an exceedance for NH_3 in 2020 and 2021.

1.10 References

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2 Trends in Emissions

2.1 Acidifying gases

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

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

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

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

where A is the acidification index in Mmole

m_i is the emission of pollutant i in tonnes

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

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

Figure 2.1 shows the emission of Danish acidifying gases in terms of acid equivalents. In 1990, the relative contribution in acid equivalents was almost equal for the three gases. In 2023, the most important acidification factor in Denmark is ammonia nitrogen and the relative contributions for SO_2, NO_X and NH_3 were 4 %, 30 % and 66 %, respectively. However, with regard to long-range transport of air pollution, SO_2 and NO_X are still the most important pollutants.

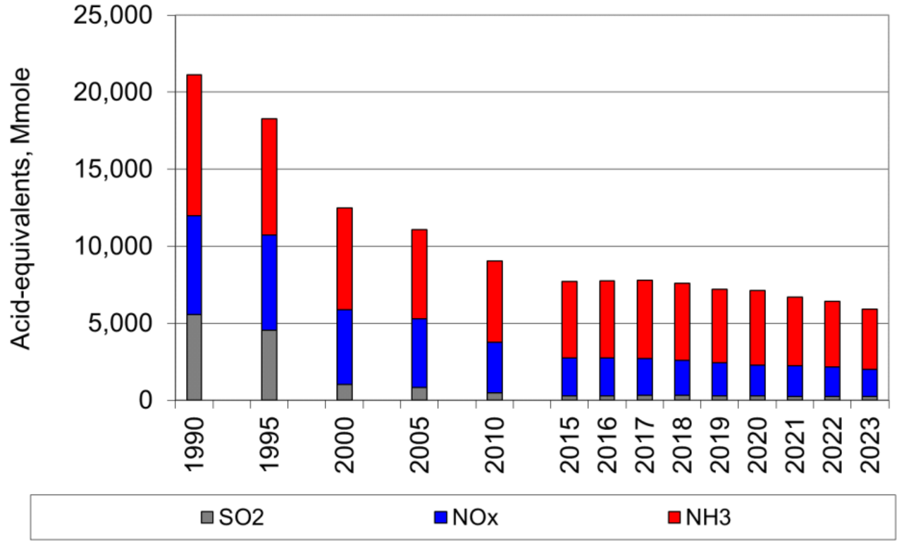


Figure 2.1 Emissions of NH_3, NO_X and SO_2 over time in acid equivalents.

2.2 Description and interpretation of emission trends by gas

2.2.1 Sulphur dioxide (SO_2)

The main part of the sulphur dioxide (SO_2) emission originates from combustion of fossil fuels, i.e. mainly coal and oil, in public power plant, district heating plants and manufacturing plants. Since 1990, the total emission has decreased by 95 %. The large reduction is mainly due to installation of desulphurisation and use of fuels with lower content of sulphur in public power and district heating plants. Despite the large reduction of the SO_2 emissions, these plants make up 30 % of the total emission. In addition, emissions from industrial combustion plants, non-industrial combustion plants and other mobile sources are important.

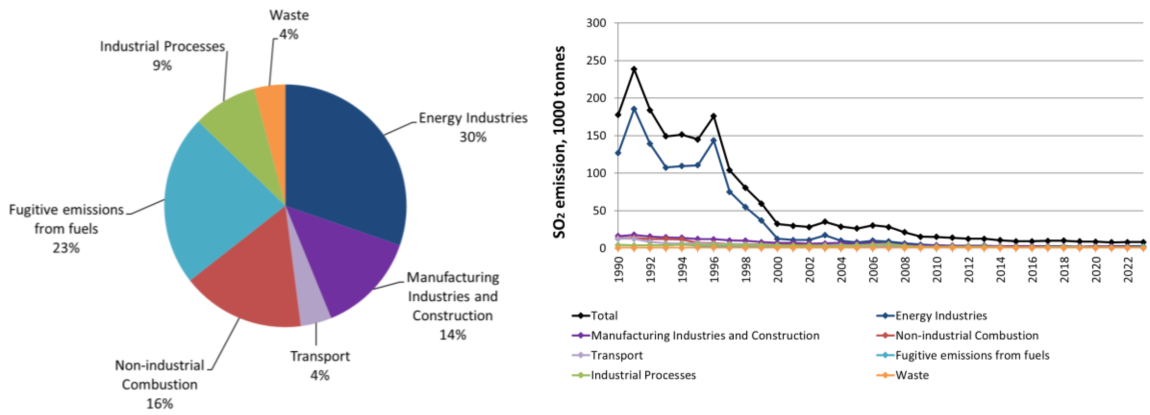


Figure 2.2 SO_2 emissions. Distribution according to the main sectors (2023) and time series for 1990 to 2023.

2.2.2 Nitrogen oxides (NO_x)

The largest sources of emissions of nitrogen oxides (NO_x) are road transport followed by other mobile sources and combustion in energy industries (mainly public power and district heating plants). The transport sector is the sector contributing the most to the emission of NO_x and, in 2023, 37 % of the Danish emissions of NO_x stems from road transport, national navigation, railways and civil aviation. In addition, emissions from national fishing and off-road vehicles contribute significantly to the NO_x emission. For non-industrial combustion plants, the main sources are combustion of gas oil, natural gas and wood in residential plants. The emissions from energy industries have decreased by 85 % from 1990 to 2023. In the same period, the total emission decreased by 73 %. The reduction is due to the increasing use of catalyst cars and installation of low-NO_x burners and denitrifying units in power plants and district heating plants.

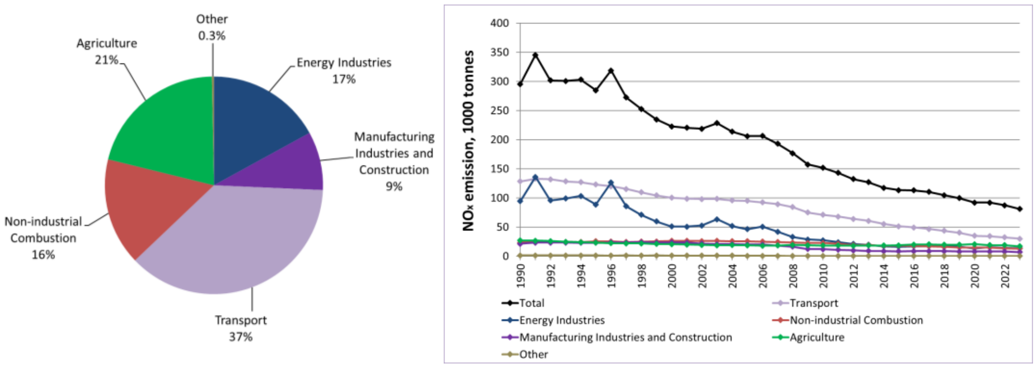


Figure 2.3 NO_X emissions. Distribution according to the main sectors (2023) and time series for 1990 to 2023.

2.2.3 Ammonia (NH_3)

Almost all atmospheric emissions of ammonia (NH_3) result from agricultural activities. Only a minor part of the total emission originates from stationary combustion (1.5 %), road transport (1.0 %), industrial processes (0.5 %) and waste (1.0 %). The share for road transport was increasing during the 1990's and early 2000's due to increasing use of catalyst cars. In recent years, the share has been decreasing due to more advanced catalysts being implemented. The total ammonia emission has decreased by 57 % since 1990.

The major part of the emission from agriculture stems from livestock manure (37 %) and agricultural soils (58 %). The largest source for manure management is losses of ammonia occurring during the handling of the manure in animal housing systems. For agricultural soils, the emissions are mainly stemming from application of mineral fertiliser, application of animal manure, growing crops and crop residues.

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

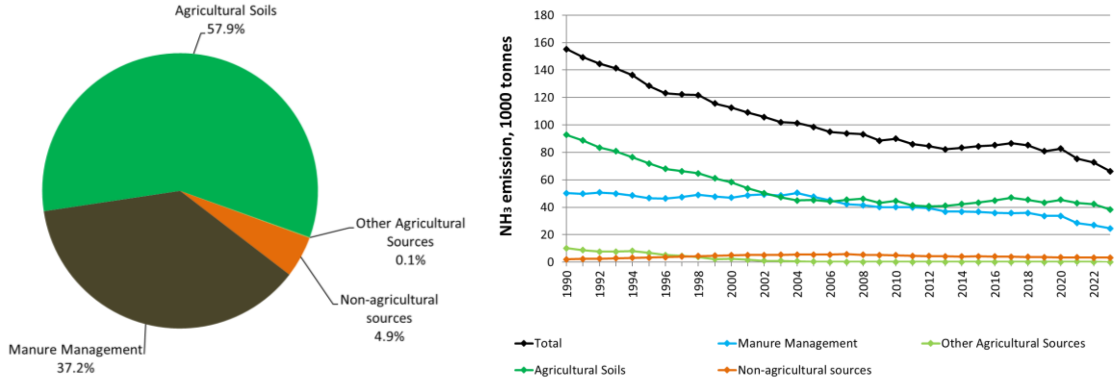


Figure 2.4 NH_3 emissions. Distribution on the main sectors (2023) and time series for 1990 to 2023.

2.3 Other air pollutants

2.3.1 Non-Methane Volatile Organic Compounds (NMVOC)

The emissions of Non-Methane Volatile Organic Compounds (NMVOC) originate from many different sources and can be divided into two main groups: incomplete combustion and evaporation. Small combustion plants (e.g. residential wood burning) is a big source of NMVOC originating from combustion. Other important sources are road vehicles and other transport sources such as national navigation. NMVOC from road transportation vehicles have been decreasing since 1990, due to the introduction of catalyst cars. The evaporative emissions mainly originate from the agricultural sector, use of solvents, and the extraction, handling and storage of oil and natural gas. The total anthropogenic emissions have decreased by 55 % since 1990, largely due to the increased use of catalyst cars and reduced emissions from use of solvents.

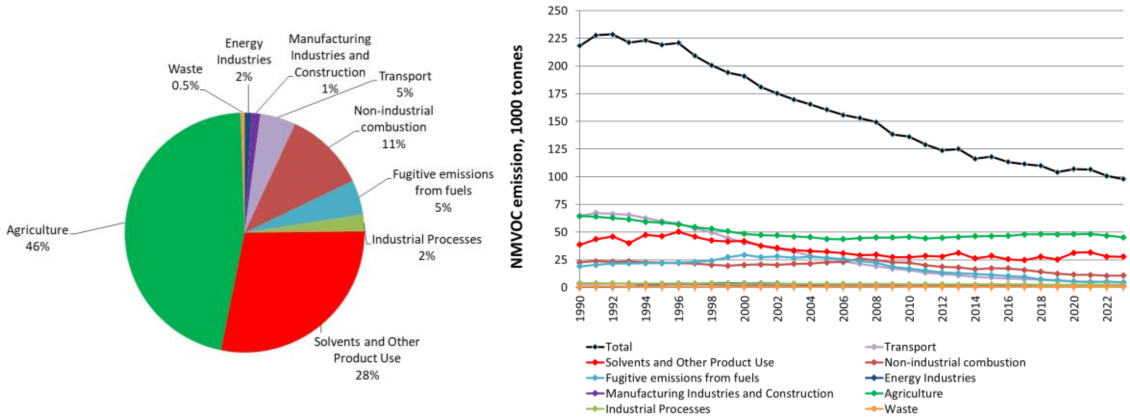


Figure 2.5 NMVOC emissions. Distribution according to the main sectors (2023) and time series for 1990 to 2023.

2.3.2 Carbon monoxide (CO)

Non-industrial combustion plants are the main source to the total CO emission. For the non-industrial sector, emissions from the residential sector is dominating and has decreased due to newer technologies but fluctuates with the wood consumption. Transport is the second largest contributor to the total CO emission in 2023 (24 %), showing a decrease of 91 % from 1990 to 2023. The major transport source is passenger cars, which made up 59 % in 1990, but has decreased to 18 % in 2023. The main driver is the increase of catalyst cars. In 1990, a law forbidding the burning of agricultural crop residues on fields was implemented, which caused a significant reduction in CO emission. The total CO emission decreased further by 75 % from 1990 to 2023, largely because of decreasing emissions from road transport and residential combustion.

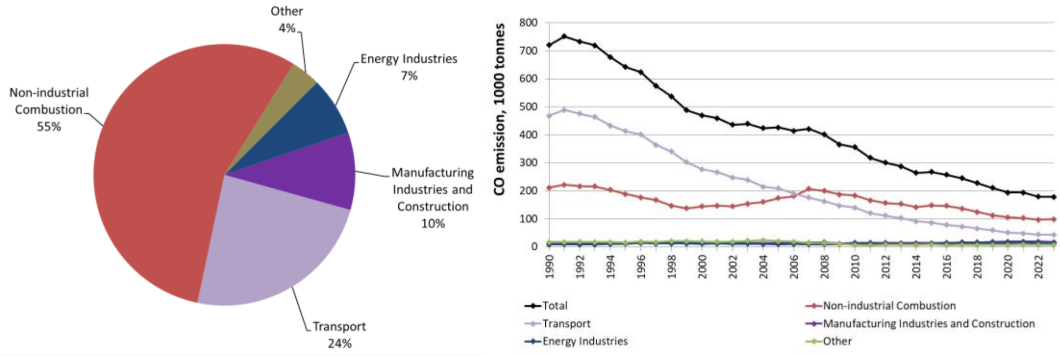


Figure 2.6 CO emissions. Distribution according to the main sectors (2023) and time series for 1990 to 2023.

2.3.3 Particulate matter (PM)

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

The largest $PM_{2.5}$ emission source is residential plants (51 %), road transport (10 %) and other mobile sources (8 %). Emissions from residential plants increased by 58 % from 1990 to 2007, followed by a decrease of 60 % from 2007 to 2023. The increase was caused by increasing wood consumption while the decrease has been caused by a slightly lower wood consumption (until 2016) combined with legislative demands on new wood stoves and boilers. From 2016, the wood consumption decreased significantly leading to a significant decrease in emissions with a small increase again from 2022 to 2023. For the road transport sector, exhaust emissions account for less than a sixth (13 %) of the emissions, while the remaining emissions come from tyre and brake wear and road abrasion. For other mobile sources, the most important sources are off-road vehicles and machinery in the industrial sector and in the agricultural/forestry sector (12 % and 20 %, respectively). The $PM_{2.5}$ emission decreased by 52 % from 1990 to 2023, but most of the reduction has occurred after 2008.

The largest TSP emission sources are agriculture and non-industrial combustion (77 % and 9 % of total TSP emission in 2023, respectively). Residential plants is the largest source in the non-industrial combustion sector, making up 7 % of the national total TSP emission in 2023.The TSP emissions from transport are also important and include both exhaust emissions and the non-exhaust emissions from brake and tyre wear and road abrasion. The non-exhaust emissions account for 95 % of the TSP emission from road transport in 2023.

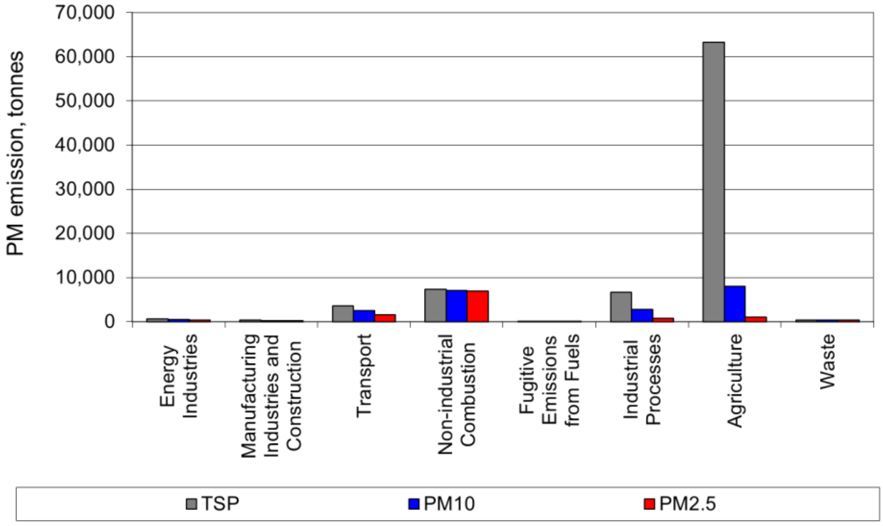


Figure 2.7 PM emissions per sector for 2023.

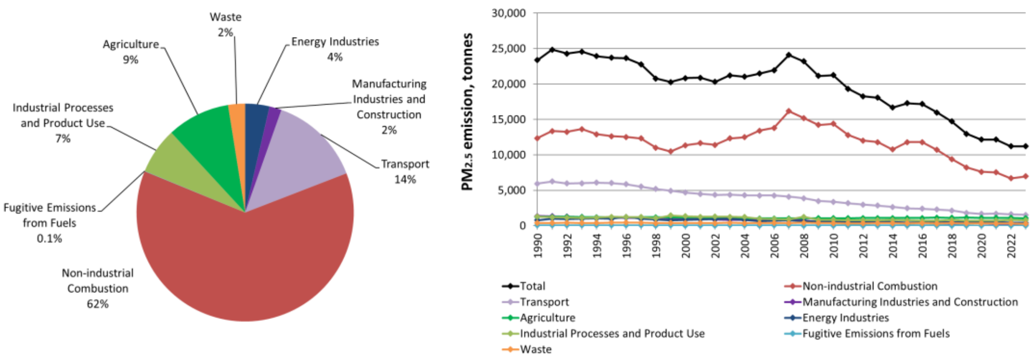


Figure 2.8 $PM_{2.5}$ emissions. Distribution according to the main sectors (2023) and time series for 1990 to 2023.

2.3.4 Black carbon (BC)

The black carbon (BC) emission inventory is reported for the years 1990 onwards. The main sources are residential plants and road transport contributing 45 % and 16 % in 2023, respectively. From 1990 to 2023, the total BC emission decreased by 70 %. The trend for non-industrial combustion is mainly controlled by the trend for the wood consumption in the residential sector.

BC emissions from the transport sector decreased by 88 % from 1990 to 2023, mainly due to implementing of new EURO norms and improved technology. An important factor is the use of particle filters for heavy-duty vehicles and passenger cars, which reduce the BC emission effectively.

BC emissions from fugitive emissions from fuels, which is mainly due to storage of coal, decreased by 88 % from 1990 to 2023, in line with the decrease of the coal consumption in electricity and heat production.

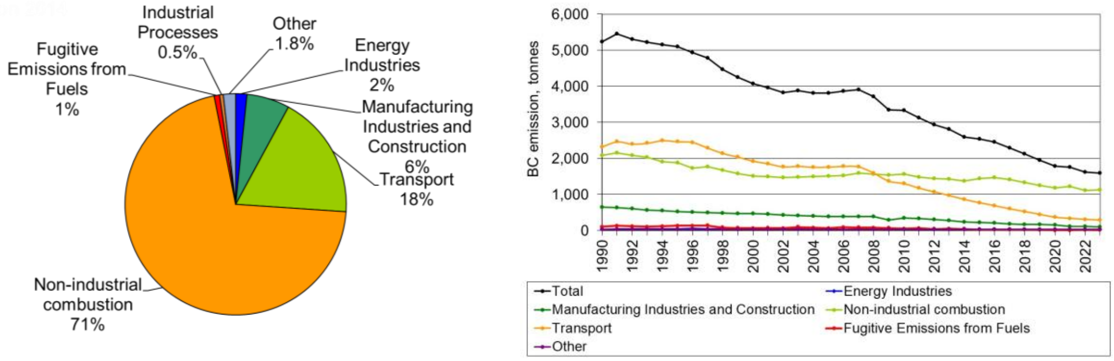


Figure 2.9 BC emissions. Distribution according to the main sectors (2023) and time series for 1990 to 2023.

2.3.5 Heavy metals

In general, the most important sources of heavy metal emissions are combustion of fuels and waste. The heavy metal emissions have decreased substantially in recent years, except for Cu. The reductions span from 23 % to 93 % for Zn and Hg, respectively. The reason for the reduced emissions is mainly increased use of gas cleaning devices at power and district heating plants (including waste incineration plants) as well as lower fuel consumption. The large reduction in the Pb emission is due to a shift towards unleaded gasoline, the latter being essential for catalyst cars. The major source of Cu is automobile tyre and break wear (90 % in 2023) and the 27 % increase in total emission from 1990 to 2023 owe to increasing mileage.

Table 2.1 Emissions of heavy metals.

Heavy metals, kilogramme	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
1990	1368	1213	8062	49 624	3156	22 664	132 503	4244	75 520
2023	206	592	2328	62 932	211	3967	12 703	452	57 788
Reduction, %	85	51	71	-27	93	82	90	89	23

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

Cadmium (Cd)

The main sources of emissions of cadmium (Cd) to air are mainly combustion of wood, wood waste and municipal waste. Non-industrial combustion contributes 70 % in 2023, of which 93 % comes from residential plants. Emissions from residential plants have increased by 107 % from 1990 to 2023 due to increasing wood consumption. Emissions from energy industries, manufacturing industries and construction, and industrial processes have decreased by 88 % since 1990. The decreasing emission from energy industries is mainly related to the decreasing combustion of coal and better flue gas cleaning. In the transport sector emissions from passenger cars is the main source contributing with 55 % of the sectoral emission in 2023.

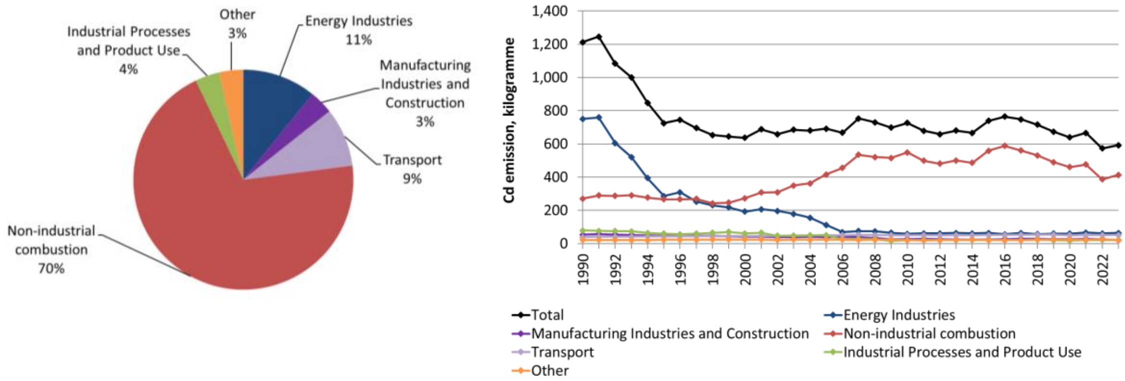


Figure 2.10 Cd emissions. Distribution by main sectors (2023) and time series for 1990 to 2023.

Mercury (Hg)

The largest sources of mercury (Hg) emissions to air are waste incineration and coal combustion in energy industries. Due to improved flue gas cleaning and decreasing coal combustion the emissions from Energy industries decreased by 76 % from 1990-2000. The trend has continued in the following years and the corresponding decrease from 1990-2023 is 96 %. Non-industrial combustion is dominated by wood combustion in residential plants while the main contributions to emissions from manufacturing industries and construction are food processing, beverages and tobacco, and non-metallic minerals. The variations in emissions from industrial processes owe to the closure in 2002 followed by re-opening and a second shut down in 2005 of the only Danish electro-steelwork.

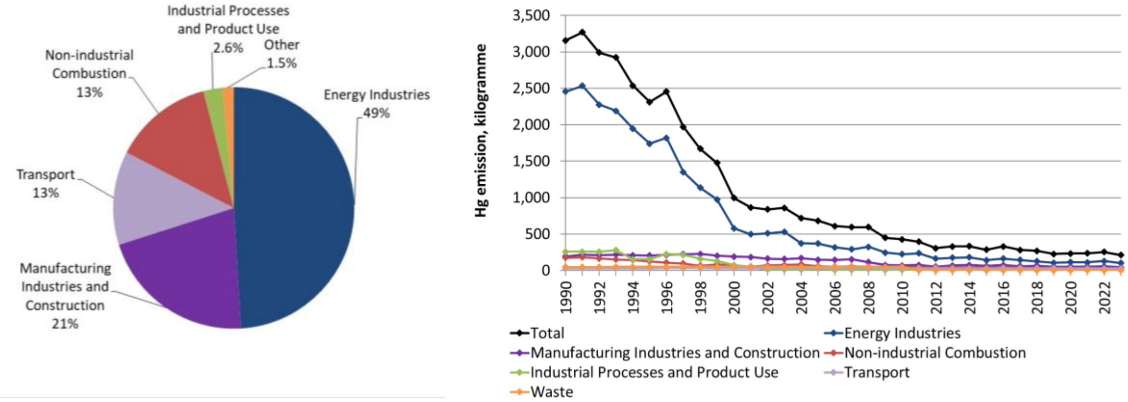


Figure 2.11 Hg emissions. Distribution by main sectors (2023) and time series for 1990 to 2023.

Lead (Pb)

The main lead (Pb) emission sources are transport, waste, non-industrial combustion and industrial processes. In earlier years combustion of leaded gasoline was the major contributor to Pb emissions to air but the shift toward use of unleaded gasoline for transport have decreased the Pb emission from transport by 93 % from 1990-2023. The trend in the Pb emission from non-industrial combustion from 1990 to 2023 is a decrease of 47 %. In the non-industrial combustion sector the dominant source is wood combustion in residential plants, which has been increasing from 1990 to 2023, but counterbalanced by decreasing emissions from stationary combustion in commercial/institutional and in agriculture/forestry/fishing. The decreasing emission from energy industries (97 % from 1990 to 2023) is caused by the deceasing coal combustion and more efficient particle abatement.

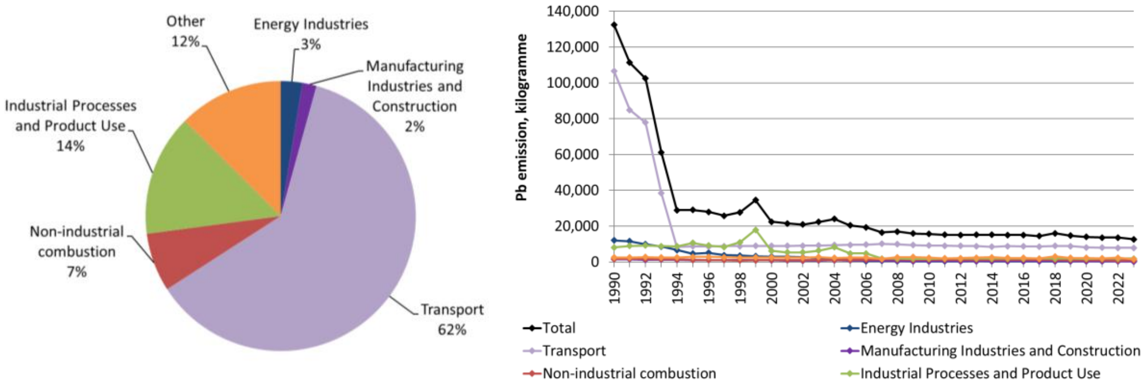


Figure 2.12 Pb emissions. Distribution by main sectors (2023) and time series for 1990 to 2023.

2.3.6 Polycyclic aromatic hydrocarbons (PAHs)

The present emission inventory for polycyclic aromatic hydrocarbons (PAH) includes four PAHs: benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene and indeno(1,2,3-cd)pyrene. The major part of the total PAH emission is benzo(b)fluoranthene and benzo(a)pyrene, which contribute by 33 % and 30 %, respectively in 2023.

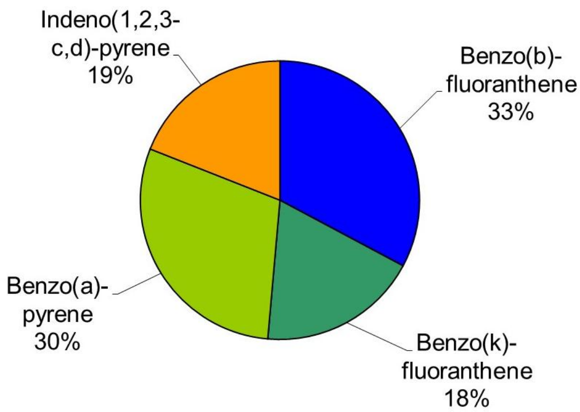


Figure 2.13 PAH emissions. Distribution according to reported PAHs in 2023.

The most important source of PAHs emissions is combustion in the residential sector (mostly wood burning) making up 71 % of the total emission in 2023. The decreasing emission trend from 1990 is due to decreasing emissions from the residential sector caused by newer technologies with more complete combustion and a decrease in wood consumption, especially after 2016. The PAH emission from combustion in residential plants has decreased by 69 % from 1990 to 2023.

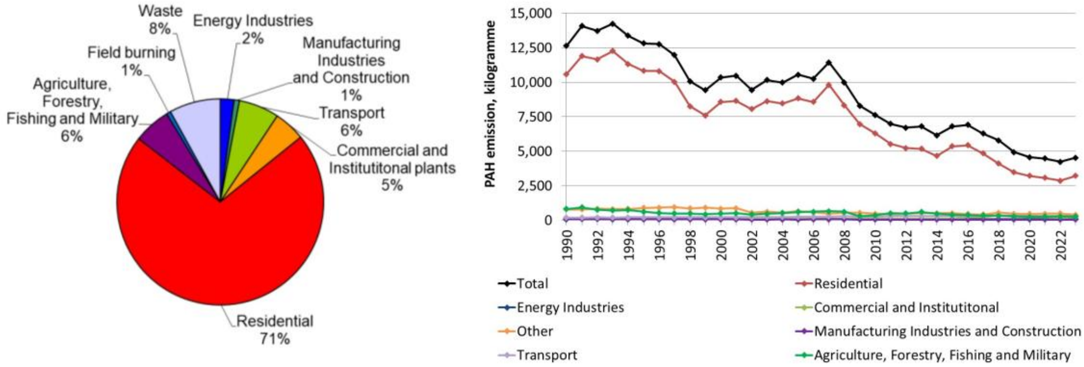


Figure 2.14 PAH emissions. Distribution according to the main sectors (2023) and time series for 1990 to 2023.

2.3.7 Dioxins and furans

The major part of the dioxin emission owes to wood combustion in the residential sector, mainly in wood stoves and ovens without flue gas cleaning. Residential plants (mainly wood combustion) accounts for 69 % of the national dioxin emission in 2023. The contribution to the total dioxin emission from the waste sector (17 % in 2023) mainly owes to accidental fires, especially building fires. The emissions of dioxins from energy industries are dominated by emissions from combustion of biomass such as wood, wood waste and to a lesser extend agricultural waste. In total, the emission has decreased by 63 % since 1990, mainly due to a decrease from energy industries caused by improved abatement at coal fired power plants (and lower coal consumption) and waste incineration plants. However, most of the reduction took place from 1990 to 1999. Emissions from non-industrial combustion (mainly wood combustion in residential plants) have increased as newer technologies has higher emission factors compared to older technologies. However, in later years the reduced wood consumption has led to falling emissions.

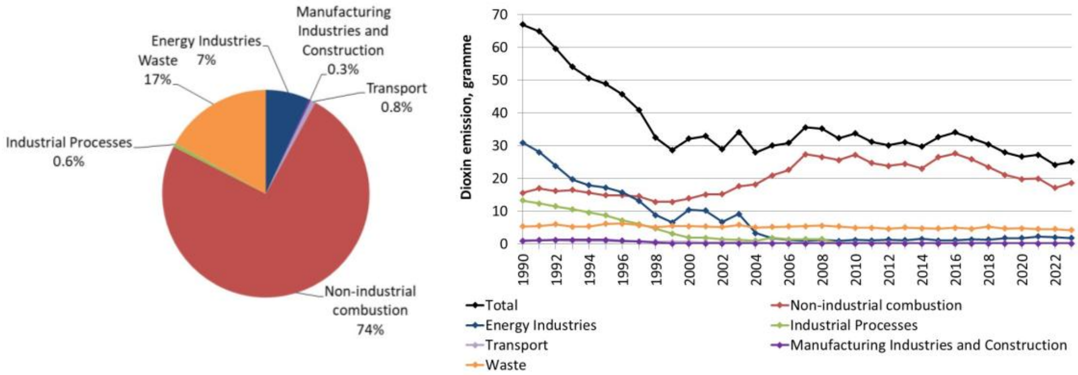


Figure 2.15 Emissions of dioxins and furans. Distribution according to the main sectors (2023) and time series for 1990 to 2023.

2.3.8 Hexachlorobenzene (HCB)

Stationary combustion accounts for 44 % of the estimated national hexachlorobenzene (HCB) emission in 2023. This owes mainly to combustion of municipal solid waste in CHP plants. Transport is an important source, too, making up 32 % of the total emission in 2023. Emissions from transport have increased by 57 % since 1990 due to increasing diesel consumption. The HCB emission from stationary plants has decreased 84 % since 1990 mainly due to improved flue gas cleaning in MSW incineration plants. The emission from agriculture was very high in the early 1990'ties due to the use of pesticides containing impurities of HCB. The HCB emission from agriculture decreased by 90 % from 1990 to 2000 and by 92 % from 1990 to 2023, causing the share of HCB emission from agriculture to drop from 33 % in 1990 to 17 % in 2023. The emission from industrial processes has decreased due to the closure of steel production and secondary aluminium production in Denmark.

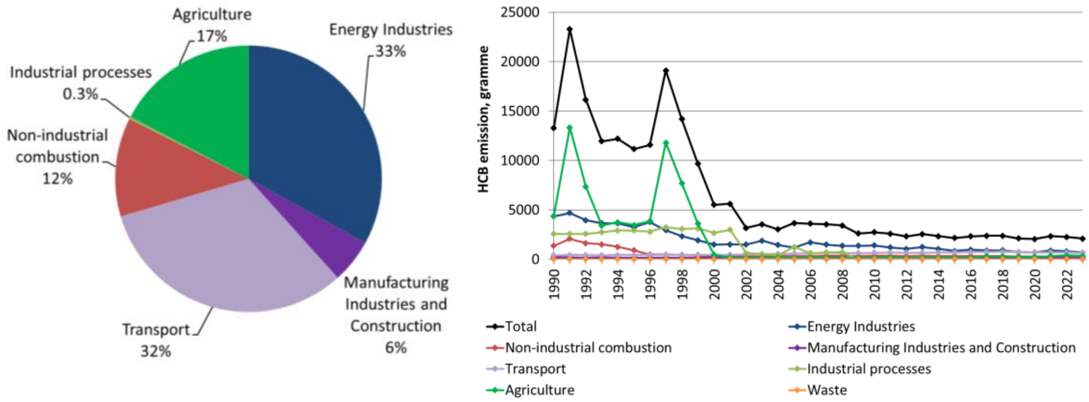


Figure 2.16 HCB emissions. Distribution according to the main sectors (2023) and time series for 1990 to 2023.

2.3.9 Polychlorinated biphenyls (PCBs)

Energy industries accounts for 54 % of the estimated national polychlorinated biphenyls (PCBs) emission in 2023. This owes mainly to combustion of biomass and coal. The emission from energy industries has decreased by 77 % since 1990 due to the lower fuel consumption, especially of coal. The emission from industrial processes was dominated by the steel production, which explains the trend as the plant closed down during 2001 and briefly reopened in 2005.

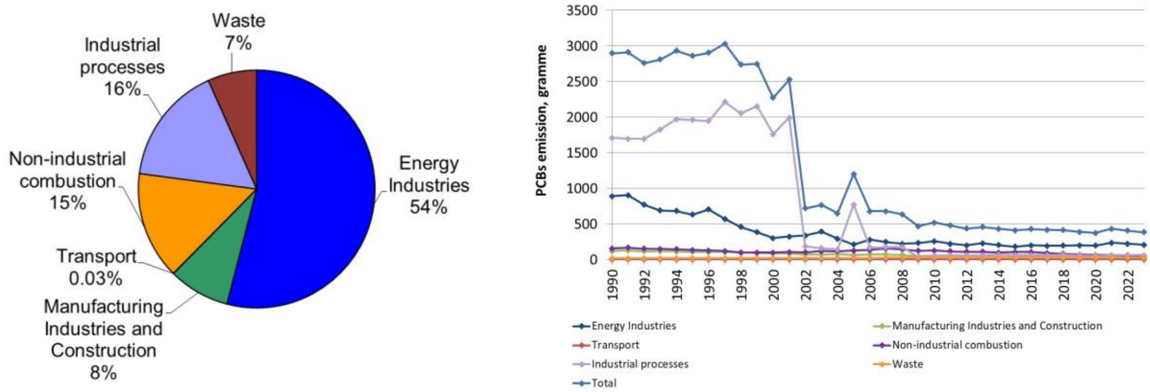


Figure 2.17 PCBs emissions. Distribution according to the main sectors (2023) and time series for 1990 to 2023.

3 Energy

3.1 Overview of the sector

The energy sector is reported in three main chapters:

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

Summary tables for the emissions from the energy sector in 2023 are shown below.

Table 3.1.1 SO_2, NO_x, NMVOC, CO, PM and BC emissions from the energy sector, 2023.

	NO_x	NMVOC	SO_x	NH_3	$PM_{2.5}$	PM_{10}	TSP	BC	CO
	kt NO_2	kt	kt SO_2	kt	kt	kt	kt	kt	kt
1A1 Energy Industries	13.77	0.94	2.46	0.02	0.41	0.48	0.63	0.03	12.9
1A2 Manufacturing industries and Construction	7.04	1.12	1.10	0.07	0.20	0.24	0.29	0.10	17.1
1A3 Transport	30.12	4.72	0.34	0.66	1.54	2.54	3.56	0.29	42.7
1A4 Other Sectors	11.67	10.48	1.25	0.90	6.91	7.01	7.26	1.11	95.8
1A5 Other	1.27	0.27	0.09	0.00	0.05	0.05	0.05	0.02	3.2
1B1 Fugitive Emissions from fuels, Solid fuels	-	-	-	-	0.00	0.02	0.02	0.01	-
1B2 Fugitive Emissions from fuels, Oil and Natural gas	0.05	4.59	1.85	-	0.00	0.00	0.00	0.00	0.1
Energy, Total	63.92	22.11	7.10	1.65	9.11	10.34	11.82	1.55	171.7

Table 3.1.2 HM emissions from the energy sector, 2023.

	Pb	Cd	Hg	As	Cr	Cu	Ni	Se	Zn
	t	t	t	t	t	t	t	t	t
1A1 Energy Industries	0.33	0.06	0.10	0.05	0.25	0.18	0.32	0.26	0.53
1A2 Manufacturing industries and Construction	0.21	0.02	0.04	0.05	0.06	0.06	0.42	0.04	0.85
1A3 Transport	7.83	0.05	0.03	0.03	1.05	59.17	2.90	0.07	30.84
1A4 Other Sectors	0.89	0.41	0.03	0.02	0.74	0.21	0.08	0.04	16.67
1A5 Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
1B1 Fugitive Emissions from fuels, Solid fuels	-	-	-	-	-	-	-	-	-
1B2 Fugitive Emissions from fuels, Oil and Natural gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy, Total	9.26	0.55	0.20	0.15	2.10	59.63	3.71	0.42	48.95

Table 3.1.3 PAH, dioxin, HCB and PCB emissions from the energy sector, 2023.

	PCDD/ PCDF	Benzo(a) - pyrene	Benzo(b) -fluoran-thene	Benzo(k)-fluoran-thene	Indeno-(1,2,3-cd)-py-rene	HCB	PCB
	g I-Teq	t	t	t	t	kg	kg
1A1 Energy Industries	1.73	0.01	0.05	0.03	0.01	0.69	0.21
1A2 Manufacturing industries and Construction	0.06	0.00	0.01	0.01	0.01	0.11	0.03
1A3 Transport	0.19	0.06	0.09	0.08	0.06	0.67	0.00
1A4 Other Sectors	18.63	1.17	1.21	0.65	0.67	0.24	0.06
1A5 Other	0.00	0.00	0.00	0.00	0.00	0.01	0.00
1B1 Fugitive Emissions from fuels, Solid fuels	-	-	-	-	-	-	-
1B2 Fugitive Emissions from fuels, Oil and Natural gas	0.00	0.00	0.00	0.00	0.00	-	-
Energy, Total	20.62	1.25	1.36	0.77	0.75	1.72	0.30

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

This chapter includes stationary combustion plants in the NFR sectors 1A1, 1A2 and 1A4.

3.2.1 Source category description

Source category definition

Stationary combustion plants are included in the emission source subcategories.

- 1A1 Energy, Fuel consumption, Energy Industries
  - 1A1a Public electricity and heat production
  - 1A1b Petroleum refining
  - 1A1c Oil and gas extraction
- 1A2 Energy, Fuel consumption, Manufacturing Industries and Construction
  - 1A2a Iron and steel
  - 1A2b Non-ferrous metals
  - 1A2c Chemicals
  - 1A2d Pulp, Paper and Print
  - 1A2e Food processing, beverages and tobacco
  - 1A2f Non-metallic minerals
  - 1A2 g viii Other manufacturing industry
- 1A4 Energy, Fuel consumption, Other Sectors
  - 1A4a i Commercial/Institutional plants.
  - 1A4b i Residential plants.
  - 1A1c i Agriculture/Forestry.

The emission and fuel consumption data included in tables and figures in Chapter 3.2 only include emissions originating from stationary combustion plants of a given NFR sector.

The consumption of fuel consumption in for military use (1A5) in stationary combustion plants (heating in military buildings) has been included in commercial/institutional plants (1A4a).

All pipeline compressors on the natural gas grid are electric compressors. Hence fuel consumption and emissions are NO in the sector 1A3e i Pipeline transport. The fuel consumption in the Danish gas treatment plant is included in sector 1A1cii Oil and gas extraction.

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

In the Danish emission database, all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution) according the CORINAIR system. The emission inventories are prepared from a complete emission database based on the SNAP source categories. Danish Centre for Environment and Energy, Aarhus University (DCE) has modified the SNAP categorisation to enable direct reporting of the disaggregated data for manufacturing industries and construction. Aggregation to the NFR source category codes is based on a correspondence list enclosed in Annex 3A-1. Stationary combustion is defined as combustion activities in the SNAP sectors 01 – 03, not including SNAP 0303.

3.2.2 Emission share from stationary combustion compared to national total

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

Table 3.2.1 Emission share from stationary combustion compared to national total, 2023.

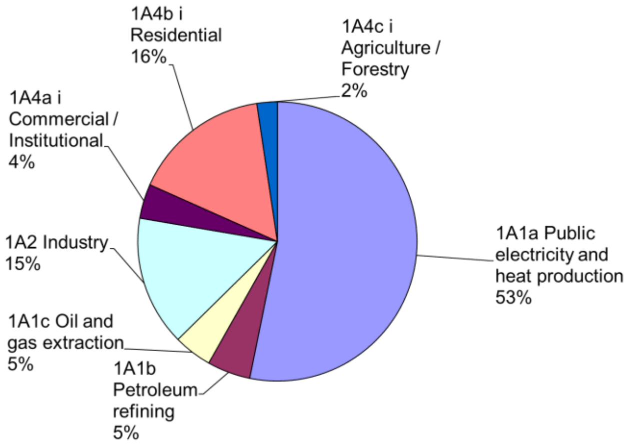
Pollutant	Emission share, %
SO_2	56%
NO_x	29%
NMVOC	10%
CO	40%
NH_3	1.5%
TSP	9%
PM_{10}	34%
$PM_{2.5}$	63%
BC	64%
As	54%
Cd	83%
Cr	44%
Cu	0.7%
Hg	80%
Ni	20%
Pb	11%
Se	72%
Zn	30%
HCB	44%
PCDD/F	81%
Benzo(a)pyrene	88%
Benzo(b)fluoranthene	85%
Benzo(k)fluoranthene	81%
Indeno(123c,d)pyrene	79%
PCB	77%

3.2.3 Fuel consumption data

In 2023, the total fuel consumption for stationary combustion plants was 323 PJ of which 142 PJ was fossil fuels and 182 PJ was biomass

Fuel consumption distributed according to the stationary combustion subcategories is shown in Figure 3.2.1 and Figure 3.2.2. The fuel consumption in Public electricity and heat production adds up to 53 % of the fuel consumption in stationary combustion plants. Other source categories with high fuel consumption are Residential and Industry.

Fuel consumption including biomass



Fuel consumption, fossil fuels

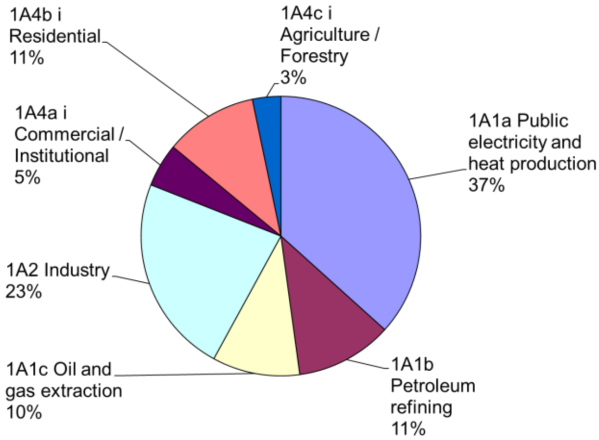


Figure 3.2.1 Fuel consumption of stationary combustion source categories, 2023. Based on DEA (2024a).

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

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

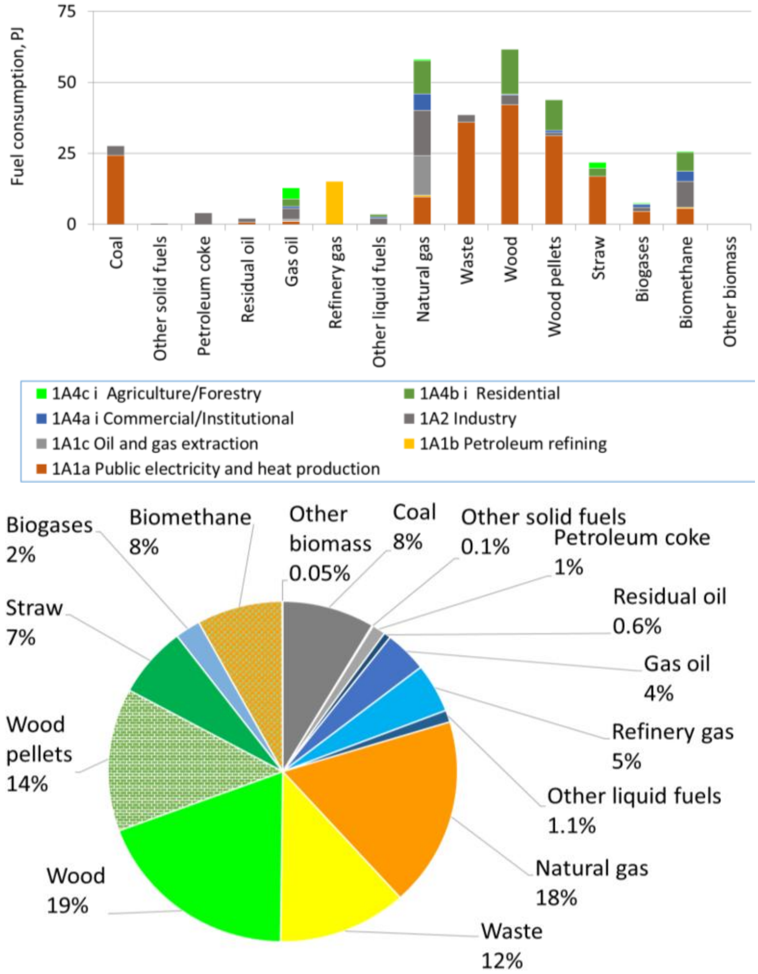


Figure 3.2.2 Fuel consumption of stationary combustion 2023, disaggregated to fuel type. Based on DEA (2024a).

Time series for fuel consumption for stationary combustion plants are presented in Figure 3.2.3. The fuel consumption for stationary combustion was 37 % lower in 2023 than in 1990, while the fossil fuel consumption was 70 % lower and the biomass fuel consumption 4.5 times the level in 1990.

The consumption of waste and biomass has increased since 1990 whereas the consumption of fossil fuels has decreased.

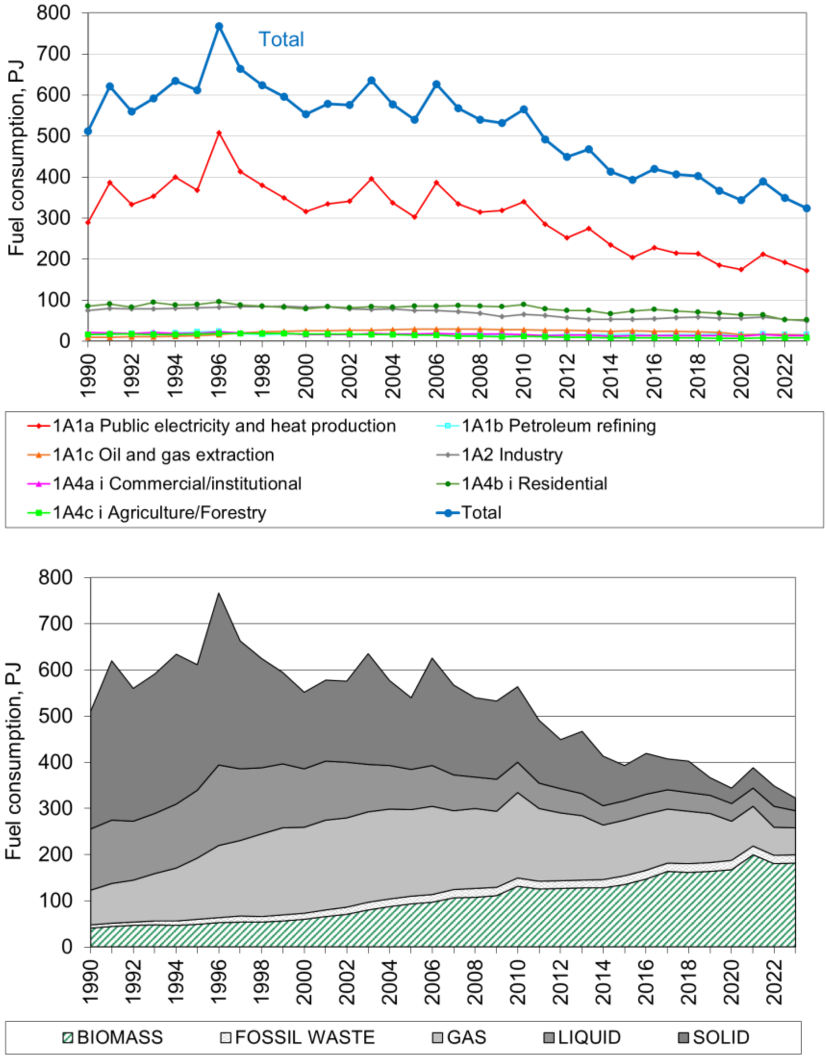


Figure 3.2.3 Fuel consumption time series, stationary combustion. Based on DEA (2024a).

The fluctuations in the time series for fuel consumption are mainly a result of electricity import/export, but also of outdoor temperature variations from year to year. This, in turn, leads to fluctuations in emission levels. The fluctuations in electricity trade, fuel consumption and NO_x emission are illustrated and compared in Figure 3.2.4. In 1990, the Danish net electricity import was large causing relatively low fuel consumption, whereas the fuel consumption was high in 1996, 2003 and 2006 due to a large net electricity export. In 2023, the net electricity import was 11 PJ, whereas there was a 5 PJ net electricity import in 2022.

The Danish electricity production is highly dependent on the electricity trade with especially Germany, Sweden, and Norway. To be able to follow the national energy consumption, the Danish Energy Agency (DEA) produces a correction of the observed fuel consumption and CO_2 emission without random variations in electricity import/export and in ambient temperature. This fuel consumption trend is also illustrated in Figure 3.2.4. The estimates are based on DEA (2016d) and updated data (DEA, 2024d). The corrections are included here to explain the fluctuations in the time series for fuel rates and emissions.

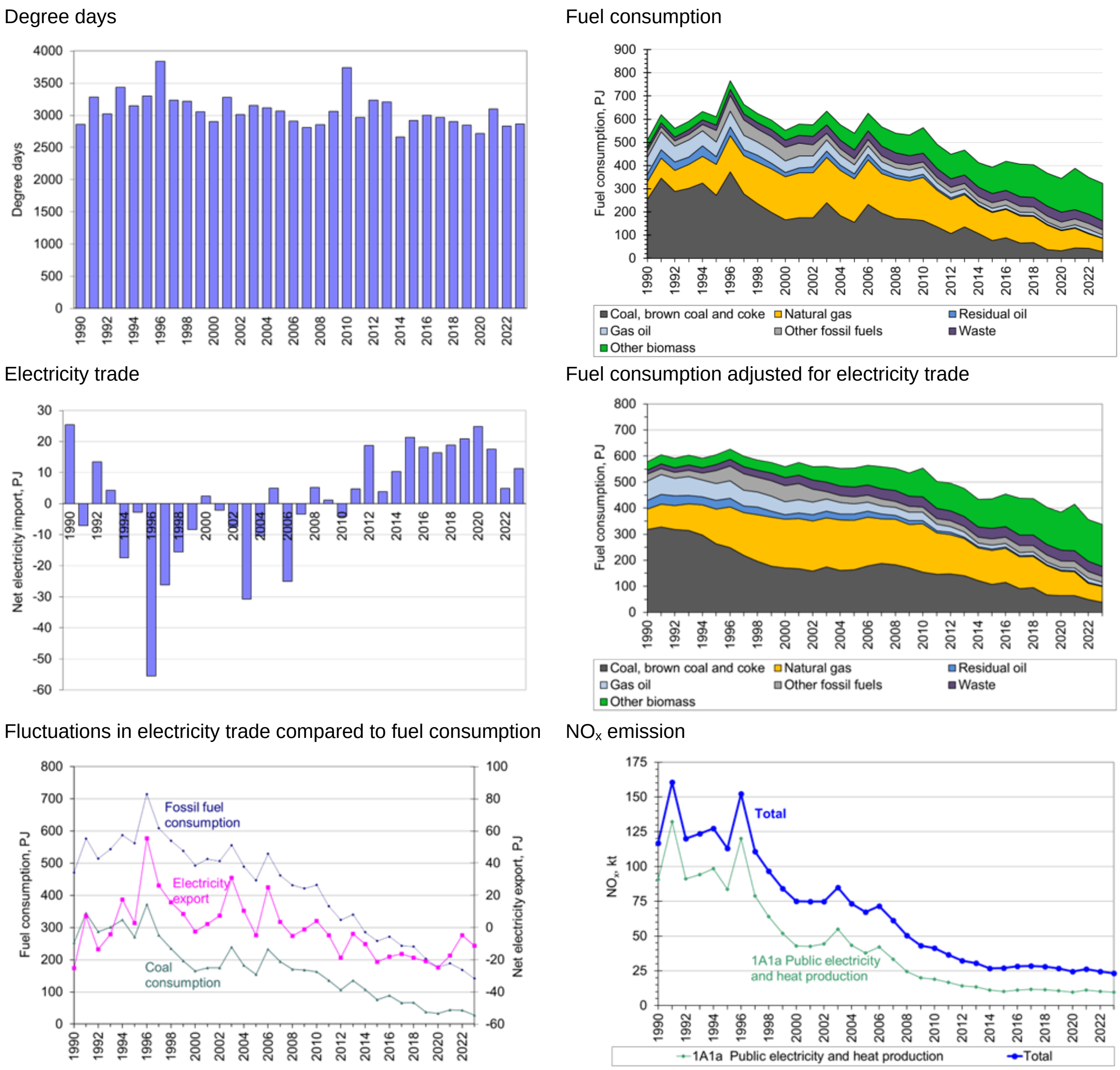


Figure 3.2.4 Comparison of time series fluctuations for electricity trade, fuel consumption and NO_x emission. Based on DEA (2024a).

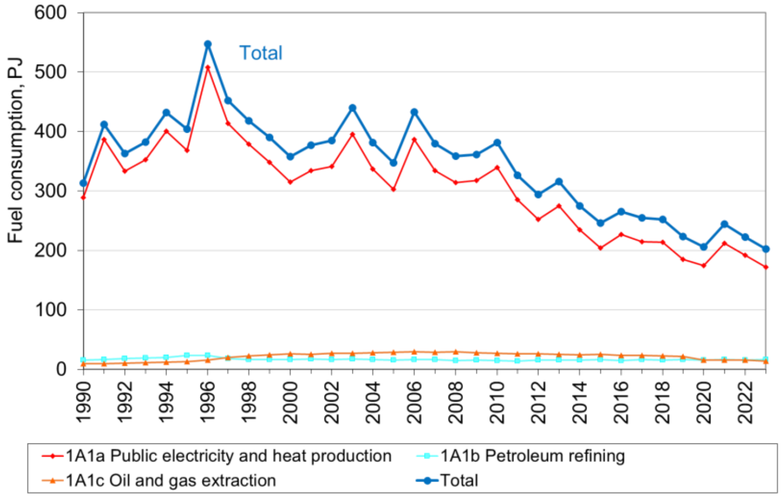
Fuel consumption time series for the subcategories to stationary combustion are shown in Figure 3.2.5 – 3.2.7.

Fuel consumption for Energy industries fluctuates due to electricity trade as discussed above. The fuel consumption in 2023 was 35 % lower than in 1990 and the fossil fuel consumption was 72 % lower. The fluctuation in electricity production is based on fossil fuel consumption in the subcategory Public electricity and heat production. The energy consumption in Oil and gas extraction is mainly natural gas used in gas turbines in the offshore industry. The biomass fuel consumption in Energy industries in 2023 added up to 120 PJ, which is 7.4 times the level in 1990 but 2 % lower than in 2022.

The fuel consumption in Industry was 35 % lower in 2023 than in 1990 (Figure 3.2.6) and the fossil fuel consumption was 53 % lower. The fuel consumption in industrial plants decreased considerably after 2006 as a result of the financial crisis. The biomass fuel consumption in Industry in 2023 added up to 16 PJ, which is 2.7 times the consumption in 1990.

The fuel consumption in Other Sectors decreased 41 % since 1990 (Figure 3.2.7). The large decrease in fuel consumption from 2021 to 2022 is related to the high energy prices in the winter 2022/-23. The fossil fuel consumption in Other Sectors decreased 74 % since 1990 and was 10% lower than in 2022. The biomass fuel consumption in Other sectors in 2023 added up to 45 PJ, which is 2.4 times the consumption in 1990. The consumption of wood and wood pellets in residential plants in 2023 was 3.0 times the consumption in 1990.

Time series for subcategories are shown in Chapter 3.2.5.



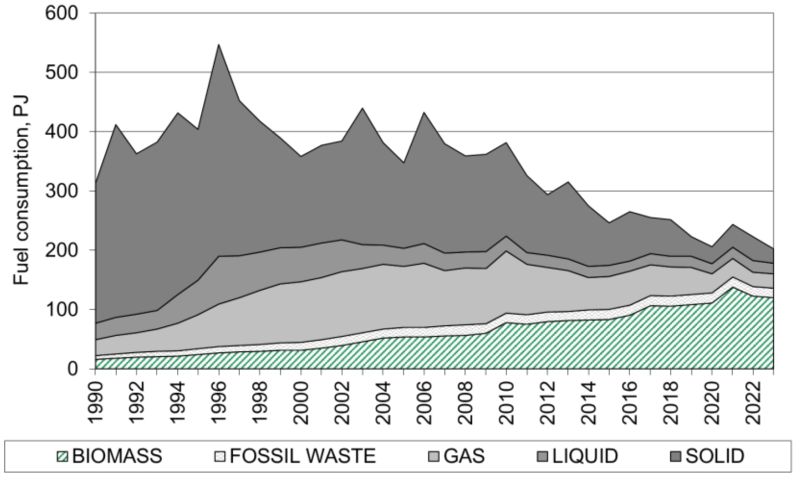


Figure 3.2.5 Fuel consumption time series for subcategories - 1A1 Energy Industries.

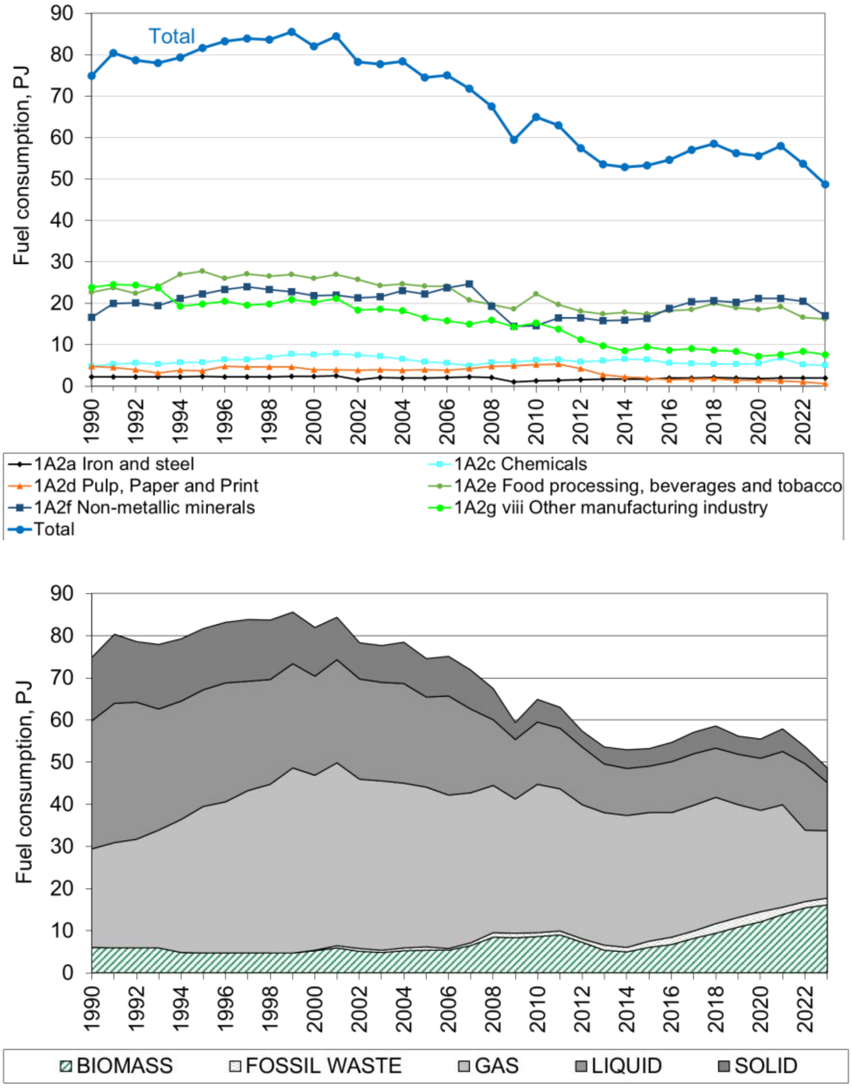


Figure 3.2.6 Fuel consumption time series for subcategories - 1A2 Industry.

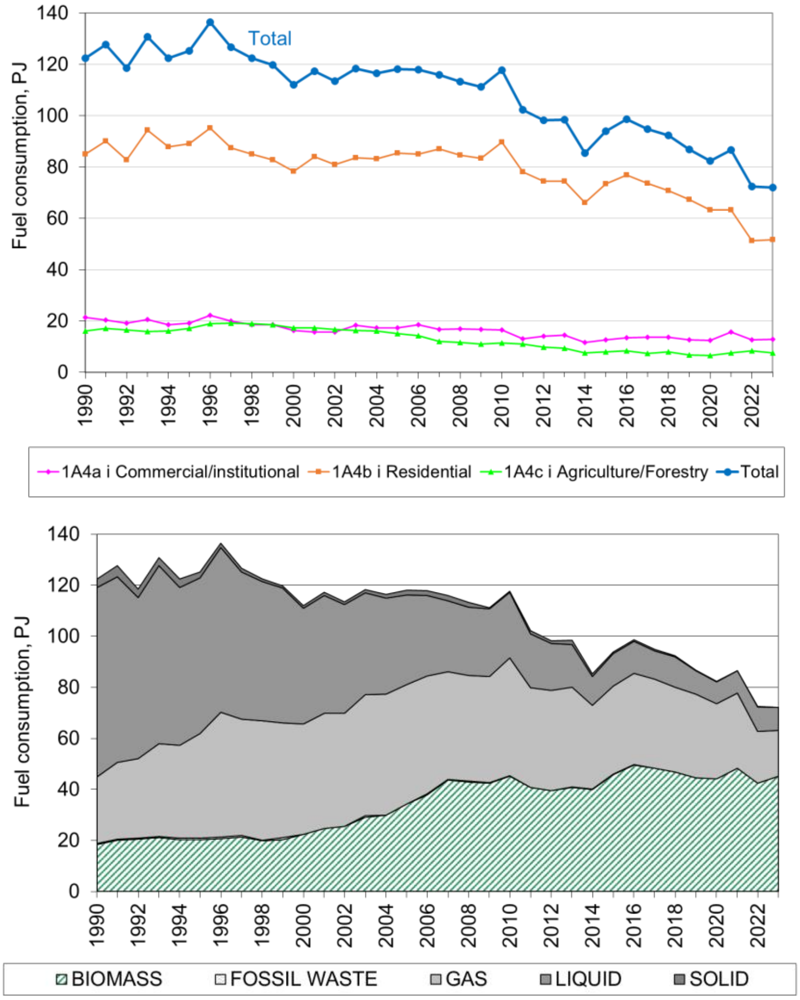


Figure 3.2.7 Fuel consumption time series for subcategories – 1A4 Other sectors

3.2.4 Emissions

SO_2

Stationary combustion is the largest emission source for SO_2 accounting for 56 % of the national emission in 2023. Table 3.2.2 presents the SO_2 emission inventory for the stationary combustion subcategories.

The largest emission sources are Industry accounting for 24 % of the emission and Public electricity and heat production accounting for 46 % of the emission from stationary combustion.

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

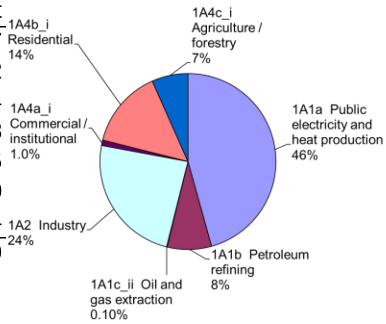
The main emission sources for Public electricity and heat production are large power plants, and combustion of straw and wood in district heating plants. Flue gas desulphurisation equipment is installed in large power plants. In the Danish inventory, the source category Public electricity and heat production is further disaggregated. Figure 3.2.8 shows the SO_2 emission from Public electricity and heat production on a disaggregated level. District heating boilers < 50 MW and Power plants >300MW$_{th}$ are the main emission sources, accounting for 49 % and 24 % of the emission.

The time series for SO_2 emission from stationary combustion is shown in Figure 3.2.9. The SO_2 emission from stationary combustion plants has decreased by 97 % since 1990 and 99 % since 1980. The large emission decrease is mainly a result of the reduced emission from Public electricity and heat production, made possible due to installation of desulphurisation plants and due to the use of fuels with lower sulphur content. The emission from other source categories also decreased considerably since 1990. Time series for subcategories are shown in Chapter 3.2.5.

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

Table 3.2.2 SO_2 emission from stationary combustion plants, 2023[1)].

		SO_2, t
1A1a	Public electricity and heat production	2087
1A1b	Petroleum refining	372
1A1c	Oil and gas extraction	4
1A2	Industry	1098
1A4a	Commercial/Institutional	45
1A4b	Residential	660
1A4c	Agriculture/Forestry	304
Total		4569



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

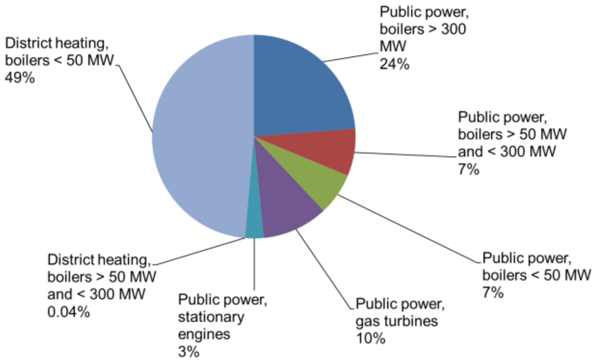


Figure 3.2.8 Disaggregated SO_2 emissions from 1A1a Public electricity and heat production.

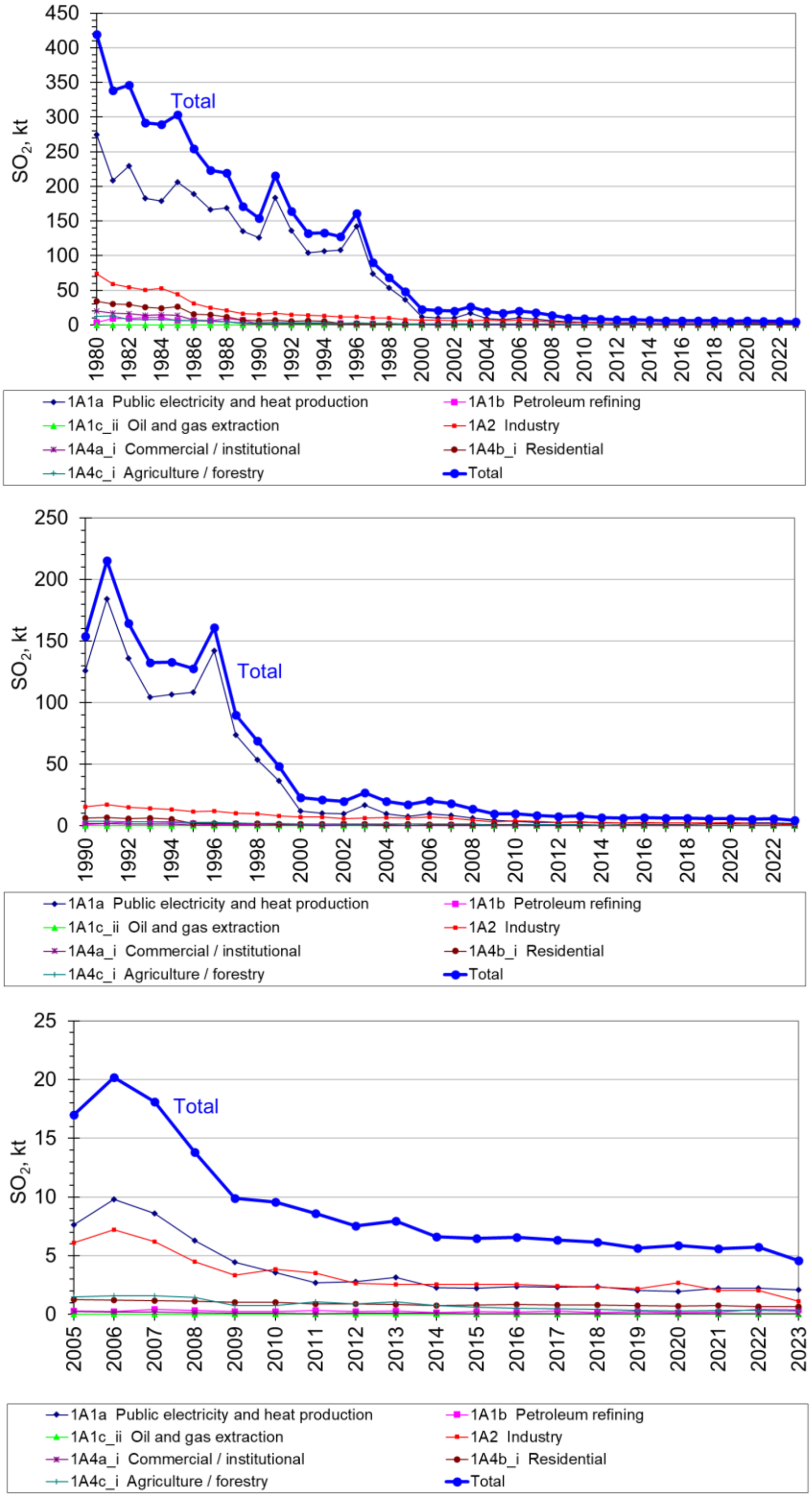


Figure 3.2.9 SO_2 emission time series for stationary combustion.

NO_x

Stationary combustion accounted for 29% of the national NO_x emission in 2023. Table 3.2.3 shows the NO_x emission inventory for stationary combustion subcategories.

Public electricity and heat production is the largest emission source accounting for 42 % of the emission from stationary combustion plants. The emission from Public power boilers > 50 MW_{th} accounts for 39 % of the emission in this subcategory, and District heating < 50MW for 25 %.

Industrial combustion plants are also an important emission source accounting for 22 % of the emission. The main industrial emission source is cement production, which accounts for 46 % of the emission from industrial plants.

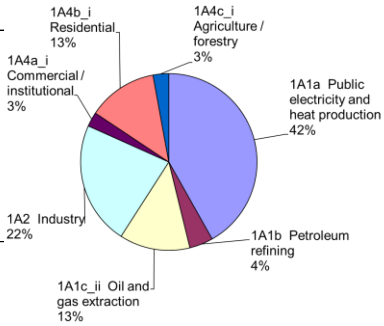
Residential plants account for 13 % of the NO_x emission. Oil and gas extraction, which is mainly offshore gas turbines accounts for 13 % of the NO_x emission.

Time series for NO_x emission from stationary combustion are shown in Figure 3.2.10. NO_x emission from stationary combustion plants has decreased by 80 % since 1990 and 84 % since 1985. The reduced emission is largely a result of the reduced emission from Public electricity and heat production due to installation of low NO_x burners, selective catalytic reduction (SCR) units and selective non-catalytic reduction (SNCR) units. The fluctuations in the time series follow the fluctuations in Public electricity and heat production, which, in turn, result from electricity trade fluctuations.

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

Table 3.2.3 NO_x emission from stationary combustion plants, 2023[1)].

	NO_x, t
1A1a Public electricity and heat production	9749
1A1b Petroleum refining	1008
1A1c Oil and gas extraction	3018
1A2 Industry	5262
1A4a Commercial/Institutional	618
1A4b Residential	2980
1A4c Agriculture/Forestry	671
Total	23305



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

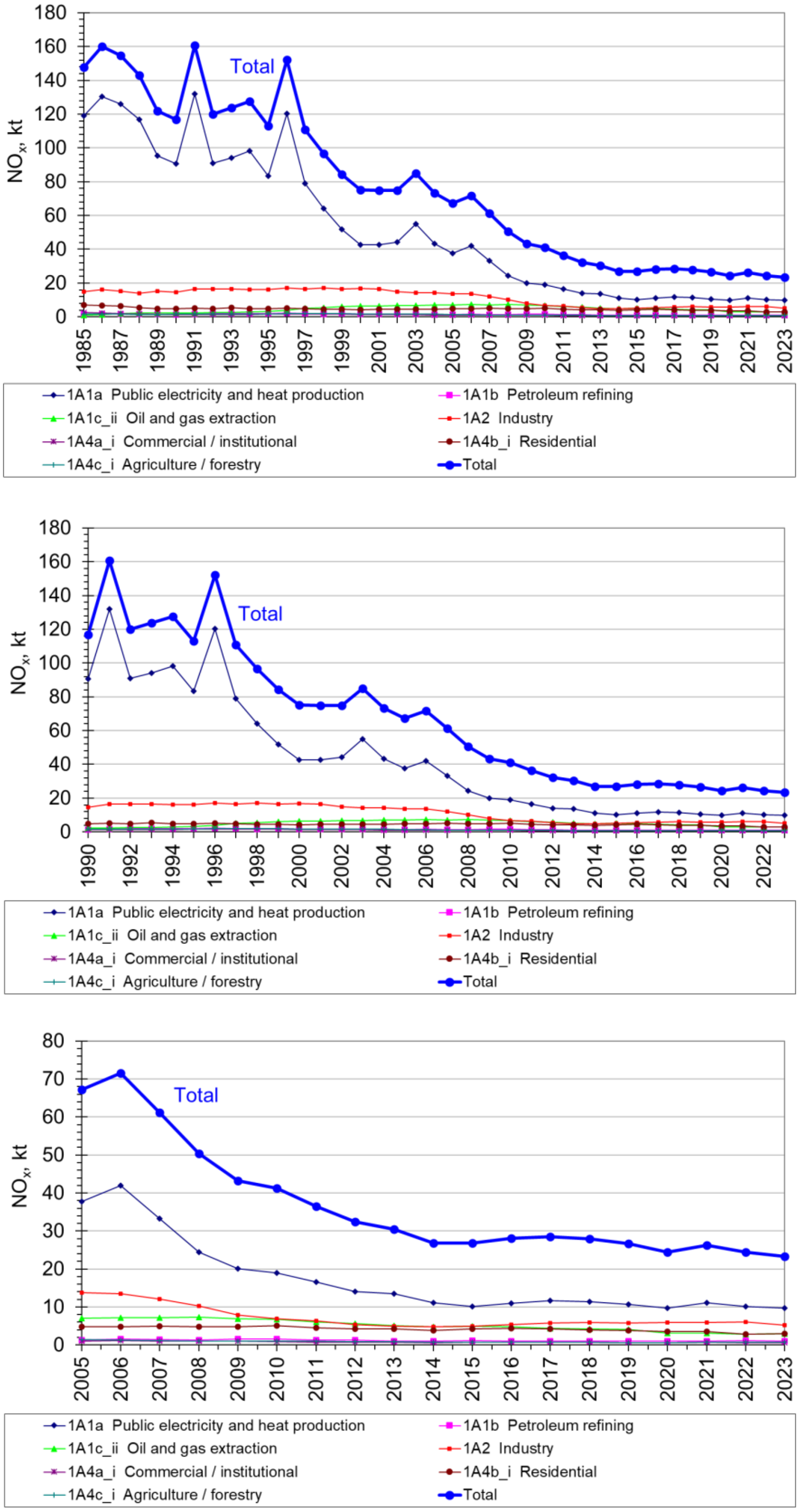


Figure 3.2.10 NO_x emission time series for stationary combustion.

NMVOC

Stationary combustion plants accounted for 10 % of the national NMVOC emission in 2023. Table 3.2.4 presents the NMVOC emission inventory for the stationary combustion subcategories.

Residential plants are the largest emission source accounting for 71 % of the emission from stationary combustion plants. For residential plants NMVOC is mainly emitted from wood and straw combustion, see Figure 3.2.11.

Public electricity and heat production is also a considerable emission source, accounting for 9 % of the emission. Lean-burn gas engines have a relatively high NMVOC emission factor and are the most important emission source in this subcategory (see Figure 3.2.11). The gas engines are fuelled by natural gas, biomethane or biogas.

Agricultural plants accounted for 13% of the emission in 2023. Combustion of straw was the main emission source in this category.

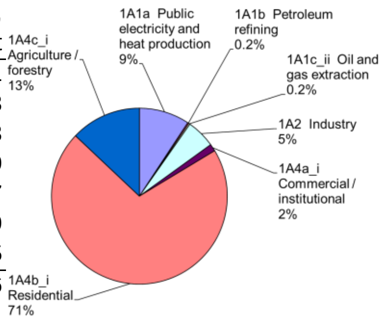
The time series for NMVOC emission from stationary combustion is shown in Figure 3.2.12. The emission has decreased by 44 % from 1990 and 50 % from 1985. The emission increased until 2007 and decreased after 2007. The increased emission is mainly a result of the increasing wood consumption in residential plants and of the increased use of lean-burn gas engines in CHP plants. The decrease after 2007 is a result of lower emission from residential wood combustion and the low number of operation hours for the lean burn gas engines.

The emission from residential plants has decreased 43 % since 1990. The NMVOC emission from residential wood combustion was 34 % lower in 2023 than in 1990. The consumption of wood in residential plants increased until 2007. However, the emission factor has decreased since 1990 due to installation of modern stoves and boilers with improved combustion technology. The use of wood in residential boilers and stoves was relatively low in 1998-99 resulting in a lower emission level.

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

Table 3.2.4 NMVOC emission from stationary combustion plants, 2023[1)].

	NMVOC, t
1A1a Public electricity and heat production	891
1A1b Petroleum refining	23
1A1c Oil and gas extraction	23
1A2 Industry	509
1A4a Commercial/Institutional	127
1A4b Residential	6789
1A4c Agriculture/Forestry	1245
Total	9606



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

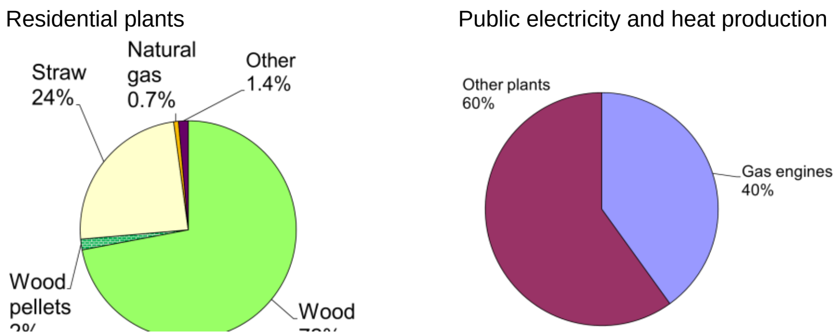


Figure 3.2.11 NMVOC emission from Residential plants and from Public electricity and heat production, 2023.

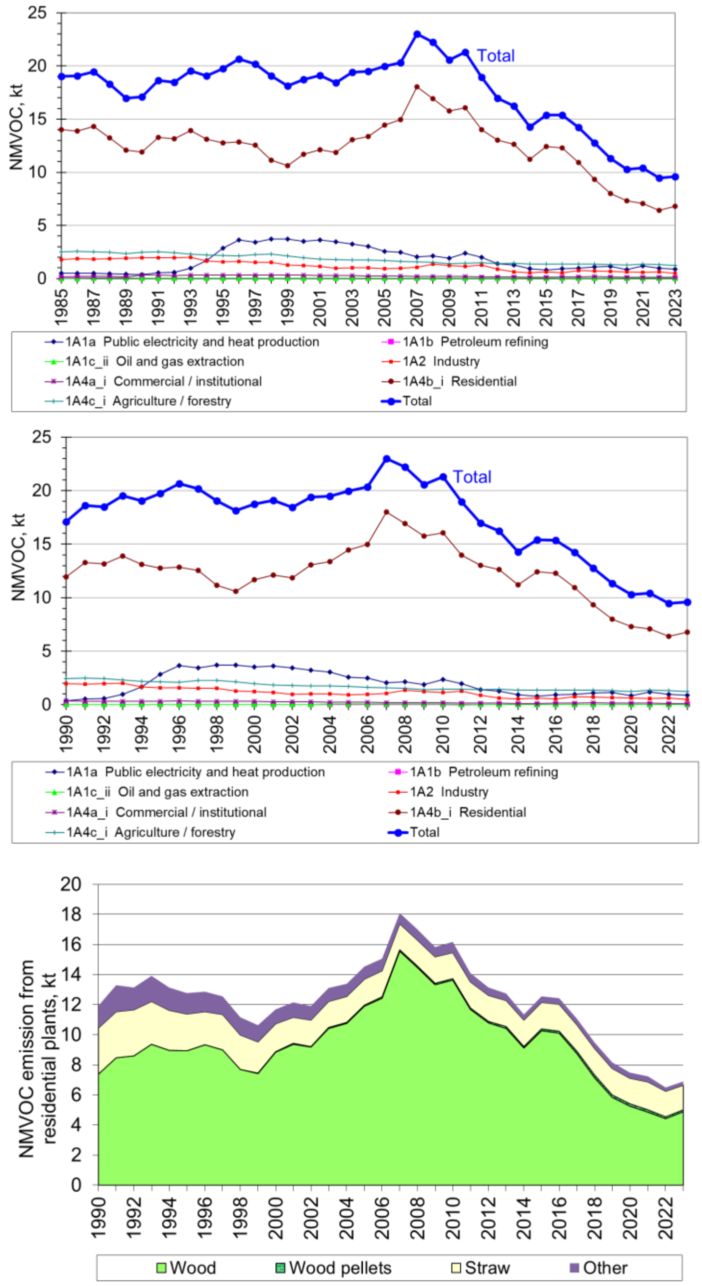


Figure 3.2.12 (a) NMVOC emission time series for stationary combustion and (b) Fuel specific emissions for residential plants.

CO

Stationary combustion accounts for 40 % of the national CO emission in 2023. Table 3.2.5 presents the CO emission inventory for stationary combustion subcategories.

Residential plants are the largest emission source, accounting for 66 % of the emission. Wood combustion accounted for 80 % of the emission from residential plants in 2023, see Figure 3.2.13. Combustion of straw and wood pellets are also a considerable emission sources, whereas the emission from other fuels used in residential plants is almost negligible.

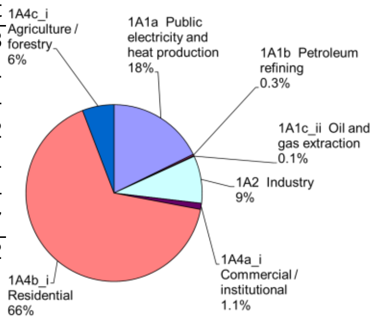
The time series for CO emission from stationary combustion is shown in Figure 3.2.14. The emission has decreased by 59 % from 1985 and 55 % from 1990. The time series for CO from stationary combustion plants follow the time series for CO emission from residential plants.

The increase of wood consumption in residential plants in 1999-2007 is reflected in the time series for CO emission. The consumption of wood in residential plants in 2007 was 3.1 times the 1990 level. In 2023, the consumption was 1.8 times the 1990 consumption level. The decreased CO-emission in 2007-2023 is mainly a result of implementation of improved residential wood combustion technologies and the fact that the rapid increase of wood consumption until 2007 have stopped.

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

Table 3.2.5 CO emission from stationary combustion plants, 2023[1)].

	CO, t
1A1a Public electricity and heat production	12633
1A1b Petroleum refining	211
1A1c Oil and gas extraction	74
1A2 Industry	6172
1A4a Commercial/Institutional	791
1A4b Residential	47064
1A4c Agriculture/Forestry	4137
Total	71082



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

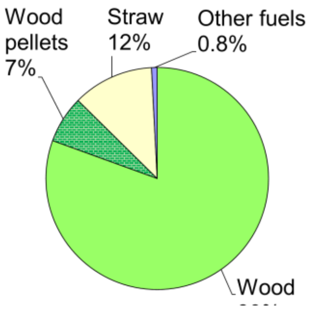
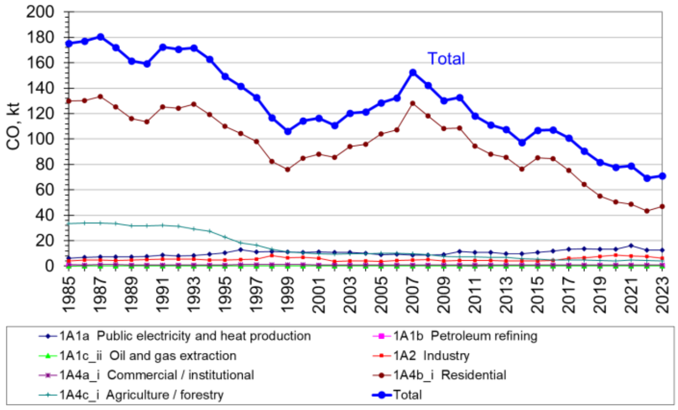
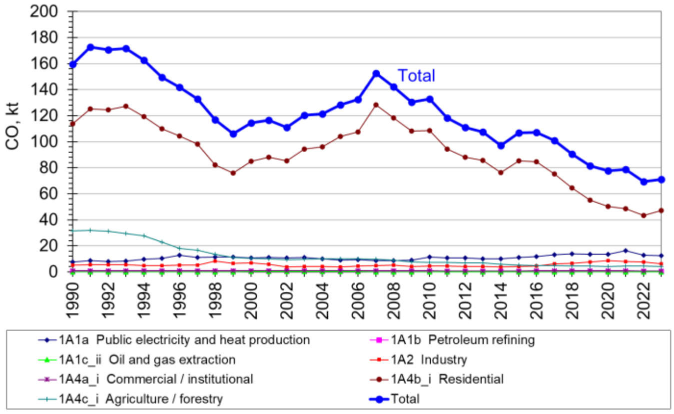


Figure 3.2.13 CO emission sources, Residential plants, 2023.

Stationary combustion, 1985-2023



Stationary combustion, 1990-2023



1A4b Residential plants, fuel origin

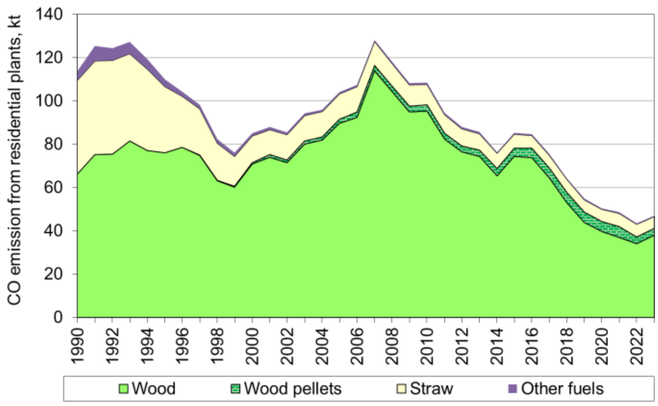


Figure 3.2.14 CO emission time series for stationary combustion.

NH_3

Stationary combustion plants accounted for 1.5 % of the national NH_3 emission in 2023.

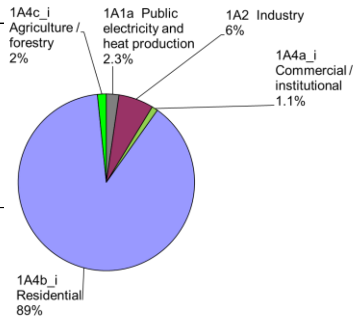
The NH_3 emission from non-residential plants is small and default emission factors are only available for biomass combustion in EEA Guidebook (EEA, 2023). However, based on national references, the NH_3 emission from waste incineration has been included in the Danish inventory.

Table 3.2.6 shows the NH_3 emission inventory for the stationary combustion subcategories. Residential plants account for 89 % of the emission. Wood combustion accounts for 82 % of the emission from residential plants, straw for 3 %, and wood pellets for 15%.

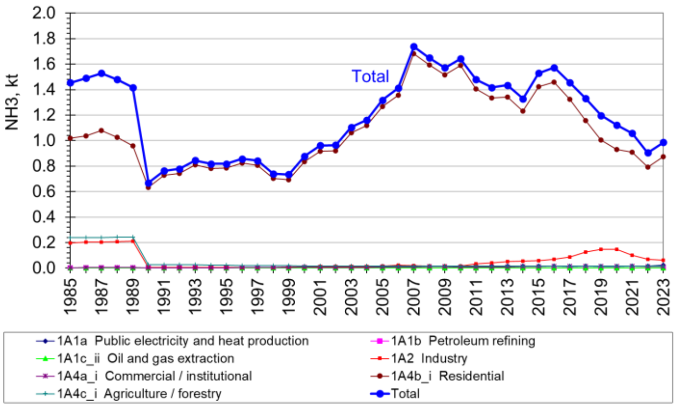
The time series for NH_3 emission is presented in Figure 3.2.15. The NH_3 emission has increased 48 % from 1990.

Table 3.2.6 NH_3 emission from stationary combustion plants, 2023[1)].

	NH_3, t
1A1a Public electricity and heat production	23
1A1b Petroleum refining	-
1A1c Oil and gas extraction	-
1A2 Industry	63
1A4a Commercial/Institutional	11
1A4b Residential	873
1A4c Agriculture/Forestry	16
Total	986



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



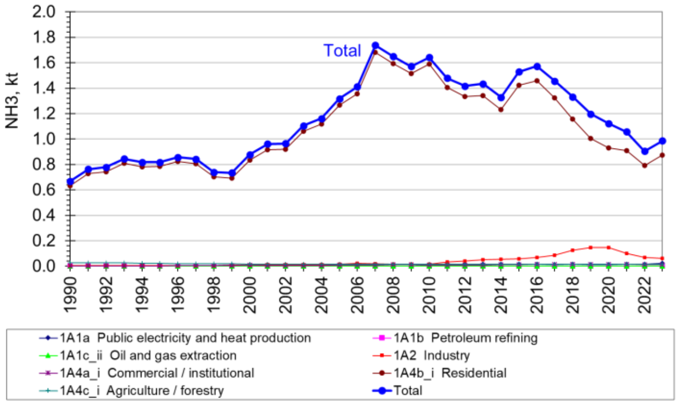


Figure 3.2.15 NH_3 emission time series, stationary combustion plants.

Particulate matter (PM)

TSP from stationary combustion accounted for 9 % of the national emission in 2023. The emission shares for PM_{10} and $PM_{2.5}$ are 34 % and 63 %, respectively.

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

Table 3.2.7 and Figure 3.2.16 show the PM emission inventory for the stationary combustion subcategories. Residential plants is the largest emission source accounting for 80 % of the $PM_{2.5}$ emission from stationary combustion plants.

The primary sources of PM emissions are

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

The PM emission from wood combusted in residential plants is the predominant source. Thus, 58 % of the $PM_{2.5}$ emission from stationary combustion is emitted from residential wood combustion. This corresponds to 35 % of the national emission.

Figure 3.2.17 shows the fuel consumption and the $PM_{2.5}$ emission of residential plants. Wood combustion accounts for 70 % of the $PM_{2.5}$ emission from residential plants, wood pellets for 9 %f and straw for 21 %.

Emission inventories for PM are reported for the years 1990-2023. The time series for PM emission from stationary combustion is shown in Figure 3.2.18. The time series for PM emission from stationary combustion plants follows the time series for PM emission from residential plants. The emissions of TSP, PM_{10} and $PM_{2.5}$ was 38 %, 41 % and 40 % lower in 2023 than in 1990.

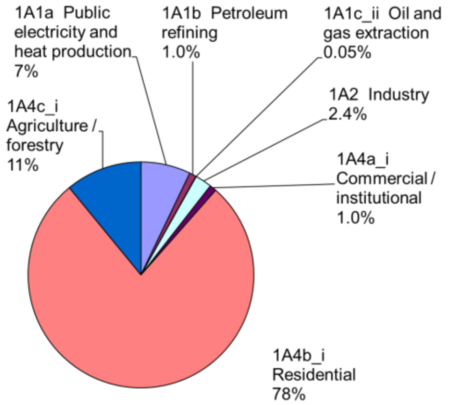
The PM emissions increased until 2007 and decreased after 2007. The increase until 2007 was caused by the increased wood combustion in residential plants. However, the PM emission factors have decreased for this emission source category due to installation of modern stoves and boilers. The stabilisation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

Table 3.2.7 PM emission from stationary combustion plants, 2023[1].

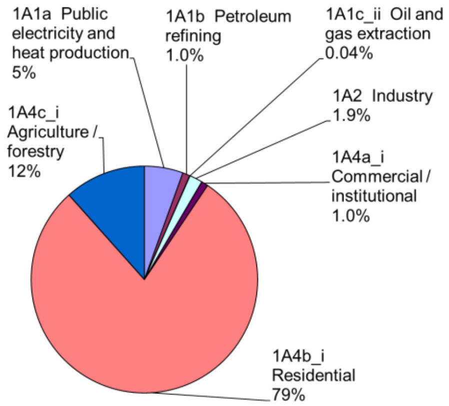
		TSP, t	PM_{10}, t	$PM_{2.5}$, t
1A1a	Public electricity and heat production	553	404	326
1A1b	Petroleum refining	76	76	76
1A1c	Oil and gas extraction	4	3	3
1A2	Industry	185	136	96
1A4a	Commercial/Institutional	75	71	68
1A4b	Residential	6015	5770	5675
1A4c	Agriculture/Forestry	849	848	846
Total		7757	7307	7091

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

TSP



PM_{10}



$PM_{2.5}$

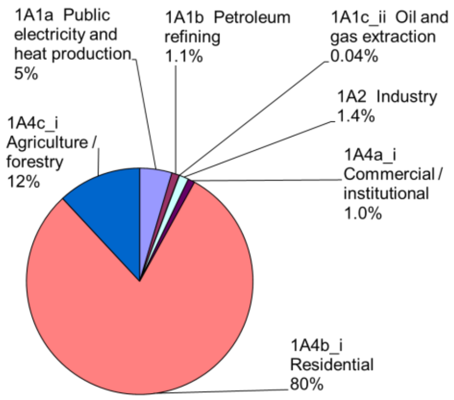
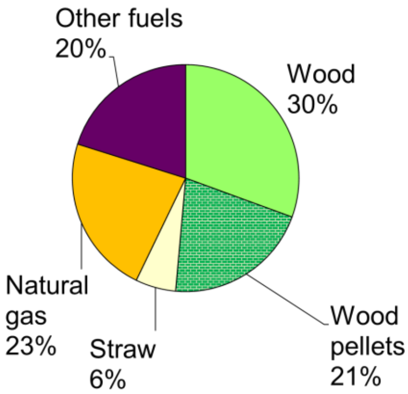


Figure 3.2.16 PM emission sources, stationary combustion plants, 2023.

Fuel consumption from residential plants



$PM_{2.5}$ emission from residential plants

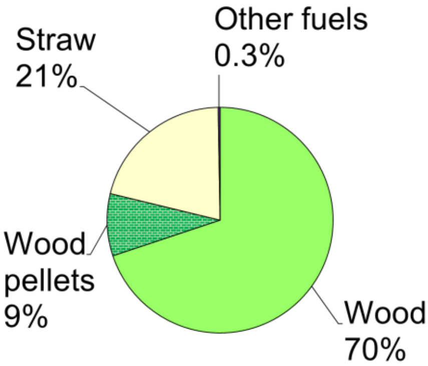
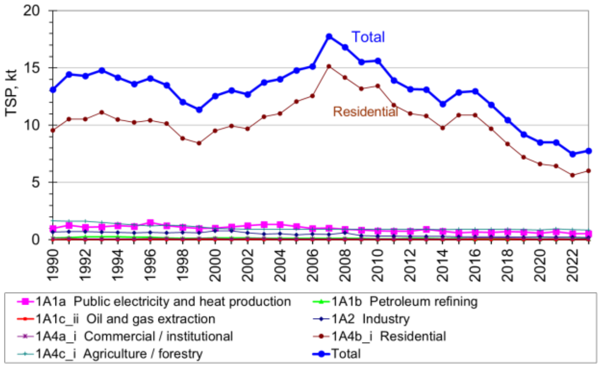
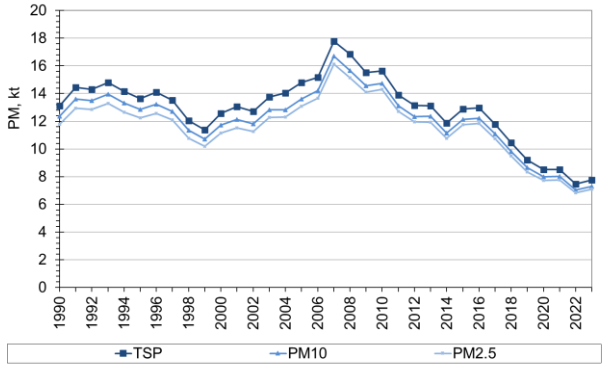


Figure 3.2.17 Fuel consumption and $PM_{2.5}$ emission from residential plants.

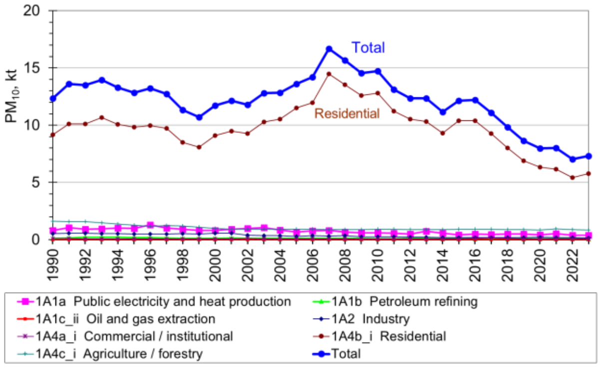
TSP time series



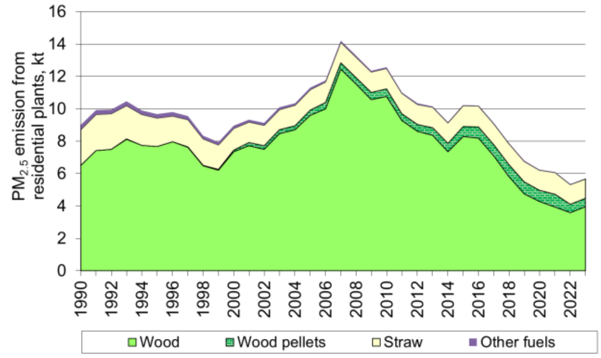
PM time series



PM_{10} time series



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



$PM_{2.5}$ time series

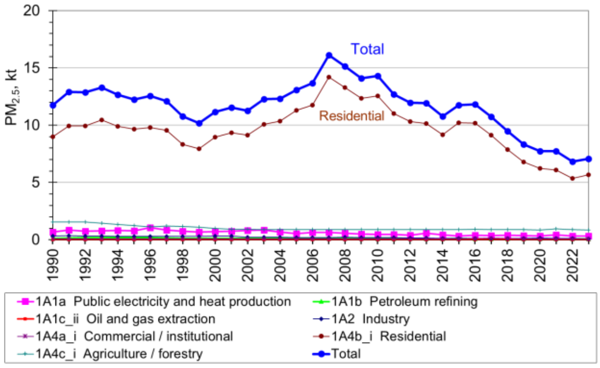


Figure 3.2.18 PM emission time series for stationary combustion.

Black carbon (BC)

Black carbon (BC) from stationary combustion accounted for 64 % of the national emission in 2023. Residential combustion is the main emission source accounting for 70 % of the emission from stationary combustion. Plants in Agriculture/forestry account for 24 % of the emission.

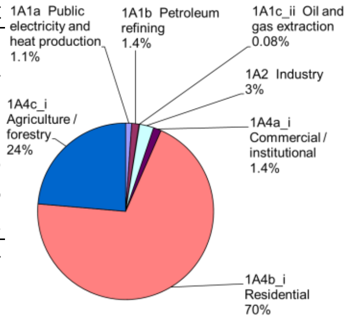
Combustion of straw, wood and wood pellets are the main emission sources for residential plants accounting for 47%, 43 %, and 11 % respectively.

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

BC emissions are reported for year 1990 onwards. Figure 3.2.19 shows time series for BC emission. The emission in 2023 was 27 % lower than in 1990.

Table 3.2.8 BC emission from stationary combustion plants, 2023[1)].

	BC, t
1A1a Public electricity and heat production	11
1A1b Petroleum refining	14
1A1c Oil and gas extraction	0.82
1A2 Industry	27
1A4a Commercial/Institutional	15
1A4b Residential	715
1A4c Agriculture/Forestry	242
Total	1024



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

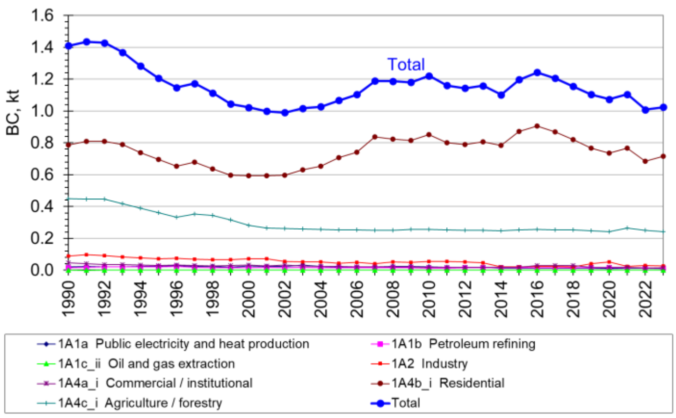


Figure 3.2.19 BC emission time series for stationary combustion.

Heavy metals

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

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

Table 3.2.9 Heavy metal emission from stationary combustion plants, 2023[1)].

	As, kg	Cd, kg	Cr, kg	Cu, kg	Hg, kg	Ni, kg	Pb, kg	Se, kg	Zn, kg
1A1a Public electricity and heat production	40	31	147	133	96	209	305	239	270
1A1b Petroleum refining	5	33	101	50	6	111	24	23	256
1A1c Oil and gas extraction	2	0	0	0	1	0	0	0	0
1A2 Industry	54	19	50	60	43	415	205	45	511
1A4a Commercial/Institutional	1	1	3	4	2	3	4	1	9
1A4b Residential	8	384	679	178	19	59	797	15	15110
1A4c Agriculture/Forestry	1	26	48	14	2	6	64	3	1034
Total	111	493	1029	438	170	802	1399	327	17190
Emission share from stationary combustion	54%	83%	44%	0.7%	80%	20%	11%	72%	30%

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

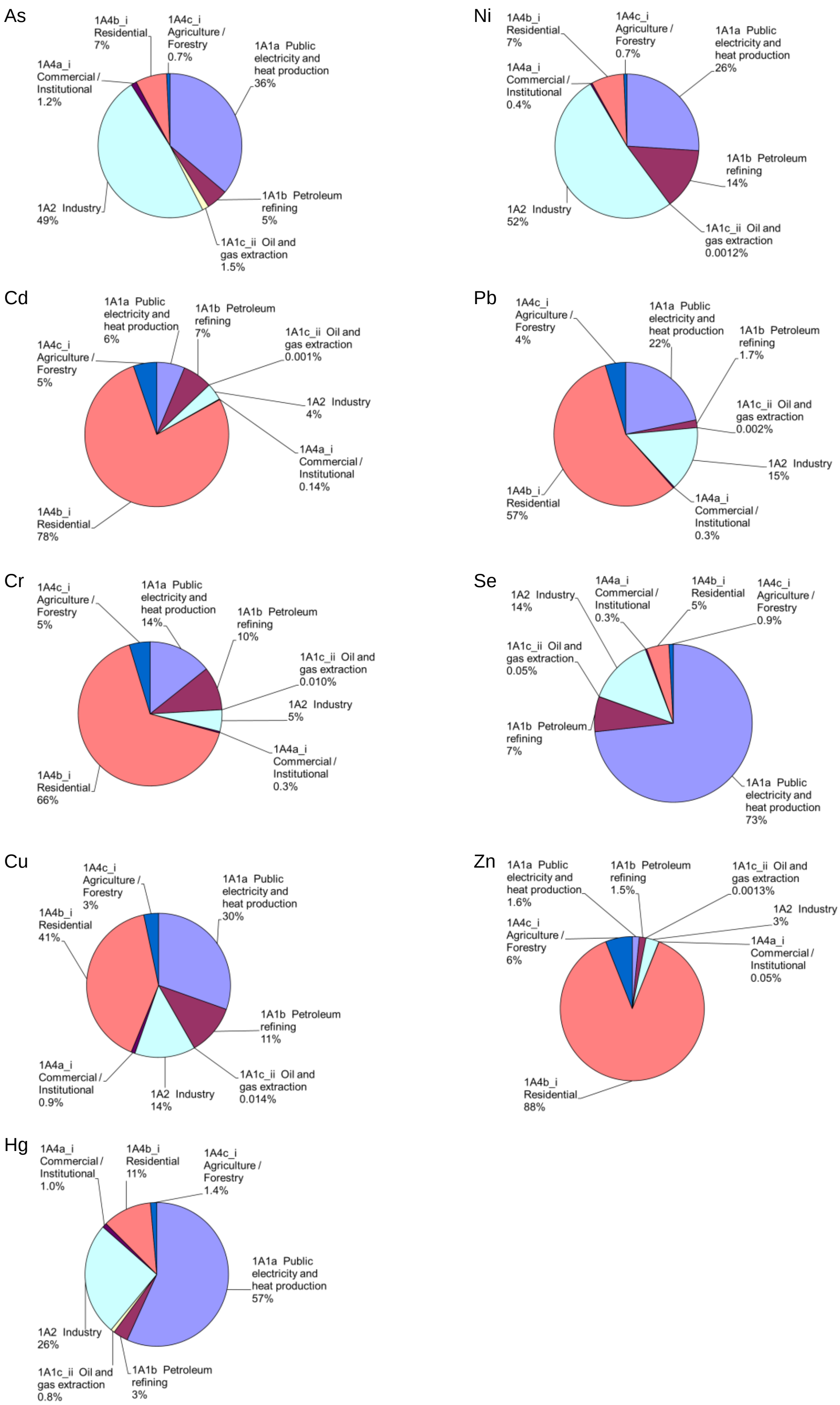


Figure 3.2.20 Heavy metal emission sources, stationary combustion plants, 2023.

The time series for heavy metal emissions are provided in Figure 3.2.21. Emissions of all heavy metals have decreased considerably (45 % - 94 %) since 1990, see Table 3.2.10. Emissions have decreased despite increased incineration of waste. This has been possible due to installation and improved performance of gas cleaning devices in waste incineration plants and also in large power plants, the latter being a further important emission source. The Zn and Cd emissions decrease only 45 % and 54 % respectively. The smaller decrease compared to other HMs is due to a relatively high emission share from residential wood combustion even in 1990.

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

Table 3.2.10 Decrease in heavy metal emission 1990-2023.

Pollutant	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Decrease since 1990, %	90	54	82	88	94	94	91	92	45

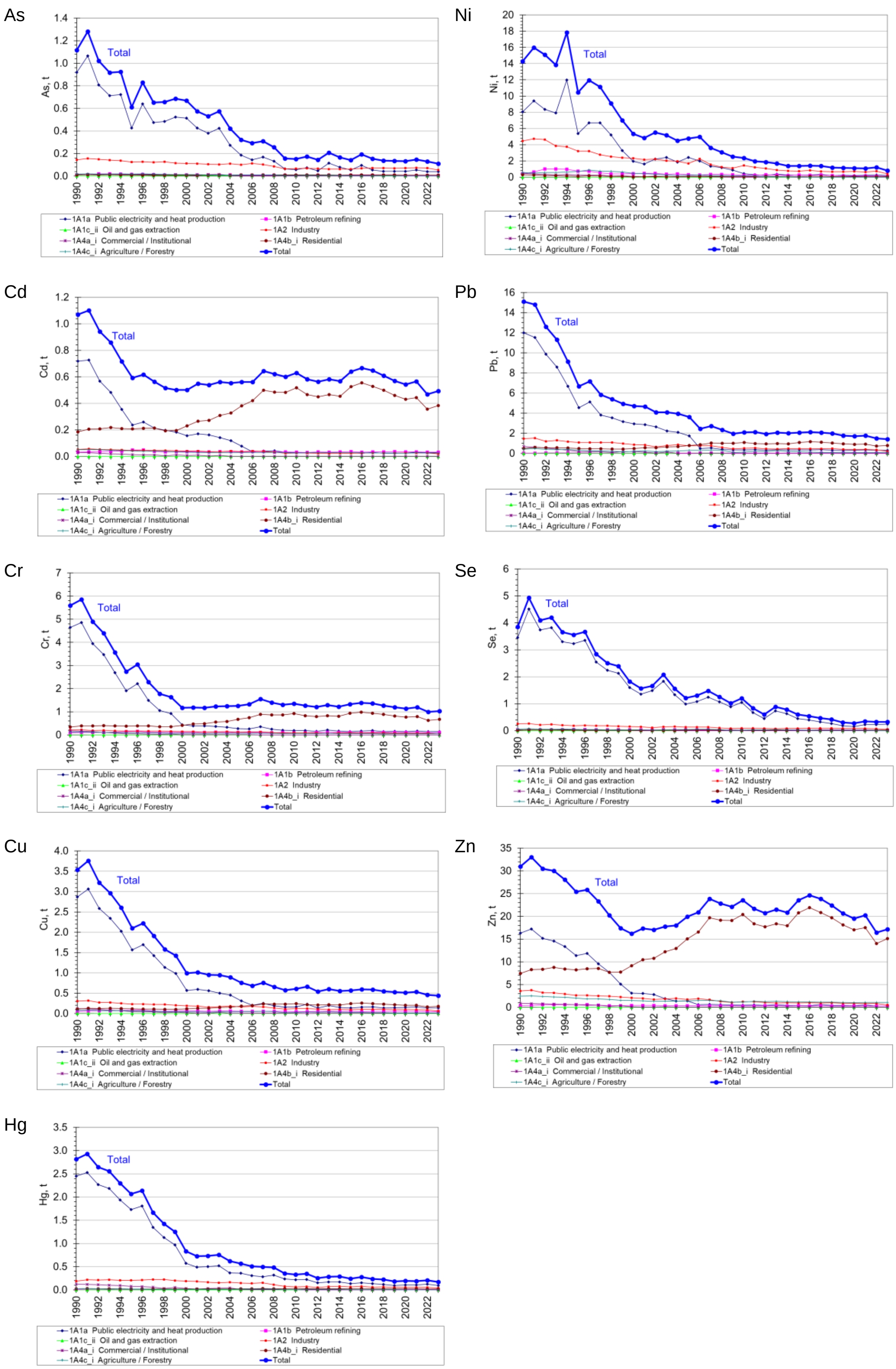


Figure 3.2.21 Heavy metal emission time series, stationary combustion plants.

Polycyclic aromatic hydrocarbons (PAH)

Stationary combustion plants accounted for more than 78 % of the PAH emission in 2023.

Table 3.2.11 and Figure 3.2.22 present the PAH emission inventories for the stationary combustion subcategories. Residential combustion is the largest emission source accounting for more than 80 % of the emission. Combustion of wood is the predominant source, accounting for more than 94 % of the PAH emission from residential plants, see Figure 3.2.23.

The time series for PAH emissions are presented in Figure 3.2.24. The time series for wood combustion in residential plants is also provided in Figure 3.2.24. The wood combustion in residential plants has increased whereas the emission factors have decreased due to installation of new residential wood combustion units. The consumption of wood applied in residential plants has decreased in 2016-2023.

Table 3.2.11 PAH emission from stationary combustion plants, 2023[1)].

	Benzo(a)-pyrene, kg	Benzo(b)-fluoran-thene, kg	Benzo(k)-fluoran-thene, kg	Indeno (1,2,3-c,d) pyrene, kg
1A1a Public electricity and heat production	12	46	30	8.7
1A1b Petroleum refining	0.02	0.08	0.02	0.03
1A1c Oil and gas extraction	0.07	0.24	0.07	0.13
1A2 Industry	0.9	9	10	4
1A4a Commercial/Institutional	63	83	28	45
1A4b Residential	1035	1035	584	574
1A4c Agriculture/Forestry	72	84	32	47
Total	1183	1258	684	679
Emission share from stationary combustion	88%	85%	81%	79%

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

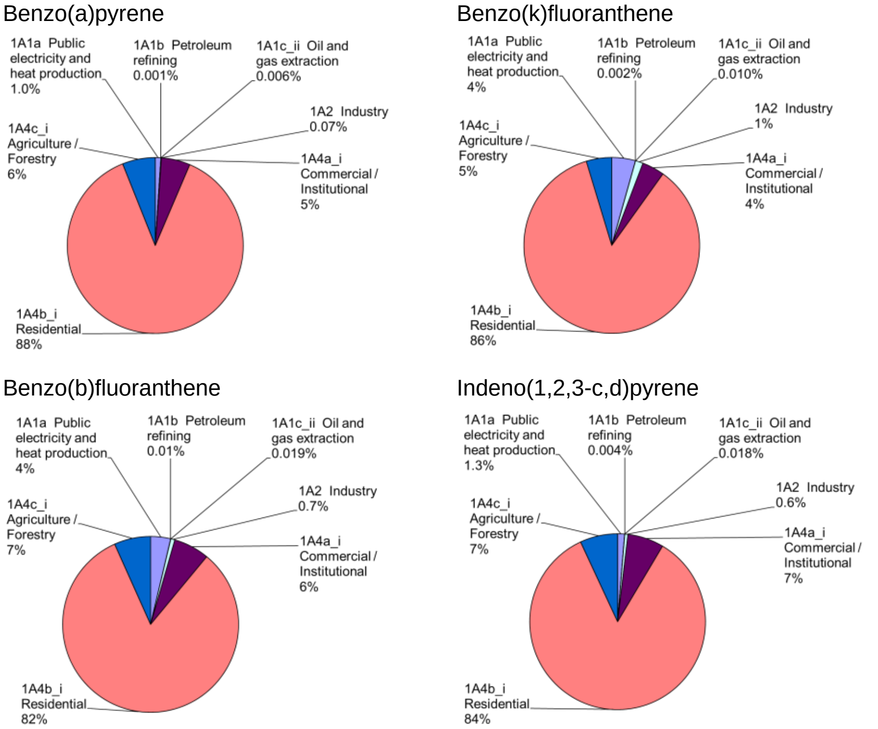


Figure 3.2.22 PAH emission sources, stationary combustion plants, 2023.

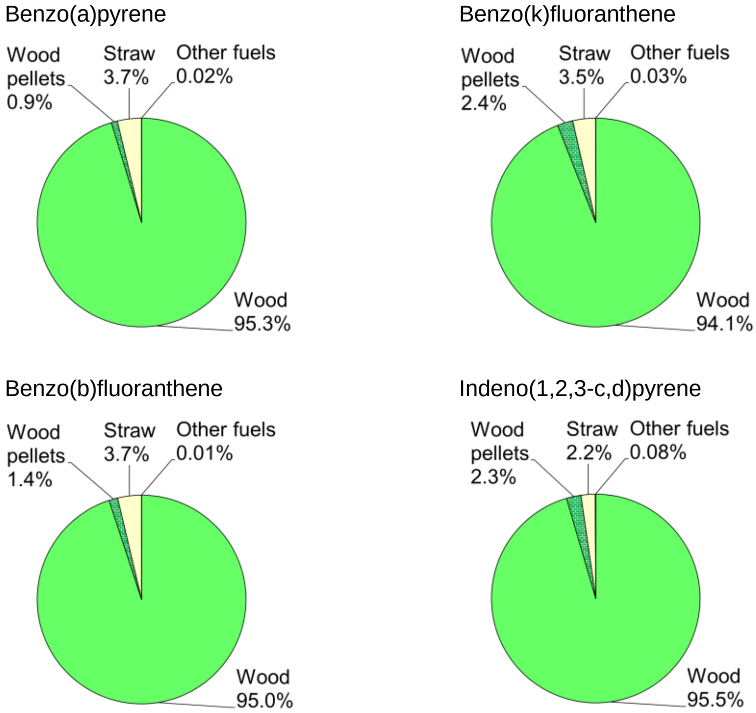


Figure 3.2.23 PAH emission from residential combustion plants (stationary), fuel origin.

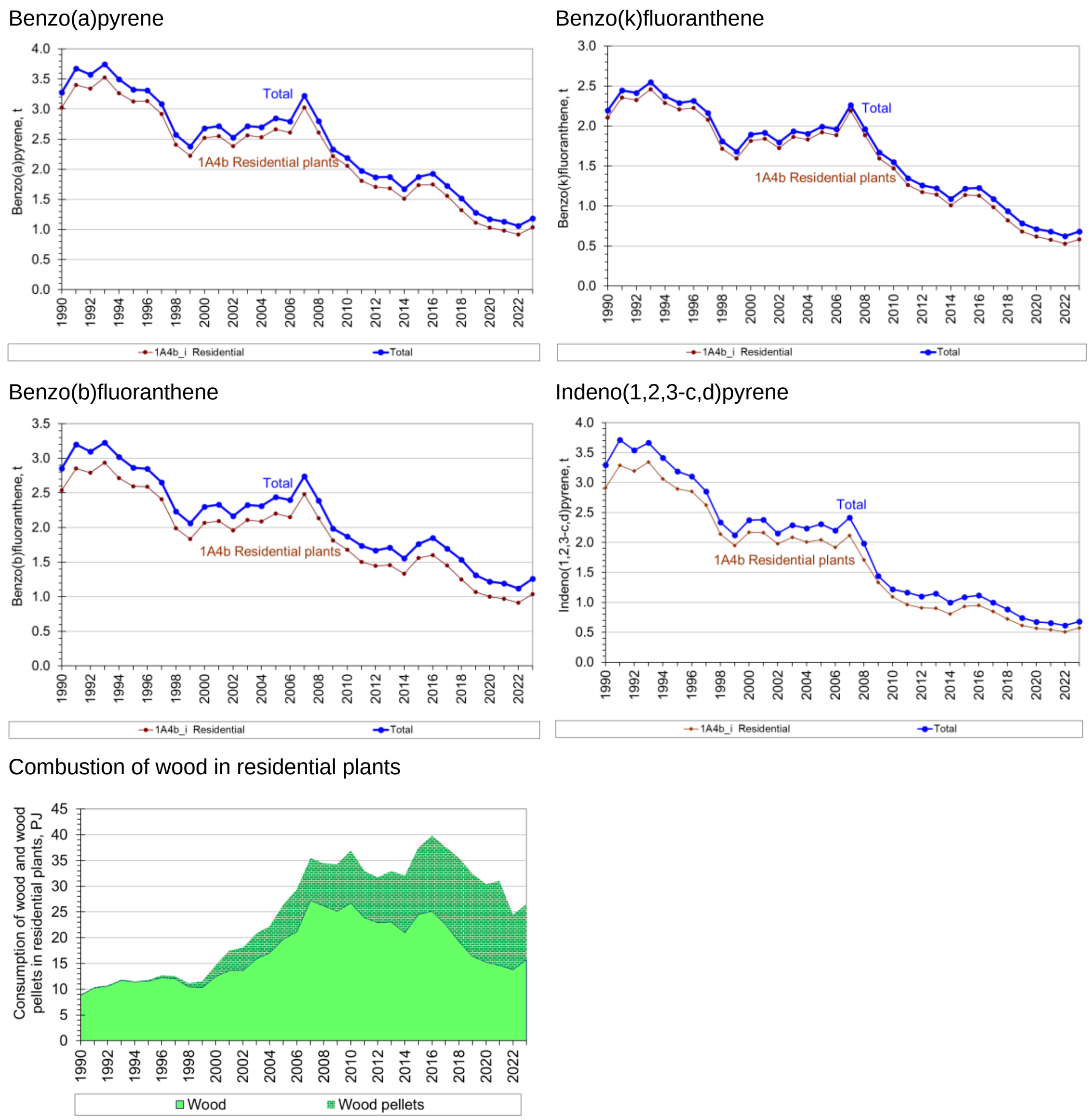


Figure 3.2.24 PAH emission time series, stationary combustion plants. Comparison with wood consumption in residential plants.

Polychlorinated dibenzodioxins and -furans (PCDD/F)

Stationary combustion plants accounted for 81 % of the national emission of polyclorinated dibenzodioxins and –furans (PCDD/F) in 2023.

Table 3.2.12 presents the PCDD/F emission inventories for the stationary combustion subcategories. In 2023, the emission from residential plants accounted for 85 % of the emission. Combustion of wood and wood pellets are the predominant sources accounting for 70 % and 21 % of the emission from residential plants (Figure 3.2.25).

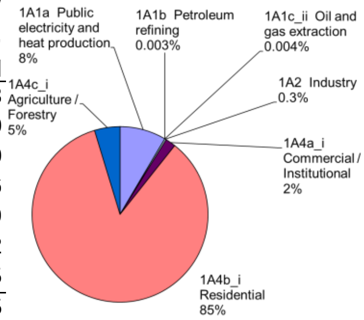
The time series for PCDD/F emission is presented in Figure 3.2.26. The PCDD/F emission has decreased 57 % since 1990 mainly due to installation of dioxin filters in waste incineration plants.

The emission from residential plants has increased due to increased wood consumption in this source category. However, both wood consumption and emission of PCDD/F have decreased since 2016 for residential plants.

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

Table 3.2.12 PCDD/F emission from stationary combustion plants, 2023[1)].

	PCDD/F, g I-teq
1A1a Public electricity and heat production	1.73
1A1b Petroleum refining	0.00
1A1c Oil and gas extraction	0.00
1A2 Industry	0.06
1A4a Commercial/Institutional	0.39
1A4b Residential	17.22
1A4c Agriculture/Forestry	0.95
Total	20.35



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

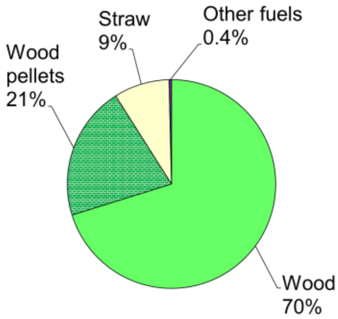
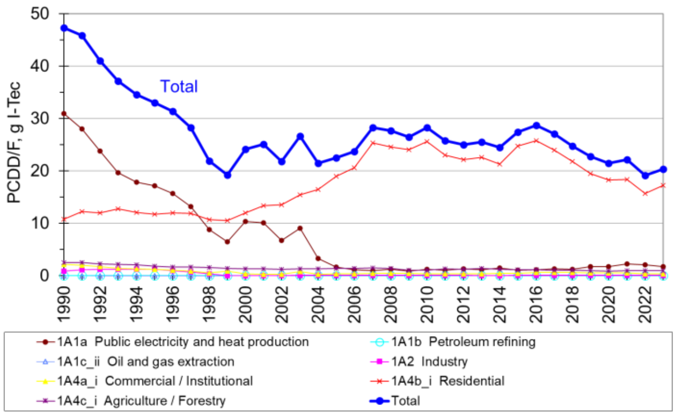
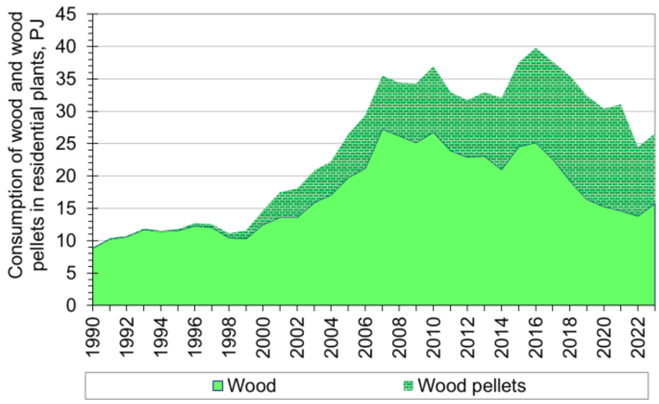


Figure 3.2.25 PCDD/F emission from residential plants, fuel origin.



Combustion of wood in residential plants



Time series for residential PCDD/F-emission

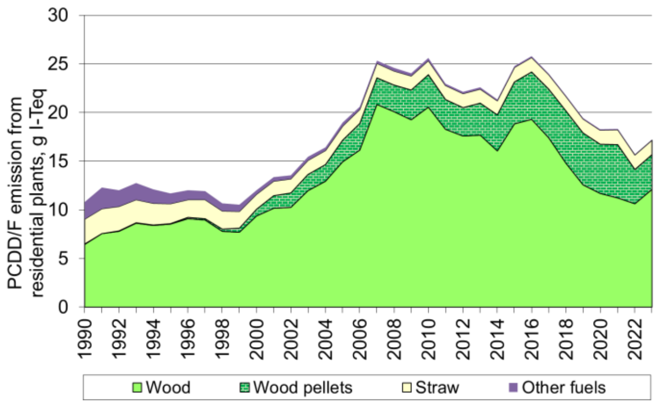


Figure 3.2.26   PCDD/F emission time series, stationary combustion plants.

Hexachlorobenzene (HCB)

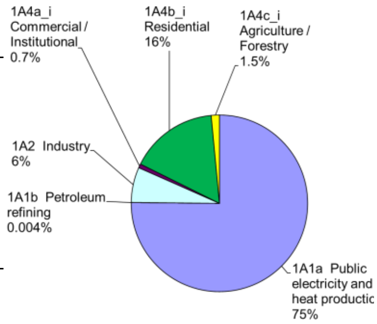
Stationary plants accounted for 44 % of the estimated national emission of hexachlorobenzene (HCB) in 2023.

Table 3.2.13 shows the HCB emission inventory for the stationary combustion subcategories. Public electricity and heat production account for 75 % of the emission. Residential plants account for 16 % of the emission.

The time series for HCB emission is presented in Figure 3.2.27. The HCB emission has decreased 84 % since 1990 mainly due to improved flue gas cleaning in waste incineration plants. The high emission from residential plants in 1990-1995 is related to combustion of coal in residential plants.

Table 3.2.13 HCB emission from stationary combustion plants, 2023[1)].

	HCB, kg
1A1a Public electricity and heat production	0.689
1A1b Petroleum refining	0.00004
1A1c Oil and gas extraction	0.0001
1A2 Industry	0.059
1A4a Commercial/Institutional	0.007
1A4b Residential	0.148
1A4c Agriculture/Forestry	0.014
Total	0.917



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

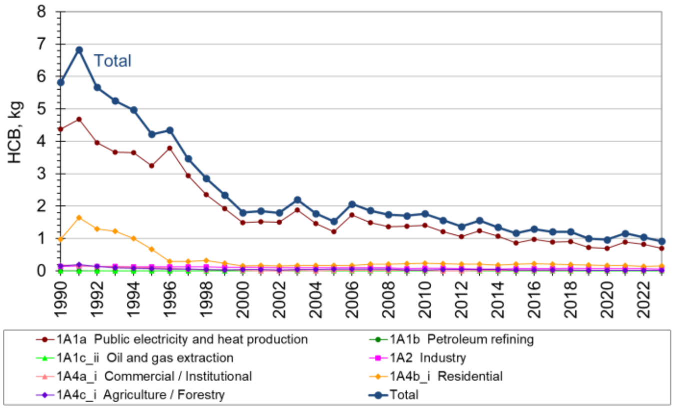


Figure 3.2.27 HCB emission time series, stationary combustion plants.

Polychlorinated biphenyls (PCB)

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

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

Furthermore, teq values based on TEF are reported as WHO_{2005}-teq or WHO_{1998}-teq. This difference is however typically less than 50%[1].

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

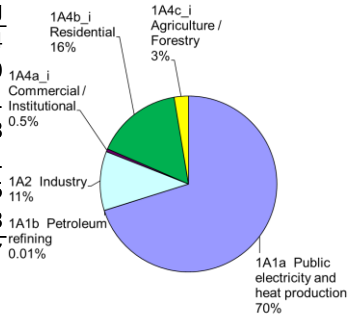
Stationary plants accounted for 77 % of the estimated national PCB emission in 2023.

Table 3.2.14 shows the dl-PCB emission inventory for the stationary combustion subcategories. Public electricity and heat production accounted for 70 % of the emission in 2023. Residential plants accounted for 16 % of the emission.

The time series for dl-PCB emission is presented in Figure 3.2.28. The dl-PCB emission has decreased 74 % since 1990. The decrease is mainly a result of the flue gas cleaning devices that have been installed in waste incineration plants for dioxin reduction.

Table 3.2.14 PCB emission from stationary combustion plants, 2023[1)].

	PCB, kg
1A1a Public electricity and heat production	0.224
1A1b Petroleum refining	0.00020
1A1c Oil and gas extraction	0.00001
1A2 Industry	0.038
1A4a Commercial/Institutional	0.001
1A4b Residential	0.045
1A4c Agriculture/Forestry	0.008
Total	0.317



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

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

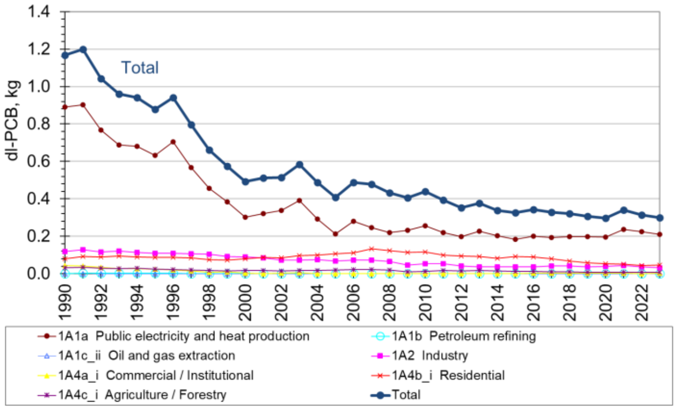


Figure 3.2.28 PCB emission time series, stationary combustion plants.

3.2.5 Trend for subsectors

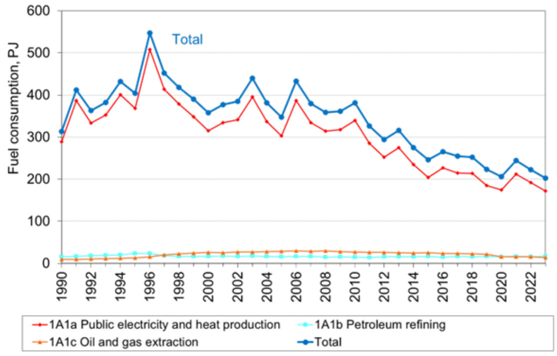
In addition to the data for stationary combustion, this chapter presents and discusses data for each of the subcategories in which stationary combustion is included. Time series are presented for fuel consumption and emissions.

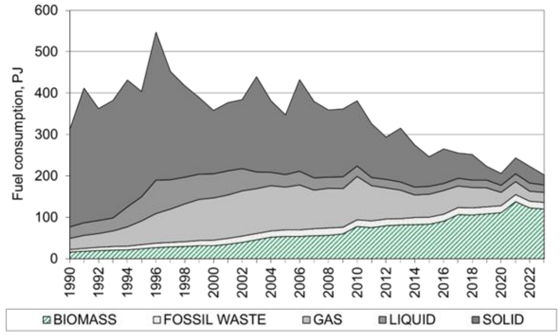
1A1 Energy industries

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

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

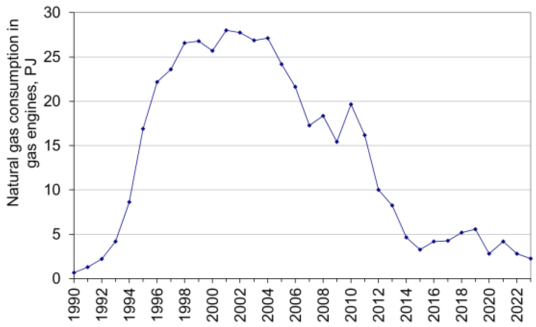
Figure 3.2.29 – 3.2.33 present time series for Energy industries. Public electricity and heat production is the largest subcategory accounting for the main part of all emissions. Time series are discussed below for each subcategory.

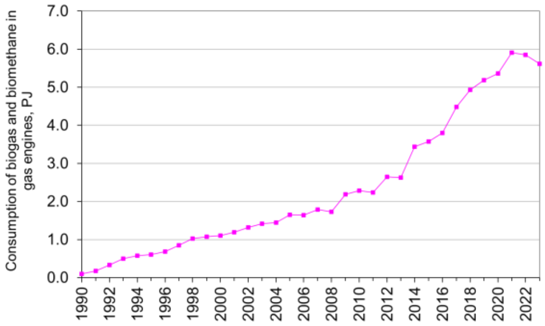




Natural gas fuelled engines

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





Residual oil in petroleum refining

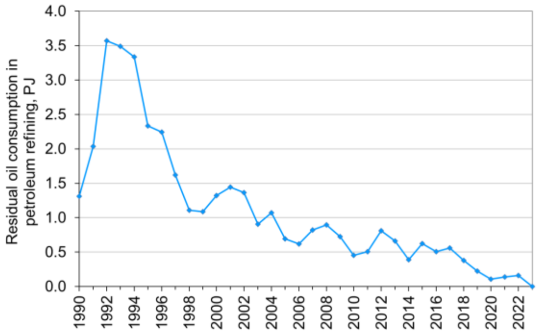
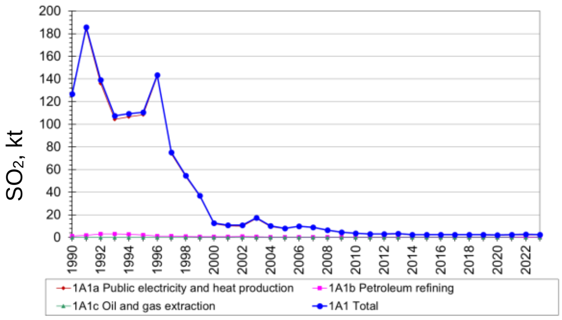
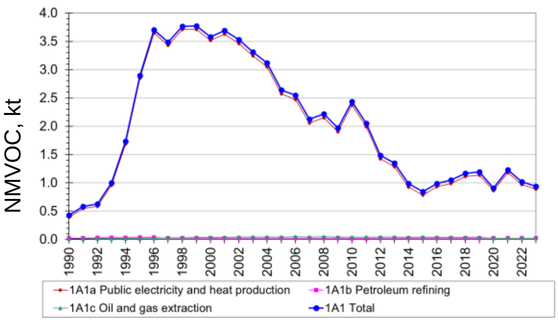


Figure 3.2.29 Time series for fuel consumption, 1A1 Energy industries.





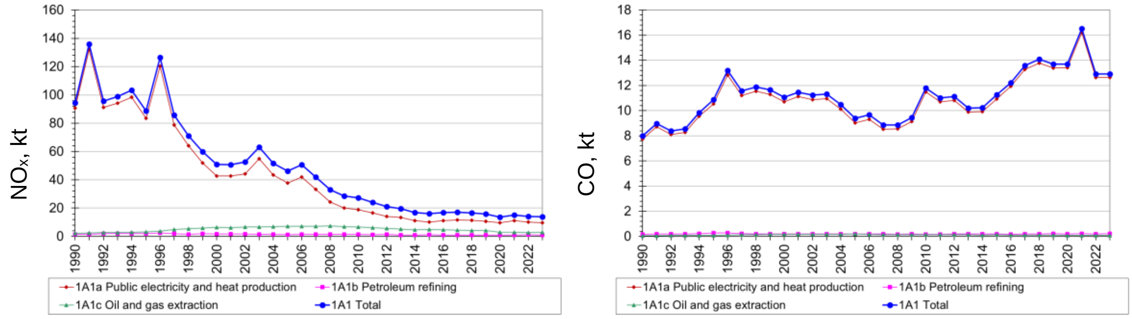


Figure 3.2.30 Time series for SO_2, NO_x, NMVOC and CO emission, 1A1 Energy industries.

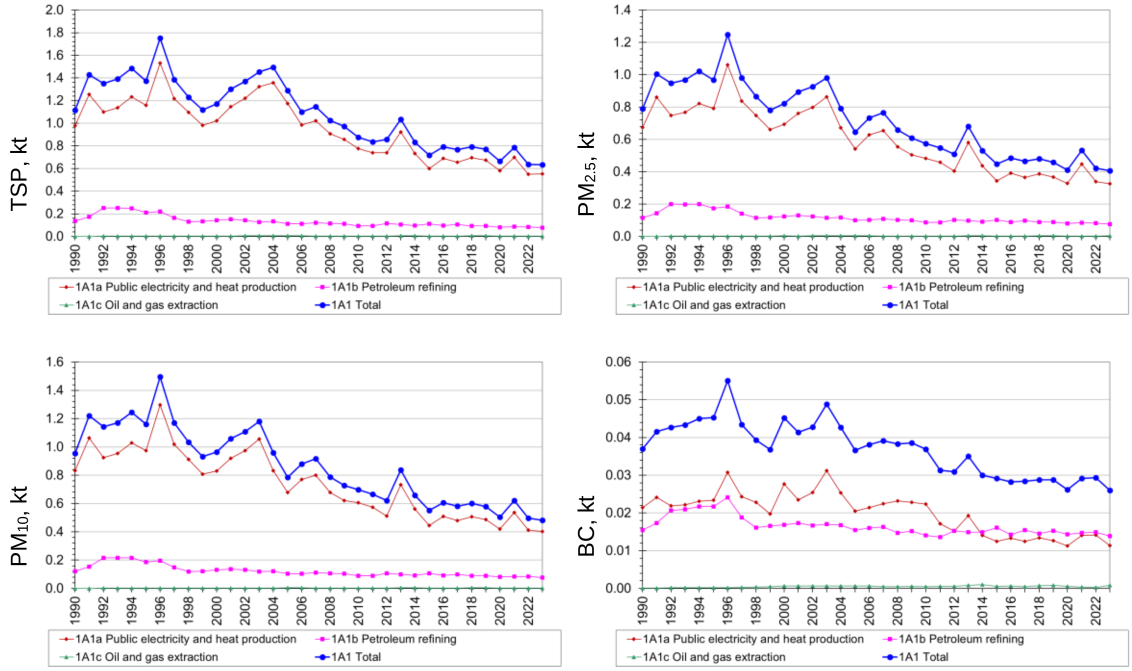


Figure 3.2.31 Time series for PM and BC emission, 1A1 Energy industries.

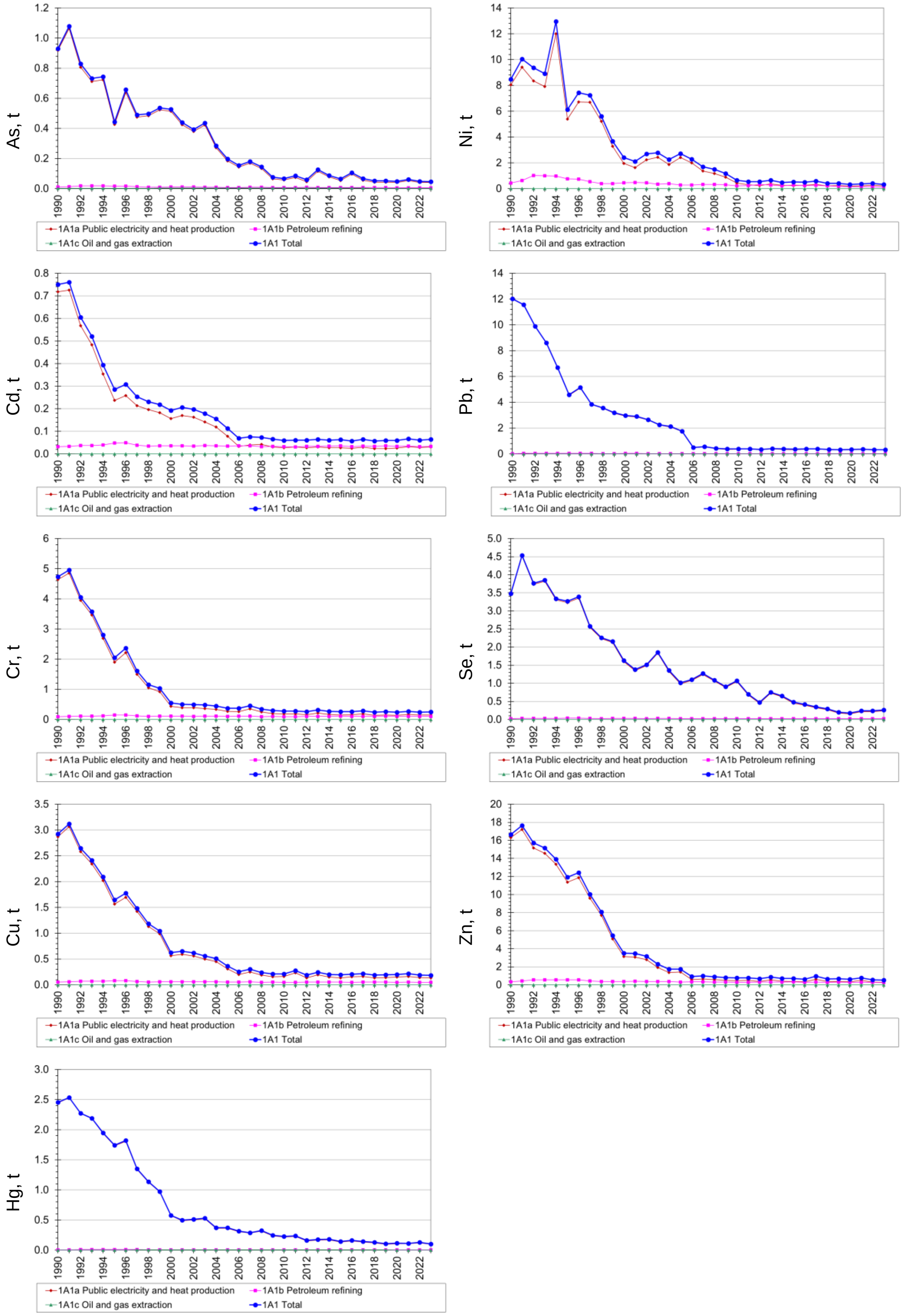


Figure 3.2.32 Time series for HM emission, 1A1 Energy industries.

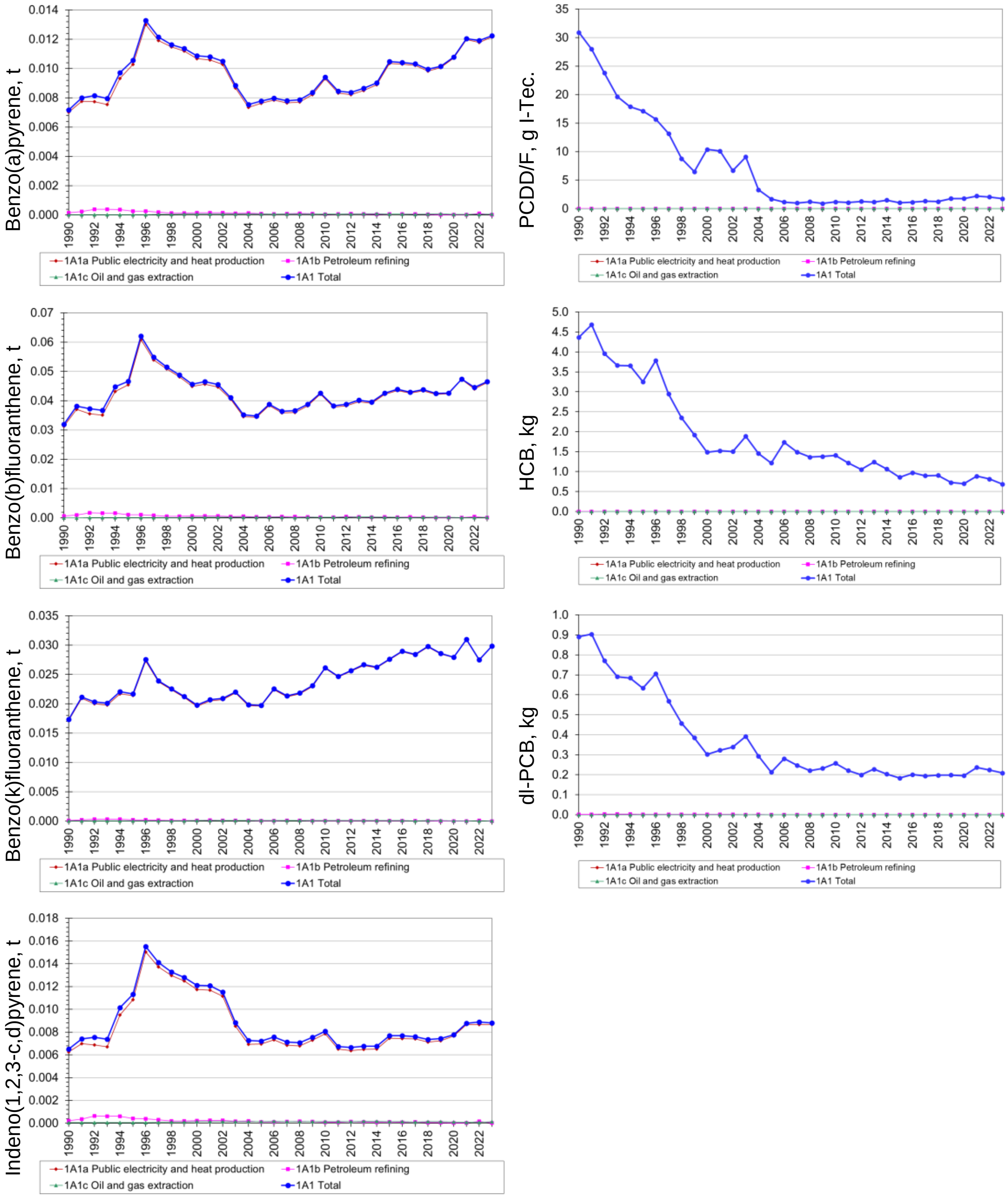


Figure 3.2.33   Time series for PAH, PCDD/F, HCB and dl-PCB emission, 1A1 Energy industries.

1A1a Public electricity and heat production

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

The fuel consumption in public electricity and heat production was 41 % lower in 2023 than in 1990. The fossil fuel consumption 81 % lower and the biomass consumption in 2023 was 7.4 times the 1990-level. In addition to fuel type changes, the total fuel consumption is also influenced by the fact that the Danish wind and solar power production has increased.

The fuel consumption has decreased from 2022 to 2023 partly due to a higher electricity import in 2023. The electricity production based on wind turbines and solar power plants have increased whereas the production based on fuels have decreased (DEA, 2024e). The production of district heating has increased, but this increase is partly based on biomass and solar heating.

As discussed in Chapter 3.2.2 the fuel consumption fluctuates mainly because of electricity trade. Coal is the fuel that is affected the most by the fluctuating electricity trade.

Coal was the main fuel in the source category in the 1990s, but the consumption has been decreasing in later years. The coal consumption in 2023 was only 10 % of the 1990 consumption in this sector. The consumption of natural gas increased in 1990-2000 but has decreased since 2010. A considerable part of the natural gas was combusted in gas engines (Figure 3.2.29). The consumption of wood, wood pellets and waste has increased.

The SO_2 emission has decreased 98 % from 1990 to 2023. This decrease is a result of both lower sulphur content in fuels and installation and improved performance of desulphurisation plants. The emission was 6 % lower in 2023 than in 2022.

The NO_x emission has decreased 89 % since 1990 due to installation of low NO_x burners, selective catalytic reduction (SCR) units and selective non-catalytic reduction (SNCR) units. The fluctuations in time series follow the fluctuations in fuel consumption and electricity trade. The NO_x emission was 4 % lower in 2023 than in 2022.

The emission of NMVOC in 2023 was 2.3 times the emission in 1990. The emission increased until 1996 and decreased after 2002. This is a result of the large number of gas engines installed in Danish CHP plants. The decreasing emission after 2004 is results of the decreasing fuel consumption for natural gas engines (Figure 3.2.29). In addition, the NMVOC emission factor for engines decreased in 1995-2007 due to introduction of an emission limits for unburned hydrocarbon[2] (DEPA, 2005).

The CO emission in 2023 was 63 % higher than in 1990. The fluctuations follow the fluctuations of the fuel consumption. In addition, the emission from gas engines is considerable.

[2] Including methane.

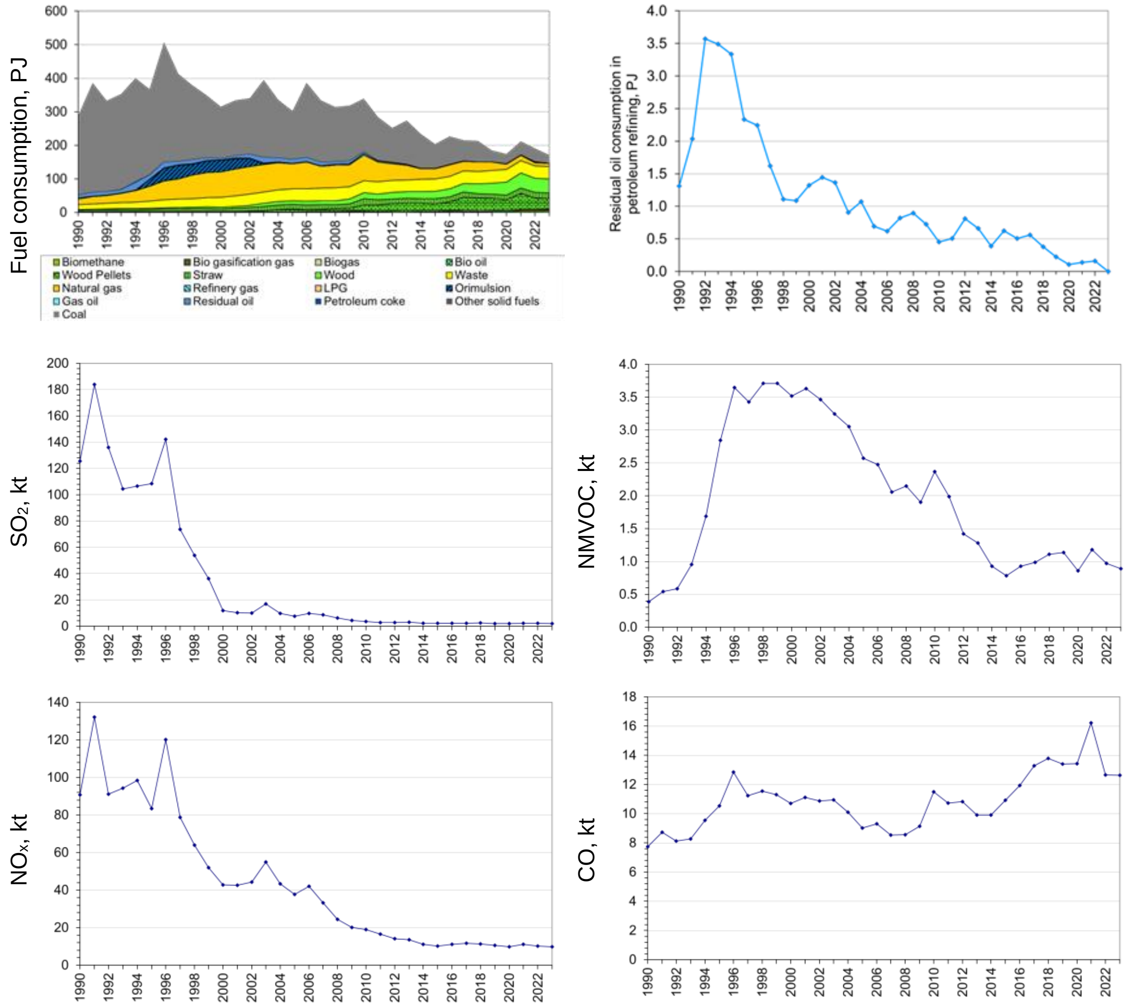


Figure 3.2.34 Time series for 1A1a Public electricity and heat production.

1A1b Petroleum refining

Petroleum refining is a small source category regarding both fuel consumption and emissions for stationary combustion. Presently two refineries are operating in Denmark. Figure 3.2.35 shows the time series for fuel consumption and emissions.

The significant decrease in both fuel consumption and emissions in 1996 is a result of the closure of a third refinery. The fuel consumption has increased 6 % since 1990.

The emission of SO_2 has shown a pronounced decrease (68 %) since 1990, mainly because decreased consumption of residual oil also shown in Figure 3.2.35. The increase in SO_2 emission in 1990-1992 also follows the residual oil consumption. The increase of the SO_2-emission from 2021 to 2022 relate to a shutdown and startup of one refinery. Data for SO_2 are plant specific since 2005.

The NO_x emission in 2023 was 27 % lower than in 1990. Since 2005, data for NO_x are plant specific data stated by the refineries.

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

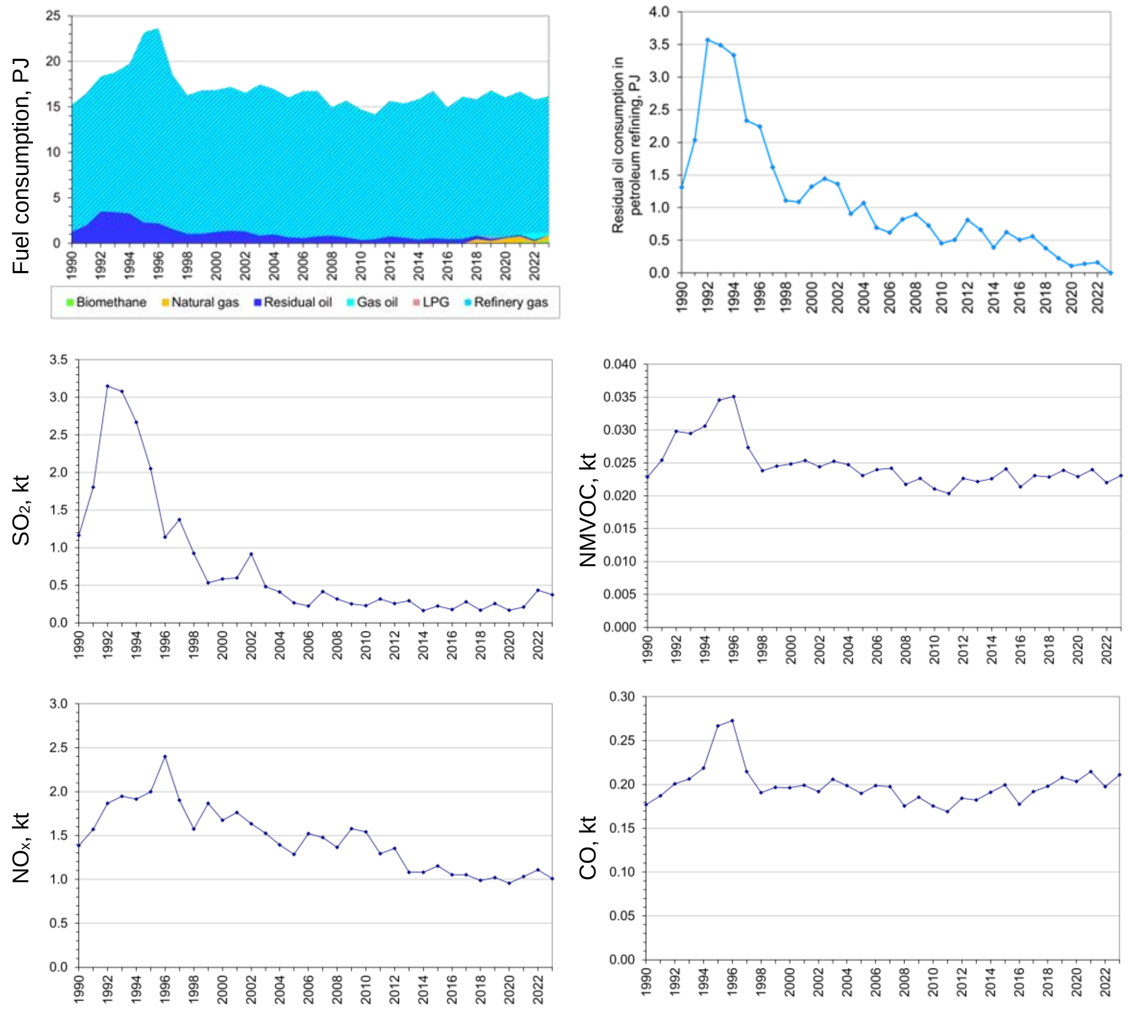


Figure 3.2.35 Time series for 1A1b Petroleum refining.

1A1c Oil and gas extraction

The source category Oil and gas extraction comprises natural gas consumption in the offshore industry and in addition a small consumption in the Danish gas treatment plant[3]. Gas turbines are the main plant type. Fugitive emissions from fuels are not included in the sector. Venting and flaring are included in the sector 1B2c Venting and Flaring.

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

The fuel consumption in 2023 was 56 % higher than in 1990. The fuel consumption has decreased since 2008. The large decrease between 2019 and 2020 is related to renovation of the largest gas field, Tyra.

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

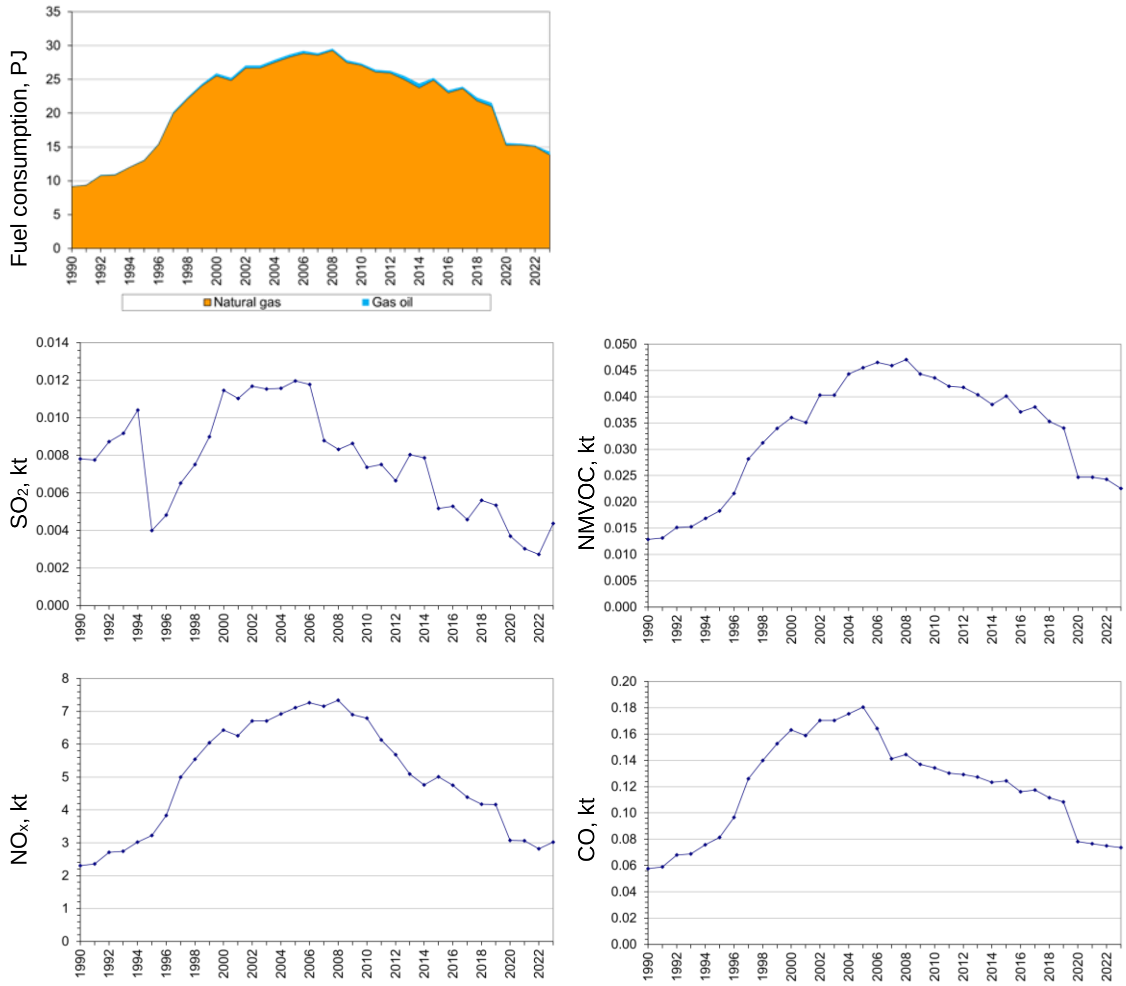


Figure 3.2.36   Time series for 1A1c Oil and gas extraction.

[3] Nybro.

1A2 Industry

Manufacturing industries and construction (Industry) consists of both stationary and mobile sources. In this chapter, only stationary sources are included.

The emission source category 1A2 Industry consists of the subcategories:

- 1A2a Iron and steel
- 1A2b Non-ferrous metals
- 1A2c Chemicals
- 1A2d Pulp, paper and print
- 1A2e Food processing, beverages and tobacco
- 1A2f Non-metallic minerals
- 1A2 g viii Other manufacturing industry

Figure 3.2.37 - 3.2.41 show the time series for fuel consumption and emissions. The subsectors Non-metallic minerals, Other manufacturing industry and Food processing, beverages and tobacco are the main subsectors for fuel consumption and emissions.

The total fuel consumption in industrial combustion was 35 % lower in 2023 than in 1990. The consumption of fossil fuels was 53 % lower. The fuel consumption in industrial plants decreased considerably after 2006 as a result of the financial crisis. The biomass fuel consumption in Industry in 2023 added up to 16 PJ, which is 2.7 times the consumption in 1990. The consumption of coal and liquid fossil fuels have decreased since 1990.

The SO_2 emission has decreased 93 % since 1990. This is mainly a result of lower consumption of residual oil in the industrial sector (Figure 3.2.37). Further, the sulphur content of residual oil and several other fuels has decreased since 1990 due to legislation and tax laws.

The NO_x emission has decreased 64 % since 1990 due to the reduced emission from industrial boilers in general. Cement production is the main emission source accounting for 46 % of the emission from industrial combustion in 2023 and more than 28 % of the emission in 1990-2023.

The NO_x emission from cement production was reduced considerably in 2009-2013. The emission increased in 2013-2023. The NO_x emission from cement industry was 46 % of the total emission from manufacturing industries and construction in 2023. The NO_x emission from cement production was reduced 63 % since 1990. The reduced emission is a result of installation of SCR on all production units at the cement production plant in 2004-2007[4] and improved performance of the SCR units in recent years. A NO_x tax was introduced in 2010 (DMT, 2008). The increase in 2015-2023 is related to a reduction of the NO_x-tax from 2015 (DMT, 2015) and an increased production.

The NMVOC emission has decreased 74 % since 1990. The decrease is mainly a result of decreased emission factor for combustion of wood in industrial boilers. The emission from gas engines has however increased considerably after 1995 due to the increased fuel consumption that is a result of the installation of a large number of industrial CHP plants (Figure 3.2.37). The NMVOC

[4] To meet emission limit.

emission factor for gas engines is much higher than for boilers regardless of the fuel.

The CO emission in 2023 was 19 % higher than in 1990. The main sources of emission are combustion of wood and cement production. The CO emission from mineral wool production is included in the industry sector (2A6). The increased of emission in 1998 is related to the cement production plant in Denmark. The CO emission increased due to combustion of more paper pulp. In the following years, the combustion of this fuel was improved to decrease the CO emission (Annual environmental reports from Aalborg Portland, 1998-2002).

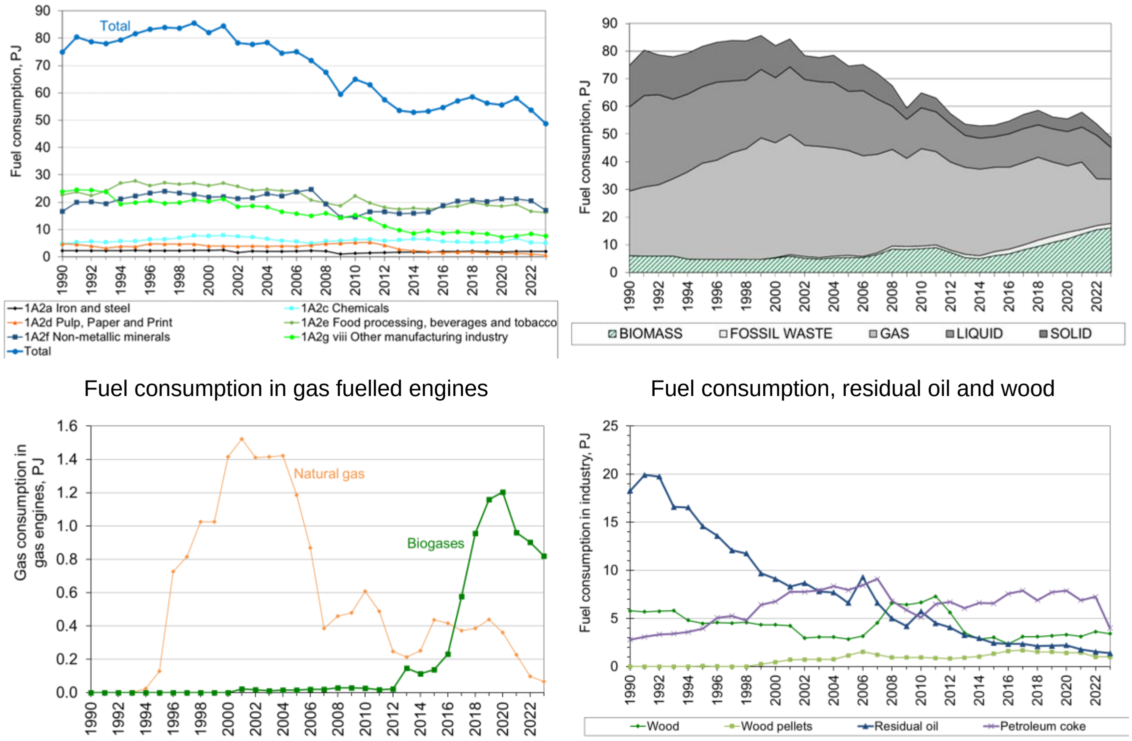


Figure 3.2.37 Time series for fuel consumption, 1A2 Industry.

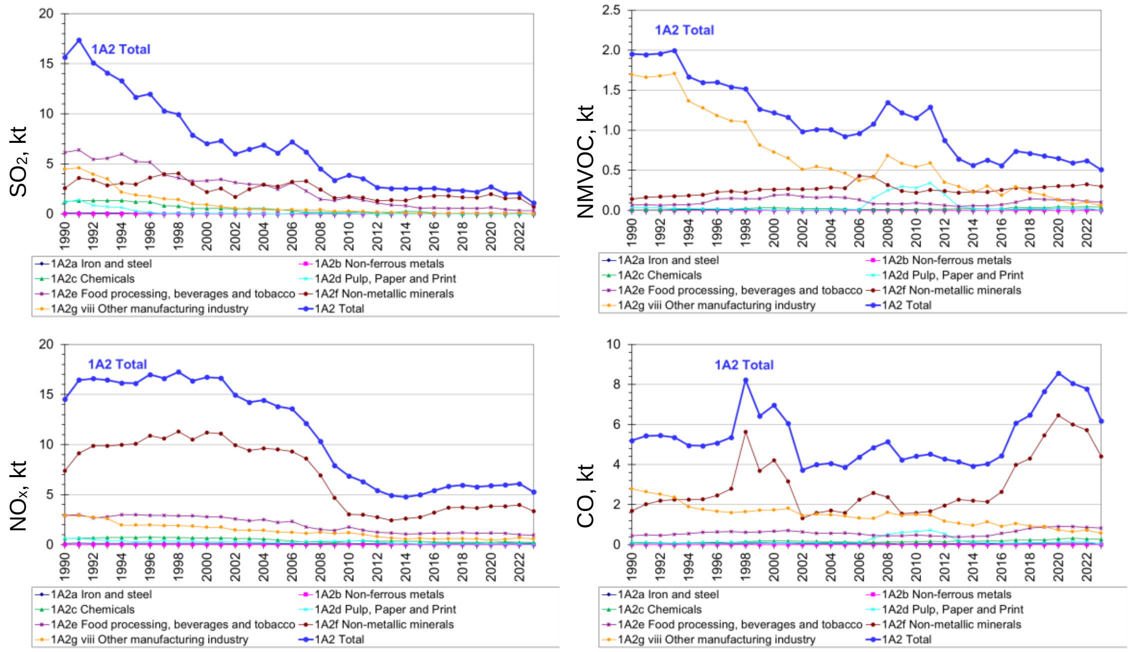


Figure 3.2.38 Time series for SO_2, NO_x, NMVOC and CO emission, 1A2 Industry.

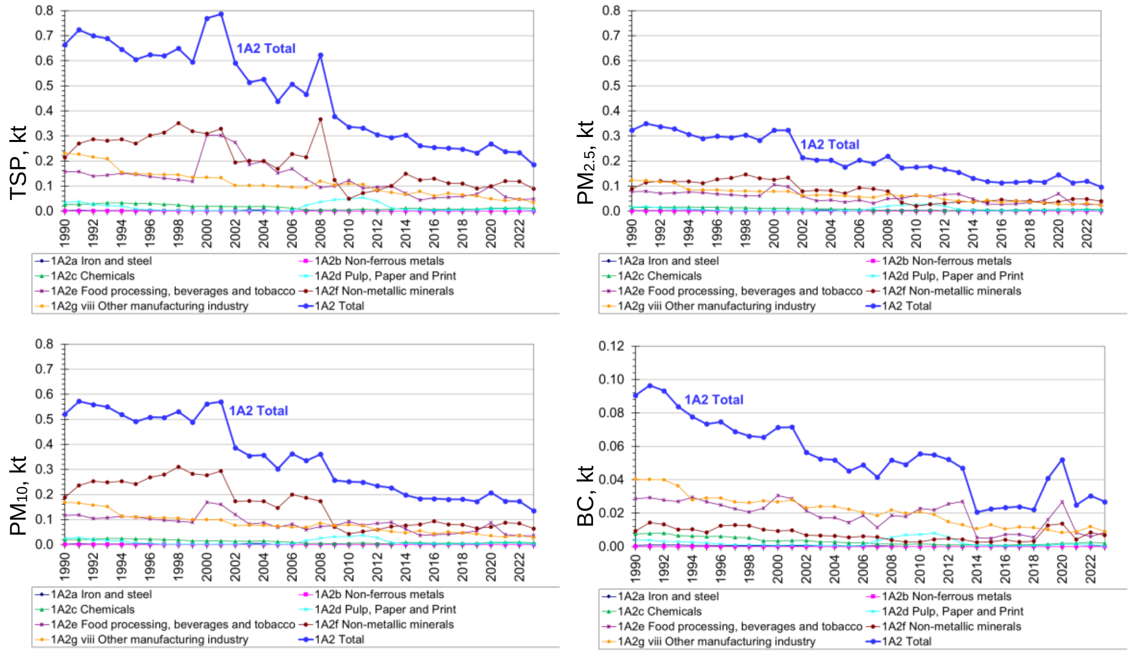


Figure 3.2.39 Time series for PM and BC emission, 1A2 Industry.

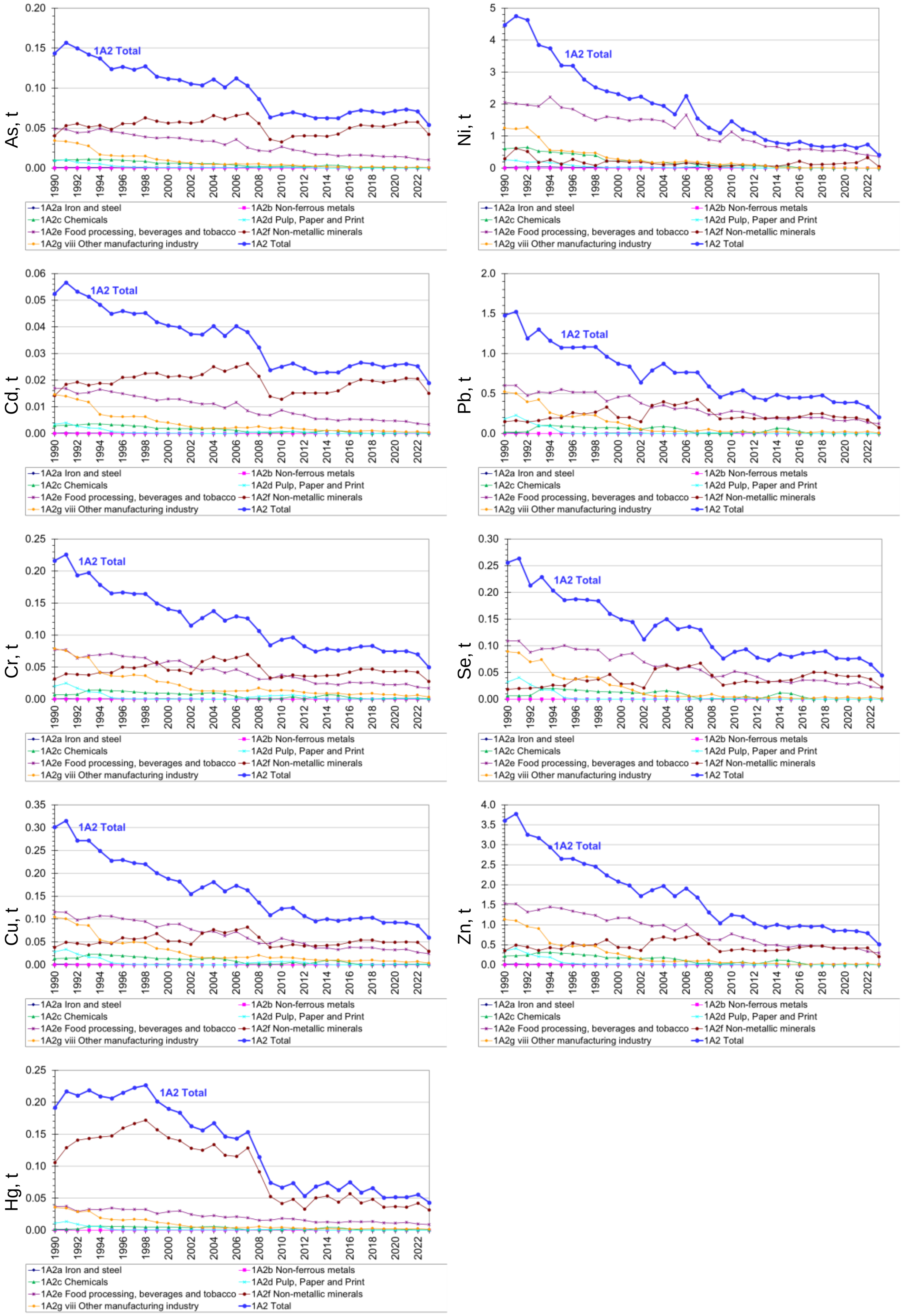


Figure 3.2.40 Time series for HM emission, 1A2 Industry.

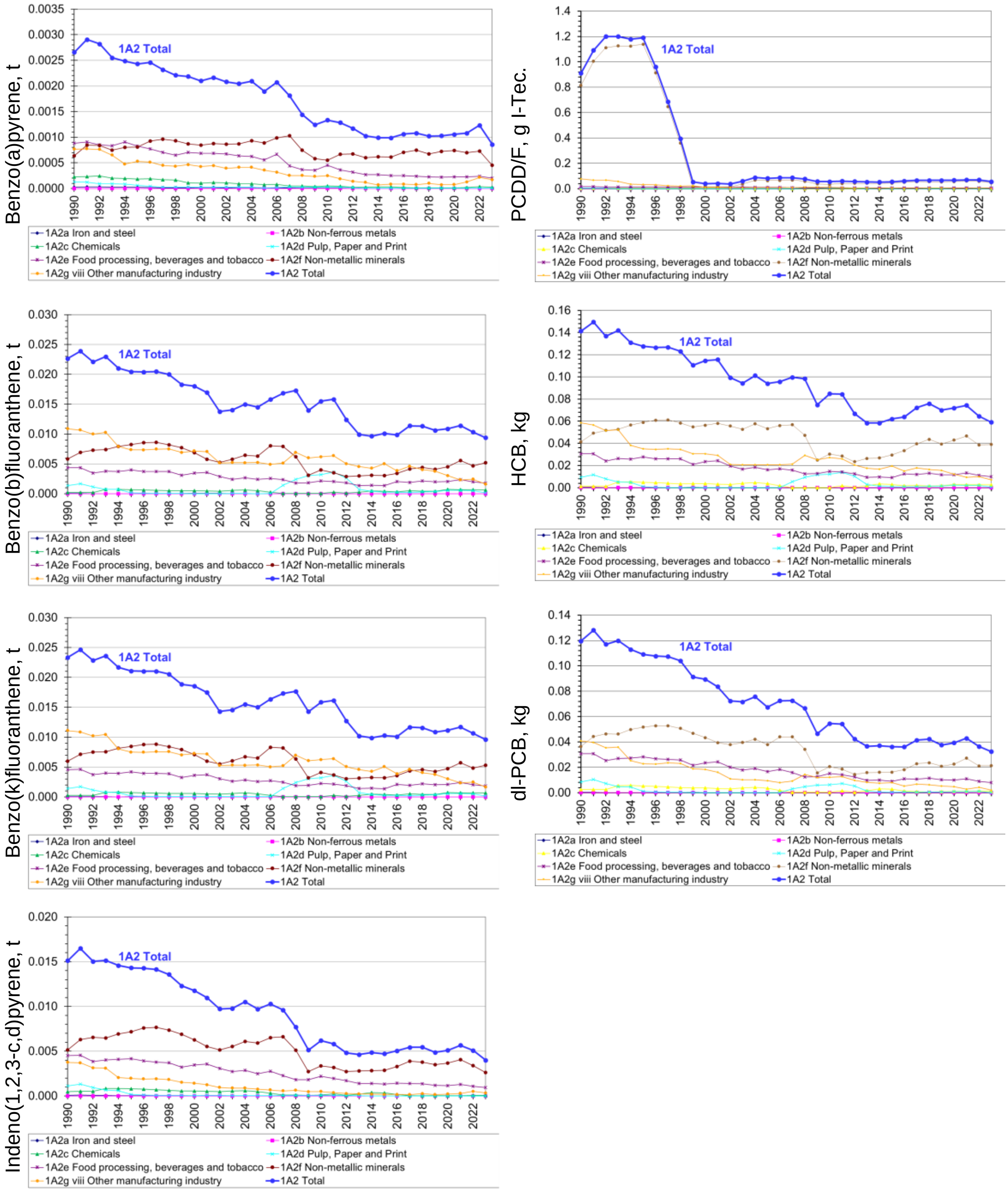


Figure 3.2.41 Time series for PAH, PCDD/F, HCB and dioxin-like PCB emission, 1A2 Industry

1A2a Iron and steel

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

Natural gas is the main fuel in the subsector. In recent years, the consumption of biomethane is also considerable. An increasing part of the distributed gas is biomethane.

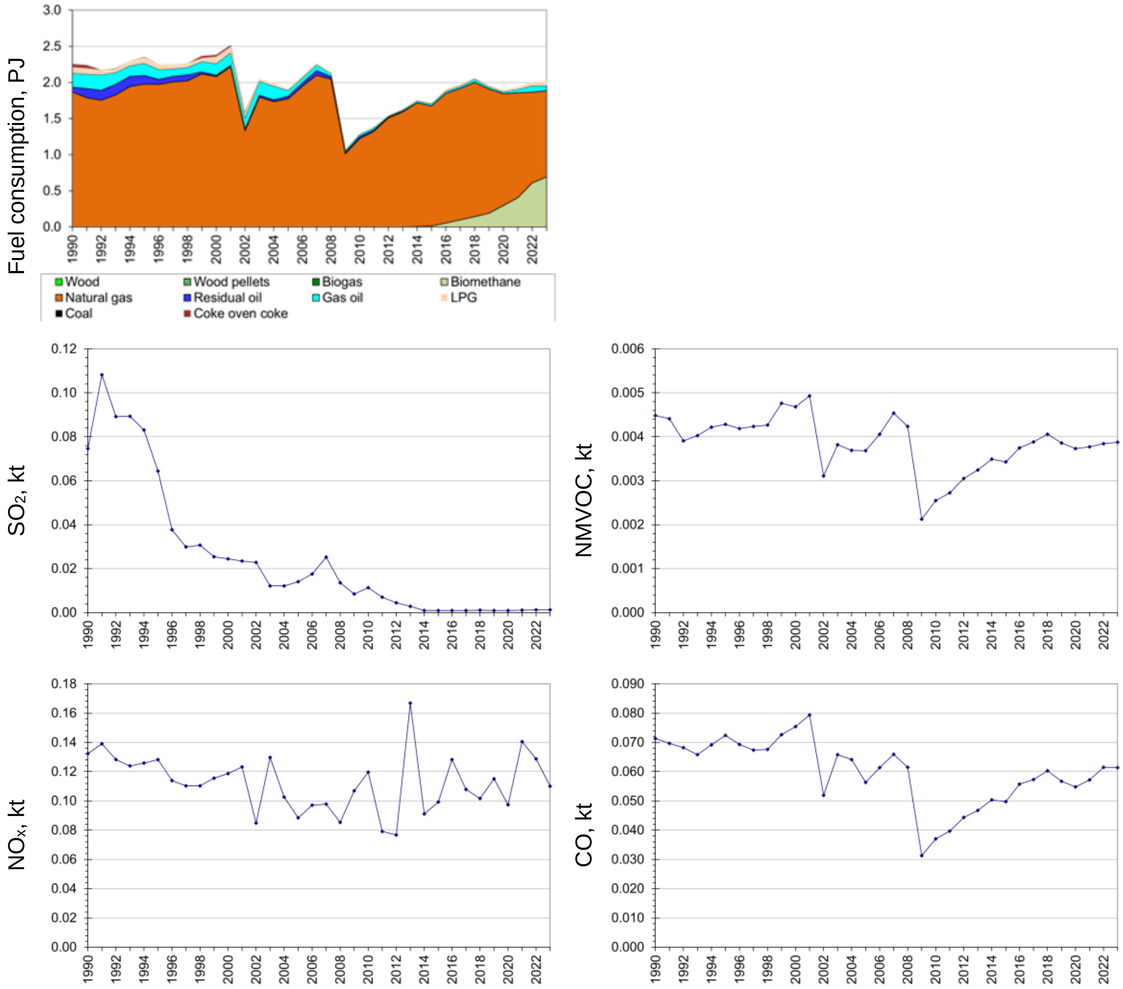


Figure 3.2.42 Time series for 1A2a Iron and steel.

1A2b Non-ferrous metals

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

1A2c Chemicals

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

The fuel consumption was 5 % higher in 2023 than in 1990. Natural gas and in recent years also biomethane are the main fuels in this subsector. The consumption of residual oil has decreased and the SO_2 emission follows this fuel consumption.

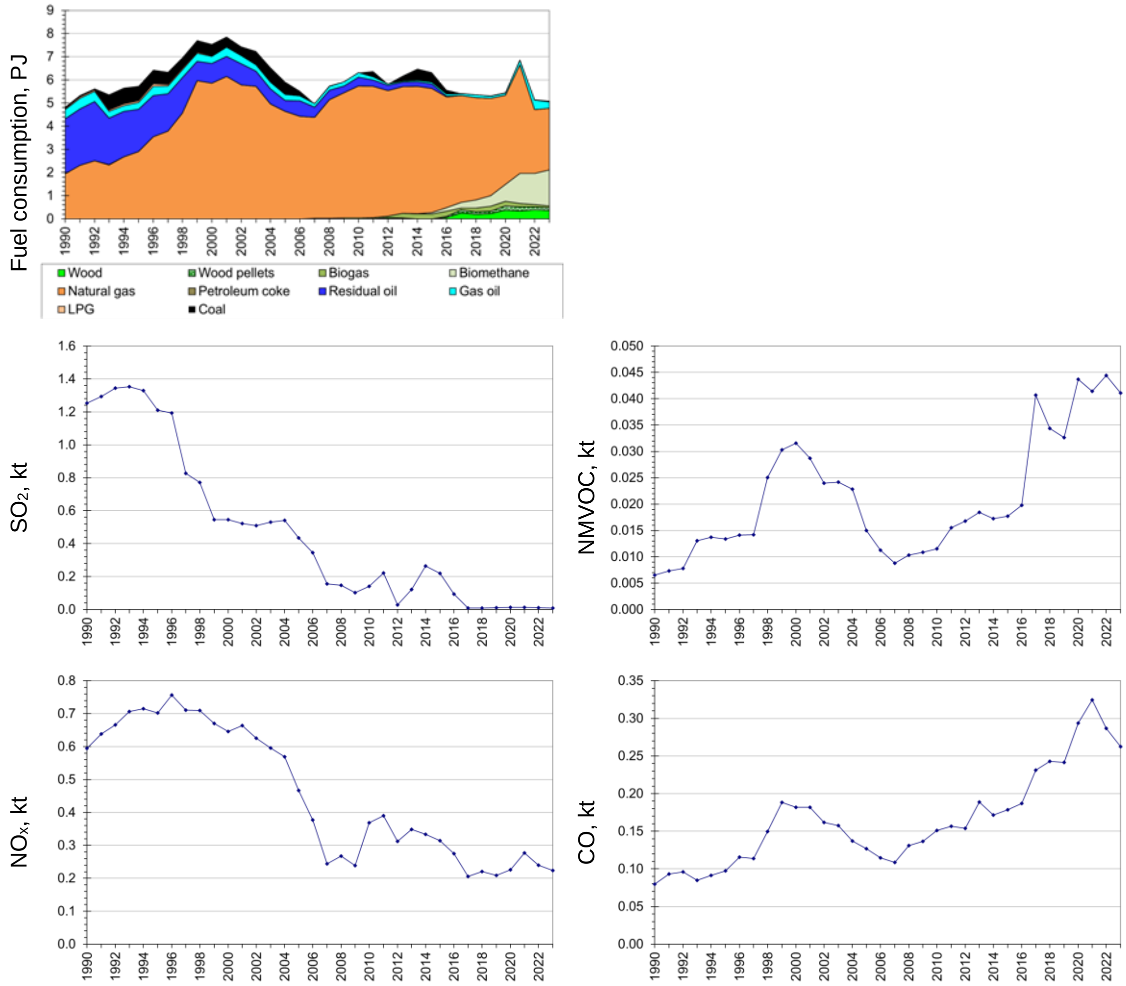


Figure 3.2.43 Time series for 1A2c Chemicals.

1A2d Pulp, paper and print

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

The fuel consumption has decreased 86 % from 1990. The time series are related to both closure of plants and new combustion units in exiting plants. In addition, the liberalisation of the electricity market caused less operational hours of a natural gas fuelled gas turbine. Natural gas, and in 2007-2013 and 2020-2022 also wood, are the main fuels in the subsector.

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

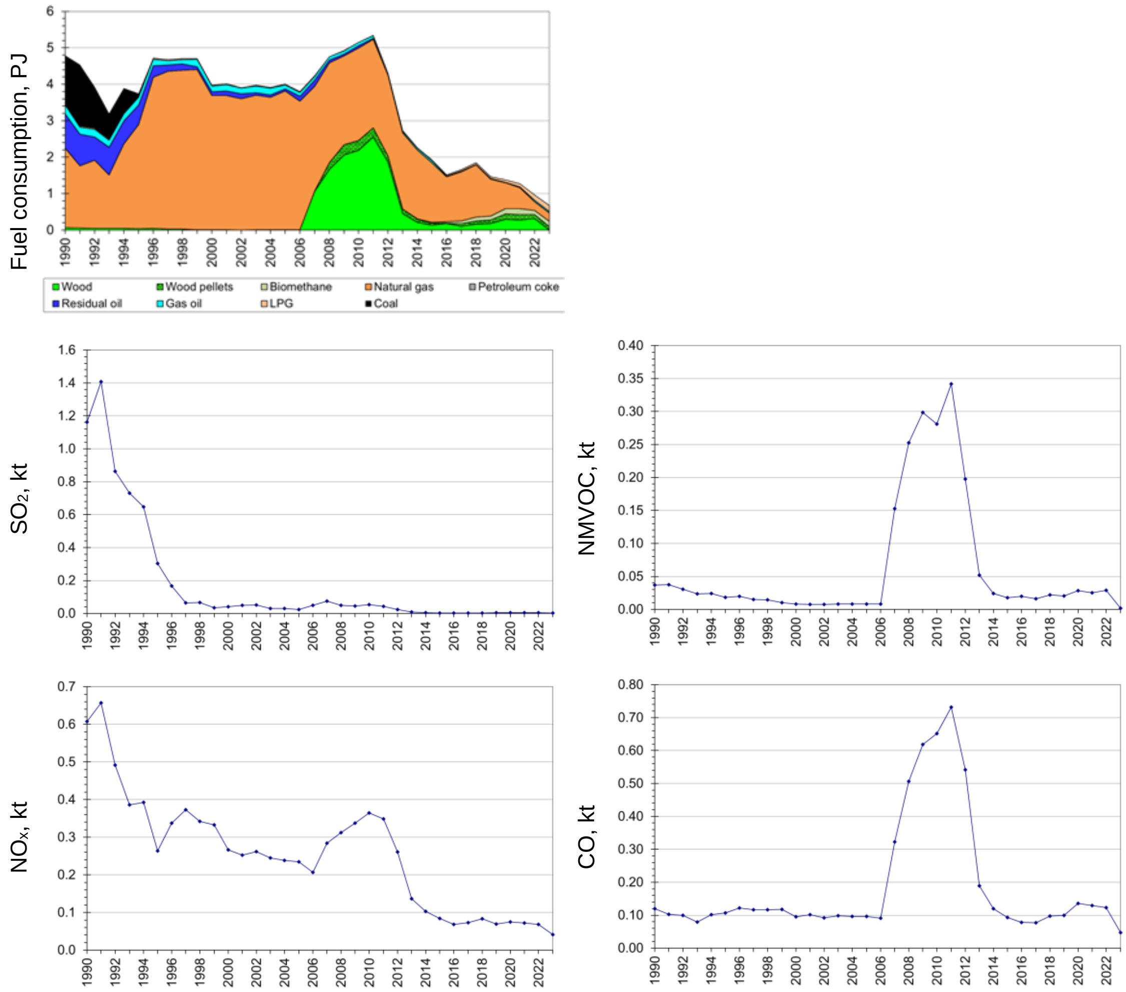


Figure 3.2.44 Time series for 1A2d Pulp, paper and print.

1A2e Food processing, beverages and tobacco

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

The fuel consumption decreased 28 % since 1990. Natural gas, biomethane, residual oil and coal are the main fuels in the subsector. The consumption of coal and residual oil has decreased.

The decreased consumption of residual oil and coal is reflected in the SO_2 emission time series. The time series for NMVOC and CO are influenced by the time series for consumption of natural gas and biogases in gas engines, see also Figure 3.2.37.

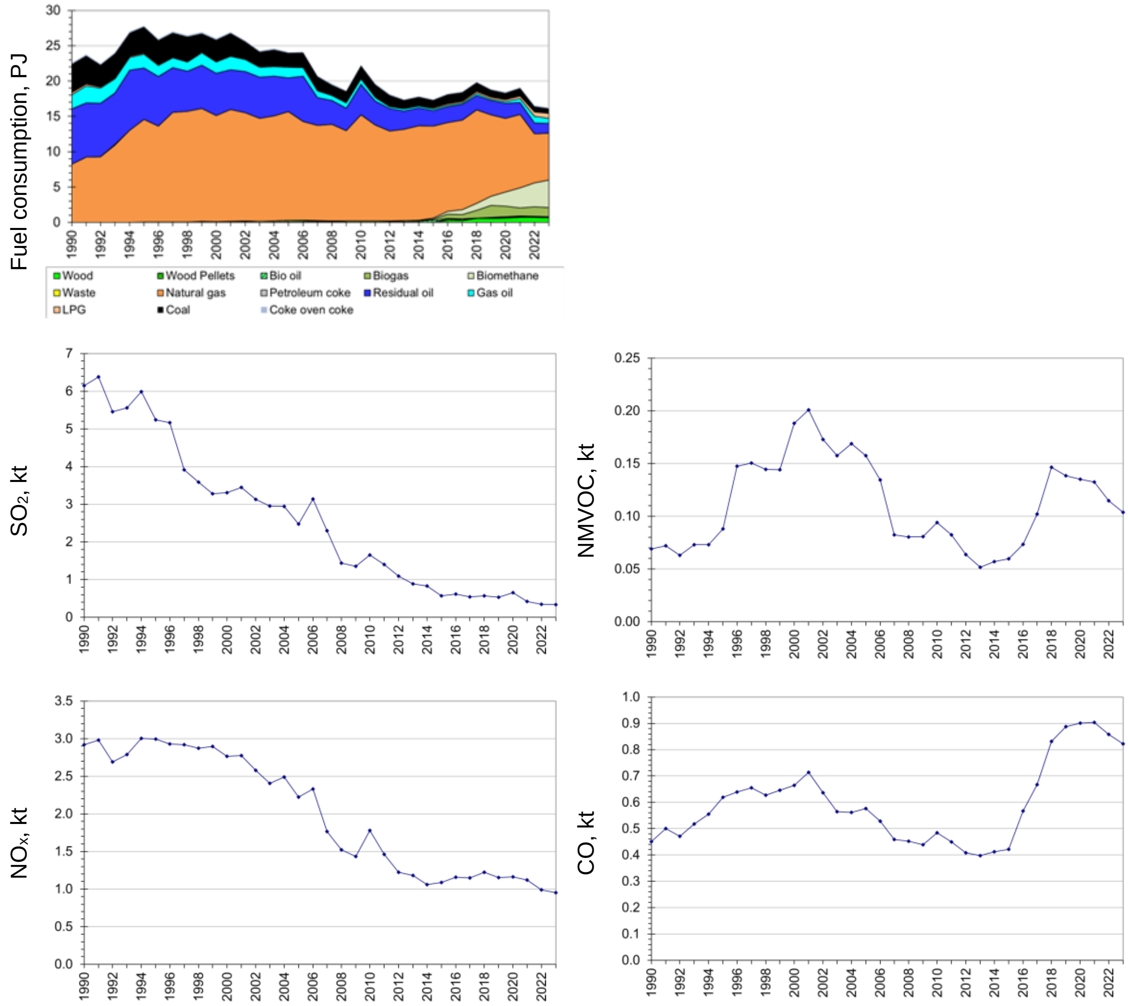


Figure 3.2.45 Time series for 1A2e Food processing, beverages and tobacco.

1A2f Non-metallic minerals

Non-metallic minerals is a considerable industrial subsector. The subsector includes cement production that is a major industrial emission source in Denmark. Production of mineral wool and glass is also included in the subsector. Figure 3.2.46 shows the time series for fuel consumption and emissions of SO_2, NO_x, NMVOC and CO.

The fuel consumption in 2023 was 3 % higher than in 1990. Due to the global recession, cement production decreased in 2008 and 2009, but then increased again. This is reflected in the time series for fuel consumption. Petroleum coke, natural gas, biomethane, waste and coal are the main fuels in the subsector in recent years. The consumption of coal has decreased.

The emission of SO_2 was 72 % lower in 2023 than in 1990.

The emission of NO_x was 54 % lower in 2023 than in 1990.The reduced NO_x emission is a result of installation of SCR on all production units at the cement production plant in 2004-2007[5] and improved performance of the SCR units in the following years. A NO_x tax was introduced in 2010 (DMT, 2008). The increased emission after 2015 is related to a reduction of the NO_x-tax (DMT, 2015) and an increased production rate.

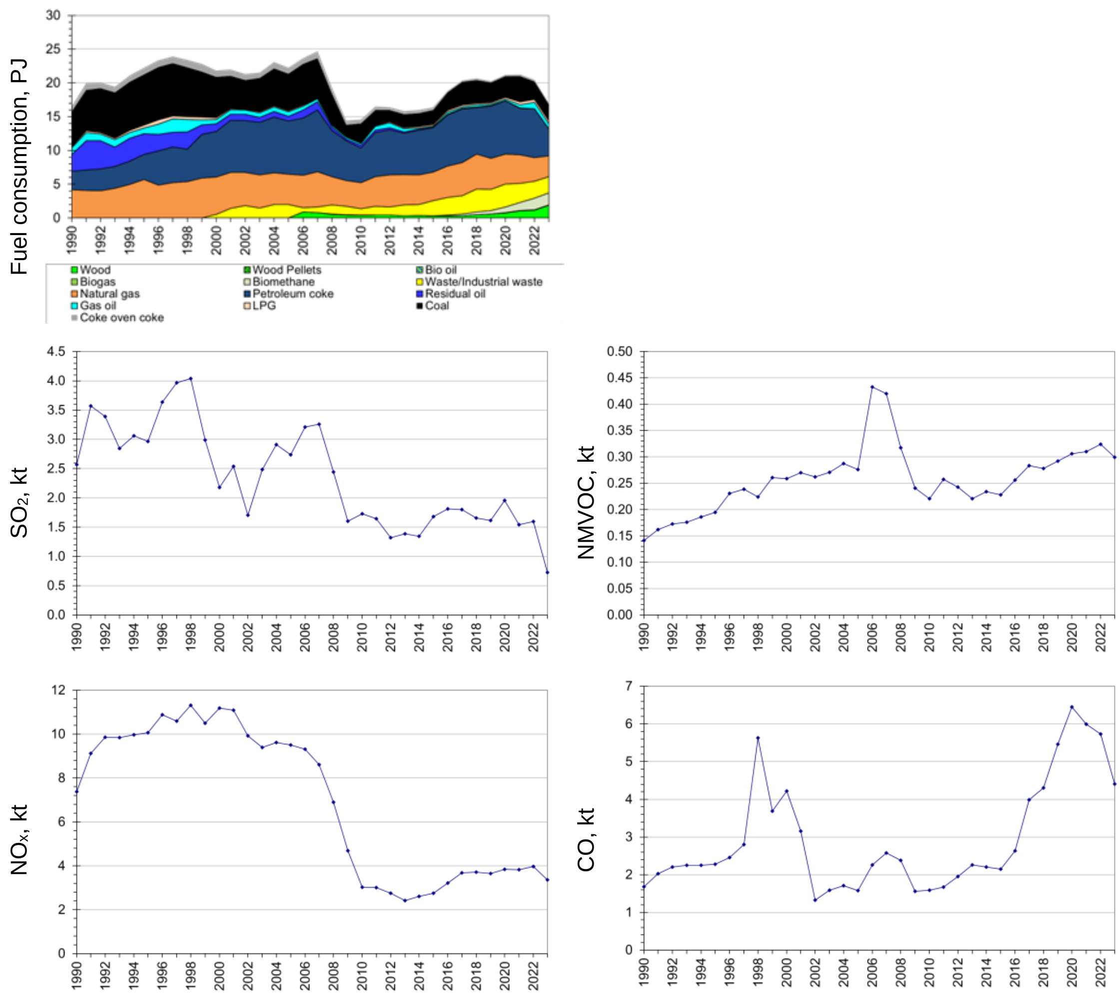


Figure 3.2.46 Time series for 1A2f Non-metallic minerals

[5] To meet emission limit.

1A2g Other manufacturing industry

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

The fuel consumption decreased 68 % since 1990. Natural gas, biomethane, wood and gas oil were the main fuels in the subsector in 2023. The consumption of coal and oil has decreased since 1990.

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

The NO_x emission decreased 80 % since 1990.

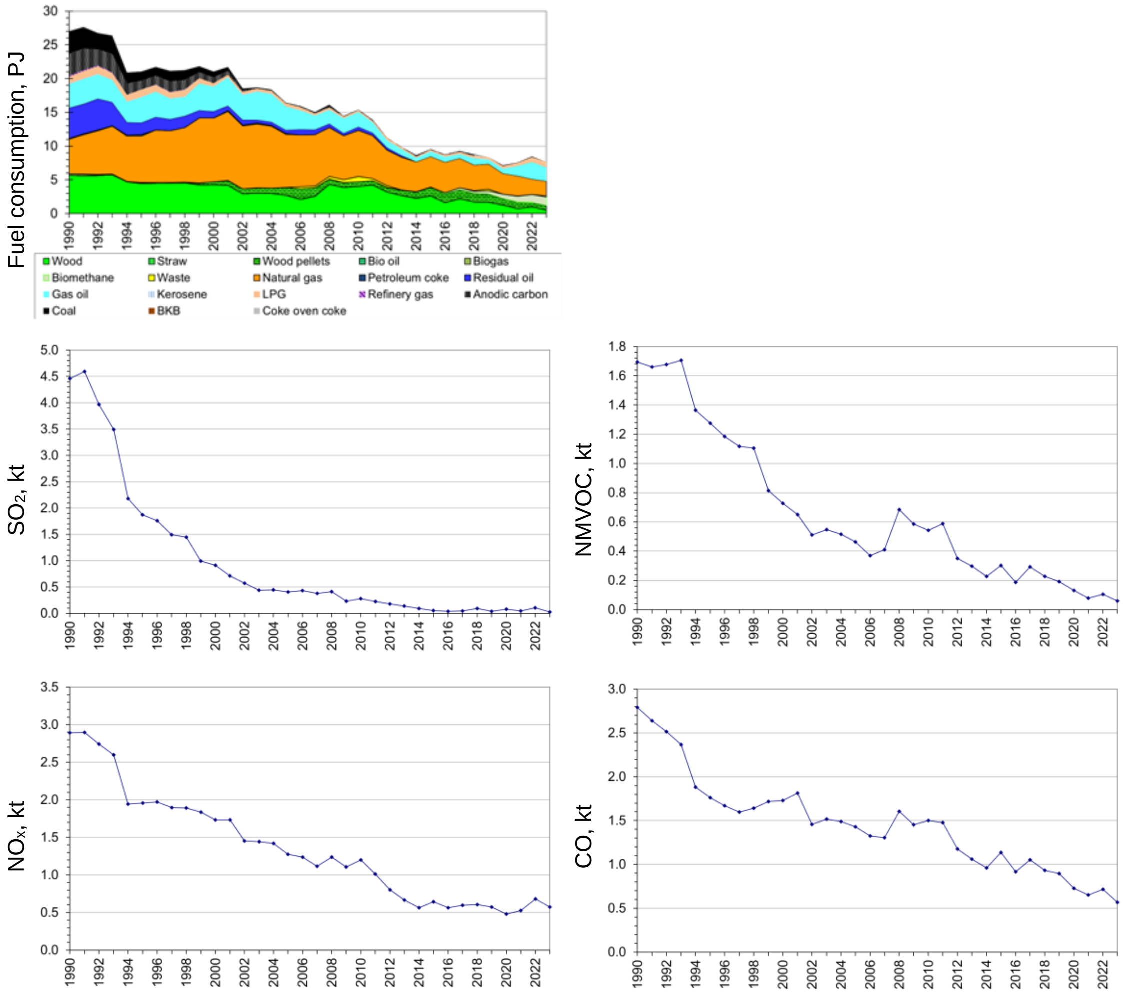


Figure 3.2.47 Time series for 1A2g Other manufacturing industry.

1A4 Other Sectors

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

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

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

The PM emissions increased until 2007 and decreased after 2007. The increase until 2007 was caused by the increased wood combustion in residential plants. However, the PM emission factors have decreased for this emission source category due to installation of modern stoves and boilers (see Chapter 3.2.7). The stabilisation of wood consumption in residential plants in 2007-2023 has resulted in a decrease of PM emission from stationary combustion after 2007. The PM emission data for residential wood combustion include condensable particles.

The emission of BC was 24 % lower in 2023 than in 1990. The largest emission sources for BC is combustion of wood and straw in residential plants and in agricultural/forestry plants. The consumption of wood in residential plants has increased since 1990, but the emission factor has decreased due to implementation of new improved stoves and boilers, see Chapter 3.2.7.

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

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

The emission of PCDD/F has increased 20 % since 1990. The main emission sources are residential combustion of wood, wood pellets, and straw. The dioxin emission factors for residential wood combustion are dependent on the wood origin but independent of stove technology (Chapter 3.2.7). Thus, the dioxin emission from residential wood combustion has not decreased similar to e.g. the PM and PAH emissions due to replacements of old stoves and boilers.

The emission of dl-PCBs has decreased 64 % since 1990.

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

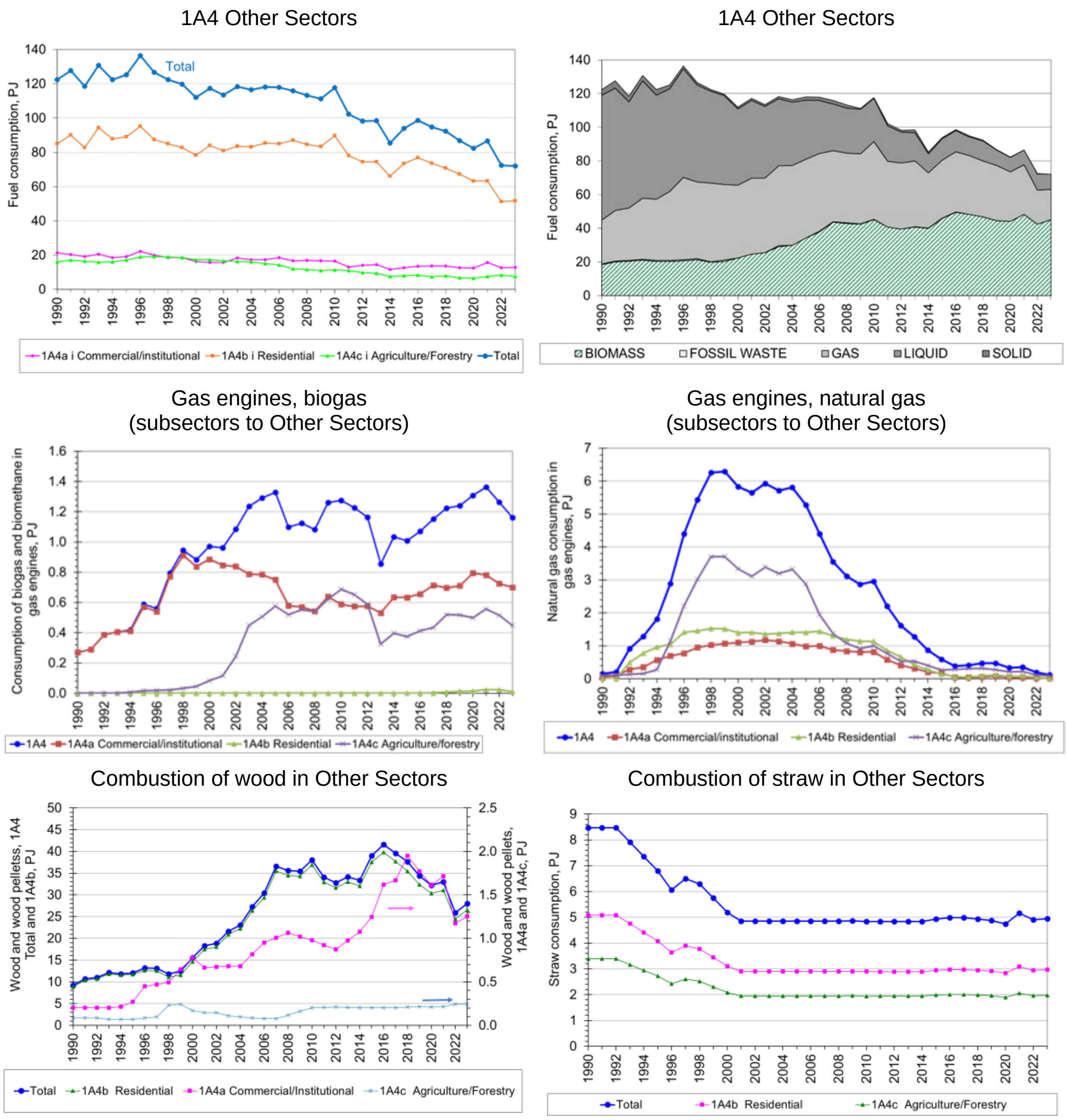


Figure 3.2.48 Time series for fuel consumption, 1A4 Other Sectors.

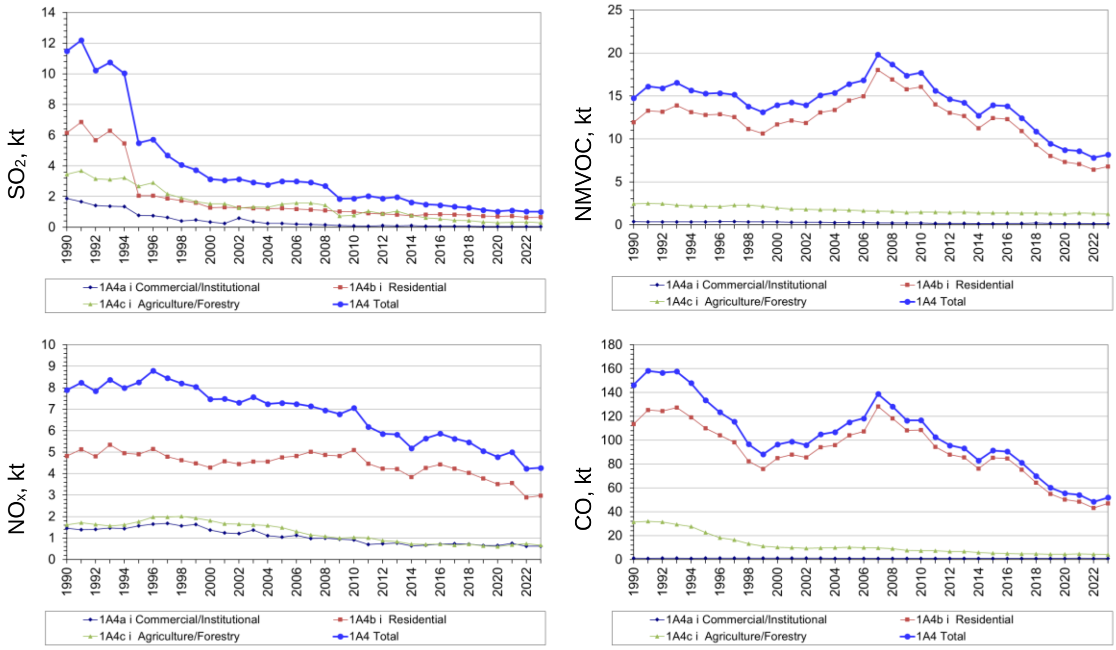


Figure 3.2.49 Time series for SO_2, NO_x, NMVOC and CO emission, 1A4 Other Sectors.

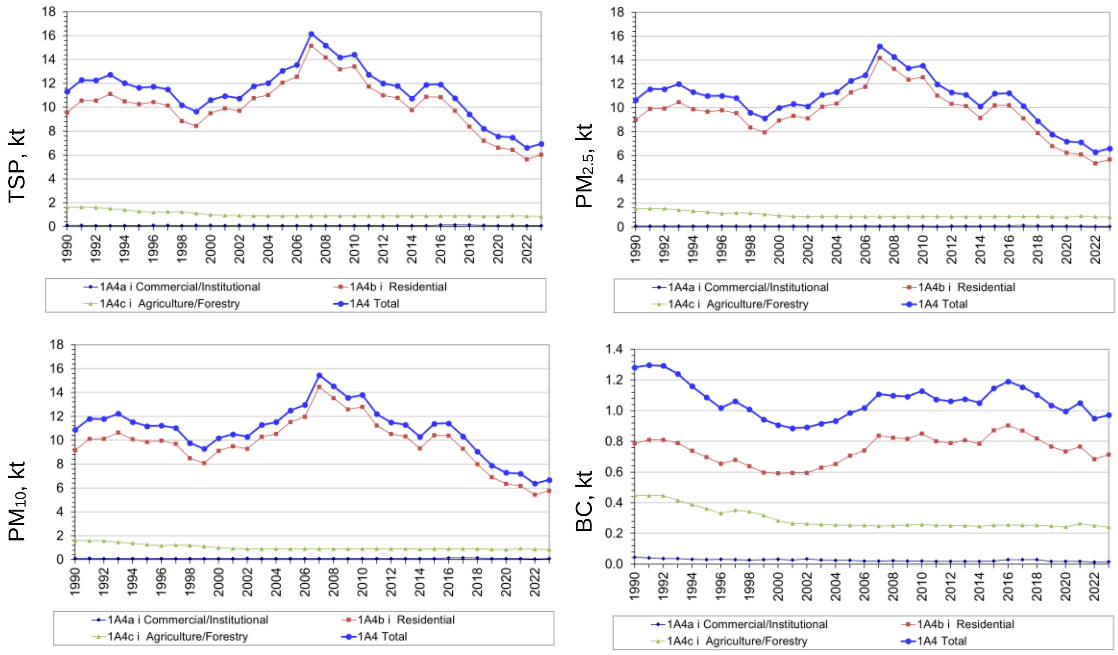


Figure 3.2.50 Time series for PM and BC emission, 1A4 Other Sectors.

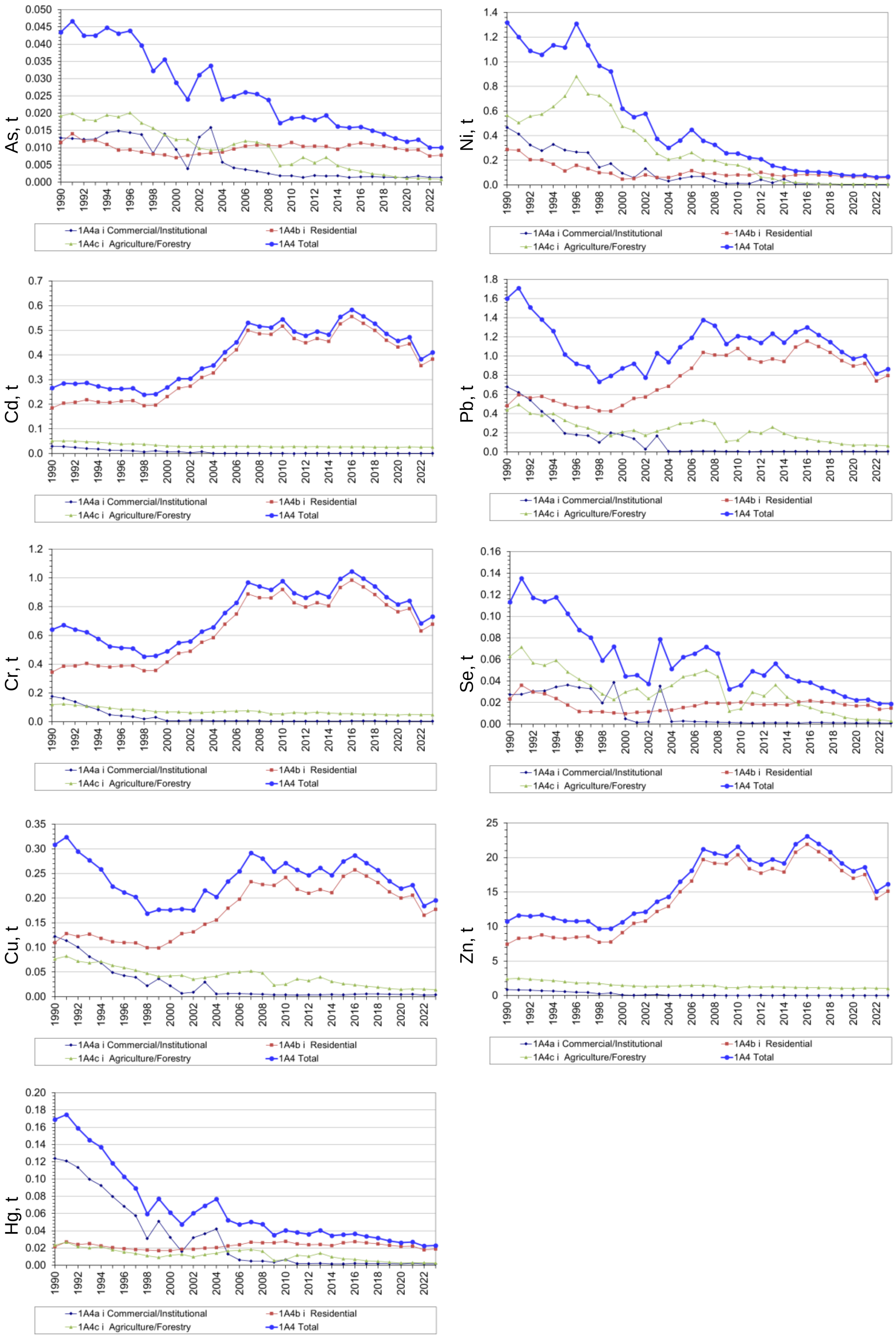


Figure 3.2.51 Time series for HM emission, 1A4 Other Sectors.

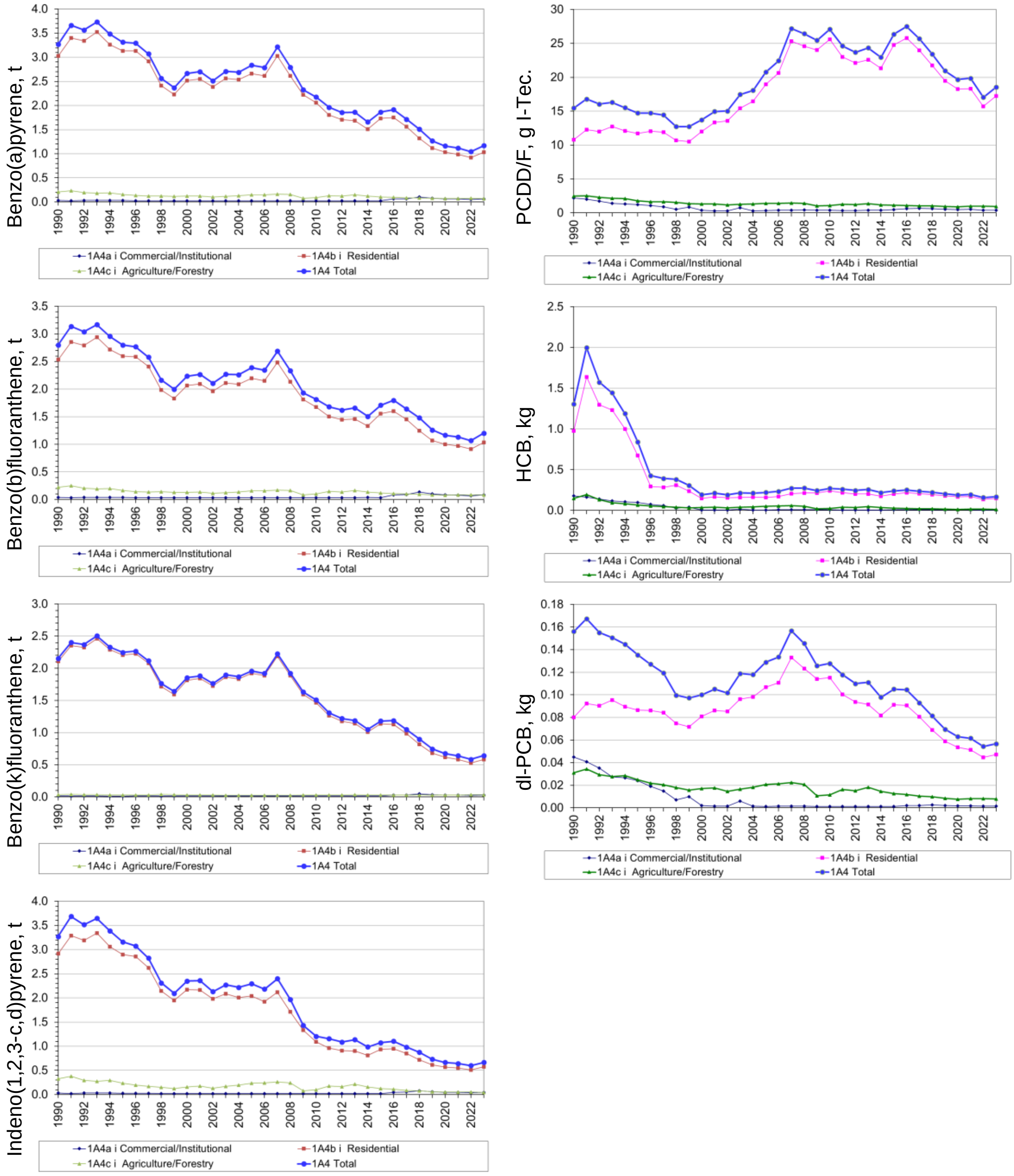


Figure 3.2.52 Time series for PAH, PCDD/F, HCB and dioxin-like PCB emission, 1A4 Other Sectors.

1A4a i Commercial and institutional plants

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

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

The fuel consumption in Commercial/institutional plants has decreased 40 % since 1990 and the fuels applied have changed. In later years, the main fuel is natural gas and biomethane. The consumption of gas oil has decreased since 1990.

The SO_2 emission has decreased 98 % since 1990. The decrease is a result of both the change of fuel from gas oil to natural gas and of the lower sulphur content in gas oil and in residual oil. The lower sulphur content (0.05 % for gas oil since 1995 and 0.7 % for residual oil since 1997) is a result of Danish tax laws (DEPA, 1998).

The NO_x emission was 58 % lower in 2023 than in 1990. The decrease is mainly a result of the lower fuel consumption but also the change from gas oil to natural gas has contributed to the decrease. The emission from wood combustion has increased.

The NMVOC emission in 2023 was 64 % lower than the 1990 emission level. The combustion of wood has increased but the emission factor has decreased. The increase and decrease of natural gas consumption in gas engines (Figure 3.2.48) is also reflected in the time series for NMVOC emission.

The CO emission has decreased 24 % since 1990. This is a result of the change of fuels used in the sector. The emission from wood has increased whereas the emission from gas oil has decreased.

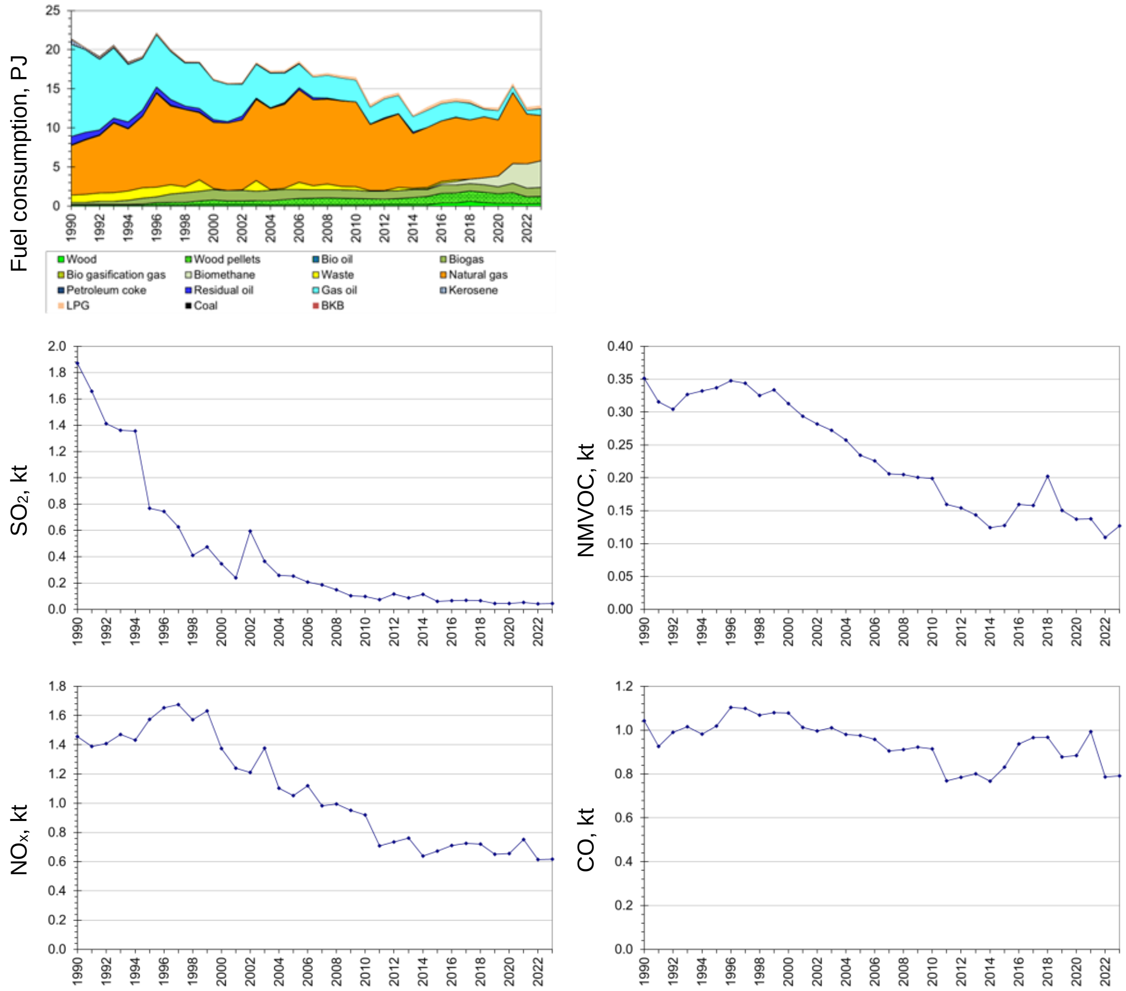


Figure 3.2.53 Time series for 1A4a Commercial /institutional.

1A4b i Residential plants

The emission source category Residential plants consists of both stationary and mobile sources. In this chapter, only stationary sources are included (1A4b i). Figure 3.2.54 – Figure 3.2.57 shows the time series for fuel consumption and emissions. Time series for emissions of PM, PAHs, PCDD/F, HCB and dl-PCBs are also shown for this subsector because residential plants is a large emission source for these pollutants. The time series for residential combustion of wood and wood pellets is also shown in the figures.

The methodology applied for the emission inventory for residential wood combustion is explained in chapter 3.2.7.

For residential plants, the total fuel consumption was 39 % lower in 2023 than in 1990. Both energy savings, increased use of district heating, and installation of electrical heat pumps added to the lower fuel consumption in 2023.

The large decrease (19 %) from 2021 to 2022 was caused by high fuel prices in the winter 2022/2023, especially for natural gas/biomethane and wood pellets.

The consumption of gas oil has decreased since 1990 whereas the consumption of wood, wood pellets and biomethane has increased considerably.

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

The large decrease (89 %) of SO_2 emission from residential plants is mainly a result of a change of sulphur content in gas oil since 1995. The lower sulphur content (less than 0.05 %) is a result of Danish tax laws (DEPA, 1998). In addition, the consumption of gas oil has decreased and the consumption of natural gas that results in very low SO_2 emissions has increased. Finally, coal consumption in residential plants in the early 1990s was a considerable emission source for SO_2 emission until 1996.

The NO_x emission has decreased by 38 % since 1990. As mentioned above the fuel consumption has decreased 39 %. The emission factor for wood is higher than for natural gas and gas oil and both consumption and the emission factor for wood have increased[6]. However, the NO_x emission factor for natural gas has decreased.

The emission of NMVOC has decreased 43 % since 1990. The consumption of wood has increased but the emission factor has decreased since 1990. The emission factors for wood and straw are higher than for liquid or gaseous fuels.

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

The CO emission has decreased 59 % since 1990. The use of wood that is the main source of emission has increased whereas the emission factor has decreased. The emission from combustion of straw has decreased whereas the consumption of wood pellets has increased since 1990.

The NH_3 emission increased from 1990-2007 and decreased after 2007. The emission from residential wood combustion is the predominant source all years. The emission factor for older stoves/boilers is higher than for the modern stoves/boilers. The decreased consumption of wood and the decreasing implied emission factor for residential wood combustion (due to replacement of older units) both cause a decreasing NH_3-emission after 2007.

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

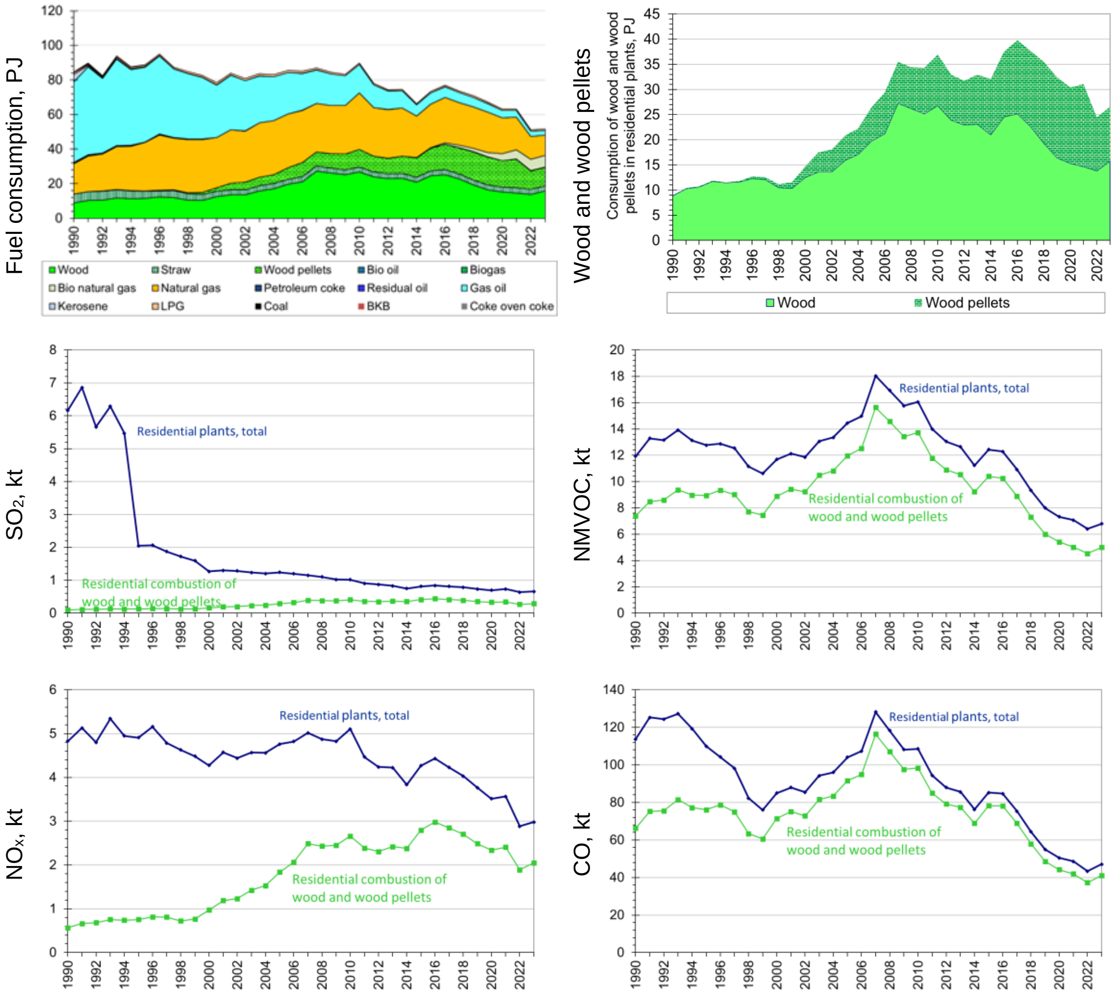


Figure 3.2.54 Time series for fuel consumption and emissions from 1A4b Residential plants.

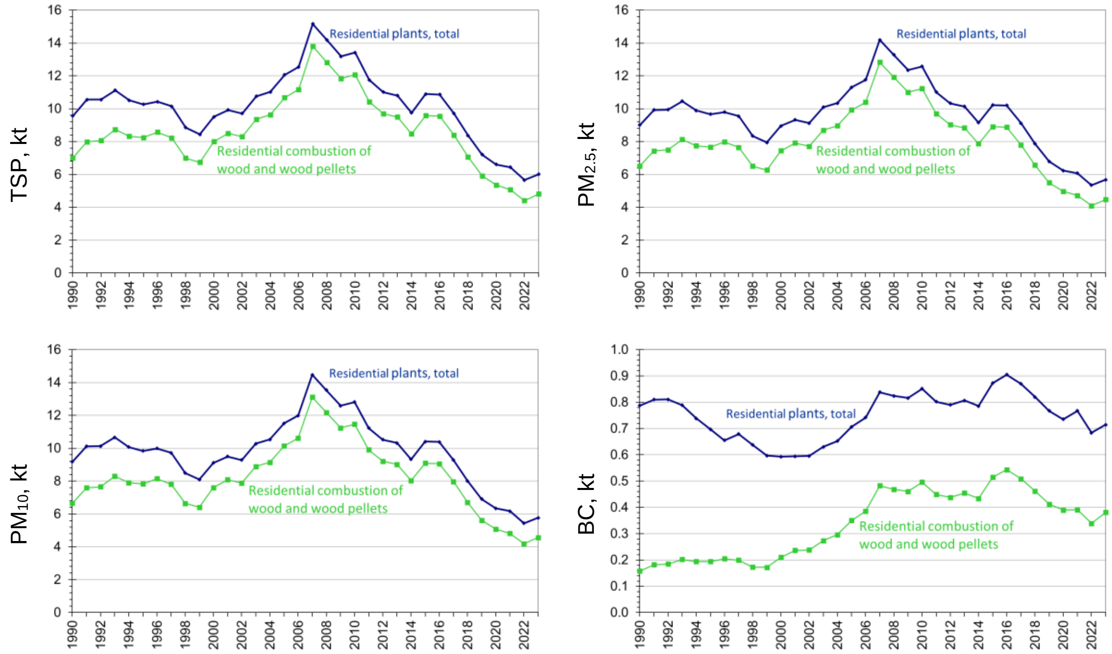


Figure 3.2.55 Time series for PM emissions from Residential plants.

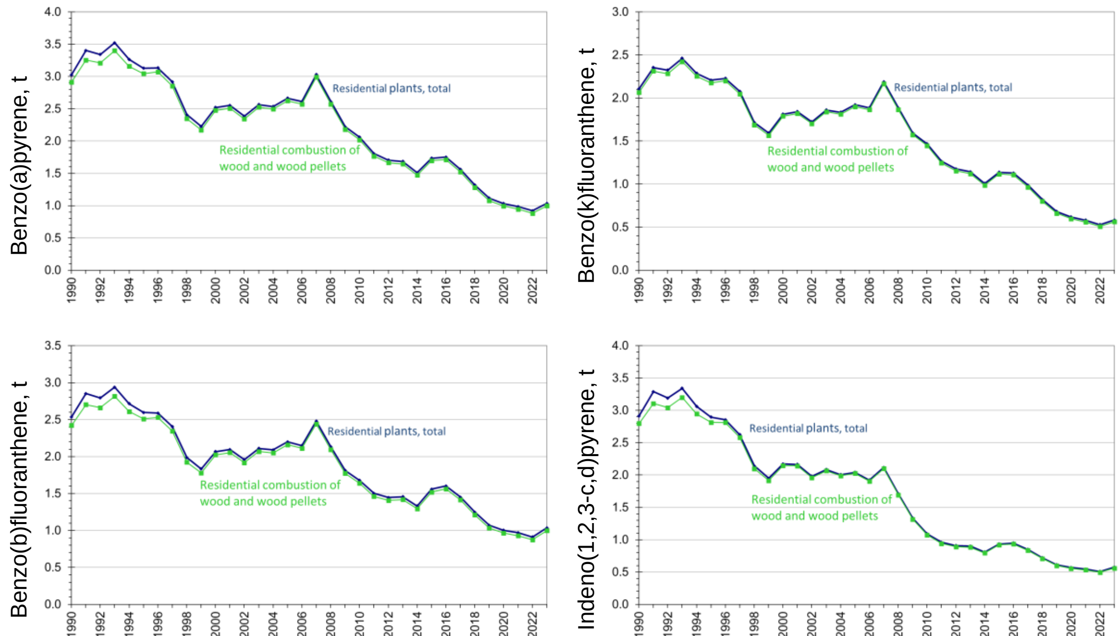


Figure 3.2.56 Time series for PAH emissions from Residential plants.

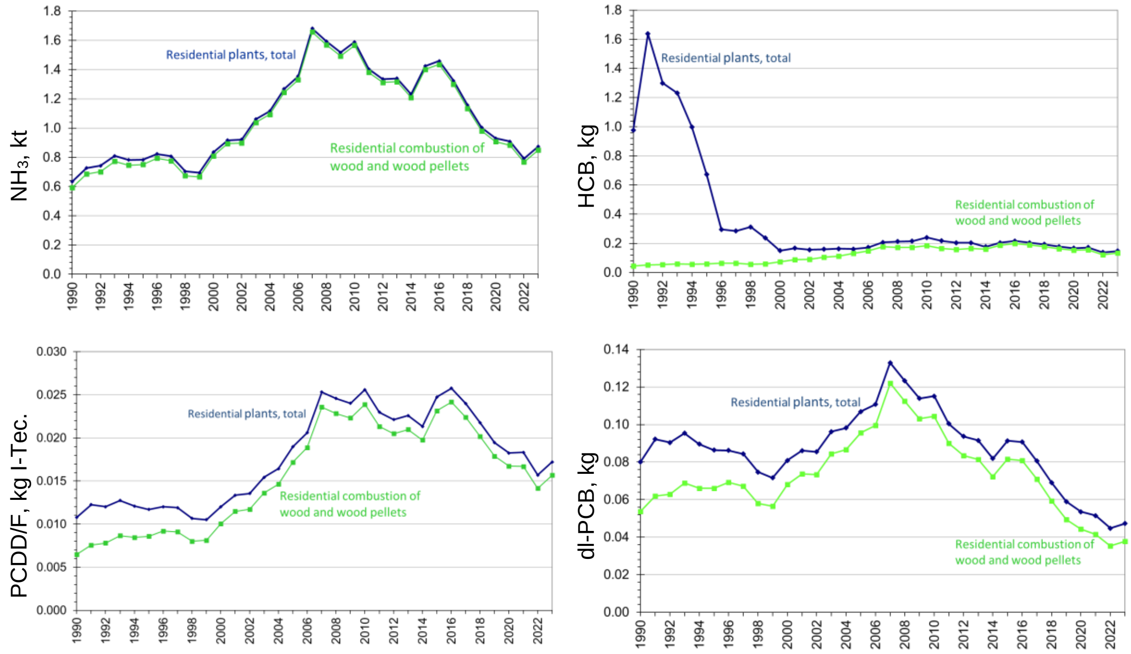


Figure 3.2.57 Time series for emissions of NH_3, PCDD/F, HCB and dl-PCBs from Residential plants.

1A4c i Agriculture/forestry

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

For plants in Agriculture/forestry, the fuel consumption has decreased 53 % since 1990.

The type of fuel that has been applied has changed since 1990. In the years 1994-2004, the consumption of natural gas was high, but after 2004, the consumption decreased again. A large part of the natural gas consumption has been applied in gas engines (Figure 3.2.48). Most CHP plants in Agriculture/forestry based on gas engines came in operation in 1995-1999. The decrease after 2004 is a result of the liberalisation of the electricity market.

The consumption of coal, residual oil and straw has decreased since 1990. The consumption of biogas has increased.

The SO_2 emission was 91 % lower in 2023 than in 1990.

The emission of NO_x was 58 % lower in 2023 than in 1990.

The emission of NMVOC has decreased 49 % since 1990.

The CO emission has decreased 87 % since 1990. The major emission source is combustion of straw. In addition to the decrease of straw consumption, the emission factor for straw has also decreased since 1990.

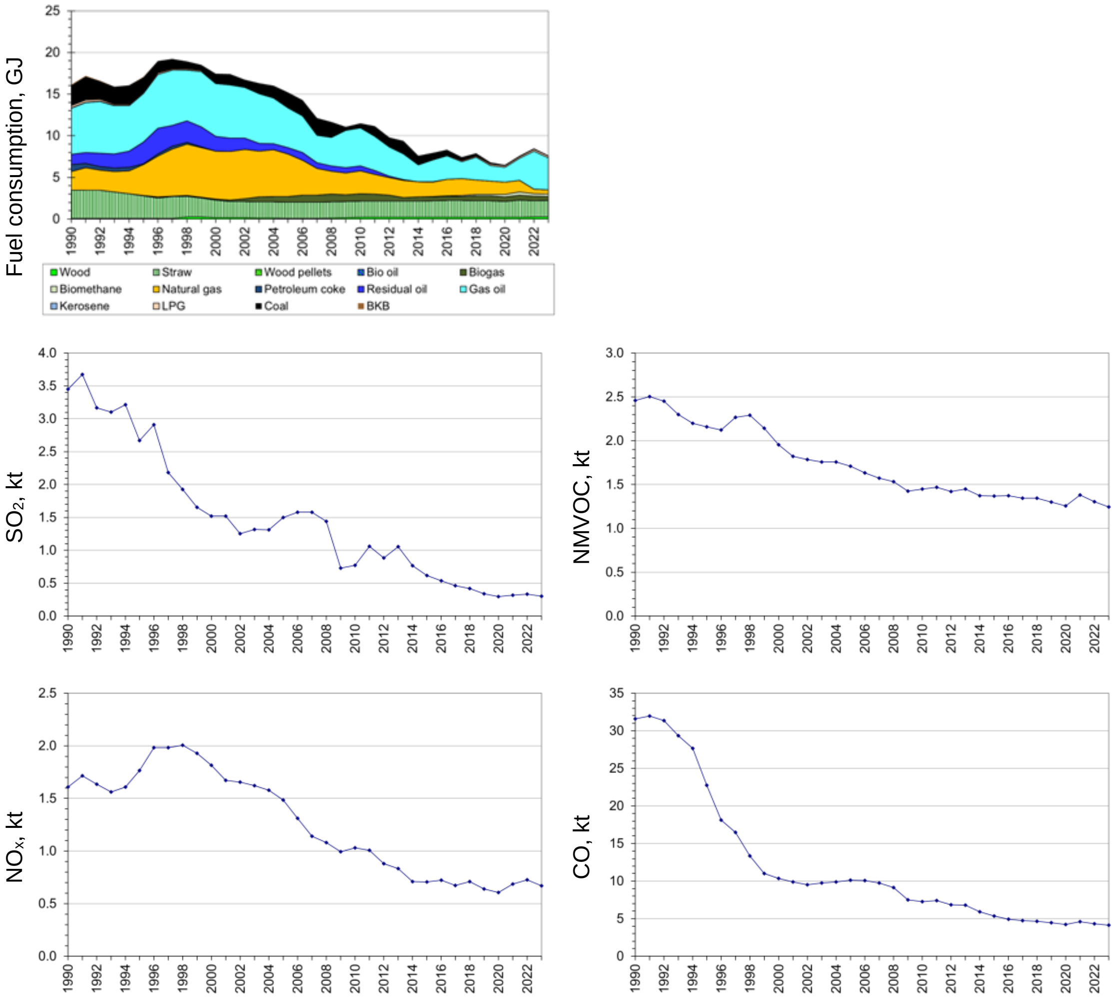


Figure 3.2.58 Time series for 1A4c Agriculture/Forestry.

3.2.6 Methodological issues

The Danish emission inventory is based on the CORINAIR (CORe INventory on AIR emissions) system, which is a European program for air emission inventories. CORINAIR includes methodology structure and software for inventories. The methodology is described in the EEA Guidebook (EEA, 2023). Emission data are stored in MS Access databases, from which data are transferred to the reporting formats.

In the Danish emission database, all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution) according the CORINAIR system. The emission inventories are prepared from a complete emission database based on the SNAP source categories. Aggregation to the source category codes used in CRF is based on a correspondence list enclosed in Annex 3A-1.

The emission inventory for stationary combustion is based on activity rates from the Danish energy statistics. General emission factors for various fuels, plants and sectors have been determined. Some large plants, such as power plants, are registered individually as large point sources and plant-specific emission data are used.

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

Large point sources

Large emission sources such as power plants, industrial plants and refineries are included as large point sources in the Danish emission database. Each point source may consist of more than one part, e.g. a power plant with several units. By registering the plants as point sources in the database, it is possible to use plant-specific emission factors.

In the inventory for the year 2023, 71 stationary combustion plants are specified as large point sources. Plant specific emission data are available from 63 of the plants[7]. The point sources include:

- Power plants and decentralised CHP plants.
- Waste incineration plants.
- Large industrial combustion plants.
- Petroleum refining plants.

The criteria for selection of point sources are:

- All centralized power plants, including smaller units.
- All units with a capacity of above 25 MW_e.
- All district heating plants with an installed effect of 50 MW_{th} or above and significant fuel consumption.
- All waste incineration plants obligated to report environmental data annually according to Danish law (DEPA, 2010b; DEPA, 2020b).
- Industrial plants,

[7] For CO_2 or other pollutants.

- With an installed effect of 50 MW_{th} or above and significant fuel consumption.
- With a significant process related emission.

The fuel consumption of stationary combustion plants registered as large point sources in the 2023 inventory was 167 PJ. This corresponds to 52 % of the overall fuel consumption for stationary combustion.

A list of the large point sources for 2023 is provided in Annex 3A-6. The number of large point sources registered in the databases increased from 1990 to 2022. Aggregated fuel consumption rates for the large point sources are also shown in Annex 3A-6.

The emissions from a point source are based either on plant specific emission data or, if plant specific data are not available, on fuel consumption data and the general Danish emission factors. Which emission data are plant-specific is shown in Annex 3A-6.

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

Table 3.2.15 Emission share, plant specific data.

Pollutant	Share from plant specific data, %
SO_2	46%
NO_x	41%
NMVOC	0.3%
CO	9%
NH_3	6.7%
TSP	2.5%
PM_{10}	2.1%
$PM_{2.5}$	1.7%
BC	1.0%
As	18%
Cd	2.8%
Cr	4%
Cu	6%
Hg	56%
Ni	5%
Pb	3%
Se	52%
Zn	0.5%
PCDD/F	2.5%

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

- Annual environmental reports / environmental reporting available on the Danish EPA home page[8] (PRTR data), DEPA (2024b)
- Emission data reported by Ørsted[9], the major power plant operator in Denmark
- Additional emission data reported to DCE

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

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

If plant-specific emission factors are not available, general area source emission factors are used.

Area sources

Fuels not combusted in large point sources are included as source category specific area sources in the emission database. Plants such as residential boilers, small district heating plants, small CHP plants and some industrial boilers are defined as area sources. Emissions from area sources are based on fuel consumption data and emission factors. Further information on emission factors is provided in Chapter 3.2.8.

Activity rates, fuel consumption

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

Fuel consumption data are presented in Chapter 3.2.3.

The fuel consumption of the NFR category Manufacturing industries and construction (corresponding to SNAP category 03) is disaggregated into industrial subsectors based on the DEA data set aggregated for the Eurostat reporting (DEA, 2024c).

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

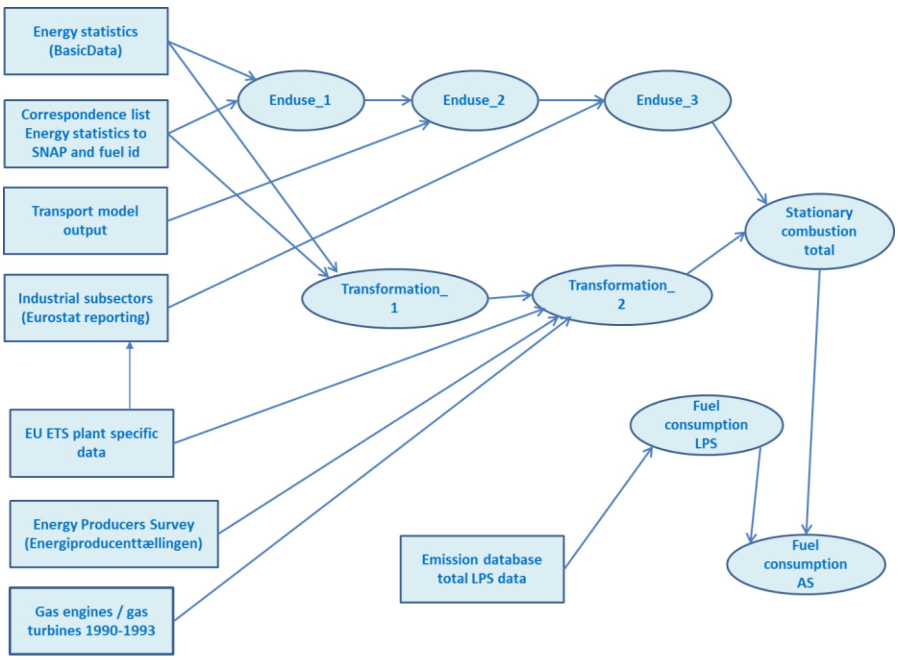


Figure 3.2.59 Fuel consumption data flow.

Both traded and non-traded fuels are included in the Danish energy statistics. Thus, for example, estimation of the annual consumption of non-traded wood is included.

Petroleum coke purchased abroad and combusted in Danish residential plants (border trade of 100-628 TJ in 1992-2018[10]) is not included in the Danish inventory. This is in agreement with the IPCC Guidelines (IPCC, 2006).

The fuel consumption data for large point sources refer to the EU Emission Trading Scheme (EU ETS) data for plants for which the Danish CO_2 emission inventory also refer to EU ETS.

For all other large point sources, the fuel consumption refers to an annually updated DEA database; the Energy Producers Survey (DEA, 2024b). The Energy Producers Survey includes the fuel consumption of each district heating and power-producing plant, based on data reported by plant operators. The consistency between EU ETS reporting and the Energy Producers Survey (DEA, 2024b) is checked by the DEA and discrepancies are corrected prior to the use in the emission inventory.

The fuel consumption of area sources is calculated as total fuel consumption in the energy statistics minus fuel consumption included in the emission inventory database in large point sources.

Fuel consumption for 1A1c Oil and gas extraction

The fuel consumption data for natural gas applied in 1A1c Oil and gas extraction reported in the EU ETS are not in agreement with the energy statistics for 1990-2020. This is because data in the energy statistics was earlier based on the default net calorific value (NCV) for natural gas applied in Denmark, whereas the EU ETS data were based on fuel analysis of the natural gas applied offshore at each individual platform. For 2021 onwards, the fuel consumption in the energy statistics is in agreement with the EU ETS data. The fuel consumption data applied in the emission inventory for natural gas refer to the EU ETS data.

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

Fuel consumption for 1A1b Petroleum refining

The EU ETS data for fuel consumption reported by the two Danish refineries are not always in agreement with the energy statistics due to the use of default values for net calorific value (NCV) in the energy statistics. The EU ETS data are based on fuel analysis. Refinery gas is only applied in the two refineries. The total consumption of refinery gas applied in the emission inventories is based on the EU ETS data.

Biomethane

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

[10] No border trade of petroleum coke in 2019-2023.

Gas distributed in the Danish gas distribution system consists of (fossil) natural gas and biomethane. In the emission inventory (NFR), the biomethane part has been assumed equal for all appliances in Denmark, except for offshore consumption. This assumption is in agreement with the Danish energy statistics (DEA, 2024a) and with the IPCC Guidelines (2006). According to IPCC Guidelines (2006) the GHG emission inventories should be based on physical data, and thus the trading of certificates are not included in the inventories. In 2023, 36.7 % of the energy content in distributed gas was biomethane (DEA, 2024a).

In the EU ETS data system, trading of biomethane certificates has been included in the fuel consumption data from the reporting for year 2021. This agrees with the EU Guidance document for biomass issues in the EU ETS (EU, 2022), see *Chapter 5.3 Biogas in natural gas grids* that specifies the system requirements for the purchase of biomethane certificates. In the EU ETS data set for Denmark, all distributed gas is considered (fossil) natural gas if no biomethane certificates have been purchased. The differences regarding biomethane cause some differences when comparing CO_2 emission data in CRT and the sum of EU ETS emission data.

In the emission inventory, plant specific fuel consumption data for (fossil) natural gas and biomethane from EU ETS are implemented in the emission inventory by adding natural gas and biomethane and afterwards dividing into the two fuels according to the national split for pipeline gas.

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

Biogas and biomethane distributed in the town gas grid
The energy statistics includes a consumption of biogas and biomethane for town gas production. In 2023, 129 TJ biogas and 170 TJ biomethane was distributed in the town gas grid.

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

Town gas
Town gas (the fossil part) has been included in the fuel category natural gas. The consumption of town gas in Denmark is very low, e.g. 0.5 PJ in 2023. In 1990, the town gas consumption was 1.6 PJ, and the consumption has been steadily decreasing throughout the time series.

In Denmark, town gas is produced based on natural gas[11]. The use of coal for town gas production ceased in the early 1980s.

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

[11] Biomethane and biogas is part of the input fuels for town gas production, but in the emission inventory these fuels are treated as part of the fuel categories biomethane and biogas, see above.

Table 3.2.16 Composition of town gas currently used (KE, 2015).

Component	Town gas, % (mol.)
Methane	43.9
Ethane	2.9
Propane	1.1
Butane	0.5
Carbon dioxide	0.4
Nitrogen	40.5
Oxygen	10.7

The lower heating value of the town gas is 20.31 MJ per Nm^3 and the CO_2 emission factor 56.1 kg per GJ. This is very close to the emission factor used for natural gas in 2015 (57.06 kg per GJ). According to the supplier, both the composition and heating value will change during the year. It has not been possible to obtain a yearly average.

In earlier years, the composition of town gas was somewhat different. Table 3.2.17 shows data for town gas composition in 2000-2005. These data are constructed with the input from Københavns Energi (KE) (Copenhagen Energy) and Danish Gas Technology Centre (DGC), (Jeppesen, 2007; Kristensen, 2007). The data refer to three measurements performed several years apart, the first in 2000 and the latest in 2005.

Table 3.2.17 Composition of town gas, data from 2000-2005.

Component	Town gas, % (mol.)
Methane	22.3-27.8
Ethane	1.2-1.8
Propane	0.5-0.9
Butane	0.13-0.2
Higher hydrocarbons	0-0.6
Carbon dioxide	8-11.6
Nitrogen	15.6-20.9
Oxygen	2.3-3.2
Hydrogen	35.4-40.5
Carbon monoxide	2.6-2.8

The lower calorific value was between 15.6 and 17.8 MJ per Nm^3. The CO_2 emission factors - derived from the few available measurements - are in the range of 52-57 kg per GJ.

Due to the scarce data available and the very low consumption of town gas compared to consumption of natural gas (< 0.5 %), the methodology will be applied unchanged in future inventories.

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

Biogas

Biogas includes landfill gas, sludge gas and manure/organic waste gas[12]. In 2023, 82 % of the produced biogas was upgraded to biomethane. An increas-

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

ing part of the biogas is upgraded to biomethane. Data from the Danish Energy Agency specifies production and consumption of each of the biogas types (DEA, 2023e).

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

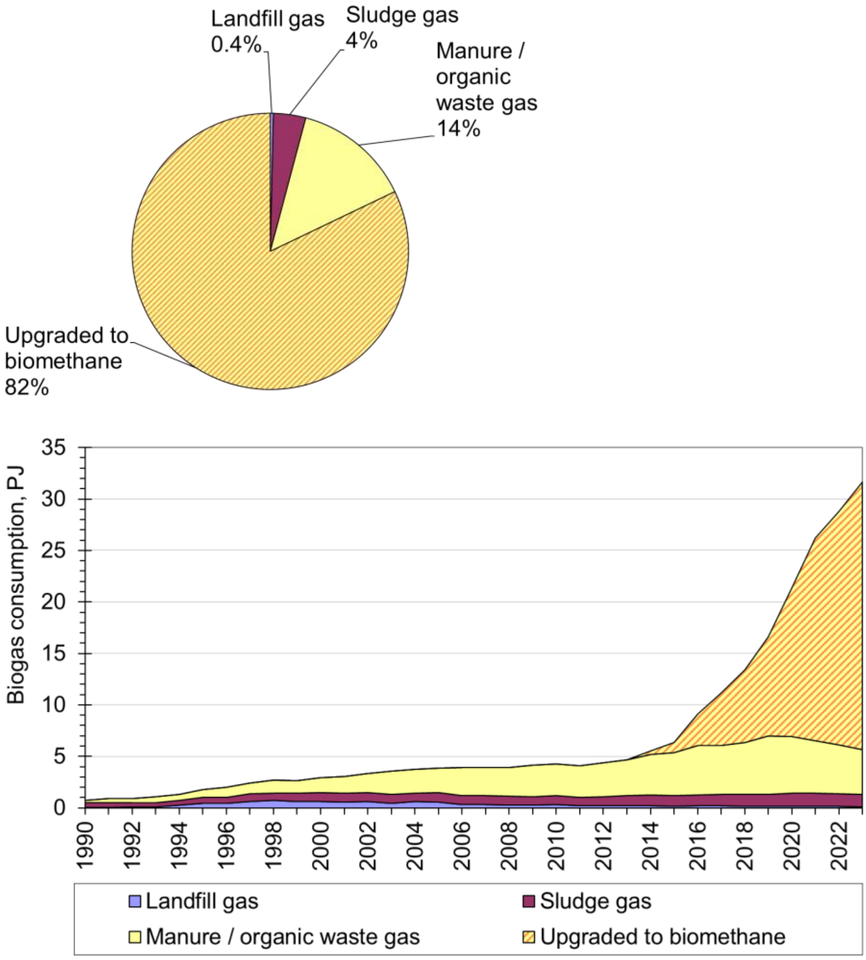


Figure 3.2.60 Biogas types (including biomethane) 2023 and the corresponding time series 1990-2023 (DEA, 2024e; DEA 2024a).

Waste

All waste incineration in Denmark is utilised for heat and/or power production and thus included in the energy sector. The waste incinerated in Denmark for energy production consists of the waste fractions shown in Figure 3.2.61. In 2021, 2 % of the incinerated waste was hazardous waste.

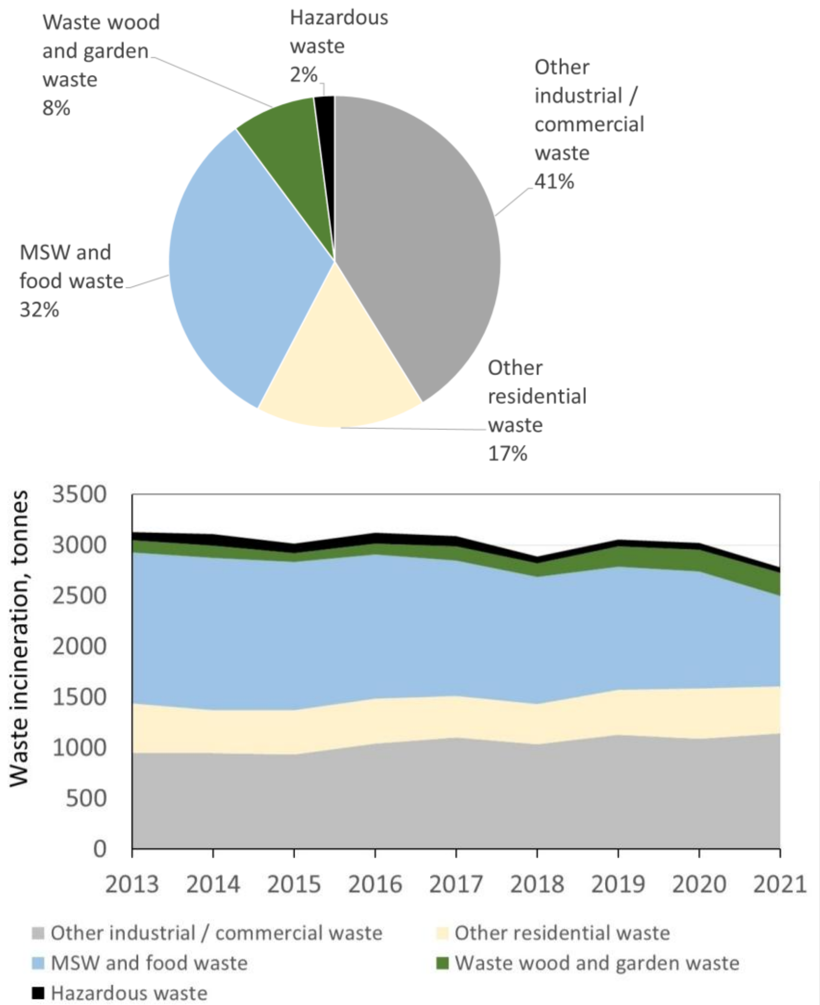


Figure 3.2.61 Waste fractions (weight) for incinerated waste in 2021 and the corresponding time series 2013-2021 (DEPA Waste statistics for 2021, 2023).

In connection to the project estimating an improved CO_2 emission factor for waste (Astrup et al., 2012), the fossil energy fraction was calculated. The fossil fraction was not measured or estimated as part of the project, but the flue gas measurements combined with data from Fellner & Rechberger (2010) indicated a fossil energy part of 45 %. The energy statistics also applies this fraction in the national statistics.

Fuels used for non-energy purposes

The Danish national energy statistics includes three fuels used for non-energy purposes: bitumen, white spirit and lubricants. The total consumption for non-energy purposes is relatively low, e.g. 7.9 PJ in 2023. The use of fuels for non-energy purposes is included in the inventory in sector 2D Non-energy products from fuels and solvent use.

The non-energy use of fuels is included in the reference approach for Climate Convention reporting and appropriately corrected in line with the IPCC Guidelines (IPCC, 2006). The reference approach is included in NID Chapter 3.4 (Nielsen et al., 2025a).

3.2.7 Residential wood combustion

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

Residential wood combustion, fuel consumption

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

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

Table 3.2.18 Overview of the wood burning technologies.

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

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

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

Technology	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Stoves (-1989)	5059	5505	4684	4829	4390	2069	430	299	193	137
Stoves (1990-2007)	189	1456	3004	6476	8545	7389	3971	3639	3277	3536
Stoves (2008-2014)	0	0	0	0	172	350	218	208	197	224
Stoves (2015-2016)	0	0	0	0	0	48	60	57	54	62
Stoves (2017-)	0	0	0	0	0	0	120	143	162	216
Eco labelled stoves / new advanced stoves (-2014)	0	0	0	1079	4003	5400	3347	3194	3004	3398
Eco labelled stoves / new advanced stoves (2015-2016)	0	0	0	0	0	432	538	515	487	555
Eco labelled stoves / new advanced stoves (2017-)	0	0	0	0	0	0	1076	1288	1461	1943
Open fireplaces and similar	215	276	289	439	581	533	331	317	300	342
Masonry heat accumulating stoves and similar	51	65	69	104	138	126	79	75	71	81
Boilers with accumulation tank (-1979)	1108	1064	745	566	1	0	0	0	0	0
Boilers without accumulation tank (-1979)	1108	1064	745	566	1	0	0	0	0	0
Boilers with accumulation tank (1980-)	681	1355	1965	3866	6307	6195	3905	3738	3535	4029
Boilers without accumulation tank (1980-)	426	773	1012	1786	2661	2029	1211	1159	1096	1250
Pellet boilers / pellet stoves	117	201	2112	6690	10105	12999	15101	16460	10652	10759

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

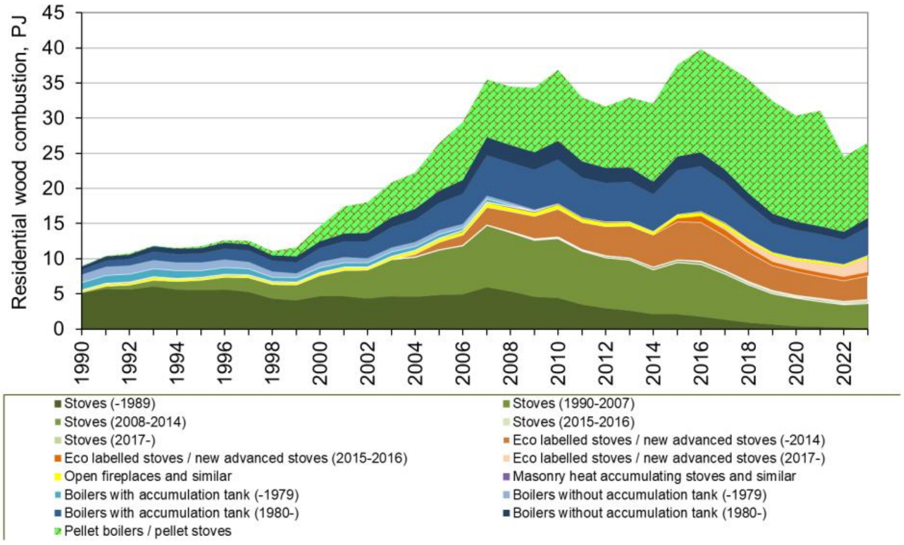


Figure 3.2.62 Technology specific wood consumption rates in residential plants.

Residential wood combustion, technology specific EMFs

For the pollutants NO_x, NMVOC, CO, NH_3, TSP, PM_{10}, $PM_{2.5}$, BC, PCB and PAH emission factors have been based on fuel consumption data and technology specific emission factors for 15 different technologies. Technology specific emission factors and implied emission factors for 2023 are shown in Table 3.2.20. References for the technology specific emission factors are shown in Table 3.2.21 and time series for IEFs are shown in Table 3.2.22.

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

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

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

Table 3.2.20 Technology specific emission factors for residential wood combustion and IEF for log wood/wood chips, 2023.

Technology	NO_x, g/GJ	NMVOC, g/GJ	CO, g/GJ	NH_3, g/GJ	TSP, g/GJ	PM_{10}, g/GJ	$PM_{2.5}$, g/GJ	BC, g/GJ	PCDD/F, ng/GJ	dl-PCBs, ng/GJ	Benzo (a) pyrene, mg/GJ	Benzo (b) fluoran-thene, mg/GJ	Benzo (k) fluoran-thene, mg/GJ	Indeno (1.2.3-c,d) pyrene, mg/GJ
Stoves (-1989)	50	1200	8000	70	1000	950	930	17	1048	7049	116	55	119	62
Stoves (1990-2007)	50	600	4000	70	500	475	465	17	1048	7049	48	59	50	27
Stoves (2008-2014)	80	350	1900	37	389	370	362	31	1048	931	43	65	19	31
Stoves (2015-2016)	80	350	1900	37	317	301	295	31	1048	931	43	65	19	31
Stoves (2017-)	80	350	1900	37	253	240	235	31	1048	931	43	65	19	31
Eco labelled stoves / new advanced stoves (-2014)	75	175	1900	37	253	240	235	31	1048	466	43	65	19	31
Eco labelled stoves / new advanced stoves (2015-2016)	75	175	1900	37	190	181	177	31	1048	466	43	65	19	31
Eco labelled stoves / new advanced stoves (2017-)	75	175	1900	37	127	121	118	31	1048	466	43	65	19	31
Open fireplaces and similar	50	600	4000	74	882	838	820	34	55	60	35	25	29	21
Masonry heat accumulating stoves and similar	50	600	2402	70	63	60	59	18	282	7049	17	8	10	25
Boilers with accumulation tank (-1979)	80	350	9001	74	588	559	547	24	282	7049	991	926	632	1092
Boilers without accumulation tank (-1979)	80	350	10890	74	736	699	684	24	282	7049	991	926	632	1092
Boilers with accumulation tank (1980-)	95	175	1613	37	64	61	60	6	282	466	90	60	40	40
Boilers without accumulation tank (1980-)	95	350	1952	37	335	318	312	6	282	931	120	80	50	60
IEF residential log wood/wood chips, 2023	**75.4**	**310**	**2403**	**45.7**	**270**	**257**	**251**	**19.4**	**766**	**2075**	**62.6**	**62.3**	**34.8**	**34.7**
Pellet boilers / pellet stoves	**80**	**10**	**300**	**12**	**51**	**48**	**47**	**7**	**333**	**466**	**0.9**	**1.3**	**1.3**	**1.2**

Technology specific references and assumptions

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

Table 3.2.21 Emission factors for residential wood combustion.

	Pollutant	Emission factor	Unit	Reference
Stoves (-1989)	NO_x	50	g/GJ	Pettersson et al. (2011). Also applied in EEA (2023), Small combustion, Table 3-40, Tier 2, Conventional stoves.
Stoves (1990-2007)	NO_x	50	g/GJ	Pettersson et al. (2011). Also applied in EEA (2023), Small combustion, Table 3-40, Tier 2, Conventional stoves.
Stoves (2008-2014)	NO_x	80	g/GJ	Pettersson et al. (2011). Also applied in EEA (2023), Small combustion, Table 3-41, Tier 2, High-efficiency stoves.
Stoves (2015-2016)	NO_x	80	g/GJ	Same as Stoves (2008-2014)
Stoves (2017-)	NO_x	80	g/GJ	Same as Stoves (2008-2014)
Eco labelled stoves / new advanced stoves (-2014)	NO_x	75	g/GJ	Andersen & Hvidbjerg (2017)
Eco labelled stoves / new advanced stoves (2015-2016)	NO_x	75	g/GJ	Andersen & Hvidbjerg (2017)
Eco labelled stoves / new advanced stoves (2017-)	NO_x	75	g/GJ	Andersen & Hvidbjerg (2017)
Open fireplaces and similar	NO_x	50	g/GJ	Pettersson et al. (2011). Also applied in EEA (2023), Small Combustion, Tier 2, Open fireplaces, Table 3-39
Masonry heat accumulating stoves and similar	NO_x	50	g/GJ	Pettersson et al. (2011). Also applied in EEA (2023), Small combustion, Tier 2, Table 3-40, conventional stoves.
Boilers with accumulation tank (-1979)	NO_x	80	g/GJ	Pettersson et al. (2011). Also applied in EEA (2023), Small combustion, Tier 2, Table 3-43, conventional boilers.
Boilers without accumulation tank (-1979)	NO_x	80	g/GJ	Pettersson et al. (2011). Also applied in EEA (2023), Small combustion, Tier 2, Table 3-43, conventional boilers.
Boilers with accumulation tank (1980-)	NO_x	95	g/GJ	Pettersson et al. (2011). Also applied in EEA (2023), Small combustion, Tier 2, Table 3-42, advanced / ecolabelled stoves and boilers.
Boilers without accumulation tank (1980-)	NO_x	95	g/GJ	Pettersson et al. (2011). Also applied in EEA (2023), Small combustion, Tier 2, Table 3-42, advanced / ecolabelled stoves and boilers.
Pellet boilers / pellet stoves	NO_x	80	g/GJ	Pettersson et al. (2011). Also applied in EEA (2023), Small combustion, Tier 2, Table 3-44, pellet stoves and boilers.
Stoves (-1989)	NMVOC	1200	g/GJ	Assumed two times Stoves (1990-2007). Pettersson et al. (2011). Also applied in EEA (2023), Small combustion, table 3-40, Tier 2, Conventional stoves; 600 g/GJ (20 g/GJ - 3000 g/GJ).

	Pollutant	Emission factor	Unit	Reference
Stoves (1990-2007)	NMVOC	600	g/GJ	Pettersson et al. (2011). Also applied in EEA (2023), Small combustion, Table 3-40, Tier 2, Conventional stoves.
Stoves (2008-2014)	NMVOC	350	g/GJ	Johansson et al. (2004). Also applied in EEA (2023), Small combustion, Table 3-41, High-efficiency stoves.
Stoves (2015-2016)	NMVOC	350	g/GJ	Same as Stove (2008-2014)
Stoves (2017-)	NMVOC	350	g/GJ	Same as Stove (2008-2014)
Eco labelled stoves / new advanced stoves (-2014)	NMVOC	175	g/GJ	Assumed ½ Stoves (2008-2014). The EEA (2023) emission factor for advanced / ecolabelled stoves and boilers is 250 g/GJ, but this emission factor has not been revised since the 2009 version of the Guidebook.
Eco labelled stoves / new advanced stoves (2015-2016)	NMVOC	175	g/GJ	Same as ecolabelled stoves (-2014).
Eco labelled stoves / new advanced stoves (2017-)	NMVOC	175	g/GJ	Same as ecolabelled stoves (-2014).
Open fireplaces and similar	NMVOC	600	g/GJ	Pettersson et al. (2011) and McDonald et al. (2000). Also applied in EEA (2023), Small combustion, Open fireplaces, Table 3-39.
Masonry heat accumulating stoves and similar	NMVOC	600	g/GJ	Pettersson et al. (2011). Also applied in EEA (2023), Small combustion, Table 3-40, conventional stoves.
Boilers with accumulation tank (-1979)	NMVOC	350	g/GJ	Johansson et al. (2004). Also applied in EEA (2023), Small combustion, Table 3-43, Conventional boilers.
Boilers without accumulation tank (-1979)	NMVOC	350	g/GJ	Johansson et al. (2004). Also applied in EEA (2023), Small combustion, Table 3-43, Conventional boilers.
Boilers with accumulation tank (1980-)	NMVOC	175	g/GJ	Assumed equal to ecolabelled stoves (-2014).
Boilers without accumulation tank (1980-)	NMVOC	350	g/GJ	Assumed 2 times the emission from boilers with accumulation tank (1980-)
Pellet boilers / pellet stoves	NMVOC	10	g/GJ	Johansson et al. (2004) and Boman et al. (2011). Also applied in EEA (2023), Small combustion, Table 3-44, Pellet stoves and boilers.
Stoves (-1989)	CH_4	430	g/GJ	Methane emissions from residential biomass combustion, Paulrud et al. (2005) (SMED report, Sweden)
Stoves (1990-2007)	CH_4	215	g/GJ	Assumed ½ the emission factor for stoves (-1989).
Stoves (2008-2014)	CH_4	125	g/GJ	Estimated based on the emission factor for stoves (1990-2007) and the emission factors for NMVOC.
Stoves (2015-2016)	CH_4	125	g/GJ	Same as stoves (2008-2014)
Stoves (2017-)	CH_4	125	g/GJ	Same as stoves (2008-2014)
Eco labelled stoves / new advanced stoves (-2014)	CH_4	2	g/GJ	Low emissions from wood burning in an ecolabelled residential boiler. Olsson & Kjällstrand (2005).
Eco labelled stoves / new advanced stoves (2015-2016)	CH_4	2	g/GJ	Same as advanced / ecolabelled stoves
Eco labelled stoves / new advanced stoves (2017-)	CH_4	2	g/GJ	Same as advanced / ecolabelled stoves

	Pollutant	Emission factor	Unit	Reference
Open fireplaces and similar	CH_4	430	g/GJ	Assumed equal to stoves (-1989).
Masonry heat accumulating stoves and similar	CH_4	215	g/GJ	Assumed equal to stoves (-1989).
Boilers with accumulation tank (-1979)	CH_4	211	g/GJ	Methane emissions from residential biomass combustion, Paulrud et al 2005 (SMED report, Sweden)
Boilers without accumulation tank (-1979)	CH_4	256	g/GJ	Methane emissions from residential biomass combustion, Paulrud et al 2005 (SMED report, Sweden)
Boilers with accumulation tank (1980-)	CH_4	50	g/GJ	Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004)
Boilers without accumulation tank (1980-)	CH_4	50	g/GJ	Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004)
Pellet boilers / pellet stoves	CH_4	3	g/GJ	Methane emissions from residential biomass combustion, Paulrud et al 2005 (SMED report, Sweden)
Stoves (-1989)	CO	8000	g/GJ	Assumed two times Stoves (1990-2007). This emission factor refers to Pettersson et al. (2011) and Goncalves et al. (2012). Also applied in EEA (2023), Small combustion, Table 3-40, Tier 2, Conventional stoves; 4000 g/GJ (1000 g/GJ - 10000 g/GJ).
Stoves (1990-2007)	CO	4000	g/GJ	Pettersson et al. (2011) and Goncalves et al. (2012). Also applied in EEA (2023), Small combustion, Table 3-40, Tier 2, conventional stoves.
Stoves (2008-2014)	CO	1900	g/GJ	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Stoves (2015-2016)	CO	1900	g/GJ	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Stoves (2017-)	CO	1900	g/GJ	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Eco labelled stoves / new advanced stoves (-2014)	CO	1900	g/GJ	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Eco labelled stoves / new advanced stoves (2015-2016)	CO	1900	g/GJ	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Eco labelled stoves / new advanced stoves (2017-)	CO	1900	g/GJ	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Open fireplaces and similar	CO	4000	g/GJ	Goncalves et al. (2012). Also applied in EEA (2023), Small Combustion, Table 3-39 Open fireplaces.
Masonry heat accumulating stoves and similar	CO	2402	g/GJ	Kindbom et al. (2017)
Boilers with accumulation tank (-1979)	CO	9001	g/GJ	Winther (2008)
Boilers without accumulation tank (-1979)	CO	10890	g/GJ	Winther (2008)
Boilers with accumulation tank (1980-)	CO	1613	g/GJ	Winther (2008)
Boilers without accumulation tank (1980-)	CO	1952	g/GJ	Winther (2008)
Pellet boilers / pellet stoves	CO	300	g/GJ	Schmidl et al. (2011) and Johansson et al. (2004). Also applied in EEA (2023), Small Combustion, Table 3-44 Pellet stoves and boilers.

	Pollutant	Emission factor	Unit	Reference
Stoves (-1989)	NH_3	70	g/GJ	Roe et al. (2004)
Stoves (1990-2007)	NH_3	70	g/GJ	Roe et al. (2004)
Stoves (2008-2014)	NH_3	37	g/GJ	Roe et al. (2004)
Stoves (2015-2016)	NH_3	37	g/GJ	Roe et al. (2004)
Stoves (2017-)	NH_3	37	g/GJ	Roe et al. (2004)
Eco labelled stoves / new advanced stoves (-2014)	NH_3	37	g/GJ	Roe et al. (2004)
Eco labelled stoves / new advanced stoves (2015-2016)	NH_3	37	g/GJ	Roe et al. (2004)
Eco labelled stoves / new advanced stoves (2017-)	NH_3	37	g/GJ	Roe et al. (2004)
Open fireplaces and similar	NH_3	74	g/GJ	Roe et al. (2004)
Masonry heat accumulating stoves and similar	NH_3	70	g/GJ	Roe et al. (2004)
Boilers with accumulation tank (-1979)	NH_3	74	g/GJ	Roe et al. (2004)
Boilers without accumulation tank (-1979)	NH_3	74	g/GJ	Roe et al. (2004)
Boilers with accumulation tank (1980-)	NH_3	37	g/GJ	Roe et al. (2004)
Boilers without accumulation tank (1980-)	NH_3	37	g/GJ	Roe et al. (2004)
Pellet boilers / pellet stoves	NH_3	12	g/GJ	Roe et al. (2004)
Stoves (-1989)	TSP	1000	g/GJ	Glasius et al. (2005)
Stoves (1990-2007)	TSP	500	g/GJ	Glasius et al. (2005), Glasius et al. (2007), Kindbom et al. (2017) and Schleicher (2018)
Stoves (2008-2014)	TSP	389	g/GJ	Kindbom et al. (2017)
Stoves (2015-2016)	TSP	317	g/GJ	MST (2015). Limit value 5 g/kg.
Stoves (2017-)	TSP	253	g/GJ	MST (2015). Limit value 4 g/kg.
Eco labelled stoves / new advanced stoves (-2014)	TSP	253	g/GJ	Nordic Ecolabelling limit 2012 update for hand fed stove for temporary firing or inset stove (4 g/kg).
Eco labelled stoves / new advanced stoves (2015-2016)	TSP	190	g/GJ	Nordic Ecolabelling limit update for hand fed stove for temporary firing or inset stove (3 g/kg).
Eco labelled stoves / new advanced stoves (2017-)	TSP	127	g/GJ	Nordic Ecolabelling limit update
Open fireplaces and similar	TSP	882	g/GJ	Alves et al. (2011)
Masonry heat accumulating stoves and similar	TSP	63	g/GJ	Tissari et al. (2009)
Boilers with accumulation tank (-1979)	TSP	588	g/GJ	Winther (2008)
Boilers without accumulation tank (-1979)	TSP	736	g/GJ	Winther (2008)
Boilers with accumulation tank (1980-)	TSP	64	g/GJ	Winther (2008)
Boilers without accumulation tank (1980-)	TSP	335	g/GJ	Winther (2008)
Pellet boilers / pellet stoves	TSP	51	g/GJ	Kindbom et al. (2017)
Stoves (-1989)	PM_{10}	950	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (1990-2007)	PM_{10}	475	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (2008-2014)	PM_{10}	370	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP

	Pollutant	Emission factor	Unit	Reference
Stoves (2015-2016)	PM_{10}	301	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (2017-)	PM_{10}	240	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Eco labelled stoves / new advanced stoves (-2014)	PM_{10}	240	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Eco labelled stoves / new advanced stoves (2015-2016)	PM_{10}	181	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Eco labelled stoves / new advanced stoves (2017-)	PM_{10}	121	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Open fireplaces and similar	PM_{10}	838	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Masonry heat accumulating stoves and similar	PM_{10}	60	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers with accumulation tank (-1979)	PM_{10}	559	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers without accumulation tank (-1979)	PM_{10}	699	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers with accumulation tank (1980-)	PM_{10}	61	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers without accumulation tank (1980-)	PM_{10}	318	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Pellet boilers / pellet stoves	PM_{10}	48	g/GJ	95% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (-1989)	$PM_{2.5}$	930	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (1990-2007)	$PM_{2.5}$	465	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (2008-2014)	$PM_{2.5}$	362	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (2015-2016)	$PM_{2.5}$	295	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (2017-)	$PM_{2.5}$	235	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Eco labelled stoves / new advanced stoves (-2014)	$PM_{2.5}$	235	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Eco labelled stoves / new advanced stoves (2015-2016)	$PM_{2.5}$	177	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Eco labelled stoves / new advanced stoves (2017-)	$PM_{2.5}$	118	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP

	Pollutant	Emission factor	Unit	Reference
Open fireplaces and similar	$PM_{2.5}$	820	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Masonry heat accumulating stoves and similar	$PM_{2.5}$	59	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers with accumulation tank (-1979)	$PM_{2.5}$	547	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers without accumulation tank (-1979)	$PM_{2.5}$	684	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers with accumulation tank (1980-)	$PM_{2.5}$	60	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Boilers without accumulation tank (1980-)	$PM_{2.5}$	312	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Pellet boilers / pellet stoves	$PM_{2.5}$	47	g/GJ	93% of TSP. Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP
Stoves (-1989)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Stoves (1990-2007)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Stoves (2008-2014)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Stoves (2015-2016)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Stoves (2017-)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Eco labelled stoves / new advanced stoves (-2014)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Eco labelled stoves / new advanced stoves (2015-2016)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Eco labelled stoves / new advanced stoves (2017-)	PCDD/F	1048	ng/GJ	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).
Open fireplaces and similar	PCDD/F	55	ng/GJ	Gullet et al. (2005)
Masonry heat accumulating stoves and similar	PCDD/F	282	ng/GJ	Assumed equal to boilers
Boilers with accumulation tank (-1979)	PCDD/F	282	ng/GJ	Glasius et al. (2005), Glasius et al. (2007), Hübner et al. (2005) and Hedman et al. (2006)
Boilers without accumulation tank (-1979)	PCDD/F	282	ng/GJ	Glasius et al. (2005), Glasius et al. (2007), Hübner et al. (2005) and Hedman et al. (2006)
Boilers with accumulation tank (1980-)	PCDD/F	282	ng/GJ	Glasius et al. (2005), Glasius et al. (2007), Hübner et al. (2005) and Hedman et al. (2006)
Boilers without accumulation tank (1980-)	PCDD/F	282	ng/GJ	Glasius et al. (2005), Glasius et al. (2007), Hübner et al. (2005) and Hedman et al. (2006)

	Pollutant	Emission factor	Unit	Reference
Pellet boilers / pellet stoves	PCDD/F	333	ng/GJ	Hedman et al. (2006)
Stoves (-1989)	Benzo(a)	116	µg/GJ	Glasius et al. (2005)
Stoves (1990-2007)	Benzo(a)	48	µg/GJ	Glasius et al. (2005) except for Benzo(b)fluoranthene that refers to Schleicher (2018)
Stoves (2008-2014)	Benzo(a)	43	µg/GJ	Schleicher (2018)
Stoves (2015-2016)	Benzo(a)	43	µg/GJ	Schleicher (2018)
Stoves (2017-)	Benzo(a)	43	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (-2014)	Benzo(a)	43	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2015-2016)	Benzo(a)	43	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2017-)	Benzo(a)	43	µg/GJ	Schleicher (2018)
Open fireplaces and similar	Benzo(a)	35	µg/GJ	Gullet et al. (2003)
Masonry heat accumulating stoves and similar	Benzo(a)	17	µg/GJ	Tissari et al. (2007)
Boilers with accumulation tank (-1979)	Benzo(a)	991	µg/GJ	Winther (2008)
Boilers without accumulation tank (-1979)	Benzo(a)	991	µg/GJ	Winther (2008)
Boilers with accumulation tank (1980-)	Benzo(a)	90	µg/GJ	Johansson et al. (2006)
Boilers without accumulation tank (1980-)	Benzo(a)	120	µg/GJ	Johansson et al. (2006)
Pellet boilers / pellet stoves	Benzo(a)	0.9	µg/GJ	Orasche et al. (2012), distribution between Benzo(b)fluoranthene and Benzo(k)fluoranthene according to Lamberg et al. (2011).
Stoves (-1989)	Benzo(b)	55	µg/GJ	Glasius et al. (2005)
Stoves (1990-2007)	Benzo(b)	59	µg/GJ	Glasius et al. (2005) except for Benzo(b)fluoranthene that refers to Schleicher (2018)
Stoves (2008-2014)	Benzo(b)	65	µg/GJ	Schleicher (2018)
Stoves (2015-2016)	Benzo(b)	65	µg/GJ	Schleicher (2018)
Stoves (2017-)	Benzo(b)	65	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (-2014)	Benzo(b)	65	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2015-2016)	Benzo(b)	65	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2017-)	Benzo(b)	65	µg/GJ	Schleicher (2018)
Open fireplaces and similar	Benzo(b)	25	µg/GJ	Gullet et al. (2003)
Masonry heat accumulating stoves and similar	Benzo(b)	7.6	µg/GJ	Tissari et al. (2007)
Boilers with accumulation tank (-1979)	Benzo(b)	926	µg/GJ	Winther (2008)
Boilers without accumulation tank (-1979)	Benzo(b)	926	µg/GJ	Winther (2008)
Boilers with accumulation tank (1980-)	Benzo(b)	60	µg/GJ	Johansson et al. (2006)
Boilers without accumulation tank (1980-)	Benzo(b)	80	µg/GJ	Johansson et al. (2006)
Pellet boilers / pellet stoves	Benzo(b)	1.3	µg/GJ	Orasche et al. (2012), distribution between Benzo(b)fluoranthene and Benzo(k)fluoranthene according to Lamberg et al. (2011).
Stoves (-1989)	Benzo(k)	119	µg/GJ	Glasius et al. (2005)

	Pollutant	Emission factor	Unit	Reference
Stoves (1990-2007)	Benzo(k)	50	µg/GJ	Glasius et al. (2005) except for Benzo(b)fluoranthene that refers to Schleicher (2018)
Stoves (2008-2014)	Benzo(k)	19	µg/GJ	Schleicher (2018)
Stoves (2015-2016)	Benzo(k)	19	µg/GJ	Schleicher (2018)
Stoves (2017-)	Benzo(k)	19	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (-2014)	Benzo(k)	19	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2015-2016)	Benzo(k)	19	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2017-)	Benzo(k)	19	µg/GJ	Schleicher (2018)
Open fireplaces and similar	Benzo(k)	29	µg/GJ	Gullet et al. (2003)
Masonry heat accumulating stoves and similar	Benzo(k)	9.5	µg/GJ	Tissari et al. (2007)
Boilers with accumulation tank (-1979)	Benzo(k)	632	µg/GJ	Winther (2008)
Boilers without accumulation tank (-1979)	Benzo(k)	632	µg/GJ	Winther (2008)
Boilers with accumulation tank (1980-)	Benzo(k)	40	µg/GJ	Johansson et al. (2006)
Boilers without accumulation tank (1980-)	Benzo(k)	50	µg/GJ	Johansson et al. (2006)
Pellet boilers / pellet stoves	Benzo(k)	1.3	µg/GJ	Orasche et al. (2012), distribution between Benzo(b)fluoranthene and Benzo(k)fluoranthene according to Lamberg et al. (2011).
Stoves (-1989)	Indeno	62	µg/GJ	Glasius et al. (2005)
Stoves (1990-2007)	Indeno	27	µg/GJ	Glasius et al. (2005) except for Benzo(b)fluoranthene that refers to Schleicher (2018)
Stoves (2008-2014)	Indeno	31	µg/GJ	Schleicher (2018)
Stoves (2015-2016)	Indeno	31	µg/GJ	Schleicher (2018)
Stoves (2017-)	Indeno	31	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (-2014)	Indeno	31	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2015-2016)	Indeno	31	µg/GJ	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2017-)	Indeno	31	µg/GJ	Schleicher (2018)
Open fireplaces and similar	Indeno	21	µg/GJ	Gullet et al. (2003)
Masonry heat accumulating stoves and similar	Indeno	25	µg/GJ	Tissari et al. (2007)
Boilers with accumulation tank (-1979)	Indeno	1092	µg/GJ	Winther (2008)
Boilers without accumulation tank (-1979)	Indeno	1092	µg/GJ	Winther (2008)
Boilers with accumulation tank (1980-)	Indeno	40	µg/GJ	Johansson et al. (2006)
Boilers without accumulation tank (1980-)	Indeno	60	µg/GJ	Johansson et al. (2006)
Pellet boilers / pellet stoves	Indeno	1.2	µg/GJ	Orasche et al. (2012), distribution between Benzo(b)fluoranthene and Benzo(k)fluoranthene according to Lamberg et al. (2011).
Stoves (-1989)	dl-PCB	7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).

	Pollutant	Emission factor	Unit	Reference
Stoves (1990-2007)	dl-PCB	7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Stoves (2008-2014)	dl-PCB	931	ng/GJ	Hedman (2006), modern boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Stoves (2015-2016)	dl-PCB	931	ng/GJ	Same as stoves (2008-2014).
Stoves (2017-)	dl-PCB	931	ng/GJ	Same as stoves (2008-2014).
Eco labelled stoves / new advanced stoves (-2014)	dl-PCB	466	ng/GJ	Hedman (2006), assumed ½ stoves (2017-)
Eco labelled stoves / new advanced stoves (2015-2016)	dl-PCB	466	ng/GJ	Same as Eco labelled stoves / new advanced stoves (-2014)
Eco labelled stoves / new advanced stoves (2017-)	dl-PCB	466	ng/GJ	Same as Eco labelled stoves / new advanced stoves (-2014)
Open fireplaces and similar	dl-PCB	60	ng/GJ	Hedman et al. (2006), Open fireplaces
Masonry heat accumulating stoves and similar	dl-PCB	7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Boilers with accumulation tank (-1979)	dl-PCB	7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Boilers without accumulation tank (-1979)	dl-PCB	7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Boilers with accumulation tank (1980-)	dl-PCB	466	ng/GJ	Assumed equal to Eco labelled stoves / new advanced stoves (-2014)
Boilers without accumulation tank (1980-)	dl-PCB	931	ng/GJ	Hedman (2006), modern boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Pellet boilers / pellet stoves	dl-PCB	466	ng/GJ	Hedman (2006), assumed ½ modern boiler.
Stoves (-1989)	BC	17	g/GJ	Schleicher (2018)
Stoves (1990-2007)	BC	17	g/GJ	Schleicher (2018)
Stoves (2008-2014)	BC	31	g/GJ	Andersen & Hvidbjerg (2017)
Stoves (2015-2016)	BC	31	g/GJ	Andersen & Hvidbjerg (2017)
Stoves (2017-)	BC	31	g/GJ	Andersen & Hvidbjerg (2017)
Eco labelled stoves / new advanced stoves (-2014)	BC	31	g/GJ	Andersen & Hvidbjerg (2017)
Eco labelled stoves / new advanced stoves (2015-2016)	BC	31	g/GJ	Andersen & Hvidbjerg (2017)
Eco labelled stoves / new advanced stoves (2017-)		31	g/GJ	Andersen & Hvidbjerg (2017)
Open fireplaces and similar	BC	34	g/GJ	Alves et al. (2011)
Masonry heat accumulating stoves and similar		18	g/GJ	Tissari et al. (2007)
Boilers with accumulation tank (-1979)	BC	24	g/GJ	Kindbom et al. (2017)
Boilers without accumulation tank (-1979)	BC	24	g/GJ	Kindbom et al. (2017)
Boilers with accumulation tank (1980-)	BC	6	g/GJ	Kindbom et al. (2017)
Boilers without accumulation tank (1980-)	BC	6	g/GJ	Kindbom et al. (2017)
Pellet boilers / pellet stoves	BC	7	g/GJ	Kindbom et al. (2017)

Implied emission factors for residential wood, time series

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

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

Year	NO_x, g/GJ	NMVOC, g/GJ	CO, g/GJ	NH_3, g/GJ	TSP, g/GJ	PM_{10}, g/GJ	$PM_{2.5}$, g/GJ	BC, g/GJ	PCDD/F, ng/GJ	dl-PCB, ng/GJ	Benzo(a)-pyrene, mg/GJ	Benzo(b)-fluoran-thene, mg/GJ	Benzo(k)-fluoran-thene, mg/GJ	Indeno (1,2,3-c,d)-pyrene, mg/GJ
1990	63.2	836	7488	67.0	792	752	737	17.8	731	6076	330	274	234	316
1991	63.3	823	7302	66.5	776	737	722	17.6	733	6000	316	263	225	302
1992	63.4	810	7118	66.1	760	722	707	17.3	734	5924	303	251	215	287
1993	63.6	798	6934	65.6	744	707	692	17.1	735	5849	290	240	206	272
1994	63.7	785	6753	65.2	728	692	677	16.9	736	5774	276	228	197	258
1995	63.8	773	6574	64.8	712	677	663	16.7	738	5701	263	217	188	243
1996	63.9	761	6397	64.3	697	662	648	16.5	739	5629	250	206	179	229
1997	64.0	748	6208	63.9	680	646	633	16.2	741	5560	237	195	170	214
1998	64.1	734	6022	63.5	664	631	617	16.0	743	5492	224	183	161	200
1999	64.2	721	5838	63.1	647	615	602	15.8	746	5425	211	172	152	185
2000	64.3	708	5656	62.7	631	600	587	15.6	747	5359	198	161	143	171
2001	64.4	691	5448	62.3	611	581	569	15.4	749	5293	184	151	134	157
2002	64.5	673	5240	61.9	592	562	550	15.2	751	5226	171	140	124	143
2003	64.5	656	5037	61.6	572	544	533	15.0	753	5162	159	130	115	129
2004	65.3	629	4785	60.3	548	520	509	15.2	755	4921	146	119	106	116
2005	66.0	603	4544	59.1	524	498	487	15.4	758	4687	133	109	96	102
2006	66.5	587	4359	58.1	507	482	472	15.5	761	4509	121	99	87	89
2007	67.0	570	4176	57.2	491	466	456	15.6	764	4333	109	89	79	77
2008	67.6	553	3988	56.1	473	450	440	15.7	766	4142	98	79	71	64
2009	68.3	530	3771	55.0	452	430	421	15.8	766	3930	86	70	62	52
2010	69.0	508	3555	53.9	431	410	401	15.9	766	3718	75.0	60.6	53.5	39.6
2011	69.5	489	3443	53.3	417	396	388	16.1	766	3588	73.6	60.7	51.6	39.0
2012	70.0	471	3335	52.6	403	383	375	16.4	766	3459	72.3	60.8	49.8	38.4
2013	70.5	453	3228	52.0	390	370	363	16.7	766	3330	71.0	60.9	48.1	37.8
2014	71.0	435	3125	51.3	377	358	351	17.0	766	3200	69.7	61.1	46.4	37.3
2015	71.5	418	3025	50.7	363	345	338	17.2	766	3071	68.6	61.2	44.8	36.8
2016	72.0	401	2929	50.0	349	332	325	17.5	766	2941	67.4	61.3	43.2	36.4
2017	72.5	386	2838	49.4	336	319	313	17.8	766	2814	66.5	61.4	41.7	36.0
2018	73.0	371	2752	48.7	324	307	301	18.1	766	2686	65.6	61.6	40.3	35.7
2019	73.5	357	2672	48.1	312	296	290	18.3	766	2560	64.8	61.8	39.1	35.4
2020	74.0	344	2596	47.5	300	285	279	18.6	766	2435	64.2	61.9	37.9	35.2
2021	74.4	332	2526	46.9	289	275	269	18.9	766	2312	63.5	62.1	36.7	35.0
2022	74.9	320	2461	46.2	279	265	260	19.1	766	2192	63.0	62.2	35.7	34.8
2023	75.4	310	2403	45.7	270	257	251	19.4	766	2075	62.6	62.3	34.8	34.7

3.2.8 Emission factors

For each fuel and SNAP category (sector and e.g. type of plant), a set of general area source emission factors has been determined. The emission factors are either nationally referenced or based on the EEA Guidebook (EEA, 2023)[13].

Time series are provided in Annex 3A-4.

SO_2 emission factors

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

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

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

[13] And former editions of the EEA Guidebook.

Table 3.2.23 SO_2 emission factors and references, 2023.

Fuel type	Fuel	NFR	NFR_name	SNAP	SO_2 emission factor, g/GJ	Reference
Solid	Anodic carbon [1)]	1A2g	Industry - other	032002	855	DCE estimate based on plant specific data.
	Coal	1A1a	Public electricity and heat production	0101	12	DCE estimate based on emission data reported by plant owners and fuel consumption data from EU ETS (2024).
				0102	557	DCE estimate based on country specific coal data from Dong Energy (Jensen, 2017) and coal import data from DEA (2024c).
		1A2a-g	Industry	03 except 0309, 0316, and 030701	557	DCE estimate based on country specific coal data from Dong Energy (Jensen, 2017) and coal import data from DEA (2024c).
		1A2e	Industry, food, beverages and tobacco	0309	231	DCE estimate based on plant specific data for 2010.
		1A2f	Cement industry	0316	67	DCE estimate based on plant specific data for 2011-2015.
		1A2g	Mineral wool production	Mineral wool 030701	557	DCE estimate based on country specific coal data from Dong Energy (Jensen, 2017) and coal import data from DEA (2024c).
		1A4b i	Residential	020200	557	DCE estimate based on country specific coal data from Dong Energy (Jensen, 2017) and coal import data from DEA (2024c).
		1A4c i	Agriculture/ Forestry	0203	557	DCE estimate based on country specific coal data from Dong Energy (Jensen, 2017) and coal import data from DEA (2024c).
	Fly ash fossil	1A1a	Public electricity and heat production	010101	12	Assumed equal to coal.
	BKB	1A4b	Residential	0202	557	Assumed equal to coal. DCE assumption.
	Coke oven coke	1A2a-g	Industry	03	557	Assumed equal to coal. DCE assumption.
		1A2e	Industry, food, beverages and tobacco	0309	231	DCE estimate based on plant specific data for 2010.
		1A2g	Mineral wool production	Mineral wool 030701	557	Assumed equal to coal. DCE assumption.
		1A4b	Residential	0202	557	Assumed equal to coal. DCE assumption.
Liquid	Petroleum coke	1A2a-g	Industry	03	605	DCE calculation based on DEPA (2001b), DEPA (2014), DEA (2016a) and EMEP (2006).
		1A2g	Cement industry	0316	67	DCE estimate based on plant specific data for 2011-2015.
		1A4a	Commercial/ Institutional	0201	605	DCE calculation based on DEPA (2001b), DEPA (2014), DEA (2016a) and EMEP (2006).
		1A4b	Residential	0202	605	DCE calculation based on DEPA (2001b), DEPA (2014), DEA (2016a) and EMEP (2006).
		1A4c	Agriculture/ Forestry	0203	605	DCE calculation based on DEPA (2001b), DEPA (2014), DEA (2016a) and EMEP (2006).
	Residual oil	1A1a	Public electricity and heat production	0101	100	DCE estimate based on plant specific data for 2008 and 2009.
				0102	344	DCE estimate based on EOF (2017) and DEA (2016a)
		1A1b	Petroleum refining	010306	339	DCE estimate based on plant specific data for year 2019.
		1A2a-g	Industry	03	344	DCE estimate based on EOF (2017) and DEA (2016a)
		1A4a	Commercial/ Institutional	0201	344	DCE estimate based on EOF (2017) and DEA (2016a)
		1A4b	Residential	0202	344	DCE estimate based on EOF (2017) and DEA (2016a)

Fuel type	Fuel	NFR	NFR_name	SNAP	SO_2 emission factor, g/GJ	Reference
		1A4c i	Agriculture/ Forestry	0203	344	DCE estimate based on EOF (2017) and DEA (2016a)
	Gas oil	1A1a	Public electricity and heat production	0101 0102	5.7	DCE estimate based on DEA (2022e)
		1A1b	Petroleum refining	010306	5.7	DCE estimate based on DEA (2022e)
		1A1c	Oil and gas extraction	0105	5.7	DCE estimate based on DEA (2022e)
		1A2a-g	Industry	03	5.7	DCE estimate based on DEA (2022e)
		1A4a	Commercial/ Institutional	0201	5.7	DCE estimate based on DEA (2022e)
		1A4b i	Residential	0202	5.7	DCE estimate based on DEA (2022e)
		1A4c	Agriculture/Forestry	0203	5.7	DCE estimate based on DEA (2022e)
	Kerosene	1A2g	Industry - other	03	5	DCE estimate based on Tønder (2004) and Shell (2013).
		1A4a	Commercial/ Institutional	0201	5	DCE estimate based on Tønder (2004) and Shell (2013).
		1A4b i	Residential	0202	5	DCE estimate based on Tønder (2004) and Shell (2013).
		1A4c i	Agriculture/ Forestry	0203	5	DCE estimate based on Tønder (2004) and Shell (2013).
	LPG	1A1a	Public electricity and heat production	All	0.13	DCE estimate based on Augustesen (2003), Krebs (2003) and DEA (2016a).
		1A2a-g	Industry	03	0.13	DCE estimate based on Augustesen (2003), Krebs (2003) and DEA (2016a).
		1A4a	Commercial/ Institutional	0201	0.13	DCE estimate based on Augustesen (2003), Krebs (2003) and DEA (2016a).
		1A4b i	Residential	0202	0.13	DCE estimate based on Augustesen (2003), Krebs (2003) and DEA (2016a).
		1A4c i	Agriculture/ Forestry	0203	0.13	DCE estimate based on Augustesen (2003), Krebs (2003) and DEA (2016a).
	Refinery gas	1A1b	Petroleum refining	0103	1	DCE estimate based on plant specific data for one plant, average value for 1995-2002.
Gas	Natural gas	1A1a	Public electricity and heat production	0101, 0102, except engines	0.43	DCE estimate based on data from Energinet (2017) and Energinet (2013)
				010105, engines	0.5	Kristensen (2003)
		1A1b	Petroleum refining	0103	0.43	DCE estimate based on data from Energinet (2017) and Energinet (2013)
		1A1c	Oil and gas extraction	0105	0.43	DCE estimate based on data from Energinet (2017) and Energinet (2013)
		1A2a-g	Industry	03 except engines	0.43	DCE estimate based on data from Energinet (2017) and Energinet (2013)
				Engines	0.5	Kristensen (2003)
		1A4a	Commercial/ Institutional	0201 except engines	0.43	DCE estimate based on data from Energinet (2017) and Energinet (2013)
				Engines	0.5	Kristensen (2003)
		1A4b i	Residential	0202 except engines	0.43	DCE estimate based on data from Energinet (2017) and Energinet (2013)
				Engines	0.5	Kristensen (2003)

Fuel type	Fuel	NFR	NFR_name	SNAP	SO_2 emission factor, g/GJ	Reference
		1A4c i	Agriculture/ Forestry	0203 except engines	0.43	DCE estimate based on data from Energinet (2017) and Energinet (2013)
				Engines	0.5	Kristensen (2003)
Waste	Waste	1A1a	Public electricity and heat production	0101	8.3	Nielsen et al. (2010a)
				0102	14	DCE estimate based on plant specific data for four plants, 2009 data.
		1A2a-g	Industry	03	14	Assumed equal to district heating plants (DCE assumption).
		1A4a	Commercial/ Institutional	0201	14	Assumed equal to district heating plants (DCE assumption).
	Industrial waste	1A2f	Industry – non-metallic minerals	031600	67	DCE estimate based on plant specific data for 2011-2015.
Bio-mass	Wood	1A1a	Public electricity and heat production	0101	1.9	Nielsen et al. (2010a)
				0102	11	EEA (2023), Energy Industries Table 3.15 Wood
		1A2a-g	Industry	03	11	EEA (2023), Manufacturing industries and construction (combustion, Table 3-5 Biomass
		1A4a	Commercial/ Institutional	0201	11	EEA (2023), Small combustion Table 3-10 and Table 3-45 to 3-48 wood.
		1A4b i	Residential	0202	11	EEA (2023), Small combustion Table 3-6 Residential, solid biomass and Table 3-39 to 3-44 Residential, wood.
		1A4c i	Agriculture/ Forestry	0203	11	EEA (2023), Small combustion Table 3-10 and Table 3-45 to 3-48 wood.
	Straw	1A1a	Public electricity and heat production	0101	49	Nielsen et al. (2010a)
				0102	115	Assumed equal to farmhouse boilers.
		1A4b i	Residential	0202	115	Jensen et al. (2017)
		1A4c i	Agriculture/ Forestry	0203	115	Jensen et al. (2017)
	Wood pellets	1A1a	Public electricity and heat production	0101	1.9	Nielsen et al. (2010a)
		1A2a-g	Industry	03	11	EEA (2023), Manufacturing industries and construction (combustion, Table 3-5 Biomass
		1A4a	Commercial/ Institutional	0201	11	EEA (2023), Small combustion Table 3-10 and Table 3-45 to 3-48 wood.
		1A4b i	Residential	0202	11	EEA (2023), Small combustion Table 3-6 Residential, solid biomass and Table 3-39 to 3-44 Residential, wood.
		1A4c i	Agriculture/ Forestry	0203	11	EEA (2023), Small combustion Table 3-10 and Table 3-45 to 3-48 wood.
	Bio oil	1A1a	Public electricity and heat production	0101	0.3	DCE estimate based on Folkecenter for Vedvarende Energi (2000) and DEA (2016a).
				0102	0.3	DCE estimate based on Folkecenter for Vedvarende Energi (2000) and DEA (2016a).
		1A2a-g	Industry	03	0.3	DCE estimate based on Folkecenter for Vedvarende Energi (2000) and DEA (2016a).
		1A4b i	Residential	0202	0.3	DCE estimate based on Folkecenter for Vedvarende Energi (2000) and DEA (2016a).

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

1) The fuel is not applied in 2023

NO_x emission factors

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

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

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

Table 3.2.24 NO_x emission factors and references, 2023.

Fuel type	Fuel	NFR	NFR_name	SNAP	NO_x emission factor, g/GJ	Reference
Solid	Anodic carbon[1)]	1A2g	Industry - other	032000	183	Assumed equal to coal. DCE assumption.
	Coal	1A1a	Public electricity and heat production	0101	16.9	DCE estimate based on plant specific emission data and EU ETS (2024)
				0102	95	DEPA (2001a)
		1A2a-g	Industry	03 except cement production	183	DCE estimate based on plant specific data for four plants in 2015.
		1A2f	Industry, cement production	0316	233	DCE estimate based on plant specific data for 2023.
		1A4b i	Residential	020200	95	DEPA (2001a)
		1A4c i	Agriculture/ Forestry	0203	95	DEPA (2001a)
	Fly ash fossil	1A1a	Public electricity and heat production	0101	16.9	Assumed equal to the emission factor for coal.
	BKB	1A4b	Residential	0202	95	Assumed equal to coal. DCE assumption.
	Coke oven coke	1A2a-g	Industry	03	183	Assumed equal to coal. DCE assumption.
		1A4b	Residential	0202	95	Assumed equal to coal. DCE assumption.
Liquid	Petroleum coke	1A2a-g	Industry	03	129	Assumed equal to residual oil. DCE assumption.
			Industry, non-metallic minerals, cement	0316	233	DCE estimate based on plant specific data for 2023.
		1A4a	Commercial/ Institutional	0201	51	EEA (2023). Tier 1, Small combustion, Table 3-5, liquid fuels applied in residential plants.
		1A4b	Residential	0202	51	EEA (2023). Tier 1, Small combustion, Table 3-5 liquid fuels applied in residential plants.
		1A4c	Agriculture/ Forestry	0203	51	EEA (2023). Tier 1, Small combustion, Table 3-5 liquid fuels applied in residential plants.
	Residual oil	1A1a	Public electricity and heat production	0101	138	DCE estimate based on plant specific data for 2008, 2009 and 2010. Plant specific data refer to: Energinet (2009); Energinet (2010); Energinet (2011): EU ETS (2009-2011)
				0102	142	DEPA (2001a)
		1A1b	Petroleum refining	010306	142	EEA (2023), Energy Industries, Table 4-4 Tier 2 emission factors for source category 1.A.1.b, process furnaces using residual oil
		1A2a-g	Industry	03	129	DCE estimate based on plant specific data for 2015.
		1A2f	Industry, non-metallic minerals, cement	0316	233	DCE estimate based on plant specific data for 2023.
		1A4a	Commercial/ Institutional	0201	142	DEPA (2001a)
		1A4b	Residential	0202	142	DEPA (2001a)
		1A4c i	Agriculture/ Forestry	0203	142	DEPA (2001a)
	Gas oil	1A1a	Public electricity and heat production	010101, 010102, 010103	114	DCE estimate based on plant specific data for 2011.
				010104	230	DCE estimate based on plant specific data year 2015.
				010105	942	Nielsen et al. (2010a)
				0102	130	DEPA (2016b), DEPA (2012b), DEPA (2003b) and DEPA (1990)

Fuel type	Fuel	NFR	NFR_name	SNAP	NO_x emission factor, g/GJ	Reference
		1A1b	Petroleum refining	010306	65	EEA (2023), Energy Industries, Table 4-7 Tier 2 emission factors for source category 1.A.1.b, process furnaces, using gas oil
		1A1c	Oil and gas extraction	010500	215	Assumed equal to natural gas combustion applied in offshore gas turbines. DCE assumption.
		1A2a-g	Industry	03 except engines and turbines	130	DEPA (2016b), DEPA (2012b), DEPA (2003b) and DEPA (1990)
				Turbines	230	DCE estimate based on plant specific data year 2015.
				Engines	942	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201	52	DEPA (2001a)
				Engines	942	Nielsen et al. (2010a)
		1A4b i	Residential	0202	52	DEPA (2001a)
				Engines	942	Nielsen et al. (2010a)
		1A4c	Agriculture/Forestry	0203	52	DEPA (2001a)
				Engines	942	Nielsen et al. (2010a)
	Kerosene	1A2g	Industry - other	03	51	EEA (2023). Small Combustion Table 3-5. The emission factor is for liquid fuels combusted in residential plants.
		1A4a	Commercial/ Institutional	0201	51	EEA (2023). Small Combustion Table 3-5. The emission factor is for liquid fuels combusted in residential plants.
		1A4b i	Residential	0202	51	EEA (2023). Small Combustion Table 3-5. The emission factor is for liquid fuels combusted in residential plants.
		1A4c i	Agriculture/ Forestry	0203	51	EEA (2023). Small Combustion Table 3-5. The emission factor is for liquid fuels combusted in residential plants.
	LPG	1A1a	Public electricity and heat production	All	96	IPCC (1996).
		1A2a-g	Industry	03	96	IPCC (1996).
		1A4a	Commercial/ Institutional	0201	71	IPCC (1996).
		1A4b i	Residential	0202	47	IPCC (1996)
		1A4c i	Agriculture/ Forestry	0203	71	IPCC (1996)
	Refinery gas	1A1b	Petroleum refining	010304	170	DCE estimate based on plant specific data for a gas turbine in year 2000.
				010306	56	DCE estimate based on plant specific data for year 2015.
Gas	Natural gas	1A1a	Public electricity and heat production	010101, 010102	28	DEPA (2012b); DEPA (2015); DEPA (2016b)
				010103	30.32	Schweitzer & Kristensen (2015)
				010104	48	Nielsen et al. (2010a)
				010105	135	Nielsen et al. (2010a)
				0102	30.32	Schweitzer & Kristensen (2015)
		1A1b	Petroleum refining	0103	30.32	Schweitzer & Kristensen (2015)
		1A1c	Oil and gas extraction	010504	186	Estimate based on plant specific data. Nielsen & Bay (2024)
		1A2a-g	Industry	03	30.32	Schweitzer & Kristensen (2015)
				Engines	135	Nielsen et al. (2010a)

Fuel type	Fuel	NFR	NFR_name	SNAP	NO_x emission factor, g/GJ	Reference
				Turbines	48	Nielsen et al. (2010a)
		1A2f		030700 030703	87	DCE estimate based on plant specific data for 11 clay production plants, EU ETS (2011-2012); DEPA (2012b)
				030701 030702	30.32	Schweitzer & Kristensen (2015)
		1A4a	Commercial/ Institutional	0201	30.32	Schweitzer & Kristensen (2015)
				Engines	135	Nielsen et al. (2010a)
		1A4b i	Residential	0202	15.7	Schweitzer & Kristensen (2014)
				Engines	135	Nielsen et al. (2010a)
		1A4c i	Agriculture/ Forestry	0203	30.32	Schweitzer & Kristensen (2015)
				Engines	135	Nielsen et al. (2010a)
Waste	Waste	1A1a	Public electricity and heat production	0101	83	DCE estimate based on plant specific data for year 2023.
				0102	164	DCE estimate based on plant specific data for year 2000.
		1A2a-g	Industry	03	164	DCE estimate based on plant specific data for district heating plants in year 2000.
		1A4a	Commercial/ Institutional	0201	164	DCE estimate based on plant specific data for district heating plants in year 2000.
	Industrial waste	1A2f	Industry – non-metallic minerals, cement	031600	233	DCE estimate based on plant specific data for 2023.
Bio-mass	Wood	1A1a	Public electricity and heat production	010101 010102	33	Average emission factor for four power plants, 2018
				010103 010104	81	Nielsen et al. (2010a)
				0102	90	Serup et al. (1999)
		1A2a-g	Industry	03	90	Serup et al. (1999)
		1A4a	Commercial/ Institutional	0201	90	Serup et al. (1999)
		1A4b i	Residential	0202	75.4	Nielsen et al. (2021). The methodology for estimating this emission factor is also included in Chapter 3.2.7.
		1A4c i	Agriculture/ Forestry	0203	90	Serup et al. (1999)
	Straw	1A1a	Public electricity and heat production	0101	125	Nielsen et al. (2010a)
				0102	90	Nikolaisen et al. (1998)
		1A4b i	Residential	0202	154	Jensen et al. (2017)
		1A4c i	Agriculture/ Forestry	0203	154	Jensen et al. (2017)
	Wood pellets	1A1a	Public electricity and heat production	010101 010102	33	Average emission factor for four power plants, 2018
				010103 010104	81	Nielsen et al. (2010a)
				0102	90	Serup et al. (1999)
		1A2a-g	Industry	03	90	Serup et al. (1999)
		1A4a	Commercial/ Institutional	0201	90	Serup et al. (1999)
		1A4b i	Residential	0202	80	Nielsen et al. (2021).
		1A4c i	Agriculture/ Forestry	0203	90	Serup et al. (1999)
	Bio oil	1A1a	Public electricity and heat production	0101	114	Assumed equal to gas oil. DCE assumption.
				0102	130	Assumed equal to gas oil. DCE assumption.
		1A2a-g	Industry	03	130	Assumed equal to gas oil. DCE assumption.

Fuel type	Fuel	NFR	NFR_name	SNAP	NO_x emission factor, g/GJ	Reference
				Engines	942	Assumed equal to gas oil. DCE assumption.
		1A4b i	Residential	0202	52	Assumed equal to gas oil. DCE assumption.
	Biogas	1A1a	Public electricity and heat production	0101, not engines	28	Assumed equal to large natural gas fuelled boilers.
				Engines	202	Nielsen et al. (2010a)
				0102	28	DEPA (2001a)
		1A2a-g	Industry	03, not engines	28	Assumed equal to large natural gas fuelled boilers.
				03, engines	202	Nielsen et al. (2010a)
				030902	30.32	Assumed equal to large natural gas fuelled boilers.
		1A4a	Commercial/ Institutional	0201, not engines	28	DEPA (2001a)
				020105	202	Nielsen et al. (2010a)
		1A4b	Residential	0202	15.7	Assumed equal to natural gas
		1A4c i	Agriculture/ Forestry	0203, not engines	28	DEPA (2001a)
				020304	202	Nielsen et al. (2010a)
	Bio gasification gas	1A1a	Public electricity and heat production	010105	173	Nielsen et al. (2010a)
	Biomethane	1A1a	Public electricity and heat production	010101 010102	28	Assumed equal to natural gas. DCE assumption.
				010103	30.32	Assumed equal to natural gas. DCE assumption.
				0102	30.32	Assumed equal to natural gas. DCE assumption.
		1A2a-g	Industry	03, except engines and turbines	30.32	Assumed equal to natural gas. DCE assumption.
				03, gas turbines	48	Assumed equal to natural gas. DCE assumption.
				03, engines	135	Assumed equal to natural gas. DCE assumption.
		1A2f		030700 030703	87	Assumed equal to natural gas. DCE assumption.
				030701 030702	30.32	Assumed equal to natural gas. DCE assumption.
		1A4a	Commercial/ Institutional	0201	30.32	Assumed equal to natural gas. DCE assumption.
				0201, engines	135	Assumed equal to natural gas. DCE assumption.
		1A4b	Residential	0202	15.7	Assumed equal to natural gas. DCE assumption.
				0202, engines	135	Assumed equal to natural gas. DCE assumption.
		1A4c	Agriculture/ Forestry	0203	30.32	Assumed equal to natural gas. DCE assumption.
				0203, engines	135	Assumed equal to natural gas. DCE assumption.

1) The fuel is not applied in 2023

NMVOC emission factors

The NMVOC emission factors for 2023 and references are shown in Table 3.2.25.

The emission factors for NMVOC refer to:

- An emission measurement program for decentralised CHP plants (Nielsen et al., 2010a).
- The EEA Guidebook (EEA, 2023) and former editions.
- Aggregated emission factor based on the technology distribution for residential wood combustion (Nielsen et al., 2021b).
- DGC Danish Gas Technology Centre 2001, Naturgas – Energi og miljø (DGC, 2001).
  Gruijthuijsen & Jensen (2000). Energi- og miljøoversigt, Danish Gas Technology Centre, 2000 (In Danish).

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

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

The emission factor for combustion of straw in residential and agricultural plants is based on emission factor for boilers installed before and after 2022 and a 4 % linear annual replacement of old boilers. The emission factors for NMVOC are 600 g/GJ for old boilers and 9 g/GJ for new boilers. The emission factor for old boilers refer to EEA (2023)[14]. The emission factor for new boilers refer to Danish legislation (DEPA, 2022), assuming 50 % automatic boilers and 50 % manual fed boilers.

[14] EEA (2023), Tier 1, Small Combustion Table 3-6

Table 3.2.25 NMVOC emission factors and references, 2023.

Fuel type	Fuel	NFR	NFR_name	SNAP	NMVOC, g/GJ	Reference
Solid	Anodic carbon [2)]	1A2g	Industry - other	0320	10	Assumed equal to coal. DCE assumption.
	Coal	1A1a	Public electricity and heat production	0101 0102	1.0	EEA (2023), Tier 1, Energy Industries Table 3-2, public electricity and heat production, hard coal
		1A2a-g	Industry	03	10	EEA (2023), Tier 1, Industry Table 3-2, Manufacturing industries, solid fuels. Assumed lower interval.
		1A4c i	Agriculture/ Forestry	0203	88.8	EEA (2023), Tier 1, Small combustion Table 3-7
	Fly ash fossil	1A1a	Public electricity and heat production	0101	1.0	Assumed equal to coal. DCE assumption.
	BKB	1A4b i	Residential	0202	484	EEA (2023), Tier 1, Small combustion Table 3-3
	Coke oven coke	1A2a-g	Industry	03	10	EEA (2023), Tier 1, Industry Table 3-2, assumed lower interval.
		1A4b	Residential	0202	484	EEA (2023), Tier 1, Small combustion Table 3-3, hard coal, and brown coal, residential
Liquid	Petroleum coke	1A2a-g	Industry	03	25	EEA (2023) Tier 1, Industry Table 3-4, liquid fuels, residential
		1A4a	Commercial/ Institutional	0201	20	EEA (2023), Tier 1, Small combustion Table 3-9
		1A4b	Residential	0202	20	EEA (2023), Tier 1 for 1A4a/1A4c have been applied (DCE assumption). Small combustion, liquid fuels, Table 3-9.
		1A4c	Agriculture/ Forestry	0203	20	EEA (2023), Tier 1 for 1A4a/c, Small combustion, Table 3-9
	Residual oil	1A1a	Public electricity and heat production	010101 010102 010103	0.8	Nielsen et al. (2010a)
				010104	2.3	EEA (2023), Tier 1, Energy Industries Table 3-6
				010105	2.3	EEA (2023), Tier 1, Energy Industries Table 3-6
				010203	2.3	EEA (2023), Tier 1, Energy Industries Table 3-6
		1A1b	Petroleum refining	010306	2.3	EEA (2023), assumed equal to public electricity and heat production.
		1A2a-g	Industry	03 except engines	0.8	Nielsen et al. (2010a)
				Engines	25	EEA (2023), Tier 1, Industry Table 3-4
		1A4a	Commercial/ Institutional	0201	20	EEA (2023), Tier 1, Small combustion Table 3-9
		1A4b	Residential	0202	20	EEA (2023), Tier 1, Small combustion Table 3-9, assumed equal to 1A4a/1A4c.
		1A4c i	Agriculture/ Forestry	0203	20	EEA (2023), Small combustion Tier 1, Table 3-9
	Gas oil	1A1a	Public electricity and heat production	010101 010102 010103	0.8	EEA (2023), Tier 1, Energy Industries Table 3-7
				010104	0.19	EEA (2023), Tier 2, Energy Industries Table 3-20

Fuel type	Fuel	NFR	NFR_name	SNAP	NMVOC, g/GJ	Reference
				010105	37.1	EEA (2023), Tier 2, Energy Industries Table 3-21
				0102	0.8	EEA (2023), Tier 1, Energy Industries Table 3-7
		1A1b	Petroleum refining	010306	0.8	EEA (2023), Tier 1, Energy Industries Table 3-7
		1A1c	Oil and gas extraction	010500	0.8	EEA (2023), Tier 1, Energy Industries Table 3-7
		1A2a-g	Industry	03 boilers	0.8	EEA (2023), Tier 1, Energy Industries Table 3-7
				Gas turbines	0.19	EEA (2023), Tier 2, Energy Industries Table 3-20
				Engines	37.1	EEA (2023), Tier 2, Energy Industries Table 3-21
		1A4a	Commercial/ Institutional	0201 except engines	20	EEA (2023), Tier 1, Small Combustion Table 3-9
				Engines	37.1	EEA (2023), Tier 2, Energy Industries Table 3-21
		1A4b i	Residential	0202	20	EEA (2023), Tier 1, Small Combustion Table 3-9
				Engines	37.1	EEA (2023), Tier 2, Energy Industries Table 3-21
		1A4c	Agriculture/Forestry	0203	20	EEA (2023), Tier 1, Small Combustion Table 3-9
	Kerosene	1A2a-g	Industry	03	0.8	EEA (2023), Tier 1, Energy Industries Table 3-7
		1A4a	Commercial/ Institutional	0201	20	EEA (2023), Tier 1, Small Combustion Table 3-9
		1A4b i	Residential	0202	20	EEA (2023), Tier 1, Small Combustion Table 3-9
		1A4c i	Agriculture/ Forestry	0203	20	EEA (2023), Tier 1, Small Combustion Table 3-9
	LPG	1A1a	Public electricity and heat production	0101 0102	0.8	EEA (2023), Tier 1, Energy Industries Table 3-7
		1A2a-g	Iron and steel	03	0.8	EEA (2023), Tier 1, Energy Industries Table 3-7
		1A4a	Commercial/ Institutional	0201	20	EEA (2023), Tier 1, Small Combustion Table 3-9
		1A4b i	Residential	0202	20	EEA (2023), Tier 1, Small Combustion Table 3-9
		1A4c i	Agriculture/ Forestry	0203	20	EEA (2023), Tier 1, Small Combustion Table 3-9
	Refinery gas	1A1b	Petroleum refining	0103	1.4	Assumed equal to natural gas fuelled gas turbines. DCE assumption.
Gas	Natural gas	1A1a	Public electricity and heat production	010101 010102 010103	2	Danish Gas Technology Centre (2001).
				010104	1.6	Nielsen et al. (2010a)
				010105	92	Nielsen et al. (2010a)
				0102	2	Danish Gas Technology Centre (2001).
		1A1b	Petroleum refining	0103	2	Danish Gas Technology Centre (2001).
		1A1c	Oil and gas extraction	0105	1.6	Nielsen et al. (2010a)
		1A2a-g	Industry	03 except engines and turbines	2	Danish Gas Technology Centre (2001).
				Turbines	1.6	Nielsen et al. (2010a)
				Engines	92	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201 except engines	2	Danish Gas Technology Centre (2001).
				Engines	92	Nielsen et al. (2010a)
		1A4b i	Residential	0202 except engines	4	Gruijthuijsen & Jensen (2000)

Fuel type	Fuel	NFR	NFR_name	SNAP	NMVOC, g/GJ	Reference
				Engines	92	Nielsen et al. (2010a)
		1A4c i	Agriculture/ Forestry	0203 except engines	2	Danish Gas Technology Centre (2001).
				Engines	92	Nielsen et al. (2010a)
Waste	Waste	1A1a	Public electricity and heat production	0101	0.56	Nielsen et al. (2010a)
				0102	0.56	Nielsen et al. (2010a). The CHP emission factor has been applied for other plant categories.
		1A2a-g	Industry	03	0.56	Nielsen et al. (2010a). The CHP emission factor has been applied for other plant categories.
		1A4a	Commercial/ Institutional	0201	0.56	Nielsen et al. (2010a). The CHP emission factor has been applied for other plant categories.
	Industrial waste	1A2f	Industry	0316	0.56	Nielsen et al. (2010a). The CHP emission factor has been applied for other plant categories.
Bio-mass	Wood	1A1a	Public electricity and heat production	0101	5.1	Nielsen et al. (2010a)
				0102	7.3	EEA (2023), Tier 1, Energy Industries Table 3-8
		1A2a-g	Industry	03	84	Estimate based on country specific data, see (1)
		1A4a	Commercial/ Institutional	0201	175	Estimate based on country specific data, see (1)
		1A4b i	Residential	0202	310	Nielsen et al. (2021) The methodology for estimating this emission factor is also included in Chapter 3.2.7.
		1A4c i	Agriculture/ Forestry	0203	175	Estimate based on country specific data, see (1)
	Straw	1A1a	Public electricity and heat production	0101	0.78	Nielsen et al. (2010a)
				0102	7.3	EEA (2023), Tier 1, Energy Industries Table 3-8
		1A4b i	Residential	0202	553	Time series based on DEPA (2022) and EEA (2023), Tier 1, Small Combustion Table 3-6
		1A4c i	Agriculture/ Forestry	0203	553	Time series based on DEPA (2022) and EEA (2023), Tier 1, Small Combustion Table 3-6
				020302	12	EEA (2023), Tier 2, Small Combustion Table 3-45
	Wood pellets	1A1a	Public electricity and heat production	0101	5.1	Nielsen et al. (2010a)
				0102	7.3	EEA (2023), Tier 1, Energy Industries Table 3-8
		1A2a-g	Industry	03	10	Nielsen et al. (2021b)
		1A4a	Commercial/ Institutional	0201	10	Nielsen et al. (2021b)
		1A4b i	Residential	0202	10	Nielsen et al. (2021b)
		1A4c i	Agriculture/ Forestry	0203	10	Nielsen et al. (2021b)
	Bio oil	1A1a	Public electricity and heat production	010102	0.8	EEA (2023), Tier 1, Energy Industries Table 3-7 (gas oil)
				010105	37	EEA (2023), Tier 2, Energy Industries Table 3-21 (gas oil, large stationary CI reciprocating engines)
				0102	0.8	EEA (2023), Tier 1, Energy Industries Table 3-7 (gas oil)

Fuel type	Fuel	NFR	NFR_name	SNAP	NMVOC, g/GJ	Reference
		1A2a-g	Industry	03, not engines	0.8	EEA (2023), Tier 1, Energy Industries Table 3-7 (gas oil)
				010105	37	EEA (2021), Tier 2, Energy Industries Table 3-21 (gas oil, large stationary CI reciprocating engines)
		1A4b i	Residential	0202	20	EEA (2023), Tier 1, Small combustion Table 3-9 (liquid fuels)
	Biogas	1A1a	Public electricity and heat production	0101	2	Assumed equal to natural gas. DCE assumption.
				010105	10	Nielsen et al. (2010a)
				0102	2	Assumed equal to natural gas. DCE assumption.
		1A2a-g	Industry	03 except engines	2	Assumed equal to natural gas. DCE assumption.
				Engines	10	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201 except engines	2	Assumed equal to natural gas. DCE assumption.
				Engines	10	Nielsen et al. (2010a)
		1A4b	Residential	0202	4	Assumed equal to natural gas. DCE assumption.
		1A4c i	Agriculture/ Forestry	0203 except engines	2	Assumed equal to natural gas. DCE assumption.
				Engines	10	Nielsen et al. (2010a)
	Bio gasification gas	1A1a	Public electricity and heat production	010105	2	Nielsen et al. (2010a)
				0101 except engines	2	Assumed equal to natural gas. DCE assumption.
	Biomethane	1A1a	Public electricity and heat production	0101 except engines	2	Assumed equal to natural gas. DCE assumption.
				0101, gas turbines	1.6	Assumed equal to natural gas. DCE assumption.
				0101, engines	92	Assumed equal to natural gas. DCE assumption.
				0102	2	Assumed equal to natural gas. DCE assumption.
		1A1b	Petroleum refining	0103	2	Assumed equal to natural gas. DCE assumption.
		1A2a-g	Industry	03	2	Assumed equal to natural gas. DCE assumption.
				03, gas turbines	1.6	Assumed equal to natural gas. DCE assumption.
				03, gas engines	92	Assumed equal to natural gas. DCE assumption.
		1A4a	Commercial/ Institutional	0201	2	Assumed equal to natural gas. DCE assumption.
				0201, engines	92	Assumed equal to natural gas. DCE assumption.
		1A4b	Residential	0202	4	Assumed equal to natural gas. DCE assumption.
				0202, engines	92	Assumed equal to natural gas. DCE assumption.
		1A4c	Agriculture/ Forestry	0203	2	Assumed equal to natural gas. DCE assumption.
				0203, engines	92	Assumed equal to natural gas. DCE assumption.

1) The emission factor for combustion of wood in commercial/institutional plants, agricultural plants and industrial plants have been aggregated based on technology specific emission factors: industrial plants with production of electricity or district heating: 12 g/GJ (EEA, 2023) and other plants 350 g/GJ (EEA, 2023) in 1990-1995 and 175 g/GJ (EEA, 2023) since 2002 (DCE assumption). The aggregated emission factors for 2023 are 84 g/GJ for industrial plants and 175 g/GJ for commercial/institutional/agricultural plants. A time series has been applied in the inventory.

2) The fuel is not applied in 2023.

CO emission factors

The CO emission factors 2023 and references are shown in Table 3.2.26.

The emission factors for CO refer to:

- The EEA Guidebook (EEA, 2023)[15].
- An emission measurement program for decentralised CHP plants (Nielsen et al., 2010a).
- Danish legislation (DEPA, 2001a)
- Nielsen et al. (2021). Aggregated emission factor based on the technology distribution for residential wood combustion and technology specific emission factors. See Chapter 3.2.7.
- DCE estimate based on annual environmental reports for Danish waste incineration plants without power production, year 2000.
- Nikolaisen et al. (1998)
- Jensen & Nielsen (1990)
- Bjerrum (2002)
- Sander (2002)
- Gruijthuijsen & Jensen (2000)
- Kristensen & Kristensen (2004)

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

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

The emission factor for combustion of straw in residential and agricultural plants is based on emission factor for boilers installed before and after 2022 and a 4 % linear annual replacement of old boilers. The emission factors for CO are 2000 g/GJ for old boilers and 312 g/GJ for new boilers. The emission factor for old boilers refer to EEA (2023), Jensen & Nielsen (1990), Bjerrum (2002) and Kristensen & Kristensen (2004). The emission factor for new boilers refer to Danish legislation (DEPA, 2022), assuming 50 % automatic boilers and 50 % manual fed boilers.

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

Table 3.2.26 CO emission factors and references 2023.

Fuel type	Fuel	NFR	NFR_name	SNAP	CO emission factor, g/GJ	Reference
Solid	Anodic carbon [1)]	1A2a-g	Industry	03	10	Assumed the same emission factor as for coal. DCE assumption.
	Coal	1A1a	Public electricity and heat production	0101 and 0102	10	Sander (2002)
		1A2a-g	Industry	03	10	Assumed equal to boilers in public electricity and heat production. DCE assumption.
		1A4b i	Residential	0202	4787	EEA (2023), Tier 2, Small Combustion Table 3-15, residential boilers, solid fuels
		1A4c i	Agriculture/ Forestry	0203	931	EEA (2023), Tier 1, Small Combustion Table 3-7, 1A4a/c hard coal and brown coal
	Fly ash fossil	1A1a	Public electricity and heat production	0101	10	Assumed equal to coal. DCE assumption.
	BKB	1A4b i	Residential	0202	4787	EEA (2023), Tier 2, Small Combustion Table 3-15, residential boilers, solid fuels
	Coke oven coke	1A2a-g	Industry	03	10	Assumed the same emission factor as for coal. DCE assumption.
		1A4b	Residential	0202	4787	EEA (2023), Tier 2, Small Combustion Table 3-15, residential boilers, solid fuels
Liquid	Petroleum coke	1A1a	Public electricity and heat production	0101	66	EEA (2023), Tier 1, Manufacturing industries and construction Table 3-4 for liquid fuels.
		1A2a-g	Industry	03	66	EEA (2023), Tier 1, Manufacturing industries and construction Table 3-4 for liquid fuels.
		1A4a	Commercial/Institutional	0201	93	EEA (2023), Tier 1, Small Combustion Table 3-9
		1A4b	Residential	0202	93	EEA (2023), Tier 1, Small Combustion Table 3-9 (assumed equal to the emission factor for 1A4a/1A4c).
		1A4c	Agriculture/ Forestry	0203	93	EEA (2023), Tier 1, Small Combustion Table 3.9
	Residual oil	1A1a	Electricity and heat production	010101 010104 010105	15	Sander (2002)
				010102 010103	2.8	Nielsen et al. (2010a)
				0102	15.1	EEA (2023), Tier 1, Energy Industries Table 3-6.
		1A1b	Petroleum refining	010306	6	EEA (2019), Tier 2, Energy Industries Table 4-4. No emission factor available in EEA (2023).
		1A2a-g	Industry	03 except engines	2.8	Nielsen et al. (2010a)
				Engines	130	EEA (2023). Tier 2 emission factor for gas oil fuelled engines in Energy Industries, Table 3-21. Refers to Nielsen et al. (2010a).
		1A4a	Commercial/Institutional	0201	40	EEA (2023). Tier 2, Small Combustion Table 3-25.
		1A4b	Residential	0202	57	EEA (2023), Tier 1, Small Combustion Table 3-5

Fuel type	Fuel	NFR	NFR_name	SNAP	CO emission factor, g/GJ	Reference
		1A4c i	Agriculture/ Forestry	0203	40	EEA (2023). Tier 2, Small Combustion Table 3-25.
	Gas oil	1A1a	Public electricity and heat production	0101 except engines	15	Sander (2002)
				Engines	130	Nielsen et al. (2010a)
				0102	16.2	EEA (2023), Tier 1, Energy Industries Table 3-7, gas oil
		1A1b	Petroleum refining	010306	16.2	EEA (2023), Tier 1, Energy Industries Table 4-7, gas oil
		1A1c	Oil and gas extraction	0105	15	Sander (2002)
		1A2a-g	Industry	03 except gas turbines and engines	66	EEA (2023), Tier 1, Manufacturing industries and construction Table 3-4 for liquid fuels.
				Gas turbines	15	Sander (2002)
				Engines	130	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201 except engines	40	EEA (2023). Tier 2, Small Combustion Table 3-24.
				Engines	130	Nielsen et al. (2010a)
		1A4b i	Residential	0202 except engines	3.7	EEA (2023). Tier 2, Small Combustion Table 3-18. Gas oil applied in small residential boilers.
				Engines	130	Nielsen et al. (2010a)
		1A4c	Agriculture/Forestry	0203	40	EEA (2023). Tier 2, Small Combustion Table 3-24.
	Kerosene	1A2a-g	Industry	03	66	EEA (2023), Tier 1, Manufacturing industries and construction Table 3-4 for liquid fuels.
		1A4a	Commercial/ Institutional	0201	40	EEA (2023). Tier 2, Small Combustion Table 3-24.
		1A4b i	Residential	0202	3.7	EEA (2023). Tier 2, Small Combustion Table 3-18. Gas oil applied in small residential boilers.
		1A4c i	Agriculture/ Forestry	0203	40	EEA (2023). Tier 2, Small Combustion Table 3-24.
	LPG	1A1a	Public electricity and heat production	0101 and 0102	16.2	EEA (2023), Tier 1, Energy Industries Table 3-7
		1A2a-g	Industry	03	66	EEA (2023), Tier 1, Manufacturing industries and construction Table 3.4 for liquid fuels.
		1A4a	Commercial/ Institutional	0201	40	EEA (2023). Tier 2, Small Combustion Table 3-24.
		1A4b i	Residential	0202	3.7	EEA (2023). Tier 2, Small Combustion Table 3-18. Gas oil applied in small residential boilers.
		1A4c i	Agriculture/ Forestry	0203	40	EEA (2023). Tier 2, Small Combustion Table 3-24.
	Refinery gas	1A1b	Petroleum refining	0103	12.1	EEA (2019). Tier 1, Energy Industries Table 4.2 for refinery gas applied in petroleum refining. The emission factor is not included in EEA (2023).
Gas	Natural gas	1A1a	Public electricity and heat production	010101 and 010102	15	Sander (2002)
				010103	28	DEPA (2001a)
				010104	4.8	Nielsen et al. (2010a)
				010105	58	Nielsen et al. (2010a)
				0102	28	DEPA (2001a)
		1A1b	Petroleum refining	0103	28	Assumed equal to district heating plants.
		1A1c	Oil and gas extraction	0105	4.8	Nielsen et al. (2010a)

Fuel type	Fuel	NFR	NFR_name	SNAP	CO emission factor, g/GJ	Reference
		1A2a-g	Industry	03 except gas turbines and engines	28	DEPA (2001a)
				Gas turbines	4.8	Nielsen et al. (2010a)
				Engines	58	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201 except engines	28	DEPA (2001a)
				Engines	58	Nielsen et al. (2010a)
		1A4b i	Residential	0202 except engines	20	Gruijthuijsen & Jensen (2000)
				Engines	58	Nielsen et al. (2010a)
		1A4c i	Agriculture/ Forestry	0203 except engines	28	DEPA (2001a)
				Engines	58	Nielsen et al. (2010a)
Waste	Waste	1A1a	Public electricity and heat production	0101	3.9	Nielsen et al. (2010a)
				0102	10	DCE calculation based on annual environmental reports for Danish plants year 2000.
		1A2a-g	Industry	03	10	DCE calculation based on annual environmental reports for Danish plants year 2000.
		1A4a	Commercial/ Institutional	0201	10	DCE calculation based on annual environmental reports for Danish plants year 2000.
	Industrial waste	1A2f	Industry	0316	10	Assumed equal to waste, district heating plants. DCE assumption.
Biomass	Wood	1A1a	Public electricity and heat production	0101	90	Nielsen et al. (2010a)
				010203	240	DEPA (2001a)
		1A2a-g	Industry	03	240	DEPA (2001a)
		1A4a	Commercial/ Institutional	020100	240	DEPA (2001a)
		1A4b i	Residential	0202	2403	Nielsen et al. (2021). The methodology for estimating this emission factor is also included in Chapter 3.2.7.
		1A4c i	Agriculture/ Forestry	020300	240	DEPA (2001a)
	Straw	1A1a	Public electricity and heat production	0101	67	Nielsen et al. (2010a)
				0102	325	DEPA (2001a); Nikolaisen et al (1998)
		1A4b i	Residential	0202	1865	DEPA (2022); EEA (2007); Jensen & Nielsen (1990) and Bjerrum (2002), Kristensen & Kristensen (2004). Time series.
		1A4c i	Agriculture/ Forestry	0203	1865	DEPA (2022); EEA (2007); Jensen & Nielsen (1990) and Bjerrum (2002), Kristensen & Kristensen (2004). Time series.
				020302	325	DEPA (2001a); Nikolaisen et al (1998)
	Wood pellets	1A1a	Public electricity and heat production	0101	90	Nielsen et al. (2010a)
				010203	240	DEPA (2001a)
		1A2a-g	Industry	03	240	DEPA (2001a)
		1A4a	Commercial/ Institutional	020100	240	DEPA (2001a)

Fuel type	Fuel	NFR	NFR_name	SNAP	CO emission factor, g/GJ	Reference
		1A4b i	Residential	0202	300	Nielsen et al. (2021b)
		1A4c i	Agriculture/ Forestry	020300	240	DEPA (2001a)
	Bio oil	1A1a	Public electricity and heat production	0101	15	Assumed same emission factor as for gas oil. DCE assumption.
				0102	16.2	Assumed same emission factor as for gas oil. DCE assumption.
		1A2a-g	Industry	03	66	Assumed same emission factor as for gas oil. DCE assumption.
		1A4b i	Residential	0202	3.7	Assumed same emission factor as for gas oil. DCE assumption.
	Biogas	1A1a	Public electricity and heat production	0101 except engines	36	DEPA (2001a)
				Engines	310	Nielsen et al. (2010a)
				0102	36	DEPA (2001a)
		1A2a-g	Industry	03 except engines	36	DEPA (2001a)
				Engines	310	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201 except engines	36	DEPA (2001a)
				Engines	310	Nielsen et al. (2010a)
		1A4b	Residential	0202	20	Assumed equal to natural gas. DCE assumption.
		1A4c i	Agriculture/ Forestry	0203 except engines	36	DEPA (2001a)
				Engines	310	Nielsen et al. (2010a)
	Bio gasification gas	1A1a	Public electricity and heat production	010105	586	Nielsen et al. (2010a)
				010101	36	DEPA (2001a)
	Biomethane	1A1a	Public electricity and heat production	010101, 010102	15	Assumed equal to natural gas. DCE assumption.
				010103	28	Assumed equal to natural gas. DCE assumption.
				0101, gas turbines	4.8	Assumed equal to natural gas. DCE assumption.
				0101, engines	58	Assumed equal to natural gas. DCE assumption.
				0102	28	Assumed equal to natural gas. DCE assumption.
		1A1b	Petroleum refining	0103	28	Assumed equal to natural gas. DCE assumption.
		1A2a-g	Industry	03	28	Assumed equal to natural gas. DCE assumption.
				03, gas turbines	4.8	Assumed equal to natural gas. DCE assumption.
				03, engines	58	Assumed equal to natural gas. DCE assumption.
		1A4a	Commercial/ Institutional	0201	28	Assumed equal to natural gas. DCE assumption.
				0201, engines	58	Assumed equal to natural gas. DCE assumption.
		1A4b i	Residential	0202	20	Assumed equal to natural gas. DCE assumption.
				0202, engines	58	Assumed equal to natural gas. DCE assumption.
		1A4c i	Agriculture/ Forestry	0203	28	Assumed equal to natural gas. DCE assumption.
				0203, engines	58	Assumed equal to natural gas. DCE assumption.

1) The fuel has not been applied in 2023.

NH_3 emission factors

NH_3 emissions have been estimated for:

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

The NH_3 emission factors 2023 and references are shown in Table 3.2.27.

The emission factor for waste incineration plants refers to a Danish emission measurement programme (Nielsen et al., 2010a). The emission factor for residential wood combustion is based on Nielsen et al. (2021). All other emission factors refer to the EEA (2023).

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

Table 3.2.27 NH_3 emission factors and references, 2023.

Fuel	NFR (SNAP)	Emission factor, g/GJ	Reference
Coal	1A4b	0.3	EEA (2023), Tier 1, Small combustion Table 3-3
BKB	1A4b	0.3	EEA (2023), Tier 1, Small combustion Table 3-3
Coke oven coke	1A4b	0.3	EEA (2023), Tier 1, Small combustion Table 3-3
Wood	1A4b	45.66	Nielsen et al. (2021). The methodology for estimating this emission factor is included in Chapter 3.2.7.
Wood	1A4a, 1A4c, 1A2	1	EEA (2023), Tier 1, Small Combustion Table 3-10.
Wood pellets	1A4b, 1A4a, 1A4c, 1A2	12	Nielsen et al. (2021b).
Waste	1A1a	0.29	Nielsen et al. (2010a)
Straw	1A4b, 1A4c	8	EEA (2023), Tier 1, Small Combustion Table 3-6.
Straw	1A4a, 1A2	1	EEA (2023), Tier 1, Small Combustion Table 3-10.

Particulate matter (PM) emission factors

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

- The TNO/CEPMEIP emission factor database (TNO, 2001).
- Danish legislation:
  - DEPA (2001a), The Danish Environmental Protection Agency, Luftvejledningen (legislation from Danish Environmental Protection Agency).
  - DEPA (1990), The Danish Environmental Protection Agency, Bekendtgørelse 698 (legislation from Danish Environmental Protection Agency).

- DEPA (1995), The Danish Environmental Protection Agency, Bekendtgørelse 518 (legislation from Danish Environmental Protection Agency).
- DEPA (2022), The Danish Environmental Protection Agency, Bekendtgørelse 199, 2022.

- Calculations based on plant-specific emission data from a considerable number of waste incineration plants.
- Calculations based on plant-specific emission data from 7 power plants combusting wood and/or wood pellets.
- Nielsen et al. (2021b). See also Chapter 6.13.
- Two emission measurement programs for decentralised CHP plants (Nielsen et al., 2010a; Nielsen & Illerup, 2003).
- An emission measurement program for large power plants (Livbjerg et al., 2001).
- Additional personal communication concerning straw combustion in residential plants (Kristensen, 2017c).

Emission factor time series have been estimated for residential wood combustion, combustion of wood and wood pellets in power plants, combustion of straw in residential / agricultural plants, waste incineration in CHP plants, and waste incineration in other plants. All other emission factors have been considered constant in 1990-2023. The time series are included in Annex 3A-4.

Further details for residential wood combustion are included in Chapter 3.2.7.

The emission factor for combustion of straw in residential and agricultural plants is based on emission factor for boilers installed before and after 2022 and a 4 % linear annual replacement of old boilers. The emission factors for TSP are 433 g/GJ for old boilers and 26 g/GJ for new boilers. The emission factor for old boilers refer to Kristensen, (2017c). The emission factor for new boilers refer to Danish legislation (DEPA, 2022), assuming 50 % automatic boilers and 50 % manual fed boilers.

Table 3.2.28 PM emission factors and references, 2023.

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

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

fuel_type	fuel	fuel	nfr	snap_id	TSP, g/GJ	Reference for TSP	PM_{10}, g/GJ	$PM_{2.5}$, g/GJ	Reference for PM_{10} and $PM_{2.5}$ emission factors or for the PM_{10} and the $PM_{2.5}$ fraction
	115A	Industrial waste	1A2f	0316	4.2	The emission factor has been estimated by DCE based on plant specific data from MSW incineration plants, district heating, 2008	3.2	2.1	The emission factors have been estimated by DCE based on plant specific data from MSW incineration plants, district heating, 2008
Biomass	111A	Wood	1A1a	0101	1.3	DCE estimate based on data from 7 plants, 2020	1.3	1.3	Assumed equal to TSP due to flue gas cleaning in power plants.
				0102	19	DEPA (2001a)	13	10	DEPA (2001a), TNO (2001)
			1A2 a-g	03	19	DEPA (2001a)	13	10	DEPA (2001a), TNO (2001)
			1A4a i	0201	143	DEPA (2001a)	143	135	TNO (2001)
			1A4b i	0202	270.2	Nielsen et al. (2021b). See also Chapter 3.2.7.	256.7	251.4	Nielsen et al. (2021b). See also Chapter 3.2.7.
			1A4c i	0203	143	DEPA (2001a)	143	135	TNO (2001)
	117A	Straw	1A1a i	0101	2.3	Nielsen et al. (2010a)	1.71	1.11	Nielsen & Illerup (2003)
				0102	21	DEPA (2001a)	15	12	TNO (2001)
			1A4b i	0202	400	Kristensen (2017c) and DEPA (2022). Time series.	400	400	Zefeng (2011)
			1A4c I	0203	400	Kristensen (2017c) and DEPA (2022). Time series.	400	400	Zefeng (2011)
				020302	21	DEPA (2001a)	15	12	TNO (2001)
	122A	Wood pellets	1A1a	0101	1.3	DCE estimate based on data from 7 plants, 2020	1.3	1.3	Assumed equal to TSP due to flue gas cleaning in power plants.
				0102	19	DEPA (2001a)	13	10	DEPA (2001a), TNO (2001)
			1A2 a-g	03	19	DEPA (2001a)	13	10	DEPA (2001a), TNO (2001)
			1A4a i	0201	51	Nielsen et al. (2021). See also Chapter 3.2.7.	48	47	Nielsen et al. (2021). See also Chapter 3.2.7.
			1A4b i	0202	51	Nielsen et al. (2021). See also Chapter 3.2.7.	48	47	Nielsen et al. (2021). See also Chapter 3.2.7.
			1A4c i	0203	51	Nielsen et al. (2021). See also Chapter 3.2.7.	48	47	Nielsen et al. (2021). See also Chapter 3.2.7.
	215A	Bio oil	1A1a	0101	5	Assuming same emission factors as for gas oil (DCE assumption)	5	5	Assuming same emission factors as for gas oil (DCE assumption)
				0102	5	Assuming same emission factors as for gas oil (DCE assumption)	5	5	Assuming same emission factors as for gas oil (DCE assumption)
			1A2a-g	03	5	Assuming same emission factors as for gas oil (DCE assumption)	5	5	Assuming same emission factors as for gas oil (DCE assumption)
			1A4b i	0202	5	Assuming same emission factors as for gas oil (DCE assumption)	5	5	Assuming same emission factors as for gas oil (DCE assumption)

fuel_type	fuel	fuel	nfr	snap_id	TSP, g/GJ	Reference for TSP	PM_{10}, g/GJ	$PM_{2.5}$, g/GJ	Reference for PM_{10} and $PM_{2.5}$ emission factors or for the PM_{10} and the $PM_{2.5}$ fraction
	309A	Biogas	1A1a	0101, not engines	1.5	DEPA (1990), DEPA (1995)	1.5	1.5	All TSP emission is assumed to be <2,5µm (DCE assumption)
				010105	2.63	Nielsen & Illerup (2003)	0.451	0.206	Nielsen & Illerup (2003)
				0102	1.5	DEPA (1990), DEPA (1995)	1.5	1.5	All TSP emission is assumed to be <2,5µm (DCE assumption)
			1A2a-g	Engines	2.63	Nielsen & Illerup (2003)	0.451	0.206	Nielsen & Illerup (2003)
				Other	1.5	DEPA (1990), DEPA (1995)	1.5	1.5	All TSP emission is assumed to be <2,5µm (DCE assumption)
			1A4a i	0201	1.5	DEPA (1990), DEPA (1995)	1.5	1.5	All TSP emission is assumed to be <2,5µm (DCE assumption)
				Engines	2.63	Nielsen & Illerup (2003)	0.451	0.206	Nielsen & Illerup (2003)
			1A4b	0202	0.1	Biogas upgraded for the town gas grid. Assumed equal to natural gas	0.1	0.1	Biogas upgraded for the town gas grid. Assumed equal to natural gas
			1A4c i	0203	1.5	DEPA (1990), DEPA (1995)	1.5	1.5	All TSP emission is assumed to be <2,5µm (DCE assumption)
				Engines	2.63	Nielsen & Illerup (2003)	0.451	0.206	Nielsen & Illerup (2003)
	310A	Bio gasification gas	1A1a	010105	2.63	Same emission factor as for biogas assumed (DCE assumption)	0.451	0.206	Same emission factor as for biogas assumed (DCE assumption)
				010101	0.2	Assumed equal to LPG	0.2	0.2	Assumed equal to LPG
	315A	Biomethane	1A1a	0101	0.1	Assumed equal to natural gas	0.1	0.1	Assumed equal to natural gas
				Gas turbines	0.1	Assumed equal to natural gas	0.061	0.051	Assumed equal to natural gas
				Engines	0.76	Assumed equal to natural gas	0.189	0.161	Assumed equal to natural gas
				0102	0.1	Assumed equal to natural gas	0.1	0.1	Assumed equal to natural gas
			1A2a-g	03	0.1	Assumed equal to natural gas	0.1	0.1	Assumed equal to natural gas
				Gas turbines	0.1	Assumed equal to natural gas	0.061	0.051	Assumed equal to natural gas
				Engines	0.76	Assumed equal to natural gas	0.189	0.161	Assumed equal to natural gas
			1A4a	0201	0.1	Assumed equal to natural gas	0.1	0.1	Assumed equal to natural gas
				Engines	0.76	Assumed equal to natural gas	0.189	0.161	Assumed equal to natural gas
			1A4b	0202	0.1	Assumed equal to natural gas	0.1	0.1	Assumed equal to natural gas
				Engines	0.76	Assumed equal to natural gas	0.189	0.161	Assumed equal to natural gas
			1A4c	0203	0.1	Assumed equal to natural gas	0.1	0.1	Assumed equal to natural gas
				Engines	0.76	Assumed equal to natural gas	0.189	0.161	Assumed equal to natural gas

1) The fuel has not been applied in 2023

Black carbon (BC) emission factors

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

Emission factor fractions for BC all refer to EEA (2023). All emission factors are shown as percentage of $PM_{2.5}$ and in g per GJ.

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

Table 3.2.29 BC fraction of $PM_{2.5}$, 2023.

Fuel	Fuel	NFR	SNAP	BC share of $PM_{2.5}$	BC emission factor, g/GJ	Reference for BC share
101A	Anodic carbon	1A2	03	2.2%	0.154	EEA (2023), Energy Industries, Table 3-2
102A	Coal	1A1a	0101	2.2%	0.0462	EEA (2023), Energy Industries, Table 3-2
102A	Coal	1A1a	0102	2.2%	0.11	EEA (2023), Energy Industries, Table 3-2
102A	Coal	1A2	03	6.4%	0.448	EEA (2023), Manufacturing Industries, Table 3-2
102A	Coal	1A4a	0201	6.4%	0.448	EEA (2023), Small Combustion, Table 3-7
102A	Coal	1A4b	0202	6.4%	0.448	EEA (2023), Small Combustion, Table 3-3
102A	Coal	1A4c	0203	6.4%	0.448	EEA (2023), Small Combustion, Table 3-7
103A	Fly ash fossil	1A1a	010104	2.2%	0.0462	Assumed equal to coal. DCE assumption.
106A	BKB	1A2	03	6.4%	0.448	EEA (2023), Manufacturing Industries, Table 3-2
106A	BKB	1A4a	0201	6.4%	0.448	EEA (2023), Small Combustion, Table 3-7
106A	BKB	1A4b	0202	6.4%	0.448	EEA (2023), Small Combustion, Table 3-3
106A	BKB	1A4c	0203	6.4%	0.448	EEA (2023), Small Combustion, Table 3-7
107A	Coke oven coke	1A4b	0202	6.4%	0.448	EEA (2023), Small Combustion, Table 3-3
107A	Coke oven coke	1A2	0301	6.4%	0.448	EEA (2023), Manufacturing Industries, Table 3-2
110A	Petroleum coke	1A1a	0101	5.6%	0.168	EEA (2023), Energy Industries, Table 3-5 and Table 3-1.
110A	Petroleum coke	1A2	03	56.0%	1.68	EEA (2023), Manufacturing Industries, Table 3-4
110A	Petroleum coke	1A4a	0201	56.0%	16.8	EEA (2023), Small Combustion, Table 3-9
110A	Petroleum coke	1A4b	0202	8.5%	2.55	EEA (2023), Small Combustion, Table 3-5
110A	Petroleum coke	1A4c	0203	56.0%	16.8	EEA (2023), Small Combustion, Table 3-9
203A	Residual oil	1A1a	010101	5.6%	0.14	EEA (2023), Energy Industries, Table 3-5
203A	Residual oil	1A1a	010102, 010103	5.6%	0.4424	EEA (2023), Energy Industries, Table 3-5
203A	Residual oil	1A1a	0102	5.6%	0.14	EEA (2023), Energy Industries, Table 3-5
203A	Residual oil	1A1b	010306	5.6%	1.96	EEA (2023), Energy Industries, Table 4-6
203A	Residual oil	1A2	03	56.0%	2.688	EEA (2023), Manufacturing Industries, Table 3-4
203A	Residual oil	1A4a	0201	56.0%	3.92	EEA (2023), Small Combustion, Table 3-9
203A	Residual oil	1A4b	0202	8.5%	0.595	EEA (2023), Small Combustion, Table 3-5
203A	Residual oil	1A4c	0203	56.0%	3.92	EEA (2023), Small Combustion, Table 3-9
204A	Gas oil	1A1a	0101, 0102	33.5%	1.675	EEA (2023), Energy Industries, Table 3-7
204A	Gas oil	1A1a	010104	33.5%	1.675	EEA (2023), Energy Industries, Table 3-20
204A	Gas oil	1A1a	010105	78.0%	3.9	EEA (2023), Energy Industries, Table 3-21
204A	Gas oil	1A1b	010306	33.5%	1.675	EEA (2023), Energy Industries, Table 4-7
204A	Gas oil	1A1c	010500	33.5%	1.675	EEA (2023), Energy Industries, Table 3-20
204A	Gas oil	1A2	03	56.0%	2.8	EEA (2023), Manufacturing Industries, Table 3-4
204A	Gas oil	1A2	03 turbines	33.5%	1.675	EEA (2023), Energy Industries, Table 3-20
204A	Gas oil	1A2	03 engines	78.0%	3.9	EEA (2023), Energy Industries, Table 3-21
204A	Gas oil	1A4a	0201	56.0%	2.8	EEA (2023), Small Combustion, Table 3-9

Fuel	Fuel	NFR	SNAP	BC share of $PM_{2.5}$	BC emission factor, g/GJ	Reference for BC share
204A	Gas oil	1A4a	020105	78.0%	3.9	EEA (2023), Energy Industries, Table 3-21
204A	Gas oil	1A4b	0202	3.9%	0.195	EEA (2023), Small Combustion, Table 3-18
204A	Gas oil	1A4b	020204	78.0%	3.9	EEA (2023), Energy Industries, Table 3-21
204A	Gas oil	1A4c	0203	56.0%	2.8	EEA (2023), Small Combustion, Table 3-9
204A	Gas oil	1A4c	020304	78.0%	3.9	EEA (2023), Energy Industries, Table 3-21
206A	Kerosene	1A2	03	56.0%	2.8	EEA (2023), Manufacturing Industries, Table 3-4
206A	Kerosene	1A4a	0201	56.0%	2.8	EEA (2023), Small Combustion, Table 3-9
206A	Kerosene	1A4b	0202	8.5%	0.425	EEA (2023), Small Combustion, Table 3-5
206A	Kerosene	1A4c	0203	56.0%	2.8	EEA (2023), Small Combustion, Table 3-9
225A	Orimulsion	1A1a	010101	2.2%	0.0352	Assumed equal to coal. DCE assumption.
303A	LPG	1A1a	0101	2.5%	0.005	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A1a	010104	2.5%	0.005	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A1a	0102	2.5%	0.005	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A2b	010306	2.5%	0.005	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A2	03	4.0%	0.008	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A4a	020100	4.0%	0.008	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A4a	020105	4.0%	0.008	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A4b	0202	5.4%	0.0108	Assumed equal to natural gas. DCE assumption.
303A	LPG	1A4c	0203	4.0%	0.008	Assumed equal to natural gas. DCE assumption.
308A	Refinery gas	1A2	03	18.4%	0.92	EEA (2023), Energy Industries, Table 4-4
308A	Refinery gas	1A1a	010101	18.4%	0.92	EEA (2023), Energy Industries, Table 4-4
308A	Refinery gas	1A1a	010203	18.4%	0.92	EEA (2023), Energy Industries, Table 4-4
308A	Refinery gas	1A1b	0103	18.4%	0.92	EEA (2023), Energy Industries, Table 4-4
301A	Natural gas	1A1a	0101	2.5%	0.0025	EEA (2019), Energy Industries, Table 3-4. The emission factor is not included in EEA (2023).
301A	Natural gas	1A1a	010104	2.5%	0.001275	EEA (2019), Energy Industries, Table 3-17. The emission factor is not included in EEA (2023), Table 3-19.
301A	Natural gas	1A1a	010105	2.5%	0.004025	EEA (2023), Energy Industries, Table 3-22
301A	Natural gas	1A1a	010200	2.5%	0.0025	EEA (2019), Energy Industries, Table 3-4. The emission factor is not included in EEA (2023).
301A	Natural gas	1A1c	0105	2.5%	0.001275	EEA (2019), Energy Industries, Table 3-4. The emission factor is not included in EEA (2023).
301A	Natural gas	1A1c	010504	2.5%	0.001275	EEA (2019), Energy Industries, Table 3-17. The emission factor is not included in EEA (2023), Table 3-19.
301A	Natural gas	1A2	03	4.0%	0.004	EEA (2023), Manufacturing Industries, Table 3-3
301A	Natural gas	1A2	03 turbines	2.5%	0.001275	EEA (2019), Energy Industries, Table 3-17. The emission factor is not included in EEA (2023), Table 3-19.
301A	Natural gas	1A2	03 engines	2.5%	0.004025	EEA (2023), Energy Industries, Table 3-22
301A	Natural gas	1A4a	0201	4.0%	0.004	EEA (2023), Small Combustion, Table 3-8
301A	Natural gas	1A4a	020104	2.5%	0.001275	EEA (2019), Energy Industries, Table 3-17. The emission factor is not included in EEA (2023), Table 3-19.

Fuel	Fuel	NFR	SNAP	BC share of $PM_{2.5}$	BC emission factor, g/GJ	Reference for BC share
301A	Natural gas	1A4a	020105	2.5%	0.004025	EEA (2023), Energy Industries, Table 3-22
301A	Natural gas	1A4b	0202	5.4%	0.0054	EEA (2023), Small Combustion, Table 3-16
301A	Natural gas	1A4b	020204	2.5%	0.004025	EEA (2023), Energy Industries, Table 3-22
301A	Natural gas	1A4c	020300	4.0%	0.004	EEA (2023), Small Combustion, Table 3-8
301A	Natural gas	1A4c	020303	2.5%	0.001275	EEA (2019), Energy Industries, Table 3-17. The emission factor is not included in EEA (2023).
301A	Natural gas	1A4c	020304	2.5%	0.004025	EEA (2023), Energy Industries, Table 3-22
114A	Waste	1A1a	0101	3.5%	0.01015	EEA (2023), Municipal waste Incineration, Table 3-1
114A	Waste	1A1a	0102	3.5%	0.0735	EEA (2023), Municipal waste Incineration, Table 3-1
114A	Waste	1A2	03	3.5%	0.0735	EEA (2023), Municipal waste Incineration, Table 3-1
114A	Waste	1A4a	0201	3.5%	0.0735	EEA (2023), Municipal waste Incineration, Table 3-1
115A	Industrial waste	1A2	03	3.5%	0.0735	EEA (2023), Municipal waste Incineration, Table 3-1
111A	Wood	1A1a	0101	3.3%	0.0429	EEA (2023), Energy Industries, Table 3-8
111A	Wood	1A1a	0102	3.3%	0.33	EEA (2023), Energy Industries, Table 3-8
111A	Wood	1A2	03	28.0%	2.8	EEA (2023), Manufacturing Industries, Table 3-5
111A	Wood	1A4a	0201	28.0%	37.8	EEA (2023), Small Combustion, Table 3-10
111A	Wood	1A4b	0202	-	19.4	See residential wood combustion, Chapter 3.2.7
111A	Wood	1A4c	0203	28.0%	37.8	EEA (2023), Small Combustion, Table 3-10
117A	Straw	1A1a	0101	3.3%	0.03663	EEA (2023), Energy Industries, Table 3-8
117A	Straw	1A1a	0102	3.3%	0.396	EEA (2023), Energy Industries, Table 3-8
117A	Straw	1A2	03	28.0%	3.36	EEA (2023), Manufacturing Industries, Table 3-5
117A	Straw	1A4b	0202	28.0%	112.1	Time series based on DEPT (2022) and EEA (2019), Small Combustion, Table 3-10 (Assumed equal to agricultural plants)
117A	Straw	1A4c	020300	28.0%	112.1	Time series based on DEPT (2022) and EEA (2019), Small Combustion, Table 3-10 (Assumed equal to agricultural plants)
122A	Wood pellets	1A1a	0101	3.3%	0.0429	EEA (2023), Energy Industries, Table 3-8
122A	Wood pellets	1A1a	0102	3.3%	0.33	EEA (2023), Energy Industries, Table 3-8
122A	Wood pellets	1A2	0301	28.0%	2.8	EEA (2023), Manufacturing Industries, Table 3-5
122A	Wood pellets	1A4a	0201	-	7	See residential wood combustion, Chapter 3.2.7
122A	Wood pellets	1A4b	0202	-	7	See residential wood combustion, Chapter 3.2.7
122A	Wood pellets	1A4c	0203	-	7	See residential wood combustion, Chapter 3.2.7
215A	Bio oil	1A1a	0101	33.5%	1.675	Assumed equal to gas oil. DCE assumption.
215A	Bio oil	1A1a	010105	78.0%	3.9	Assumed equal to gas oil. DCE assumption.
215A	Bio oil	1A1a	0102	33.5%	1.675	Assumed equal to gas oil. DCE assumption.
215A	Bio oil	1A2	03	56.0%	2.8	EEA (2023), Manufacturing Industries, Table 3-4
215A	Bio oil	1A2	03 engines	78.0%	3.9	Assumed equal to gas oil. DCE assumption.
215A	Bio oil	1A4a	020105	78.0%	3.9	Assumed equal to gas oil. DCE assumption.
215A	Bio oil	1A4b	020200	3.9%	0.295	Assumed equal to gas oil. DCE assumption.
215A	Bio oil	1A4b	020304	78.0%	3.9	Assumed equal to gas oil. DCE assumption.
309A	Biogas	1A1a	0101	3.3%	0.0495	Assumed % equal to wood. DCE assumption
309A	Biogas	1A1a	010105	3.3%	0.006798	Assumed % equal to wood. DCE assumption

Fuel	Fuel	NFR	SNAP	BC share of $PM_{2.5}$	BC emission factor, g/GJ	Reference for BC share
309A	Biogas	1A1a	0102	3.3%	0.0495	Assumed % equal to wood. DCE assumption
309A	Biogas	1A2	03	28.0%	0.42	Assumed % equal to wood. DCE assumption
309A	Biogas	1A1c	010505	3.3%	0.006798	Assumed % equal to wood. DCE assumption
309A	Biogas	1A4a	0201	28.0%	0.42	Assumed % equal to wood. DCE assumption
309A	Biogas	1A4c	0203	28.0%	0.0054	Assumed % equal to wood. DCE assumption
310A	Bio gasification gas	1A1a	010105	3.3%	0.006798	Assumed % equal to wood. DCE assumption
310A	Bio gasification gas	1A2	03 engines	28.0%	0.05768	Assumed % equal to wood. DCE assumption
310A	Bio gasification gas	1A4a	020105	3.3%	0.006798	Assumed % equal to wood. DCE assumption
310A	Bio gasification gas	1A4c	020304	28.0%	0.05768	Assumed % equal to wood. DCE assumption
315A	Biomethane	1A1a	0101, except engines	2.5%	0.0025	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A1a	010105 Engines	2.5%	0.004025	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A1a	0102	2.5%	0.0025	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A1b	0103	2.5%	0.0025	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A2	03	4.0%	0.004	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A2	03, Engines	2.5%	0.004025	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A4a	0201	4.0%	0.004	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A4a	0201, engines	2.5%	0.004025	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A4b	0202	5.4%	0.0054	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A4b	0202, engines	2.5%	0.004025	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A4c	0203	4.0%	0.004	Assumed equal to natural gas. DCE assumption.
315A	Biomethane	1A4c	0203, engines	2.5%	0.004025	Assumed equal to natural gas. DCE assumption.

Heavy metals emission factors

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

The HM emission factors 2023 and references are shown in Table 3.2.30.

The emission factors for HM refer to:

- Two emission measurement programmes carried out on Danish decentralised CHP plants (Nielsen et al., 2010a; Nielsen & Illerup, 2003).
- Implied Emission Factors for power plants based on plant specific data reported by the power plant owners.
- A CONCAWE study (Gon & Kuenen, 2009)

- Data for Danish natural gas (Gruijthuijsen, 2001; Energinet, 2010)
- The EEA Guidebook (EEA, 2023).
- Struschka et al. (2008)
- Hedberg et al. (2002)

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

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

Table 3.2.30 HM emission factors and references, 2023.

fuel_type	fuel_gr_abbr	nfr	nfr_name	snap	As mg/GJ	Cd mg/GJ	Cr mg/GJ	Cu mg/GJ	Hg mg/GJ	Ni mg/GJ	Pb mg/GJ	Se mg/GJ	Zn mg/GJ	Reference
Solid	Anodic carbon	1A2g	Industry	All	4	1.8	13.5	17.5	7.9	13	134	1.8	200	EEA (2023), Tier 1, Industry Table 3-2.
	Coal	1A1a	Public electricity and heat production	All	0.51	0.07	0.86	0.48	1.3	0.97	0.62	5.9	1.9	Implied emission factor 2008 estimated by DCE based on plant specific emission data for power plants.
		All other	All other	All	4	1.8	13.5	17.5	7.9	13	134	23	200	EEA (2023), Tier 1, Industry Table 3-2. For Se: Tier 1, Energy Industries Table 3-2. See also Nielsen et al. (2013c).
	Fly ash fossil	1A1a	Public electricity and heat production	0101	0.51	0.07	0.86	0.48	1.3	0.97	0.62	5.9	1.9	Implied emission factor 2008 estimated by DCE based on plant specific emission data for power plants.
	BKB	1A4b i	Residential	0202	2.5	1.5	11.2	22.3	5.1	12.7	130	1.8	220	EEA (2023), Tier 1, Small Combustion Table 3-3. For Se Tier 1, Small Combustion Table 3-7 (for 1A4a/c).
	Coke oven coke	1A2 a-g	Industry	All	4	1.8	13.5	17.5	7.9	13	134	1.8	200	EEA (2023), Tier 1, Industry, Table 3-2.
		1A4b	Residential	0202	2.5	1.5	11.2	22.3	5.1	12.7	130	1.8	220	EEA (2023), Tier 1, Small Combustion, Table 3-3. For Se Tier 1, Small Combustion Table 3-7 (for 1A4a/c).
Liquid	Petroleum coke	all	All	All	3.98	1.2	2.55	5.31	0.341	255	4.56	2.06	87.8	EEA (2023), Tier 1, Energy Industries Table 3-6 (for heavy fuel oil)
	Residual oil	1A1a	Public electricity and heat production	All	2.1	0.53	2.6	2.4	0.21	362	2.6	1.2	7.4	Implied emission factor 2008 estimated by DCE based on plant specific emission data for power plants.
		All other	All other	All	3.98	1.2	2.55	5.31	0.341	255	4.56	2.06	87.8	EEA (2023), Tier 1, Energy Industries Table 3-6 (for heavy fuel oil)
	Gas oil	-	Engines	all	0.055	0.011	0.2	0.3	0.11	0.013	0.15	0.22	58	Nielsen et al. (2010a)
		-	All other	All	0.002	0.001	0.2	0.13	0.12	0.005	0.012	0.002	0.42	Gon & Kuenen (2009)
	Kerosene	All	All	All	0.002	0.001	0.2	0.13	0.12	0.005	0.012	0.002	0.42	Assumed equal to gas oil. DCE assumption.

fuel_type	fuel_gr_abbr	nfr	nfr_name	snap	As mg/GJ	Cd mg/GJ	Cr mg/GJ	Cu mg/GJ	Hg mg/GJ	Ni mg/GJ	Pb mg/GJ	Se mg/GJ	Zn mg/GJ	Reference
	LPG	All	All	All	0.002	0.001	0.2	0.13	0.12	0.005	0.012	0.002	0.42	EEA (2023), Tier 1, Small Combustion Table 3-5 (for 1A4b, other liquid fuels)
	Refinery gas	1A1b	Petroleum refining	All	0.352	2.19	6.69	3.29	0.372	7.37	1.61	1.56	17.0	EEA (2023), Tier 1, Energy Industries, Table 4-2 (for refinery gas, 1A1b).
Gas	Natural gas	-	Engines	All	0.05	0.003	0.05	0.01	0.1	0.05	0.04	0.01	2.9	Nielsen et al. (2010a)
		-	All other	All	0.119	0.00025	0.00076	0.000076	0.1	0.00051	0.0015	0.0112	0.0015	Gruijthuijsen (2001). For Hg: Nielsen et al. (2010a). For Se: EEA (2023), Tier 1, Energy Industries Table 3-4.
Waste	Waste	-	All	All	0.59	0.44	1.56	1.3	1.79	2.06	5.52	1.11	2.33	Nielsen et al. (2010a).
	Industrial waste	1A2f	Industry - Other	All	0.59	0.44	1.56	1.3	1.79	2.06	5.52	1.11	2.33	Nielsen et al. (2010a).
Biomass	Wood and wood pellets	-	All non-residential	All	0.19	0.27	2.34	2.6	0.4	2.34	3.62	0.5	2.3	For Cd, Hg and Zn: Nielsen et al. (2010a) For Cr, Cu, Ni and Pb: Nielsen & Illerup (2003). For As: Struschka et al. (2008). For Se: Hedberg et al. (2002).
		1A4b i	Residential	All	0.19	13	23	6	0.56	2	27	0.5	512	For As and Hg: Struschka et al. (2008). For Cd and Ni: Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011). For Cr: Hedberg et al. (2002), Struschka et al. (2008). For Cu, Pb and Zn: Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) For Se: Hedberg et al. (2002).
	Straw	1A1a	Public electricity and heat production	All	0.19	0.32	1.6	1.7	0.31	1.7	6.2	0.5	0.41	For Cd, Hg and Zn: Nielsen et al. (2010a). For Cr, Cu, Ni and Pb: Nielsen & Illerup (2003). For As and Se: Struschka et al. (2008) (see also EEA (2023), small combustion, Table 3-10)

fuel_type	fuel_gr_abbr	nfr	nfr_name	snap	As mg/GJ	Cd mg/GJ	Cr mg/GJ	Cu mg/GJ	Hg mg/GJ	Ni mg/GJ	Pb mg/GJ	Se mg/GJ	Zn mg/GJ	Reference
		1A4b i	Residential	0202	0.19	13	23	6	0.56	2	27	0.5	512	EEA (2023), Tier 1, Small Combustion, Residential plants, Biomass, Table 3-6.
		1A4c i	Agriculture/ Forestry	0203	0.19	13	23	6	0.56	2	27	0.5	512	EEA (2023), Tier 1, Small Combustion, Residential plants, Biomass, Table 3-6.
	Bio oil	-	Engines	engines	0.055	0.011	0.2	0.3	0.11	0.013	0.15	0.22	58	Assumed equal to gas oil. DCE assumption.
		-	All other	-	0.002	0.001	0.2	0.13	0.12	0.005	0.012	0.002	0.42	Assumed equal to gas oil. DCE assumption.
	Biogas	-	All non-residential	All	0.04	0.002	0.18	0.31	0.12	0.23	0.005	0.21	3.95	Nielsen et al. (2010a)
		1A4b	Residential	All	0.119	0.00025	0.00076	0.000076	0.1	0.00051	0.0015	0.0112	0.0015	Assumed equal to natural gas (biogas upgraded for distribution in the town gas grid).
	Bio gasification gas	1A1a	Public electricity and heat production	010105	0.12	0.009	0.029	0.045	0.54	0.014	0.022	0.18	0.058	Nielsen et al. (2010a)
				010101	0.002	0.001	0.2	0.13	0.12	0.005	0.012	0.002	0.42	Assumed equal to gas oil. DCE assumption.
	Biomethane	-	All except engines	All	0.119	0.00025	0.00076	0.000076	0.1	0.00051	0.0015	0.0112	0.0015	Assumed equal to natural gas.
			Engines	engines	0.05	0.003	0.05	0.01	0.1	0.05	0.04	0.01	2.9	Assumed equal to natural gas.

PAH emission factors

The PAH emission factors 2023 and references are shown in Table 3.2.31.

The emission factors for PAH refer to

- Research carried out by TNO (Berdowski et al., 1995).
- Research carried out by Statistics Norway (Finstad et al., 2001).
- An emission measurement program performed on biomass-fuelled plants. The project was carried out for the Danish Environmental Protection Agency (Jensen & Nielsen, 1996).
- Finstad et al. (2001).
- Two emission measurement programs carried out on Danish decentralised CHP plants (Nielsen et al., 2010a; Nielsen & Illerup, 2003).
- Additional information from the gas sector (Jensen, 2001).
- EEA (2023).
- Nielsen et al. (2021b).

In general, emission factors for PAH are uncertain.

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

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

Table 3.2.31 PAH emission factors and references, 2023.

fuel_type	fuel_id	fuel_gr_abbr	nfr_id	snap_id	Benzo(a)-pyrene µg per GJ	Benzo(b)-fluoranthene µg per GJ	Benzo(k)-fluoranthene µg per GJ	Indeno-(1,2,3-c,d)-pyrene µg per GJ	Reference
Solid	102A	Anodic carbon	1A2g	0320	23	929	929	698	Finstad et al. (2001)
		Coal	1A1a	All	0.7	37	29	1.1	EEA (2023). Tier 1, Energy Industries Table 3-2
			1A2 a-g	All	23	929	929	698	Finstad et al. (2001)
			1A4c i	0203	59524	63492	1984	119048	Finstad et al. (2001)
	103A	Fly ash fossil	1A1a	0101	0.7	37	29	1.1	EEA (2023). Tier 1, Energy Industries Table 3-2
	106A	BKB	1A4b i	0202	59524	63492	1984	119048	Finstad et al. (2001) (Same emission factor as for coal is assumed. DCE assumption)
	107A	Coke oven coke	1A2 a-g	All	23	929	929	698	Finstad et al. (2001)
			1A4b	0202	59524	63492	1984	119048	Finstad et al. (2001)
Liquid	110A	Petroleum coke	1A2 a-g	All	80	42	66	160	Finstad et al. (2001). Assumed equal to residual oil.
			1A4a i	All	80	42	66	160	Finstad et al. (2001). Assumed equal to residual oil.
			1A4b i	All	80	42	66	160	Finstad et al. (2001). Assumed equal to residual oil.
			1A4c i	All	80	42	66	160	Finstad et al. (2001). Assumed equal to residual oil.
	203A	Residual oil	1A1a	All	109.6	475.41	93.21	177.28	Finstad et al. (2001)
			1A1b	010306	109.6	475.41	93.21	177.28	Finstad et al. (2001)
			1A2 a-g	All	80	42	66	160	Finstad et al. (2001)
			1A4a i	All	80	42	66	160	Finstad et al. (2001)
			1A4b i	All	80	42	66	160	Finstad et al. (2001)
			1A4c i	All	80	42	66	160	Finstad et al. (2001)
	204A	Gas oil	1A1a	Not engines	109.6	475.41	93.21	177.28	Finstad et al. (2001)
				Engines	1.9	15	1.7	1.5	Nielsen et al. (2010a)
			1A1b	010306	109.6	475.41	93.21	177.28	Finstad et al. (2001)
			1A1c	010500	109.6	475.41	93.21	177.28	Finstad et al. (2001)
			1A2 a-g	Not engines	80	42	66	160	Finstad et al. (2001)
				Engines	1.9	15	1.7	1.5	Nielsen et al. (2010a)
			1A4a i	Not engines	80	42	66	160	Finstad et al. (2001)
				Engines	1.9	15	1.7	1.5	Nielsen et al. (2010a)
			1A4b i	0202	80	42	66	160	Finstad et al. (2001)
			1A4c i	0203	80	42	66	160	Finstad et al. (2001)
Gas	301A	Natural gas	1A1a	010104	1	1	2	3	Nielsen & Illerup (2003)
				010105	1.2	9	1.7	1.8	Nielsen et al. (2010a)
			1A1c	010504	1	1	2	3	Nielsen & Illerup (2003)
			1A2 a-g	Turbines	1	1	2	3	Nielsen & Illerup (2003)
				Engines	1.2	9	1.7	1.8	Nielsen et al. (2010a)
			1A4a i	020105	1.2	9	1.7	1.8	Nielsen et al. (2010a)
			1A4b i	020202	0.133	0.663	0.265	2.653	Jensen (2001)

fuel_type	fuel_id	fuel_gr_abbr	nfr_id	snap_id	Benzo(a)-pyrene	Benzo(b)-fluoranthene	Benzo(k)-fluoranthene	Indeno-(1,2,3-c,d)-pyrene	Reference
				020204	1.2	9	1.7	1.8	Nielsen et al. (2010a)
			1A4c i	020304	1.2	9	1.7	1.8	Nielsen et al. (2010a)
Waste	114A	Waste	1A1a	All	0.8	1.7	0.9	1.1	Nielsen et al. (2010a)
			1A4a i	0201	0.8	1.7	0.9	1.1	Nielsen et al. (2010a)
	115A	Industrial waste	1A2f	0316	0.8	1.7	0.9	1.1	Nielsen et al. (2010a)
Biomass	111A	Wood	1A1a	0101	11	15	5	10	Nielsen et al. (2010a)
				0102	6.46	1292.52	1292.52	11.56	Finstad et al. (2001)
			1A2 a-g	all	6.46	1292.52	1292.52	11.56	Finstad et al. (2001)
			1A4a i	0201	168707	221769	73469	119728	Finstad et al. (2001)
			1A4b i	All	62554	62317	34806	34721	Nielsen et al. (2021b). Time series.
			1A4c i	all	168707	221769	73469	119728	Finstad et al. (2001)
	117A	Straw	1A1a	0101	0.5	0.5	0.5	0.5	Nielsen et al. (2010a)
				0102	1529	3452	1400	1029	Berdowski et al. (1995)
			1A4b i	0202	12956	12828	6912	4222	Berdowski et al. (1995)
			1A4c i	0203	12956	12828	6912	4222	Berdowski et al. (1995)
	122A	Wood pellets	1A1a	0101	11	15	5	10	Nielsen et al. (2010a)
				0102	6.46	1292.52	1292.52	11.56	Finstad et al. (2001)
			1A2 a-g	03	6.46	1292.52	1292.52	11.56	Finstad et al. (2001)
			1A4a i	0201	900	1300	1300	1200	Nielsen et al. (2020)
			1A4b i	0202	900	1300	1300	1200	Nielsen et al. (2020)
	215A	Bio oil	1A1a	All	109.6	475.41	93.21	177.28	Same emission factors as for gas oil is assumed (DCE assumption).
			1A2 a-g	All	80	42	66	160	Same emission factors as for gas oil is assumed (DCE assumption).
			1A4b i	0202	80	42	66	160	Same emission factors as for gas oil is assumed (DCE assumption).
	309A	Biogas	Engines	All	1.3	1.2	1.2	0.6	Nielsen et al. (2010a)
	310A	Bio gasification gas	Engines	010105	2	2	2	2	Nielsen et al. (2010a)
	315A	Biomethane	1A4b i	0202	0.133	0.663	0.265	2.653	Jensen (2001)
			Gas turbines	-	1	1	2	3	Assumed equal to natural gas
			Engines	-	1.2	9	1.7	1.8	Assumed equal to natural gas

PCDD/F emission factors

The PCDD/F emission factors 2023 and references are shown in Table 3.2.32.

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

The emission factors for decentralised CHP plants[16] refer to an emission measurement program for these plants (Nielsen et al. 2010a).

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

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

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

- Residential wood combustion
- Waste incineration plants.

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

Table 3.2.32 Emission factors for PCDD/F, 2023.

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

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

HCB emission factors

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

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

Table 3.2.33 Emission factors for HCB, 2023.

Fuel	NFR (SNAP)	Emission factor, ng/GJ	Reference
Coal	1A1, 1A2	6,700	Grochowalski & Konieczyński (2008); EEA (2023) Energy Industries Table 3-2
Coal	1A4b	1,200,000	Syc et al. (2011)
Coal	1A4a and 1A4c	23,000	Syc et al. (2011)
Other solid fuels	1A1, 1A2	6,700	Assumed equal to coal.
Other solid fuels	1A4	1,200,000	Assumed equal to coal.
Liquid fuels[1)]	1A1, 1A2, 1A4	220	Nielsen et al. (2010a)
Gaseous fuels	1A1, 1A2, 1A4	-	Negligible
Waste	1A1, 1A2, 1A4	4300	Nielsen et al. (2010a). A time series have been estimated. The emission factor for 1990 (190,000 ng/GJ) refer to Pacyna et al. (2003).
Wood and wood pellets	1A1, 1A2	5,000	EEA (2023) Energy Industries Table 3-8.
Wood and wood pellets	1A4	5,000	EEA (2023) Small Combustion Table 3-8.
Straw	1A1, 1A2	113	Nielsen et al. (2010a)
Straw	1A4	5,000	EEA (2023) Energy Industries Table 3-8.
Biogas	1A1, 1A2, 1A4	190	Nielsen et al. (2010a)
Bio gasification gas	1A1, 1A2, 1A4	800	Nielsen et al. (2010a)
Biomethane	1A1, 1A2, 1A4	-	Negligible

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

For coal, the emission factor from Grochowalski & Konieczyński (2008) is applied for Energy Industries and for industrial plants. This emission factor is also applied in the EEA Guidebook (EEA, 2023).

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

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

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

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

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

For wood combustion, the emission factors from EEA (2023) are applied for both Energy industries, industrial plants and for non-industrial plants. For residential wood combustion, it would be relevant to estimate a time series. However, the currently available data are considered insufficient for this estimate.

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

The emission factor for Energy Industries and industrial combustion refer to Nielsen et al. (2010a). For non-industrial plants, the EEA (2023) emission factor is applied.

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

PCB emission factors

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

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

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

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

Furthermore, teq values based on TEF are reported as WHO_{2005}-teq or WHO_{1998}-teq. This difference is however typically less than 50%[17].

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

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

Table 3.2.34 Emission factors for ∑dl-PCB, stationary combustion, 2023

Fuel	NFR (SNAP)	Emission factor, ∑ dl-PCB, ng/GJ	Emission factor, PCB, ng WHO_{1998}-teq/GJ	Reference
Coal	1A1	839	3.16	Grochowalski & Konieczyński (2008)
Coal	1A2	5,700	53	Thistlethwaite (2001a)
Coal	1A4	7,403	66	Syc et al. (2011)
Other solid fuels	1A1	839	3.16	Assumed equal to coal.
Other solid fuels	1A2	5,700	53	Assumed equal to coal.
Other solid fuels	1A4	7,403	66	Assumed equal to coal.
Residual oil and orimulsion	1A1, 1A2, 1A4	839	3.2	The teq value refers to Dyke et al. (2003). The TEQ value is equal to the emission factor for coal combustion in power plants and the sum of dioxin-like PCB congeners has been assumed equal to the corresponding factor for coal.
Gas oil	1A1, 1A2, 1A4	93	0.11	Nielsen et al. (2010a)
Other liquid fuels[1)]	1A1, 1A2, 1A4	93	0.11	Assumed equal to gas oil.
Gaseous fuels	1A1, 1A2, 1A4	-	-	Negligible
Waste	1A1, 1A2, 1A4	109 (time series)	0.28 (time series)	Nielsen et al. (2010a). A time series have been estimated. The emission factor for 1990 (46,000 ng/GJ or 117 ng WHO1998teq/GJ) have been estimated based on the assumption that the PCB emission factor time series follow the PCDD/F time series.
Wood	1A1, 1A2, 1A4a/c	2,800	21	Thistlethwaite (2001a)
Wood	1A4b	2,075 (time series)	-	Hedman et al. (2006). A time series have been estimated based on time series for technologies applied in Denmark.
Straw	1A1, 1A2	3,110	31.2	Assumed equal to residential plants.
Straw	1A4	3,110	31.2	Syc et al. (2011)
Wood pellets	1A1, 1A2, 1A4a/c, 1A4b	465.5	-	Hedman et al. (2006).
Biogas	1A1, 1A2, 1A4	90	0.13	Nielsen et al. (2010a)
Bio gasification gas	1A1, 1A2, 1A4	144	0.17	Nielsen et al. (2010a)
Biomethane	1A1, 1A2, 1A4	-	-	Negligible

1) Except LPG and refinery gas.

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

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

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

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

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

Year	Waste incineration ∑dl-PCB, ng/GJ	Residential wood combustion[1)] ∑dl-PCB, ng/GJ
1990	45671	6076
1991	38063	6000
1992	30433	5924
1993	22825	5849
1994	19773	5774
1995	16721	5701
1996	13690	5629
1997	10638	5560
1998	7586	5492
1999	5515	5425
2000	3423	5359
2001	3423	5293
2002	3423	5226
2003	3423	5162
2004	1766	4921
2005	109	4687
2006	109	4509
2007	109	4333
2008	109	4142
2009	109	3930
2010	109	3718
2011	109	3588
2012	109	3459
2013	109	3330
2014	109	3200
2015	109	3071
2016	109	2941
2017	109	2814
2018	109	2686
2019	109	2560
2020	109	2435
2021	109	2312
2022	109	2192
2023	109	2075

1. Wood pellets not included.

Implied emission factors

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

3.2.9 Uncertainty

According to the EEA Guidelines (EEA, 2023), uncertainty estimates should be estimated. Uncertainty estimates include uncertainty with regard to the total emission inventory as well as uncertainty with regard to trends.

Methodology

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

The uncertainty estimates are based on emission data for the base year and year 2023 as well as on uncertainties for fuel consumption and emission factors for each of the NFR source categories. Residential plants have however been split in two parts: Residential wood combustion and other residential plants.

The base year for all pollutants is 1990.

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

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

Table 3.2.36 Uncertainty rates for fuel consumption, %.

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

Table 3.2.37 Uncertainty rates for emission factors, %.

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

Results

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

The total emission uncertainty is 5.9 % for SO_2 and 9.6 % for NO_x.

Table 3.2.38 Uncertainty estimates, tier 1 approach, 2023.

Pollutant	Uncertainty Total emission, %	Trend 1990-2022, %	Uncertainty Trend, %-age points
SO_2	±5.9	-97	±0.1
NO_x	±9.6	-80	±1.5
NMVOC	±54	-44	±7.3
CO	±59	-55	±10.0
NH_3	±114	48	±112
TSP	±125	-41	±11.4
PM_{10}	±126	-41	±11.5
$PM_{2.5}$	±127	-40	±10.8
BC	±549	-12	±218
As	±70	-90	±6.1
Cd	±421	-54	±164
Cr	±239	-82	±42
Cu	±364	-88	±43
Hg	±43	-94	±1.9
Ni	±72	-94	±3.1
Pb	±207	-91	±19
Se	±41	-92	±1.3
Zn	±162	-45	±73
HCB	±758	-84	±26
PCDD/F	±471	-57	±171
Benzo(a)pyrene	±847	-64	±23
Benzo(b)fluoranthene	±799	-56	±35
Benzo(k)fluoranthene	±827	-69	±40
Indeno(1,2,3-c,d)pyrene	±832	-79	±15
PCB	±722	-74	±27

3.2.10 Source specific QA/QC and verification

An updated quality manual for the Danish GHG emission inventories was published in 2020 (Nielsen et al., 2020a). The quality manual describes the concepts of quality work and definitions of sufficient quality, critical control points and a list of Point for Measuring (PM). Details about the source specific QA/QC is included in Annex 3A-10.

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

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

3.2.11 Source specific improvements and recalculations

Recalculations for stationary combustion are shown in Table 3.2.39.

For SO_2 the recalculation for stationary combustion is below ±0.15 % for 1990-2022. The small recalculations for 2022 are related to the revised energy statistics (DEA, 2024a) and updated data for disaggregation to industrial subsectors (DEA, 2024c). The largest recalculation for 2022 is the lower consumption of wood chips in industrial plants in the updated energy statistics.

For NO_x, the recalculation is below ±0.4% for 1990-2022. The recalculation for 2022 is -0.4 %. The recalculation for 2022 is related to the revision of the energy statistics, mainly the lower consumption of wood chips in industrial plants and the lower consumption of natural gas and biomethane in commercial/institutional plants[18].

For NMVOC, the recalculation is below ±0.4% for 1990-2022. The recalculation for 2022 is -0.4 %. This recalculation is related to the lower consumption of wood chips in industrial plants in the updated energy statistics. In addition, the emission factor for NMVOC for wood applied in industrial plants has been revised for 2021-2022.

For CO, the recalculation for stationary combustion is below ±0.3% for 1990-2022. The recalculation for 2022 is -0.3 %. The recalculation for 2022 is related to the revised energy statistics, mainly the lower consumption of wood chips in industrial plants.

For NH_3, the recalculations are below ±0.1 %in 1990-2022. The recalculation for 2022 is -0.1 %. The recalculation for 2022 is related to the revised energy statistics, mainly the lower consumption of wood chips in industrial plants and the lower consumption of firewood in residential plants.

The recalculations for PMs are below ±0.2 % for 1990-2022. The recalculation for emission of $PM_{2.5}$ in 2022 is -0.14 %. The recalculations for 2022 are related to the revised energy statistics, mainly the lower consumption of wood in industrial plants, residential plants and commercial/institutional plants.

The recalculations for BC are below ±0.3 % for 1990-2022. The recalculations are related to the revised energy statistics.

For HMs, the reported emissions 1990-2022 are below ±0.4 % for 1990-2022. The recalculations are related to the revised energy statistics.

The recalculations for PCDD/F below ±0.07 % to for 1990-2022. The recalculations are related to the revised energy statistics.

For PAHs the recalculations for stationary combustion are in the interval -0.5 % to +0.01 %.

For HCB the recalculation is below ±0.3 % and for PCB the recalculations are below ±0.6 %.

[18] The energy statistics sectors Wholesale, Retail trade, Private service and Public service.

Table 3.2.39 Recalculations for stationary combustion. Emissions reported in 2025 compared to emissions reported in 2024.

	1990	1995	2000	2005	2010	2015	2020	2021	2022
	Percent								
SO_2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9
NO_x	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.6
NMVOC	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.6
CO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7
TSP	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8
PM_{10}	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8
$PM_{2.5}$	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
BC	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8
NH_3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
As	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8
Cd	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Cr	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8
Cu	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.6
Hg	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8
Ni	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
Pb	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8
Se	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
Zn	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
HCB	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7
PCDD/F	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
Benzo(a)pyrene	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.5
Benzo(b)fluoranthene	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.6
Benzo(k)fluoranthene	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7
Indeno(123cd)pyrene	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.6
PCB	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.4

Energy statistics

For stationary combustion plants, the emission estimates for the years 1990-2022 have been updated according to the latest energy statistics published by the Danish Energy Agency. The update included both end use and transformation and also a source category update. The changes in the energy statistics are largest for the years 2020, 2021 and 2022. The revisions are shown in the energy statistics. The fuel consumption has been revised for a large number of fuels for 2022, including natural gas[19], biomethane, bio oil, wood, wood pellets, gas oil and agricultural waste (straw).

Revised estimates for combustion of gas-/diesel oil, LPG and natural gas in mobile sources have resulted in revised split between stationary combustion and mobile sources. Further details about the background for the recalculation are included in the mobile combustion chapter.

Emission factors

For large plants, some additional plant specific emission data for 2022 became available during 2024. These data have been implemented.

The emission factors for NMVOC have been revised for industrial combustion of wood for the years 2021-2022.

[19] The energy statistics include a large recalculation for offshore gas turbines, but this recalculation is not reflected in the emission inventory because this fuel consumption is based on the EU ETS data in the emission inventory. Thus, the inaccuracy of the energy statistics from 2023 was never included in the emission inventory.

3.2.12 Source specific planned improvements

Plant specific emission data for 2023 available after December 2023 will be implemented.

3.2.13 References for Chapter 3.2

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3.3 Transport and other mobile sources

The emission inventory basis for mobile sources is fuel consumption information from the Danish energy statistics. In addition, background data for road transport (fleet and mileage), air traffic (aircraft type, flight numbers, origin and destination airports), national sea transport (fuel surveys, ferry technical data, number of return trips, sailing time), fisheries (vessel technical data, hours at sea), railways (e.g. train technical data, number of train km's) and non-road machinery (engine no., engine size, load factor and annual working hours) are used to make the emission estimates sufficiently detailed. Emission data mainly comes from the EMEP/EEA Air Pollutant Emission Inventory Guidebook (EMEP/EEA, 2019). However, for railways, measurements specific to Denmark are used.

In the Danish emissions database, all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution) according to the CORINAIR system. The emission inventories are prepared from a complete emission database based on the SNAP sectors. The aggregation to the sector codes used for both the UNFCCC and UNECE Conventions is based on a correspondence list between SNAP and IPCC classification codes (CRF), shown in Table 3.3.1 (mobile sources only).

Table 3.3.1 SNAP – CRF/NFR correspondence table for transport.

SNAP classification	CRF/NFR classification
0701 Road traffic: Passenger cars	1A3bi Road transport: Passenger cars
0702 Road traffic: Light duty vehicles	1A3bii Road transport: Light duty vehicles
0703 Road traffic: Heavy duty vehicles	1A3biii Road transport: Heavy duty vehicles
0704/0705 Road traffic: Mopeds and motor cycles	1A3biv Road transport: Mopeds & motorcycles
0706 Road traffic: Evaporation	1A3bv Road transport: Evaporation
0707 Road traffic: Brake and tire wear	1A3bvi Road transport: Brake and tire wear
0708 Road traffic: Road abrasion	1A3bvii Road transport: Road abrasion
0801 Military	1A5b Other, Mobile
0802 Railways	1A3c Railways
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

Military transport activities (land and air) refer to the CRF/NFR sector Other (1A5), the latter sector also including recreational craft (SNAP code 0803).

For aviation, Landing and Take Off ((LTO)[1] refers to the part of flying, which is below 1000 m. This part of the aviation emissions (SNAP codes 080501 and 080502) are included in the national emissions total as prescribed by the UNECE reporting rules. According to UNFCCC the national emissions for aviation comprise the emissions from domestic LTO (0805010) and domestic cruise (080503). The fuel consumption and emission development for aviation explained in the following are based on UNFCCC categorization, in order to be consistent with the Danish NIR report.

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

For mobile sources, the DEMOS (Danish Emission model system for Mobile Sources) model developed at DCE, Aarhus University, is used to calculate the emission inventories. The DEMOS model system comprises database models for road transport (DEMOS-Road), aviation (DEMOS-Aviation), nav-

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

igation (DEMOS-Navigation), railways (DEMOS-Rail) and non-road mobile machinery (DEMOS-NRMM).

For emission reporting purposes the output results from DEMOS are calculated in a SNAP format, as activity rates (fuel consumption) and emission factors, which are then exported directly to the central Danish CollectER database.

Apart from national inventories, the DEMOS model is used also as a calculation tool in research projects, environmental impact assessment studies, and to produce basic emission information, which requires various aggregation levels.

3.3.1 Source category description

The following description of source categories explains the development in fuel consumption and emissions for road transport and other mobile sources.

Total fuel consumption for mobile sources

Table 3.3.2 Fuel consumption (PJ) for mobile sources in 2023 in NFR sectors.

NFR ID	Fuel consumption (PJ)
Manufacturing industries/Construction (mobile)	9.1
Civil aviation (Domestic)	1.7
Road transport: Passenger cars	83.8
Road transport:Light duty vehicles	23.2
Road transport:Heavy duty vehicles	49.6
Road transport: Mopeds & motorcycles	0.9
Railways	2.4
National navigation (Shipping)	6.6
Commercial/Institutional: Mobile	2.4
Residential: Household and gardening (mobile)	0.4
Agriculture/Forestry/Fishing: Off-road agriculture/forestry	9.2
Agriculture/Forestry/Fishing: National fishing	5.0
Other. Mobile	3.7
Road transport total	157.5
Other mobile total	40.4
Domestic total	198.0
Civil aviation (International)	34.5
Navigation (international)	21.1

Table 3.3.2 shows the fuel consumption for mobile sources based on DEA statistics for 2023 in NFR sectors. The fuel consumption figures in time series 1985-2023 are given in Annex 3.B.16 (NFR format) and are shown for 2023 in Annex 3.B.15 (CollectER format). Road transport has a major share of the fuel consumption for domestic mobile sources. In 2023, this sector's fuel consumption share is 80 %, while the fuel consumption shares for Off road agriculture/forestry, Manufacturing industries (mobile) and National navigation are 5 %, 5 % and 3 %, respectively. For the remaining sectors, the total fuel consumption share is 7 %.

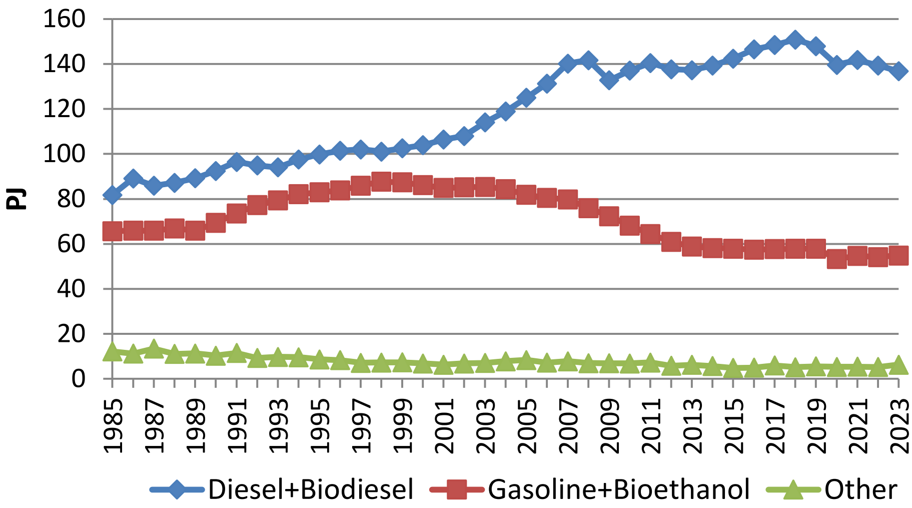

Figure 3.3.1 Fuel consumption per fuel type for domestic mobile sources 1985-2023.

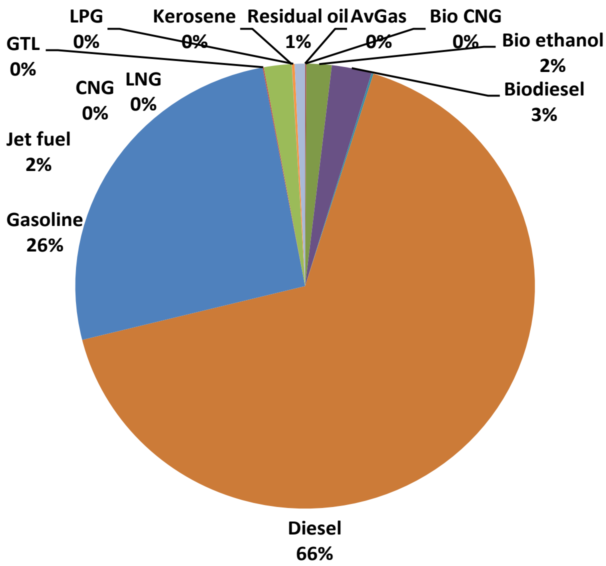

Figure 3.3.2 Fuel consumption share per fuel type for domestic mobile sources in 2023.

From 1985 to 2023, diesel (sum of diesel and biodiesel) and gasoline (sum of neat gasoline and bio ethanol) fuel consumption has changed by 67 % and -16 %, respectively (Figure 3.3.1), and in 2023 the fuel consumption shares for diesel and gasoline were 69 % and 28 %, respectively (not shown). Other fuels only have a 3 % share of the domestic mobile sources total (Figure 3.3.2). Almost all gasoline is used in road transportation vehicles. Gardening machinery and recreational craft are merely small consumers. Regarding diesel, there is considerable fuel consumption in most of the domestic mobile sources categories, whereas a more limited use of residual oil and jet fuel is being used in the navigation sector and by aviation (civil and military flights), respectively[2].

[2] The gasoline and diesel fuel sold at the conventional gas filling stations contain bio ethanol and biodiesel. Small amounts of gasoline and diesel are bought by individuals at the gas stations, filled into fuel cans and subsequently used to propel gasoline working machines (gasoline) and recreational craft (gasoline and diesel).

Fuel consumption for road transport

As shown in Figure 3.3.3, the fuel consumption for road transport[3] has generally increased until 2007, except from a small fuel consumption decline noted in 2000. Reduced traffic causes significant fuel consumption declines in 2008-2009 during the global financial crisis, and in 2020 during the periods with COVID-19 lock down and social restrictions in the Danish society. The fuel consumption development is due to a decreasing trend in the use of gasoline fuels from 1999 to 2013 combined with a steady growth in the use of diesel until 2007, and from 2014 to 2018. Within sub-sectors, passenger cars represent the most fuel-consuming vehicle category, followed by heavy-duty vehicles, light duty vehicles and 2-wheelers, in decreasing order (Figure 3.3.4). The largest fuel consumption impact related to COVID-19 is noted for passenger cars.

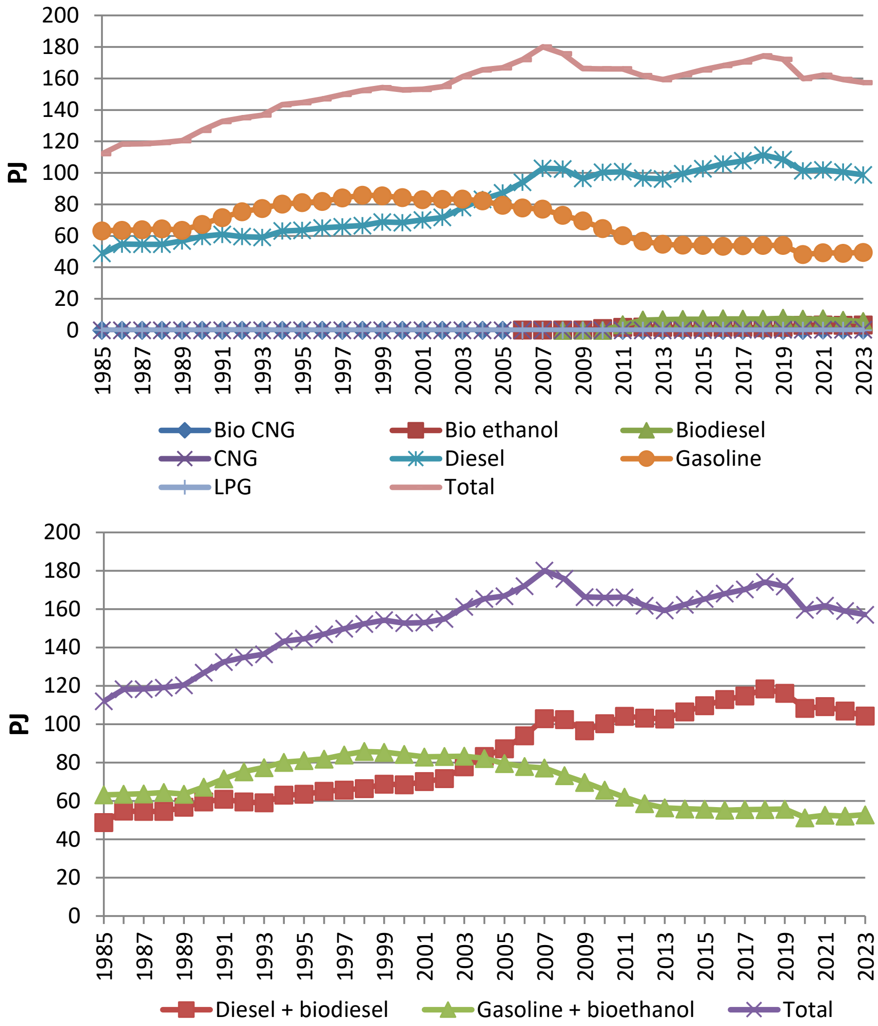

Figure 3.3.3 Fuel consumption per fuel type and as totals for road transport 1985-2023.

[3] The sum share of bioethanol and biodiesel in the gasoline and diesel fuel blends for road transport is 5.6 %, in 2023.

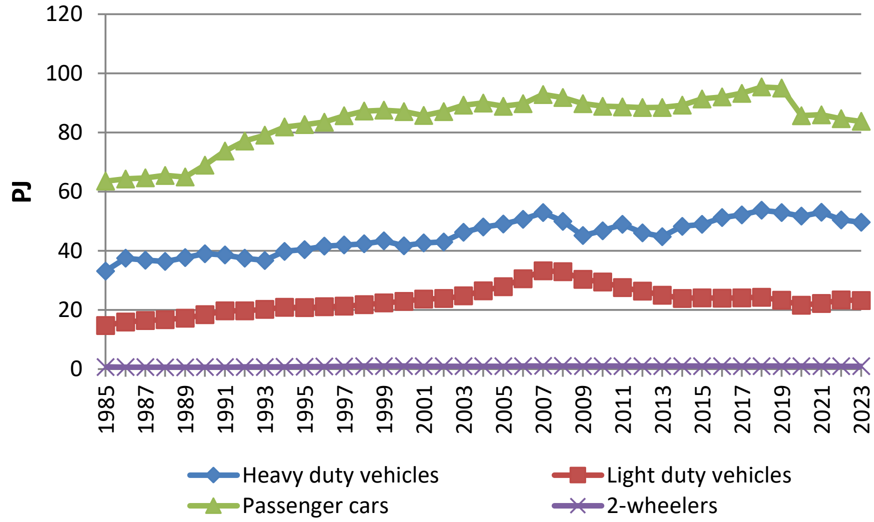

Figure 3.3.4 Total fuel consumption per vehicle type for road transport 1985-2023.

As shown in Figure 3.3.5 fuel consumption for gasoline passenger cars dominates the overall gasoline consumption trend. The development in diesel fuel consumption in recent years (Figure 3.3.6) is characterised by increasing fuel consumption for diesel passenger cars until 2018, , and fuel consumption declines from 2019 onwards, while declines in the fuel consumption for trucks and buses (heavy-duty vehicles) are noted for 2008- 2009, 2012-2013, 2019-2020 and 2021-2023, and fuel consumption reductions for light duty vehicles are noted for 2008-2014 and 2019-2020.

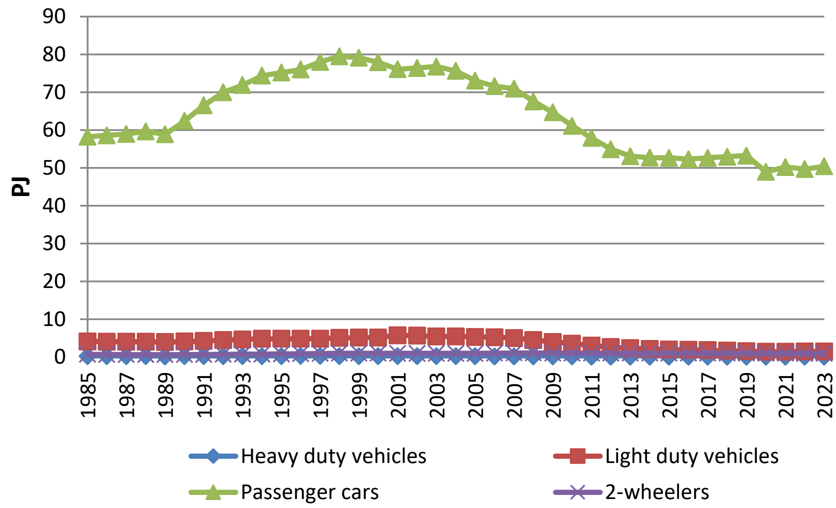

Figure 3.3.5 Gasoline fuel consumption per vehicle type for road transport 1985-2023.

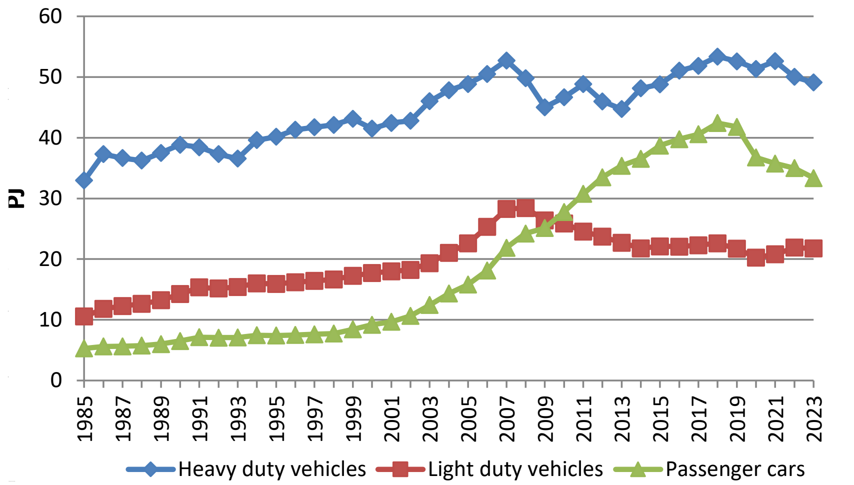

Figure 3.3.6 Diesel fuel consumption per vehicle type for road transport 1985-2023.

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onsumption shares for gasoline passenger cars, diesel heavy-duty vehicles, diesel passenger cars and diesel light duty vehicles were 32, 31, 21 and 14 %, respectively (Figure 3.3.7).

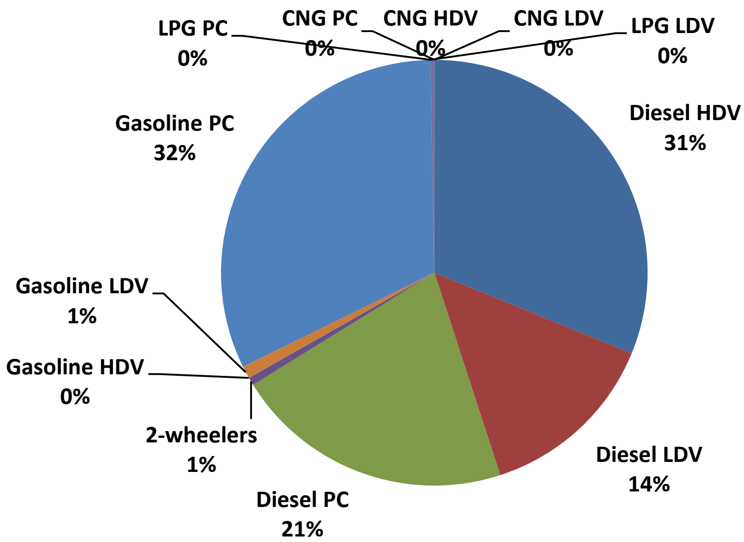


Figure 3.3.7 Fuel consumption share (PJ) per vehicle type for road transport in 2023.

Fuel consumption for other mobile sources

It must be noted that the fuel consumption figures behind the Danish inventory for mobile equipment in the agriculture, forestry, industry, household and gardening (residential), and inland waterways (part of navigation) sectors, are less certain than for other mobile sectors. For these types of machinery, the DEA statistical figures do not directly provide fuel consumption information, and fuel consumption totals are subsequently estimated from activity data and fuel consumption factors. For recreational craft, the latest historical year is 2004.

As seen in Figure 3.3.8, classified according to CRF the most important sectors are Agriculture/forestry/fisheries (1A4c), Industry-other (mobile machinery part of 1A2g) and Navigation (1A3d). Minor fuel consuming sectors are Civil Aviation (1A3a), Railways (1A3c), Other (military mobile and recreational craft: 1A5b), Commercial/institutional (1A4a) and Residential (1A4b).

The 1985-2023 time series are shown per fuel type in Figures 3.3.9-3.3.12 for diesel, gasoline, residual oil and jet fuel, and liquefied natural gas (LNG) and gas-to-liquid (GTL) manufactured from natural gas, respectively.

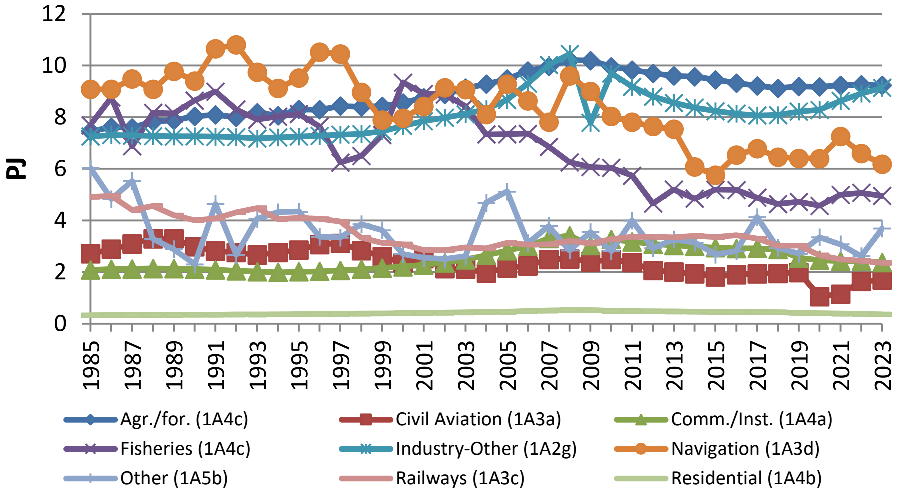


Figure 3.3.8 Total fuel consumption in CRF sectors for other mobile sources 1985-2023.

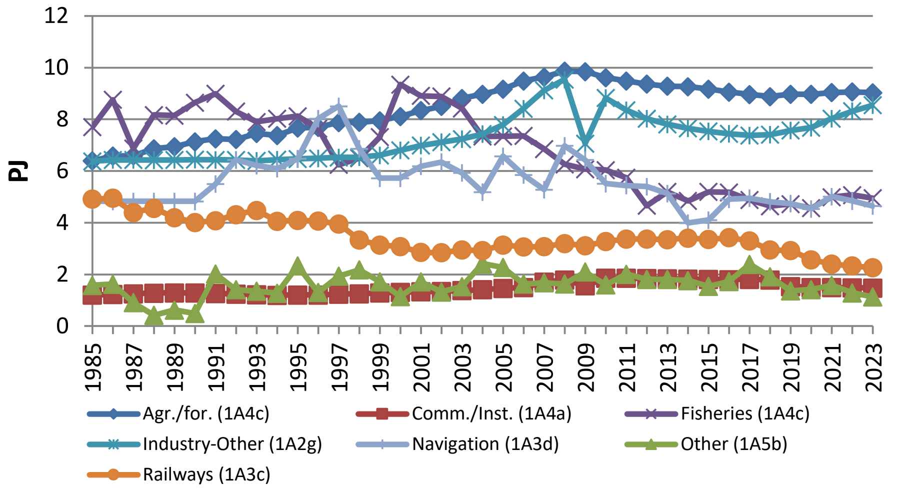


Figure 3.3.9 Diesel fuel consumption in CRF sectors for other mobile sources 1985-2023.

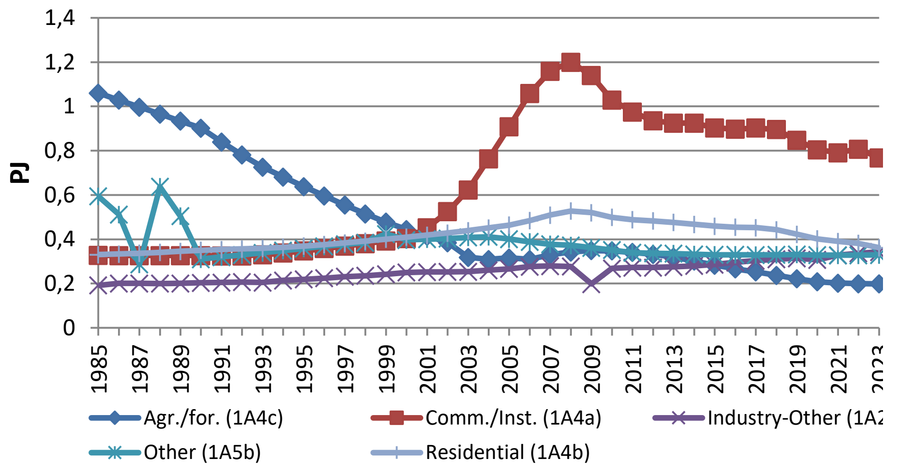


Figure 3.3.10 Gasoline fuel consumption in CRF sectors for other mobile source 1985-2023.

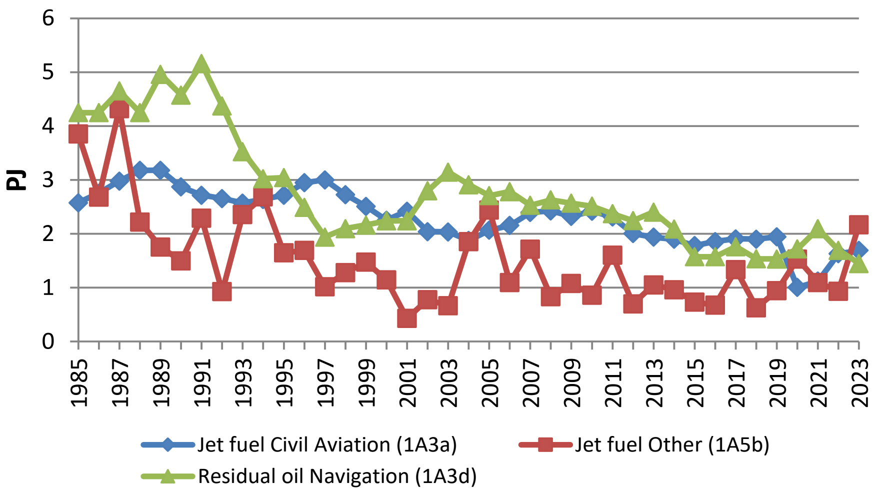


Figure 3.3.11 Residual oil and jet fuel consumption in CRF sectors for other mobile sources 1985-2023.

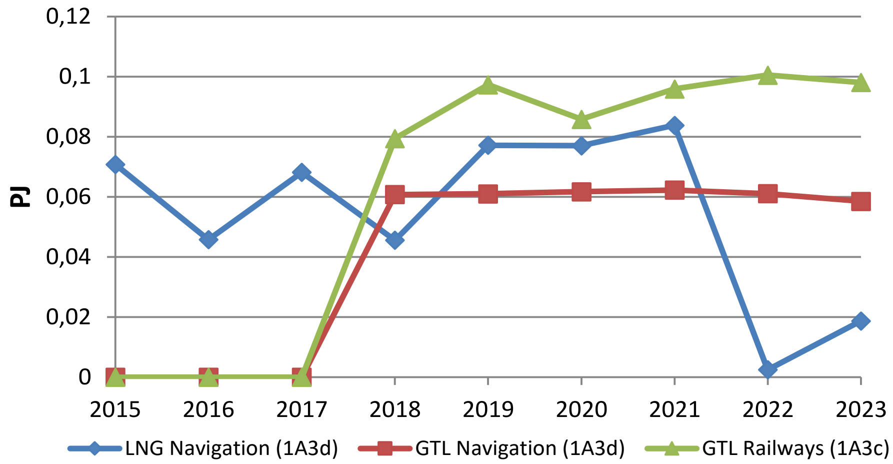


Figure 3.3.12 LNG and GTL fuel consumption in CRF sectors for other mobile sources 1985-2023.

For diesel, although the number of tractors and harvesters decrease in the entire period 1985-2020, the contemporary increase in the engine sizes of new sold machines makes the total fuel consumption for Agriculture/forestry grow until 2008. The turnover of old less fuel efficient machinery and the decline in the number of tractors and harvesters explain the fuel consumption decrease from 2008 onwards.

The fuel consumption for industry has increased from the beginning of the 1990's, due to an increase in the activities for construction machinery. The fuel consumption increase has been very pronounced in 2005-2008, for 2009; however, the global financial crisis has a significant impact on the building and construction activities. The fuel efficiency improvements for new sold machinery are the main reason for total fuel consumption decline from 2010-2018. For fisheries, the development in fuel consumption reflects the activities in this sector.

The Navigation sector comprises national sea transport (fuel consumption between two Danish ports including sea travel directly between Denmark and Greenland/Faroe Islands). For national sea transport, the diesel fuel consumption curve reflects the combination of traffic and ferries in use for regional ferries. In 1998 and 1999, a significant decline in fuel consumption is apparent. The most important explanation here is the closing of ferry service routes in connection with the opening of the Great Belt Bridge in 1997. For railways, the gradual shift towards electrification explains the lowering trend in diesel fuel consumption for this transport sector. The fuel consumed (and associated emissions) to produce electricity is accounted for in the stationary combustion part of the Danish inventories.

The largest gasoline fuel consumption is calculated for the Commercial/Institutional (1A4a) sector related to the use of household and gardening machinery. For these types of machinery, a somewhat smaller gasoline fuel consumption is calculated for the Residential (1A4b) sector. For household and gardening equipment, especially from 2001-2006, a significant fuel consumption increase is apparent due to considerable growth in the machinery stock. The gasoline fuel consumption development for Agriculture/forestry/fisheries (1A4c) is due to the gradual phasing out of gasoline-fuelled agricultural tractors until 2005 and the gradual increase in new sales of ATV's from the mid 2000's until 2011, followed by a decrease in new sales of ATV's from 2011 forward.

In terms of residual oil there has been a substantial decrease in the fuel consumption for regional ferries. The fuel consumption decline is most significant from 1991-1994 and from 1995-1997.

The considerable variations from one year to another in military jet fuel consumption are due to planning and budgetary reasons, and the passing demand for flying activities. Consequently, for some years, a certain amount of jet fuel stock-building might disturb the real picture of aircraft fuel consumption. Civil aviation has decreased until 2004, since the opening of the Great Belt Bridge in 1997, both in terms of number of flights and total jet fuel consumption. From 2011 to 2012, the total consumption of jet fuel decreased significantly due to a drop in the number of domestic flights, and in 2020 a huge decline in jet fuel consumption is noted due to the impact of COVID-19 on flight travel demand.

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

Fuel consumption for international transport

The residual oil and diesel oil fuel consumption fluctuations reflect the quantity of fuel sold in Denmark to international ferries, international warships, other ships with foreign destinations, transport to Greenland and the Faroe Islands, tank vessels and foreign fishing boats. For jet petrol, the sudden fuel consumption drop in 2002 is explained by the recession in the aviation sector due to the events of September 11, 2001 and to structural changes in the aviation business. In 2009, the impact of the global financial crisis on flying activities becomes very visible, and in 2020 a huge decline in jet fuel consumption is noted due to the impact of COVID-19 on flight travel demand.

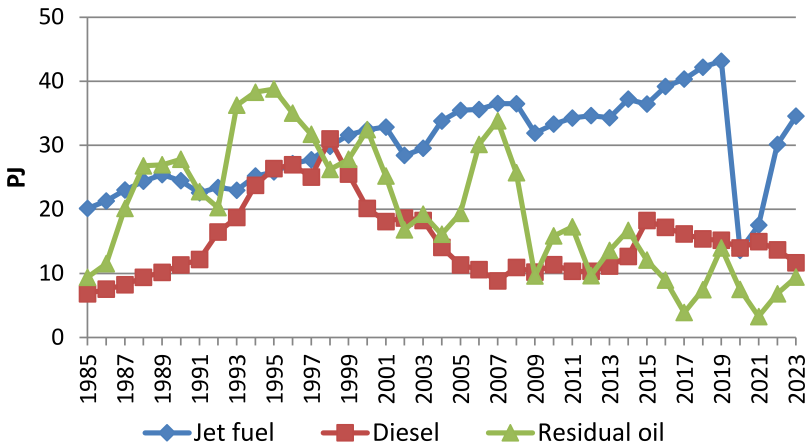


Figure 3.3.13 Bunker fuel consumption 1985-2023.

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

In Table 3.3.3 the SO_2, NO_X, NMVOC, CO NH_3, TSP, PM_{10}, $PM_{2.5}$ and BC emissions for road transport and other mobile sources are shown for 2023 in NFR sectors. The emission figures in the time series 1985-2023 are given in Annex 3.B.16 (NFR format) and are shown for 2023 in Annex 3.B.15 (CollectER format).

From 1985 to 2023, the road transport emissions of SO_2, NO_X, NMVOC, CO, PM (exhaust emissions; all size fractions) and BC have decreased by 99, 79, 93, 93, 95 and 95 %, respectively (Figures 3.3.14-3.3.19), whereas the NH_3 emissions have increased by 946 % during the same time period (Figure 3.3.20).

For other mobile sources, the emission changes for SO_2, NO_X, NMVOC, CO, PM (exhaust emissions; all size fractions) and BC are -96, -50, -67, -36, -82 and -84 %, respectively (Figures 3.3.21-3.3.25). The NH_3 emissions have increased by 15 % during the same time period (Figure 3.3.26).

Table 3.3.3 Emissions of SO_2, NO_X, NMVOC, CO NH_3, TSP, PM_{10}, $PM_{2.5}$ and BC in 2023 for road transport and other mobile sources.

	SO_2 tonnes	NO_x tonnes	NMVOC tonnes	CO tonnes	NH_3 tonnes	TSP tonnes	PM_{10} tonnes	$PM_{2.5}$ tonnes	BC tonnes
Manufacturing industries/construction (mobile)	4	1783	608	10891	2	107	107	107	73
Civil aviation (Domestic)	39	627	14	276	0	4	4	4	1
Civil Aviation (Domestic): Tyre and brake wear	0	0	0	0	0	1	1	0	0
Road transport: Passenger cars	36	10035	1889	32757	561	60	60	60	35
Road transport:Light duty vehicles	10	6308	146	1344	51	41	41	41	30
Road transport:Heavy duty vehicles	22	3138	155	1371	43	43	43	43	21
Road transport: Mopeds & motorcycles	0	108	680	5346	1	11	11	11	2
Road transport: Gasoline evaporation	0	0	1330	0	0	0	0	0	0
Road transport: Brake wear	0	0	0	0	0	685	671	267	18
Road transport: Tyre wear	0	0	0	0	0	962	577	404	147
Road transport: Road abrasion	0	0	0	0	0	1236	618	334	0
Railways	1	966	54	162	0	9	9	9	6
Railways: Train brake wear	0	0	0	0	0	83	83	42	0
Railways: Train contact wire wear	0	0	0	0	0	2	2	1	0
Railways: Train wheel and rail wear	0	0	0	0	0	187	187	94	0
National navigation (Shipping)	169	8178	395	825	0	225	223	222	25
Commercial/institutional: Mobile	1	414	672	26433	0	31	31	31	14
Residential: Household and gardening (mobile)	0	29	743	10909	0	15	15	15	1
Agriculture/forestry/fishing: Off-road agriculture/forestry	4	1912	619	5715	2	171	171	171	99
Agriculture/forestry/fishing: National fishing	232	5043	280	709	0	107	106	105	22
Other, Mobile	94	1271	268	3160	1	49	49	49	18
Domestic total	614	39811	7854	99898	661	4027	3007	2008	511
Road transport exhaust total	69	19588	4200	40818	656	154	154	154	89
Road transport non exhaust total	0	0	0	0	0	2882	1866	1005	165
Other mobile exhaust total	545	20223	3654	59079	5	717	714	712	258
Other mobile non exhaust total	0	0	0	0	0	273	272	136	0
Civil aviation (International)	794	11847	195	2086	0	96	96	96	23
Civil Aviation (International): Tyre and brake wear	0	0	0	0	0	6	5	3	0
Navigation (International)	1006	35360	1393	3829	0	1241	1228	1222	70

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

The step-wise lowering of the sulphur content in diesel fuel has given rise to a substantial decrease in the road transport emissions of SO_2 (Figure 3.3.14). In 1999, the sulphur content was reduced from 500 ppm to 50 ppm (reaching gasoline levels), and for both gasoline and diesel the sulphur content was reduced to 10 ppm in 2005. Since Danish diesel and gasoline fuels have the same sulphur percentages, at present, the 2023 shares for SO_2 emissions and fuel consumption for passenger cars, heavy-duty vehicles, light-duty vehicles and 2-wheelers are the same in each case: 53, 32, 15 and 0 %, respectively (Figure 3.3.21).

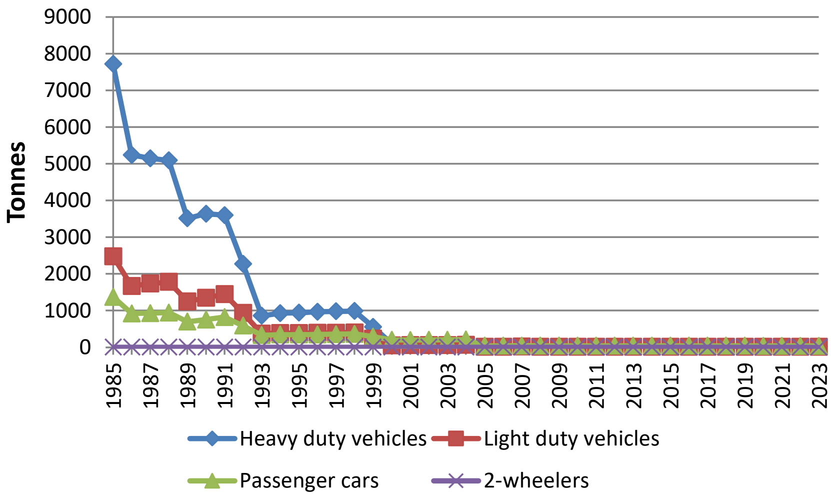


Figure 3.3.14 SO_2 emissions (tonnes) per vehicle type for road transport 1985-2023.

Historically, the emission totals of NMVOC and CO have been very dominated by the contributions coming from private cars, as shown in Figures 3.3.16- 3.3.17. However, the NMVOC and CO (and NO_x) emissions from this vehicle type have shown a steady decreasing tendency since the introduction of private catalyst cars in 1990 (EURO I) and the introduction of even more emission-efficient EURO 2, 3, 4 and 5 private cars (introduced in 1997, 2001, 2006 and 2011, respectively).

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

The most modern Euro 6d-TEMP and 6d diesel passenger cars and Euro 6d-TEMP and 6d light duty vehicles which entered the fleet in 2018 and 2021, and 2019 and 2022, respectively, however, have significantly lower NO_x emission factors compared to earlier Euro standards. Hence the gradual growth in the numbers of Euro 6d-TEMP and 6d vehicles is going to reduce the emissions for diesel passenger cars and light duty vehicles in the years to come. Relatively large NO_x emission reductions are noted for passenger cars in 2020 related to COVID-19.

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

Exhaust particulate emissions from road transportation vehicles are well below $PM_{2.5}$. The emissions from light- and heavy-duty vehicles have significantly decreased since the mid-1990s due to gradually stricter EURO emission standards. In recent years until 2008 the environmental benefit of introducing gradually cleaner diesel private cars has been somewhat outbalanced by an increase in sales of new vehicles. After 2008, the PM emissions gradually become lower due to the increasing number of Euro 5 cars equipped with particulate filter sold in Denmark from 2006 onwards (Figure 3.3.18).

BC - commonly understood as the solid part of the particulate emissions - is calculated as shares of TSP for each Euro engine technology class (Figure 3.3.19). In broad terms, the development in BC emissions follows the TSP emission trend, but deviates in some cases, most markedly for diesel cars and vans. For these vehicle types the BC share of TSP increases in moderate steps from conventional engine technologies to Euro 4. As a result, the BC emission development becomes environmentally less positive than for TSP, until the introduction of Euro 5 vehicles, for which the installed particulate filters have very high removal rates of BC.

An undesirable environmental side effect of the introduction of catalyst cars is the increase in the emissions of NH_3 from the first two generations of catalyst cars (Euro 1 and 2) compared to conventional cars. The emission factors for later catalytic converter technologies are considerably lower than the ones for Euro1 and 2, thus causing the emissions to decrease from 2001 onwards (Figure 3.3.20).

The 2023 emission shares for passenger cars, heavy-duty vehicles, light-duty vehicles and 2-wheelers for NO_x (51, 16, 32 and 1 %), NMVOC (exhaust: 45, 4, 3 and 16 %), CO (80, 4, 3 and 13 %), PM (39, 28, 26 and 7 %), BC (32, 47, 21 and 0 %), and NH_3 (85, 7, 8 and 0 %), are also shown in Figure 3.3.21.

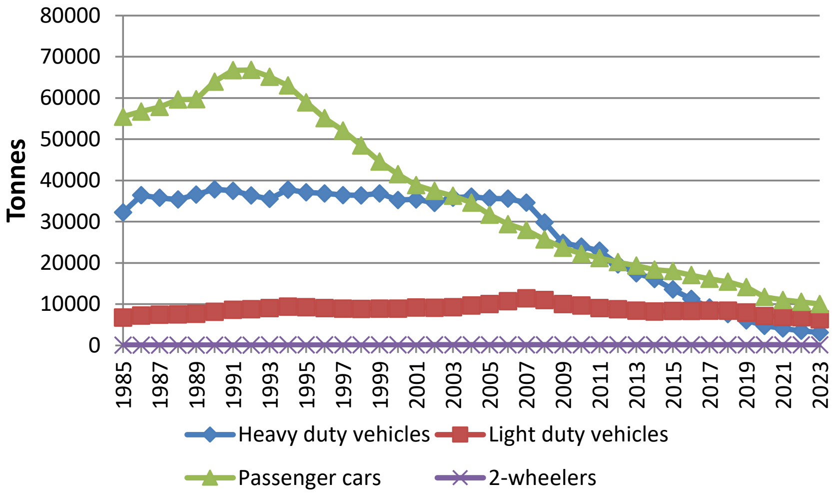


Figure 3.3.15 NO_X emissions (tonnes) per vehicle type for road transport 1985-2023.

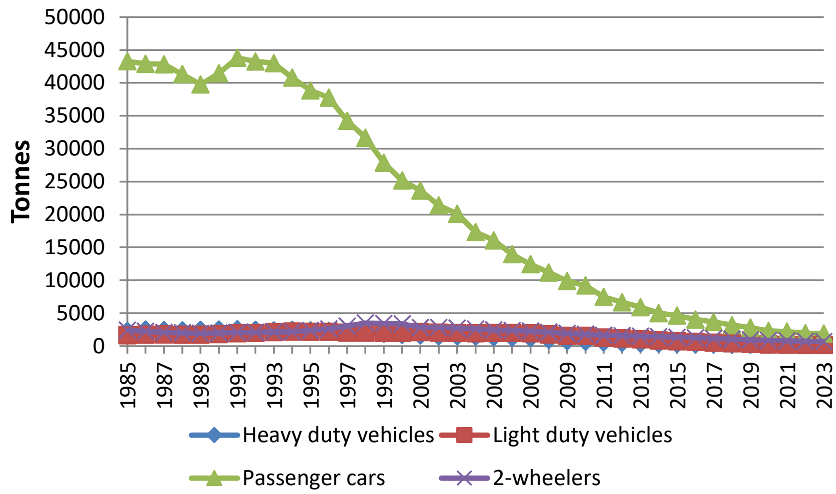


Figure 3.3.16 NMVOC emissions (tonnes) per vehicle type for road transport 1985-2023.

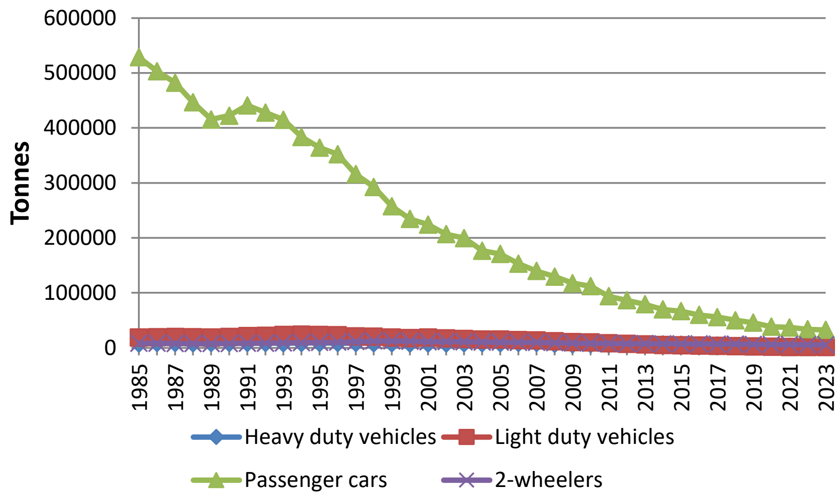


Figure 3.3.17 CO emissions (tonnes) per vehicle type for road transport 1985-2023.

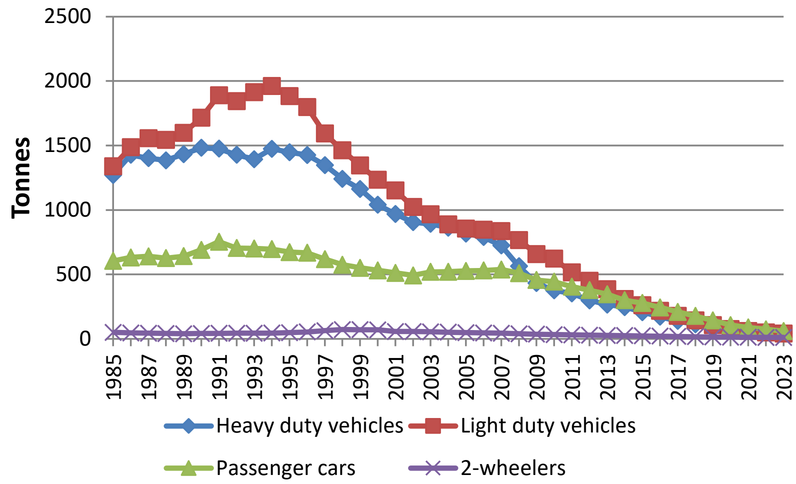


Figure 3.3.18 PM emissions (tonnes) per vehicle type for road transport 1985-2023.

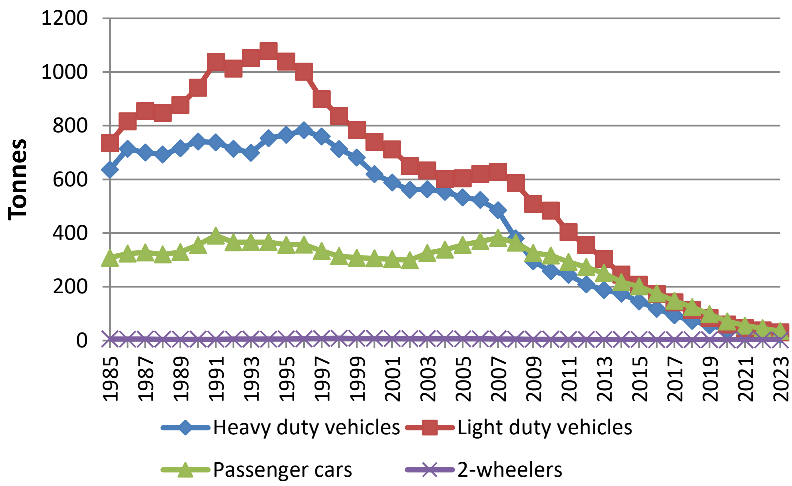


Figure 3.3.19 BC emissions (tonnes) per vehicle type for road transport 1985-2023.

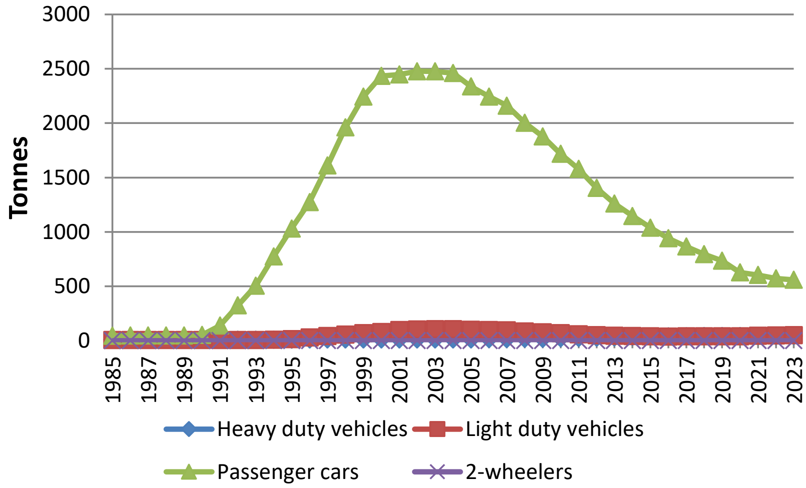


Figure 3.3.20 NH_3 emissions (tonnes) per vehicle type for road transport 1985-2023.

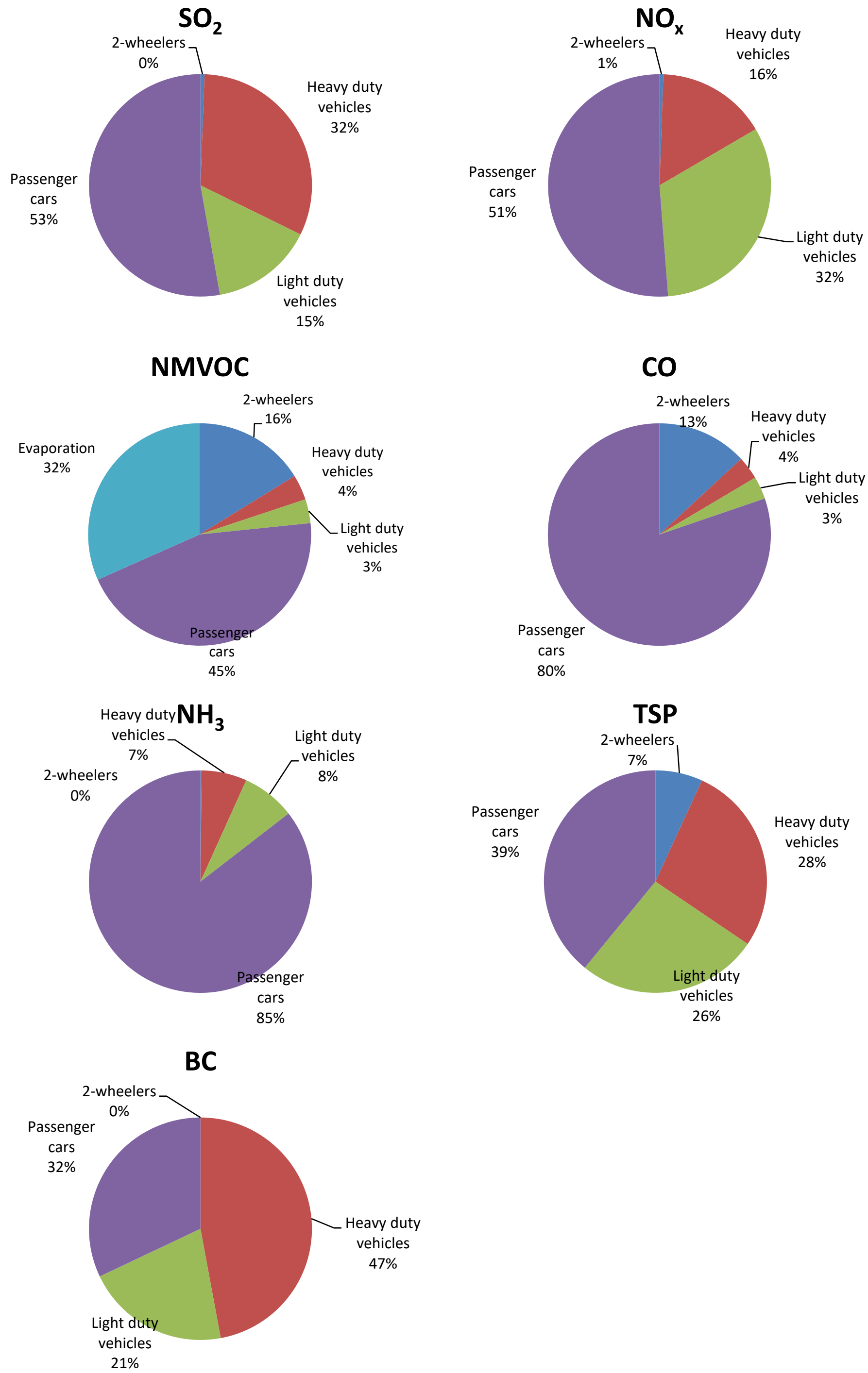


Figure 3.3.21 SO_2, NO_X, NMVOC, CO, NH_3, PM and BC emission shares pr vehicle type for road transport in 2023.

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

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

In Table 3.3.3, the non-exhaust TSP, PM_{10}, $PM_{2.5}$ and BC emissions for road transport are shown for 2023 in NFR sectors. The activity data and emission factors are also shown in Annex 3.B.15.

The respective source category distributions for TSP, PM_{10} and $PM_{2.5}$ emissions are identical for each of the non-exhaust emission types brake wear, tyre wear and road abrasion, and, hence, only the PM_{10} distributions are shown in Figure 3.3.22. For brake wear, passenger cars caused the highest emissions in 2023, followed by light-duty vehicles, trucks, buses and 2-wheelers. In the case of tyre wear and road abrasion, passenger cars caused the highest emissions in 2023, followed by trucks, light-duty vehicles, buses and 2-wheelers.

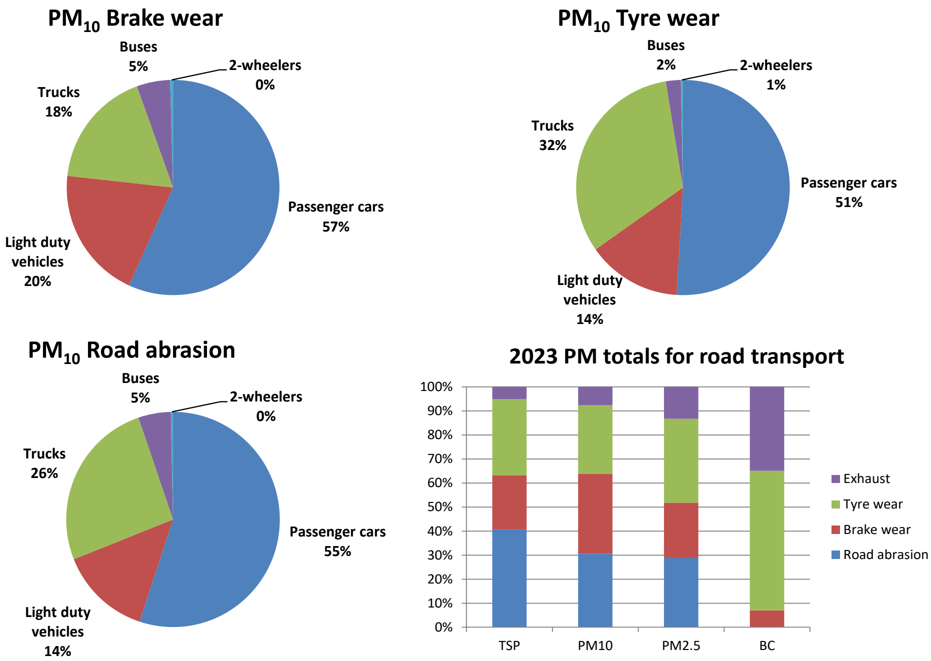


Figure 3.3.22 Brake and tyre wear and road abrasion PM_{10} emission shares and PM and BC exhaust/non-exhaust distributions for road traffic in 2023.

Figure 3.3.22 also shows the exhaust/non-exhaust distribution of the total particulate emissions from road transport, for each of the size classes TSP, PM_{10} and $PM_{2.5}$ and for BC. The exhaust emission shares of total road transport TSP, PM_{10}, $PM_{2.5}$ and BC are 5, 8, 13 and 35 %, respectively, in 2023. For brake and tyre wear and road abrasion the TSP shares are 23, 32 and 41 %, respectively. The same three sources have PM_{10} shares of 33, 29 and 31 %, respectively, $PM_{2.5}$ shares of 23, 35, 29 %, and BC shares of 7, 58 and 0 %, respectively. In general, the non-exhaust shares of total particulate emissions are expected to increase in the future as total exhaust emissions decline. The latter emission trend is due to the stepwise strengthening of exhaust emission standards for all vehicle types.

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

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

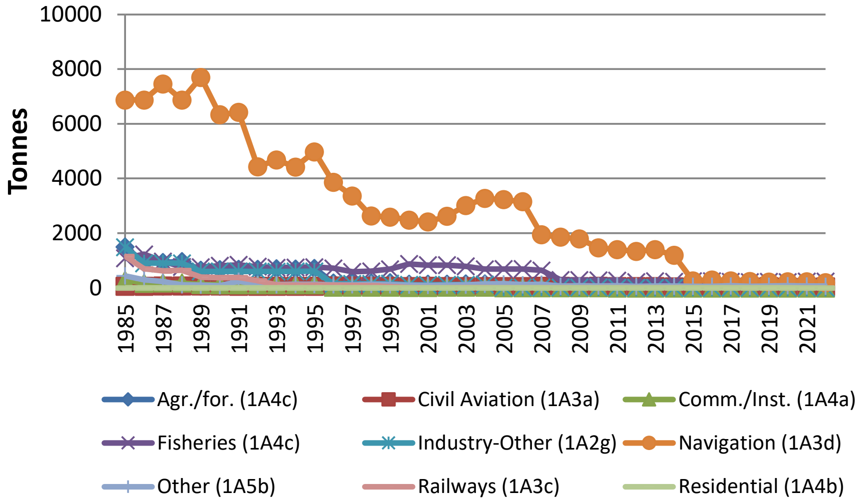


Figure 3.3.23 SO_2 emissions (ktonnes) in NFR sectors for other mobile sources 1985-2023.

NO_X emissions mainly come from diesel machinery, and the most important sources are Navigation (1A3d), Agriculture/forestry/fisheries (1A4c) and Industry (1A2f), as shown in Figure 3.3.24. The 2023 emission shares are 40, 35 and 9 %, respectively (Figure 3.3.30). Minor emissions come from the sectors Other (1A5), Railways (1A3b), Civil Aviation (1A3a), Commercial/Institutional (1A4a) and Residential (1A4b).

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

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

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

The NO_x emissions for industrial non-road machinery decline from 1985-2023. The emission reductions are, however, mostly pronounced from 2009 onwards. The NO_x emission development from 1985 to 2023 for industrial non-road machinery is the product of a rather constant fuel consumption from 1985-1999, a fuel consumption increases from 2000 to 2008, and a fuel consumption decrease from 2009 onwards (Figure 3.3.9), in combination with a development in NO_x emission factors as explained for agricultural machinery. For industrial non-road machinery, the NO_x emission impact from the global financial crisis becomes very visible for 2009.

For railways, the gradual shift towards electrification and NO_x emission factors improvements, explains the declining trend in diesel fuel consumption and NO_X emissions for this transport sector throughout the period.

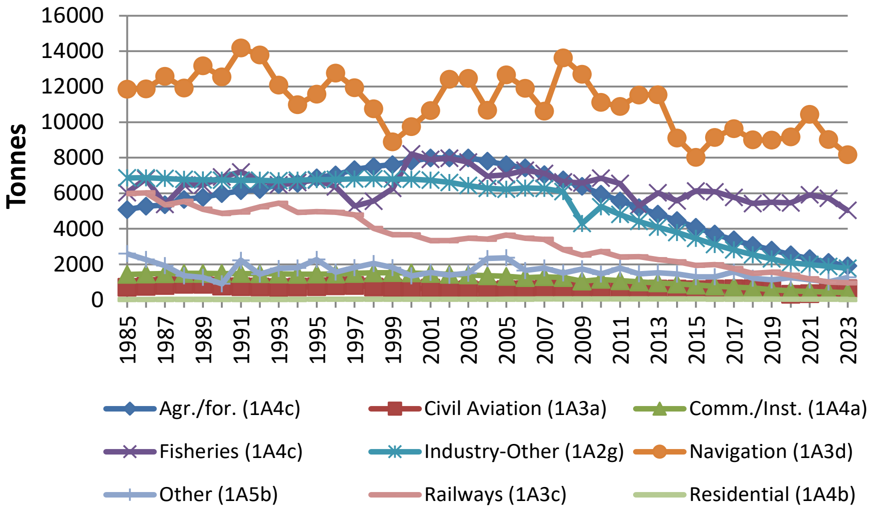


Figure 3.3.24 NO_X emissions (tonnes) in NFR sectors for other mobile sources 1985-2023.

The 1985-2023 time series of NMVOC and CO emissions are shown in Figures 3.3.25 and 3.3.26 for other mobile sources. The 2023 sector emission shares are shown in Figure 3.3.30. For NMVOC, the most important sectors are Agriculture/forestry/fisheries (1A4c), Residential (1A4b), Commercial/institutional (1A4a) and Industry (1A2g), with 2023 emission shares of 25, 20, 18 and 17 %, respectively.

The same four sectors also contribute with most of the CO emissions. For Commercial/institutional (1A4a), Residential (1A4b), Industry (1A2g) and Agriculture/forestry/fisheries (1A4c) the emission shares are 45, 19, 18 and 11 %, respectively. Minor NMVOC and CO emissions come from Navigation (1A3d), Railways (1A3c), Civil Aviation (1A3a) and Other (1A5).

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

As shown in Figure 3.3.30, for other mobile sources the largest TSP contributors in 2023 are Agriculture/forestry/fisheries (1A4c), Navigation (1A3d) and Industry (1A2f) with emission shares of 39 %, 31 % and 15 %, respectively. The remaining sectors: Railways (1A3c), Civil aviation (1A3a), Other

(1A5), Commercial/Institutional (1A4a) and Residential (1A4b) represent only minor emission sources.

The 1985-2023 TSP emissions for navigation and fisheries are determined by the fuel consumption fluctuations in these years, and the development of the emission factors, which to a major extent is a function of the fuel type and fuel sulphur content.

For agriculture/forestry non-road machinery, the TSP emissions development from 1985-2023 are also determined by the development of fuel consumption and emission factors. The diesel fuel consumption increases from 1985 to 2008 followed by a decrease from 2009 onwards (Figure 3.3.9), whereas the emission factors are gradually reduced during the whole period. Consequently, the total TSP emissions for agriculture/forestry are quite constant until 1990 and then reduced from 1991 onwards.

The TSP emissions for industrial non-road machinery decline from 1985-2023. The latter emission development is the product of gradually reduced emission factors throughout the period, in combination with a rather constant fuel consumption from 1985-1999, which later increases from 2000 to 2008 followed by a fuel consumption decrease from 2009 onwards (Figure 3.3.9). For industry, the TSP emission impact from the global financial crisis becomes very visible for 2009.

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

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

The amounts of NH_3 emissions calculated for other mobile sources are very small. The largest emission sources are Agriculture-/forestry/fisheries (1A4c), Industry (1A2f), Other (1A5b) and Railways (1A3c), with emission shares of 39 %, 34 %, 10 % and 9 %, respectively.

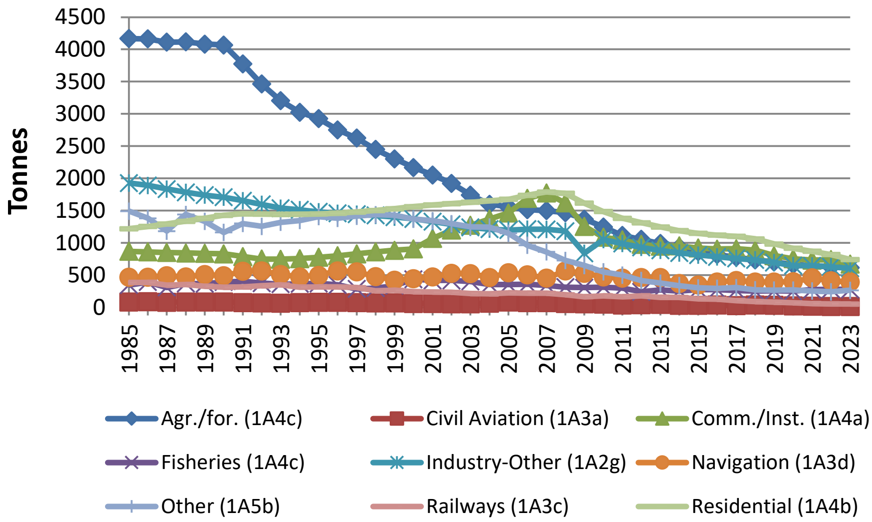


Figure 3.3.25 NMVOC emissions (tonnes) in NFR sectors for other mobile sources 1985-2023.

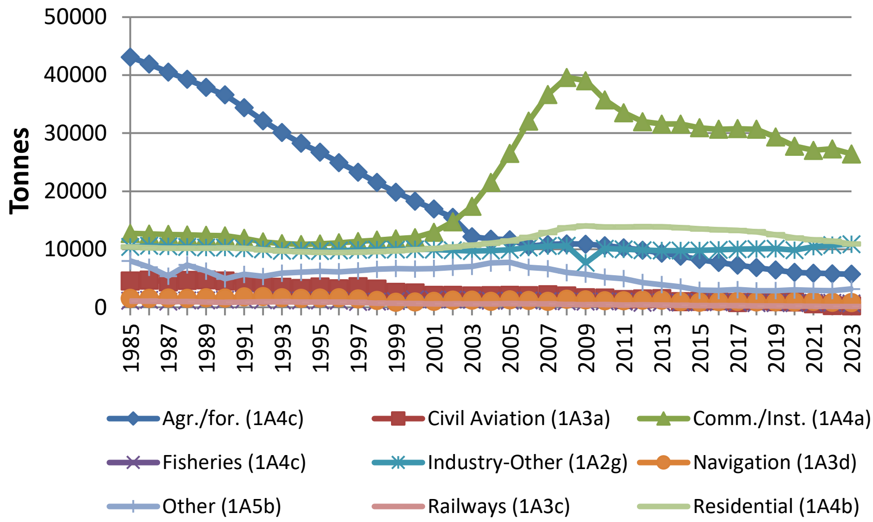


Figure 3.3.26 CO emissions (tonnes) in NFR sectors for other mobile sources 1985-2023.

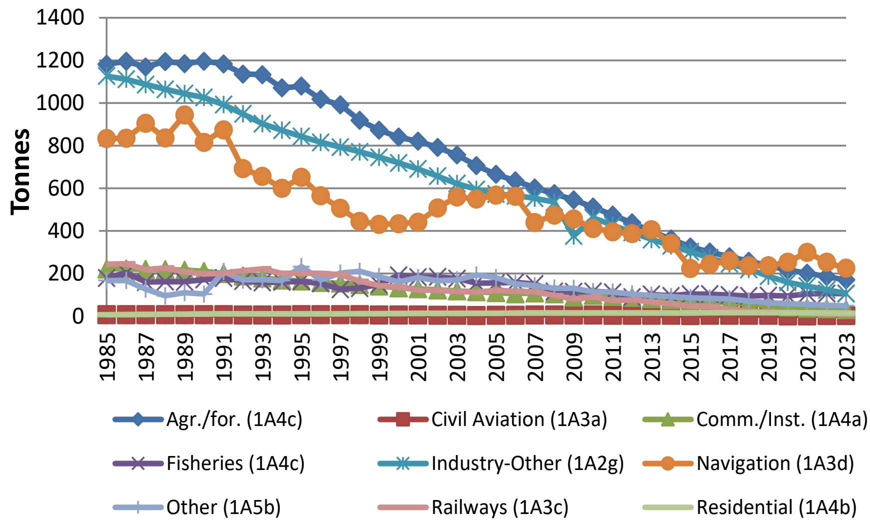


Figure 3.3.27 TSP emissions (tonnes) in NFR sectors for other mobile sources 1985-2023.

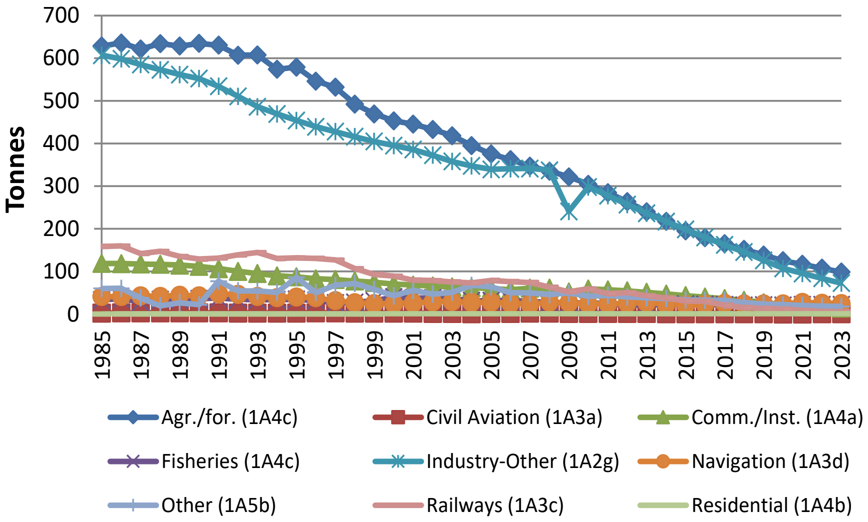


Figure 3.3.28 BC emissions (tonnes) in NFR sectors for other mobile sources 1985-2023.

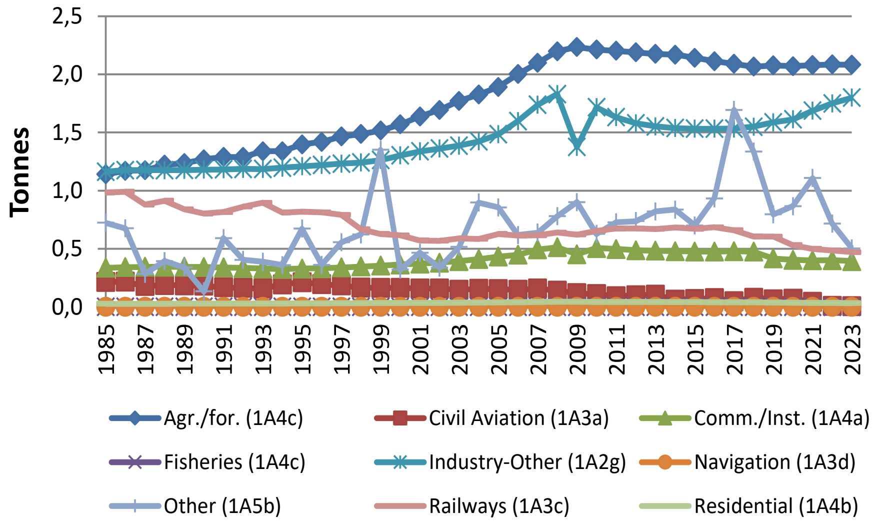


Figure 3.3.29 NH_3 emissions (tonnes) in NFR sectors for other mobile sources 1985-2023.

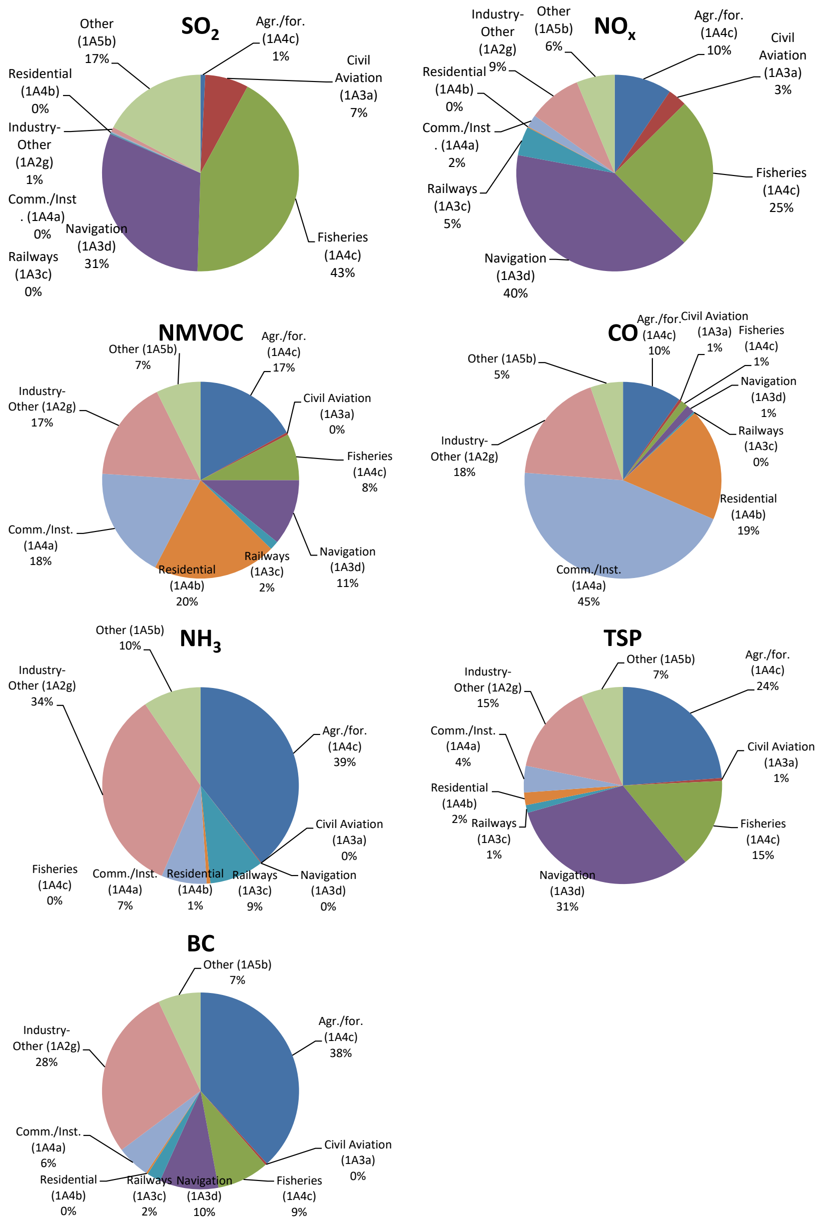


Figure 3.3.30 SO_2, NO_X, NMVOC, CO, NH_3, PM and BC emission shares pr vehicle type for other mobile sources in 2023.

Non-exhaust emissions of TSP, PM_{10} and $PM_{2.5}$ for other mobile sources

Apart from the exhaust emission estimates of particulate matter (PM), the Danish emission inventories also comprise the non-exhaust PM emissions coming from train contact wire wear, wheel and rail wear and brake wear for railways, and tyre and brake wear for aircraft landings in civil aviation.

In Table 3.3.3, the non-exhaust TSP, PM_{10} and $PM_{2.5}$ emissions for railways and civil aviation are shown for 2023 in NFR sectors. The activity data and emission factors are also shown in Annex 3.B.15.

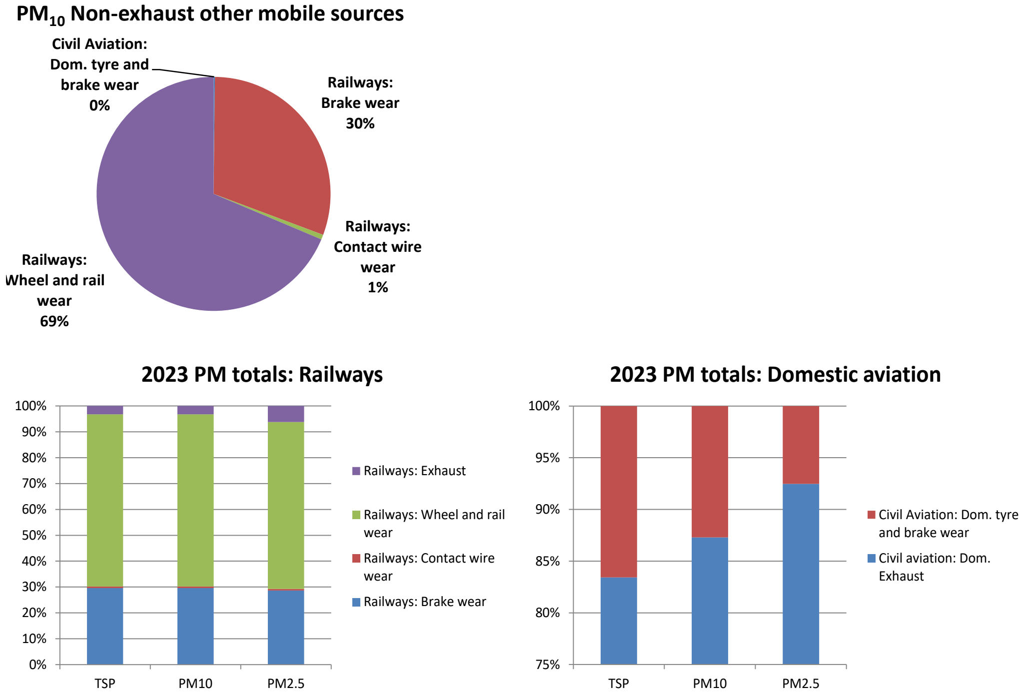


Figure 3.3.31 Non-exhaust PM_{10} emission shares for domestic civil aviation and railways, and PM exhaust/non-exhaust distributions for civil aviation and railways in 2023.

For PM_{10}, the non-exhaust emissions coming from train wheel and rail wear, brake wear and contact wire wear make up 69 %, 30 % and 1 % of the total non-exhaust emissions for other mobile sources. For railways, the exhaust emissions of TSP, PM_{10}, $PM_{2.5}$ make up 3 %, 3 % and 6 %, respectively, of the total TSP, PM_{10}, $PM_{2.5}$ emissions from railways. For civil aviation, the exhaust emissions of TSP, PM_{10}, $PM_{2.5}$ make up 34 %, 41 % and 55 %, respectively, of the total TSP, PM_{10}, $PM_{2.5}$ emissions from civil aviation.

Emissions of heavy metals

In Table 3.3.4, the heavy metal emissions for road transport and other mobile sources are shown for 2023 in NFR sectors. The emission figures in the time series 1990-2023 are given in Annex 3.B.16 (NFR format) and are shown for 1990 and 2023 in Annex 3.B.15 (CollectER format).

Table 3.3.4 Heavy metal emissions in 2023 for road transport and other mobile sources.

	Arsenic	Cadmium	Chromium	Copper	Mercury	Nickel	Lead	Selenium	Zinc
	kg	kg	kg	kg	kg	kg	kg	kg	kg
Manufacturing industries/construction (mobile)	0	2	6	4	1	2	10	0	341
Civil aviation (Domestic)	0	0	0	0	0	0	48	0	0
Civil aviation (Domestic): Tyre and brake wear	0	0	0	26	0	0	3	0	10
Road transport: Passenger cars	0	28	56	89	13	31	118	0	5660
Road transport:Light duty vehicles	0	5	16	12	3	5	29	0	997
Road transport:Heavy duty vehicles	0	7	26	19	6	7	41	0	1378
Road transport: Mopeds & motorcycles	0	0	0	0	0	0	0	0	22
Road transport: Gasoline evaporation	0	0	0	0	0	0	0	0	0
Road transport: Brake wear	7	6	78	56934	0	75	7398	14	11896
Road transport: Tyre wear	1	3	3	15	0	25	77	19	10521
Road transport: Road abrasion	0	0	25	12	0	20	58	0	93
Railways	0	0	2	1	0	0	3	0	88
Railways: Train brake wear	0	0	831	0	0	1663	0	0	0
Railways: Train contact wire wear	0	0	0	1812	0	0	0	0	0
Railways: Train wheel and rail wear	0	0	0	0	0	0	0	0	0
National navigation (Shipping)	23	2	12	23	4	1070	18	36	87
Commercial/institutional: Mobile	0	0	1	1	0	0	2	0	91
Residential: Household and gardening (mobile)	0	0	0	0	0	0	0	0	17
Agriculture/forestry/fishing: Off-road agriculture/forestry	0	2	6	4	1	2	10	0	346
Agriculture/forestry/fishing: National fishing	6	1	5	6	3	8	12	23	58
Other, Mobile	0	0	1	1	0	0	2	0	61
Domestic total	37	57	1067	58961	33	2908	7831	93	31667
Road transport exhaust total	1	40	98	120	22	43	189	0	8057
Road transport non exhaust total	8	8	106	56962	0	119	7534	33	22510
Other mobile exhaust total	29	8	32	41	11	1083	105	59	1090
Other mobile non exhaust total	0	0	831	1837	0	1663	3	0	10
Civil aviation (International)	0	0	0	0	0	0	0	0	0
Civil aviation (International): Tyre and brake wear	0	0	0	229	0	0	31	0	88
Navigation (International)	129	10	57	129	13	6923	73	147	344

The heavy metal emission estimates for road transport exhaust are based on a national research study made by Winther and Slentø (2010). The latter study calculates among other the exhaust related emissions from the vehicle fuel and engine oil.

The heavy metal emissions originating from tyre, brake and road wear is based on emission factors from COPERT 5.

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

The most important exhaust related emissions for road transport are Zn, Pb, Cu and Cr. the most important wear related emissions are Cu and Pb almost solely coming from tyre wear, and Zn from brake and tyre wear.

For other mobile sources, the most important exhaust related emission contributions are calculated for Ni, Se and As, coming from the use of marine diesel oil in fisheries and navigation and residual oil in navigation.

The most important wear related heavy metal emissions for other mobile sources comes from railways, namely Cu from train contact wire wear and Cr and Ni from train brake wear.

The figures 3.3.31 and 3.3.32 show the exhaust related heavy metal emission distributions for all road transport sources split into vehicle categories, and for other mobile sectors, respectively.

For non-road mobile machinery in agriculture, forestry, industry, commercial/institutional and recreational, as well as military and railways, fuel related emission factors from road transport are used derived for the year 2009.

For civil aviation jet fuel, no emissions are estimated due to lack of emission data, whereas for aviation gasoline fuel related emission factors for road transport gasoline is used derived for the year 2009, except for Pb where national data exist.

For navigation and fisheries, the heavy metal emission factors are fuel related, and are taken from the EMEP/EEA guidebook.

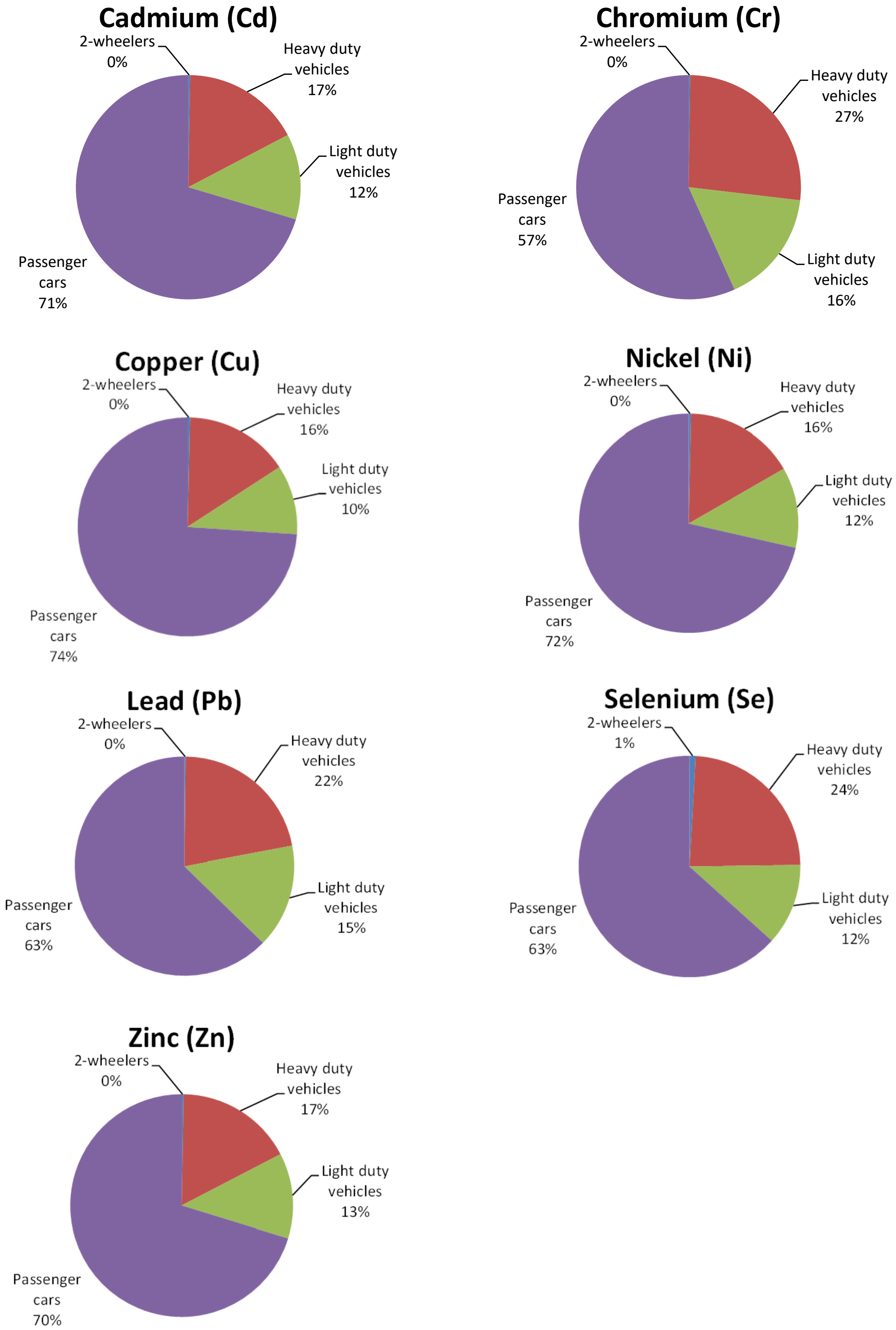


Figure 3.3.31 Exhaust related heavy metal emission shares for road transport in 2023.

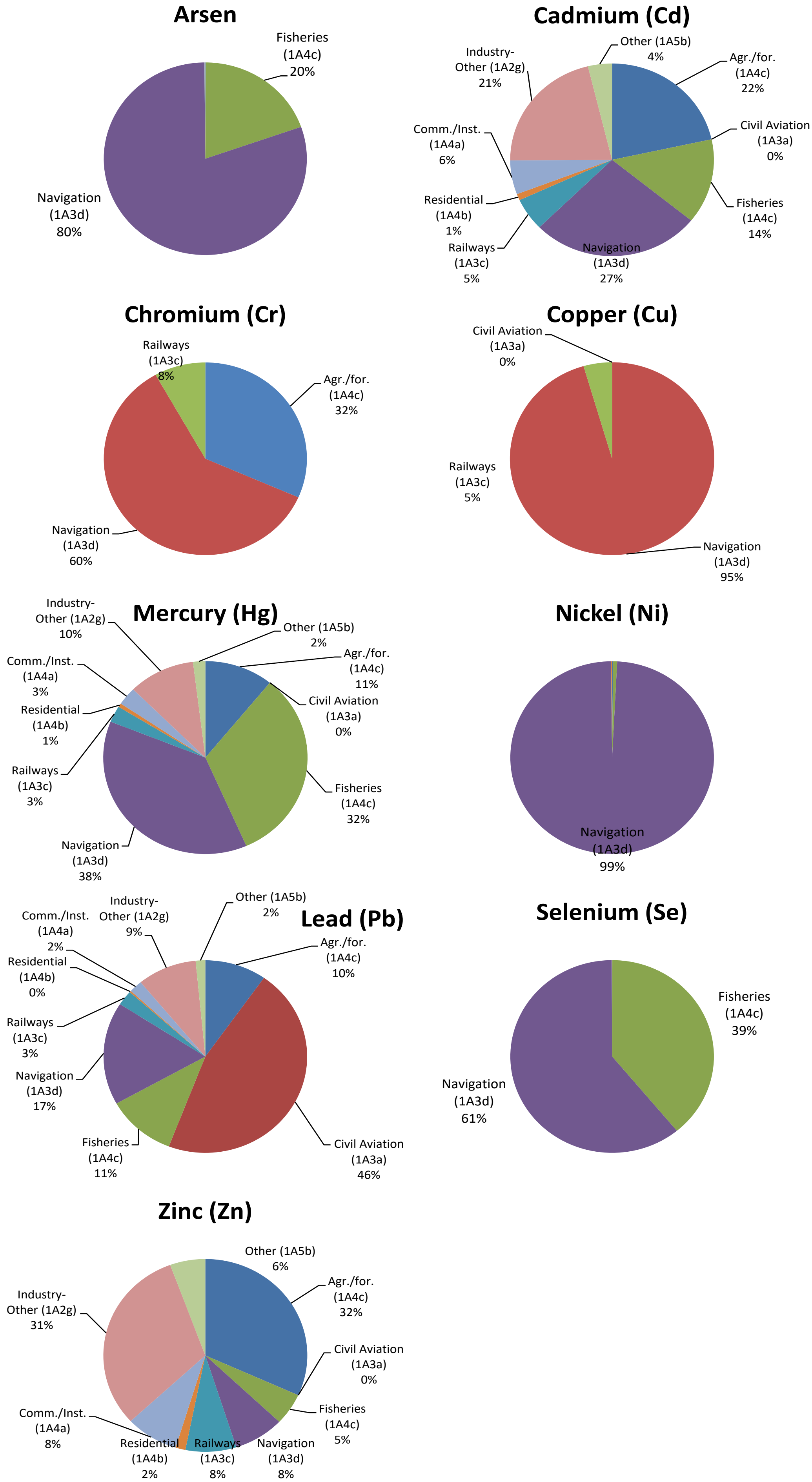


Figure 3.3.32 Exhaust related heavy metal emission shares for other mobile sources in 2023.

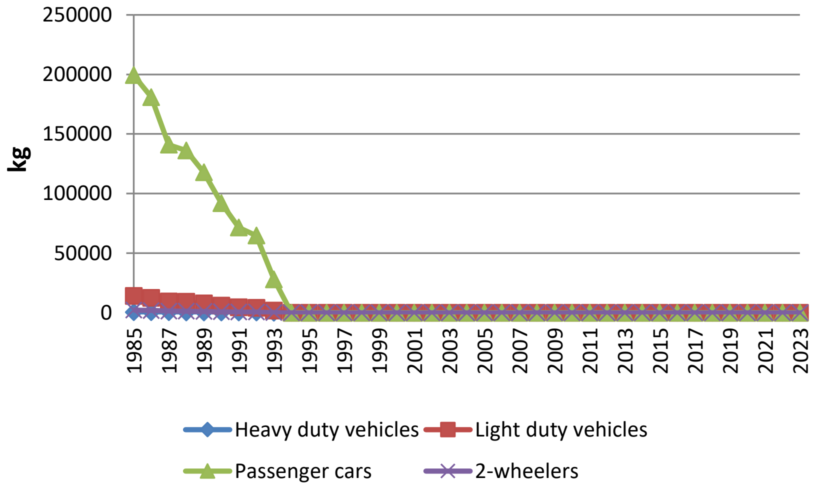


Figure 3.3.33 Exhaust related Pb emissions (kg) pr vehicle type for road transport 1985-2023.

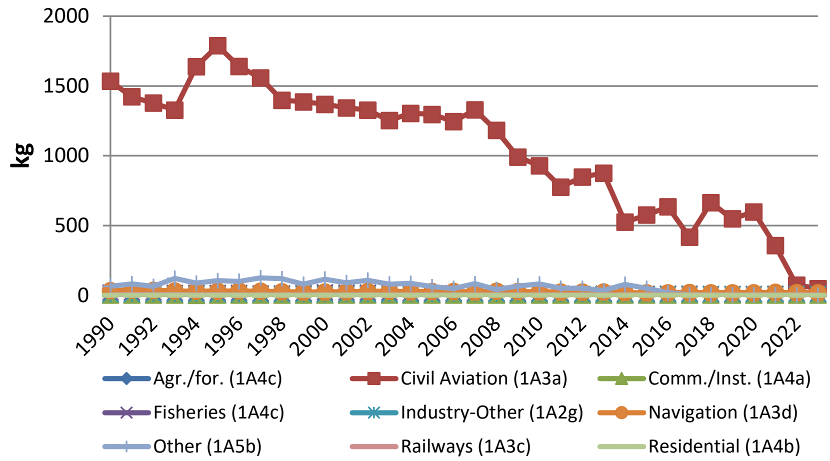


Figure 3.3.34 Exhaust related Pb emissions (kg) in NFR sectors for other mobile sources 1990-2023.

Emissions of dioxin and PAH

In Table 3.3.5, the dioxin, PAH, HCB and PCB emissions for road transport and other mobile sources are shown for 2023 in NFR sectors. The emission figures in the time series 1990-2023 are given in Annex 3.B.16 (NFR format) and are shown for 1990 and 2023 in Annex 3.B.15 (CollectER format).

Table 3.3.5 Dioxin, PAH, HCB and PCB emissions in 2023 for road transport and other mobile sources.

	HCB	Dioxins/Furans	Benzo(b) flouranthene	Benzo(k) flouranthene	Benzo(a) pyrene	Indeno (1,2,3-c,d)	PCB
	g	g	kg	kg	kg	kg	g
Manufacturing industries/construction (mobile)	0.053	0.008	4.43	4.26	2.22	2.34	0.004
Civil aviation (Domestic)	0.000	0.000	0.00	0.00	0.00	0.00	0.000
Civil aviation (Domestic): Tyre and brake wear	0.000	0.000	0.00	0.00	0.00	0.00	0.000
Road transport: Passenger cars	0.206	0.036	41.40	31.80	36.80	36.73	0.074
Road transport:Light duty vehicles	0.134	0.012	15.12	11.84	13.48	12.60	0.013
Road transport:Heavy duty vehicles	0.302	0.052	26.19	29.27	4.33	6.73	0.002
Road transport: Mopeds & motorcycles	0.000	0.016	0.44	0.15	0.24	0.52	0.003
Road transport: Gasoline evaporation	0.000	0.000	0.00	0.00	0.00	0.00	0.000
Road transport: Brake wear	0.000	0.000	0.29	0.42	0.51	0.00	0.000
Road transport: Tyre wear	0.000	0.000	0.00	0.00	3.75	0.00	0.000
Road transport: Road abrasion	0.000	0.000	0.00	0.00	0.00	0.00	0.000
Railways	0.015	0.002	0.85	0.95	0.14	0.22	0.002
Railways: Train brake wear	0	0	0	0	0	0	0
Railways: Train contact wire wear	0	0	0	0	0	0	0
Railways: Train wheel and rail wear	0	0	0	0	1	0	1
National navigation (Shipping)	0,014	0,076	3,40	1,49	0,74	5,60	0,005
Commercial/institutional: Mobile	0.009	0.005	0.91	0.78	0.46	0.58	0.001
Residential: Household and gardening (mobile)	0.000	0.002	0.08	0.03	0.04	0.09	0.001
Agriculture/forestry/fishing: Off-road agriculture/forestry	0.056	0.007	4.65	4.49	2.33	2.44	0.004
Agriculture/forestry/fishing: National fishing	0.010	0.059	3.17	1.49	0.74	5.84	0.004
Other, Mobile	0.007	0.003	0.68	0.61	0.34	0.40	0.002
Domestic total	0.804	0.278	101.61	87.58	66.93	74.49	0.934
Road transport exhaust total	0.642	0.116	83.15	73.06	54.85	56.57	0
Road transport non exhaust total	0	0	0.29	0.42	4.26	0	0
Other mobile exhaust total	0.163	0.162	18.17	14.10	7.02	17.50	0.024
Other mobile non exhaust total	0	0	0.00	0.00	0.80	0	1
Civil aviation (International)	0.000	0.000	0.00	0.00	0.00	0.00	0.000
Civil aviation (International): Tyre and brake wear	0.000	0.000	0.00	0.00	0.02	0.00	0.000
Navigation (International)	0.056	0.266	9.34	4.35	2.41	15.64	0.018

For mobile sources, road transport displays the largest emission of dioxins and PAH. The dioxin emission share for road transport is 41 % of all mobile emissions in 2023, whereas Navigation and Agriculture/forestry-/fisheries have smaller shares of 29 and 24 %. For the different PAH components, road transport shares are around 80 % of total emissions for mobile sources. The remaining emissions almost solely come from Agriculture/forestry-/fisheries, Navigation and Industry with Agriculture/forestry/fisheries as the largest source.

Figures 3.3.35 and 3.3.36 show the dioxin and PAH emission distributions into vehicle categories and other mobile sectors, respectively.

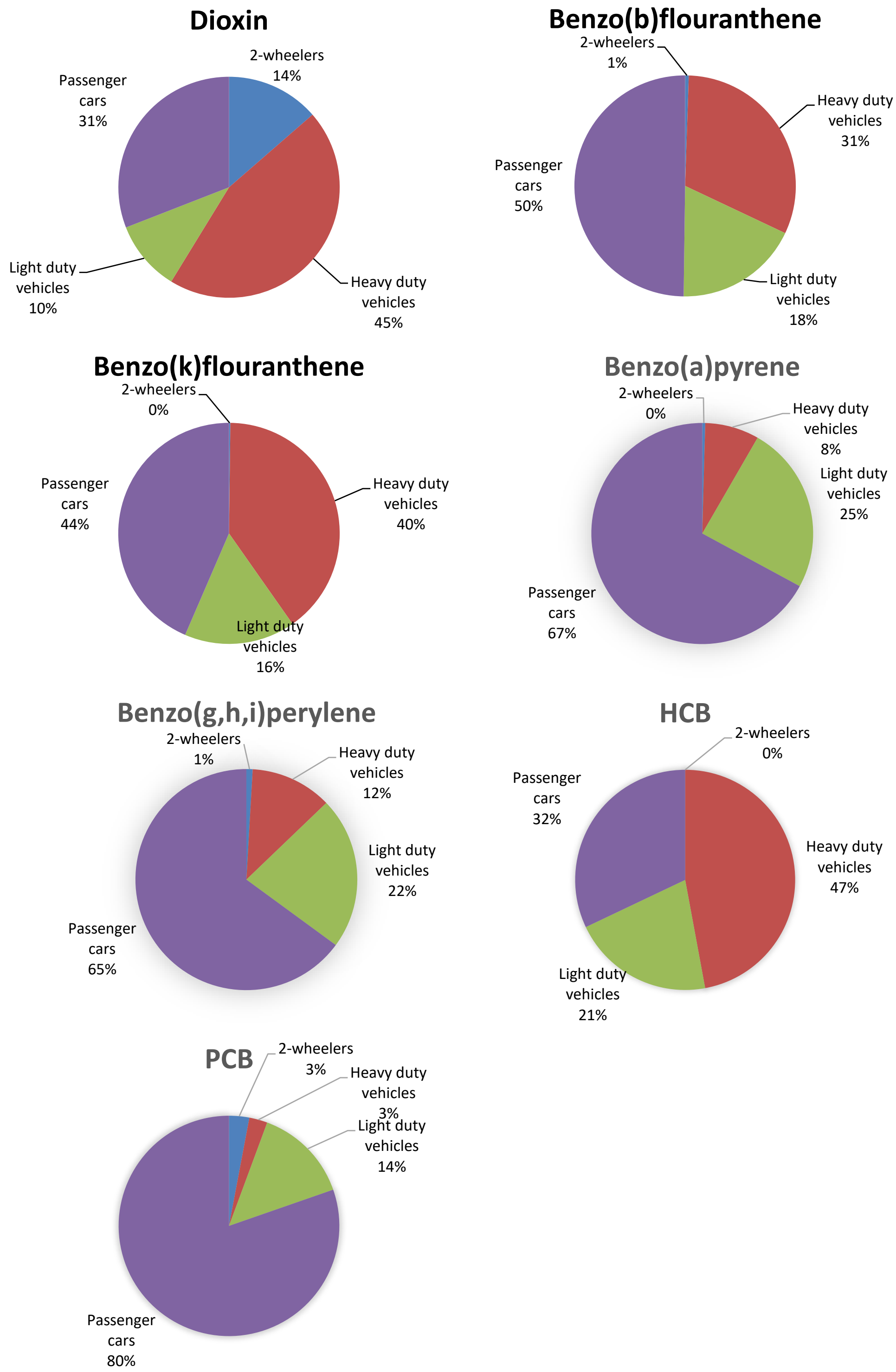


Figure 3.3.35 Dioxin, PAH, HCB and PCB emission shares for road transport in 2023.

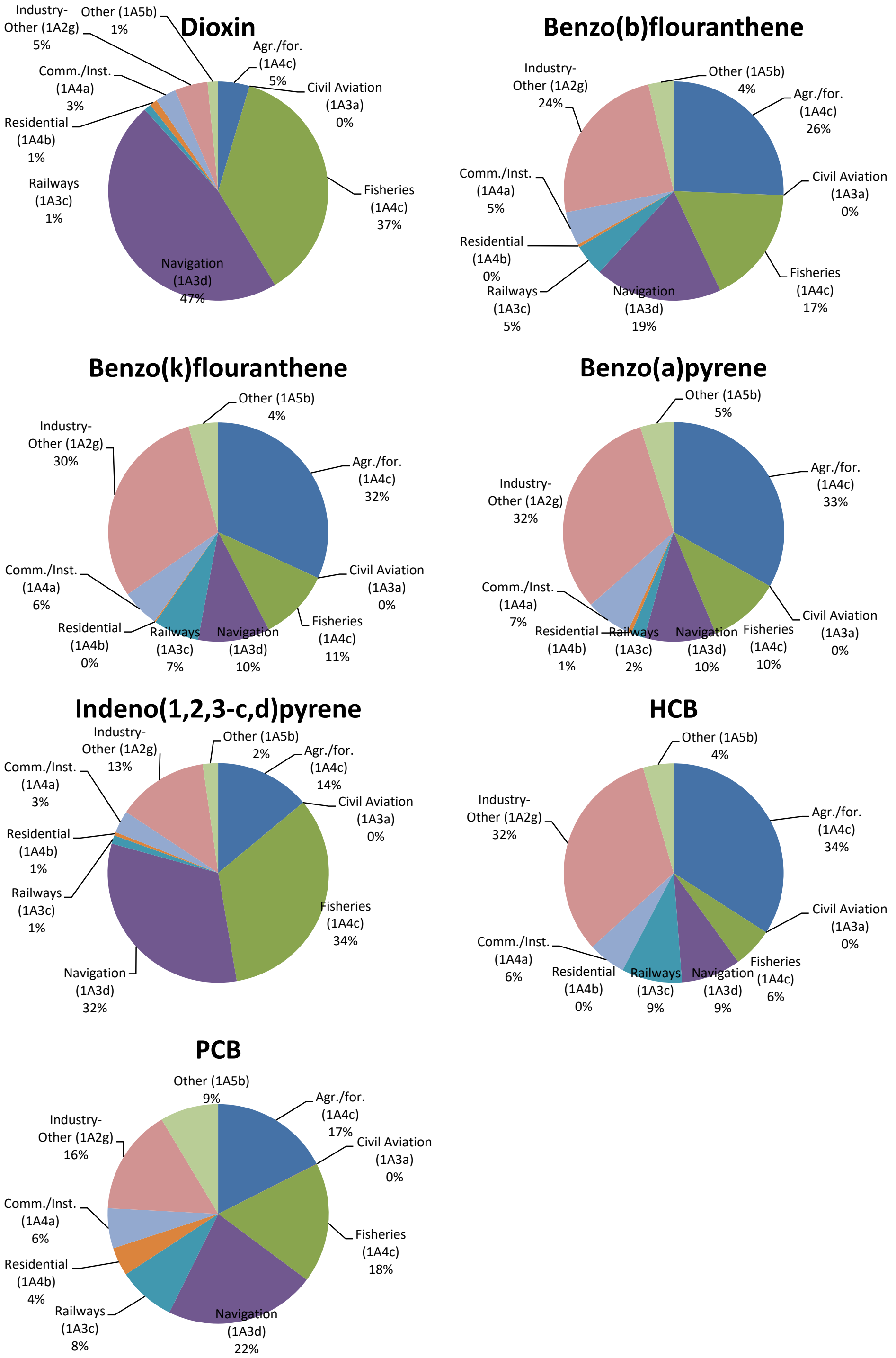


Figure 3.3.36 Dioxin, PAH, HCB and PCB emission shares for other mobile sources in 2023.

Emissions from international transport

The most important emissions from bunker fuel consumption (fuel consumption for international transport) are SO_2 and NO_x. The bunker emission totals are shown in Table 3.3.3 for 2023, split into sea transport and civil aviation. All emission figures in the 1985-2023 time series are given in Annex 3.B.16 (NFR format). In Annex 3.B.15, the emissions are also given in CollectER format for 2023.

The differences in emissions between navigation and civil aviation are much larger than the differences in fuel consumption and display a poor emission performance for international sea transport. In broad terms, the emission trends shown in Figure 3.3.37 are like the fuel consumption development.

However, for navigation, minor differences occur for the emissions of SO_2 and NO_X due to varying amounts of marine gas oil and residual oil, and for SO_2 and NO_X, the development in the emission factors also have an impact on the emission trends. For civil aviation, apart from the annual consumption of jet fuel, the development of the NO_X emissions is also due to yearly variations in LTO's per aircraft type (earlier than 2001) and aircraft type city-pair statistics (from 2001 onwards).

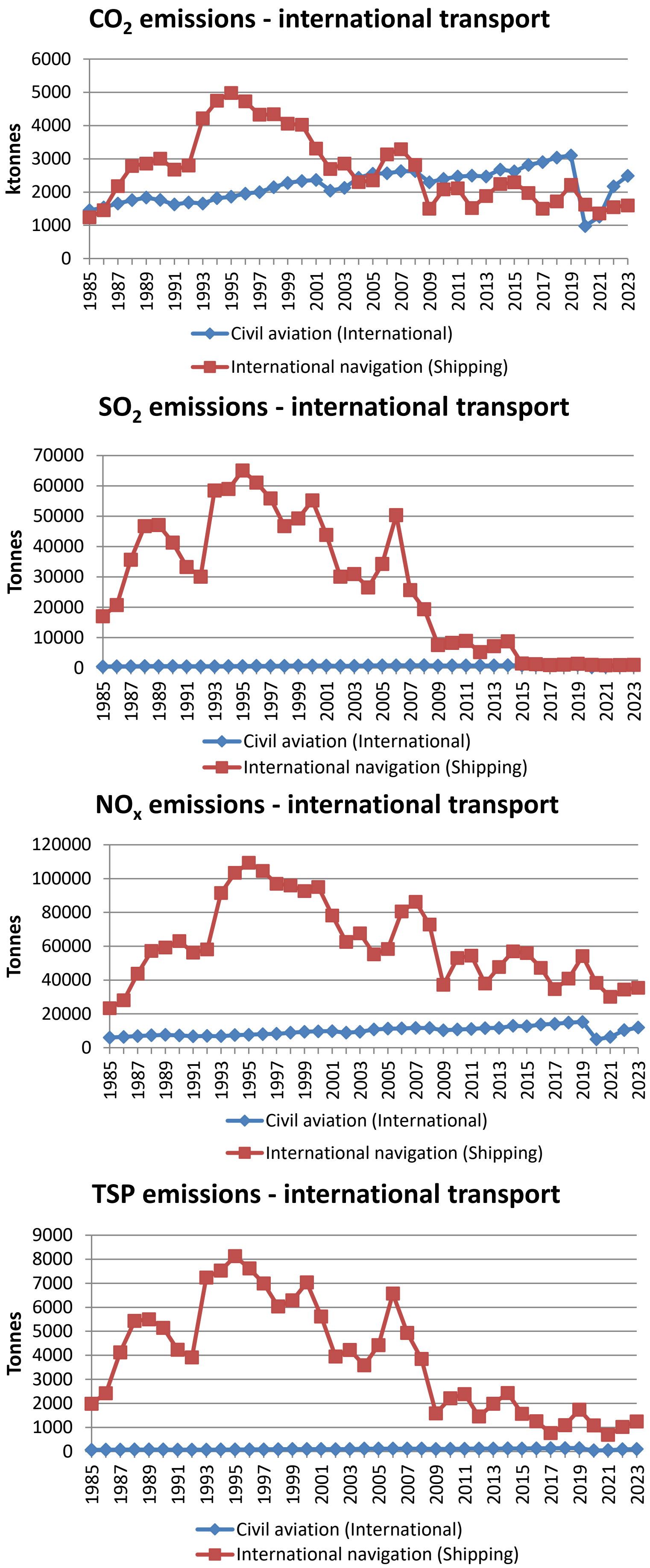


Figure 3.3.37 CO_2, SO_2, NO_X and TSP emissions for international transport 1985-2023.

3.3.2 Activity data, emission factors and calculation methodologies for Road Transport

For road transport, the detailed methodology (Tier 3) is used to make annual estimates of the Danish emissions, as described in the EMEP/EEA Air Pollutant Emission Inventory Guidebook (EMEP/EEA, 2024). The calculations are made with DEMOS-Road (Danish Emission model system for Mobile Sources) model developed at DCE, Aarhus University, using the European COPERT 5 model methodology (EMEP/EEA, 2024). In COPERT, fuel consumption and emission simulations can be made for operationally hot engines, taking into account gradually stricter emission standards and emission degradation due to catalyst wear. Furthermore, the emission effects of cold-start and evaporation are simulated.

Vehicle fleet and mileage data

Corresponding to the COPERT 5 fleet classification, DEMOS-Road groups all present and future vehicles in the Danish fleet into vehicle classes, subclasses and layers. The layer classification is a further division of vehicle subclasses into groups of vehicles with the same average fuel consumption and emission behaviour, according to EU emission legislation levels. Table 3.3.6 gives an overview of the different model classes and sub-classes, and all model layers are shown in Annex 3.B.1.

Fleet and annual mileage data are provided by DTU Transport for the vehicle categories present in COPERT 5 (Jensen, 2024). DTU Transport use data from the Danish vehicle register kept by Statistics Denmark. The vehicle register data consist of vehicle type (passenger cars, vans, trucks, buses, mopeds, motorcycles), fuel type, vehicle weight, gross vehicle weight, engine size (passenger cars registered from 2005+), Euro norm, NEDC type approval fuel efficiency value (passenger cars registered from 1997+) and vehicle first registration year. The Euro norm information is very complete in the Danish vehicle register for vehicle first registrations 2001 onwards for trucks and buses and 2011 onwards in the case of passenger cars and vans. For vehicles with no EU norm information, the EU norm is assigned, associated with the date for first registration (entry into service) listed in Table 3.3.7.

To establish engine size data for passenger cars registered before 2005, a weight class-engine size transformation key is used examined by COWI (2008) for new Danish cars from 1998. For the years before 1998, data for 1998 is used, and for the years 1999-2004, a linear interpolation between 1998 and 2005 weight class-engine size relations is used. For trucks, truck driver registration notes gathered by Statistics Denmark are used to split the fleet figures of ordinary trucks into number of solo trucks and truck-trailer combinations. Further, the registration notes make it possible to assume the average total vehicle weight of the truck trailer combination. For articulated trucks also, the registration notes make it possible to assume the average total vehicle weight of the full articulated truck.

Danish mileage data comes from the Danish Road Directorate based on the Danish vehicle inspection program. Total mileage per year and vehicle category are derived for the years 1985-2021, together with a more detailed mileage matrix examined for the year 2008 (based on detailed vehicle inspection data analysis). The detailed mileage matrix contains annual mileage per vehicle subcategory for new vehicles and for every vintage back in time, which determines the yearly mileage reduction percentages as a function of vehicle age. In a first step, the detailed mileage matrix is combined with corresponding fleet numbers to estimate intermediate total mileages for each year on a detailed fleet level. Next, each year's detailed (intermediate) mileage figures are scaled according to the difference between true and intermediate total mileage per vehicle subcategory.

DTU Transport (Jensen, 2024) also provides information of the mileage split between urban, rural and highway driving based on traffic monitoring data. The respective average speeds come from The Danish Road Directorate (e.g. Winther & Ekman, 1998). Additional data for the moped fleet and motorcycle fleet disaggregation is given by The National Motorcycle Association (Markamp, 2013) and supplementary moped stock information is obtained from The Danish Bicycle Traders Association (Johnsen, 2018) and Prince (2021).

In addition, data from a survey made by the Danish Road Directorate (Hansen, 2010) has given information of the total mileage driven by foreign cars, vans, coaches and trucks on Danish roads in 2009 and a follow-up survey in 2014 has given additional information. For trucks, the mileage contribution from foreign vehicles has been added to the total mileage on Danish roads for Danish truck-trailers and articulated trucks in two gross vehicle weight categories, < 40 tonnes and > 40 tonnes. The data has been further processed by DTU Transport; by using appropriate assumptions, the mileage have been backcasted to 1985 and forecasted to 2023.

Table 3.3.6 Model vehicle classes and sub-classes and trip speeds.

Vehicle classes	Fuel type	Engine size/weight	Trip speed [km per h] Urban	Rural	Highway
Passenger cars	Gasoline/Diesel/Plug-in hybrid	< 0.8 l.	40	70	100
Passenger cars	Gasoline/Diesel/Plug-in hybrid	0.8 - 1.4 l.	40	70	100
Passenger cars	Gasoline/Diesel/Plug-in hybrid	1.4 – 2 l.	40	70	100
Passenger cars	Gasoline/Diesel/Plug-in hybrid	> 2 l.	40	70	100
Passenger cars	2-stroke		40	70	100
Passenger cars	LPG		40	70	100
Passenger cars	CNG		40	70	100
Light commercial vehicles (LCV)	Gasoline/Diesel/LP/CNG/Plug-in hybrid	<1305 kg	40	65	80
Light commercial vehicles (LCV)	Gasoline/Diesel/LP/CNG/Plug-in hybrid	1305-1760 kg	40	65	80
Light commercial vehicles (LCV)	Gasoline/Diesel/LP/CNG/Plug-in hybrid	>1760 kg	40	65	80
Trucks	Gasoline		35	60	80
Trucks	Diesel/CNG	Rigid 3,5 - 7,5t	35	60	80
Trucks	Diesel/CNG	Rigid 7,5 - 12t	35	60	80
Trucks	Diesel/CNG	Rigid 12 - 14 t	35	60	80
Trucks	Diesel/CNG	Rigid 14 - 20t	35	60	80
Trucks	Diesel/CNG	Rigid 20 - 26t	35	60	80
Trucks	Diesel/CNG	Rigid 26 - 28t	35	60	80
Trucks	Diesel/CNG	Rigid 28 - 32t	35	60	80
Trucks	Diesel/CNG	Rigid >32t	35	60	80
Trucks	Diesel/CNG	TT/AT 14 - 20t	35	60	80
Trucks	Diesel/CNG	TT/AT 20 - 28t	35	60	80
Trucks	Diesel/CNG	TT/AT 28 - 34t	35	60	80
Trucks	Diesel/CNG	TT/AT 34 - 40t	35	60	80
Trucks	Diesel/CNG	TT/AT 40 - 50t	35	60	80
Trucks	Diesel/CNG	TT/AT 50 - 60t	35	60	80
Trucks	Diesel/CNG	TT/AT >60t	35	60	80
Urban buses	Gasoline		30	50	70
Urban buses	Diesel/CNG	< 15 tonnes	30	50	70
Urban buses	Diesel/CNG	15-18 tonnes	30	50	70
Urban buses	Diesel/CNG	> 18 tonnes	30	50	70
Coaches	Gasoline		35	60	80
Coaches	Diesel/CNG	< 15 tonnes	35	60	80
Coaches	Diesel/CNG	15-18 tonnes	35	60	80
Coaches	Diesel/CNG	> 18 tonnes	35	60	80
Mopeds	Gasoline		30	30	-
Motorcycles	Gasoline	2 stroke	40	70	100
Motorcycles	Gasoline	< 250 cc.	40	70	100
Motorcycles	Gasoline	250 – 750 cc.	40	70	100
Motorcycles	Gasoline	> 750 cc.	40	70	100

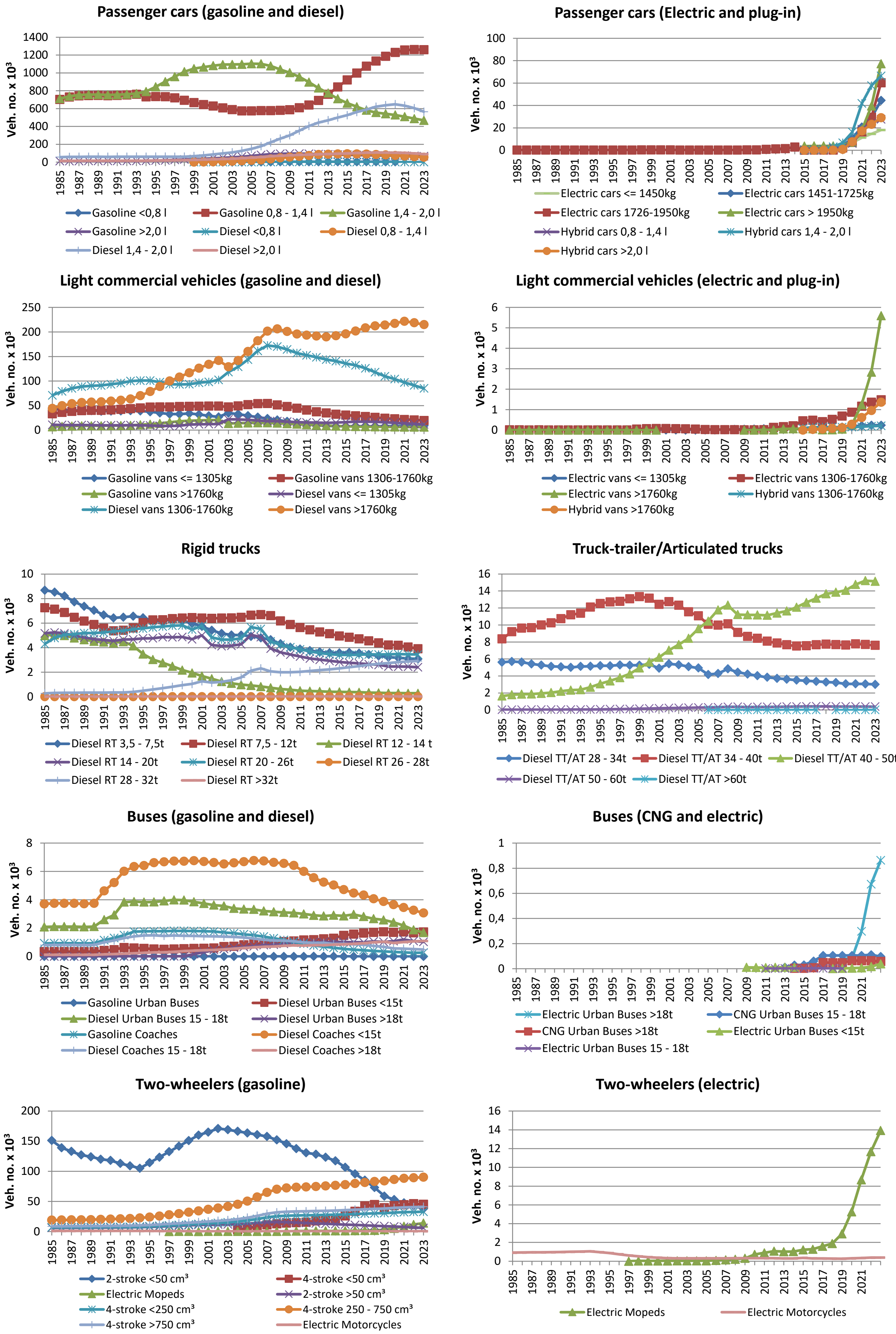


Figure 3.3.38 Number of vehicles in sub-classes in 1985-2023.

For passenger cars, the engine size differentiation is less certain for the years before 2005. The increase in the total number of passenger cars is mostly due to a growth in the number of diesel cars between 1.4 and 2 litres (from the 2000s up to now). Until 2005, there has been a decrease in the number of gasoline cars with an engine size between 0.8 and 1.4 litres. These cars, however, have also increased in numbers during the later years, while the number of 1.4-2 litres gasoline cars has decreased. Since the late 1990s, small cars (< 0.8 l gasoline and <1.4 l. diesel) has slowly begun to penetrate the fleet.

There has been a considerable growth in the number of diesel light-duty vehicles from 1985 to 2006; the number of vehicles has however decreased somewhat after 2006 due to the restructuring of car taxes that made it less advantageous buying vans for private use.

For the truck-trailer and articulated truck combinations, there is a tendency towards the use of increasingly fewer but larger trucks throughout the time periods. The decline in fleet numbers for many of the truck categories is due to the combined effects of the global financial crisis, the fleet shift towards fewer and larger trucks, international market competition (foreign transport companies are effectively gaining Danish market shares), and the reflagging of Danish commercial trucks to companies based in the neighbouring countries.

The sudden change in the level of urban bus and coach numbers from 1991 to 1995 is due to uncertain fleet data from Statistics Denmark.

The reason for the significant growth in the number of mopeds from 1994 to 2002 is the introduction of the so-called Moped 45 vehicle type. From 2004 onwards there is a switch from 2-stroke to 4-stroke in new sales for this vehicle category, and this gradually influences the composition of the total moped fleet. From 2017 onwards, there is a big increase in the number of electric mopeds, whereas the number of electric motorcycles has been quite stable for many years. The total number of motorcycles has grown throughout the 1990-2010 period and from 2012-2023.

The vehicle numbers are summed up in layers for each year (Figure 3.3.39:

$$N_{j,y} = \sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \qquad (1)$$

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

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

$$M_{j,y} = \frac{\sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \cdot M_{i,y}}{\sum_{i=FYear(j)}^{LYear(j)} N_{i,y}} \qquad (2)$$

Vehicle numbers and weighted annual mileages pr layer are shown in Annex 3.B.1 and 2.B.2 for 1985-2023. The trends in vehicle numbers per layer are also shown in Figure 3.3.39. The latter figure shows how vehicles complying with the gradually stricter EU emission levels (EURO 1-6, Euro I-VI etc.) have been introduced into the Danish motor fleet.

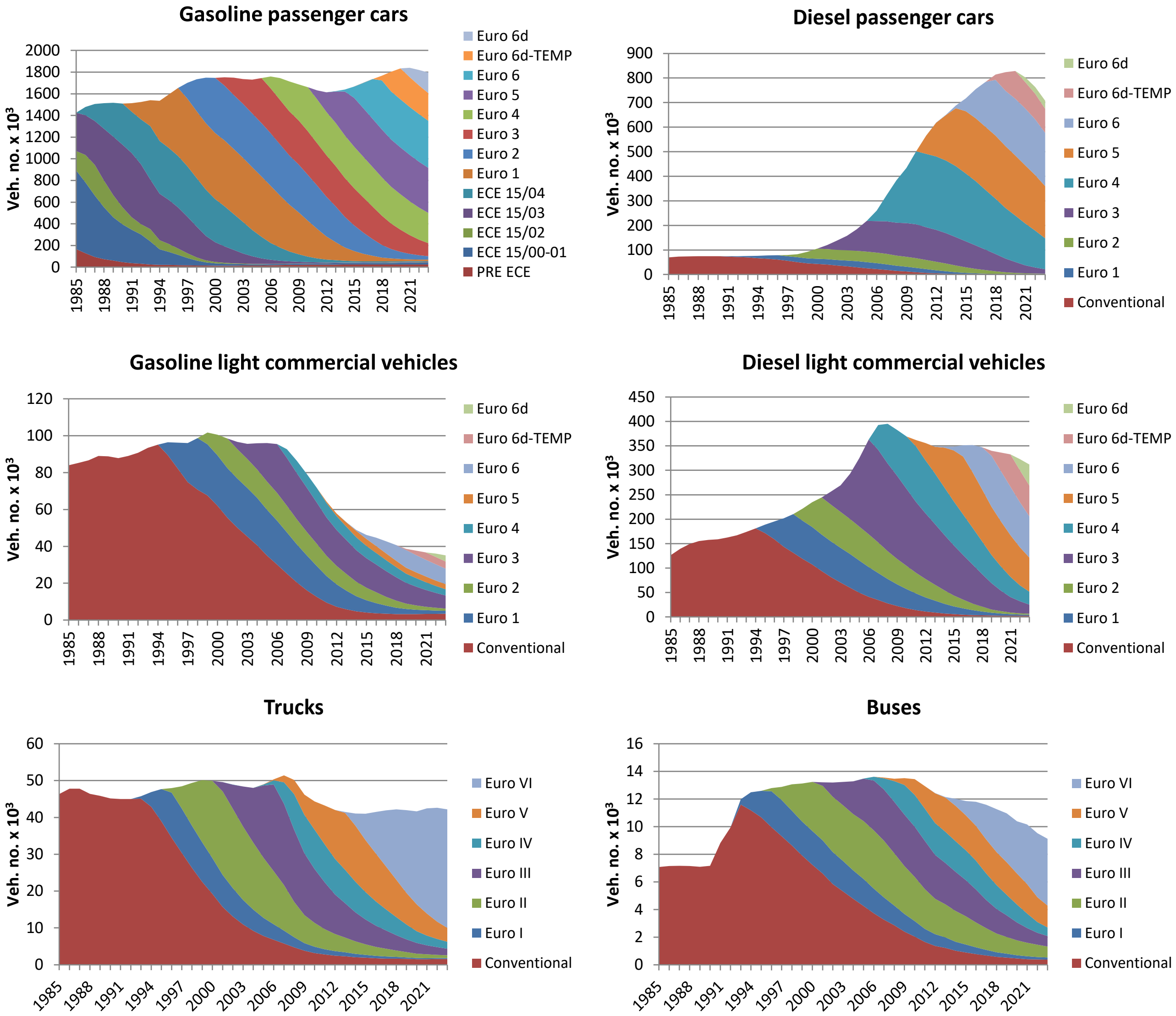


Figure 3.3.39 Layer distribution of vehicle numbers pr vehicle type in 1985-2023.

Emission legislation

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

The NEDC test cycle is not adequately describing real world driving behaviour, and consequently, for diesel cars and vans, there is an increasing mismatch between the step wise lowered EU emission limits the vehicles comply with during the NEDC test cycle, and the more or less constant emis-

[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.

sions from the same vehicles experienced during real world driving. In order to bridge this emission inconsistency gap, a new test procedure, the "World-Harmonized Light-Duty Vehicles Test Procedure" (WLTP), has been developed which simulates much more closely real world driving behaviour. The WLTP test procedure gradually take effect from 2017.

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

In the road transport emission model, compromise dates for enter into service of the Euro 6d-TEMP technology are set to 1 September 2018 and 1 September 2019, for diesel cars and vans, respectively. For Euro 6d, the enter into service dates are 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 must comply with the emission limit values agreed by the EU. An overview of the different emission layers in the road transport emission model and the corresponding EU emission directive numbers are given in Table 3.3.6. The specific emission limits are shown in Annex 2.B.3.

Table 4.2 shows the EU directive dates for new type approvals and the date for first registration (entry into service) of existing, previously type approved vehicle models. The latter date is used in the model for vehicles with no EU norm information given in the car register. In most cases the entry into service date used in the model is the same as the entry into service date specified by the EU directive.

For passenger cars and light commercial vehicles, the emission directives distinguish between three vehicle classes according to vehicle reference mass[5]: Passenger cars and light duty trucks (<1305 kg) have the same emission limits but different legislation dates. Light duty trucks (1305-1760 kg) and light duty trucks (>1760 kg) have the same legislation dates but different emission limits.

For heavy-duty vehicles (trucks and buses), the emission limits are given in g per kWh and the measurements are carried out for engines in a test bench, using the ECE R-49, EU ESC (European Stationary Cycle) and ETC (European Transient Cycle) test cycles, depending on the Euro norm and exhaust gas after-treatment system installed. For Euro VI and Euro VII engines the WHSC (World Harmonized Stationary Cycle) and WHTC (World Harmonized Transient Cycle) test cycles are used. For a description of the test cycles, see e.g. www.dieselnet.com.

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

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

Specific emission limits (Euro 7) for non-exhaust particulate emissions from brake wear and tyre wear are also comprised in EU directive 2024/1257. The emission limits are valid for new brake systems for different powertrain types and vehicle categories, and for tyres of different size classes. For further descriptions, see e.g. ICCT (2024).

For brake systems, as a first step, Euro 7 defines particulate matter limits for passenger cars and light commercial vehicles until the end of 2029. From 2030 onwards, the scope is extended to buses and trucks of categories M_2, M_3 and N_2, N_3. The emission limits will be defined for two time periods, from 2030-2034 and from 2035 onwards. To define the actual emission limits, the European Commission will submit an analysis by the end of 2027.

Brake particle emissions of brake systems for M_1 and N_1 vehicles are tested according to the UN Global Technical Regulation No. 24.8[6]. The type-approval is granted for the brake system, which can then be fitted to many vehicle models. The test procedure for heavy-duty vehicles is yet to be developed.

Tyres will be subject to type-approval testing to receive type approval for Euro 7. The test procedure and emission limits for tyre wear are under development at the United Nations Economic Commission for Europe (UNECE) and will amend the Euro 7 regulation. If a UNECE regulation is not adopted in time, the Commission is empowered to develop a tyre testing procedure and set limits instead.

Euro 7 requirements will apply to tyres of different classes at different times—first to C1 tyres (cars and LCV) from July 2028, then to C2 tyres (medium load heavy duty vehicles) from April 2030, and to C3 tyres (high load heavy duty vehicles) from April 2032. The introduction sequence is the same for all categories. In the first stage, Euro 7 applies to new tyre models that are type-approved for the first time. One year later, new vehicles put on the market must be equipped with Euro 7 type-approved tyres, and another year later, all tyres put on the market must comply with Euro 7 requirements.

In terms of the sulphur content in the fuels used by road transportation vehicles, the EU directive 2003/17/EF describes the fuel quality standards agreed by the EU. In Denmark, the sulphur content in gasoline and diesel was reduced to 10 ppm in 2005, by means of a fuel tax reduction for fuels with 10 ppm sulphur contents.

[6] United Nations Economic Commission for Europe, "Addendum 24: UN Global Technical Regulation No. 24 - Laboratory Measurement of Brake Emissions for Light-Duty Vehicles," Pub. L. No. ECE/TRANS/180/Add.24 (2023), https://unece.org/sites/default/files/2023-07/ECE-TRANS-180-Add.24.pdf.

Table 3.3.7 Overview of emission layers in the road transport emission model and the related EU emission directives.

Vehicle category	Emission layer	EU directive	Type approval	First registration date
Passenger cars (gasoline)	PRE ECE	-	-	<1970-
	ECE 15/00-01	70/220 - 74/290	1972[a]	1970[a]
	ECE 15/02	77/102	1981[b]	1979[b]
	ECE 15/03	78/665	1982[c]	1981[c]
	ECE 15/04	83/351	1987[d]	1986[d]
Passenger cars (diesel)	Conventional	-	-	<1991-
Passenger cars	Euro 1	91/441	1.7.1992[e]	1.1.1991[e]
	Euro 2	94/12	1.1.1996	1.1.1997
	Euro 3	98/69	1.1.2000	1.1.2001
	Euro 4	98/69	1.1.2005	1.1.2006
	Euro 5	715/2007(692/2008)	1.9.2009	1.1.2011
	Euro 6	715/2007(692/2008)	1.9.2014	1.9.2015
	Euro 6d-TEMP	2016/646	1.9.2017	1.9.2018
	Euro 6d	2016/646	1.1.2020	1.1.2021
	Euro 7	2024/1257	29.11.2026	29.11.2027
LCV < 1305 kg	Conventional	-	-	<1995
	Euro 1	91/441	1.10.1994	1.1.1995
	Euro 2	94/12	1.1.1998	1.1.1999
	Euro 3	98/69	1.1.2001	1.1.2002
	Euro 4	98/69	1.1.2006	1.1.2007
	Euro 5	715/2007(692/2008)	1.9.2010	1.1.2012
	Euro 6	715/2007(692/2008)	1.9.2015	1.9.2016
	Euro 6d-TEMP	2016/646	1.9.2018	1.9.2019
	Euro 6d	2016/646	1.1.2021	1.1.2022
	Euro 7	2024/1257	29.11.2026	29.11.2027
LCV 1305-1760 kg & > 1760 kg	Conventional	-	-	<1995
	Euro 1	93/59	1.10.1994	1.1.1995
	Euro 2	96/69	1.1.1998	1.1.1999
	Euro 3	98/69	1.1.2001	1.1.2002
	Euro 4	98/69	1.1.2006	1.1.2007
	Euro 5	715/2007	1.9.2010	1.1.2012
	Euro 6	715/2007	1.9.2015	1.9.2016
	Euro 6d-TEMP	2016/646	1.9.2018	1.9.2019
	Euro 6d	2016/646	1.1.2021	1.1.2022
	Euro 7	2024/1257	29.11.2026	29.11.2027
Heavy duty vehicles	Euro 0	88/77	1.10.1990	1.10.1990
	Euro I	91/542	1.10.1993	1.10.1993
	Euro II	91/542	1.10.1996	1.10.1996
	Euro III	1999/96	1.10.2000	1.10.2001
	Euro IV	1999/96	1.10.2005	1.10.2006
	Euro V	1999/96	1.10.2008	1.10.2009
	Euro VI	595/2009	1.1.2013	1.1.2014
	Euro VII	2024/1257	29.5.2028	29.5.2029
Mopeds	Conventional	-	-	-
	Euro I	97/24	2000	2000
	Euro II	2002/51	2004	2004
	Euro III	2002/51	2014[f]	2014[f]
	Euro IV	168/2013	2017	2017
	Euro V	168/2013	2021	2021
Motor cycles	Conventional		0	0
	Euro I	97/24	2000	2000
	Euro II	2002/51	2004	2004
	Euro III	2002/51	2007	2007

Continued				
	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. October 1990.

Fuel consumption and emission factors

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

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

The fuel consumption and emission factors used in DEMOS-Road come from the COPERT 5 model[7]. The source for these data is various European measurement programs. In general, the COPERT data are transformed into trip-speed dependent fuel consumption and emission factors for all vehicle categories and layers by using trip speeds as shown in Table 3.3.6. The factors are listed in Annex 3.B.4.

It should be noted that for PHEV (plug-in hybrid electric vehicles) cars and vans, the utility factor is set to 0.3, i.e. 30 % of total mileage is assumed to be battery driven, according to assumptions made by DEA (2023)[8]. The fuel consumption and emission factors for plug-in vehicles used in the Danish national emission inventories for road transport, and shown in the present NIR, only contain the part of fuel consumption and emissions related to the combustion of fossil fuel (gasoline) in the vehicles. The emissions related to the generation of the electricity used by battery electric vehicles and plug-in vehicles are included under stationary sources in the Danish emission inventories as prescribed by the UNFCCC reporting guidelines.

Adjustment for vehicle fuel efficiency

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

[7]For hydrogen fuel cell passenger cars and light commercial vehicles, hydrogen fuel cell and battery electric buses and trucks, and battery electric mopeds and motorcycles fuel consumption factor data are obtained from the HBEFA (Handbook of Emission Factors) model version 4.1 (e.g. Matzer et al., 2019).
[8] The electric driven mileage shares for Danish urban, rural and highway driving conditions are derived by weighing in electric driven mileage shares for urban, rural and highway driving conditions obtained from HBEFA.

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

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

In the Danish fleet and mileage database kept by DTU Transport, the type approval fuel efficiency value based on the NEDC driving cycle (TA_{NEDC}) is registered for each single car. In the fleet and mileage database, type approval fuel efficiency values based on the WLTP driving cycle is converted into TA_{NEDC} values by using conversion factors from NEDC to WLTP established by JRC (2017).

Further, DTU Transport calculates a modified fuel efficiency value (FC_{inuse}) with the calculation function provided by COPERT 5 that better reflects the fuel consumption in real ("inuse") traffic conditions.

The FC_{inuse} function uses TA_{NEDC}, vehicle weight, engine size and regression coefficients by first registration year, as input parameters (EMEP/EEA, 2024). For each new registration year, i, fuel type, f, and engine size, k, number based average values of TA_{NEDC} and FC_{inuse} are summed up and referred to as $\overline{TA_{NEDC}}(i,f,k)$ and $\overline{TA_{inuse}}(i,f,k)$. For vehicle new registrations after 2014, regression coefficients are used for 2014.

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

To obtain $\overline{FC_{inuse}}(i,f,k)$ values for vehicle new registrations 2015-2022, the $\overline{FC_{inuse}}(i,f,k)$ values for 2014 are adjusted for the years 2015-2022[9] with an index function (indexed from 2014), C_{ICCT} (i, f), based on the reported ICCT fuel gap figures by fuel type for the new registration years 2014-2022.

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

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

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

[9] The ICCT monitoring report include new cars up to 2017. For new cars from 2018-2023, fuel gap figures are used for cars from 2017.
[10] The factors are derived from the Common Artemis Driving Cycle (CADC), with a 1/3 weight for each of the urban, rural and highway parts of CADC.

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

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

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 (2024b).

Adjustment for EGR, SCR and particle filters

In COPERT 5, emission factors are available for Euro V heavy duty vehicles using exhaust gas recirculation (EGR) and selective catalyst reduction (SCR) exhaust emission aftertreatment systems, respectively. The estimated new sales of Euro V diesel trucks equipped with EGR and SCR during the 2006-2010 time periods has been examined by Hjelgaard and Winther (2011). These inventory fleet data are used in the Danish inventory to calculate weighted emission factors for Euro V trucks in different size categories.

In 2008-2010, environmental zones have been introduced in the four largest Danish cities in order to bring down the particulate emissions from diesel fuelled heavy duty vehicles. Driving in these environmental zones prescribe the use of diesel particulate filters.

The Danish EPA has estimated the number of Euro I-III urban buses and Euro II-III trucks and tourist buses, which have been retrofitted with filters to fulfil the emission requirements in these environmental zones (Winther, 2011). It is assumed that the retrofitted filters are wall-flow diesel particle filters (DPF), and the particulate emissions from these retrofitted vehicles are effectively the same as the particulate emissions from Euro V vehicles all with preinstalled DPF's.

In 2009, a levy was introduced on light diesel vehicles without particle filters. To avoid this levy, many older diesel cars and vans have been retrofitted with open particle filters (also named free-flow or particle oxidation catalysts), regarded as the only technically feasible solution in this case. The particle emissions for these vehicles are expected to be 30 % lower than the particle emissions from the same Euro technology with no retrofitted filter.

In addition, since 2006, economical incitements have been given to private vehicle owners to buy Euro 4 diesel passenger cars and vans with preinstalled closed (wall-flow) diesel particle filters (DPF). The particulate emissions from these vehicles are like the particulate emissions for Euro 5 vehicles all with preinstalled DPF's.

From the Danish vehicle register, information exists of the number of diesel passenger cars and vans equipped with particle filters, no information is however, available on filter type.

The inventories assume that particle filter registered pre-Euro 4 vehicles have been retrofitted with open particle filters, and PM emission factors are reduced by 30 % compared to the PM emission factors from the same Euro technology with no retrofitted filter.

It is also assumed that all filter registered Euro 4 vehicles come with preinstalled DPFs, and PM emission factors are like the PM emission factors for Euro 5 vehicles. Although a few Euro 4 vehicles may be retrofitted with open particle filters, it's impossible to distinguish between filter types from vehicle register data. Nonetheless, any error introduced in the calculations under this assumption is very small.

The particle emission data for vehicles with filter installed are included in the Danish inventory by assuming that the particle emission factors for pre-Euro 4 vehicles (these vehicles are equipped with free-flow filters) are lowered by 30 % compared with the emission factors from the same Euro technology with no filter installed. For Euro 4 vehicles (these vehicles have DPF installed) the particle emission factors for Euro 5 vehicles are used in the emission inventories.

For all vehicle categories/technology levels not represented by measurements, the emission factors are produced by using reduction factors. The latter factors are determined by assessing the EU emission limits and the relevant emission approval test conditions, for each vehicle type and Euro class.

Adjustment for Euro 5 diesel passenger cars

In COPERT 5 emission factors are available for those Euro 5 diesel passenger cars for which engine control software has been installed to reduce the emissions, because of the diesel scandal.

The Euro 5 vehicles in question were brought to vehicle workshops during the vehicle recall program from 2016-2018. A short description of the recall program and the cars included is given below:

- Engine software was updated in 70,946 cars, evenly shared by 1/3 in each of the years 2016-2018
- Vehicle first registration years of the updated cars were between 2009-2016
- Engine sizes of the updated cars were < 1.4 l (9 %) and 1.4-2 l (91 %)

In DEMOS-Road, the fleet attributes for each year were distributed into first registration year-engine size categories, according to their fleet shares in the respective first registration year-engine size categories.

The number of included cars in the software update program was provided by the Danish Safety Technology Authority (Bonde, 2021) and engine size and model year information was provided by Volkswagen (Hjortshøj, 2021).

Adjustment for biofuel usage

A literature review carried out in the Danish research project REBECA revealed no significant changes in emission factors between neat gasoline and E5 gasoline-ethanol blends for the combustion related emission components; NO_x, CO and VOC (Winther et al., 2012). Hence, due to the current low ethanol content in today’s road transport gasoline, no modifications of the neat gasoline based COPERT emission factors are made in the inventories to account for ethanol usage.

REBECa results published by Winther (2009) have shown that the emission impact of using diesel-biodiesel blends is very small at low biodiesel blend ratios. Consequently, no biofuel emission factor adjustments are needed for diesel vehicles as well. However, adjustment of the emission factors for diesel vehicles will be made if the biodiesel content of road transport diesel fuel increases to a more significant level in the future.

Adjustment for deterioration

For Euro 1-7 gasoline and diesel[11] fuelled cars and vans, the emissions of NO_X, NMVOC and CO gradually increase due to catalyst wear and are, therefore, modified as a function of total mileage. Even though the emission curves may be serrated for the individual vehicles, on average, the emissions from catalyst cars stabilize after a given cut-off mileage is reached due to OBD (On Board Diagnostics) and the Danish inspection and maintenance programme.

For each year, y, and pollutant, i, the deterioration factors are calculated per first registration year, k, for each vehicle in layer j, by using deterioration coefficients and cut-off mileages, as given in EMEP/EEA (2024), for the corresponding layer j.

These deterioration factors are given by the equation:

$$DF_{k,i,j,y} = A_{i,j} \cdot MC_{k,i,j,y} + B_{i,j} \quad (3)$$

where,

DF = the deterioration factor for a given cumulated mileage, MC, and pollutant i,

MC = the cumulated mileage of vehicles for which the correction is applied,

A_j = the degradation of the emission performance per kilometre for layer j,

B_j = the emission level of a fleet of brand-new vehicles for layer j.

Secondly, the aggregated deterioration factors per layer, are calculated by considering vehicle numbers and annual mileage levels per first registration year:

$$\mathrm{D}F_{i,j,y} = \frac{\sum_{k=FYear(j)}^{LYear(j)} DF_{k,i,y} \cdot N_{k,y} \cdot M_{k,y}}{\sum_{k=FYear(j)}^{LYear(j)} DF_{k,i,y} \cdot N_{k,y}} \quad (4)$$

For N_2O and NH_3, COPERT 5 includes emission deterioration as a linear function of mileage for gasoline fuelled EURO 1-7 passenger cars and light duty vehicles. The level of emission deterioration also relies on the content of sulphur in the fuel. The deterioration coefficients are given in EMEP/EEA (2024), for the corresponding layer. A cut-off mileage of 250 000 km is behind the calculation of the modified emission factors, and for the Danish situation the low sulphur level interval is assumed to be most representative. The deterioration factors are shown in Annex 3.B.6 for 2023.

Calculation of emissions and fuel consumption for hot engines

Emissions and fuel consumption results for operationally hot engines are calculated in DEMOS-Road for each year, layer and road type. DEMOS-

[11] For Euro 1 diesel cars and vans, adjustments due to wear only relate to NMVOC.

Road uses the COPERT V detailed calculation methodology. The calculation procedure is to combine fuel consumption and emission factors (and deterioration factors for catalyst vehicles), number of vehicles, annual mileage levels and the relevant road-type shares given in Table 3.3.6. For non-catalyst vehicles this yields:

$$E_{j,k,y} = EF_{j,k,y} \cdot S_k \cdot N_{j,y} \cdot M_{j,y} \quad (5)$$

Here E = fuel consumption/emission, EF = fuel consumption/emission factor, S = road type share and k = road type.

For catalyst vehicles the calculation becomes:

$$E_{j,k,y} = DF_{j,k,y} \cdot EF_{j,k,y} \cdot S_k \cdot N_{j,y} \cdot M_{j,y} \quad (6)$$

Calculation of extra emissions and fuel consumption for cold engines

For cars and vans, extra emissions of NO_x, VOC, CH_4, CO, PM, N_2O, NH_3 and fuel consumption from cold start are calculated separately in DEMOS-Road, using the detailed calculation methodology and cold start emission factors from COPERT 5. For SO_2 and CO_2, the extra emissions are derived from the cold start fuel consumption results.

Each trip is associated with cold-start emissions that is assumed to occur during urban driving conditions. The number of trips is distributed evenly across the months. First, cold emission factors are calculated as the hot emission factor times the cold:hot emission ratio. Secondly, the extra emission factor during cold start is found by subtracting the hot emission factor from the cold emission factor. Finally, this extra factor is applied on the part of the total mileage driven during cold start for all vehicles in the specific layer.

The cold:hot ratios depend on the average trip length and the monthly ambient temperature distribution. The Danish temperatures for 2023 are given in Rubek (2024). For previous years, temperature data are taken from similar reports available from The Danish Meteorological Institute (www.dmi.dk).

The cold:hot ratios are equivalent for gasoline fuelled passenger cars and vans, and for diesel passenger cars and vans, respectively, see EMEP/EEA (2024).

For conventional gasoline (pre-Euro 1) and pre-Euro 6 diesel vehicles the extra emissions become:

$$CE_{j,y} = \beta \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr - 1) \quad (7)$$

Where CE is the cold extra emissions, β = cold driven fraction, CEr = Cold:Hot ratio.

For gasoline Euro 1-5 catalyst vehicles, the cold:hot ratio is also trip speed dependent. The ratio is, however, unaffected by catalyst wear. The Euro I cold:hot ratio is used for all Euro 1-5 catalyst technologies. However, to comply with the gradually stricter Euro 2-5 emission standards, the catalyst light-off temperature must be reached in even shorter periods of time for newer EURO 2-5 standards. Correspondingly, the β-factor for Euro 1 gasoline vehicles is reduced stepwise for Euro 2, 3, 4 and 5, with the β-reduction factor, β_{red}.

For gasoline Euro 1-5 catalyst vehicles, the cold extra emissions are found from:

$$CE_{j,y} = \beta_{red} \cdot \beta_{Euro\ 1} \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr_{Euro\ 1} - 1) \quad (8)$$

where β_{red} = the β reduction factor for Euro 2-5.

For Euro 6 and Euro 7 vehicles, the cold extra emissions are found from:

$$CE_{j,y} = \beta_{red,Euro\ 6} \cdot \beta \cdot N_{Euro\ 6,y} \cdot M_{Euro\ 6,y} \cdot EF_{U,Euro\ 6,y} \cdot (CEr_{Euro\ 6} - 1) \quad (9)$$

For CH_4, specific emission factors for cold driven vehicles are included in COPERT 5. The β and β_{red} factors for VOC are used to calculate the cold driven fraction for each relevant vehicle layer. The NMVOC emissions during cold start are found as the difference between the calculated results for VOC and CH_4.

For N_2O and NH_3, specific cold start emission factors are also proposed by COPERT 5. For catalyst vehicles, however, just like in the case of hot emission factors, the emission factors for cold start are functions of cumulated mileage (emission deterioration). The level of emission deterioration also relies on the content of sulphur in the fuel. The deterioration coefficients are given in EMEP/EEA (2024), for the corresponding layer. For cold start, the cut-off mileage and sulphur level interval for hot engines are used, as described in the deterioration factors paragraph.

Cold start emissions from diesel fueled heavy duty trucks are also estimated in DEMOS-Road using the COPERT V methodology. The calculations include the emission components of NO_x, CO and VOC, and consider Euro V, Euro VI and Euro VII trucks of all size categories.

For these vehicle layers, j, each trip is associated with cold start over emissions, and the cold start emissions are assumed to be evenly distributed across urban, rural and highway driving conditions and all months during the year, y.

The extra emissions during cold start are calculated with the following equation:

$$CECOLD_{i,j,y} = \beta_{j,y} \cdot N_{j,y} \cdot M_{j,y} \cdot eCOLD_{i,j} \quad (10)$$

Where

$ECOLD_{i,j}$ = cold-start emissions of pollutant i, produced by vehicle layer j.

$eCOLD_{i,j}$ = cold-start emissions per km of pollutant i produced by vehicle layer j.

$\beta_{j,y}$ = fraction of mileage driven with a cold engine for vehicle of layer j in year y,

$N_{j,y}$ = number of vehicles of layer j,

$M_{j,y}$ = total annual mileage per vehicle of layer j in year y

The beta parameter is calculated as a function of the yearly average trip length for vehicles of layer j, ($ltrip_{j,y}$) with the assumption that the driving distance with a cold engine of a heavy-duty vehicle is 8.25 km. Hence the β = fraction is calculated as follows:

$$\beta_{j,y} = 8.25/ltrip_{j,y} \quad (11)$$

Data for average trip lengths for trucks of different size categories are provided by Statistics Denmark (2024) for all inventory years.

The cold emission factor depends on the vehicle speed and the monthly ambient temperature distribution, and is calculated for each vehicle layer, j, and emission component, i, as follows:

$$eCOLD_{i,j,y} = A_{i,j} \cdot V + B_{i,j} \cdot ta + C_{i,j} \quad (12)$$

Where:

A, B, C = Regression coefficients for emission component i, and layer y

V = vehicle speed (km/h)

ta = ambient temperature (degrees Celsius)

Calculation of evaporative emissions from gasoline vehicles

For each year, evaporative emissions of hydrocarbons are calculated for hot and warm running loss, hot and warm soak and diurnal evaporation. The calculations in DEMOS-Road follow the Tier 2 approach in COPERT 5. The basic emission factors are season related (predefined by four ambient temperature intervals), for Danish climate conditions the temperature intervals [-5, 10], [0, 15] and [10, 25] ^{o}C are used. The emission factors are shown in more details in EMEP/EEA (2024).

Running loss emissions originate from vapour generated in the fuel tank while the vehicle is running. The distinction between hot and warm running loss emissions depends on engine temperature, i.e. the engine being either hot or cold. The emissions are calculated as annual mileage (broken down into cold and hot mileage totals using the β-factor) times the respective emission factors. For vehicles equipped with evaporation control (catalyst cars) only hot running loss emissions occur.

$$E_{j,y}^{R} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot ((1-\beta) \cdot HR + \beta \cdot WR) \quad (13)$$

Where E^R is running loss emissions, l_{trip} = the average trip length, and HR and WR are the hot and warm running loss emission factors, respectively.

Hot and warm soak emissions also occur for carburettor vehicles (no evaporation control), whereas for catalyst cars (evaporation control) only hot soak emissions occur. The soak emissions are calculated as number of trips (broken down into cold and hot trip numbers using the β-factor) times respective emission factors:

$$E_{j,y}^{S} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot ((1-\beta) \cdot HS + \beta \cdot WS) \quad (14)$$

Where E^S is the soak emission, l_{trip} = the average trip length, and HS and WS are the hot and warm soak emission factors, respectively.

Average maximum and minimum temperatures pr month are used in combination with diurnal emission factors to estimate the diurnal emissions from both carburettor and catalyst vehicles E^D:

$$E_{j,y}^{D} = 365 \cdot N_{j,y} \cdot e^{D} \tag{15}$$

Each year's total is the sum of each layer's running loss, soak loss and diurnal emissions.

Calculation of non-exhaust particulate emissions from road transport

The TSP, PM_{10}, $PM_{2.5}$, BC, heavy metal and PAH emissions arising from tyre and brake wear (SNAP 0707), and the TSP, PM_{10}, $PM_{2.5}$ and heavy metal emissions from road abrasion (SNAP 0708) are estimated as prescribed by the UNECE convention reporting format. The emissions are calculated in DEMOS-Road by multiplying the total annual mileage per vehicle category with the correspondent average emission factors for each source type. The calculation procedure is consistent with the COPERT 5 model approach used in DEMOS-Road to estimate the Danish national emissions coming from exhaust.

TSP tyre wear emission factors (mg/vkm) for different vehicle categories are taken from EMEP/EEA (2024). These tyre wear emission factors are further differentiated according to urban, rural and highway driving using relative trip speed correction functions from EMEP/EEA (2024).

From EMEP/EEA (2024) one gets that 60 % and 42 % of tyre wear TSP is emitted as PM_{10} and $PM_{2.5}$, respectively, thus enabling the calculation of PM_{10} and $PM_{2.5}$ emission factors (mg/vkm).

For brake wear and road abrasion the emission factors (mg/vkm) also come from EMEP/EEA (2024). The PM_{10} and $PM_{2.5}$ fractions of emitted TSP are 0.98 and 0.39 for brake wear, respectively, and 0.5 and 0.27 for road abrasion, respectively. The emission factors and total emissions for 2023 are shown in Annex 3.B.15. For all three non-exhaust sources, the non-exhaust emission factors for heavy metals are estimated using the content of heavy metals in worn material (emitted as TSP) given in EMEP/EEA (2024).

Energy balance between inventory and sales

The calculated fuel consumption in DEMOS-Road must equal the statistical fuel sale totals according to the UNFCCC and UNECE emissions reporting format. The statistical fuel sales for road transport are derived from the Danish Energy Authority data (see DEA, 2024).

For gasoline, the DEA sales data for road transport are adjusted at first, to account for e.g. non-road and recreational craft fuel consumption, which are not directly stated in the statistics. Please refer to paragraph 3.3.3 for further information regarding the transformation of DEA fuel data. Next, the fuel and emission results for all gasoline vehicles are scaled with the percentage difference between the bottom-up gasoline fuel consumption on Danish roads and total gasoline fuel sold.

For diesel, the DEA sales data for road transport are adjusted at first, to account for recreational craft fuel consumption, which are not directly stated in the statistics.

The DEA data for diesel consist of fuel sold in Denmark and used on Danish roads and fuel sold in Denmark and used abroad (diesel border sales). The latter diesel fuel contribution is estimated by the Danish Ministry of Taxation based on studies on fuel price differences across borders, fuel discount for haulage contractors and fuel tanking behavior of truck and bus operators as well as private cars (see e.g. the Danish Ministry of Taxation, 2015).

The diesel border sales (diesel used abroad) is allocated to truck-trailer and articulated trucks (TT/AT trucks) in two total vehicle weight categories, < 40 tonnes and > 40 tonnes, and coaches.

The distribution of the diesel used abroad is split into the three vehicle categories by using the relative fuel consumption used in Denmark by foreign TT/AT trucks (< 40 tonnes and > 40 tonnes) and coaches (calculated based on mileage driven in Denmark by foreign trucks (paragraph 3.3.2) and corresponding fuel consumption factors).

The calculated "border" scaling factors of the TT/AT trucks and coaches in the model, i.e. the ratio between the total model fuel consumption (model fuel consumption in Denmark and model fuel consumption abroad) and the model fuel consumption in Denmark for these vehicle categories are shown in (Figure 3.3.25).

The total model fuel consumption for all vehicle categories is subsequently calculated in a first step, as the product of fuel consumption factors and corresponding total mileage, the latter being adjusted for mileage driven outside Denmark, as described above in the case of TT/AT trucks and coaches (adjusted bottom-up diesel fuel consumption).

Next, the percentage difference between the first step model diesel fuel consumption (adjusted bottom-up diesel fuel consumption) and the total diesel fuel sold in Denmark is used to scale fuel and emission results for all diesel vehicles regardless of vehicle category (Figure 3.3.26). The data behind the Figures 3.3.25 and 3.3.26 are also listed in Annex 3.B.8.

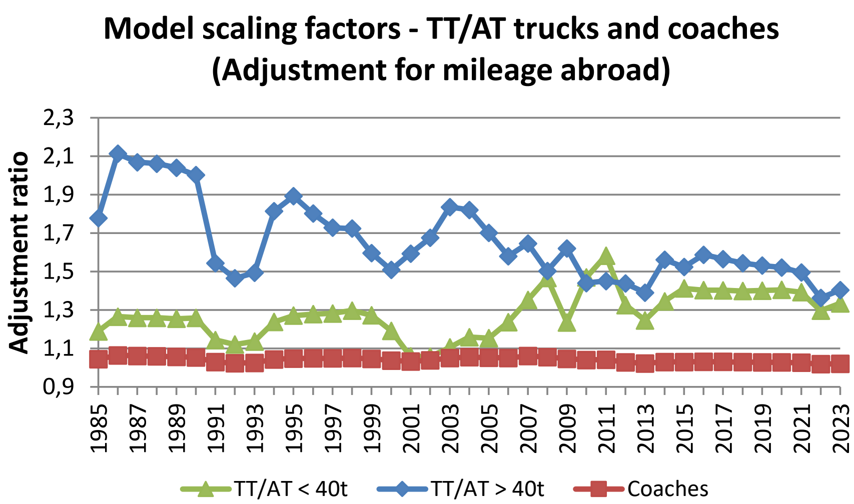


Figure 3.3.40 Fuel and emission adjustment ratios for TT/AT trucks and coaches: Bottom-up fuel consumption plus diesel used abroad vs bottom-up fuel consumption.

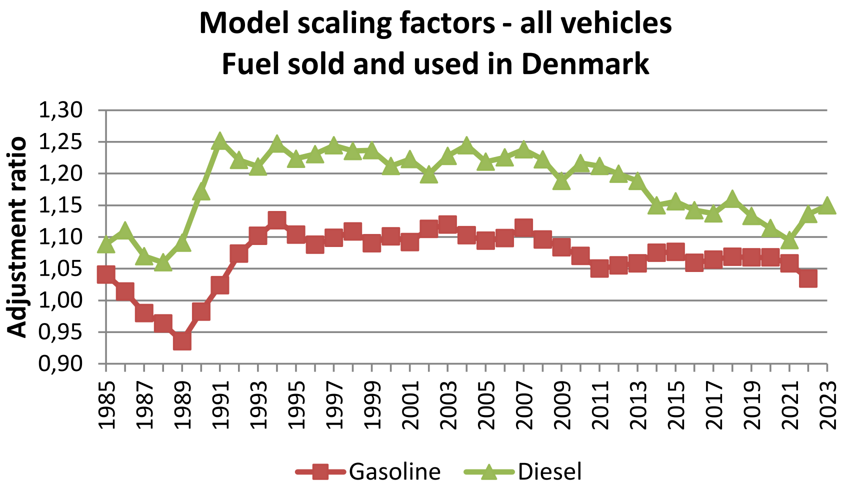


Figure 3.3.41 Gasoline and diesel fuel ratios (fuel and emission adjustment factors) regardless of vehicle category: Fuel sold and used in Denmark vs bottom-up fuel consumption used in Denmark

The reasons for the differences between DEA sales figures and bottom-up fuel estimates shown in Figure 3.3.41 are mostly due to a combination of the uncertainties related to COPERT 5 fuel consumption factors, allocation of vehicle numbers in sub-categories, annual mileage, trip speeds and mileage splits for urban, rural and highway driving conditions.

The final fuel consumption and emission factors are shown in Annex 3.B.7 for 1985-2023. The total fuel consumption and emissions are shown in Annex 3.B.8, pr vehicle category and as grand totals, for 1985-2023 (and NFR format in Annex 3.B.16. In Annex 3.B.15, fuel consumption and emission factors as well as total emissions are given in CollectER format for 2023.

In Table 3.3.8, the aggregated emission factors for SO_2, NO_X, NMVOC, CO, NH_3, TSP and BC are shown in CollectER format for Danish road transport.

Table 3.3.8 Fuel-based emission factors for SO_2, NO_X, NMVOC, CO, NH_3, TSP & BC for road transport in Denmark (2023).

SNAP ID	Category	Mode	Fuel type	Emission factors[1] [g pr GJ]								
				Tier level	CH_4 % of VOC	SO_2	NO_X	NMVOC	CO	NH_3	TSP	BC
070101	Passenger cars	Highway	Bio CNG	Tier 3	62.6	0.00	5.58	9.83	201.11	9.54	0.55	0.08
070101	Passenger cars	Highway	Bio ethanol	Tier 3	20.1	0.00	47.56	10.98	454.84	16.42	0.30	0.05
070101	Passenger cars	Highway	Biodiesel	Tier 3	0.4	0.00	234.41	1.79	11.45	2.32	1.23	0.98
070101	Passenger cars	Highway	CNG	Tier 3	62.6	0.00	5.58	9.83	201.11	9.54	0.55	0.08
070101	Passenger cars	Highway	Diesel	Tier 3	0.4	0.47	234.41	1.79	11.45	2.32	1.23	0.98
070101	Passenger cars	Highway	Gasoline	Tier 3	20.1	0.46	47.56	10.98	454.84	16.42	0.30	0.05
070101	Passenger cars	Highway	LPG	Tier 3	6.0	0.00	260.57	43.73	1050.86	8.53	0.57	0.08
070102	Passenger cars	Rural	Bio CNG	Tier 3	50.5	0.00	9.24	10.87	115.42	4.10	0.58	0.09
070102	Passenger cars	Rural	Bio ethanol	Tier 3	14.4	0.00	50.72	13.55	352.59	8.68	0.30	0.05
070102	Passenger cars	Rural	Biodiesel	Tier 3	0.5	0.00	213.43	2.21	24.22	2.46	1.08	0.85
070102	Passenger cars	Rural	CNG	Tier 3	50.5	0.00	9.24	10.87	115.42	4.10	0.58	0.09
070102	Passenger cars	Rural	Diesel	Tier 3	0.5	0.47	213.43	2.21	24.22	2.46	1.08	0.85
070102	Passenger cars	Rural	Gasoline	Tier 3	14.4	0.46	50.72	13.55	352.59	8.68	0.30	0.05
070102	Passenger cars	Rural	LPG	Tier 3	6.5	0.00	304.74	72.93	383.28	4.08	0.70	0.09
070103	Passenger cars	Urban	Bio CNG	Tier 3	34.5	0.00	17.50	13.40	113.88	2.11	0.37	0.05
070103	Passenger cars	Urban	Bio ethanol	Tier 3	5.6	0.00	64.15	103.68	1310.77	2.59	0.24	0.04
070103	Passenger cars	Urban	Biodiesel	Tier 3	2.4	0.00	215.02	4.07	54.41	1.66	2.06	1.22
070103	Passenger cars	Urban	CNG	Tier 3	34.5	0.00	17.50	13.40	113.88	2.11	0.37	0.05
070103	Passenger cars	Urban	Diesel	Tier 3	2.4	0.47	215.02	4.07	54.41	1.66	2.06	1.22
070103	Passenger cars	Urban	Gasoline	Tier 3	5.6	0.46	64.15	103.68	1310.77	2.59	0.24	0.04
070103	Passenger cars	Urban	LPG	Tier 3	2.9	0.00	194.84	226.74	939.46	2.93	0.60	0.08
070201	Light duty vehicles	Highway	Bio CNG	Tier 3	48.8	0.00	7.81	12.32	138.64	6.60	0.58	0.09
070201	Light duty vehicles	Highway	Bio ethanol	Tier 3	28.4	0.00	75.90	6.12	334.13	13.67	0.26	0.04
070201	Light duty vehicles	Highway	Biodiesel	Tier 3	0.3	0.00	298.46	4.08	16.86	1.94	1.81	1.42
070201	Light duty vehicles	Highway	CNG	Tier 3	48.8	0.00	7.81	12.32	138.64	6.60	0.58	0.09
070201	Light duty vehicles	Highway	Diesel	Tier 3	0.3	0.47	298.46	4.08	16.86	1.94	1.81	1.42
070201	Light duty vehicles	Highway	Gasoline	Tier 3	28.4	0.46	75.90	6.12	334.13	13.67	0.26	0.04
070201	Light duty vehicles	Highway	LPG	Tier 3	1.4	0.00	350.03	175.55	642.17	0.00	0.65	0.07
070202	Light duty vehicles	Rural	Bio CNG	Tier 3	34.6	0.00	10.25	14.09	108.06	2.69	0.57	0.09
070202	Light duty vehicles	Rural	Bio ethanol	Tier 3	19.2	0.00	68.54	9.08	261.16	7.59	0.21	0.03
070202	Light duty vehicles	Rural	Biodiesel	Tier 3	0.6	0.00	283.80	4.40	14.23	2.01	1.44	1.10
070202	Light duty vehicles	Rural	CNG	Tier 3	34.6	0.00	10.25	14.09	108.06	2.69	0.57	0.09
070202	Light duty vehicles	Rural	Diesel	Tier 3	0.6	0.47	283.80	4.40	14.23	2.01	1.44	1.10
070202	Light duty vehicles	Rural	Gasoline	Tier 3	19.2	0.46	68.54	9.08	261.16	7.59	0.21	0.03
070202	Light duty vehicles	Rural	LPG	Tier 3	2.4	0.00	371.20	152.49	375.36	0.00	0.68	0.08
070203	Light duty vehicles	Urban	Bio CNG	Tier 3	25.4	0.00	18.03	14.42	114.19	1.38	0.37	0.06
070203	Light duty vehicles	Urban	Bio ethanol	Tier 3	6.4	0.00	60.58	71.07	1494.33	1.76	0.17	0.03
070203	Light duty vehicles	Urban	Biodiesel	Tier 3	1.4	0.00	270.38	6.60	20.30	1.43	2.52	1.78
070203	Light duty vehicles	Urban	CNG	Tier 3	25.4	0.00	18.03	14.42	114.19	1.38	0.37	0.06
070203	Light duty vehicles	Urban	Diesel	Tier 3	1.4	0.47	270.38	6.60	20.30	1.43	2.52	1.78
070203	Light duty vehicles	Urban	Gasoline	Tier 3	6.4	0.46	60.58	71.07	1494.33	1.76	0.17	0.03
070203	Light duty vehicles	Urban	LPG	Tier 3	1.4	0.00	216.73	355.19	762.90	0.00	0.57	0.06
070301	Heavy duty vehicles	Highway	Bio CNG	Tier 3	132.2	0.00	27.16	-8.26	46.77	0.68	0.38	0.06
070301	Heavy duty vehicles	Highway	Bio ethanol	Tier 3	3.6	0.00	723.71	291.12	434.80	0.31	0.00	0.00
070301	Heavy duty vehicles	Highway	Biodiesel	Tier 3	16.9	0.00	45.03	2.58	22.27	0.92	0.72	0.34
070301	Heavy duty vehicles	Highway	CNG	Tier 3	132.2	0.00	27.16	-8.26	46.77	0.68	0.38	0.06
070301	Heavy duty vehicles	Highway	Diesel	Tier 3	16.9	0.47	45.03	2.58	22.27	0.92	0.72	0.34
070301	Heavy duty vehicles	Highway	Gasoline	Tier 3	3.6	0.46	723.71	291.12	434.80	0.31	0.00	0.00
070302	Heavy duty vehicles	Rural	Bio CNG	Tier 3	104.3	0.00	29.07	-1.11	47.65	0.42	0.39	0.06
070302	Heavy duty vehicles	Rural	Bio ethanol	Tier 3	4.1	0.00	673.96	408.80	497.42	0.32	0.00	0.00
070302	Heavy duty vehicles	Rural	Biodiesel	Tier 3	17.7	0.00	71.19	2.96	29.43	0.85	0.89	0.46
070302	Heavy duty vehicles	Rural	CNG	Tier 3	104.3	0.00	29.07	-1.11	47.65	0.42	0.39	0.06
070302	Heavy duty vehicles	Rural	Diesel	Tier 3	17.7	0.47	71.19	2.96	29.43	0.85	0.89	0.46
070302	Heavy duty vehicles	Rural	Gasoline	Tier 3	4.1	0.46	673.96	408.80	497.42	0.32	0.00	0.00
070303	Heavy duty vehicles	Urban	Bio CNG	Tier 3	76.7	0.00	29.46	6.09	45.90	0.25	0.39	0.06
070303	Heavy duty vehicles	Urban	Bio ethanol	Tier 3	3.2	0.00	614.40	598.28	601.22	0.28	0.00	0.00
070303	Heavy duty vehicles	Urban	Biodiesel	Tier 3	13.1	0.00	121.93	3.76	41.76	0.70	1.57	0.85
070303	Heavy duty vehicles	Urban	CNG	Tier 3	76.7	0.00	29.46	6.09	45.90	0.25	0.39	0.06
070303	Heavy duty vehicles	Urban	Diesel	Tier 3	13.1	0.47	121.93	3.76	41.76	0.70	1.57	0.85
070303	Heavy duty vehicles	Urban	Gasoline	Tier 3	3.2	0.46	614.40	598.28	601.22	0.28	0.00	0.00

Continued…													
070400	Mopeds	Urban	Bio ethanol	Tier 3	1.7	0.00	186.05	2181.67	4172.80	1.24	25.28	4.08
070400	Mopeds	Urban	Gasoline	Tier 3	1.7	0.46	186.05	2181.67	4172.80	1.24	25.28	4.08
070501	Motorcycles	Highway	Bio ethanol	Tier 3	13.3	0.00	165.71	409.97	6646.91	1.13	8.53	1.54
070501	Motorcycles	Highway	Gasoline	Tier 3	13.3	0.46	165.71	409.97	6646.91	1.13	8.53	1.54
070502	Motorcycles	Rural	Bio ethanol	Tier 3	13.7	0.00	114.96	461.45	5880.05	1.31	9.96	1.80
070502	Motorcycles	Rural	Gasoline	Tier 3	13.7	0.46	114.96	461.45	5880.05	1.31	9.96	1.80
070503	Motorcycles	Urban	Bio ethanol	Tier 3	9.8	0.00	73.26	635.86	5457.45	1.21	9.14	1.65
070503	Motorcycles	Urban	Gasoline	Tier 3	9.8	0.46	73.26	635.86	5457.45	1.21	9.14	1.65

References. SO_2: Country specific; NO_X, NMVOC, CO, NH_3, PM and BC: COPERT 5.

3.3.3 Activity data and emission factors for other mobile sources

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

The emission calculations are made for each sub-sector in the DEMOS model using the detailed method as described in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2024)[12].

Civil aviation

The activity data used in DEMOS-Aviation consists of air traffic statistics provided by the Danish Civil Aviation and Railway Authority and Copenhagen Airport. Fuel statistics for jet fuel consumption and aviation gasoline are obtained from the Danish energy statistics (DEA, 2024a).

For 2001 onwards, the Danish Civil Aviation and Railway Authority provides data records per flight (city-pairs). Each flight record consists of e.g. ICAO codes for aircraft type, origin and destination airport, maximum take off mass (MTOM), flight call sign and aircraft registration number.

In DEMOS-Aviation, each aircraft type is paired with a representative aircraft type, for which fuel consumption and emission data exist in the EMEP/EEA databank. As a basis, the aircraft 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 aircraft type relation table already established in DEMOS-Aviation (e.g. Winther, 2024).

Additional aircraft types that are not present in the aircraft type relation table are identified by using different aircraft dictionaries and internet lookups. To select the most appropriate aircraft representative type, the main selection criteria are the identified aircraft type, aircraft maximum takeoff mass, engine types, and number of engines. During this sequence, small aircraft with piston engines using aviation gasoline are excluded from the calculations.

Annex 3.B.10 shows the correspondence table between the actual aircraft type codes and representative aircraft types behind the Danish inventory. Annex 3.B.10 also show the number of LTO's per representative aircraft type for domestic and international flights starting from Copenhagen Airport and

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

other airports, respectively[13], in a time series from 2001-2023. The airport split is necessary to make due to the differences in LTO emission factors (cf. section 3.3.4).

The same type of LTO activity data for the flights for Greenland and the Faroe Islands are shown in Annex 3.B.10 also, further detailed into origin-destination airport pairs and associated flight distances. This level of detail meets the demand from UNFCCC to provide precise documentation for the part of the inventory for the Kingdom of Denmark being outside the Danish mainland.

The ideal flying distance (great circle distance) between the city-pairs is calculated by DCE in a separate database. The calculation algorithm uses a global latitude/altitude coordinate table for airports. In cases when airport coordinates are not present in DEMOS-Aviation, these are looked up on the internet and entered the database accordingly. In practise, the actual distance flown are longer than the great circle distance between two airports, and in addition, the LTO flight phase has an extent of 15 NM. This is adjusted for in DEMOS-Aviation, as explained in section 3.3.4.

For inventory years prior to 2001, detailed LTO/aircraft type statistics are obtained from Copenhagen Airport (for this airport only), while information of total take off numbers for other Danish airports is provided by the Danish Civil Aviation and Railway Authority. The assignment of representative aircraft types for Copenhagen Airport is done as described above. For the remaining Danish airports, representative aircraft types are not directly assigned. Instead, appropriate average assumptions are made relating to the fuel consumption and emission data part.

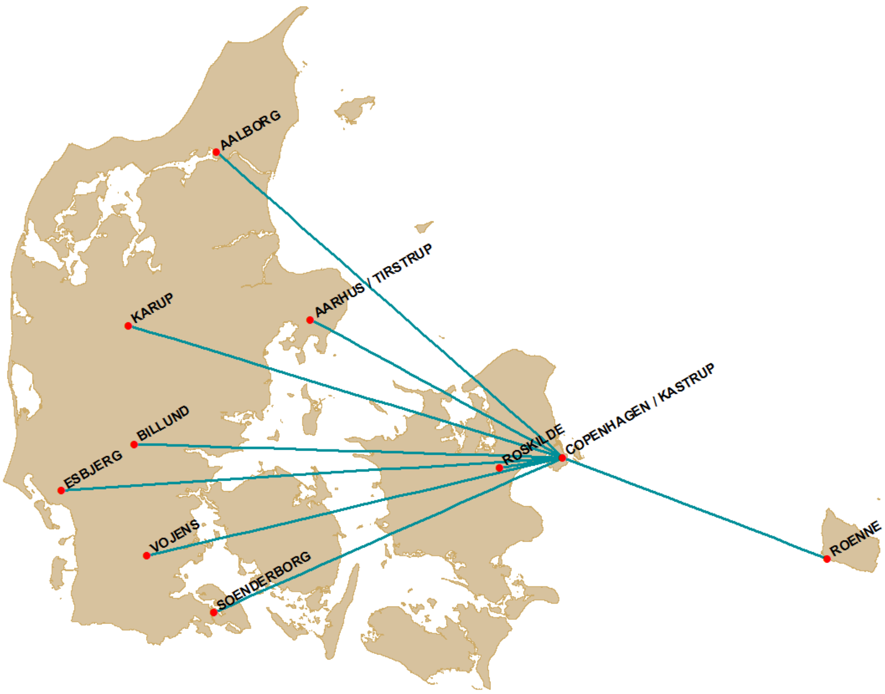


Figure 3.3.42 Most frequent domestic flying routes for large aircraft in Denmark.

[13] Excluding flights for Greenland and the Faroe Islands. These flights are separately listed in Annex 3.B.10.

Copenhagen Airport is the starting or end point for most of the domestic aviation made by large aircraft in Denmark (Figure 3.3.42; routes to Greenland/Faroe Islands are not shown). Even though many domestic flights not touching Copenhagen Airport are also reported in the flight statistics kept by the Danish Civil Aviation and Railway Authority, these flights, however, are predominantly made with small piston engine aircraft using aviation gasoline. Hence, the consumption of jet fuel by flights not using Copenhagen Airport is merely marginal.

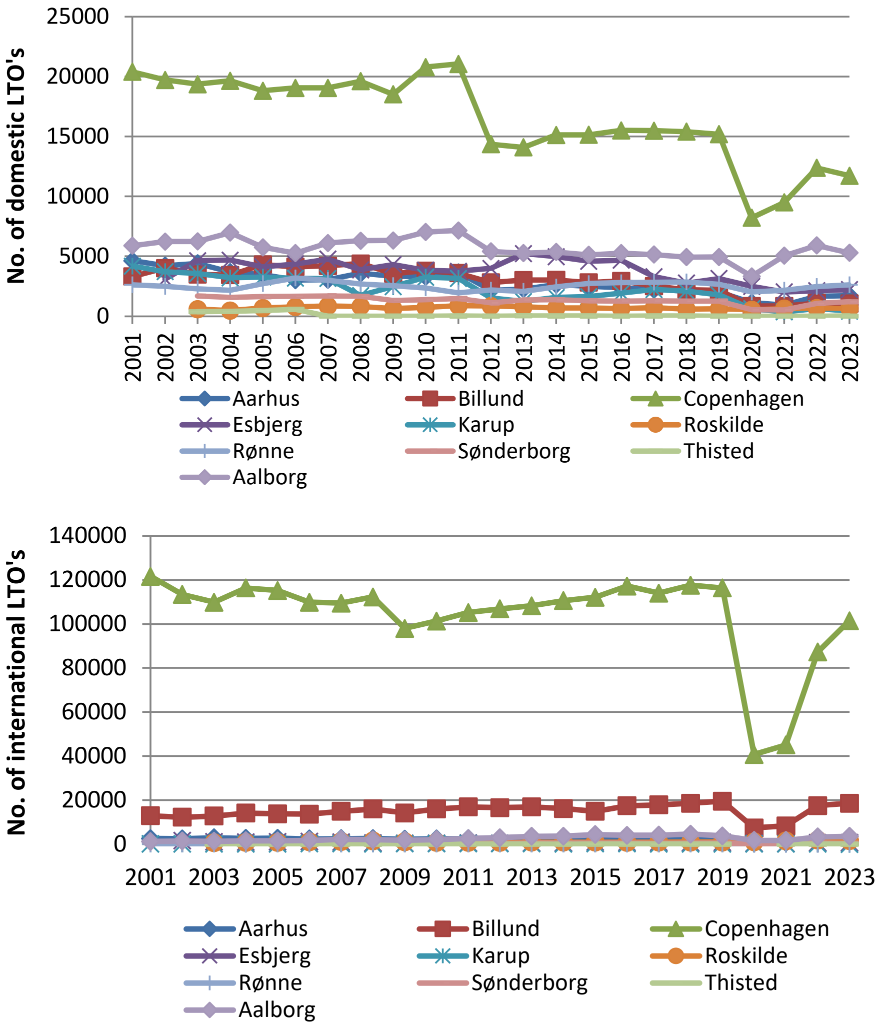


Figure 3.3.43 No. of LTO's for the most important airports in Denmark 2001-2023.

Figure 3.3.43 shows the number of domestic and international LTO's for Danish airports[14], in a time series from 2001-2023.

Non-road mobile machinery and recreational craft

Non-road mobile machinery is used in the agricultural, forestry, industrial, commercial/institutional and residential sectors, and the activity data are gathered from numerous sources. The activity data for non-road mobile machinery are described in the following together with activity data for recreational craft.

[14] Flights for Greenland and the Faroe Islands are included under domestic in the figure.

Detailed tractor fleet data for 2003-2020 and total numbers 1950-2002 for tractors in the Danish motor register are provided by Statistics Denmark (2021a, 2021b).

Total numbers for tractors (tractors in motor register and other tractors) for 1982-2005 are provided by Statistics Denmark (2021c). Total numbers for tractors (tractors in motor register and other tractors) for 1974-1981 are found in consecutive statistical publications e.g. Agricultural statistics 1974 (Statistics Denmark, 1975), as well as supplementary stock numbers per fuel type (diesel and gasoline).

Supplementary new sales data in kW classes are provided by the Association of Danish Agricultural Machinery Dealers for 1982-2018. Engine load factors and annual working hours for tractors come from Bak et al. (2003).

Number of forestry machines, engine size, annual working hours and average lifetimes are provided by the Danish Forest Association (Clemmensen, 2024).

For the most important types of building and construction machinery used in industry, annual new sales data for 1996 onwards has been provided by the Association of Danish Agricultural Machinery Dealers (Fasting, 2024).

Forklift sales data has been provided by the Association of Producers and Distributors of Fork Lifts in Denmark for 1976-2019. Further, WITS (World Industrial Truck Sales) and FEM (Federation European Material) forklift sales figures for Denmark in 2000-2023 as well as branch distribution information has been provided by Toyota Material Handling (Christensen, 2024).

For telescopic loaders, branch distribution information has been provided by Scantruck (Faurby, 2021).

The share of Stage IIIB and IV diesel engines used in the building and construction sector with preinstalled diesel particle filters, has been estimated in different engine size classes, based on questionnaire answers from the most important mobile machinery manufacturers and Danish machinery importers (Winther, 2022b).

From engine manufacturers engine load factors have been provided based on electronic engine power registrations (Sjøgren 2016; Mikkelsen 2016) in the case of building and construction machinery. Further, equipment size - engine size relations, equipment scrapping curves and annual working hours as a function of machinery age has been included in the model (Sjøgren 2016; Mikkelsen 2016; Brun 2018; Christensen 2018).

For the most important types of household and gardening machinery used in commercial/institutional and residential, annual new sales data for 2006 onwards is provided by the Association for Industrial Technics, Tools and Automation (BITVA: Brancheforeningen for industriel teknik, værktøj og automation), see Gade (2024). Until 2018 new sales data was provided by the Dealers Association of Electric Tools and Gardening Machinery (LTEH: Leverandørforeningen for Transportabelt Elværktøj og Havebrugsmaskiner). Further, equipment size - engine size relations, equipment scrapping curves and annual working hours as a function of machinery age has been provided by LTEH (Nielsen and Schösser, 2016) and by Nielsen (2022) and Schösser (2022).

The total number of refrigerating units for long distance transport trucks has been estimated for 1990 and 2021 by Teknologisk Institut (1992, 2022). Based on these data, a linear development in the number of refrigerating units from 1990 to 2023 has been assumed. For distribution lorries, the total number of refrigerating units for distribution lorries has been estimated for 1990 by the Teknologisk Institut (1992), and a proportional increase in the number of units has been assumed based on the development in the number of Danish inhabitants from 1990 to 2023.

For a remaining group of non-road mobile machinery types with low emission contributions (e.g. pumps, generators, compressors), total stock numbers from 1990 to 2023 have been estimated based on 1990 stock numbers from Teknologisk Institut (1992, 1993) and a proportional development of the stock numbers with GDP. For these machinery types, load factors, engine sizes and annual working hours has been gathered by Winther et al. (2006).

The stock development from 1985-2023 for the most important types of machinery are shown in Figures 3.3.44-3.3.51 below. The stock data are also listed in Annex 3.B.11, together with figures for load factors, engine sizes and annual working hours. As regards stock data for the remaining machinery types, please refer to Winther et al. (2006) and Winther (2023).

It is important to note that key experts in the field of industrial non-road activities assume a significant decrease in the activities for 2009 due to the global financial crisis. This reduction is in the order of 25 % for 2009 for industrial non-road activities in general (pers. comm. Per Stjernqvist, Volvo Construction Equipment 2010). For forklifts 5 % and 20 % activity reductions are assumed for 2008 and 2009, respectively (pers. comm. Peter H. Møller, Rocla A/S).

For agriculture, the total number of agricultural tractors and harvesters per year are shown in the Figures 3.3.44-3.3.45, respectively.

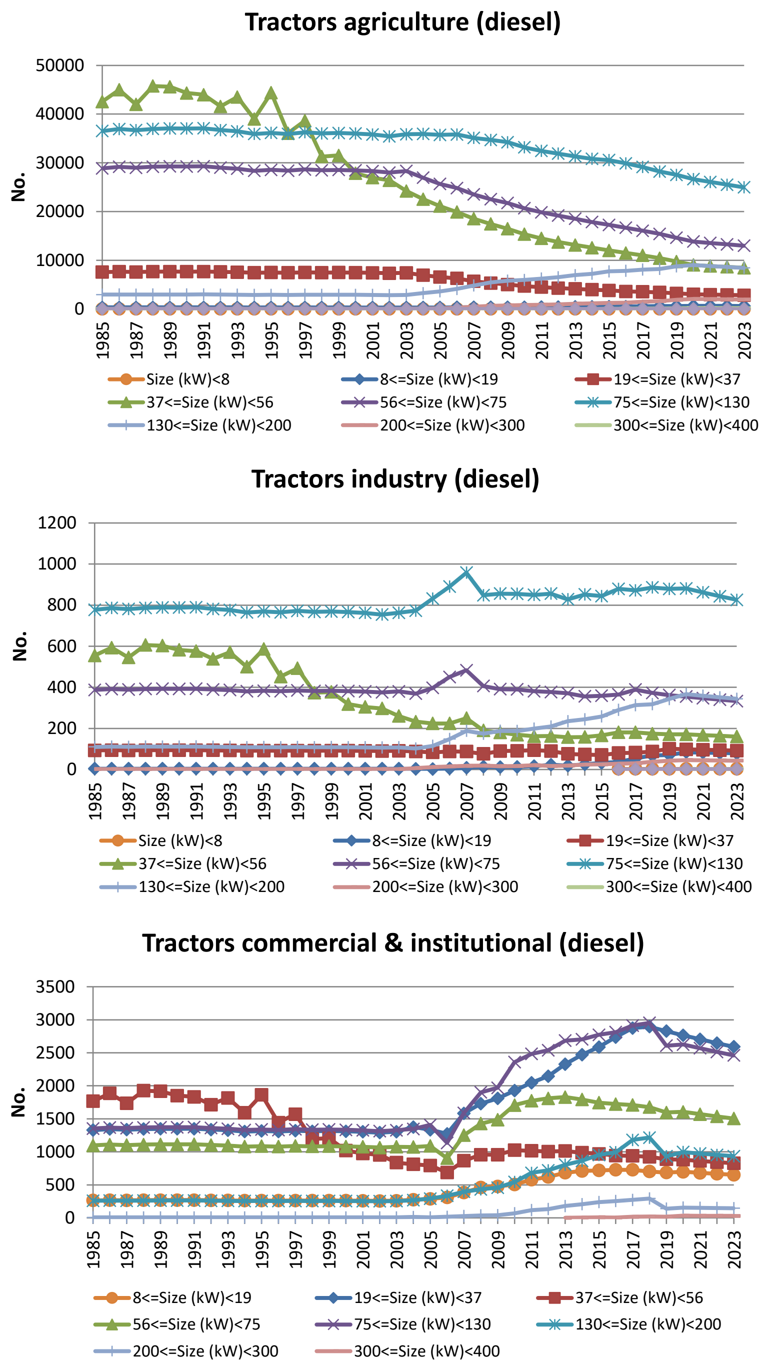


Figure 3.3.44 Total numbers in kW classes for tractors from 1985 to 2023.

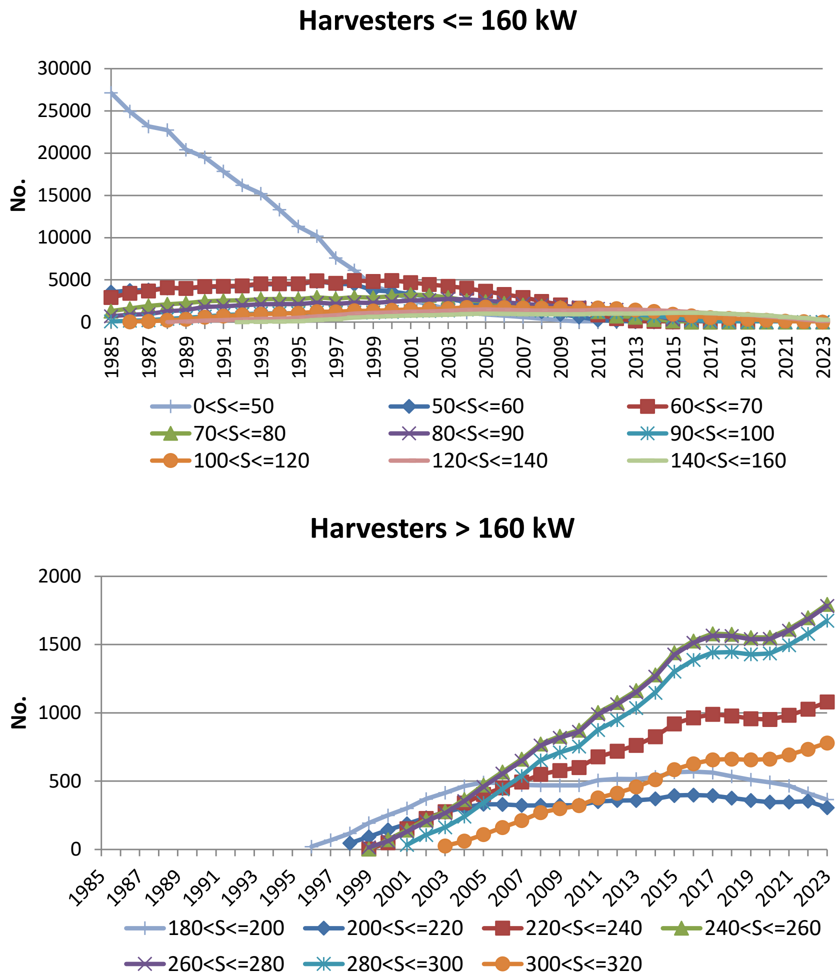


Figure 3.3.45 Total numbers in kW classes for harvesters from 1985 to 2023.

The tractor and harvester developments towards fewer vehicles and larger engines, shown in Figure 3.3.46, are very clear. From 1985 to 2023, tractor and harvester numbers decrease by around 48 % and 75 %, respectively, whereas the average increase in engine size for tractors is 121 %, and 395 % for harvesters, in the same period.

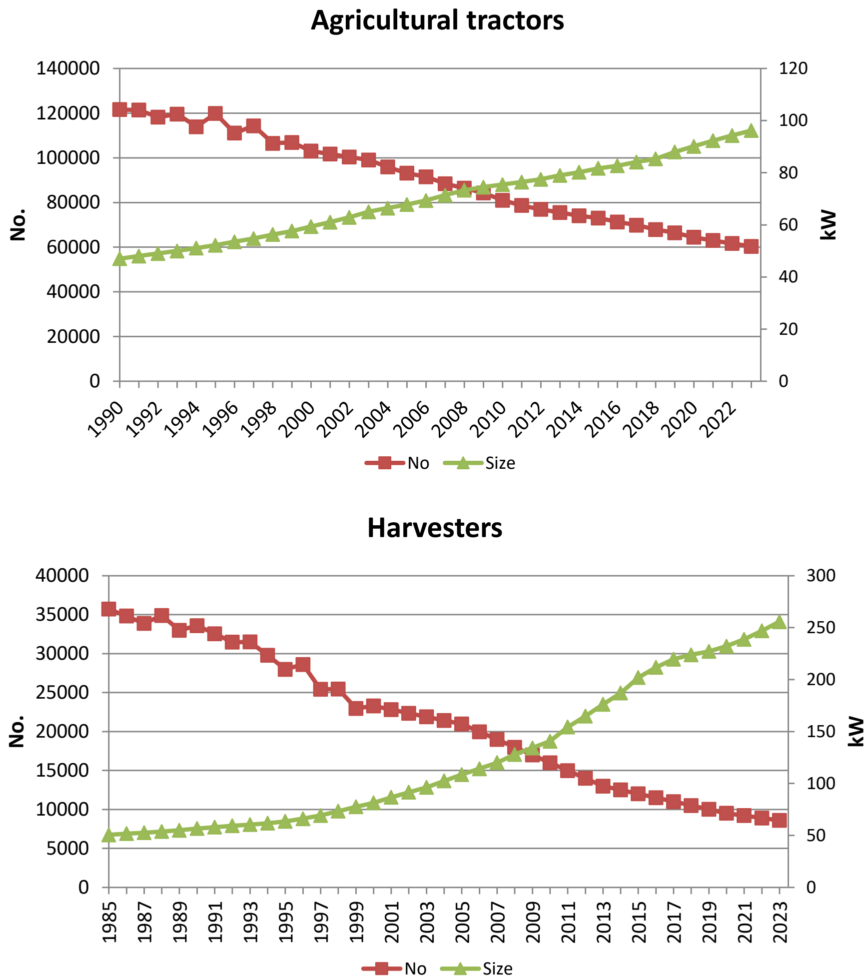


Figure 3.3.46 Total numbers and average engine size for tractors and harvesters from 1985 to 2023.

The most important non road machinery types for industry are different types of construction machinery and forklifts. The Figures 3.3.47 and 3.3.48 show the 1985-2023 stock development for specific types of construction machinery and diesel forklifts. Due to lack of data, 1996-1999 average sales data for construction machinery is used for 1995 and back. It is, however, assumed that telescopic loaders first enter use in 1986 (Jensen, Scantruck 2016). For most of the machinery types there is an increase in machinery numbers from 1990 onwards, due to increased construction activities.

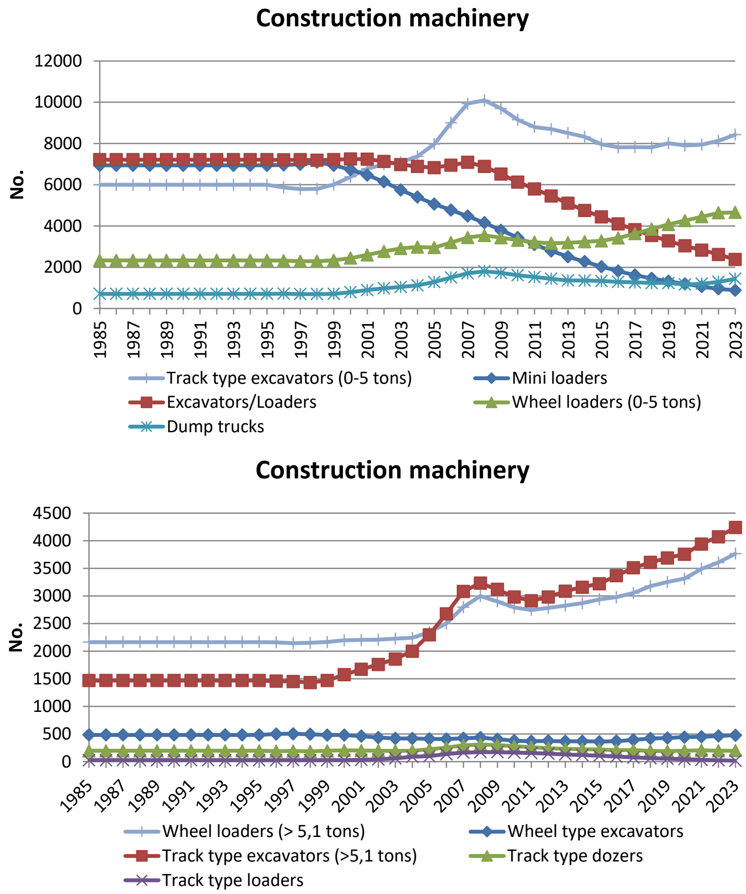


Figure 3.3.47 1985-2023 stock development for specific types of construction machinery.

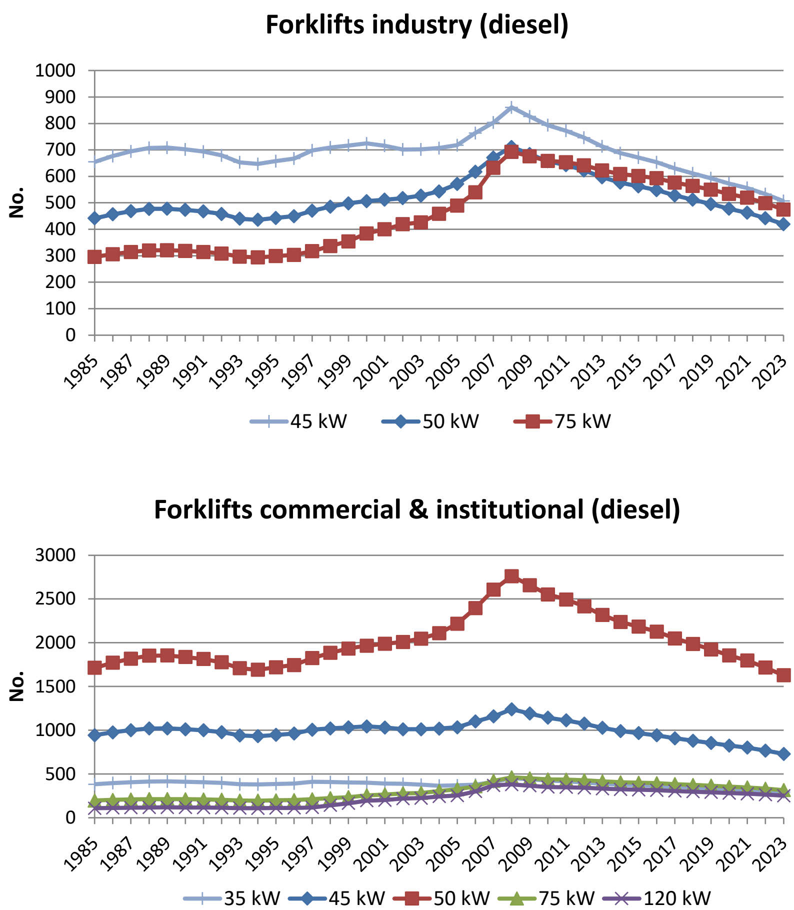
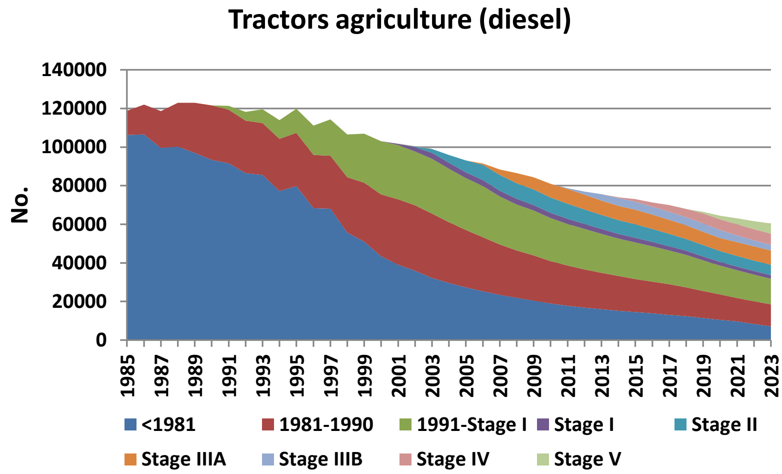


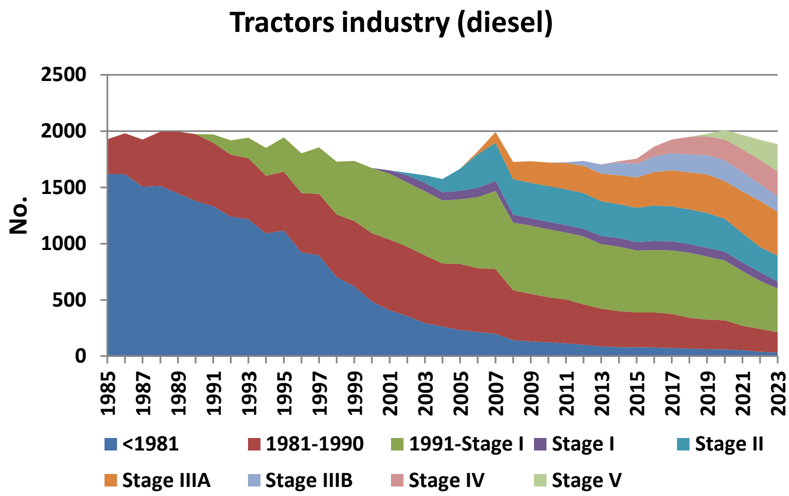
Figure 3.3.48 Total numbers of diesel forklifts in kW classes from 1985 to 2023.

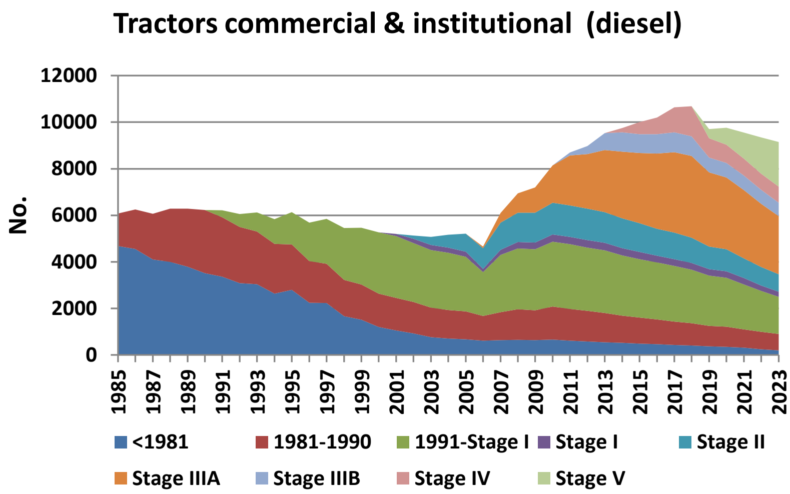
Figure 3.3.49 shows the emission layer distribution for the total stock of tractors, harvesters, construction machinery (most important types, Figure 3.3.47) and diesel forklifts from 1990-2023.

The penetration of the different pre-Euro engine classes, and engine stages complying with the gradually stricter EU stage I-V emission limits is very visible from Figure 3.3.49.

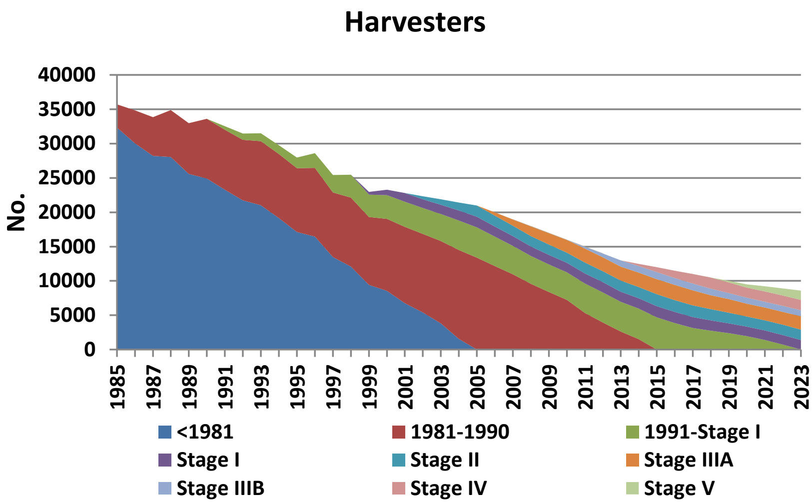
The EU emission directive stage implementation years relate to engine size, and hence, for all four machinery groups the emission level shares into specific size segments will differ slightly from the picture shown in Figure 3.3.49.

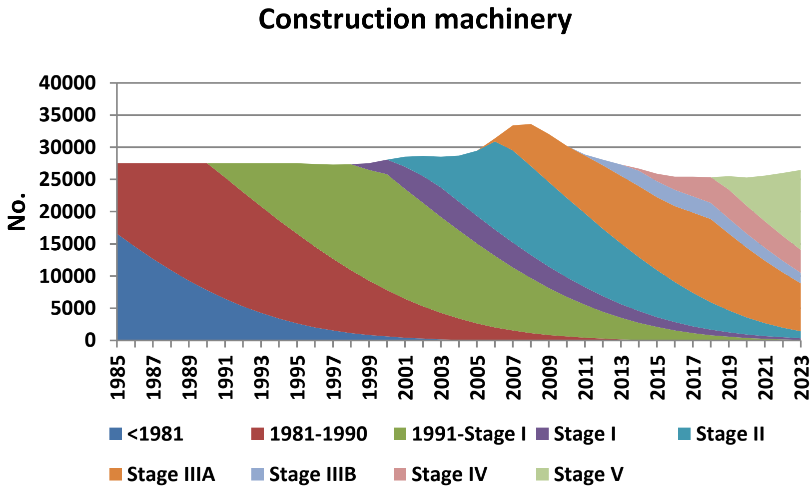

Tractors agriculture (diesel)
No.
140000
120000
100000
80000
60000
40000
20000
0
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
<1981
1981-1990
1991-Stage I
Stage I
Stage II
Stage IIIA
Stage IIIB
Stage IV
Stage V

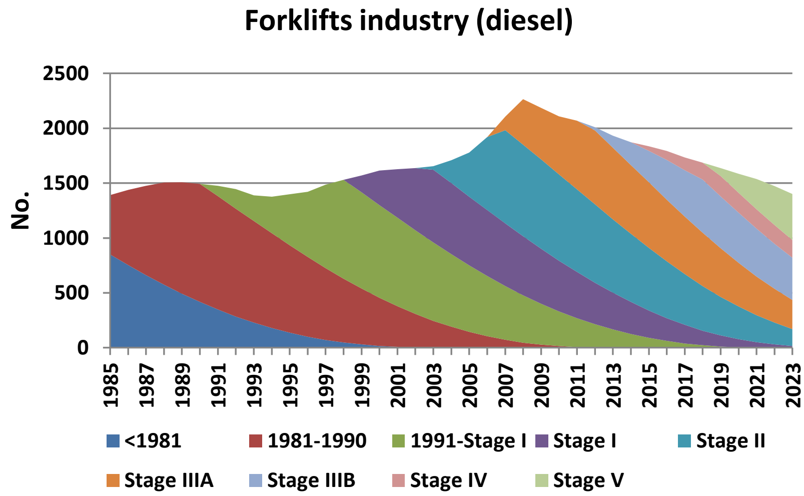

Tractors industry (diesel)
No.
2500
2000
1500
1000
500
0
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
<1981
1981-1990
1991-Stage I
Stage I
Stage II
Stage IIIA
Stage IIIB
Stage IV
Stage V


Tractors commercial & institutional (diesel)
No.
12000
10000
8000
6000
4000
2000
0
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
<1981
1981-1990
1991-Stage I
Stage I
Stage II
Stage IIIA
Stage IIIB
Stage IV
Stage V

Continued


Harvesters
No.
40000
35000
30000
25000
20000
15000
10000
5000
0
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
<1981
1981-1990
1991-Stage I
Stage I
Stage II
Stage IIIA
Stage IIIB
Stage IV
Stage V


Construction machinery
No.
40000
35000
30000
25000
20000
15000
10000
5000
0
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
<1981
1981-1990
1991-Stage I
Stage I
Stage II
Stage IIIA
Stage IIIB
Stage IV
Stage V


Forklifts industry (diesel)
No.
2500
2000
1500
1000
500
0
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
<1981
1981-1990
1991-Stage I
Stage I
Stage II
Stage IIIA
Stage IIIB
Stage IV
Stage V

Continued

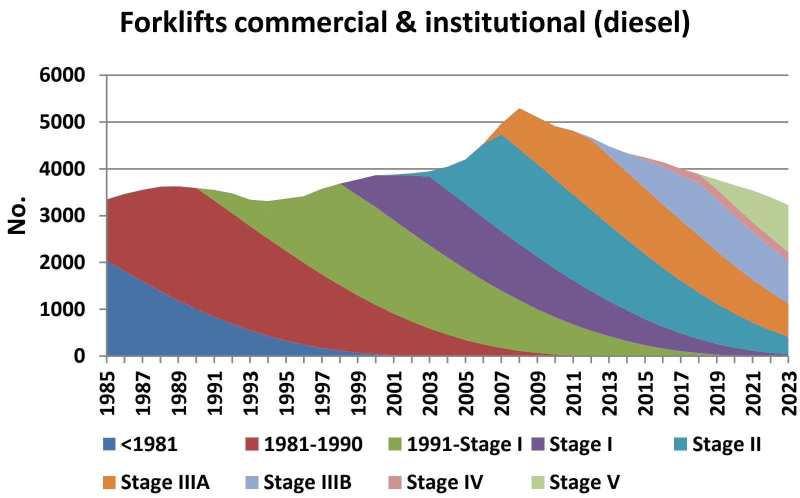


Figure 3.3.49 Layer distribution for tractors, harvesters, construction machinery and diesel forklifts (1985 to 2023).

The 1990-2023 stock development for the most important household and gardening machinery used in commercial/institutional and residential is shown in Figure 3.3.50.

The activities made with private and professional equipment types are grouped into the Residential (1.A.4b) and Commercial/institutional (1.A.4.a) inventory sectors, respectively.

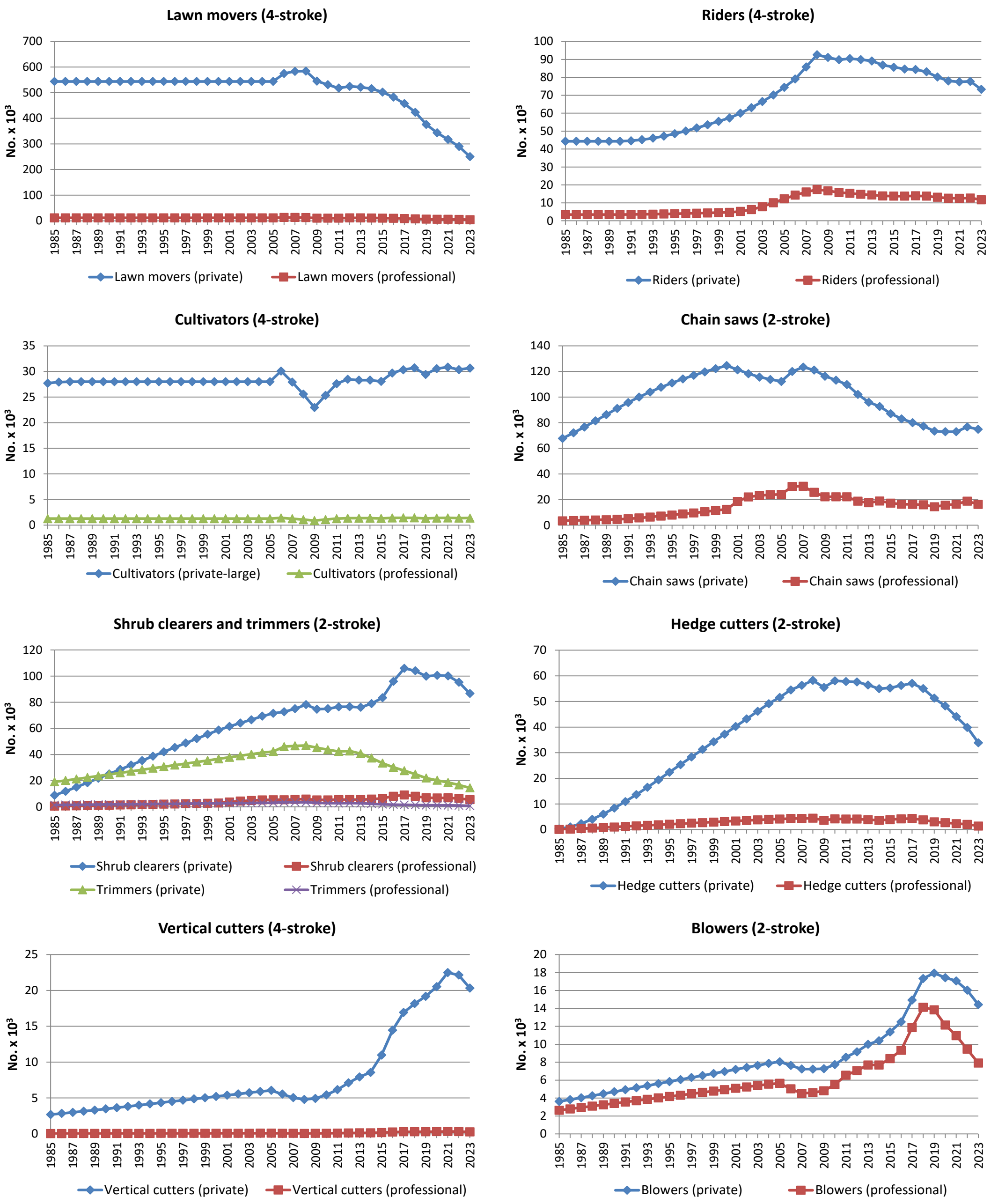


Figure 3.3.50 Stock developments 1985-2023 for the most important household and gardening machinery types.

The total stock development for the most important household and gardening machinery types is shown in Figure 3.3.51 split into 2-stroke and 4-stroke machinery for Residential (1.A.4b) and Commercial/Institutional (1.A.4.a). For the same stock division, the emission layer distribution is also shown in Figure 3.3.51. The penetration of new technologies occurs faster for working machinery in Commercial/institutional (1.A.4.a) compared with Residential (1.A.4.b), due to the shorter maximum lifetimes for the working equipment used by professionals.

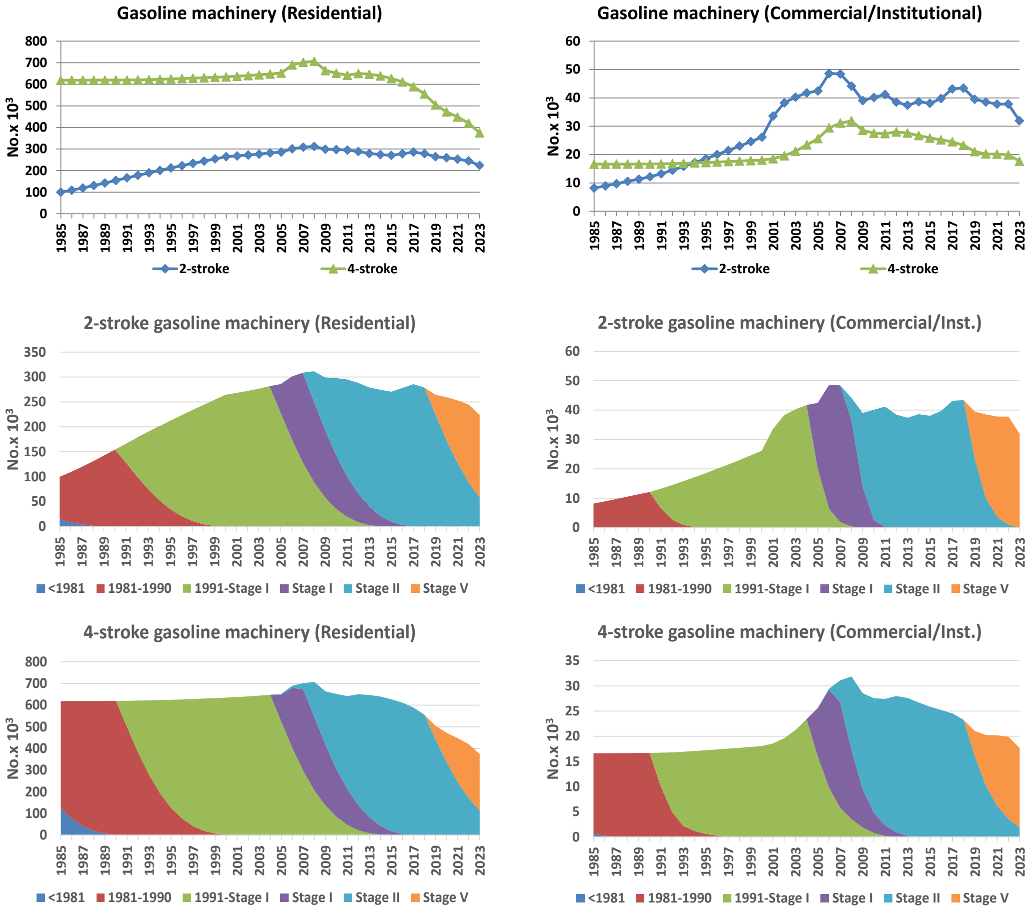


Figure 3.3.51 Layer distribution for the most important household and gardening machinery types split into residential and commercial/institutional (1985-2023).

Figure 3.3.52 shows the development in numbers of different recreational craft from 1985-2023. The 2004 stock data for recreational craft are used for 2005+, due to lack of data from the Danish Sailing Association.

For diesel boats, increases in stock and engine size are expected during the whole period, except for the number of motorboats (< 27 ft.) and the engine sizes for sailing boats (<26 ft.), where the figures remain unchanged. A decrease in the total stock of sailing boats (<26 ft.) by 21 % and increases in the total stock of yawls/cabin boats and other boats (<20 ft.) by around 25 % are expected. Due to a lack of information specific to Denmark, the shifting rate from 2-stroke to 4-stroke gasoline engines is based on a German non-road study (IFEU, 2004).

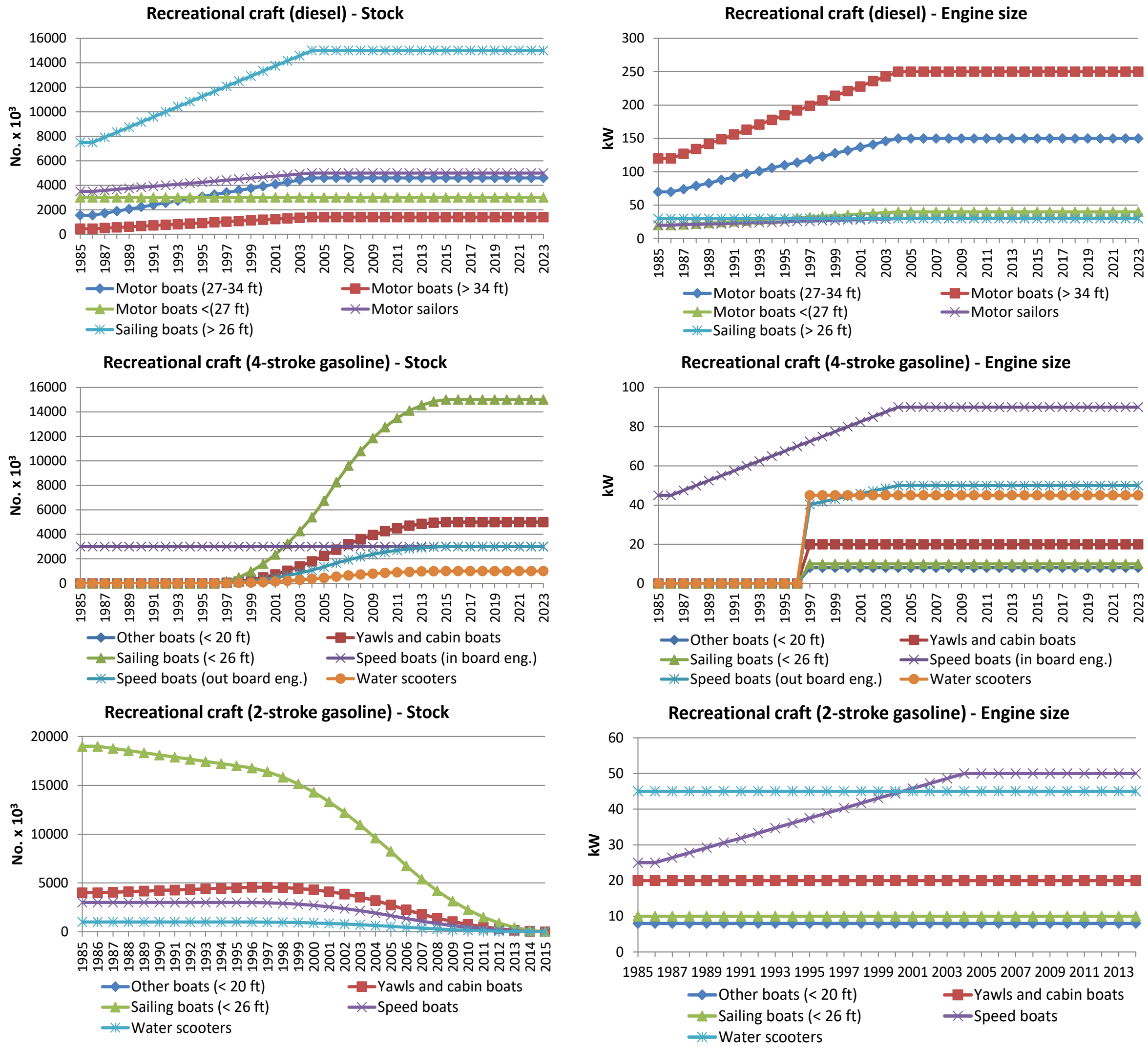


Figure 3.3.52 1985-2023 Stock and engine size development for recreational craft.

National navigation

National navigation includes the activities made by domestic ferries, fuel sold in Denmark and used for freight transport between Denmark and Greenland or the Faroe Island, and fuel used for the remaining part of the traffic between two Danish ports.

Table 3.3.9 lists the most important domestic ferry routes (regional ferries) in Denmark in the period 1990-2023. For these ferry routes and the years 1990-2005, the following detailed traffic and technical data have been gathered by Winther (2008): Ferry name, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size, share of annual trips and sailing time (single trip).

For 2006-2023, the above mentioned traffic and technical data for specific ferries have been provided by Riis-Sørensen (2024) in the case of Mols-Linien (Sjællands Odde-Ebeltoft, Sjællands Odde-Århus, Kalundborg-Århus, Køge-Rønne, Tårs-Spodsbjerg), by Jørgensen (2017) for Færgen A/S (Køge-Rønne, Tårs-Spodsbjerg, Kalundborg-Samsø), by Kruse (2015) for Samsø Rederi (Hou-Sælvig), by Mortensen (2015) for Færgeselskabet Læsø (Frederikshavn-Læsø) and by Eriksen (2017) for Ærøfærgerne (Svendborg-Ærøskøbing). For Esbjerg/Hanstholm/-Hirtshals-Torshavn traffic and technical data have been provided by Dávastovu (2010).

Table 3.3.9 Regional ferry routes in the Danish inventory.

Ferry service	Service period
Esbjerg-Torshavn	1990-1995, 2009+
Halsskov-Knudshoved	1990-1999
Hanstholm-Torshavn	1991-1992, 1999+
Hirtshals-Torshavn	2010
Hou-Sælvig	1990+
Hundested-Grenaa	1990-1996
Frederikshavn-Læsø	1990+
Kalundborg-Juelsminde	1990-1996
Kalundborg-Samsø	1990+
Kalundborg-Århus	1990+
Korsør-Nyborg, DSB	1990-1997
Korsør-Nyborg, Vognmandsruten	1990-1999
København-Rønne	1990-2004
Køge-Rønne	2004+
Sjællands Odde-Ebeltoft	1990+
Sjællands Odde-Århus	1999+
Svendborg-Ærøskøbing	1990+
Tårs-Spodsbjerg	1990+

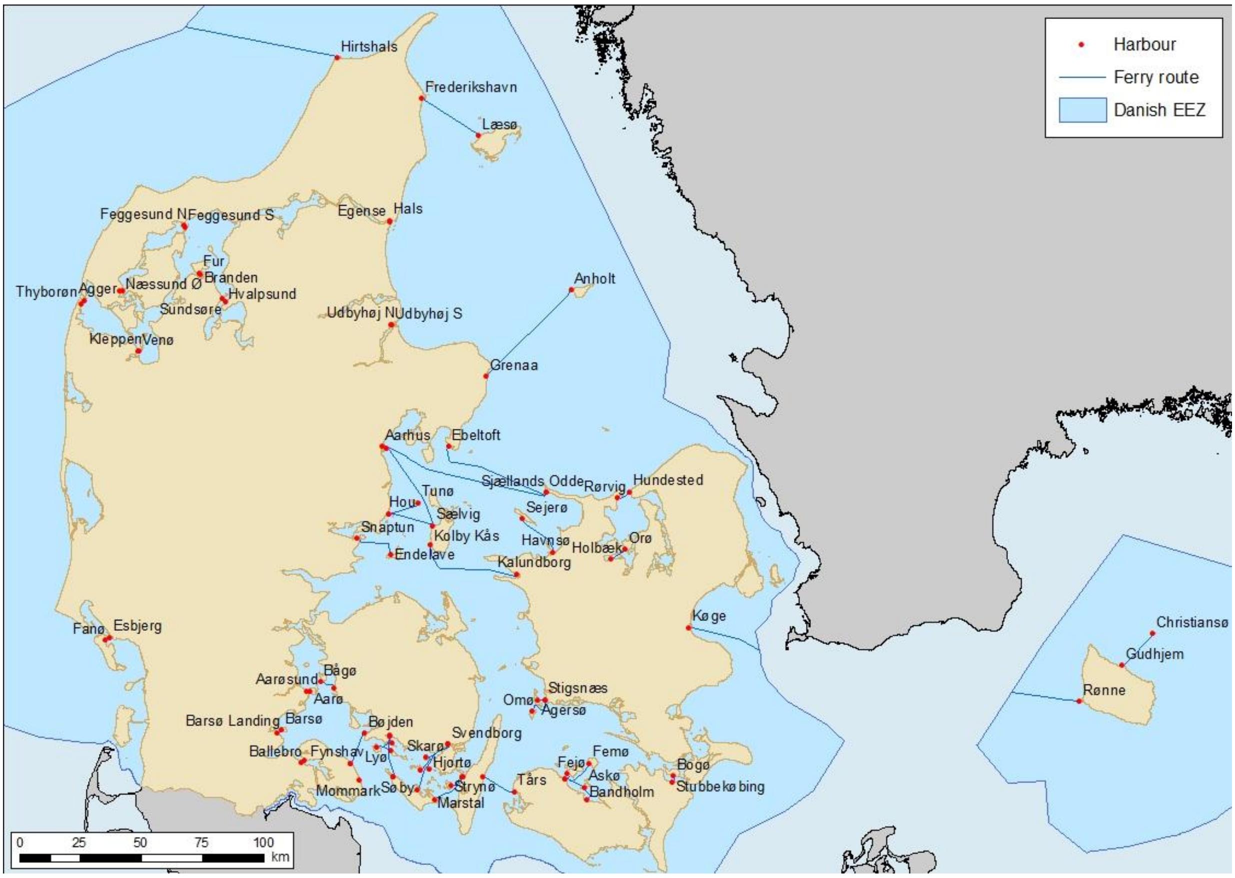


Figure 3.3.53 Domestic ferry routes in Denmark (2023).

Table 3.3.10 lists the small ferry routes (island and short cut ferries) included in the Danish inventory for the period 1990-2023. For these ferry routes and the years 1990-2023, the following detailed traffic and technical data have been gathered by Rasmussen (2017) and Andersen (2019): Ferry name, engine size (MCR), engine year, share of annual trips and sailing time (single trip). Supplementary data for engine type, fuel type and average load factor is provided by Kristensen (2017).

Table 3.3.10 Small ferry routes in the Danish inventory.

Ferry service	Service period
Assens-Baagø	1990+
Ballebro-Hardeshøj	1990+
Bandholm-Askø	1990+
Barsø Landing-Barsø	2018+
Branden-Fur	1990+
Bøjden-Fynshav	1990+
Esbjerg-Fanø	1990+
Feggesund overfart	1990+
Fejø-Kragenæs	1990+
Femø-Kragenæs	1990+
Frederikssund-Roskilde	1999-2000
Fåborg-Avernakø-Lyø	1990+
Fåborg-Søby	1990+
Grenaa-Anholt	1990+
Gudhjem-Christiansø	2015+
Hals-Egense	1994+
Havnsø-Sejerø	1990+
Holbæk-Orø	1990+
Horsens-Endelave	1990+
Hov-Tunø	1990+
Hundested-Rørvig	1990+
Hvalpsund-Sundsøre	1990+
Kastrup-Rønne	1990
Kleppen-Venø	1990+
Korsør-Lohals	1990+
Kragenæs-Askø	2020+
København-Århus	1992-1993
Næssund overfart	1990+
Rudkøbing-Marstal	-2013
Rudkøbing-Strynø	1990+
Stigsnæs-Agersø	1990+
Stigsnæs-Omø	1990+
Stubbekøbing-Bogø	1990+
Svendborg-Skarø-Drejø	1990+
Sælvig-Aarhus	2021+
Søby-Fynshav	2009+
Søby-Mommark	-2009
Thyborøn-Agger	1990+
Udbyhøj Nord - Udbyhøj Syd	2017+
Aarø-Aarøsund	1990+

The number of round trips per ferry route from 1990 to 2023 is provided by Statistics Denmark (2024a). Figure 3.3.53 show all ferry routes in use in 2023 (Esbjerg/Hanstholm/Hirtshals-Torshavn not shown).

For all ferry routes, detailed data in terms of ferry name, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size, number of trips and sailing time (single trip) is shown in Annex 3.B.12 for the years 1985-2023. There is a lack of historical traffic data for 1985-1989, and hence, data for 1990 is used for these years, to support the fuel consumption and emission calculations.

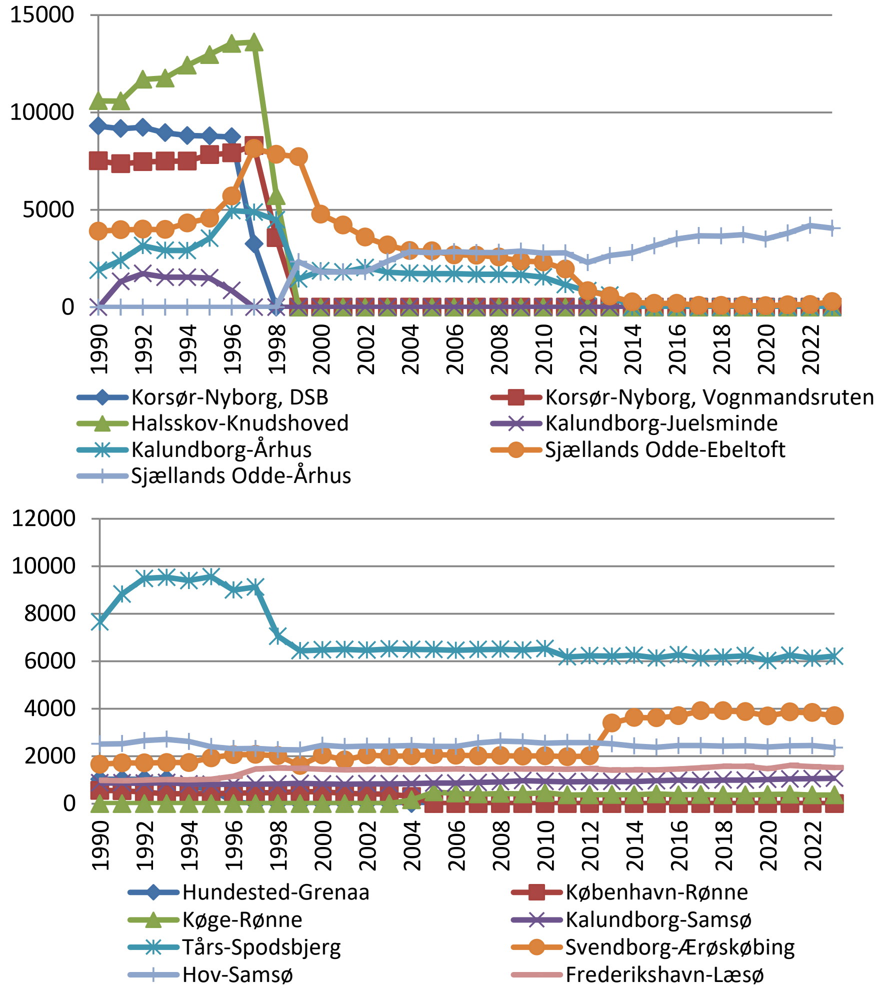


Figure 3.3.54 No. of round trips for the most important ferry routes in Denmark 1990-2023.

It is seen from Table 3.3.9 (and Figure 3.3.54) that several ferry routes were closed in the period from 1996-1998, mainly due to the opening of the Great Belt Bridge (connecting Zealand and Funen) in 1997. Hundested-Grenaa and Kalundborg-Juelsminde was closed in 1996, Korsør-Nyborg (DSB) closed in 1997, and Halsskov-Knudshoved and Korsør-Nyborg (Vognmandsruten) was closed in 1998. The ferry line København-Rønne was replaced by Køge-Rønne in 2004 and from 1999, a new ferry connection was opened between Sjællands Odde and Århus.

The fuel sold for freight transport by Royal Arctic Line between Aalborg (Denmark) and Greenland is included under other national sea transport in the Danish inventories. In this case all fuel is bought in Denmark (Rasmussen, 2024). The fuel used by freight transport between Denmark and the Faroe Islands (Eimskip) is bought outside Denmark (Helgason, 2024), and hence, not included in the Danish inventories.

Fuel used for the remaining part of the traffic between two Danish ports, other national sea transport, is taken as the difference between 1) DEA national fuel sales for national sea transport minus fuel consumption at Danish offshore installations (offshore reduced fuel sales[15]) and 2) the bottom-up calculated fuel consumption for Danish ferries[16].

For years when the fuel estimates for ferries (not including the ferry to the Faroe Islands) are higher than the "offshore reduced" fuel sold for national sea transport, fuel is taken from fisheries in the case of marine diesel (1985-1999). For heavy fuel oil, the missing fuel amount is taken from stationary sources (1985-1986, 1988, 1994-1996) and international sea transport (2015 onwards).

The LNG fuel calculated for Danish ferries differ from the LNG fuel sales for national navigation reported in the DEA fuel statistics. Subsequently, an inventory fuel balance is made to account for the total LNG fuel sold reported in the DEA fuel statistics.

National Fishing

For fishing vessels, electronic log data for 1985-2020 are provided by the Danish Fisheries Agency (Hernov, 2021) and for 2021-2023 by Aarhus University (Andersen, 2024) 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), gross tonnes (GT), total installed engine power (kW) and hours at sea.

Average engine load factors (%) are taken from Winther and Martinsen (2020) based on data provided by Hanstholm Fisheries Association (Amdissen, 2020).

Figure 3.3.55 show hours at sea for the Danish fishing vessels split into OAL classes for the years 1990-2023.

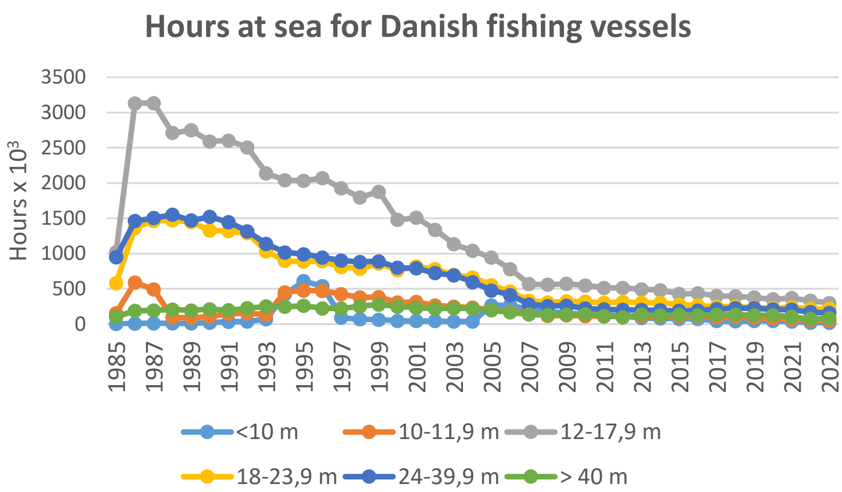


Figure 3.3.55 Total hours at sea for Danish fishing vessels 1990-2023.

[15] The diesel fuel sold to "offshore installations" are reported as sold for national navigation by the reporting oil companies in the energy statistics.
[16] A small amount of GTL is used by a few island and short-cut ferry lines from 2018 onwards. In energy units, this fuel is a part of the total fuel consumption for ferries subtracted from total DEA statistical fuel sales. For national navigation, the latter statistics only comprise diesel fuel as a liquid fuel.

Railways

The activity data for railways used in the DEMOS-Rail model consists of the total energy use for Danish railways activities from 1985-2023 provided by DEA (2024a). In addition, data for train km, train litra km, passenger km or occupancy rates and train litra service weight[17] are gathered from various sources:

- For regional and intercity trains, using diesel or electricity as a fuel depending on litra type, train km, train litra km and passenger occupancy rates are provided by Danish State Railways (DSB) for the period 2019-2023 (Mølgård, 2024).
- Urban trains ("'S-tog") are electric, and train km and passenger km data are taken from Statistics Denmark (2023b). Train litra km are estimated based on train km and supplementary data from DSB annual reports, e.g. Årsrapport 2023 (DSB, 2024).
- Metro trains are also electric, and train km, train litra km and passenger km data are provided by Metro (Fredericks, 2024).
- Private railways lines mainly use diesel, although a few lines are electrified. Train km, train litra km and passenger km data are provided by the Danish Civil Aviation and Railway Authority (Schelde, 2024), and data splits into litra sub types are provided by the private railway companies.
- Train service weight data for the different train litra types are gathered from relevant web pages (e.g. www.jernbanen.dk) and the weight of a passenger is set to 70 kg.
- Train km, train litra km and train litra performance weight (train litra service weight + total weight of passengers at average occupancy) are used to calculate the total train tonnes km.

For several private railway companies, the following data has been collected for each railway line operated by the companies: Litra type, Litra new sales year, Euro emission level, fuel type, fuel consumption factors, number of seats/standing rooms, and percentage distribution of annual Litra km driven per Litra type (Hjortsø, 2022; Hansen, 2022; Jensen, 2022). For railway lines not able to provide data, and for the earliest years in the time series in general, supplementary data has been gathered from relevant web pages (e.g. www.jernbanen.dk).

Figure 3.3.56 show train litra km and tonnes train km for DSB, private railways and S-tog and Metro per litra type in 2023.

[17] Train service weight: The weight of the train including 2/3 load of supply (fuel etc.) and staff (Jernbaneleksikon jernbaneordbog jernbane leksikon ordbog (jernbanen.dk).

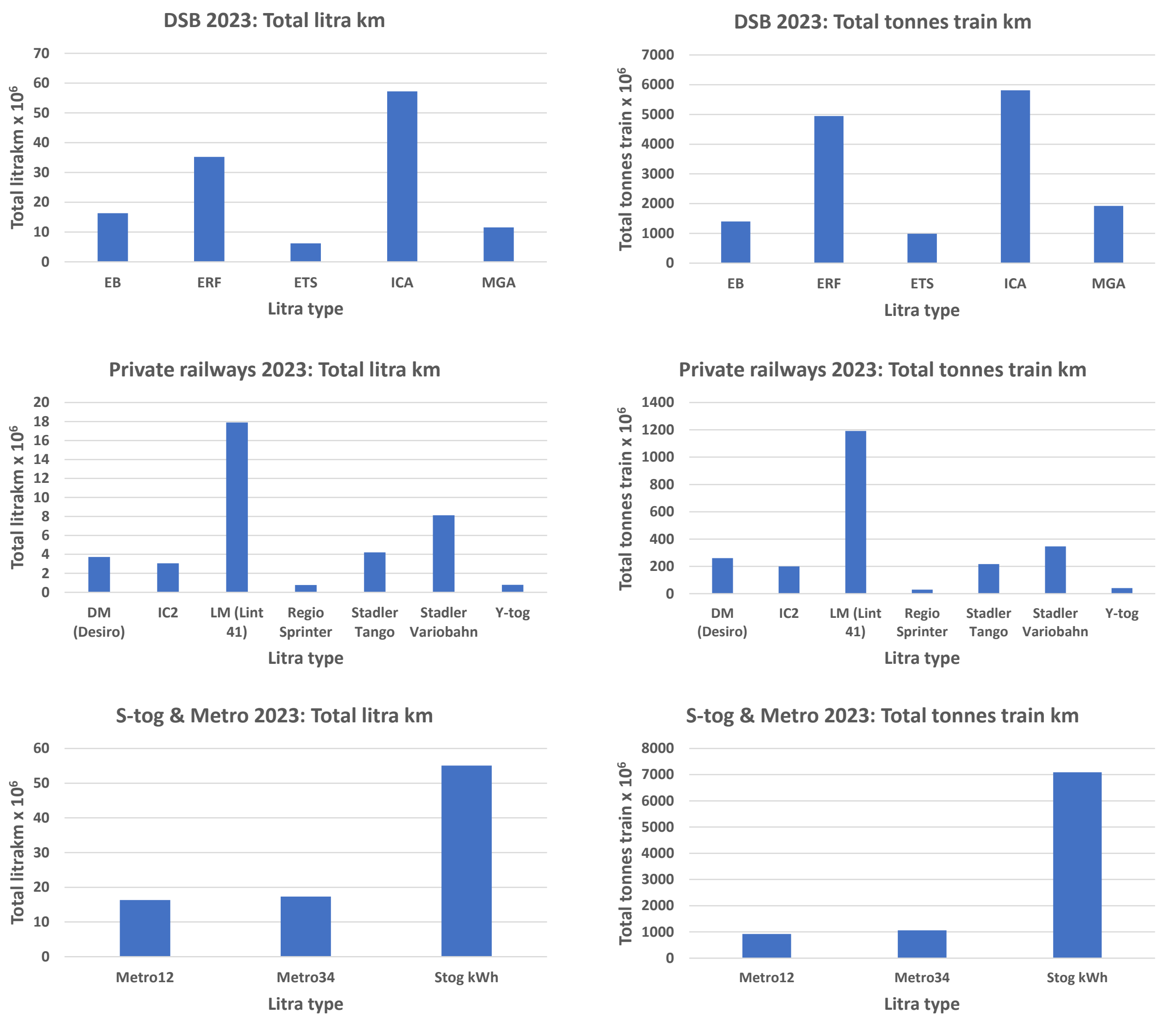


Figure 3.3.56 Train litra km and tonnes train km for DSB, private railways and S-tog and Metro per litra type in 2023.

In railways, the predominant part of diesel is used by DSB. For 2019-2023, the bottom-up calculated fuel consumption for DSB and private railway companies is subtracted from total diesel fuel sold, and the residual amount of fuel is allocated to DSB. For 1985-2018, the bottom-up calculated fuel consumption for private railway companies[18] is subtracted from total diesel fuel sold for railways in the DEA energy statistics, and the residual amount of fuel is allocated to DSB.

For railways, train litra km and tonnes train km for DSB, private railways and S-tog and Metro per litra type is shown in Annex 3.B.13 for the years 1985-2023.

Military

The activity data for military activities consists of fuel consumption information from DEA (2024).

International navigation

The activity data for international navigation consists of fuel consumption information from DEA (2024a).

[18] A small amount of GTL is used by private railways from 2018 onwards. In energy units, this fuel is a part of the total fuel consumption for railways subtracted from total DEA statistical fuel sales. For railways, the latter statistics only comprise diesel fuel as a liquid fuel.

For international navigation, the fuel basis is in principle fuel sold in Danish ports for vessels with a foreign destination (i.e. outside the Kingdom of Denmark), as prescribed by the IPCC guidelines. However, it must be noted that fuel sold for sailing activities between Denmark and Greenland/Faroe Islands are reported as international in the DEA energy statistics. Hence, for inventory purposes to follow the IPCC guidelines, the fuel estimated for the ferry routes Esbjerg/Hanstholm/Hirtshals-Torshavn, and fuel bought by Royal Arctic Line is transferred from international sea transport to national sea transport in fuel sales, prior to inventory fuel input.

The activity data for international navigation consists of fuel consumption information from DEA (2024a).

For all sectors, fuel consumption figures are given in Annex 3.B.15 for the years 1990 and 2023 in CollectER format, and fuel consumption time series are given in Annex 3.B.16 in NFR format.

Emission legislation

For other mobile sources, the engines 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 influence the emissions of CH_4, the latter emission component forming a part of total VOC. Only for ships, have legislative limits for specific fuel consumption been internationally agreed to reduce the emissions of CO_2.

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

For diesel, the directives 97/68 and 2004/26 (Table 3.3.11) relate to Stage I-IV non-road mobile machinery other than agricultural and forestry tractors and the directives have different implementation dates for machinery operating under transient and constant loads. The latter directive also comprises emission limits for Stage IIIA and IIIB railways machinery (Table 3.3.15). For Stage I-IV tractors the relevant directives are 2000/25 and 2005/13 (Table 3.3.11).

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

For gasoline non road mobile machinery, the directive 2002/88 distinguishes between Stage I and II hand-held (SH) and not hand-held (NS) types of machinery (Table 3.3.12). Emissions are tested using one of the specific constant load ISO 8178 test cycles (D2, G1, G2, G3) depending on the type of machinery.

For Stage V non road mobile machinery, EU directive 2016/1628 relate to diesel non-road mobile machinery other than agricultural tractors (Table 3.3.11) and railways machinery (Table 3.3.15) and gasoline non-road mobile machinery (Table 3.3.12). EU directive 167/2013 relate to Stage V agricultural and forestry tractors (Table 3.3.10).

Table 3.3.11 Overview of EU emission directives relevant for diesel fuelled non-road mobile machinery.

Stage	Engine size	CO	VOC	NO_x	$VOC+NO_x$	PM	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 3.3.12 Overview of the EU Emission Directives relevant for gasoline fueled non-road mobile machinery.

	Category	Engine size [ccm]	CO [g pr kWh]	HC [g pr kWh]	NO_X [g pr kWh]	HC+NO_X [g pr kWh]	Implement. date
EU Directive 2002/88	Stage I						
Hand-held	SH1	S<20	805	295	5.36	-	1/2 2005
	SH2	20≤S<50	805	241	5.36	-	1/2 2005
	SH3	50≤S	603	161	5.36	-	1/2 2005
Not hand-held	SN3	100≤S<225	519	-	-	16.1	1/2 2005
	SN4	225≤S	519	-	-	13.4	1/2 2005
	Stage II						
Hand-held	SH1	S<20	805	-	-	50	1/2 2008
	SH2	20≤S<50	805	-	-	50	1/2 2008
	SH3	50≤S	603	-	-	72	1/2 2009
Not hand-held	SN1	S<66	610	-	-	50	1/2 2005
	SN2	66≤S<100	610	-	-	40	1/2 2005
	SN3	100≤S<225	610	-	-	16.1	1/2 2008
	SN4	225≤S	610	-	-	12.1	1/2 2007
EU Directive 2016/1628	Stage V						
Hand-held (<19 kW)	NRSh-v-1a	S<50	805	-	-	50	2019
	NRSh-v-1b	50≤S	805	-	-	72	2019
Not hand-held (P<19 kW)	NRS-vr/vi-1a	80≤S<225	610	-	-	10	2019
	NRS-vr/vi-1b	S≥225	610	-	-	8	2019
Not hand-held (19=<P<30 kW)	NRS-v-2a	S≤1000	610	-	-	8	2019
	NRS-v-2b	S>1000	4.40*	-	-	2.70*	2019
Not hand-held (30=<P<56 kW)	NRS-v-3	any	4.40*	-	-	2.70*	2019

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

For recreational craft, Directive 2003/44 comprises the Stage I emission legislation limits for diesel engines, and for 2-stroke and 4-stroke gasoline engines, respectively. The CO and VOC emission limits depend on engine size (kW) and the inserted parameters presented in the calculation formulas in Table 3.3.13. For NO_x, a constant limit value is given for each of the three engine types. For TSP, the constant emission limit regards diesel engines only.

In Table 3.3.14, the Stage II emission limits are shown for recreational craft. CO and HC+NOx limits are provided for gasoline engines depending on the rated engine power and the engine type (stern-drive vs. outboard) while CO, HC+NOx, and particulate emission limits are defined for compression ignition (CI) engines depending on the rated engine power and the swept volume.

Table 3.3.13 Overview of the EU Emission Directive 2003/44 for recreational craft.

Engine type	Impl. date	CO=A+B/P^n			HC=A+B/P^n			NO_x	TSP
		A	B	n	A	B	n		
2-stroke gasoline	1/1 2007	150.0	600.0	1.0	30.0	100.0	0.75	10.0	-
4-stroke gasoline	1/1 2006	150.0	600.0	1.0	6.0	50.0	0.75	15.0	-
Diesel	1/1 2006	5.0	0.0	0	1.5	2.0	0.5	9.8	1.0

Table 3.3.14 Overview of the EU Emission Directive 2013/53 for recreational craft.

Diesel engines					
Swept Volume, SV	Rated Engine Power, P_N	Implement date	CO	HC + NO_x	PM
l/cyl.	kW		g/kWh	g/kWh	g/kWh
SV < 0.9	P_N < 37				
	37 <= P_N < 75 (*)	18/1 2017	5	4.7	0.30
	75 <= P_N < 3 700	18/1 2017	5	5.8	0.15
0.9 <= SV < 1.2	P_N < 3 700	18/1 2017	5	5.8	0.14
1.2 <= SV < 2.5		18/1 2017	5	5.8	0.12
2.5 <= SV < 3.5		18/1 2017	5	5.8	0.12
3.5 <= SV < 7.0		18/1 2017	5	5.8	0.11
Gasoline engines					
Engine type	Rated Engine Power, P_N		CO	HC + NO_x	PM
	kW		g/kWh	g/kWh	g/kWh
Stern-drive and inboard engines	P_N <= 373	18/1 2017	75	5	-
	373 <= P_N <= 485	18/1 2017	350	16	-
	P_N > 485	18/1 2017	350	22	-
Outboard engines and PWC engines (**)	P_N <= 4.3	18/1 2017	500 – (5.0 x P_N)	15.7 + ($50/PN^{0.9}$)	-
	4.3 <= P_N <= 40	18/1 2017	500 – (5.0 x P_N)	15.7 + ($50/PN^{0.9}$)	-
	P_N > 40	18/1 2017	300		-

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

Table 3.3.15 Overview of the EU Emission Directives relevant for railway locomotives and motorcars.

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

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

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

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

For NO_x, the emission regulations fall in five categories:

1) For engines of a type or model for which the date of manufacture of the first individual production model was before 1 January 1996, and for which the production date of the individual engine was before 1 January 2000.
2) For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 1996, or for individual engines with a production date on or after 1 January 2000.
3) For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2004.
4) For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2008, or for individual engines with a production date on or after 1 January 2013.
5) For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2014.

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

The limit values for NO_x are given by the formulae in Table 3.3.16.

Table 3.3.16 Current certification limits for NO_x for turbo jet and turbo fan engines.

	Engines first produced before 1.1.1996 & for engines manufactured before 1.1.2000	Engines first produced on or after 1.1.1996 & for engines manufactured on or after 1.1.2000	Engines for which the date of manufacture of the first individual production model was on or after 1 January 2004	Engines first produced on or after 1.1.2008 & for engines manufactured on or after 1.1.2013	Engines for which the date of manufacture of the first individual production model was on or after 1.1.2014
Applies to engines >26.7 kN	$Dp/F_{oo} = 40 + 2\pi_{oo}$	$Dp/F_{oo} = 32 + 1.6\pi_{oo}$			
Engines of pressure ratio less than 30					
Thrust more than 89 kN			$Dp/F_{oo} = 19 + 1.6\pi_{oo}$	$Dp/F_{oo} = 16.72 + 1.4080\pi_{oo}$	$7.88 + 1.4080\pi_{oo}$
Thrust between 26.7 kN and not more than 89 kN			$Dp/F_{oo} = 37.572 + 1.6\pi_{oo} - 0.208F_{oo}$	$Dp/F_{oo} = 38.54862 + (1.6823\pi_{oo}) – (0.2453F_{oo}) – (0.00308\pi_{oo}F_{oo})$	$Dp/F_{oo} = 40.052 + 1.5681\pi_{oo} - 0.3615F_{oo} - 0.0018\ \pi_{oo} \times F_{oo}$
Engines of pressure ratio more than 30 and less than 62.5 (104.7)					
Thrust more than 89 kN			$Dp/F_{oo} = 7+2.0\pi_{oo}$	$Dp/F_{oo} = -1.04+(2.0*\pi_{oo})$	
Thrust between 26.7 kN and not more than 89 kN			$Dp/F_{oo} = 42.71 +1.4286\pi_{oo} - 0.4013F_{oo} +0.00642\pi_{oo}F_{oo}$	$Dp/F_{oo} = 46.1600 + (1.4286\pi_{oo}) – (0.5303F_{oo}) – (0.00642\pi_{oo}F_{oo})$	
Engines with pressure ratio 62.5 or more					
Engines with pressure ratio 82.6 or more			$Dp/F_{oo} = 32+1.6\pi_{oo}$	$Dp/F_{oo} = 32+1.6\pi_{oo}$	
Engines of pressure ratio more than 30 and less than (104.7)					
Thrust more than 89 kN					$Dp/F_{oo} = -9.88 + 2.0\pi_{oo}$
Thrust between 26.7 kN and not more than 89 kN					$Dp/F_{oo} = 41.9435 + 1.505\pi_{oo} - 0.5823F_{oo} + 0.005562\pi_{oo} \times F_{oo}$
Engines with pressure ratio 104.7 or more					$Dp/F_{oo} = 32 + 1.6\pi_{oo}$

Source: International Standards and Recommended Practices, Environmental Protection, ICAO Annex 16 Volume II , 3rd edition July 2008, plus amendments: Amendment 7 (17 November 2011), Amendment 8 (July 2014)

where:

D_p = the sum of emissions in the LTO cycle in g.

F_{oo} = thrust at sea level take-off (100 %).

π_{oo} = pressure ratio at sea level take-off thrust point (100 %).

The equivalent limits for HC and CO are $D_p/F_{oo} = 19.6$ for HC and $D_p/F_{oo} = 118$ for CO (ICAO Annex 16 Vol. II paragraph 2.2.2). Smoke is limited to a regulatory smoke number = 83 $(F_{oo})^{-0.274}$ or a value of 50, whichever is the lower.

A further description of the technical definitions in relation to engine certification as well as actual engine exhaust emission measurement data can be found in the ICAO Engine Exhaust Emission Database. The latter database is accessible from "www.easa.europa.eu/domains/environment/icao-aircraft-engine-emissions-databank" hosted by the European Aviation Safety Agency (EASA).

Emission standards of non-volatile Particulate Matter (nvPM) mass and number for jet engines of rated thrust greater than 26.7 kN were adopted by the ICAO Council in March 2020. The emission standards are applicable from 1 January 2023 onwards to new type and in-production engines with rated thrust greater than 26.7 kN. The emission standards are explained in more details on the ICAO website https://www.icao.int/environmental-protection/Pages/LAQ_TechnologyStandards.aspx.

The new emission standards replace the SN standard for engines of rated thrust greater than 26.7 kN. Given that the nvPM standards are not applicable to engines of rated thrust less or equal to 26.7 kN, these smaller engines will still need to comply with the SN standard.

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

The baseline NO_x emission regulation of Annex VI applies for diesel engines with a power output higher than 130 kW, which are installed on a ship constructed on or after 1 January 2000 and diesel engines with a power output higher than 130 kW which undergo major conversion on or after 1 January 2000.

The baseline NO_x emission limits for ship engines in relation to their rated engine speed (n) given in RPM (Revolutions Per Minute) are the following:

- 17 g pr kWh, n < 130 RPM
- 45 x n-0.2 g pr kWh, 130 ≤ n < 2000 RPM
- 9.8 g pr kWh, n ≥ 2000 RPM

The further amendment of Annex VI Regulation 13 contains a three-tiered approach in order to strengthen the emission standards for NO_x. The three-tier approach comprises the following:

- Tier I: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2000 and prior to 1 January 2011 (initial regulation).
- Tier II: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2011.
- Tier III[19]: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2016 operating in the North American ECA or the United States Caribbean Sea ECA and diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2021 operating in the Baltic Sea and North Sea ECA.

The three tier NOx emission limit functions are shown in Table 3.3.17.

Table 3.3.17 Tier I-III NOx emission limits for ship engines in MARPOL Annex VI.

	NO_x limit	RPM (n)
Tier I	17 g pr kWh	n < 130
	45 x· n-0.2 g pr kWh	130 ≤ n < 2000
	9,8 g pr kWh	n ≥ 2000
Tier II	14.4 g pr kWh	n < 130
	44 x· n-0.23 g pr kWh	130 ≤ n < 2000
	7.7 g pr kWh	n ≥ 2000
Tier III	3.4 g pr kWh	n < 130
	9 x· n-0.2 g pr kWh	130 ≤ n < 2000
	2 g pr kWh	n ≥ 2000

[19] For ships operating in a designated Emission Control Area. Outside a designated Emission Control Area, Tier II limits apply.

Further, the NO_x Tier I limits are to be applied for existing engines with a power output higher than 5000 kW and a displacement per cylinder at or above 90 litres, installed on a ship constructed on or after 1 January 1990 but prior to 1 January 2000.

In relation to the sulphur content in heavy fuel and marine gas oil used by ship engines, Table 3.3.18 shows the EU and IMO (Regulation 14 plus amendments) legislation in force for SECA (Sulphur Emission Control Area) areas and outside SECA's.

Table 3.3.18 Current legislation in relation to marine fuel quality.

Legislation	Marine area	Heavy fuel oil		Gas oil	
		S- %	Implement. date	S- %	Implement. date
EU-directive 93/12		None		0.2[1]	01.10.1994
EU-directive 1999/32		None		0.2	01.01.2000
EU-directive 2005/33[2]	SECA - Baltic sea	1.5	11.08.2006	0.1	01.01.2008
	SECA - North sea	1.5	11.08.2007	0.1	01.01.2008
	Outside SECA's	None		0.1	01.01.2008
MARPOL Annex VI	SECA – Baltic sea	1.5	19.05.2006		
	SECA – North sea	1.5	21.11.2007		
	Outside SECA	4.5	19.05.2006		
MARPOL Annex VI amendments	SECA's	1	01.03.2010		
	SECA's	0.1	01.01.2015		
	Outside SECA's	3.5	01.01.2012		
	Outside SECA's	0.5	01.01.2020		

[1] Sulphur content limit for fuel sold inside EU.

[2] From 1.1.2010 fuel with a sulphur content higher than 0.1 % must not be used in EU ports for ships at berth exceeding two hours.

For non-road machinery, the EU directive 2003/17/EC gives a limit value of 10 ppm sulphur in diesel (from 2011).

Emission factors

The SO_2 emission factors are fuel related and rely on the sulphur contents given in the relevant EU fuel directives or in the Danish legal announcements. However, for jet fuel the default factor from IPCC (2006) is used. For ferries operated by Mols Linjen fuel sulphur data from fuel suppliers are used from 2017 onwards, and for small ferries fuel sulphur data from fuel suppliers are used in all inventory years.

Road transport diesel is assumed to be used by engines in military, railways (apart from railway lines using GTL) and recreational craft. Road transport gasoline is assumed to be used by non-road working machinery and recreational craft. Hence, these types of machinery have the same SO_2 emission factors, as for road transport. For GTL a fuel sulphur content of 5 ppm is used based on fuel supplier's information.

Time series of fuel sulphur contents for the relevant fuel types and their references are listed in Annex 3.B.14.

Annex 3.B14 also list the lower heating values (LHV) for the inventory fuel types together with their references. The LHV's are used to transform emission factors from g/kg fuel into g/MJ or fuel results from kg into MJ if needed in the inventories.

For all mobile sources, the emission factor source for NH_3, PAH and PCB is the EMEP/EEA guidebook (EMEP/EEA, 2024).

For BC, the emission factor source is Comer et al. (2017) for national sea transport and fisheries, apart for ferries using GTL. In this case BC emission factors for marine diesel is used due to lack of data. The BC emission factors for the remaining inventory categories come from (EMEP/EEA, 2024).

The heavy metal emission factors related to fuel combustion for road transport and other mobile sources originate from Winther and Slentø (2010), except for national sea transport and fisheries. For the latter two mobile sectors, the heavy metal emission factor source is the EMEP/EEA guidebook (EMEP/EEA, 2024). For civil aviation jet fuel, no heavy metal emission factors are proposed due to lack of data.

For HCB, the emission factors come from Nielsen et al. (2014).

The non-exhaust emission factors for railways wear of contact lines (TSP, PM_{10}, $PM_{2.5}$ and Cu), rails and train wheels (TSP, PM_{10} and $PM_{2.5}$) and brakes (TSP, PM_{10}, $PM_{2.5}$, Cr and Ni), are taken from Vanherle et al. (2021). The latter source also provides the non-exhaust emission factors for tyre and brake wear (TSP, PM_{10} and $PM_{2.5}$) for domestic and international civil aviation. For aircraft tyre wear, the non-exhaust emission factors for heavy metals are estimated using the content of heavy metals in road transport tyres.

In the case of military ground equipment, due to lack of fleet/activity and emission data, aggregated emission factors for gasoline and diesel are derived from total road traffic emission results. For piston engine aircraft using aviation gasoline, emission factors from (EMEP/EEA, 2024) are used.

For railways, fuel consumption, NO_x, VOC, CO and TSP emission factors are derived from specific Danish emission measurements from the Danish State Railways (Mølgård, 2023). For private railway lines, fuel consumption, NO_x, VOC, CO, TSP and BC emission factors are estimated for the different train type technologies using diesel or GTL. The NMVOC emission factors for railways are derived from the VOC emission factors using a NMVOC/CH_4 split, based on expert judgement.

For non-road machinery in agriculture, forestry, industry, commercial/institutional and residential, and for recreational craft, the fuel consumption, NO_x, VOC, CO and TSP emission factors are derived from various European measurement programs; see IFEU (2004, 2009), Notter and Schmied (2015) and Winther (2023). For non-road machinery equipped with particle filters (DPF), TSP emission factors come from ICCT (2016). The NMVOC/CH_4 split is taken from IFEU (2009).

For national sea transport and fisheries, the fuel consumption and NO_x emission factors predominantly come from the engine manufacturer MAN Energy Solutions, as a function of engine production year. The CO and VOC emission factors come from the Danish TEMA2015 emission model (Ministry of Transport, 2015). TSP emission factors are provided by IMO (2015), whereas the PM_{10} and $PM_{2.5}$ size fractions are obtained from MAN Energy Solutions.

Specifically for the ferries used by Mols Linjen, fuel consumption, NO_x, VOC and CO emission factors are provided by Kristensen (2008), originating from engine measurements (Hansen et al., 2004; Wismann, 1999; PHP, 1996). Complimentary emission factor data for new ferries is provided by Kristensen (2013) and engine load specific emission data is provided by Nielsen (2022).

For island and short-cut ferries using GTL, fuel consumption, NO_x, VOC, CO and TSP emission factors are taken from Winther (2022a).

For the LNG fueled ferry in service on the Hou-Sælvig route, fuel consumption factors are provided by Kruse (2015) and NO_x, NMVOC, CO and TSP emission factors are taken from Bengtsson et al. (2011).

For marine engines using diesel or residual oil, VOC/CH_4 splits are taken from EMEP/EEA (2024) and all emission factors are shown in Annex 3.B.12.

For national sea transport, international sea transport and fisheries, total fuel consumption and aggregated emission factors per fuel type are shown Annex 3.B.12 for the years 1985-2023. Total fuel consumption and emission factors per ferry per route are also shown Annex 3.B.12 for 2023. For fisheries as well, total engine MWh's produced, total fuel consumption, fuel balance factors and emission factors are shown Annex 3.B.12 for 1985-2023.

The source for aviation (jet fuel) fuel consumption and emission factors is the EMEP/EEA guidebook (EMEP/EEA, 2024). For a number of different representative aircraft types, the EMEP/EEA guidebook comprises fuel flow and NO_x, CO and VOC emission indices for the four LTO modes and distance-based fuel consumption and emission factors for cruise. For auxiliary power units (APU), ICAO (2020) is the data source for APU load specific fuel consumption, NO_x, CO and VOC emission factors for different APU aircraft groups to be linked with the different representative aircraft types. VOC/CH_4 splits for aviation are taken from EMEP/EEA (2024).

For all sectors, emission factors are given in CollectER format in Annex 3.B.15 for 2023. Table 3.3.19 shows the emission factors for SO_2, NO_X, NMVOC, CO, NH_3, TSP and BC in CollectER format used to calculate the emissions from other mobile sources in Denmark.

Factors for deterioration, transient loads and gasoline evaporation for non-road mobile machinery

The emission effects of engine wear are considered for diesel and gasoline engines by using the so-called deterioration factors. For diesel engines alone, transient factors are used in the calculations, to account for the emission changes caused by varying engine loads. The evaporative emissions of NMVOC are estimated for gasoline fuelling and tank evaporation. The factors for deterioration, transient loads and gasoline evaporation are taken from IFEU (2004, 2009, 2014) and are shown in Annex 3.B.10. For more details regarding the use of these factors, please refer to paragraph 3.1.4 or Winther et al. (2006).

Engine load adjustment factors for marine engines

For marine engines, specific fuel consumption (sfc) and emission factors are found to vary with engine load, and hence engine load adjustment factors, LAF, are used in the fleet activity calculations for ferries and fishing vessels to account for these engine load changes. For sfc and NO_x, N_2O, CO, VOC and PM, engine load adjustment functions are provided by IMO (2015) based on Starcrest (2013). Only sfc is adjusted in the calculations, due to the actual engine load levels for ferries and fishing vessels in the Danish inventories. The load adjustment factors are shown in Annex 3.B.12.

For a few ferries operated by Mols Linjen actual engine loads and engine load specific emission data provided by Riis-Sørensen (2024) is used to calculate precise sfc and emission factors of NO_x, CO and VOC.

Table 3.3.19 Fuel based emission factors for SO_2, NO_X, NMVOC, CO, NH_3, TSP and BC for other mobile sources in Denmark (2023).

SNAP ID	Category	Fuel type	Tier level	CH_4 % of VOC	Emission factors[1] [g pr GJ] SO_2	NO_X	NMVOC	CO	NH_3	TSP	BC
080100	Military	Diesel	Tier 1	8.4	0.44	159.86	3.17	25.13	1.50	1.23	0.81
080100	Military	Gasoline	Tier 1	5.9	0.43	55.12	73.24	722.46	9.45	0.48	0.08
080100	Military	Jet fuel	Tier 1	9.6	22.99	250.57	24.94	229.89	0.00	1.16	0.56
080200	Railways	Diesel	Tier 3	3.7	0.47	415.08	22.25	63.72	0.20	3.86	2.51
080200	Railways	GTL	Tier 3	3.7	0.23	281.57	36.66	179.96	0.20	2.83	1.84
080300	Recreational craft	Bio ethanol	Tier 3	2.7	0.00	504.74	374.92	7060.69	0.11	4.29	0.21
080300	Recreational craft	Biodiesel	Tier 3	2.4	0.00	530.39	89.63	339.27	0.17	44.75	16.56
080300	Recreational craft	Diesel	Tier 3	2.4	46.84	530.39	89.63	339.27	0.17	44.75	16.56
080300	Recreational craft	Gasoline	Tier 3	2.7	0.46	504.74	374.92	7060.69	0.11	4.29	0.21
080402	National sea traffic	Diesel	Tier 3	2.0	21.16	1206.14	63.54	114.21	0.00	20.05	3.76
080402	National sea traffic	GTL	Tier 3	2.0	0.23	964.51	51.56	144.06	0.00	10.83	5.60
080402	National sea traffic	LNG	Tier 3	74.0	0.00	161.63	92.45	269.39	0.00	8.51	0.22
080402	National sea traffic	Residual oil	Tier 3	2.0	48.90	1732.86	65.68	193.88	0.00	90.57	4.90
080403	Fishing	Diesel	Tier 3	2.0	46.84	1018.40	56.60	143.09	0.00	21.55	4.44
080404	International sea traffic	Diesel	Tier 1	2.0	46.84	1477.48	63.16	173.59	0.00	24.49	2.36
080404	International sea traffic	Residual oil	Tier 1	2.0	48.90	1926.55	69.77	191.76	0.00	101.48	4.52
080501	Air traffic. Dom. < 3000 ft.	AvGas	Tier 1	2.0	22.83	71.70	422.10	18219.00	1.60	10.00	1.50
080501	Air traffic. Dom. < 3000 ft.	Jet fuel	Tier 3	10.0	22.99	310.05	14.19	401.24	0.00	1.84	0.68
080502	Air traffic. Int. < 3000 ft.	Jet fuel	Tier 3	10.0	22.99	321.46	18.98	184.50	0.00	2.71	1.27
080503	Air traffic. Dom. > 3000 ft.	Jet fuel	Tier 3	0.0	22.99	335.25	7.50	97.55	0.00	1.66	0.43
080504	Air traffic. Int. > 3000 ft.	Jet fuel	Tier 3	0.0	22.99	323.01	6.45	58.63	0.00	2.93	0.68
080600	Agriculture	Bio ethanol	Tier 3	12.2	0.00	107.40	1085.90	18590.77	1.50	30.45	1.52
080600	Agriculture	Diesel	Tier 3	2.4	0.47	219.83	29.94	230.88	0.21	18.97	11.50
080600	Agriculture	Gasoline	Tier 3	12.2	0.46	107.40	1085.90	18590.77	1.50	30.45	1.52
080700	Forestry	Bio ethanol	Tier 3	6.0	0.00	54.79	3754.76	17915.98	0.09	82.19	4.11
080700	Forestry	Diesel	Tier 3	2.4	0.47	52.52	14.63	174.51	0.21	1.73	1.08
080700	Forestry	Gasoline	Tier 3	6.0	0.46	54.79	3754.76	17915.98	0.09	82.19	4.11
080800	Industry	Bio ethanol	Tier 3	3.5	0.00	113.93	1051.79	26586.50	0.08	22.68	1.13
080800	Industry	Diesel	Tier 3	2.4	0.47	199.98	27.92	206.40	0.20	11.61	8.47
080800	Industry	Gasoline	Tier 3	3.5	0.46	113.93	1051.79	26586.50	0.08	22.68	1.13
080800	Industry	LPG	Tier 3	5.0	0.00	139.80	33.20	13.98	0.21	0.70	0.03
080900	Household and gardening	Bio ethanol	Tier 3	2.4	0.00	80.26	2054.18	30149.92	0.09	41.07	2.05
080900	Household and gardening	Gasoline	Tier 3	2.4	0.46	80.26	2054.18	30149.92	0.09	41.07	2.05
081100	Commercial and institutional	Bio ethanol	Tier 3	4.1	0.00	64.22	810.23	33984.64	0.09	14.98	0.75
081100	Commercial and institutional	Diesel	Tier 3	2.4	0.47	234.96	30.98	223.92	0.20	13.42	9.20
081100	Commercial and institutional	Gasoline	Tier 3	4.1	0.46	64.22	810.23	33984.64	0.09	14.98	0.75
081100	Commercial and institutional	LPG	Tier 3	5.0	0.00	139.80	33.20	13.98	0.21	0.70	0.03
080501	Air traffic. Dom. < 3000 ft.	AvGas	Tier 1	2.0	22.83	71.70	422.10	18219.00	1.60	10.00	1.50
080501	Air traffic. Dom. < 3000 ft.	Jet fuel	Tier 3	10.0	22.99	314.07	13.61	204.88	0.00	1.74	0.56
080502	Air traffic. Int. < 3000 ft.	Jet fuel	Tier 3	10.0	22.99	325.62	16.80	190.28	0.00	2.34	0.95
080503	Air traffic. Dom. > 3000 ft.	Jet fuel	Tier 3	0.0	22.99	420.00	4.36	54.97	0.00	2.44	0.49
080504	Air traffic. Int. > 3000 ft.	Jet fuel	Tier 3	0.0	22.99	349.23	3.80	41.55	0.00	2.81	0.60

SO_2: Country-specific; Military: Aggregated emission factors for road transport; Railways (NO_x, CO, NMVOC and TSP): Danish State Railways; Agriculture, forestry, industry, household gardening and recreational craft (NO_x, CO, VOC and TSP): IFEU (2004, 2009, 2014), Notter and Schmied (2015), ICCT (2016); National navigation/National fishing/International navigation: MAN B&W (NO_x), Ministry of Transport (2015) (CO, NMVOC), IMO (TSP), specific data from Mols Linjen (NO_x, CO, NMVOC, TSP) & LNG emission factors (NO_x, CO, NMVOC, TSP) from Bengtsson et al. (2011) & GTL emission factors (NO_x, CO, NMVOC, TSP) from Winther (2022a); Aviation (NO_X, CO, NMVOC, TSP): EMEP/EEA.

3.3.4 Calculation methods for other mobile sources

Civil aviation

For aviation, the domestic and international estimates are made separately for landing and takeoff (LTOs < 3000 ft), and cruising (> 3000 ft).

By using the LTO mode specific fuel flow and emission indices from EMEP/EEA (2024), the fuel consumption and emission factors for the full LTO cycle are estimated for each of the representative aircraft types used in the Danish inventory.

The fuel consumption for one LTO cycle is calculated according to the following sum formula:

$$FC_{LTO}^{a} = \sum_{m=1}^{5} t_m \cdot ff_{a,m} \quad (16)$$

Where FC = fuel consumption (kg), m = LTO mode (approach/landing, taxi in, taxi out, take off, climb out), t = times in mode (s), ff = fuel flow (kg per s), a = representative aircraft type.

The emissions for one LTO cycle are estimated as follows:

$$E_{LTO}^{a} = \sum_{m=1}^{5} FC_{a,m} \cdot EI_{a,m} \quad (17)$$

Where EI = emission index (g per kg fuel). Due to lack of specific airport data for approach/descent, take off and climb out, standardised times-in-modes of 4, 0.7 and 2.2 minutes are used as defined by ICAO (ICAO, 1995). For taxi in and taxi out, specific times-in-modes data are provided by Eurocontrol for the airports present in the Danish inventory. The taxi times-in-modes data are shown in Annex 3.B.10 for the years 2001-2023.

The fuel consumption and emissions for aircraft auxiliary power units (APU's) are calculated with the same method used to estimate LTO fuel consumption and emissions for aircraft main engines (formulas 16 and 17). ICAO (2020) is the data source for APU load specific fuel flows (kg per s) and emission rates (g per kg fuel) for different APU aircraft groups (characterised by seating capacity and age). APU times-in-modes for arrival, start-up, boarding and main engine start are also provided by ICAO (2020), whereas push back time intervals are taken from an emission study made in Copenhagen Airport (Ellermann et al., 2011; Winther et al., 2015).

For each representative aircraft type, the calculated fuel consumption and emission factors per LTO are shown in Annex 3.B.10 for Copenhagen Airport and other airports (aggregated) for 2023. APU data for fuel flows, emission rates and times-in-modes are also shown in Annex 3.B.10, together with the correspondence table for APU group-representative aircraft type.

The calculations for cruise use the distance specific fuel consumption and emissions given by EMEP/EEA (2024) per representative aircraft type. Data interpolations or extrapolations are made – in each case determined by the actual flown distance between the origin and the destination airports.

The actual flown distance between two airports can be derived as a function of the great circle distance (GCD) between the airports in question, also considering the extent of the LTO flight phase (15 NM = 27.78 km) which is a constant for all aircraft types. The relation between actual distance and GCD flown is taken from the German TREMOD AV model (Knörr et al., 2012).

- For GCD <= 100 NM (<= 185.2 km), 60 km is added to the great circle distance (GCD) to find the actual distance flown. For GCD > 100 NM (>185.2 km), 4 % additional flown distance is added for the part of GCD > 100

NM (>185.2 km). In both cases, 15 NM (=27.78 km) from the LTO flight phase is subtracted from the actual flown distance, to find the actual flown distance during cruise:

- Actual flown cruise distance (GCD <= 185.2 km) = GCD + 60 km – 27.78 km
- Actual flown cruise distance (GCD > 185.2 km) = (GCD – 185.2 km) x 1,04 + 185.2 km + 60 km – 27.78 km.

If the actual flown cruise distance, y, is smaller than the maximum cruise distance for which fuel consumption and emission data are given in the EMEP/EEA data bank, the fuel consumption or emission E (y) becomes:

$$E(y) = E_{x_i} + \frac{(y-x_i)}{x_{i+1}-x_i} \cdot (E_{x_{i+1}} - E_{x_i}) \quad y<x_{max},\ i = 0,1,2\ldots max\text{-}1 \qquad (18)$$

In (17) x_i and x_{max} denominate the separate cruise distances and the maximum cruise distance, respectively, with known fuel consumption and emissions. If the actual flown distance, y, exceeds x_{max} the maximum figures for fuel consumption and emissions must be extrapolated and the equation then becomes:

$$E(y) = E_{x_{max}} + \frac{(y-x_{max})}{x_{max}-x_{max-1}} \cdot (E_{x_{max}} - E_{x_{max-1}}) \quad y>x_{max} \qquad (19)$$

Total results are summed up and categorised according to each flight's destination airport code to distinguish between domestic and international flights.

Non-exhaust TSP, PM_{10} and $PM_{2.5}$ emissions for aircraft tyre wear and brakes during landing for all flights are calculated in DEMOS-Aviation, as a function of aircraft MTOM (Maximum Take Off Mass).

Total aircraft MTOM per airport per year support the calculations. Emission factors reported as 0.223 gPM_{10}/tonnes MTOM for brake wear and 0.253 gPM_{10}/tonnes MTOM for tyre wear are taken from Vanherle et al. (2021).

PM_{10}/TSP and $PM_{2.5}$/PM_{10} size ratios of 0.98 and 0.4 for brakes and 0.6 and 0.7 for tyres, respectively, are taken from EMEP/EEA (2024) reported for road transport non-exhaust PM, due to lack of relevant PM size fraction data for aircraft non-exhaust PM. The similar assumption for the $PM_{2.5}$/PM_{10} ratios has been made by Underwood et al. (2010) for Heathrow Airport.

Annex 3.B.10 shows the average fuel consumption and emission factors per representative aircraft type for cruise flying, as well as total distance flown, for 2023[20]. The factors are split between Copenhagen Airport and other airports and distinguish between domestic and international flights.

Specifically for flights between Denmark and Greenland or the Faroe Islands, for each representative aircraft type, the flight distances are directly shown in Annex 3.B.10, which go into the cruise calculation expressions 18 and 19.

The overall fuel precision (fuel balance) in the model is 0.92 in 2023, derived as the fuel ratio between model estimates and statistical sales. The fuel dif-

[20] Excluding flights for Greenland and the Faroe Islands.

ference is accounted for by adjusting cruising fuel consumption and emissions in the model according to domestic and international cruising fuel shares.

For inventory years before 2001, the calculation procedure is to estimate each year's fuel consumption and emissions for LTO based on LTO/aircraft type statistics from Copenhagen Airport, and total take off numbers for other airports provided by the Danish Transport and Construction Agency. Due to lack of aircraft type specific LTO data, fuel consumption and emission factors derived for domestic LTO's in Copenhagen Airport is used for all LTO's in other airports. In a next step, the total fuel consumption for cruise (true cruise fuel consumption) is found year by year as the statistical fuel consumption total minus the calculated fuel consumption for LTO.

For each inventory year, intermediate cruise fuel consumption figures split into four parts (Copenhagen/Other airports; domestic/international) are found as proportional values between part specific LTO fuel consumption values estimated as described previously, and part specific cruise:LTO fuel consumption ratios for 2001 derived from the detailed city-pair emission inventory.

Each inventory year's true cruise fuel consumption is finally split into four parts by using the intermediate cruise fuel consumption values as a distribution key. As emission factor input data for cruise, aggregated fuel related emission factors for 2001 are derived from the detailed city-pair emission inventory.

Non-road working machinery and recreational craft

Prior to adjustments for deterioration effects and transient engine operations, the fuel consumption and emissions in year X, for a given machinery type, engine size and engine age, are calculated as:

$$E_{Basis}(X)_{i,j,k} = N_{i,j,k} \cdot HRS_{i,j,k} \cdot P \cdot LF_i \cdot EF_{y,z} \qquad (20)$$

where E_{Basis} = fuel consumption/emissions in the basic situation, N = number of engines, HRS = annual working hours, P = average rated engine size in kW, LF = load factor, EF = fuel consumption/emission factor in g pr kWh, i = machinery type, j = engine size, k = engine age, y = engine-size class and z = emission level. The basic fuel consumption and emission factors are shown in Annex 3.B.11.

The deterioration factor for a given machinery type, engine size and engine age in year X depends on the engine-size class (only for gasoline), y, and the emission level, z. The deterioration factors for diesel and gasoline 2-stroke engines are found from:

$$DF_{i,j,k}(X) = \frac{K_{i,j,k}}{LT_i} \cdot DF_{y,z} \qquad (21)$$

where DF = deterioration factor, K = engine age, LT = lifetime, i = machinery type, j = engine size, k = engine age, y = engine-size class and z = emission level.

For gasoline 4-stroke engines the deterioration factors are calculated as:

$$DF_{i,j,k}(X) = \sqrt{\frac{K_{i,j,k}}{LT_i}} \cdot DF_{y,z} \qquad (22)$$

The deterioration factors inserted in (21) and (22) are shown in Annex 3.B.11. No deterioration is assumed for fuel consumption (all fuel types) or for LPG engine emissions and, hence, DF = 1 in these situations.

The transient factor for any given machinery type, engine size and engine age in year X, relies only on emission level and load factor, and is denominated as:

$$TF_{i,j,k}(X) = TF_z \qquad (23)$$

Where i = machinery type, j = engine size, k = engine age and z = emission level.

The transient factors inserted in (23) are shown in Annex 3.B.11. No transient corrections are made for gasoline and LPG engines and, hence, TF_z = 1 for these fuel types.

As a part of some engine manufacturer's emission reduction strategy, a part of the Stage IIIB and IV machines used in building and construction are equipped with preinstalled closed (wall-flow) particle filters (DPF) and hence have low particle emissions. This particle filter effect on particle emissions needs to be considered in the calculations, since the baseline emission factors for TSP more aligns with EU emission legislation limits, and these emission limits do not necessarily require particulate filters in order to be met.

The particle reduction factor, F_{dpf}, for any given machinery type, engine size and engine age in year X, depends on the share of engines with preinstalled closed particle filters, in the different size classes and emission levels:

$$F_{dpf,i,j,k}(X) = \frac{(1-S_{y,z}) \cdot EF_{y,z} + S_{y,z} \cdot EF_{dpf,y,z}}{EF_{y,z}} \qquad (24)$$

Where F_{dpf}, = particle reduction factor, S = Share of engines with preinstalled DPF's, i = machinery type, j = engine size, and k = engine age. This emission reduction factor relates to PM and BC emissions from Stage IIIB and IV diesel engines with preinstalled DPF's[21]. The emissions from all other non-road machines are not affected by this adjustment.

The final calculation of fuel consumption and emissions in year X for a given machinery type, engine size and engine age, is the product of the expressions 17-21:

$$E(X)_{i,j,k} = E_{Basis}(X)_{i,j,k} \cdot TF(X)_{i,j,k} \cdot (1 + DF(X)_{i,j,k}) \cdot F_{dpf,i,j,k}(X) \qquad (25)$$

The evaporative hydrocarbon emissions from fuelling are calculated as:

$$E_{Evap,fueling,i} = FC_i \cdot EF_{Evap,fueling} \qquad (26)$$

Where $E_{Evap,fueling}$, = hydrocarbon emissions from fuelling, i = machinery type, FC = fuel consumption in kg, $EF_{Evap,fueling}$ = emission factor in g NMVOC per kg fuel.

[21] The particle emission adjustment relating to Stage IIIB and IV engines equipped with DPF's also significantly affects BC emissions, since closed particle filters very efficiently reduce BC from the exhaust.

For tank evaporation, the hydrocarbon emissions are found from:

$$E_{Evap,tank,i} = N_i \cdot EF_{Evap,tank,i} \tag{27}$$

Where $E_{Evap,tank,i}$ = hydrocarbon emissions from tank evaporation, N = number of engines, i = machinery type and $EF_{Evap,fueling}$ = emission factor in g NMVOC per year.

National navigation and international navigation

The fuel consumption and emissions in year X, for domestic ferries are calculated as:

$$E(X) = \sum_i N_i \cdot T_i \cdot S_{i,j} \cdot P_i \cdot LF_j \cdot LAF_j \cdot EF_{k,l,y} \tag{28}$$

Where E = fuel consumption/emissions, N = number of round trips, T = sailing time pr round trip in hours, S = ferry share of ferry service round trips, P = engine size in kW, LF = engine load factor, LAF = engine load adjustment factor, EF = fuel consumption/emission factor in g pr kWh, i = ferry service, j = ferry, k = fuel type, l = engine type, y = engine year.

For the remaining navigation categories, other national sea transport and international navigation, the emissions are calculated using a simplified approach:

$$E(X) = \sum_i EC_{i,k} \cdot EF_{k,l,y} \tag{29}$$

Where E = fuel consumption/emissions, EC = energy consumption, EF = fuel consumption/emission factor in g per kg fuel, i = category (other national sea transport, international navigation), k = fuel type, l = engine type, y = average engine year.

The emission factor inserted in (29) is found as an average of the emission factors representing the engine ages which are comprised by the average lifetime in a given calculation year, X:

$$EF_{k,l,y} = \frac{\sum_{year=X}^{year=X-LT} EF_{k,l}}{LT_{k,l}} \tag{30}$$

National fishing

For fishing vessels, the fuel consumption and emissions in year X, are calculated as:

$$E(X) = \sum_i T_i \cdot P_j \cdot LF_j \cdot LAF_j \cdot EF_{k,l,y} \tag{31}$$

Where E = fuel consumption/emissions, T = sailing time pr fishing trip in hours, P = engine size in kW, LF = engine load factor, LAF = engine load adjustment factor, EF = fuel consumption/emission factor in g pr kWh, i = fishing trip no., j = fishing vessel registration no., k = fuel type, l = engine type, y = engine year.

Railways

The fuel consumption and emissions in year X, for DSB (Danish State Railways, 2019-2023) and private railway lines (all years) are calculated as:

$$E(X) = \sum_i EF_{i,j,k} \cdot S_{i,j} \cdot M_{i,j} \tag{32}$$

Here E = fuel consumption/emission, EF = fuel consumption/emission factor in g per train litra km, S = Litra type share of total train litra km, M = total train litra km, i = railway line, j = Litra type and k = fuel type (diesel, GTL or electricity).

As explained in section 3.3.3, in Danish railways, the predominant part of diesel is used by DSB. For 2019-2023, the bottom-up calculated fuel consumption for DSB and private railway companies is subtracted from total diesel fuel sales reported in the statistics (DEA, 2024), and the residual amount of fuel is allocated to the residual group "other railways traffic". For 1985-2018, the bottom-up calculated fuel consumption for private railway companies[22] is subtracted from the statistical fuel sales (DEA, 2024), and the residual amount of fuel is allocated to the residual group "DSB and other railways traffic". For the residual groups "other railways traffic" and "DSB and other railways" average emission factors for DSB are used in the following calculations.

The emissions for DSB and other railways traffic in 1985-2018, and other railways traffic in 2019-2023 are calculated as:

$$E(X) = FC(X) \cdot EF(X) \qquad (33)$$

Where E = fuel consumption/emissions, FC = fuel consumption, EF = emission factor in g per kg fuel.

Non exhaust TSP, PM_{10}, $PM_{2.5}$ and Cu emissions for the wear of contact lines for electric trains (regional and intercity, urban and metro, light rail), TSP, PM_{10} and $PM_{2.5}$ emissions for the wear of rails and train wheels (all train types) and TSP, PM_{10}, $PM_{2.5}$, Cr and Ni emissions from train brakes (all trains) are calculated in DEMOS-Rail.

The emissions are calculated as the product of train litra km, train litra performance weight (train litra service weight + total weight of passengers at average occupancy) and emission factors (g/train tonnes km).

$$E(X) = \sum_i EF_{i,j,k} \cdot S_{i,j} \cdot M_{i,j} \cdot (SW_{i,j} + PW_{i,j}) \qquad (34)$$

Here E = fuel consumption/emission, EF = fuel consumption/emission factor in g per train tonnes km, S = Litra type share of total train litra km, M = total train litra km, SW = train service weight, PW = total weight of passengers at average occupancy, i = railway line, j = Litra type and k = fuel type.

Military

For military, the emissions are estimated with the simple method using fuel-related emission factors and fuel consumption from the DEA:

$$E(X) = FC(X) \cdot EF(X) \qquad (35)$$

where E = emission, FC = fuel consumption and EF = emission factor.

[22] The small amount of GTL calculated for private railways is treated as diesel in this fuel balance, because only diesel and the consumption of electricity is reported for railways in the national statistics.

The calculated emissions for other mobile sources are shown in CollectER format in Annex 3.B.15 for the years 1990 and 2023 and as time series 1985-2023 in Annex 3.B.16 (NFR format).

Energy balance between inventory and sales

Following convention rules, the DEA statistical fuel sales figures are the basis for the full Danish inventory. However, in some cases for mobile sources the DEA statistical sectors do not fully match the inventory sectors.

In the following, the transferal of fuel consumption data from DEA statistics into inventory relevant categories is explained for national navigation and national fishing, non-road mobile machinery and recreational craft, and road transport. A full list of all fuel consumption data, DEA figures as well as intermediate fuel consumption data, and final inventory input figures is shown in Annex 3.B.14.

National navigation

Fuel used for the remaining part of the traffic between two Danish ports, other national sea transport, is taken as the difference between 1) DEA national fuel sales for national sea transport minus fuel consumption at Danish offshore installations (offshore reduced fuel sales[23]) and 2) the bottom-up calculated fuel consumption for Danish ferries in DEMOS-Navigation.

For years when the fuel estimates for ferries (not including the ferry to the Faroe Islands) are higher than the “offshore reduced” fuel sold for national sea transport, fuel is taken from fisheries in the case of marine diesel (1985-1999). For heavy fuel oil, the missing fuel amount is taken from stationary sources (1985-1986, 1988, 1994-1996) and international sea transport (2015 onwards).

National fishing

For fisheries, the calculation methodology is activity based with a fuel balance, and input fuel data is in principle the diesel fuel sold for fisheries reported by DEA.

For years when diesel fuel calculated for national navigation are higher than the “Offshore reduced” fuel sold for national navigation, diesel is transferred from fisheries to national navigation in the inventories.

Incorrectly reported gasoline and heavy fuel oil for fisheries is transferred to recreational craft (reported under “Other”) and national navigation, respectively.

According to the DEA, in some cases inaccurate costumer specifications are made by the oil suppliers, which result in sector misallocation in the sales statistics between national navigation and fisheries for diesel oil and between national navigation and industry for heavy fuel oil (Peter Dal, DEA, personal communication, 2007). Further, fuel sold for vessels sailing between Denmark and Greenland/Faroe Islands are reported as international in the DEA statistics, and this fuel categorisation is different from the IPCC guideline definitions (see following paragraph “Bunkers”).

[23] According to the Danish Energy Authority, the latter diesel fuel sales are reported as sold for national navigation by the fuel sales reporting oil companies.

Inaccurate fuel sale specifications are also the reason for heavy fuel oil being reported for fisheries in the DEA statistics. No engines installed in fishing vessels use heavy fuel oil, even though a certain amount of heavy fuel oil is listed in the DEA numbers for some statistical years (H. Amdissen, Danish Fishermen's Association, personal communication, 2006).

Non-road mobile machinery and recreational craft

For diesel and LPG, the non-road fuel consumption estimated DEMOS-NRMM is partly covered by the fuel consumption amounts in the following DEA sectors: agriculture and forestry, market gardening, and building and construction. The remaining quantity of non-road diesel and LPG is taken from the DEA industry sector.

For gasoline, the DEA residential sector, together with the DEA sectors mentioned for diesel and LPG, contribute to the non-road fuel consumption total. In addition, a certain amount of fuel is transferred from DEA road transport to outbalance the bottom-up fuel consumption calculated in DEMOS-NRMM.

The amount of diesel and LPG in DEA industry not being used by non-road mobile machinery is included in the sectors, "Combustion in manufacturing industry" (0301) and "Non-industrial combustion plants" (0203) in the Danish emission inventory.

The incorrectly reported gasoline for fisheries transferred to recreational craft is far too small to outbalance the bottom-up fuel consumption for recreational craft, and hence the missing fuel amount is taken from the DEA road transport sector to fill the fuel gap. The calculated gasoline consumption for recreational craft is grouped in the "Other" inventory category together with military activities.

The bottom-up diesel estimates for recreational craft calculated in DEMOS-NRMM is subtracted from the DEA road transport sector to fill the fuel gap. This calculated diesel consumption for recreational craft is grouped in the "Other" inventory category together with military activities.

Road transport

A certain amount of gasoline is transferred from DEA road transport to outbalance the bottom-up gasoline consumption calculated for non-road mobile machinery in DEMOS-NRMM.

The bottom-up diesel estimates for recreational craft calculated in DEMOS-NRMM is subtracted from road transport and grouped in the "Other" inventory category together with military activities.

For LPG, the difference between fuel reported in DEA statistics and bottom-up estimates for road transport is outbalanced with fuel totals from "non-industrial combustion plants" (020200) in order to obtain a fuel balance.

Classification of domestic and international aviation and navigation for Denmark

The distinction between domestic and international fuel consumption and emissions from aviation and navigation for Denmark are in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. For the national emission inventory, this, in principle, means that fuel sold (and associated emissions) for flights/sea transportation starting from a seaport/airport in the Kingdom of Denmark, with destinations inside or outside the Kingdom of Denmark, are regarded as domestic or international, respectively.

Aviation

As prescribed by the IPCC guidelines, for aviation, the fuel consumption and emissions associated with flights inside the Kingdom of Denmark are counted as domestic.

This report includes flights from airports in Denmark and associated jet fuel sales. Hence, the flights between airports in Denmark and flights from Denmark to Greenland and the Faroe Islands are classified as domestic and flights from Danish airports with destinations outside the Kingdom of Denmark are classified as international flights.

In Greenland and in the Faroe Islands, the jet fuel sold is treated as domestic. This decision becomes reasonable when considering that almost no fuel is bunkered in Greenland/the Faroe Islands by flights other than those going to Denmark.

Navigation

In DEA statistics, the domestic fuel total consists of fuel sold to Danish ferries and other ships sailing between two Danish ports. The DEA international fuel total consists of the fuel sold in Denmark to international ferries, international warships, other ships with foreign destinations, transport to Greenland and the Faroe Islands, tank vessels and foreign fishing boats.

In order to follow the IPCC guidelines the bottom-up fuel estimates for the ferry routes between Denmark and the Faroe Islands, and fuel sold in Denmark to vessels engaged in freight transportation between Denmark and Greenland/Faroe Islands are being subtracted from the fuel sales figures for international sea transport prior to inventory fuel input.

In Greenland, all marine fuel sales are treated as domestic. In the Faroe Islands, fuel sold in Faroese ports for Faroese fishing vessels and other Faroese ships is treated as domestic. The fuel sold to Faroese ships bunkering outside Faroese waters and the fuel sold to foreign ships in Faroese ports or outside Faroese waters is classified as international (Lastein and Winther, 2003).

Conclusively, the domestic/international fuel split (and associated emissions) for navigation is not determined with the same precision as for aviation. It is considered, however, that the potential of incorrectly allocated fuel quantities is only a small part of the total fuel sold for navigational purposes in the Kingdom of Denmark.

3.3.5 Uncertainties and time series consistency

For the emission components reported to the UNECE LRTAP convention, emission uncertainty estimates are made for road transport and other mobile sources using the guidelines for estimating uncertainties in the EMP/EEA guidebook (EMEP/EEA, 2024). However, for TSP, PM_{10}, $PM_{2.5}$ and BC the latter source indicates no uncertainty factor and, instead, this factor is based on expert judgement.

The activity data uncertainty factor is assumed to be 2 and 10 % for road transport and other mobile sources, respectively, based on expert judgement.

The uncertainty estimates should be regarded as preliminary only and may be subject to changes in future inventory documentation. The calculations are shown in Annex 3.B.17 for all emission components.

Table 3.3.20 Uncertainties for activity data, emission factors and total emissions in 2023 and as a trend.

Pollutant	Emission factor uncertainties [%] Road	Other	Emission uncertainties [%] Overall 2023	Trend
SO_2	50	50	46	1
NO_x	50	100	57	8
NMVOC	50	100	54	4
CO	50	100	63	9
NH_3	1000	1000	992	559
TSP	50	100	45	8
PM_{10}	50	100	47	5
$PM_{2.5}$	50	100	52	2
BC	50	100	57	2
Arsenic	1000	1000	811	95
Cadmium	1000	1000	870	193
Chromium	1000	1000	831	88
Copper	1000	1000	965	62
Mercury	1000	1000	749	113
Nickel	1000	1000	946	23
Lead	1000	1000	983	0
Selenium	1000	1000	735	189
Zinc	1000	1000	963	34
Dioxins	1000	1000	717	125
Benzo(b) flouranthene	1000	1000	840	156
Benzo(k) flouranthene	1000	1000	854	228
Benzo(a) pyrene	1000	1000	900	182
indeno(1,2,3-c,d) pyrene	1000	1000	799	141
HCB	1000	1000	823	205
PCB	1000	1000	823	19

As regards time series consistency, background flight data cannot be made available on a city-pair level from 2000 or earlier. However, aided by LTO/aircraft statistics for these years and the use of proper assumptions, a good level of consistency is still obtained in this part of the transport inventory.

The time series of emissions for mobile machinery in the agriculture, forestry, industry, household and gardening (residential), and inland waterways (part of navigation) sectors are less certain than time series for other sectors, since DEA statistical figures do not explicitly provide fuel consumption information for working equipment and machinery.

3.3.6 Quality assurance/quality control (QA/QC)

It is the intention to publish every second year a sector report for road transport and other mobile sources. The last sector report concerned the 2022 inventory (Winther, 2024).

The QA/QC descriptions of the Danish emission inventories for transport are given in Nielsen et al. (2024).

3.3.7 Recalculations

The following recalculations and improvements of the emission inventories have been made since the previous emission reporting in 2023. The absolute and percentage emission changes in 2005 and 2022 since the previous emission reporting are shown in the table in the end of this section.

For road transport the following changes have been made.

- The source for fuel consumption factors for gasoline, diesel and CNG vans as well as BEV and PHEV passenger cars and vans is now COPERT instead of HBEFA previously used.
- For passenger cars and vans, emission factors for the future Euro 7 emission class have been implemented in the model based on COPERT model updates.
- For heavy duty vehicles and buses, emission factors for the future Euro VII emission class have been implemented in the model based on COPERT model updates.
- Cold start CO, NO_x and VOC emissions for Euro V-VII heavy duty trucks has been implemented in the model based on new cold start emission factors in the COPERT model and trip km data from Statistics Denmark.
- The BEV passenger car vehicle category has been split into four vehicle weight classes based on COPERT data, enabling more precise estimates of TSP, PM_{10} and $PM_{2.5}$ emissions for tyre, brake and road wear.
- The PHEV passenger car vehicle category has been split into four vehicle weight classes based on COPERT data. This vehicle category split enables more precise estimates of fuel consumption and emissions during combustion and more precise estimates of non-exhaust PM emissions during battery usage.
- The fuel consumption and emission factors for CNG trucks and buses have been updated in the inventories based on COPERT model updates.
- Relatively large updates from DEA in the sale statistics for border fuel sales for 2022 have been implemented in the inventories.
- The mileage distribution into urban, rural and highway driving has been updated for all historical years in the fleet and mileage data provided by DTU transport.
-
- The total mileage for foreign heavy duty trucks driven on Danish roads has been updated for the years 2017-2022 in the fleet and mileage data provided by DTU transport.
- A small error in the model input value for gasoline fuel consumption in 2022 has been corrected.
- Errors in fleet data from Statistics Denmark related to type approval NEDC and WLTP values for passenger cars has been corrected for the years 2019-2021.
- Errors in the calculation of in-use fuel factors for gasoline and diesel passenger cars have been corrected for the years 2021 and 2022.

Navigation

For navigation the following changes have been made.

- For the years 2019, 2020, 2021 and 2023 updated data on engine load factors for Sjællands Odde – Aarhus, Sjællands Odde – Ebeltoft and Køge –

Rønne provided by Molslinjen, has been used in the calculations. For Sjællands Odde – Aarhus, Sjællands Odde – Ebeltoft sailing times have been slightly modified for 2023.

Fisheries
For fisheries no changes have been made.

Agriculture/forestry
For agriculture/forestry the following changes have been made.

- Small updates in stock numbers in 2020-2022 has been included in the model.

Industry
For industry the following changes have been made.

- Small updates in stock numbers in 2020-2022 has been included in the model.

Commercial and institutional
For commercial and institutional the following changes have been made.

- Small updates in stock data for gasoline fuelled working machinery in 2022 has been included in the model.

Residential
For residential the following changes have been made.

- Small updates in stock data for gasoline fuelled working machinery in 2020-2022 has been included in the model.

Railways
For railways the following changes have been made.

- A fuel balance error has been corrected for 2022 in the railways inventory model.

Civil aviation
For civil aviation the following changes have been made.

The model used for calculating civil aviation emissions has been updated by replacing the previous fuel consumption and emission factors for representative aircraft types (262 types) with fuel consumption and emission factors for a new and more comprehensive list of representative aircraft types (278 types) provided by Eurocontrol and published in the EMEP/EEA guidebook (EMEP/EEA, 2024).

Other (Military and recreational craft)
Updated emission factors derived from the road transport model in the case of military equipment for all years have caused small emission changes from 1985-2022.

3.3.8 Improvements

Fuel consumption and emission factors for road transport vehicles will be updated by the time when new data becomes available from COPERT model updates.

Table 3.3.21 The absolute and percentage emission changes in 2005 and 2022 since the previous emission reporting.

Year	Pollutant	Difference	Agr./for. (1A4c)	Civil Aviation (1A3a)	Comm./Inst. (1A4a)	Fisheries (1A4c)	Industry-Other (1A2g)	Navigation (1A3d)	Other (1A5b)	Railways (1A3c)	Residential (1A4b)	Road (1A3b)
2005	BC	Tonnes	0	-1	0	0	0	0	0	0	0	24
	CH_4	Tonnes	0	0	0	0	0	0	0	0	0	1
	CO	Tonnes	0	68	0	0	0	0	3	0	0	-3652
	CO_2	kTonnes	0	0	0	0	0	0	0	0	0	0
	N_2O	Tonnes	0	0	0	0	0	0	0	0	0	2
	NH_3	Tonnes	0	0	0	0	0	0	0	0	0	-13
	NMVOC	Tonnes	0	1	0	0	0	0	0	0	0	-364
	NO_x	Tonnes	0	-7	0	0	0	0	14	0	0	318
	PM_{10}	Tonnes	0	-1	0	0	0	0	0	0	0	48
	$PM_{2.5}$	Tonnes	0	-1	0	0	0	0	0	0	0	39
	SO_2	Tonnes	0	0	0	0	0	0	0	0	0	0
	TSP	Tonnes	0	-1	0	0	0	0	0	0	0	59
2022	BC	Tonnes	0	-1	0	0	2	0	0	1	0	-3
	CH_4	Tonnes	0	0	0	0	1	0	0	0	0	-9
	CO	Tonnes	23	29	0	0	384	22	0	17	9	-970
	CO_2	kTonnes	1	0	0	0	8	0	0	26	0	-73
	N_2O	Tonnes	0	0	0	0	0	0	0	1	0	-4
	NH_3	Tonnes	0	0	0	0	0	0	0	0	0	-21
	NMVOC	Tonnes	1	2	0	0	19	4	0	8	2	-91
	NO_x	Tonnes	1	23	0	0	38	184	1	150	0	154
	PM_{10}	Tonnes	0	0	0	0	2	0	0	1	0	-8
	$PM_{2.5}$	Tonnes	0	-1	0	0	2	0	0	1	0	-8
	SO_2	Tonnes	0	0	0	0	0	4	0	0	0	0
	TSP	Tonnes	0	0	0	0	2	0	0	1	0	-18
2005	BC	%	0,0	-33,1	0,0	0,0	0,0	0,0	0,5	0,0	0,0	1,5
	CH_4	%	0,0	0,8	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,1
	CO	%	0,0	3,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-1,8
	CO_2	%	0,0	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	N_2O	%	0,0	0,1	0,0	0,0	0,0	0,0	0,4	0,0	0,0	0,6
	NH_3	%	0,0	0,0	0,0	#DIV/0!	0,0	#DIV/0!	1,1	0,0	0,0	-0,5
	NMVOC	%	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-1,4
	NO_x	%	0,0	-1,2	0,0	0,0	0,0	0,0	0,6	0,0	0,0	0,4
	PM_{10}	%	0,0	-12,2	0,0	0,0	0,0	0,0	0,2	0,0	0,0	1,2
	$PM_{2.5}$	%	0,0	-13,1	0,0	0,0	0,0	0,0	0,2	0,0	0,0	1,2
	SO_2	%	0,0	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	TSP	%	0,0	-11,5	0,0	0,0	0,0	0,0	0,2	0,0	0,0	1,2
2022	BC	%	0,0	-42,4	0,0	0,0	2,0	1,3	0,0	15,0	0,6	-1,2
	CH_4	%	0,5	12,0	0,0	0,0	3,3	0,8	0,0	16,3	0,5	-3,0
	CO	%	0,4	10,5	0,0	0,0	3,7	2,5	0,0	11,5	0,1	-2,2
	CO_2	%	0,2	-0,1	0,0	0,0	1,2	0,0	0,1	17,1	0,1	-0,7
	N_2O	%	0,2	0,2	0,0	0,0	1,1	0,0	-0,1	17,0	0,0	-0,9
	NH_3	%	0,3	0,0	0,0	#DIV/0!	1,1	#DIV/0!	0,9	17,0	0,1	-3,0
	NMVOC	%	0,2	13,2	0,0	0,0	3,1	0,9	0,0	16,3	0,2	-2,0
	NO_x	%	0,0	4,4	0,0	0,0	2,1	2,1	0,1	17,7	0,0	0,7
	PM_{10}	%	0,0	-11,2	0,0	0,0	2,0	0,0	0,0	0,3	0,6	-0,4
	$PM_{2.5}$	%	0,0	-12,8	0,0	0,0	2,0	0,0	0,0	0,6	0,6	-0,7
	SO_2	%	0,2	-0,1	0,0	0,0	1,3	2,1	0,2	17,5	0,1	-0,6
	TSP	%	0,0	-10,0	0,0	0,0	2,0	0,0	0,0	0,3	0,6	-0,6

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3.4 Fugitive emissions

This chapter covers fugitive emissions from fuels in the NFR sector 1B. Fugitive emissions from fuels include emissions from production, storage, refining, transport, venting and flaring of oil and natural gas. Denmark has no production of solid fuels, and accordingly only emissions from storage in coal piles are included in the emission inventory. The fugitive sector consists of the following NFR categories:

1B1 Solid fuels
1B2a Oil
1B2b Natural gas
1B2c Venting and flaring
1B2d Other*
** not occurring in the Danish emission inventory*

Most fugitive emission sources are of minor importance compared to the total Danish emissions. Fugitive and national total emissions for selected pollutants are given in Table 3.4.1.

3.4.1 Source category description

According to the IPCC sector definitions the category *fugitive emissions from fuels* is a sub-category under the main-category Energy (Sector 1). The category *fugitive emissions from fuels* (Sector 1B) is segmented into sub-categories covering emissions from solid fuels *(coal mining and handling (1B1a), solid fuel transformation (1B1b) and other (1B1c))*, oil *(1B2a)*, natural gas *(1B2b)*, venting and flaring *(1B2c)* and other *(1B2d)*. The sub-categories relevant for the Danish emission inventory are shortly described below according to Danish conditions:

1B1a: Fugitive emission from solid fuels: Coal mining is not occurring in Denmark. Accordingly, only emissions from storage in coal piles are included in the emission inventory.

1B2a: Fugitive emissions from oil include emissions from exploration, storage, and transmission of crude oil, distribution of oil products and fugitive emissions from refining. Emission from oil production is included in gas production in category 1B2b.

1B2b: Fugitive emissions from natural gas include emissions from exploration, production, transmission of natural gas, distribution of natural gas and town gas, and post-meter emissions. Fuel consumption in the Danish gas treatment plant used for gas heating and drying is included under category 1A1cii (Oil and gas extraction). All pipeline compressors on the natural gas grid are electric compressors. Hence fuel consumption and emissions are not occurring (NO) in the category 1A3e i Pipeline transport. The fuel consumption in the Danish gas treatment plant is included in category 1A1cii Oil and gas extraction.

1B2c: Venting and flaring include activities onshore and offshore. Flaring occurs both offshore in upstream oil and gas production, and onshore in gas treatment and storage facilities, in refineries and in natural gas transmission and distribution. Venting occurs in gas treatment and storage facilities. Venting of gas is assumed negligible in oil and gas production and in refineries, as controlled venting enters the gas flare system.

Fugitive and national total emissions are given in Table 3.4.1. Note that the data presented in Chapter 3 relate to Denmark only, whereas information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 7.

Table 3.4.1 National and fugitive emissions of CO_2, CH_4 N_2O and GHG in 2023, and the fugitive emissions share of national total emissions.

	National emission	Fugitive emission	Fugitive/national emission
	kt	kt	%
SO_2	8	1.85	22.7
NOx	82	0.05	0.1
CO	178	0.08	0.04
NMVOC	98	4.59	4.7
$PM_{2.5}$	11	0.01	0.1
BC	2	0.01	0.8

Table 3.4.2 summarizes the Danish fugitive emissions in 2023 for selected pollutants.

Table 3.4.2 Summary of the Danish fugitive emissions in 2023.

NFR category	snap category	Pollutant	Emission	Unit	Share of total
1B1a	Storage of solid fuel	TSP	27.684	tonnes	94.9%
1B1a	Storage of solid fuel	PM_{10}	24.362	tonnes	94.2%
1B1a	Storage of solid fuel	$PM_{2.5}$	6.644	tonnes	81.7%
1B1a	Storage of solid fuel	BC	18.456	tonnes	99.6%
1B2ai	Offshore loading of oil	NMVOC	79.791	tonnes	0.3%
1B2ai	Onshore loading of oil	NMVOC	9.300	tonnes	<0.1%
1B2ai	Storage of crude oil	NMVOC	252.460	tonnes	1.0%
1B2aiv	Petroleum products processing	NMVOC	2722.000	tonnes	11.2%
1B2aiv	Sulphur recovery plants	SO_2	373.850	tonnes	73.6%
1B2av	Service stations (including refuelling of cars)	NMVOC	644.118	tonnes	2.7%
1B2b	Production of gas	NMVOC	1335.574	tonnes	5.5%
1B2b	Natural gas transmission	NMVOC	47.719	tonnes	0.2%
1B2b	Natural gas distribution	NMVOC	116.461	tonnes	0.5%
1B2b	Town gas distribution	NMVOC	17.183	tonnes	<0.1%
1B2b	Post-meter - industrial and power plants	NMVOC	0.006	tonnes	<0.1%
1B2b	Post-meter - commercial and residential	NMVOC	9.376	tonnes	<0.1%
1B2b	Post-meter - natural gas fired vehicles	NMVOC	0.006	tonnes	<0.1%
1B2c	Venting in gas storage	NMVOC	6.182	tonnes	<0.1%
1B2c	Flaring in oil refinery	SO_2	133.790	tonnes	26.3%
1B2c	Flaring in oil refinery	NO_x	7.434	tonnes	15.3%
1B2c	Flaring in oil refinery	NMVOC	16.010	tonnes	<0.1%
1B2c	Flaring in oil refinery	CO	27.853	tonnes	32.8%
1B2c	Flaring in oil refinery	TSP	0.186	tonnes	0.6%
1B2c	Flaring in oil refinery	PM_{10}	0.186	tonnes	0.7%
1B2c	Flaring in oil refinery	$PM_{2.5}$	0.186	tonnes	2.3%
1B2c	Flaring in oil refinery	BC	0.045	tonnes	0.2%
1B2c	Flaring in gas and oil extraction	SO_2	0.612	tonnes	0.1%
1B2c	Flaring in gas and oil extraction	NO_x	39.624	tonnes	81.5%
1B2c	Flaring in gas and oil extraction	NMVOC	49.288	tonnes	0.2%
1B2c	Flaring in gas and oil extraction	CO	55.086	tonnes	64.9%
1B2c	Flaring in gas and oil extraction	TSP	1.256	tonnes	4.3%
1B2c	Flaring in gas and oil extraction	PM_{10}	1.256	tonnes	4.9%
1B2c	Flaring in gas and oil extraction	$PM_{2.5}$	1.256	tonnes	15.5%
1B2c	Flaring in gas and oil extraction	BC	0.029	tonnes	0.2%
1B2c	Flaring in gas storage	SO_2	0.021	tonnes	<0.1%
1B2c	Flaring in gas storage	NO_x	1.553	tonnes	3.2%
1B2c	Flaring in gas storage	NMVOC	0.681	tonnes	<0.1%
1B2c	Flaring in gas storage	CO	1.928	tonnes	2.3%
1B2c	Flaring in gas storage	TSP	0.044	tonnes	0.2%
1B2c	Flaring in gas storage	PM_{10}	0.044	tonnes	0.2%
1B2c	Flaring in gas storage	$PM_{2.5}$	0.044	tonnes	0.5%
1B2c	Flaring in gas storage	BC	<0.001	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	SO_2	<0.001	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	NO_x	0.012	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	NMVOC	0.013	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	CO	0.015	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	TSP	<0.001	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	PM_{10}	<0.001	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	$PM_{2.5}$	<0.001	tonnes	<0.1%
1B1a	Storage of solid fuel	TSP	27.684	tonnes	94.9%
1B1a	Storage of solid fuel	PM_{10}	24.362	tonnes	94.2%
1B1a	Storage of solid fuel	$PM_{2.5}$	6.644	tonnes	81.7%
1B1a	Storage of solid fuel	BC	18.456	tonnes	99.6%
1B2ai	Offshore loading of oil	NMVOC	79.791	tonnes	0.3%
1B2ai	Onshore loading of oil	NMVOC	9.300	tonnes	<0.1%
1B2ai	Storage of crude oil	NMVOC	252.460	tonnes	1.0%
1B2aiv	Petroleum products processing	NMVOC	2722.000	tonnes	11.2%
1B2aiv	Sulphur recovery plants	SO_2	373.850	tonnes	73.6%
1B2av	Service stations (including refuelling of cars)	NMVOC	644.118	tonnes	2.7%
1B2b	Production of gas	NMVOC	1335.574	tonnes	5.5%

1B2b	Natural gas transmission	NMVOC	47.719	tonnes	0.2%
1B2b	Natural gas distribution	NMVOC	116.461	tonnes	0.5%
1B2b	Town gas distribution	NMVOC	17.183	tonnes	<0.1%
1B2b	Post-meter - industrial and power plants	NMVOC	0.006	tonnes	<0.1%
1B2b	Post-meter - commercial and residential	NMVOC	9.376	tonnes	<0.1%
1B2b	Post-meter - natural gas fired vehicles	NMVOC	0.006	tonnes	<0.1%
1B2c	Venting in gas storage	NMVOC	6.182	tonnes	<0.1%
1B2c	Flaring in oil refinery	SO_2	133.790	tonnes	26.3%
1B2c	Flaring in oil refinery	NO_x	7.434	tonnes	15.3%
1B2c	Flaring in oil refinery	NMVOC	16.010	tonnes	<0.1%
1B2c	Flaring in oil refinery	CO	27.853	tonnes	32.8%
1B2c	Flaring in oil refinery	TSP	0.186	tonnes	0.6%
1B2c	Flaring in oil refinery	PM_{10}	0.186	tonnes	0.7%
1B2c	Flaring in oil refinery	$PM_{2.5}$	0.186	tonnes	2.3%
1B2c	Flaring in oil refinery	BC	0.045	tonnes	0.2%
1B2c	Flaring in gas and oil extraction	SO_2	0.612	tonnes	0.1%
1B2c	Flaring in gas and oil extraction	NO_x	39.624	tonnes	81.5%
1B2c	Flaring in gas and oil extraction	NMVOC	49.288	tonnes	0.2%
1B2c	Flaring in gas and oil extraction	CO	55.086	tonnes	64.9%
1B2c	Flaring in gas and oil extraction	TSP	1.256	tonnes	4.3%
1B2c	Flaring in gas transmission and distribution	PM_{10}	<0.001	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	$PM_{2.5}$	<0.001	tonnes	<0.1%
1B2c	Flaring in gas transmission and distribution	BC	<0.001	tonnes	<0.1%

3.4.2 Activity data, emission factors and emissions for fugitive sources

The following paragraphs describe the methodology for emission calculation for fugitive sources, including activity data, emission factors and annual emissions. The order follows the IPCC structure (1B1 Solid fuels, 1B2a Oil, 1B2b Natural gas, 1B2c Venting and flaring), with the exceptions that exploration of gas is included in the paragraph for exploration of oil, and that production of oil is included in the paragraph for production of gas, due to similar methodologies and data providers.

Fugitive emissions from solid fuels (1B1)

Coal mining is not occurring in Denmark, and emissions from solid fuels only include particulate matter and black carbon from storage of coal in piles.

Activity data

Coal production is not occurring in Denmark. The annual total amount of coal used are included in the import statistics provided by DEA (DEA, 2024b). Coal is primarily used in power plants, and the annual fluctuations in the import rates mainly owe to variations in electricity import/export and temperature variations. The time series show a decreasing trend due to a shift of fuels in power and heat production from coal and oil to natural gas, waste and biomass (Figure 3.4.1). The increase in 2022 owe to Danish policy regarding energy security, where the Danish government allowed two power plants to burn coal and oil.

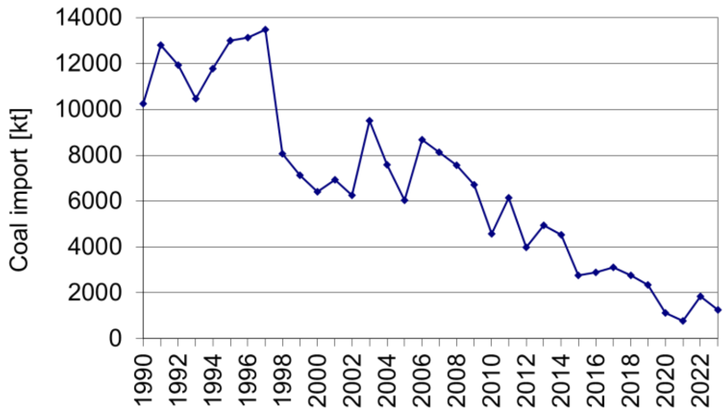

Figure 3.4.1 Import of coal.

Emission factors

The emission factors are listed in Table 3.4.3. Emissions of particulate matter (PM) from coal storage are estimated using emission factors from the Coordinated European Particulate Matter Emission Inventory Program, CEPMEIP (Visschedijk et al., 2004). Abatement technologies are used to reduce the dust from coal storage, e.g. wind protection and spraying of water with or without additives. According to the Integrated Pollution Prevention and Control Reference Document on Best Available Techniques on Emissions from Storage July 2006 (European Commission, 2006) the abatement efficiency is 80-95 % for spraying with water without additives and 90-99 % for spraying with water with additives. The US-EPA (1996) include efficiency of using water sprays and chemical stabilizer or wetting agents, respectively, both given as 40 % for $PM_{2.5}$. The abatement efficiencies of 90 % for TSP and 40 % for $PM_{2.5}$ are used in the Danish emission inventory and 78% is applied for PM_{10} (average of the efficiencies for TSP and $PM_{2.5}$).

Denmark has a long tradition for environmental awareness and regulation. There has been focus on dust from coal storage as early as in the 1980s, as the medium sized coal fired plants typically are located in urban areas. In 1980 the Danish Environmental Protection Agency appointed a steering committee for a project assessing the issues associated with change to coal for the medium sized combustion plants. Because most of the large coal piles are located in or near urban areas, where the large harbours and several large coalfired plants are located, and because of the early awareness and regulation, the emission reducing due to use of abatement technologies are applied for the years 1990 forward.

The BC emission factor is estimated as a fraction of the TSP emission factor, based on characteristics for other bituminous coal included in the 2006 IPCC Guidelines Volume 2, Chapter 1 (Equation 3.4.1).

Equation 3.4.1

$$EF_{BC} = EF_{TSP} \cdot C \cdot H \cdot 0.001$$

where EF_{BC} is the emission factor for BC [g/Mg], EF_{TSP} is the emission factor for TSP [g/Mg], C is the carbon content [kg C/GJ], and H is the heating value [GJ/Mg]. The EF_{BC} estimation is based on C = 25.8 kg C/GJ and H = 25.8 GJ/Mg, as given for other bituminous coal in IPCC (2006).

The estimated BC emission factor exceed the $PM_{2.5}$ and the PM_{10} emission factors as coal dust for the major part consist of larger particles. For combustion sources, the BC emission factor does not exceed the $PM_{2.5}$ emission factor. While coal dust is not BC in the traditional sense (from incomplete combustion), it is carbon that is primarily dark black in colour and absorbs across the visible spectrum (Khan et al., 2017). According to the Reporting Guidelines (UNECE, 2015), BC is defined as follow: ""Black carbon" (BC), which means carbonaceous particulate matter that absorbs light".

The same abatement efficiency is applied for BC as for TSP, as the BC emission factor is based on the TSP emission factor.

Table 3.4.3 Emission factors used to estimate particulate emissions from coal storage.

	TSP	PM_{10}	$PM_{2.5}$	BC
Emission factor, unabated [g/tonnes]	150	60	6	100
Abatement efficiency [%]	90	78	40	90
Emission factor, abated [g/tonnes]	15	13,2	3,6	10

Emissions

Emissions from coal storage (Figure 3.4.2) are proportional to the import rates, and the causes of the variations are described above.

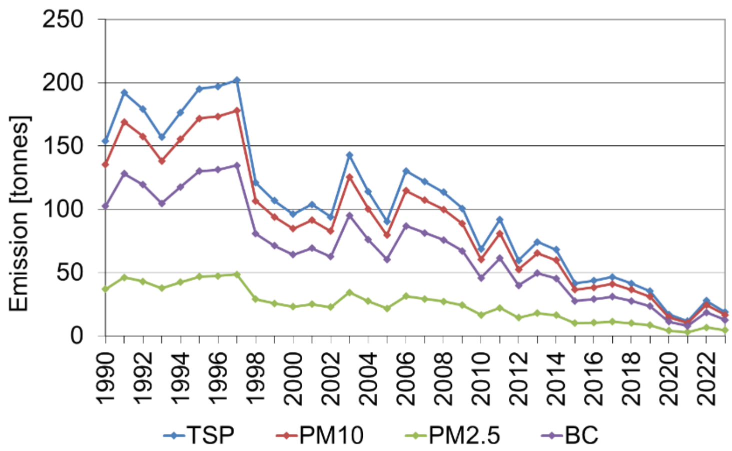

Figure 3.4.2 Emissions from coal storage.

Fugitive emissions from oil (1B2a)

The emissions from oil derive from exploration, production, onshore and offshore loading of ships, onshore oil tanks, service stations and refineries. Exploration of both oil and gas are described in this paragraph. Production of oil are described in the paragraph covering production of gas, as the emissions are reported as included elsewhere (notation key IE) and are included in category 1B2b.

Exploration, production, transport (1B2ai)

Oil and natural gas production take place offshore in the Danish part of the North Sea. Most of the oil and gas produced at the North Sea are brought ashore by pipeline; gas is led to the Nybro gas terminal and oil is led to the terminal in Fredericia (Figure 3.4.3). Oil is brought ashore by ship from the Siri platform.

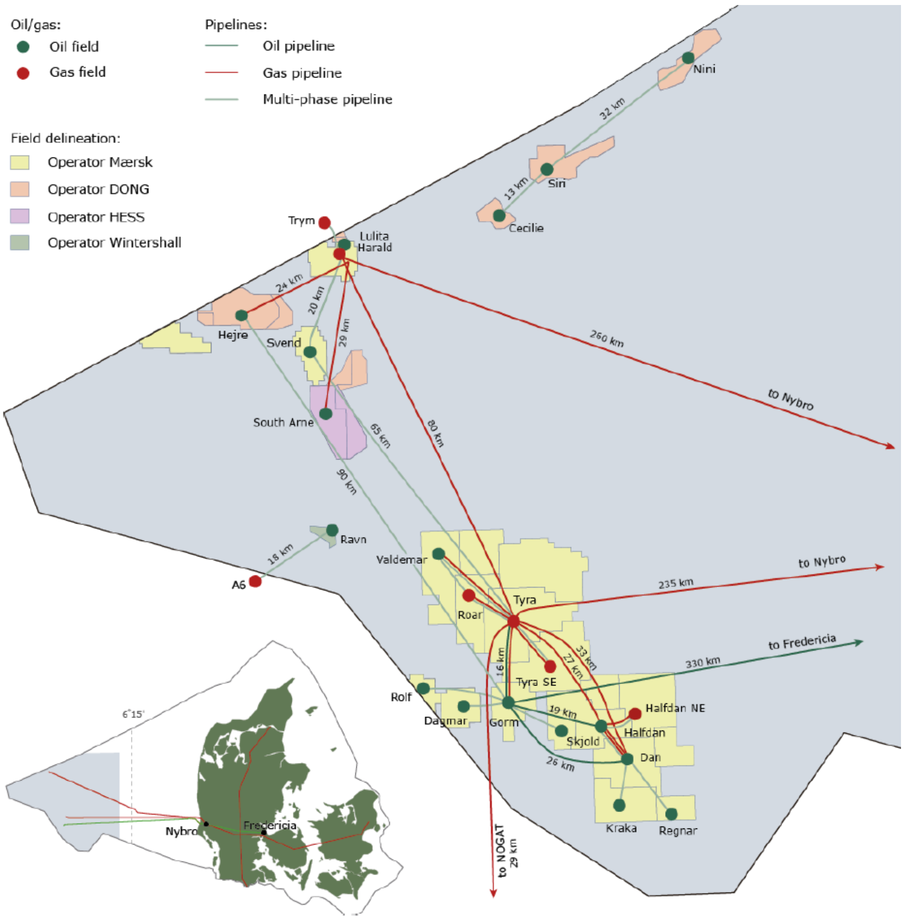

Figure 3.4.3 Production facilities in the North Sea (Danish Energy Agency, 2015).

Exploration

Activity data

Activity data for oil and gas exploration are provided annually by the Danish Energy Agency (Erichsen, 2024). Exploration of oil and gas is given separately for each exploration drilling and fluctuate significantly over the time series. The largest oil rates are seen for 1990, 2002 and 2005, while relatively large gas rates are seen for more years of the time series. Explored rates are shown in Figure 3.4.4.

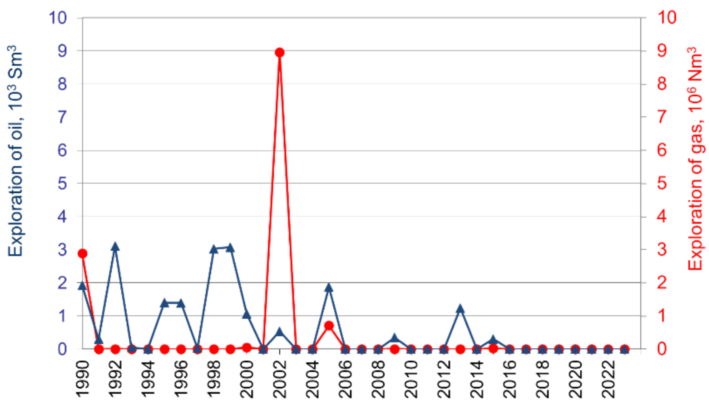

Figure 3.4.4 Exploration of oil and gas.

Emission factors

Emissions from exploration are calculated from the same emissions that are used for flaring in upstream oil and gas production. Further description on the emission factors, which are based on DEPA (2008) and EMEP/EEA (2019), is included in the Section *Fugitive emissions from venting and flaring (1B2c)* below.

Emissions

Calculated NMVOC emissions from exploration of oil and gas are shown in Figure 3.4.5. There is no correlation between emissions from oil and gas, as the individual exploration drillings have different ratios between oil and gas rates.

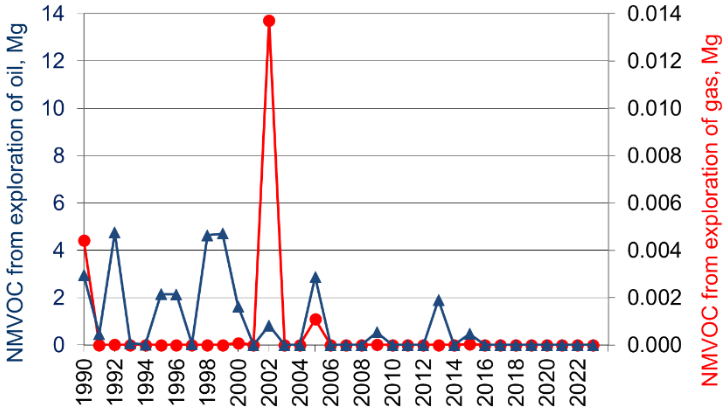

Figure 3.4.5 NMVOC emissions from exploration of oil and gas.

Production

See Section *Fugitive emissions from natural gas (1B2b) - Production*.

Transport

Activity data

Fugitive emissions of oil transport include loading of ships from storage tanks or directly from the wells. Activity data for loading offshore and onshore are provided by the Danish Energy Agency (DEA, 2024a) and from the annual self-regulating reports and supporting information from Danish Oil Pipe A/S (Boesen, 2024), respectively.

The rates of oil loaded offshore to ships roughly follow the trend of the oil production (Figure 3.4.6). Offshore loading of ships was introduced in 1999. In earlier years, the produced oil was transported to land via pipeline.

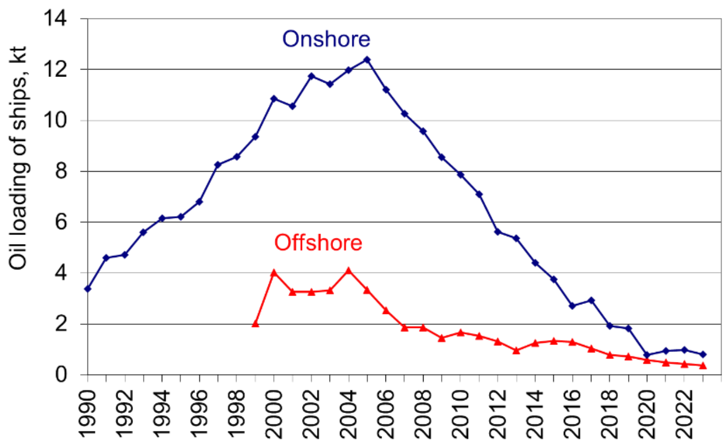

Figure 3.4.6 Onshore and offshore loading of ships.

Emission factors

Emissions from offshore loading are based on the default emission factors for offshore loading of ships from the 2019 IPCC Refinement (IPCC, 2019). A

50/50 split between loading with/without VRU is assumed in the emission calculations.

Emission factors for onshore loading is based on annual reports from the Harbour Terminal for the years 2012 onwards; A/S Dansk Shell 2013-2021 and Crossbridge 2022-2024 (Crossbridge – Havneterminalen, 2024), which include loaded amounts, standard NMVOC emission factors and emissions of NMVOC (2013-2017) or VOC (2019-2020). Estimation of CH_4 emission factors assumes that NMVOC make up 80 % of VOC in accordance with the annual reports for the harbour terminal.

The emission factor for 2012 is applied for the earlier years in the time series. The NMVOC emission factor show a significant decrease from 2016-2019 due to installation of a new vapour recovery unit (VRU2) during 2017. No emissions were reported for 2018 but has been estimated according to the environmental approval for VRU2 (Danish EPA, 2017) which include a requirement of 85 % emission reduction of the VRU2. For years with only VOC emission data, NMVOC is assumed to make up 80% of VOC, in accordance with the annual reports for the harbour terminal. Emission factors for loading of ships offshore and onshore are listed in Table 3.4.4.

Table 3.4.4 NMVOC emission factors for loading of ships onshore and offshore.

Source	NMVOC EF	Unit	Reference
Ships offshore	0.63	$Mg/1000m^3$	IPCC, 2019
Ships onshore, 1985-2012	584	g/tonne	A/S Dansk Shell - Havneterminalen, 2013
Ships onshore, 2013	587	g/tonne	A/S Dansk Shell - Havneterminalen, 2014
Ships onshore, 2014-2016	584	g/tonne	A/S Dansk Shell - Havneterminalen, 2015, 2016, 2017
Ships onshore, 2017	334	g/tonne	A/S Dansk Shell - Havneterminalen, 2018
Ships onshore, 2018	88	g/tonne	A/S Dansk Shell - Havneterminalen, 2019 Danish EPA, 2017
Ships onshore, 2019	7	g/tonne	A/S Dansk Shell - Havneterminalen, 2020
Ships onshore, 2020	8	g/tonne	A/S Dansk Shell - Havneterminalen, 2021
Ships onshore, 2021	10	g/tonne	Crossbridge - Havneterminalen, 2022
Ships onshore, 2022	10	g/tonne	Crossbridge - Havneterminalen, 2023
Ships onshore, 2023	9	g/tonne	Crossbridge - Havneterminalen, 2024

Emissions

NMVOC emissions from transport of oil are shown in Figure 3.4.7.

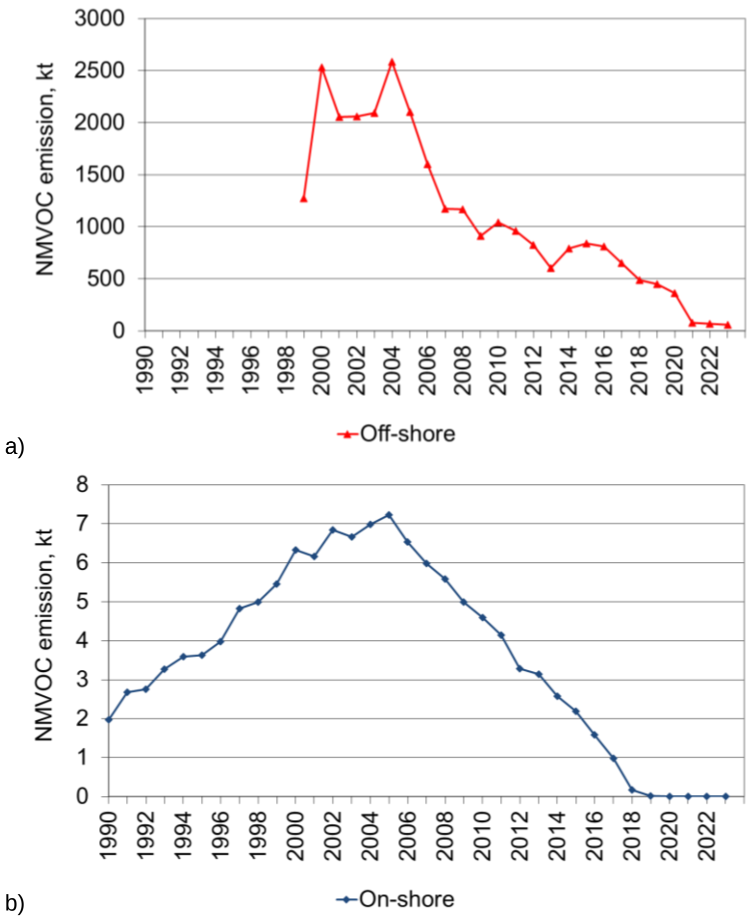

Figure 3.4.7 NMVOC emissions from a) offshore loading and b) onshore loading.

Refining/storage (1B2aiv)

Activity data

Emissions from oil refinery processes include non-combustion emissions from handling and storage of feedstock (raw oil), from the petroleum product processing and from handling and storage of products, and emissions from storage and handling at the oil terminal. Emissions from flaring in refineries are included in the Section *Fugitive emissions from venting and flaring (1B2c)*. Emissions related to process furnaces in refineries are included in stationary combustion.

The EMEP/EEA Guidebook lists potential emissions from catalytic cracking unit regenerators with partial burn and without a CO boiler and from fluid coking units. In Denmark, these processes are not used. In Denmark, visbreaking (a thermal cracking process) is used at refineries instead of the aforementioned processes. No information on emissions from this process is available from the emissions reported by the Danish refineries, and as no method is included in the 2019 EMEP/EEA Guidebook, this source is not included in the emission inventory.

Rates of crude oil processed in the two Danish refineries are given in their annual environmental report (Crossbridge, 2024; Kalundborg Refinery, 2024). Until 1996 a third refinery was in operation, leading to a decrease in the crude oil rate from 1996 to 1997. Activity date is shown in Figure 3.4.8.

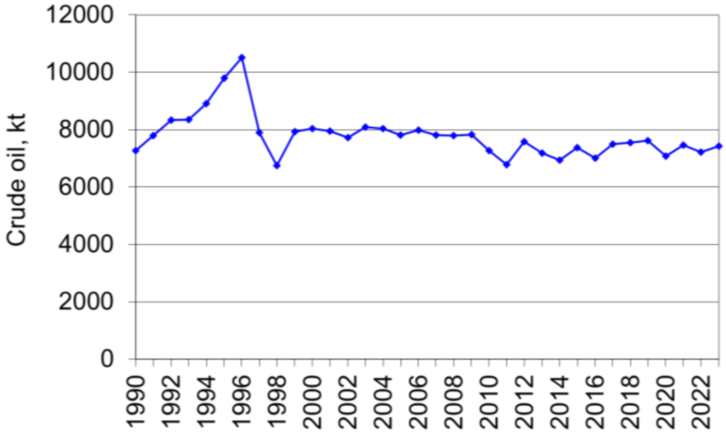

Figure 3.4.8 Crude oil processed in Danish refineries.

Annual emissions from storage and handling at the crude oil terminal are provided in the annual self-regulating reports and supporting information from Danish Oil Pipe A/S (Boesen, 2024). NMVOC emissions are shown in Figure 3.4.10.

Emission factors

Emissions of SO_2 and VOC are given by the refineries. Only one of the two refineries has made a split between NMVOC and CH_4. For the other refinery, it is assumed that 10 % of the VOC emission is CH_4 and the remaining 90 % is NMVOC (Hjerrild & Rasmussen, 2014).

Emissions from storage tanks at the Oil terminal are provided annually by Danish Oil Pipe A/S. During 2009 new emission reducing technologies (degassing unit) were installed at the crude oil terminal, leading to a significant decrease of the emissions as shown in Figure 3.4.9.

Emissions

Refineries are a significant source to fugitive emissions of SO_2, the most important activity being flaring. In 1990-1993, emissions from petroleum product processing were included in emissions from flaring in refineries (NFR category 1B2c). From 1994 the data delivery format was changed, which made it possible to split the emissions into contributions from flaring and processing, respectively. Emissions from processing are included in NFR category 1B2aiv from 1994 and forward.

SO_2 and NMVOC emissions are shown in Figure 3.4.9. One refinery was shut down in 1996 leading to lower emissions in 1997. Technical improvements of the sulphur recovery system at one of the two Danish refineries lead to a decrease of SO_2 emissions from 1996-1998. The large emissions from 2005 and onwards owe to shutdowns due to maintenance and accidents. Further, construction and initialisation of new facilities and problems related to the ammonium thiosulphate (ATS) plant at the one refinery has led to increased emissions. In 2007, the capacity of the ATS plant was increased followed by commissioning difficulties. The large emission in 2023 is due to a high number of days with outage of the CLAUS unit (124 days in 2024) and/or the SCOT unit (145 days in 2024).

The increase of NMVOC from 2005 to 2006 owes implementation of results from a DIAL measurement campaign at one refinery, which showed larger emissions than previous. According to the environmental department at that refinery, fugitive emissions from oil processing in refineries are not correlated to any measured parameters but are expected to follow a more random pattern. In 2022 the same refinery implemented a new estimation method, which substituted the previous approach, where the latest measured emission was reported for the years between measurement campaigns, and as no better methodology was available.

The new methodology is based on quantification of older measurements based on a study for a Norwegian refinery. This study (ADD Novatech, 2017) compares DIAL measurements with different calculation methods (OGI, AP-42 and EPA). The new estimates indicated that the DIAL measurement was too high (~90% for CH_4 and ~75% for nmVOC), and the study concluded that the DIAL emissions were not applicable and that the new estimation method should be used. The Danish refinery is comparable to the on in the study, though the Danish refinery is smaller. The new methodology is used in the national emission inventories. Calculations are available for 2022 and 2023, and according to the refinery it is not possible to make similar estimates for earlier years due to lack of information. Accordingly, a linear interpolation has been made from 2006 to 2022.

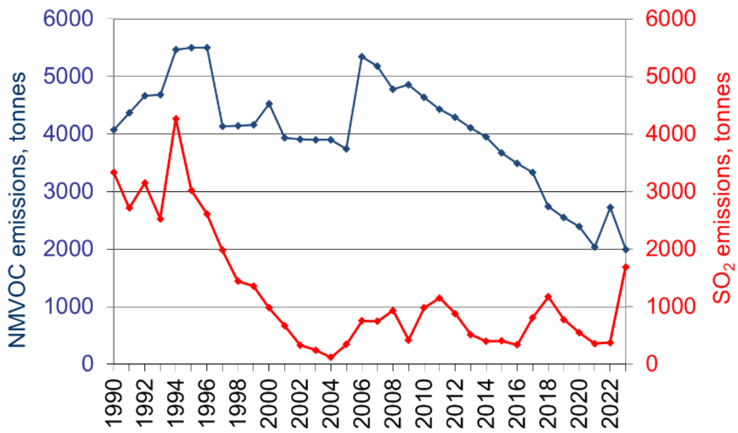

Figure 3.4.9 SO_2 and NMVOC emissions from crude oil processing including sulphur recovery in Danish refineries.

Annual emissions from storage and handling at the crude oil terminal are provided in the annual self-regulating reports and supporting information from Danish Oil Pipe A/S (Boesen, 2024). NMVOC emissions are shown in Figure 3.4.10.

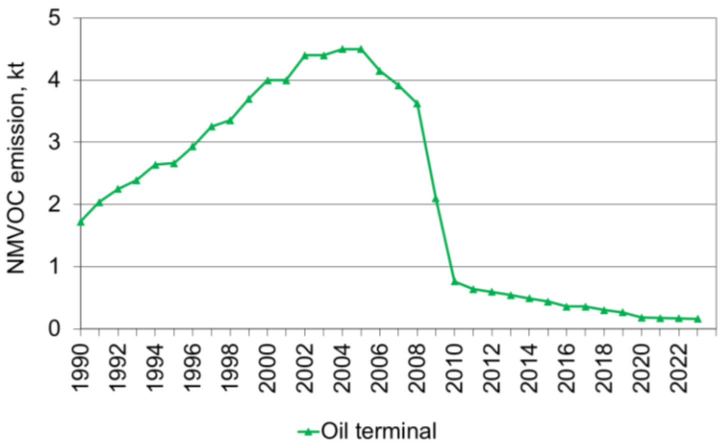

Figure 3.4.10 NMVOC emissions from storage at the crude oil terminal.

Distribution of oil products (1B2av)

Activity data

Calculations of emissions from service stations are based on gasoline sales figures from the Danish Energy statistics (DEA, 2024b). The gasoline sales show an increase from 1990-1998 and a decreasing trend since 1999 as shown in Figure 3.4.11.

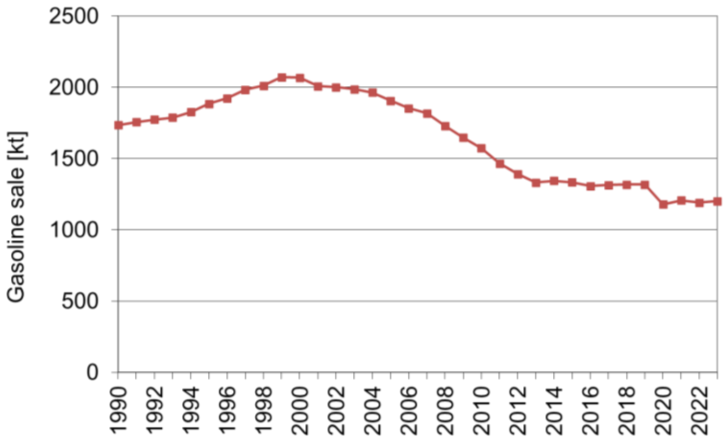

Figure 3.4.11 Gasoline sales in Denmark.

Emission factors

The NMVOC emission from service stations is calculated by use of different emission factors for the time series as shown in Table 3.4.5.

In 1994, the emission factors for NMVOC from service stations were investigated by Fenhann and Kilde (1994) for 1990 and 1991, individually. The emission factors reported for reloading for 1990 are used for the years 1985-1990, while the emission factor for 1991 is used for 1991 only. In 1995, Stage I was made obligatory, and the emission factor from the 2019 EMEP/EEA Guidebook (EMEP/EEA, 2019) is applied from 1997 and onwards. Linear interpolation is applied for the years 1995-1996.

Fenhann & Kilde (1994) also include NMVOC emission factors for refuelling for the years 1990, 1991, 1992, and 1993. The same value is given for these years. From 1994, the refuelling emission factor is based on the EMEP/EEA Guidebook (EMEP/EEA, 2019). An abatement rate of 85 % is given in the 2019 EMEP/EEA Guidebook, while 60 % were given in the 2006 EMEP/EEA Guidebook (EMEP/EEA, 2006). The Danish requirement is 85 % abatement under optimal conditions, but 70 % in practice (Danish Ministry of the Environment, 1994). Based on this, 70 % abatement is applied in the emission calculations.

Table 3.4.5 Emission factors used for estimating NMVOC from service stations.

Year	Reloading of tankers [kg NMVOC per tonnes gasoline]	Source	Refuelling of vehicles [kg NMVOC per tonnes gasoline]	Source	Sum of reloading and refuelling [kg NMVOC per tonnes gasoline]
1985-1990	1.28	Fennhann & Kilde, 1994	1.52	Fennhann & Kilde, 1994	2.8
1991	0.64	Fennhann & Kilde, 1994	1.52	Fennhann & Kilde, 1994	2.16
1992	0.519	Interpolation	1.52	Fennhann & Kilde, 1994	2.039
1993	0.397	Interpolation	1.004	Fennhann & Kilde, 1994	1.401
1994	0.276	MST, 1994	0.488	EMEP/EEA 2019 with 70 % efficiency (national regulation)	0.764
1995	0.202	interpolation	0.488	EMEP/EEA 2019 with 70 % efficiency (national regulation)	0.69
1996	0.127	interpolation	0.488	EMEP/EEA 2019 with 70 % efficiency (national regulation)	0.615
1997 onwards	0.053	EMEP/EEA 2019	0.488	EMEP/EEA 2019 with 70 % efficiency (national regulation)	0.541

Emissions

Emissions from service stations are shown in Figure 3.4.12. The decrease from 1990 to 1999 owes to decreasing emission factors due to technological improvements. From 1999 to 2005, the decrease owes to a combination of decreasing gasoline sales and decreasing emission factors. Since 2005, the decreasing trend is less pronounced and only variates with the gasoline sales, which show a slight decreasing trend.

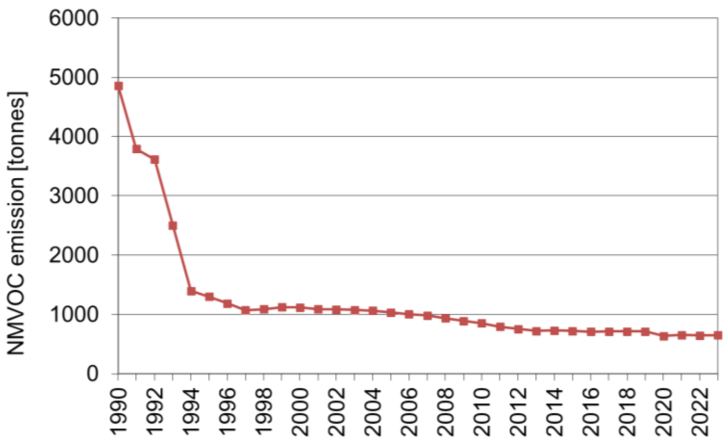

Figure 3.4.12 NMVOC emissions from service stations.

Fugitive emissions from natural gas (1B2b)

The emissions from natural gas derive from exploration, transmission, storage and distribution. Descriptions of exploration and production of natural gas are included in the sections covering exploration and production of oil *Exploration (1B2a1, 1B2b1)* and *Production (1B2a2, 1B2b2)*.

Exploration

See Section *Fugitive emissions from oil (1B2a) - Exploration*.

Production

Emissions from oil and gas production is calculated using a Tier 2 methodology based on country specific emission factors. The country specific emission factors are described below in the section "Emission factors".

Activity data

Activity data used for oil and gas production are provided by the Danish Energy Agency (DEA 2024a). As seen in Figure 3.4.13 the production of oil and gas in the North Sea has generally increased in the years 1990-2004, and since 2004 the production has decreased. Five major platforms were completed in 1997-1999, which is the main reason for the great increase in the oil production in the years 1998-2000.

The Tyra platforms are closed in the period between September 2019 and March 2024 due to redevelopment. The Tyra platforms have for 30 years been processing most of the Danish natural gas production, and the redevelopment ensures continued production from Denmark's largest producing gas field.

The gas produced in the North Sea and transported by pipeline to the treatment gas plant Nybro is dry and with low H_2S content. Following, the gas does not need any processing, which causes fugitive emissions, before going into the transmission network. The environmental approval from 2009 for Nybro states that gas processing equipment are in place, but as some parts have never been used, is has been mothballed or phased out. As follow up to the 2022 UNFCCC review, it has been verified by the senior operations supporter at Nybro that these conditions are still applicable and therefore emissions from gas processing are reported as not applicable (NA) for the entire time series.

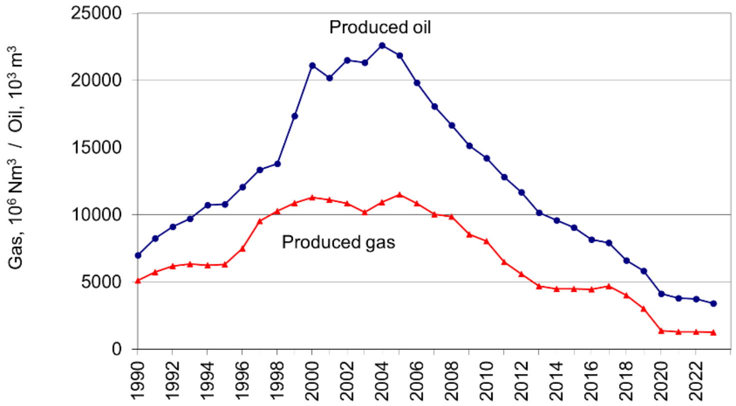

Figure 3.4.13 Production of oil and gas.

Emission factors

A Tier 2 methodology is applied, using country specific emission factors. Development of the country specific emission factors has been made in close corporation with the industry association for the Danish offshore sector (Danish Offshore) and the Danish operators TotalEnergies and INEOS Energy. The operators are providing data and information about emissions and related issues for the offshore production facilities. Both Danish operators have made drone measurements, some carried out by the independent company Explicit ApS, who have also contributed to the improvement work providing information about the measurements, including details about the state-of-the-art ISO/IEC 17025 accredited drone-flux method (DFM) developed by Explicit. There has not been drone measurement campaigns in 2023.

The country specific emission factors are based on company emission inventories for the larger operator, information from the operators' LDAR programmes, results from drone measurements, and supporting information regarding national circumstances in the offshore oil and gas production industry.

Annual emission inventories for the years 2019 to 2023 have been provided by the larger operator, including emission estimates on installation level based on the methodology in the company's guidelines. Installation specific activity data and gas composition information, and company specific emission factors are used for calculation. The emission factors, which are developed by the company's international headquarters based on experience in measurements and operating practices within the company, apply to all the company's oil and gas production operations worldwide, and are subject to annual data reporting audits by third parties. The inventory includes emission from unburnt gas for the unlit flares (cold vents), process vents (glycol units), oily water treatment, centrifugal compressors, and reciprocating compressors.

The operators provided information about leak detection and repair (LDAR). The operators are much aware of leaks due to the safety of the personnel and the environmental and safety regulations for offshore facilities. There are gas detectors all over the process offshore, which will react in case of a leak. Following, the gas leak amounts are small. Detected leaks are registered including type of leak, estimates of the leaked amounts, action required, and how the leak is or will be rectified.

In 2022, drone measurements have been carried out and the results have been provided by the operators for seven fields. The first drone measurements used the AUSEA technology. The newest measurements were using the DFM (Drone Flux Measurement) technique. The DFM method is distinguished by simultaneous measurements of wind using 3D ultrasonic anemometers, which significantly increase the identification of emission sources. The DFM method allows for a split of the emissions on source level, e.g. flare, platform structure and wellhead platform.

The fugitive emissions based on the DFM results are significantly lower than estimates in the operator emission inventories. For one of the fields the DFM measurements find site emissions around 2 kg/h while the corresponding estimate based on the company reporting guidelines is around 28 kg/h. This might be because emission factors in the company reporting guidelines mainly are based on conditions for American facilities and partly for onshore facilities, which might be subject to less strict regulation than Danish offshore facilities, e.g. due to the higher safety risk offshore.

Data from the operator do not split emissions between oil and gas production, respectively, as all the Danish facilities produce both oil and gas and following equipment leaks are related to both oil and gas production.

Annual production data of oil and natural gas, respectively and data from the operator inventories, LDAR programmes and drone measurements include emissions on field level. This allows for setting up a time series for the country specific emission factors, considering the distribution of the production between the fields. Thereby differences in the emission level between the fields are reflected.

The country specific tier 2 emission factors (Table 3.4.6) are expressed as emission per gas production, which is in accordance with API (2021), who suggest using emission factors for gas production for facilities that produce both oil and gas.

Table 3.4.6 Country specific (CS) emission factors for 2023.

	NMVOC	unit
Oil production offshore*	IE	
Gas production offshore	1.02E-03	Gg/10^6 m^3 gas produced

* Emissions from oil production are included in the country specific emission factors for gas production.

Emissions

Calculated NMVOC emissions from oil and gas production are shown in Figure 3.4.15. The annual variations follow the production rates combined with the distribution of the production on the individual fields.

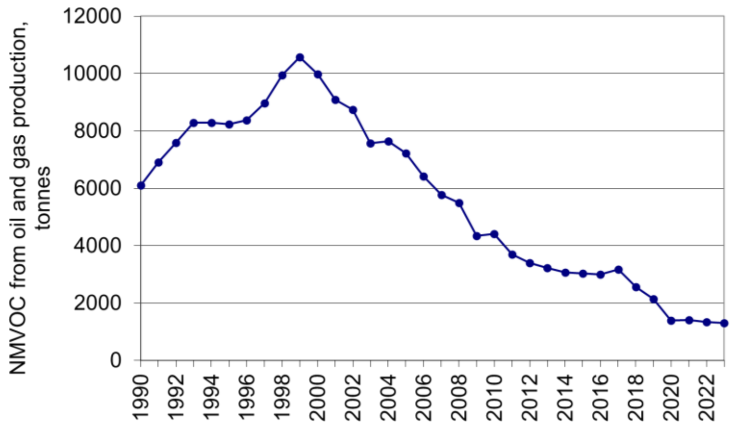

Figure 3.4.15 NMVOC emissions from production of oil and natural gas.

Transmission and storage

Activity data

The fugitive emissions from transmission and storage of natural gas are based on information from the gas transmission companies, which provide data on transmission rates, pipeline losses, and length and material of the pipeline systems. The length of the transmission pipelines is approximately 900 km.

The activity data used in the calculation of the emissions from transmission of natural gas are shown in Figure 3.4.16. Transmission rates for 1990-1998 refer to annual environmental reports of DONG Energy. For 1999-2006, the transmission rates refer to the Danish Gas Technology Centre (Karll 2002, 2003, 2004, 2005; Oertenblad 2006, 2007). From 2008 onwards, transmission rates refer to Energinet.dk (2024b). Transmission losses for 1991-1999 are based on annual environmental report of DONG Energy. The average for 1991-1995 is applied for 1990. From 2005 onwards, transmission losses are given by Energinet.dk. The average for 2005-2010 is applied for the years 2000-2004.

The variation over the time series owes mainly to variations in the winter temperature and to the variation of import/export of electricity from Norway and Sweden. The transmission rate is less than the production rate, as part of the produced natural gas is exported through the NOGAT pipeline system. The increase in 2023 is due to commissioning of the new gas pipeline, Baltic Pipe, which transport Norwegian natural gas from the North Sea via Denmark to Poland. A new receiving plant is constructed at the gas treatment plant for the Danish natural gas from the North Sea, and the Danish gas transmission network has been expanded with an approximately 210 km pipeline. The pipeline runs through a new compressor station in Zealand. The annual capacity of the Baltic Pipe is 10 billion cubic meters gas.

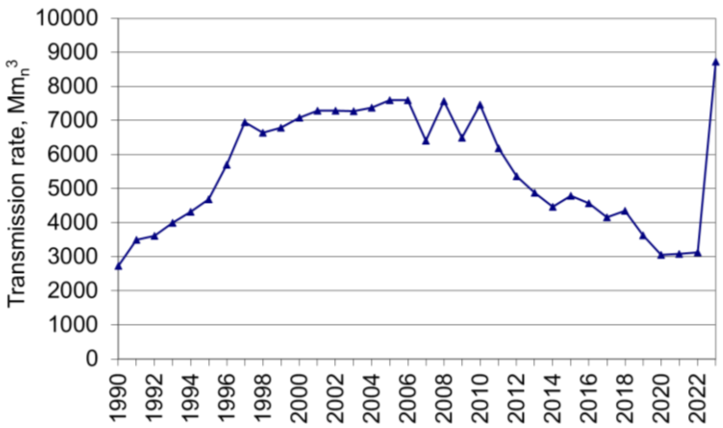

Figure 3.4.16 Rates for transmission of natural gas.

Emission factors

The fugitive emissions from transmission and storage of natural gas are based on data on gas losses from the companies and on the average annual natural gas composition given by Energinet.dk (2024c) (Table 3.4.7).

Table 3.4.7 Annual gas composition, lower heating value and density for Danish natural gas.

		Unit	1990	2000	2005	2010	2015	2020	2022	2023
Methane	CH_4	molar-%	90.92	86.97	88.97	89.95	88.80	95.9	91.70	88.06
Ethane	C_2H_6	molar-%	5.08	6.88	6.14	5.71	6.08	3.05	4.99	7.28
Propane	C_3H_8	molar-%	1.89	3.17	2.50	2.19	2.47	0.18	0.93	1.39
i-Butane	i-C_4H_{10}	molar-%	0.36	0.43	0.40	0.37	0.39	0.05	0.13	0.13
n-Butane	n-C_4H_{10}	molar-%	0.50	0.61	0.55	0.54	0.59	0.03	0.13	0.18
i-Petane	i-C_5H_{12}	molar-%	0.14	0.11	0.11	0.13	0.13	0.01	0.03	0.03
n-Petane	n-C_5H_{12}	molar-%	0.10	0.08	0.08	0.08	0.10	0.01	002	0.02
n-Hexane and heavier hydrocarbons	C^{6+}	molar-%	0.09	0.06	0.05	0.06	0.05	0.02	0.03	0.02
Nitrogen	N_2	molar-%	0.31	0.34	0.29	0.31	0.32	0.31	0.88	0.97
Carbon dioxide	CO_2	molar-%	0.60	1.35	0.90	0.66	1.07	0.44	1.16	1.93
Lower heating value	H_n	MJ/m^3_n	39.176	40.154	39.671	39.461	39.635	36.700	37.407	38.026
Density	ρ	kg/m^3_n	0.808	0.846	0.825	0.816	0.828	0.749	0.787	0.818

Emissions

The gas transmission company reports emissions of CH_4 for the years 1999-2006, based on registered loss in the transmission grid and the emission from the natural gas consumption in the pressure regulating stations. NMVOC emissions estimates are based on the CH_4 emissions and the annual composition of Danish natural gas given by Energinet.dk. For the years 1991-1998 and 2007 onwards, the NMVOC emissions for transmission are estimated based on the registered gas loss provided by the transmission company and the annual composition of Danish natural gas given by Energinet.dk. Transmission loss is not available for 1990, why the average for 1991-1995 is applied.

As the pipelines in Denmark are relatively new and made of plastic, most emissions are due to leaks during construction and maintenance. This leads to large annual fluctuations in emissions, which are not correlated to the transmission rates. E.g. the large emission in 1995 owe to a large construction work covering four different locations. The increase in 2011 owe to venting for drainage of the pipes in preparation for construction work on a new compressor station, and the increase in 2014 owe to the construction of a new major railway line. The increase in 2021 and 2022 owe to increased focus from the transmission company on improvement of the data foundation. Further, there have been more construction work than in the previous years, e.g. activities related to two biogas systems and the Baltic pipe. The decrease in 2023 is mainly due to the completion of the work on the Baltic Pipe.

Emissions of NMVOC from transmission of natural gas are shown in Figure 3.4.17.

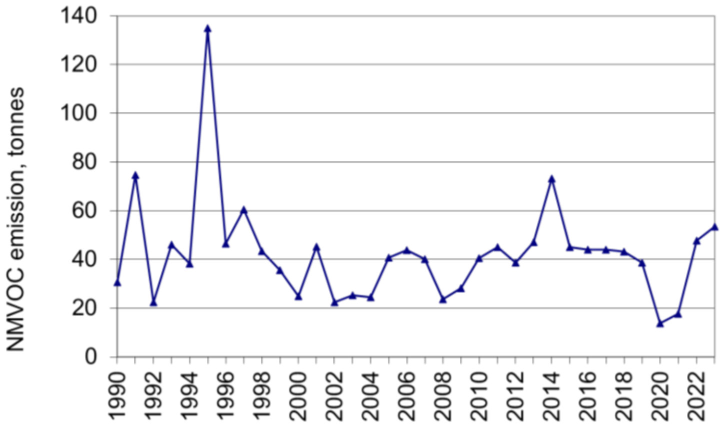

Figure 3.4.17 NMVOC emissions from transmission of natural gas.

Distribution

Gas distribution 1B2b5 covers emissions from the natural gas and town gas distribution pipelines, and gas post-meter emissions from appliances in industrial plants and power stations, in the commercial and residential sector and from natural gas fired vehicles.

Activity data

Distribution rates for 1990-1998 are estimated from the Danish energy statistics. Distribution rates are assumed to equal total Danish consumption rate minus the consumption rates of sectors that receive the gas at high pressure. The following consumers are assumed to receive high-pressure gas: town gas production companies, production platforms and power plants. In 1999-2006, distribution rates refer to DONG Energy/Danish Gas Technology Centre/Danish gas distribution companies (Karll, 2002; Karll, 2003; Karll, 2004; Karll, 2005; Oertenblad, 2006; Oertenblad, 2007). Since 2007, the distribution rates are given by the distribution companies. The fugitive losses from distribution of natural gas are only given for some companies. The average of the available "loss/distribution"-ratios is used for the remaining companies too.

Activity data for distribution of town gas are rather scarce, and calculations are based on the available data from the town gas distribution companies on gas losses from the pipelines. At present, there are two areas with town gas distribution and correspondingly two distribution companies. Two other companies in other areas were closed in 2004 and 2006, and it have not been possible to collect data for all years in the time series. The emissions have been calculated for the years with available data and the distribution loss for the first year with data has been applied for the previous years in the time series. Data is missing for the later years (1996-2003) for one of the distribution companies. The distribution rate is assumed to decrease linearly to cero over these years, and the share ("distribution loss/distribution rate") is assumed equal to the value for 1995.

Data on the distribution network are given by Energinet.dk, DGC and the distribution companies concerning length and material. The length of the distribution network is around 20.000 km. Because the distribution network in Denmark is relatively new, most of the pipelines are made of plastic (approximately 90 %). For this reason, the fugitive emission is negligible under normal operating conditions as the distribution system is basically tight with no fugitive losses. However, the plastic pipes are vulnerable and therefore most of the fugitive emissions from the pipes are caused by losses due to excavation damages, and construction and maintenance activities performed by the gas companies. These losses are either measured or estimated by calculation in each case by the gas companies. About 5 % of the distribution network is used for town gas. This part of the network is older, and the fugitive losses are larger. The fugitive losses from this network are associated with more uncertainty as it is estimated as a percentage (15 %) of the meter differential. This assumption is based on expert judgement from one of the town gas companies (Jensen, 2008). Distribution rates are shown in Figure 3.4.18.

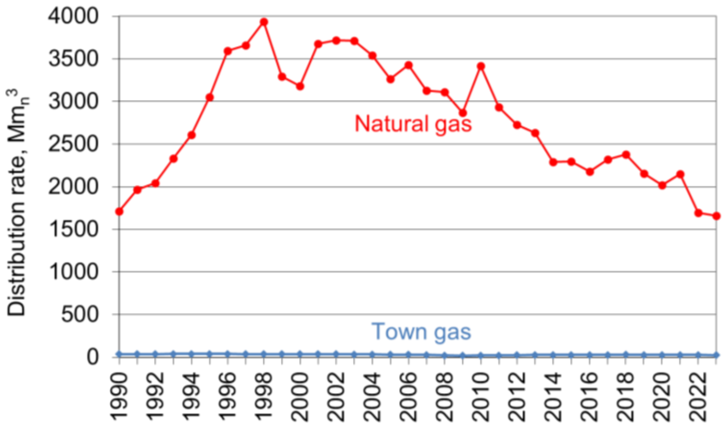

Figure 3.4.18 Distribution rates of natural gas and town gas.

Activity data for post-meter emissions natural gas consumption in industry and power plants, in the residential and commercial sector and the number of natural gas fired vehicles. Natural gas consumptions are based on the energy statistics and the number of natural gas fired vehicles are in accordance with the numbers used in the emission inventory for mobile sources (Chapter 3.3). Activity data for post-meter emissions are included in Figure 3.4.19.

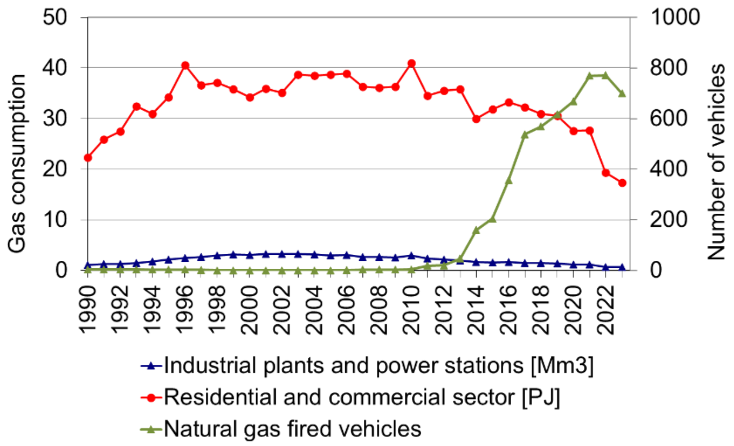

Figure 3.4.19 Distribution rates of natural gas and town gas.

Emission factors

Emissions from natural gas distribution are calculated from the fugitive losses from pipelines and the gas quality measured by Energinet.dk (Table 3.4.8). The same approach is used for town gas, which is natural gas admixed ~ 50 % ambient air. From 2014, one town gas distribution company has started to admix biogas. In 2015, the share of biogas is 17.5 %, which is expected to increase in the coming years. The admixed biogas has not been upgraded as tests of different appliances have shown that up to 40 % un-upgraded biogas can be added to the town gas without causing problems with the appliances' combustion. The gas composition of biogas is given in Table 3.4.8.

Table 3.4.8 Composition of biogas admixed to town gas (Jeppesen, 2014; Ea Energianalyse, 2014).

Methane	molar-%	60.98
Nitrogen	molar-%	0.001
Carbon dioxide	molar-%	39.02
Lower heating value	MJ/m^3_n	21.53
Density	kg/m^3_n	0.808

The distribution companies provide emissions of CH_4 for 1997 and onwards. For 1995-1996, CH_4 emissions are calculated from the registered loss from distribution and the annual composition of Danish natural gas given by Energinet.dk. As distribution losses are not available for the years 1990-1994, the percentage loss for 1995 is used.

Emission factors for post-meter emissions for appliances in industrial plants and power stations and for natural gas fired vehicles are Tier 1 emission factors from the 2019 IPCC Refinement. Emission factors for residential and commercial appliances are calculated with country specific emission factors based on Merrin & Francisco (2019) and country specific number of appliances per type. The emission factors for post-meter emissions are included in Table 3.4.9.

Table 3.4.9 Emission factors for post-meter emissions.

	Unit	NMVOC	Source
Appliances in industrial plants and power stations	t/Mm3 gas consumed	8.00E-06	2019 IPCC
Appliances in the residential and commercial sector	g/GJ	0.485	CS
Natural gas fired vehicles	t/vehicle	8.00E-06	2019 IPCC

Emissions

Emissions of NMVOC from distribution of natural gas and town gas are shown in Figure 3.4.20. Emissions from the natural gas network are variable and are associated with renovation to the network and excavation damages. The decreasing trend for town gas owe to phase-out of town gas distribution in two areas. Further relining of old pipelines has reduced the gas loss from town gas distribution.

Before 2006, the natural gas losses from distribution are based on estimates, as data are not available. Natural gas losses for the years 2001-2005 are based on loss/distribution rate in 2006. Loss rates for 1998-2000 are available in the annual environmental reports for the then distribution company, and for the years 1990-1997 the 1995 loss/distribution rate, which is available in the 1999 environmental report, is applied, which is available in the 1999 environmental report. This is the reason for the changes 1997-1998 and 2000-2001. The Danish Gas Technology Centre (DGC) has provided data on annual gas loss for natural gas distribution for the years 2020 onwards. In the later years there have been a large contribution from excavation damages particular in connection to expansion of district heating in areas where it substitutes natural gas, as the piping is about the same place and the natural gas is not disconnected until the construction work is completed.

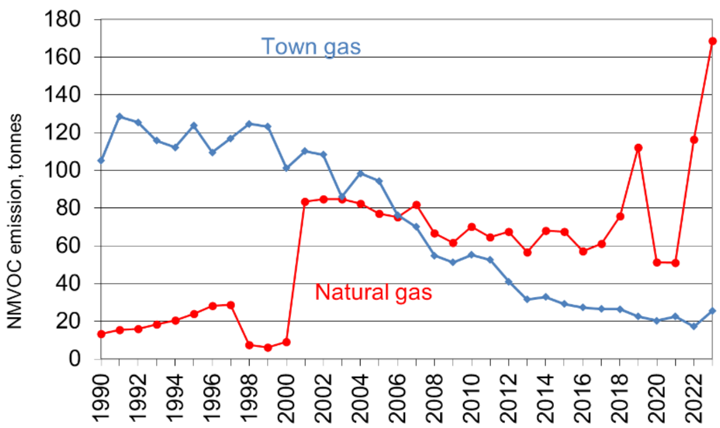

Figure 3.4.20 NMVOC emissions from distribution of gas.

Post-meter NMVOC emissions are shown in Figure 3.4.21. The annual variation depends mainly on the natural gas consumption in residential and commercial plants. Post-meter emissions from industrial plants, power plants and natural gas fired vehicles are minor.

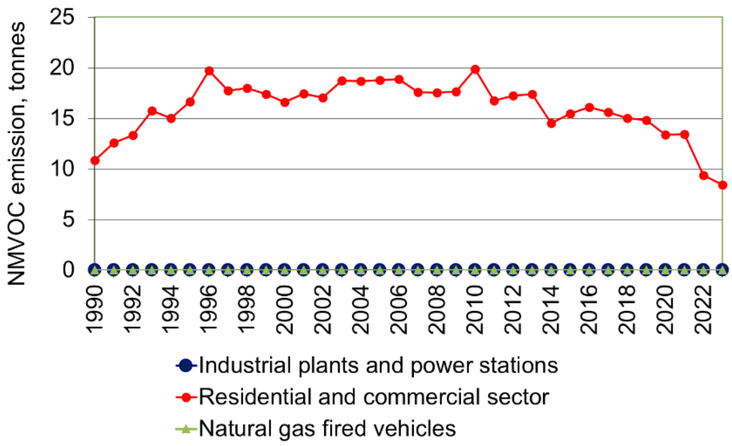

Figure 3.4.21 NMVOC post-meter emissions.

Fugitive emissions from venting and flaring (1B2c)

Venting occurs in the two Danish natural gas storage facilities. Flaring occurs in refineries, in oil and gas production, in gas treatment and storage facilities, and in gas transmission and distribution.

Venting

Activity data

The natural gas storage facilities are obligated to make environmental reports on annual basis, including data on venting. Venting of gas is assumed to be not occurring in extraction and in refineries, as controlled venting enters the gas flare system. Venting rates in gas storage facilities are shown in Figure 3.4.22. Data are not available for the years 1990-1994 for the one gas storage facility that was in operation over the entire time series, and the average for 1995-1998 is applied. The second gas storage facility was opened in 1994, leading to increasing venting rates.

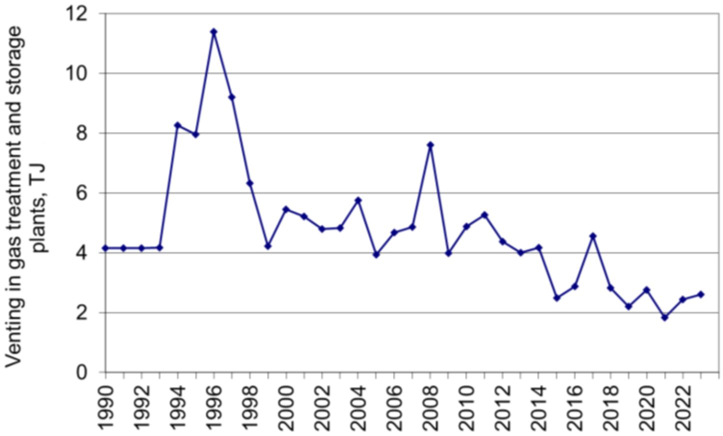

Figure 3.4.22 Venting rates in gas storage facilities.

Emission factors

Emissions of NMVOC from venting are given in the environmental reports for the gas storage facilities (Energinet.dk, 2024a).

Emissions

Venting is limited to the gas storage facilities and the emissions are of minor importance to the total fugitive emissions. Venting emissions are included in Figure 3.4.23.

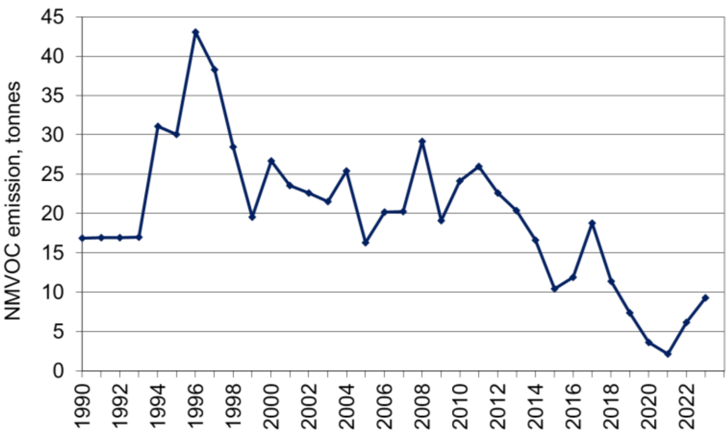

Figure 3.4.23 NMVOC emissions from venting rates in gas storage facilities.

Flaring in refineries

Activity data

Flaring rates for the two Danish refineries are given in their environmental reports and in additional data provided by the refineries directly to DCE. From 2006, flaring rates are given in the EU ETS reporting. Data are not available for the years 1990-1993, why the flaring rate for 1994 has been adopted for the previous years. Flaring rates are shown in Figure 3.4.24.

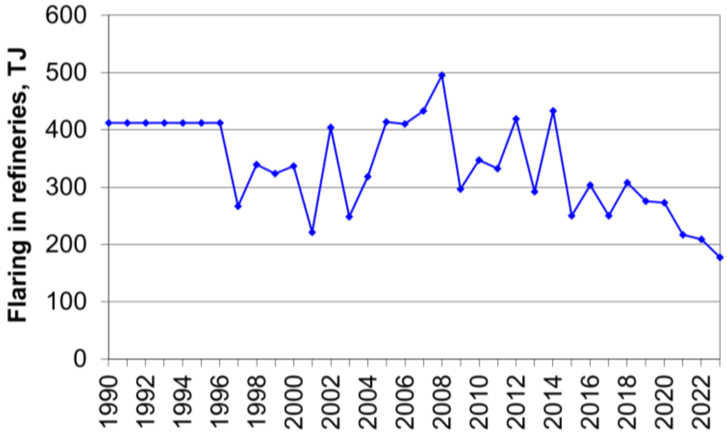

Figure 3.4.24 Flaring rates in refineries.

Emission factors

SO_2 emissions are provided annually by the refineries, while NO_x emissions are provided annually by only one refinery. The composition of refinery gas is given for 2008 by one of the two refineries. As the composition for refinery gas is very different from the composition of natural gas, the 2008 refinery gas composition is used in calculations for both Danish refineries. The NMVOC emission factor based on the 2008 refinery gas composition are applied for both refineries for the entire time series. Emissions of the remaining pollutants are based on standard emission factors from the 2019 EMEP/EEA Guidebook. Emission factors for selected pollutants are listed in Table 3.4.10.

Table 3.4.10 Emission factors for flaring in refineries.

Pollutant	Emission factor, g/GJ
NO_x	29.2
NMVOC	76.45
CO	133
TSP	0.89
PM_{10}	0.89
$PM_{2.5}$	0.89
BC	0.21

Emissions

Emissions of NMVOC and SO_2 are shown in Figure 3.4.25. The variation over the time series mainly reflects the annual variation in the activity rate for flaring. SO_2 in the early years of the time series are very uncertain as one refinery is closed, and as only very scarce amounts of information are available. It has not been possible to get further verification the data for 1990-1994.

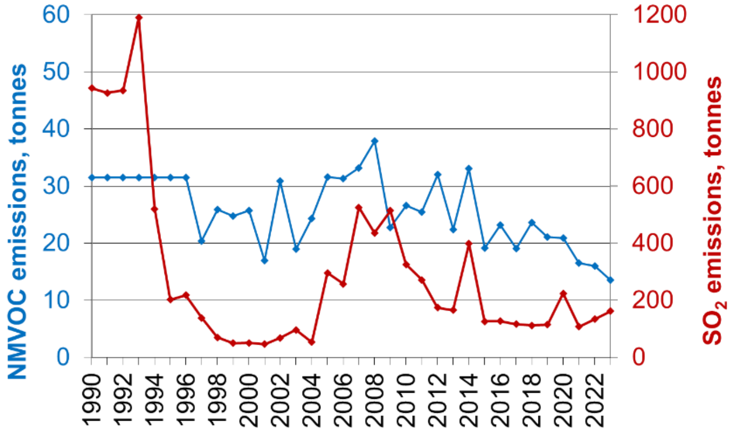

Figure 3.4.25 NMVOC and SO_2 emissions from flaring in refineries.

Flaring in upstream oil and gas production

Activity data

From 2006, data on flaring in upstream oil and gas production is given in the reports for the EU ETS and thereby emission calculation can be made for the individual production units. Before 2006, only the total flared amount is available in the annual report Denmark's oil and gas production (Danish Energy Agency, 2023a). Flaring rates are shown in Figure 3.4.26. Flaring rates in upstream oil and gas production have been decreasing over the last 10 years period in accordance with the decrease in production as seen in Figure 3.4.13. Further, there is focus on reduction of the amount being flared for environmental reasons.

The Tyra platforms are closed in the period between September 2019 and the March 2024 due to redevelopment. The Tyra platforms have for 30 years been processing most of the Danish natural gas production, and the redevelopment ensures continued production from Denmark's largest producing gas field.

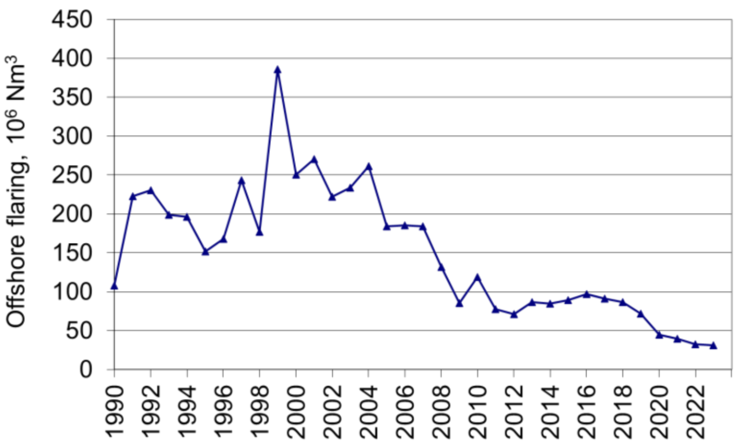

Figure 3.4.26 Flaring rates in upstream oil and gas production.

Emission factors

The emission factors for flaring in upstream oil and gas production are shown in Table 3.4.11. The NO_x emission factor is based on the conclusion in a Danish study of NO_x emissions from offshore flaring carried out by the Danish Environmental Protection Agency (DEPA, 2008). The recommended NO_x emission factor (31 008 g per GJ or 0.0015 tonnes NO_x per tonnes gas) corresponds well with the emission factors used to estimate NO_x emission in other countries with oil production in the North Sea (Netherlands: approximately 0.0014 tonnes NO_x per tonnes gas and United Kingdom: approximately 0.0013 tonnes NO_x per tonnes gas). Emission factors for all other pollutants are based on standard Tier 1 emission factors for stationary combustion of gaseous fuels in energy industries from the 2019 EMEP/EEA Guidebook.

Table 3.4.11 Emission factors for flaring in upstream oil and gas production.

Pollutant	Emission factor, g/Nm^3
SO_2	0.019
NO_x	1.23
NMVOC	1.53
CO	1.71
TSP	0.039
PM_{10}	0.039
$PM_{2.5}$	0.039
BC	0.0009

Emissions

Emissions from flaring in upstream oil and gas production are estimated from the same emission factors for all years in the time series, and the variations reflect only the variations in the flared amounts. As shown in Figure 3.4.27, there was a marked increase in the rate of flaring in upstream oil and gas production in 1997 and especially in 1999. The increase in 1997 was due to the new Dan field and the completion of the Harald field. The increase in 1999 was due to the opening of the three new fields Halfdan, Siri and Syd Arne.

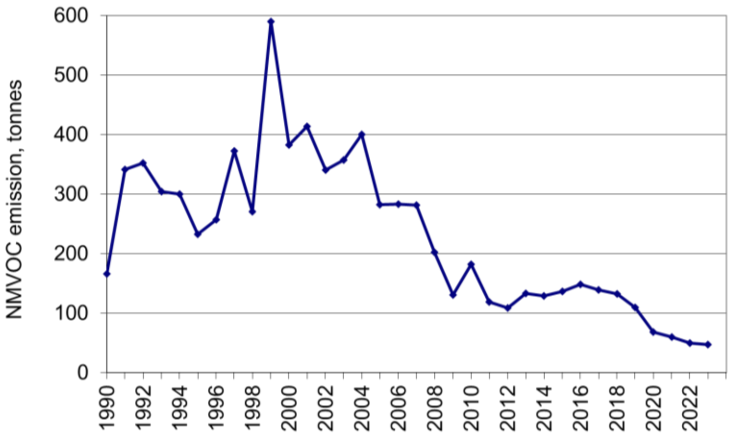

Figure 3.4.27 NMVOC emissions from flaring in upstream oil and gas production.

Flaring in gas treatment and storage facilities

Activity data

Activity data for flaring at the gas treatment facility are given in environmental reports (1994-2005) and in the EU-ETS reports (2006 onwards) and for gas storage facilities in environmental reports (Energinet.dk, 2023a). Flaring rates in gas treatment and gas storage facilities are not available before 1994. The mean value for 1994-1998 has been adopted as basis for the emission calculation for the years 1990-1993 (Figure 3.4.28). Note that one of the two gas storage facilities was not opened before 1994. The large amount of gas flared in 2007 owe to a larger maintenance work at the gas treatment plant. The increase in 2017 owe to increased flaring amount at the gas treatment plant. The increase in 2022 owe to the emissions from the receiving terminal for Baltic Pipe, which is a gas pipeline that provides Denmark and Poland with a direct access to Norway's gas fields. The receiving terminal is an expansion of the existing receiving terminal Nybro, which receive gas from the Danish production facilities in the North Sea. Baltic Pipe was in full operation from ultimo November 2022.

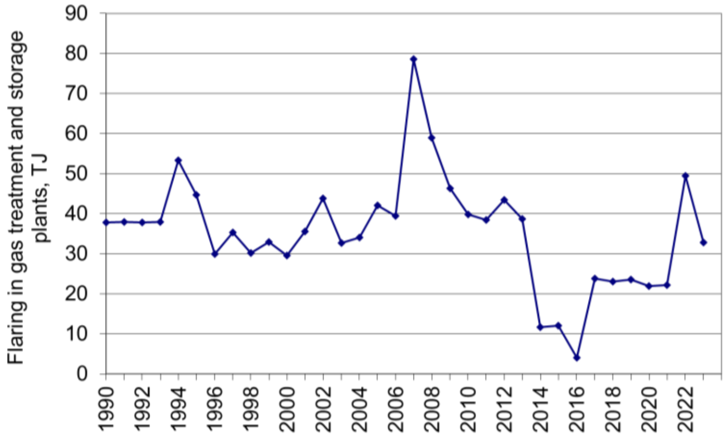

Figure 3.4.28 Flaring in gas treatment and storage facilities.

Emission factors

NMVOC emissions are provided for the relevant treatment and storage facilities. Emissions of other pollutants from flaring in gas treatment and storage facilities are calculated from the same emission factors, which are used for flaring in upstream oil and gas production (Table 3.4.11).

Emissions

Emissions from flaring in gas treatment and storage facilities are of minor importance to the total fugitive emissions. NMVOC emissions are included in Figure 3.4.29.

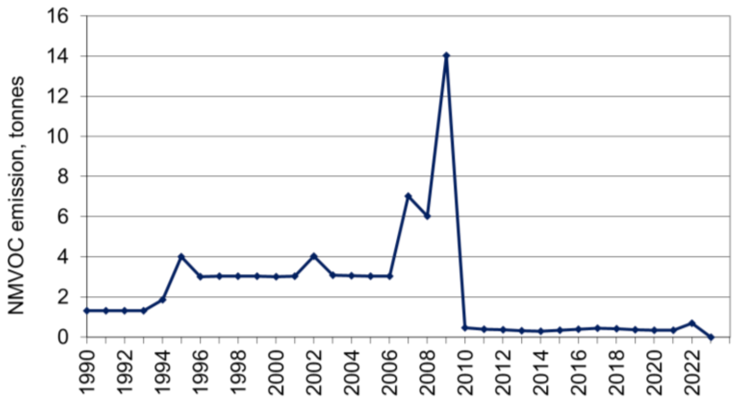

Figure 3.4.29 NMVOC emissions from flaring in gas treatment and storage facilities.

Flaring in gas transmission and distribution

Activity data

The Danish gas transmission company acquired a mobile flare, which have been used during large maintenance work since 2013. Also, flaring has occurred in gas distribution. Flaring rates are provided by the relevant companies. Total flaring amounts in gas transmission and distribution are shown in Figure 3.4.30.

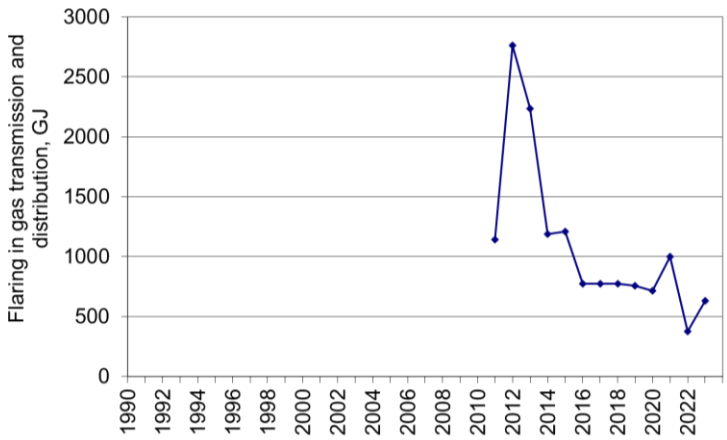

Figure 3.4.30 NMVOC emissions from flaring in gas treatment and storage facilities.

Emission factors

Emissions from flaring in gas transmission and distribution are calculated from the same emission factors, which are used for flaring in upstream oil and gas production (Table 3.4.11).

Emissions

Emissions from flaring in gas transmission and distribution are of minor importance to the total fugitive emissions. NMVOC emissions are included in Figure 3.4.31.

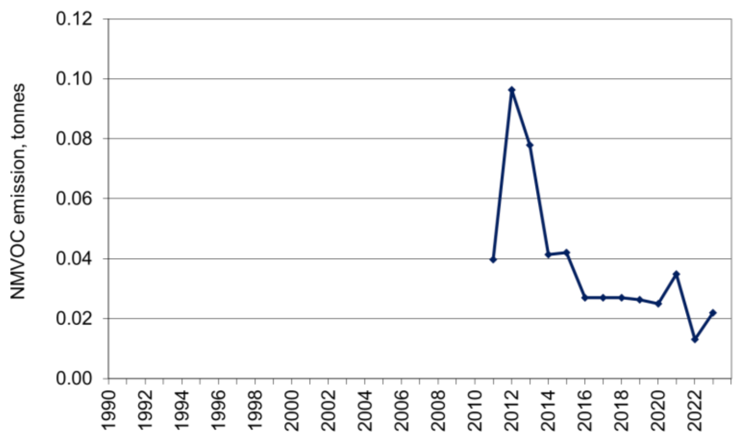

Figure 3.4.31 NMVOC emissions from flaring in gas transmission and distribution.

3.4.3 Uncertainties and time series consistency

The applied methodology for uncertainty estimates refers to Pulles & Aardenne (2004). The Danish uncertainty estimates are based on the simple approach 1 described in the 2006 IPCC Guidelines (IPCC, 2006).

Input data

The uncertainty estimates are based on the calculated emissions for the base year and for the latest inventory year, and on the uncertainty rates for both activity data and emission factors. Data are aggregated for the NFR category 1B - Fugitive Emissions from Fuels. Base year refers to 1990 for all pollutants. Emission data, activity data and emission factors are described in Section *3.4.2 Activity data, emission factors and emissions for fugitive sources*.

For each pollutant, the primary emission source/sources is/are the determinant for the overall uncertainty level. Uncertainty levels are based on the IPCC

Guidelines, the EMEP/EEA Guidebook, reports under the EU ETS and DCE assumptions. Uncertainty levels for activity data and emission factors are listed in Table 3.4.12.

Table 3.4.12 Uncertainty levels for activity rates and emission factors for NFR category 1B - Fugitive Emissions from Fuels.

Pollutant	Activity data uncertainty level, %	Emission factor uncertainty level, %
SO_2	10	25
NO_x	7.5	125
NMVOC	2	125
CO	7.5	125
TSP	2	50
PM_{10}	2	50
$PM_{2.5}$	2	50
BC	2	100
As	7.5	500
Cd	7.5	500
Cr	7.5	500
Cu	7.5	500
Hg	7.5	500
Ni	7.5	500
Pb	7.5	500
Se	7.5	500
Zn	7.5	500
PCDD/F	7.5	500
Benzo(b)fluoranthene	7.5	500
Benzo(k)fluoranthene	7.5	500
Benzo(a)pyrene	7.5	500
Indeno(1,2,3-cd)pyrene	7.5	500

Results

The uncertainty model estimates uncertainties for both the emission level and the trend. The uncertainty on the emission level for SO_2, NO_x, NMVOC and CO is 27 %, 125 %, 125 % and 125 %, respectively. For PM, the uncertainty is 50 %, for BC, the uncertainty is 100 % and for HM and PAHs, the uncertainty is 500 %.

The individual uncertainty estimates for the fugitive emission inventory are shown in Table 3.4.13. The trend refers to the years 1990 onwards for all pollutants and show a decreasing trend for all pollutants between -88 % and -57 %.

Table 3.4.13 Estimated uncertainty levels for emissions and trends for fugitive emissions.

Pollutant	Emission level uncertainty [%]	Trend [%]	Trend uncertainty [%]
SO_2	27	-57	6
NO_x	125	-70	3
NMVOC	125	-76	1
CO	125	-68	3
TSP	50	-87	0.4
PM_{10}	50	-87	0.4
$PM_{2.5}$	50	-86	0.4
BC	100	-88	0.3
As	500	-69	3
Cd	500	-57	5
Cr	500	-57	5
Cu	500	-57	5
Hg	500	-68	3
Ni	500	-57	5
Pb	500	-57	5
Se	500	-58	4
Zn	500	-57	5
PCDD/F	500	-70	3
Benzo(b) fluoranthene	500	-70	3
Benzo(k) fluoranthene	500	-71	3
Benzo(a)pyrene	500	-70	3
Indeno (1,2,3-cd) pyrene	500	-71	3

3.4.4 Source specific QA/QC and verification

A list of QA/QC tasks are performed directly in relation to the fugitive emission part of the Danish emission inventories. The following procedures are carried out to ensure the data quality:

The emission from the large point sources (refineries, gas treatment and gas storage plants) is compared with the emission reported the previous year.

Annual environmental reports are kept for subsequent control of plant-specific emission data.

Checks of data transfer are incorporated in the fugitive emission models, e.g. sum checks.

Verification of activity data from external data when data are available through more data sources (offshore fuel and flaring rates).

Data sources are incorporated in the fugitive emission models.

A manual log table in the emission databases is applied to collect information about recalculations.

Comparison with the inventory of the previous year. Any major changes are verified.

Total emission, when aggregated to reporting tables, is compared with totals based on SNAP source categories (control of data transfer).

Checking of time series in the NFR and SNAP source categories. Significant dips and jumps are controlled and explained.

Data deliveries

Table 3.4.14 lists the external data deliveries used for the inventory of fugitive emissions. Further, the table holds information on the contacts at the data delivery companies.

Table 3.4.14 List of external data sources.

Category	Data description	Data type	Reference	Contact(s)	Data agreement /comment
Exploration of oil and gas	Dataset for exploration of oil and gas, including rates and composition.	Activity data	The Danish Energy Agency	Kirsten Lundt Erichsen	Data agreement
Abandoned oil/gas wells	Number, date and location for abandoned wells	Activity data	The Danish Energy Agency	Kirsten Lundt Erichsen	No formal data agreement
Production of oil and gas	Gas and oil production. Dataset, including rates of offshore loading of ships.	Activity data	The Danish Energy Agency	Kirsten Lundt Erichsen	Not necessary due to obligation by law
	Company emission inventory data, LDAR information and drone measurement results.	Emission data and supporting information	TotalEnergies, INEOS Energy	Karina Gil Tabita Hylkjær	No formal data agreement.
Offshore flaring	Flaring in upstream oil and gas production (EU ETS data)	Activity data	The Danish Energy Agency	Rikke Brynaa Lintrup	Data agreement
Service stations	Data on gasoline sales from the Danish energy statistics.	Activity data	The Danish Energy Agency	Jytte Illerup, Ali A. Zarnaghi	Data agreement
Gas transmission	Natural gas transmission rates from the transmission company, sales and losses.	Activity data	Energinet.dk	Signe Sonne	Not necessary due to obligation by law
Onshore activities	Rates of oil transport in pipeline and onshore loading to ships. Emissions from storage of raw oil in the terminal.	Activity data and emission data	Ørsted	Søren Boesen	No formal data agreement.
Gas distribution	Natural gas and town gas distribution rates from the distribution company, sales and losses (meter differences)	Activity data	Danish Gas Technology Centre	Per Gravers Kristensen	No formal data agreement.
Emissions from refinery	Fuel consumption and emission data.	Activity data and emission data	Kalundborg Refinery, Crossbridge	Anette Holst, Trine Bjerre Kristiansen	No formal data agreement.
Treatment and storage of gas	Environmental reports and supplemental data from plants defined as large point sources (Lille Torup, Stenlille)	Activity data and emission data	Energinet.dk	Christian Guldager Corydon	No formal data agreement.
Onshore loading	Annual report for the harbour terminal.	Activity data and emission data	Crossbridge	Trine Bjerre Kristiansen	No formal data agreement.
Emission factors	Emission factors origin from a large number of sources	Emission factors	See Section *3.5.4 Activity data, emission factors and emissions for fugitive sources* regarding emission factors		

National external review

A documentation report for the sector "The Danish emission inventory for fugitive emissions from fuels" was published in 2021. The report includes detailed information on the methodology used in the emission inventories for greenhouse gases and air pollution (Plejdrup et al., 2021). The report was reviewed by Jesper Werner Løhndorf Christensen from the Danish Energy Agency.

The previous versions of the documentation report from 2015 and 2009 was reviewed by Glen Thistlethwaite from Ricardo Energy & Environment, Oxfordshire, UK and by Anette Holst, Statoil A/S, The Refinery, Kalundborg, Denmark, respectively.

3.4.5 Recalculations

The largest change from the 2024 reporting owes to exclusion of the Nord Stream emissions due to a decision made after the 2024 reporting. In 2022, explosions caused ruptures on several gas pipelines transporting natural gas between Russia and Germany. Some of the ruptures occurred within the Danish Exclusive Economic Zone. At a meeting in Working Group 1 under the EU Climate Change Committee on 5 March 2024, the European Commission informed the group that based on a meeting between DG Climate Action and ministries of Denmark and Sweden, it was clear that Denmark and Sweden would not include the emissions in the reporting on 15 March 2024. The Commission suggested that information on the emissions should be included in the report accompanying the submission but not included in the reporting tables. More information on the methodology and data used to estimate emissions from the leaks are included in the 2024 IIR (Nielsen et al., 2024).

The most significant recalculation is made for NMVOC for category 1B2aiv Fugitive emissions oil: Refining / storage due to incorporation of a new estimation methodology implemented by one refinery. The recalculations are described by source in the following section.

Service stations
The activity data is updated for 2022 according to national energy statistics. The recalculation is a reduction of 4 t NMVOC, corresponding <0.01 % of the national total NMVOC emission in 2022.

Refineries
The methodology for one refinery is updated in accordance with the new estimation methodology implemented by the refinery in 2022. Data are not available that allow for the refinery to use the methodology for earlier years, and following, the results from DIAL measurement in 2006 is maintained in the inventory and linear interpolation is applied for the years 2007-2021. The largest recalculation is a reduction of 3135 t NMVOC in 2021, corresponding 2.9 % of the national total NMVOC emission in 2021.

Gas distribution
The methodology has been adjusted for the entire time series and now considers differences in the companies' environmental reports in the reporting of activity data used in the inventory. Further, the gas loss share of transported amount of town gas is corrected for one company for 2022. The largest recalculations are an increase of 8 t NMVOC in 1991 and a decrease of 4 t in 2022, both corresponding <0.01 % of the national total NMVOC emission in 1991 and 2022, respectively.

Gas post-meter
The activity data are updated in accordance with the national energy statistics. Reporting of post-meter emissions in the CRT is changed from "1.B.2.b.v. Distribution" to "1.B.2.b.vi.1. Gas post-meter". The largest recalculation is for 2021 with a decrease of 1 t NMVOC The recalculation is insignificant compared with the national total CH4 emission.

3.4.6 Source specific implemented improvements

In 2022 one of the Danish refineries implemented a new CH_4 estimation method, and this methodology is applied in the national emission inventories. Calculations are available for 2022 and 2023, and according to the refinery it is not possible to make similar estimates for earlier years due to lack of information. Accordingly, a linear interpolation has been made from 2006 to 2022.

3.4.7 Response to NECD Review recommendation

The 2024 NECD review did not include any findings for the fugitive sector.

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4 Industrial processes and product use

4.1 Overview of the sector

The chapter on *Industrial processes and product use* (IPPU) (NFR sector 2) is outlined as follows:

- Mineral products (NFR 2A)
- Chemical industry (NFR 2B)
- Metal production (NFR 2C)
- Non-energy products from fuels and solvent use (NFR 2D)
- Other product use (NFR 2G)
- Other industry production (NFR 2H)
- Wood processing (NFR 2I)
- Other production, consumption, storage, transportation or handling of bulk products (NFR 2L)

The industrial processes included in the Danish inventory are those in large companies, e.g. cement factories, as well as a number of smaller companies e.g. iron foundries. For some processes, it is not possible to separate emissions from the fuels and the emissions stemming from the raw materials. This is especially the case for processes with contact, e.g. cement and lime production.

Table 4.1.1 presents an overview of sources and groups of pollutants included in the present reporting. Explanations to the abbreviations are given below the table. At least one of the mentioned pollutants in a pollutant group must be reported for a source category to be marked with an "x".

Table 4.1.1 Survey of IPPU sector with NFR-code included in the Danish inventory.

Industrial sector	NFR	SO_2/NO_X/ NH_3	NMVOC/ CO	PMs	HMs	POPs
Cement production	2A1	IE	IE	IE	IE	IE
Lime production	2A2	IE	IE	x	-	x
Container glass production	2A3	x	-	x	x	-
Glass wool production	2A3	x	x	x	-	-
Quarrying and mining of minerals other than coal	2A5a	-	-	x	-	-
Construction and demolition	2A5b	-	-	x	-	-
Storage, handling and transport of mineral products	2A5c	-	-	x	-	-
Production of bricks and tiles	2A6	x	-	-	-	x
Production of expanded clay products	2A6	x	-	-	-	x
Stone wool production	2A6	x	x	x	x	x
Sulphuric acid production	2B10a	x	-	-	-	-
Nitric acid production	2B2	x	-	x	-	-
Catalyst production	2B10a	x	-	x	-	-
Production of chemical ingredients	2B10a	-	x	-	-	-
Pesticide production	2B10a	x	x	-	-	-
Production of tar products	2B10a	x	x	-	x	x
Electric arc furnace steel production	2C1	x	x	x	x	x
Rolling mills steel production	2C1	IE	x	x	x	-
Grey iron foundries	2C1	IE	IE	x	x	x
Secondary aluminium production	2C3	IE	IE	x	x	x
Secondary lead production	2C5	x	IE	x	x	x
Allied metal manufacturing	2C7c	IE	IE	-	x	-
Domestic solvent use incl. fungicides	2D3a	-	x	-	-	-
Road paving with asphalt	2D3b	-	x	x	-	-
Asphalt roofing	2D3c	-	x	x	-	-
Coating applications	2D3d	-	x	-	-	-
Degreasing	2D3e	-	IE	-	-	-
Dry cleaning	2D3f	-	x	-	-	-
Chemical products	2D3g	-	x	-	-	-
Printing	2D3h	-	x	-	-	-
Other solvent use	2D3i	-	x	-	-	-
Use of fireworks	2G4	x	x	x	x	-
Use of tobacco	2G4	x	x	x	x	x
Use of shoes	2G4	-	-	x	-	-
Use of charcoal for barbeques	2G4	x	x	x	x	x
Paraffin wax use	2G4	-	x	x	-	x
Bread production	2H2	-	x	-	-	-
Wine production	2H2	-	x	-	-	-
Beer production	2H2	-	x	-	-	-
Spirits production	2H2	-	x	-	-	-
Sugar production	2H2	-	x	-	-	-
Meat curing	2H2	-	x	-	-	-
Use of margarine and solid cooking fats	2H2	-	x	-	-	-
Coffee roasting	2H2	-	x	-	-	-
Flour production	2H2	-	-	x	-	-
Wood processing	2I	-	-	x	-	-
Slaughterhouse waste	2L	x	-	-	-	-

x Included in the present inventory.

- Not included/not relevant.

IE Included elsewhere.

Table 4.1.2 presents an overview of the most significant source categories for 1990 and 2023. Many changes have occurred over the time series; some factories have closed and others have opened, Table 4.1.2 is therefore only representable for the years 1990 and 2023.

Table 4.1.2 Overview of 1990 and 2023 emissions from Industrial processes and product use (IPPU).

	Total emission from IPPU	Fraction of national total, %	Largest contributor in IPPU	Emission from largest contributor	Fraction of IPPU, %
			1990		
SO_2	4.31 kt	2.4	2A6 Other mineral products	2.96 kt	68.6
NO_x	0.96 kt	0.3	2B2 Nitric acid production	0.81 kt	84.0
NMVOC	42.51 kt	19.5	2D3i Other solvent use	21.11 kt	49.6
CO	13.74 kt	1.9	2A6 Other mineral products	11.15 kt	81.1
NH_3	0.67 kt	0.4	2A6 Other mineral products	0.27 kt	41.1
TSP	8.52 kt	8.1	2A5b Construction and demolition	5.81 kt	68.2
HMs	23.72 t	7.9	Zn from 2C1 Iron and steel production	12.02 t	50.7
POPs	0.35 t	2.8	PAHs from 2C1 Iron and steel production	0.29 t	83.6
			2023		
SO_2	0.70 kt	8.6	2A6 Other mineral products	0.49 kt	69.8
NO_x	0.06 kt	0.1	2G Other product use	0.04 kt	59.8
NMVOC	29.97 kt	30.6	2D3i Other solvent use	17.20 kt	57.4
CO	3.07 kt	1.7	2G Other product use	2.43 kt	79.0
NH_3	0.34 kt	0.5	2A6 Other mineral products	0.18 kt	53.8
TSP	6.67 kt	8.1	2A5b Construction and demolition	3.84 kt	57.6
HMs	8.18 t	5.8	Cu from 2G Other product use	3.14 t	38.4
POPs	0.07 t	1.5	PAHs from 2G Other product use	0.07 t	99.9

4.2 Mineral products

4.2.1 Source category description

The sub-sector *Mineral products* (NFR 2A) covers the following processes relevant for the Danish inventories:

- 2A1 Cement production
- 2A2 Lime production
- 2A3 Glass production
- 2A5a Quarrying and mining of minerals other than coal
- 2A5b Construction and demolition
- 2A5c Storage, handling and transport of mineral products
- 2A6 Other mineral products

The time series for emission of acidifying substances, NMVOC, particulate matter, heavy metals, and POPs from *Mineral products* (NFR 2A) is available in the NFR tables. Table 4.2.1 presents an overview of emissions from 2023.

Table 4.2.1 Overview of 2023 emissions from *Mineral products*.

	Total emission from mineral industries	Fraction of IPPU, %	Largest contributor in Mineral industries	Emission from largest contributor	Fraction of Mineral industries, %
SO_2	0.65 kt	93.1	2A6 Other mineral products	0.49 kt	75.1
NMVOC	0.07 kt	0.2	2A3 Glass production	0.05 kt	69.3
CO	0.01 kt	0.3	2A6 Other mineral products	0.01 kt	71.7
NH_3	0.28 kt	81.4	2A6 Other mineral products	0.18 kt	66.1
TSP	5.32 kt	79.8	2A5b Construction and demolition	3.84 kt	72.2
HMs	0.08 t	0.9	Pb from 2A3 Glass production	0.04 t	47.9
POPs	0.01 kg	0.02	PCBs from 2A2 Lime production	0.01 kg	94.5

4.2.2 Cement production

There is only one plant for cement production in Denmark; and this is a large point source with plant-specific emission data. It has not been possible to separate emissions from fuel consumption and emissions from process activities. Process emissions from the production of cement are therefore included in the energy section. See Chapter 3.2 and Annex 3A-6.

4.2.3 Lime production

The production of limestone ($CaCO_3$) and lime (also called burned lime or quicklime) is located at a few localities: Faxe Kalk (Lhoist group) situated in Faxe, Scandinavian Calcium Oxide ApS situated in Støvring, Dankalk A/S situated in Løgstør with limestone quarries/limeworks in Aggersund, Mjels, Poulstrup and Batum. The following category is covered:

- Lime production

The following pollutants are relevant for the lime production process:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Persistent organic pollutants: HCB, PCDD/F, PCB

Emissions associated with the fuel use are estimated and reported in the energy sector.

Methodology

Lime is produced for either sales purposes (marketed lime) or internal use (unmarketed use). In Denmark, unmarketed lime is only produced in the sugar industry. Data on the amount of marketed lime produced are available from Statistics Denmark on a national level and data on unmarketed lime are calculated from the factory specific process CO_2 emissions reported in EU-ETS. Emission factors are available from EMEP/EEA and national literature.

Activity data

The activity data regarding production of marketed lime are obtained from Statistics Denmark (2024). The addition of unmarketed lime production amounts to 1-6% of the total national lime production. The total lime production data are presented in Table 4.2.2 and the full time series in Annex 3C-1.1.

Table 4.2.2 Production of burnt lime, t.

	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Burnt lime	133796	105898	97846	75928	52380	64226	55358	62921	76402	76312

Slaking of lime does not emit any pollutants. All burnt lime that is later slaked, is included in the data presented in the table above. Adding the production of slaked lime to the activity data, would therefore result in a double counting.

Emission factors

The emission factors used to calculate the emissions from lime production are shown in Table 4.2.3 along with their respective sources. Emission factors from EMEP/EEA (2023) are valid for a controlled process (Tier 2[1]). For verification of the TSP emission factor, please refer to Hjelgaard (2023).

[1] EMEP/EEA (2023) Guidebook, chapter 2.A.2 Lime production, page 11, Table 3-3.

Table 4.2.3 Emission factors for production of lime.

Pollutant	Unit	Value	Source
TSP	kg/t	0.40	EMEP/EEA (2023)
PM_{10}	kg/t	0.20	EMEP/EEA (2023)
$PM_{2.5}$	kg/t	0.03	EMEP/EEA (2023)
BC	g/t	0.14	EMEP/EEA (2023)
HCB	mg/t	0.01	Luglio (2006)
PCDD/F	µg/t	0.02	Hansen og Hansen (2003)
PCB	mg/t	0.15	Luglio (2006)

Emission trends

The emission trends for particles and POPs for lime production are shown in Table 4.2.4 and in Figure 4.2.1. Emission data for the entire time series are available in Annex 3C-1.2.

Table 4.2.4 Emission of particles and POPs.

	Unit	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
TSP	t	53.5	42.4	39.1	30.4	21.0	25.7	22.1	25.2	30.6	30.5
PM_{10}	t	26.8	21.2	19.6	15.2	10.5	12.8	11.1	12.6	15.3	15.3
$PM_{2.5}$	t	4.0	3.2	2.9	2.3	1.6	1.9	1.7	1.9	2.3	2.3
BC	kg	18.5	14.6	13.5	10.5	7.2	8.9	7.6	8.7	10.5	10.5
HCB	g	1.1	0.8	0.8	0.6	0.4	0.5	0.4	0.5	0.6	0.6
PCDD/F	mg	2.4	1.9	1.8	1.4	0.9	1.2	1.0	1.1	1.4	1.4
PCB	g	20.1	15.9	14.7	11.4	7.9	9.6	8.3	9.4	11.5	11.4

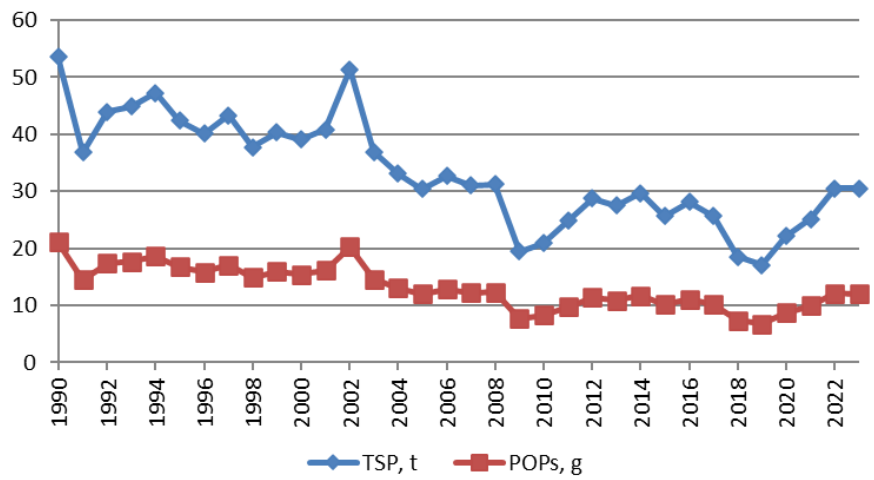

Figure 4.2.1 Emission trends for particles and POPs from lime production.

There is a peak in emissions in 2002 due to a corresponding peak for the activity data. The activity data are based on the official statistics from Statistics Denmark and there is no immediate explanation for this peak. There are very few producers in Denmark and therefore it will not be possible to obtain more detailed data from Statistics Denmark.

4.2.4 Glass production

Glass production covers production of:

- Container glass
- Industrial art glass
- Glass wool

The production of flat glass is concentrated at few European producers and none of these have plants in Denmark. The processes in Denmark are limited to mounting of sealed glazing units. The mounting process is not considered to contribute to emission of pollutants to air in Denmark.

The production of container glass for packaging is concentrated at one company: Ardagh Glass Holmegaard A/S (previously Rexam Glass Holmegaard A/S) and the production of industrial art glass products: Holmegaard A/S both situated in Fensmark, Næstved. Saint-Gobain Isover situated in Vamdrup is the only Danish producer of glass wool. The following categories are covered:

- Container glass
- Glass wool

The following pollutants are relevant for the glass production process:

- SO_2
- NMVOC
- CO
- NH_3
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: As, Cd, Cr, Ni, Pb, Se, Zn

Emissions associated with the fuel use are estimated and reported in the energy sector.

Methodology

The annual produced amount of container glass is estimated based on the consumption of raw materials. Data on raw materials are gathered from environmental reports (1997-2013) (Ardagh, 2014) and EU-ETS data (2006-2023) (Ardagh 2024). For the years prior to 1997 the production of glass is based on information contained in Illerup et al. (1999). Only one industrial art glass producer with virgin glass production exists in Denmark; Holmegaard A/S. Emissions from this production are included in the data on container glass.

The produced amount of glass wool and measured emissions are available in the company's environmental reports for 1996-2014 (Saint-Gobain Isover, 2015), and from EU-ETS and PRTR data (Saint-Gobain Isover, 2024a and 2024b). Production data back to 1990 are estimated as the constant average of 1997-1999.

Emission factors for glass wool are available from company measurements and for container glass from company measurements and EMEP/EEA (2023).

Activity data

Activity data for the production of container glass and glass wool are presented in Table 4.2.5 and Figure 4.2.2. The full time series is available in Annex 3C-1.3.

Table 4.2.5 Production of container glass and glass wool, kt product.

	1980	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Container glass	150.0	150.0	164.0	140.0	183.3	168.2	172.9	155.7	140.4	157.2	156.7	125.0
Glass wool	-	35.6	35.6	35.6	39.7	37.3	24.9	33.0	42.1	49.4	46.6	39.8

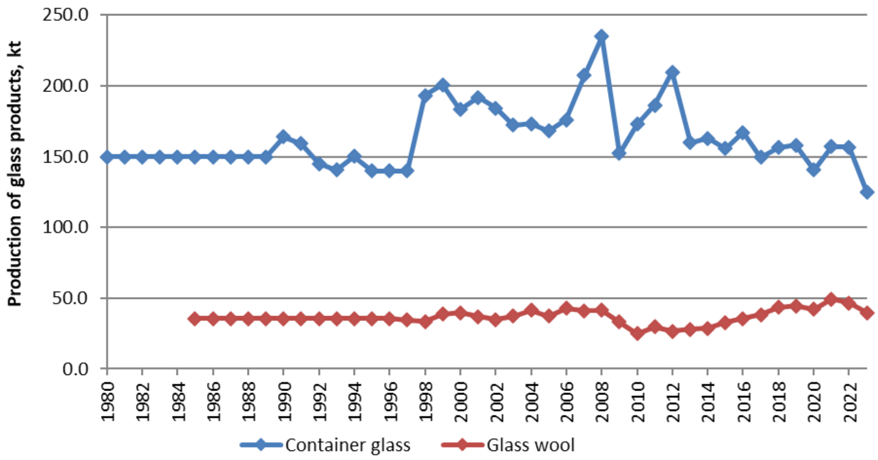

Figure 4.2.2 Activity data for container glass and glass wool production.

Both the container glass and glass wool production display a significant decrease from 2008 to 2010 that can be explained by the financial crises.

Emission factors

Yearly emissions for selected pollutants from production of container glass are available in the environmental reports/PRTR based on measurements; these provide emissions of SO_2 (2014, 2016), TSP (1997-2014), Pb (1997-2014), Se (1997-2009; 2012-2013) and Zn (1997-2001) (Ardagh, 2014 and 2015). Emissions of As, Cd, Cr and Ni are estimated from standard emission factors, the same is the case where direct emissions are not available for TSP, Pb, Se and Zn. PM_{10} and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1/0.9/0.8) and BC is estimated as 0.062 % of $PM_{2.5}$, all available from EMEP/EEA (2023), Tier 2 container glass. All used emission factors are shown in Table 4.2.6. From 2006, measured particle emissions from the singular Danish container glass producer decrease 90 % due to installation of abatement equipment; all calculated particle and heavy metal emissions are therefore also lowered with 90 % from 2006.

Table 4.2.6 Emission factors for production of container glass.

Pollutant	Applied for the years	Unit	Value	Source
SO_2	All	kg/t	1.3	Average IEF (2014;2016)
TSP	1990-1996	g/t	280	EMEP/EEA (2023)
	2015-2023	g/t	13.7	EMEP/EEA (2023) with CS abatement[1]
PM_{10}	All	% of TSP	90	EMEP/EEA (2023)
$PM_{2.5}$	All	% of TSP	80	EMEP/EEA (2023)
BC	All	% of $PM_{2.5}$	0.06	EMEP/EEA (2023)
As	1990-2005	g/t	0.29	EMEP/EEA (2023)
	2006-2023	g/t	0.03	EMEP/EEA (2023) with CS abatement[1]
Cd	1990-2005	g/t	0.12	EMEP/EEA (2023)
	2006-2023	g/t	0.01	EMEP/EEA (2023) with CS abatement[1]
Cr	1990-2005	g/t	0.37	EMEP/EEA (2023)
	2006-2023	g/t	0.04	EMEP/EEA (2023) with CS abatement[1]
Ni	1990-2005	g/t	0.24	EMEP/EEA (2023)
	2006-2023	g/t	0.02	EMEP/EEA (2023) with CS abatement[1]
Pb	1990-1996	g/t	2.9	EMEP/EEA (2023)
	2015-2023	g/t	0.29	EMEP/EEA (2023) with CS abatement[1]
Se	1990-1996	g/t	1.5	EMEP/EEA (2023)
	2010-2011; 2014-2023	g/t	0.19	Average IEF (2008-09;2012-13)
Zn	1990-1996; 2002-2005	g/t	0.23	Average IEF (2007-2001)
	2006-2023	g/t	0.02	Average IEF (2007-2001) with CS abatement[1]

[1] Country specific abatement is measured by the producer to 90 %.

The emission of NH_3 and TSP from the production of glass wool has been measured yearly for 1996-2023 and are available in the company's environmental reports (Saint-Gobain Isover, 2015 and 2024b) supplemented with personal contact to the company (Saint-Gobain Isover 2024c). NMVOC and CO have also been measured for 2007-2014 and 1996-1997 respectively. For the years where no measured emission data are available, emissions are calculated using implied emission factors (IEFs) based on the available measurements. PM_{10} and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1/0.9/0.8) from EMEP/EEA (2023). All used emission factors are shown in Table 4.2.7. Since it has not been possible to separate process emissions from the emissions from fuel combustion, the measured/calculated emissions from glass wool production presented here account for the entire production.

Table 4.2.7 Emission factors for production of glass wool.

Pollutant	Applied for the years	Unit	Value	Source
NMVOC	1985-2006	kg/t	1.35	Average IEF (2007-2009)
	2015-2023	kg/t	1.17	Average IEF (2012-2014)
CO	1985-1995; 1998-2023	kg/t	0.06	IEF (1997)
NH_3	1985-1995	kg/t	7.6	Average IEF (1996-1998)
	2015	kg/t	4.4	Average IEF (2012-2014)
TSP	1990-1995	kg/t	2.9	Average IEF (1996-2000)
PM_{10}	All	% of TSP	90	EMEP/EEA (2023)[1]
$PM_{2.5}$	All	% of TSP	80	EMEP/EEA (2023)[1]
BC	All	% of $PM_{2.5}$	2.0	EMEP/EEA (2023)[1]

[1] Chapter 2.A.3 Glass production, page 19, Table 3-5.

Emission trends

The only pollutants to which both container glass and glass wool productions contribute are particles. Table 4.2.8 and Annex 3C-1.4 shows the individual emissions from the two sources.

Table 4.2.8 Emission from glass production.

	Pollutant	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Container glass	SO_2	t	195	195	213	182	238	218.7	224.8	202.4	182.6	204.3	203.7	162.5
	TSP	t	-	-	46	39	26	7.0	1.7	2.1	1.9	2.2	2.1	1.7
	PM_{10}	t	-	-	41	35	23	6.3	1.5	1.9	1.7	1.9	1.9	1.5
	$PM_{2.5}$	t	-	-	36	31	20	5.5	1.3	1.7	1.5	1.7	1.7	1.3
	BC	kg	-	-	22	19	13	3.4	0.8	1.0	0.9	1.0	1.0	0.8
	As	kg	-	-	48	41	53	49	5.0	4.5	4.1	4.6	4.5	3.6
	Cd	kg	-	-	20	17	22	20	1.7	1.6	1.4	1.6	1.6	1.2
	Cr	kg	-	-	61	52	68	62	6.4	5.8	5.2	5.8	5.8	4.6
	Ni	kg	-	-	39	34	44	40	4.2	3.7	3.4	3.8	3.8	3.0
	Pb	kg	-	-	476	406	330	148	24	45	41	46	45	36
	Se	kg	-	-	246	210	340	107	33	30	27	30	30	24
	Zn	kg	-	-	38	32	57	39	4.0	3.6	3.2	3.6	3.6	2.9
Glass wool	NMVOC	t	-	48	48	48	54	50	32	39	49	58	55	47
	CO	t	-	2.0	2.0	2.0	2.3	2.1	1.4	1.9	2.4	2.8	2.7	2.3
	NH3	t	-	271	271	271	225	116	108	105	65	71	105	95
	TSP	t	-	-	102	102	111	85	26	38	34	19	32	29
	PM_{10}	t	-	-	92	92	100	77	23	34	30	17	29	26
	$PM_{2.5}$	t	-	-	82	82	89	68	21	30	27	15	26	23
	BC	t	-	-	1.6	1.6	1.8	1.4	0.4	0.6	0.5	0.3	0.5	0.5

4.2.5 Quarrying and mining of minerals other than coal

Quarrying and mining of minerals other than coal covers several different types of minerals and occurs all over Denmark. The following category is covered:

- Quarrying and mining of minerals other than coal

The following pollutants are relevant for quarrying and mining:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$

Methodology

The annual amount of extracted minerals is available from national statistics. These resource extraction data cover “sand and gravel”, “chalk and dolomite”, “marble, granite, sandstone, porphyry, basalt and building stone, etc.” and “other”.

Emission factors are calculated using the Tier 2 methodology spreadsheet available from EMEP/EEA (2023).

Activity data

Activity data for quarrying and mining of minerals other than coal are presented in Table 4.2.9; the full time series is available in Annex 3C-1.5.

The activity data from Statistics Denmark (2024) called “marble, granite, sandstone, porphyry, basalt and building stone, etc.” is believed to be mostly granite chippings, this category is entered in the Tier 2 model as “crushed rock”. The categories “sand and gravel” and “chalk and dolomite” are entered as “sand and gravel”. And the category “other” is entered as “Recycled aggregates” due to the lack of information on this category.

Statistical data on quarrying for the latest reporting year, is not made available in time for the reporting deadline. Therefore, the two latest reported years are the same. Activity data for the latest reporting year in this year’s submission, will be updated with the correct statistical data in next year’s submission.

Table 4.2.9 Extracted minerals other than coal, kt.

	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Crushed rock	945	1103	332	315	240	234	175	465	522	522
Sand and gravel[1]	43534	51581	63184	73805	44147	57456	64174	69879	68208	68208
Recycled aggregates	908	908	947	813	1052	1090	1315	862	625	625

[1] Incl. chalk and dolomite.

Emission factors

The applied emission factors are shown in Table 4.2.11. Emission factors are calculated based on the Tier 2 methodology calculation model spreadsheet (EMEP/EEA, 2023). All Danish quarries are small quarries (<100,000 kt annual production), in fact, all sites in the three categories are assumed to produce between 9-775 kt mineral in annual average in any year of the time series. Being a small country, Danish emission factors are calculated as one region. The average wind speed is 4.72 m per second (2011-2019 average), number of days per year with at least 1 mm natural precipitation is 155 (2016) and number of days with a wind speed > 19.3 km per hour is 105 (2016). All weather-related data are collected from DMI (2020). All additional country specific data entered into the model, are presented in Table 4.2.10.

Table 4.2.10 Country specific data used in the Tier 2 methodology calculation model.

	Crushed rock	Sand and gravel	Recycled aggregates
General data			
Number of quarries	2	100	35[a]
Material processing			
Percentage of wet processing	0 %	42 %[b]	42 %[b]
Internal transport			
Distance travelled on unpaved road	2400 km[c]	2400 km	0 km

[a] Auto-calculated from the production (i.e. activity data), [b] It rains a minimum of 1mm per day in Denmark 42% of the year, [c] Denmark is a small country with small distances and the default value is considered far too high

Table 4.2.11 Emission factors for quarrying and mining of minerals other than coal

	Unit	TSP	PM_{10}	$PM_{2.5}$
Crushed rock	g/t	77	29	6.4
Sand and gravel	g/t	18	7.4	2.0
Recycled aggregates	g/t	33	15	4.1

Emission trends

Emissions of $PM_{2.5}$ are presented in Figure 4.2.3. Emissions of TSP. PM_{10} and $PM_{2.5}$ are available in Annex 3C-1.6.

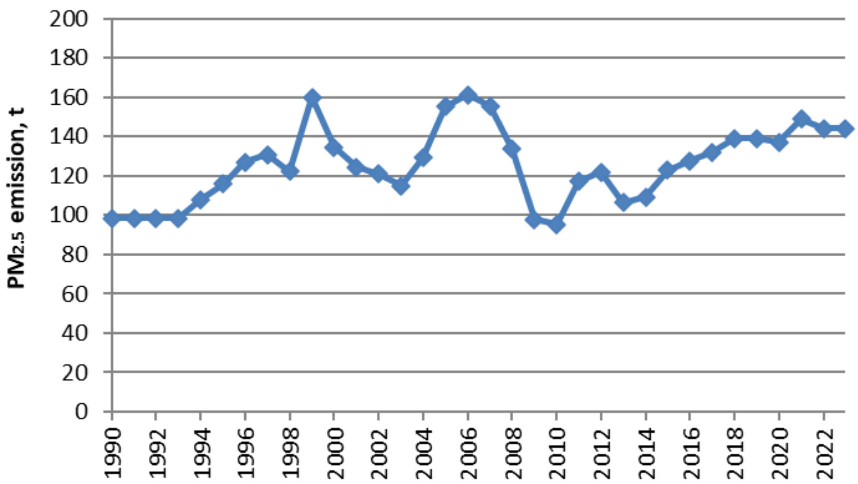

Figure 4.2.3 Emission of fine particles ($PM_{2.5}$) from quarrying and mining of other minerals than coal.

4.2.6 Construction and demolition

Construction and demolition covers the following category:

- Construction and demolition

The following pollutants are relevant for construction and demolition:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$

Methodology

Emissions from construction and demolition are calculated using the Tier 1 methodology from EMEP/EEA (2023) expressed in the following equation:

$$EM_{PM10} = EF_{PM10} \cdot A_{affected} \cdot d \cdot (1 - CE) \cdot \left(\frac{24}{PE}\right) \cdot \left(\frac{s}{9\%}\right)$$

Where: EM_{PM10} is the PM_{10} emission, EF_{PM10} is the emission factors, $A_{affected}$ is the area affected by construction activity, *d* is the duration of construction, *CE* is the efficiency of emission control measures, *PE* is the Thornthwaite precipitation-evaporation index (correction for soil moisture) and *s* is the soil silt content.

The activity data for construction ($A_{affected}$) are calculated based on national statistics on completed buildings (m^2) (detached houses, undetached houses, apartment buildings and non-residential buildings) and roads (m).

Emission factors (EF_{PM10}) are available from EMEP/EEA (2023).

Activity data

Activity data for construction and demolition are presented in Table 4.2.12. The full time series is available in Annex 3C-1.7.

Table 4.2.12 Activity of construction and demolition, million m^2.

	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Construction of houses	2.3	1.3	2.5	3.6	2.2	2.2	3.4	3.8	4.2	3.2
Construction of apartment	0.7	0.5	0.4	0.9	0.3	0.4	2.0	1.7	1.5	1.5
Construction of non-residential	5.3	4.0	6.1	4.6	3.7	2.9	2.4	2.6	3.1	3.5
Construction of road	1.8	1.7	1.6	2.2	2.9	0.8	1.0	0.9	0.8	0.9

Emission factors

The default emission factors are shown in Table 4.2.13.

Table 4.2.13 Default emission factors for different building type constructions.

Pollutant	Unit	Houses	Apartment buildings	Non-residential buildings	Road	Source
TSP	$kg/m^2/year$	0.29	1.0	3.3	7.7	EMEP/EEA (2023)
PM_{10}	$kg/m^2/year$	0.086	0.30	1.0	2.3	EMEP/EEA (2023)
$PM_{2.5}$	$kg/m^2/year$	0.0086	0.030	0.1	0.23	EMEP/EEA (2023)

The default duration (*d*) of the different construction types and the default control efficiency (*CE*) are available in EMEP/EEA (2023). The Thornthwaite precipitation-evaporation index was calculated for the years 2015-2017. The average obtained *PE* index is 75.9 which corresponds to a humid climate. Denmark is a very sandy country, and the soil silt content (*s*) is 11 % (Landbrugsministeriet, 1998). Danish roads span from 3 to 20 meters, an average road width of 12 m is assumed (DCE judgement).

Table 4.2.14 below presents the applied emission factors for the different types of construction. These emission factors correspond to:

$$EF_{PM10} \cdot d \cdot (1 - CE) \cdot \left(\frac{24}{PE}\right) \cdot \left(\frac{s}{9\%}\right)$$

Table 4.2.14 Applied emission factors for different building type constructions.

Pollutant	Unit	Houses	Apartment buildings	Non-residential buildings	Road
TSP	kg/m^2	0.056	0.290	0.530	1.489
PM_{10}	kg/m^2	0.017	0.087	0.160	0.445
$PM_{2.5}$	kg/m^2	0.002	0.009	0.016	0.044

Emission trends

Emissions of $PM_{2.5}$ are presented in Figure 4.2.4. Emissions of TSP, PM_{10} and $PM_{2.5}$ are available in Annex 3C-1.8.

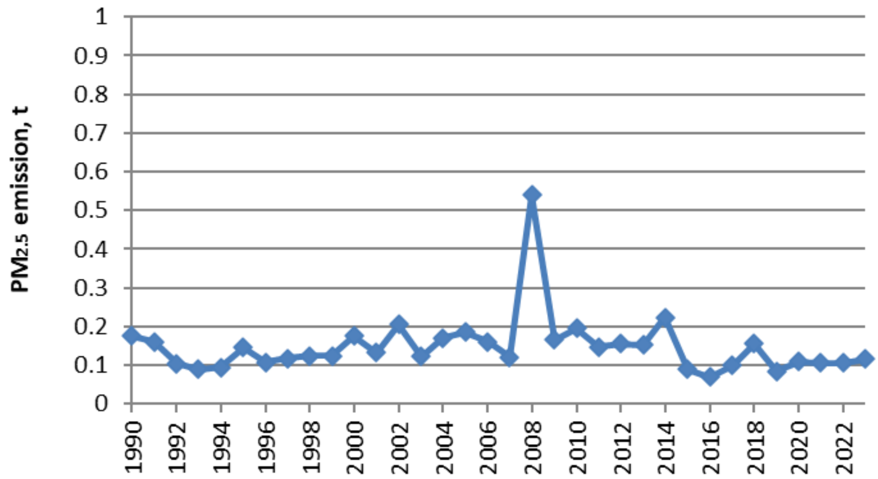

Figure 4.2.4 Emission of particulate matter ($PM_{2.5}$) from construction and demolition.

The peak in 2008 is caused by a large increase in construction of road.

4.2.7 Storage, handling and transport of mineral products

Storage, handling and transport of mineral products covers the following category:

- Storage, handling and transport of mineral products

The following pollutants are relevant for storage, handling and transport of mineral products:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$

Methodology

The activity data for storage, handling and transport of mineral products covers minerals used in cement production, ceramics production, other uses of soda ash, flue gas desulphurisation and stone wool. The particle emissions from storage, handling and transport of mineral products in lime production, glass production, quarrying/mining and construction/demolition are already included in the respective categories.

The activity data for storage, handling and transport of mineral products are gathered from the included sources individually.

Emissions from storage, is only included for cement and stone wool, as the remaining three minerals are not subject to open, outdoor storage but are stored in bags or silos. While cement and stone wool are also not stored in the open, some raw materials for their respective productions are. The affected area is evaluated for each production site individually using satellite photos and extrapolated using production data as surrogate data.

Emissions from handling are included for all five included mineral sources, while emissions from transport are not included as no emission factors are available.

Emission factors for storage and handling are available in EMEP/EEA (2023).

Activity data

Activity data for storage and handling of mineral products are presented in Table 4.2.15. Emissions from handling are calculated based on weight while emissions from storage are calculated based on area (ha). The entire time series is available in Annex 3C-1.9. The activity data presented in the NFR tables are the weight of all five included mineral sources.

Table 4.2.15 Activity of storage, handling and transport of mineral products.

	Unit	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Handling of mineral product	kt	2948	3841	4382	4386	2420	2807	3671	3918	3825	2928
Storage of mineral product	ha	1.1	1.4	1.6	1.7	1.0	1.2	1.5	1.6	1.6	1.2

Emission factors

The applied emission factors are shown in Table 4.2.16. Bulk, outdoor storage of minerals that are included in this source category are raw materials for cement and stone wool productions. As these are continuously fed into the production, abatement actions that are typically applied with long term storage are not expected to apply for Danish conditions. The emission factors for storage presented below therefore represent uncontrolled storage.

Table 4.2.16 Emission factors for storage, handling and transport of mineral products.

	Storage		Handling		
Pollutant	Value	Unit	Value	Unit	Source
TSP	12	kg/kt	16.4	t/ha	EMEP/EEA (2023)[1]
PM_{10}	6.0	kg/kt	8.2	t/ha	EMEP/EEA (2023)[1]
$PM_{2.5}$	0.6	kg/kt	0.82	t/ha	EMEP/EEA (2023)[1]

[1] Chapter 2.A.5.c Storage, handling and transport of mineral products, page 6-7, Table 3-2 and Table 3-4.

Emission trends

Emissions are presented in Figure 4.2.5 and Annex 3C-1.10.

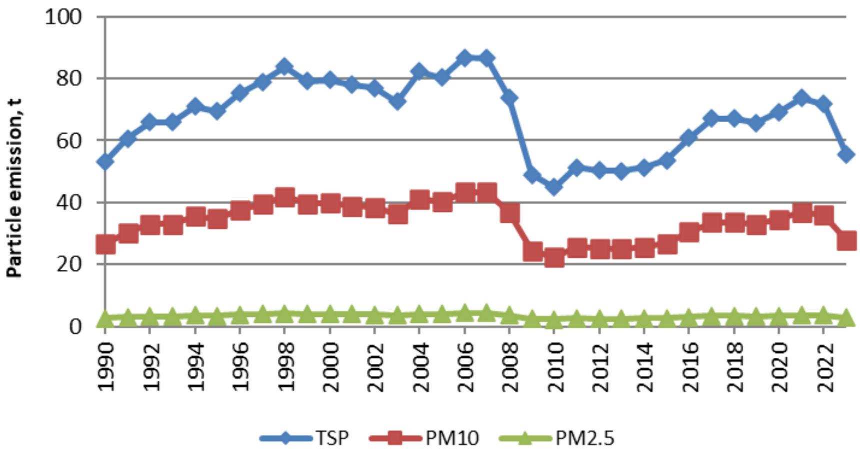

Figure 4.2.5 Emission of particulate matter from storage, handling and transport of mineral products.

4.2.8 Other mineral products

The sub-sector "Other" in the mineral industry section covers production of bricks and tiles (aggregates or bricks/blocks for construction), expanded clay products for different purposes (aggregates as absorbent for chemicals, cat litter, and for other miscellaneous purposes) and stone wool from the company Rockwool. The following categories are covered:

- Production of bricks and tiles
- Expanded clay products
- Stone wool

The following pollutants are covered:

- SO_2
- CO
- NMVOC
- NH_3
- Heavy metals: As
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Persistent organic pollutants: PCDD/F

NO_x from stone wool production is included in the energy sector (NFR 1A2f Stationary Combustion in Manufacturing Industries and Construction: Non-Metallic Minerals).

The production of bricks (and tiles) is found all over the country, where clay is available. Producers of expanded clay products are located in the northern part of Jutland. Rockwool produces stone wool at three localities in Denmark: Hedehusene[2], Vamdrup and Øster Doense.

Methodology

The SO_2 emission from the production of bricks/tiles and expanded clay products is related to the sulphur content in the raw material. The SO_2 emission and fuel consumption are known for nine different producers of ceramics for 2007-2014 (and also 2015-2023 for expanded clay production at LECA). The SO_2 emission from the fuel consumption is calculated using Danish standard emission factors, and this is subtracted from the total SO_2 emission. The remaining emission is used to calculate two SO_2 emission factors for brickworks and expanded clay production respectively for 1980-2006 based on IEF (2007-2010) and two based on IEF (2012-2014) for 2015 onward. These factors are used for all producers of bricks/tiles and for all expanded clay producers. However, from 2006 onward the expanded clay producer LECA is reported as a large point source with its own (implied) emission factors for SO_2. These emission factors are calculated using the same method as described above; i.e. the difference between total emission and fuel emission. The PCDD/F emission factor is known from national literature.

Stone wool is produced from mineral fibres and a binder. The raw materials are melted in a cupola fired by coke and natural gas. Information on emissions from some years are used as implied emission factors to calculate emissions for years where measurements are not available. Production data are used as activity data and raw material consumption is used as surrogate data to complete the time series. The data have been extracted from the environmental reports (Rockwool, 2014), reporting to PRTR (Rockwool, 2024b), EU-ETS (Rockwool, 2024a) and Statistics Denmark (2024). Measured emissions of CO and NH_3 are available for the years 2001, 2004 and 2007-2014, for NH_3 also 2015-2023 and for CO also 2021-2023 (Rockwool, 2024c). Emissions of particulate matter are available for 1995-2014 and 2016-2023 (for Doense), and for NMVOC, As and PCDD/F, the inventory is based on measured emissions for 2012-2014, 2007-2015 and 2004 respectively. Process emissions of SO_2 are included in the energy sector for 1980-2020 as Rockwool has been using SO_2

[2] The melting of minerals (cupola) has been closed down in 2002.

heavy fuels and measured emissions are difficult to separate between energy and process. But since 2021, Rockwool in Vamdrup only uses natural gas and gasoil as fuel, and SO_2 emissions are therefore reported in this sector. SO_2 emissions from the Rockwool production site in Doense is still included under Energy.

Activity data

National statistics on bricks, tiles and expanded clay (together called ceramics) contain a broad range of different products, most of them in units of numbers (no.). The consumption of limestone is therefore used as alternative activity data for these source categories; available for 2006-2023 (EU-ETS data). The national statistics are used as surrogate data; available for 1985-2023. Prior to 1985 activity data are estimated as the 1985-1989 average.

Data on the produced amount of stone wool is known for 1995-2004 (Statistics Denmark, 2024) and 2014-2023 (Rockwool, 2024a, confidential). Data on the consumption of raw materials are used as surrogate data to complete the time series. Raw material consumption is available from the annual environmental reports (Rockwool, 2014). Activity data for 1985-1994 is kept constant as the average value of 1995-1999.

The chosen activity data for "Other mineral products" are not presented in the NFR tables, they are however, shown in Table 4.2.17, Figure 4.2.6 and Annex 3C-1.11. The large point sources LECA (expanded clay products producer) and Rockwool (2006-) are not presented separately, as EU-ETS data are confidential. LECA is included in expanded clay, but stone wool is not included as this is only produced by the single producer in Denmark, i.e. Rockwool.

Table 4.2.17 Production of "Other mineral products".

	Unit	1980	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Brickworks	kt $CaCO_3$-eq	75.7	58.6	71.7	81.1	79.2	35.1	46.2	61.1	60.6	51.7	45.6
Expanded clay	kt $CaCO_3$-eq	51.5	46.2	47.5	44.0	43.3	19.1	19.5	37.5	60.9	41.0	32.9
Stone wool	kt produced	-	153.5	123.3	152.6	143.6	c	c	c	c	c	c

c: confidential

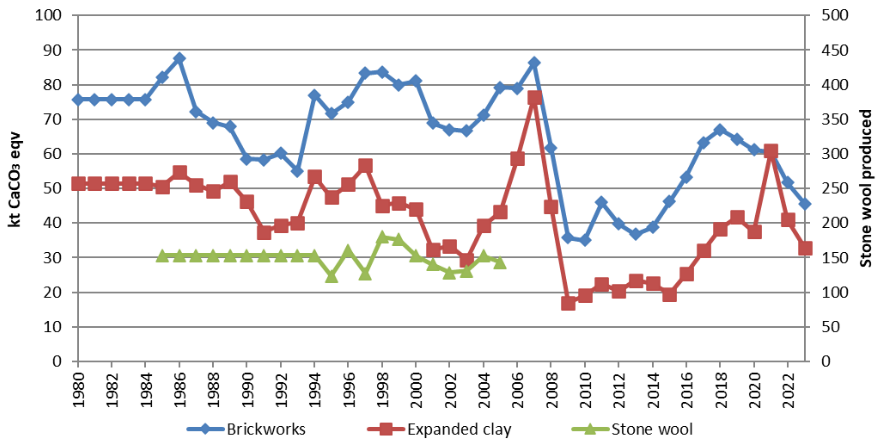

Figure 4.2.6 Consumption of $CaCO_3$ equivalents in the production of ceramics and the production of stone wool.

Both the brickworks, expanded clay productions and stone wool production displays a significant decrease from 2007 to 2009 that can be explained by the global financial crises.

Emission factors

For production of ceramics the emission factors for SO_2 are determined from the individual companies reporting of SO_2 emission (environmental reports) for the years 2007-2014 and activity for the corresponding years. The years 2015-2023 are also included for the large point source LECA. The SO_2 emissions have been adjusted for fuel related emissions to derive the process emissions. The PCDD/F emission factors shown in Table 4.2.18 are calculated from 0.018 µg per tonne product (Hansen og Hansen, 2003), using the total carbonate consumption (environmental reports), national production statistics (Statistics Denmark) and assumption of 2.5 kg per brick/tile.

Stone wool emission factors are calculated from measured emission data, i.e. implied emission factors (see Table 4.2.19 below). Stone wool emission factors for CO and NH_3 are average values measured and reported in the annual environmental reports for each Rockwool factory for the years 2001, 2004 and 2007-2014, CO is also known for 2021-2023 and NH_3 is also known for 2015-2023 (Rockwool, 2024b and 2024c). TSP emission data are available in the environmental reports for 1995-2014 and from PRTR/personal communication for 2016-2023. PM_{10} and $PM_{2.5}$ emission factors are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1/0.9/0.7). The applied emission factor for BC is actually that of glass wool from EMEP/EEA (2023). NMVOC emissions are known for Doense for 2012-2014, arsenic is measured for 2007-2015 and 2023, SO_2 is measured for Vamdrup in 2021-2023 and PCDD/F emissions are known from Henriksen et al. (2006).

Table 4.2.18 Emission factors for Other mineral products, units are per t $CaCO_3$ equivalent.

Pollutant	Applied for the years	Brickworks Value	Unit	Expanded clay Value	Unit	Source
SO_2	1980-2006	9.9	kg	51.5	kg	Average IEF[1] (2007-2010)
	2015-2023	4.4	kg	17.5[2]	kg	Average IEF[1] (2012-2014)
PCDD/F	All	0.25	µg	0.13	µg	Hansen og Hansen (2003)[3]

[1] Calculated using data from the companies' environmental reports.
[2] Average IEF value for expanded clay production 2015-2023. The actual applied EFs are one for LECA only and one for the remaining producers. The first is 0.5-21.7 kg SO_2 per t $CaCO_3$ and the latter is 110 kg SO_2 per t $CaCO_3$ (average IEF for 2012-2014).
[3] Some calculations were necessary to derive the desired units.

Table 4.2.19 Emission factors for stone wool production, units are per t produced.

Pollutant	Applied for the years	Value	Unit	Source
NMVOC	All	0.22	kg	Average IEF[1] (2012-2014)
CO	1985-2000; 2002-2003; 2005-2006	40 - 128	kg	IEFs[1] (2001; 2004; 2007-2008)
	2015-2020	0.03 - 0.24	kg	IEFs[1] (2010-2014, 2021)
NH_3	1985-2000; 2002-2003; 2005-2006	1.3 - 2.3	kg	IEFs[1] (2001; 2004; 2007)
TSP	1990-1994	0.38 - 0.89	kg	IEFs[1] (1995-2002)
	2015-2019[2]	0.54	kg	Average IEF[1] (2010-2014)
PM_{10}	All	90	% of TSP	DCE judgement
$PM_{2.5}$	All	70	% of TSP	DCE judgement
BC	All	2	% of $PM_{2.5}$	EMEP/EEA (2023)[3]
As	1990-2006	0.33-0.51	g	IEFs (2007; 2008-2014)
	2016-2022	0.0004 - 0.46	g	IEFs (2008-2014, 2023)[4]
PCDD/F	All	0.37	µg	Henriksen et al. (2006)[5]

[1] Calculated using data from the companies' environmental reports, [2] Only applied for Vamdrup, [3] Valid for glass wool, [4] Calculated using interpolation, [5] Some calculations were necessary to derive the desired units.

Emission trends

The only pollutants to which more than one source category contributes are SO_2 and PCDD/F, these two emissions are presented in the figures below. Figure 4.2.7 and Figure 4.2.8 show the emissions of SO_2 and PCDD/F respectively, emissions are presented individual for the three sources.

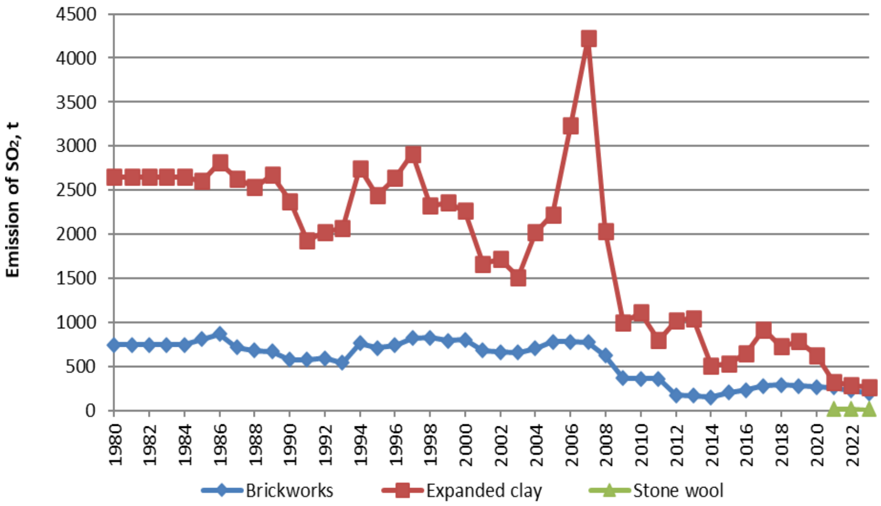

Figure 4.2.7 Emissions of SO_2 from ceramics.

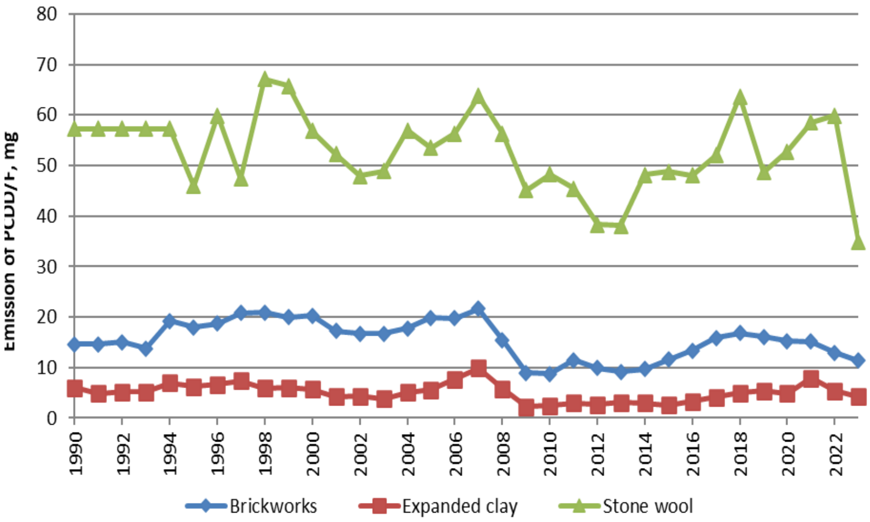

Figure 4.2.8 Emissions of PCDD/F from ceramics and stone wool.

Emissions of the remaining pollutants can be found in Annex 3C-1.12, where NMVOC, CO, NH_3, particle and As emissions stem only from stone wool production.

The measurements of CO emissions show a strong decrease from the two stone wool factories in 2009 and 2010, respectively, due to installation of abatement equipment.

4.3 Chemical industry

4.3.1 Source category description

The sub-sector *Chemical industry* (NFR 2B) covers the following processes:

- 2B2 Nitric acid/fertiliser production

- 2B10a Other chemical industry
    - Sulphuric acid production
    - Catalyst/fertiliser production
    - Production of chemical ingredients
    - Pesticide production
    - Production of tar products

The time series for emission of acidifying substances, NMVOC, particulate matter, heavy metals, and POPs from *Chemical industry* (NFR 2B) is available in the NFR tables. Table 4.3.1 presents an overview of emissions from 2023.

Table 4.3.1 Overview of 2022 emissions from *Chemical industry*.

	Total emission from Chemical industries		Fraction of IPPU, %	Largest contributor in Chemical industries	Emission from largest contributor		Fraction of Chemical industries, %
SO_2	0.004	kt	0.6	2B10a Other chemical industry	0.004	kt	100.0
NO_x	0.03	kt	40.2	2B10a Other chemical industry	0.03	kt	100.0
NMVOC	0.01	kt	0.04	2B10a Other chemical industry	0.01	kt	100.0
NH_3	0.01	kt	4.3	2B10a Other chemical industry	0.01	kt	100.0
TSP	0.002	kt	0.03	2B10a Other chemical industry	0.002	kt	100.0
HM	0.66	kg	0.008	Hg from 2B10a Other chemical industry	0.66	kg	100.0
POPs	0.3	mg	0.0004	PAH from 2B10a Other chemical industry	0.0003	g	100.0

4.3.2 Nitric and sulphuric acid production

The production of sulphuric acid, nitric acid as well as NPK fertilisers has been concentrated at one company; Kemira GrowHow A/S (Kemira GrowHow, 2004). The production of sulphuric acid and nitric acid/fertiliser ceased in 1996/7 and in the middle of 2004, respectively. The following categories are covered:

- Sulphuric acid
- Nitric acid

The following pollutants are relevant for the nitric and sulphuric acid production processes:

- SO_2
- NO_x
- NH_3
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC

Methodology

In the NFR tables, SO_2 emissions from sulphuric acid production are reported under 2B10a Other chemical industry. In this report however, these emissions are reported alongside with emissions from nitric acid production since they are produced by the same company.

Information on emissions is obtained from environmental reports, contact to the company as well as information from the county. Information on emissions of SO_2, NO_x and NH_3 is available for 1990, 1994-1997; 1990, 1994-2002 and 1989-2004 respectively, TSP is available for 1996-2004. Implied emission factors (IEF) are calculated for the years where measurements are available; these implied emission factors are then used to calculate emissions for the remaining years.

Activity data

The activity data regarding production of nitric- and sulphuric acid are obtained through environmental reports and personal communication with Kemira (Kemira GrowHow, 2004 and 2005). The data are presented in Table 4.3.2 and Annex 3C-2.1.

Table 4.3.2 Production of nitric and sulphuric acid, t.

	1980	1985	1990	1995	2000	2001	2002	2003	2004
Nitric acid	350	350	450	390	433	382	334	386	229
Sulphuric acid	188	188	148	102	NO	NO	NO	NO	NO

NO: Not occurring.

Emission factors

The calculated implied emission factors for SO_2, NO_x, NH_3 and TSP are presented in Table 4.3.3.

Table 4.3.3 IEFs for production of nitric- and sulphuric acid.

Process	Pollutant	IEF	Unit
Nitric acid	NO_x	0.95-1.79	kg/t
Nitric acid	NH_3	0.03-0.26	kg/t
Nitric acid	TSP	0.56-0.98	kg/t
Sulphuric acid	SO_2	1.40-2.69	kg/t

Due to the lack of information on the particle distributions PM_{10} and $PM_{2.5}$, these are put equal to TSP for nitric acid production. BC is estimated as 1.8 % of $PM_{2.5}$ according to EMEP/EEA (2019) (chemical industry, average).

Emission trends

The time series for SO_2 follows the amount of sulphuric acid produced, i.e. the fluctuation follows the activity until the activity ceased in 1997. The same is the case for NO_X from production of nitric acid. Emission data are presented in Figure 4.3.1 and Annex 3C-2.2.

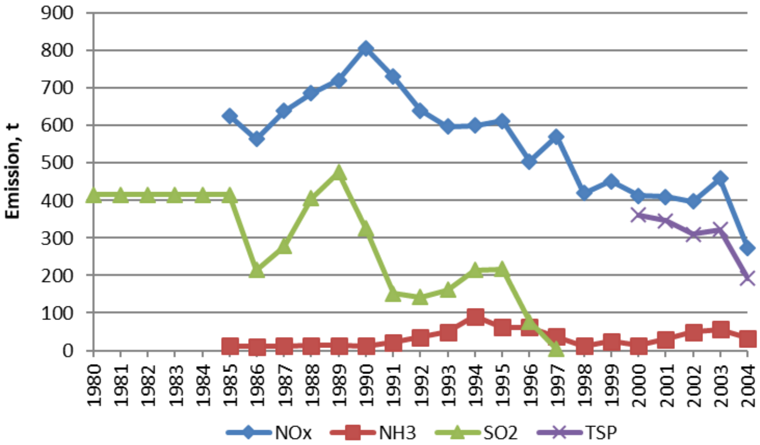

Figure 4.3.1 Emissions from nitric and sulphuric acid production.

4.3.3 Catalyst production

Production of a wide range of catalysts and potassium nitrate is concentrated at one company: Haldor Topsøe A/S situated in Frederikssund. The products are catalysts for many purposes (for hydro-processing, ammonia, $DeNO_x$, methanol, hydrogen and synthesis gas, sulphuric acid, formaldehyde, and combustion catalysts) and potassium nitrate (fertiliser). The following category is covered:

- Other: catalysts

The following pollutants are relevant for the catalyst production processes:

- NO_x
- NH_3
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC

Methodology

The emissions of NO_X, NH_3 and PM_{10} from production of catalysts and fertilisers are measured annually from 1996 to 2023 (Haldor Topsøe, 2013 and 2024). The emissions from 1985-1995 were extrapolated.

The process related NO_X emission has been estimated as 80 % of the measured total NO_X emission; Haldor Topsøe reports this assumption in their environmental report (Haldor Topsøe, 2013). The plant is equipped with a $DeNO_x$ flue gas cleaning system and depending on the efficiency of the cleaning system emissions of NH_3 will occur.

Activity data

The activity data regarding production of catalysts and fertiliser are obtained through environmental reports from Haldor Topsøe (2013) where these are available. For years where environmental reports are unavailable, production data are estimated using the drivers mentioned in Table 4.3.4. Production data are presented in Table 4.3.5 and Annex 3C-2.3, the annex also includes the applied surrogate data.

Table 4.3.4 Source of activity data.

Years	Determined by
1985-1995	Extrapolation
1996	Total production is available, the average split between the two products from 1997-2001 is applied for estimating the individual productions
1997-2012	Information from the company (Haldor Topsøe, 2013)
2013-2014	Estimated using the consumption of raw materials as surrogate data
2015-2023	Catalyst production is known from Statistics Denmark, and fertiliser production is estimated using the fuel consumption as surrogate data and the average production for 2003-2012

Table 4.3.5 Production of catalysts and potassium nitrate, kt.

	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
Catalysts produced	-	-	-	17.2	23.2	20.5	-	-	-	-
Potassium nitrate produced	-	-	-	19.2	23.3	25.9	-	-	-	-
Total produced	16.8	23.7	30.5	36.4	46.5	46.4	62.4	59.5	55.4	64.2

Emission factors

The calculated implied emission factors for NO_x, NH_3 and particles are presented in Table 4.3.6.

Table 4.3.6 Implied emission factors for production of catalysts and potassium nitrate.

	NO_x	NH_3	TSP	PM_{10}	$PM_{2.5}$	BC
Unit	t/kt	t/kt	t/kt	t/kt	t/kt	kg/kt
Range	0.32-1.76	0.11-3.70	0.03-0.70	0.03-0.56	0.02-0.42	0.4-7.5

TSP and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1/0.8/0.6) from CEPMEIP (Values for 'Production of nitrogen fertiliser'). BC is estimated as 1.8 % of $PM_{2.5}$ according to EMEP/EEA (2023) (chemical industry, average).

Emission trends

The particle emissions fluctuate, which is typically caused by variations in the performance of the filters. This is quite common for particle abatement. As such the particle emission is not directly correlated to the production, but more influenced by the efficiency of the abatement.

The NO_x emission has been reduced in spite of increasing production due to installation of $DeNO_x$ technology on the stacks. The installation of this abatement occurred in 1999 and 2000. The minor fluctuations in NO_x emission in the years since are caused by variations in the abatement efficiency, e.g. when the system is failing, problems with the dosage of NH_3, etc.

The emission of NH_3 shows an increasing trend throughout the 00's; from 14 tonnes in 2000 to 165 tonnes in 2009; in the same period the implied emission factor fluctuates around the average 1.77 tonnes per kt product but shows no trend. For the remaining time series, the NH_3 emission only varies between 7-21 tonnes with the exception of 2010 where 123 tonnes were emitted.

Emissions of NO_x, NH_3 and TSP are shown in Figure 4.3.2 and Annex 3C-2.4.

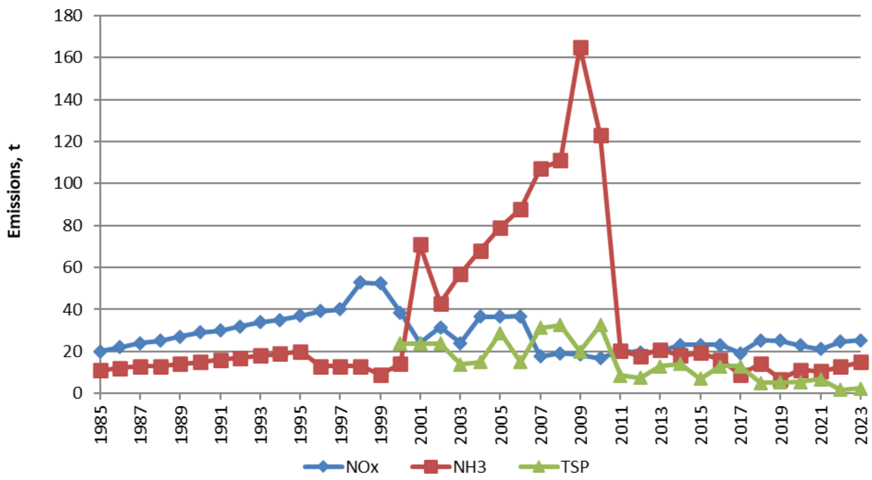

Figure 4.3.2 Emissions from catalyst and fertiliser production.

4.3.4 Production of chemical ingredients

The production of chemical ingredients takes place in a number of different companies. One of the major companies is Danisco Grindsted located in Grindsted (Danisco Grindsted, 2014). The following category is covered:

- Processes in organic chemical industry

The following pollutant is relevant for the production process of chemical ingredients:

- NMVOC

Methodology
The following description of the production of chemical ingredients is based on the historical environmental reports from the company (Danisco Grindsted, 2014).

The raw materials are primarily natural or nature identical raw materials/substances: vegetable oils, animal fatty acids, glycerine, other organic substances, mineral acidic and alkaline compounds, solvents etc. The products are emulsifiers, stabilisers, flavours, enzymes, antioxidants, pharmaceuticals, and preservatives.

Activity data
Due to confidentiality no activity data are available.

Emission factors
Due to confidentiality no emission factors are available.

Emission trends
The emission of NMVOC from production of chemical ingredients has been measured from 1997 to 2016 (Danisco Grindsted, 2014 and DuPont, 2017). The emission has in this period decreased from 85 tonnes to 9 tonnes. However, no explanation can be given on these conditions, as information on activity is not available. From 2017, emissions are estimated using implied emission factors. The NMVOC emissions are presented in Table 4.3.7 and Annex 3C-2.5.

Table 4.3.7 Emissions from the production of chemical ingredients, t.

	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
NMVOC	44	75	87	62	16	12	10	9	8	9	7

4.3.5 Pesticide production

The production of pesticides in Denmark is concentrated at one company: Cheminova A/S situated in Harboøre. The following category is covered:

- Pesticide production

The following pollutants are relevant for the pesticide production process:

- SO_2
- NMVOC

Because it is not possible to separate process and fuel emissions reported in the company's environmental reports, SO_2 emissions for this source category includes emissions from fuel consumption.

Methodology
The air emissions from Cheminova are measured from a number of sources; e.g. exhaust from process plant, sulphur recovery plant and biological sewage treatment plant. Only some of the emissions are available and they are only presented as aggregated data.

The produced amount of pesticides is known for 1996-2009 (Cheminova, 2010). Emissions of SO_2 and NMVOC are measured annually and are available for 1990-2023 and 1990-2000+2013-2023 respectively (Cheminova 2010, 2015 and 2024). For the years where data are not available, activity data are extrapolated and emissions are calculated using implied emission factors.

Activity data

Activity data for 1980-1995 are calculated using the national statistics on value of pesticides produced (million DKK) as surrogate data. For 2010-2023, no information on the production is available and activity data are estimated using DCE judgement. Activity data on the production of pesticides are presented in Table 4.3.8 and Annex 3C-2.6.

Table 4.3.8 Production of pesticides, t.

	1980	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
Pesticide production	20796	42010	37671	45320	60284	53504	40000	60000	60000	60000	60000

Emission factors

The calculated implied emission factors for pesticide production are presented in Table 4.3.9.

Table 4.3.9 Implied emission factors for pesticide production, Claus process.

	Substance	Interval[1], kg/t	Average, kg/t
Pesticides	SO_2	0.01-26.1	5.8[2]
	NMVOC	0.04-10.4	1.3[3]

[1] of 1980/1985-2022, [2] of 1990-2022, [3] of 1990-2000 and 2013-2022.

Emission trends

The emission of NMVOC from production of pesticides is reduced significantly from 1989 to 1992. The decrease can be explained by introduction of flue gas cleaning equipment rather than any decrease in activity.

The emission of SO_2 is from the sulphur regeneration plant (Claus plant) decreased drastically from 2006-2007 due to installation of a scrubber in the beginning of 2007 (Cheminova, 2008).

Emissions are presented in Figure 4.3.3 and Annex 3C-2.7.

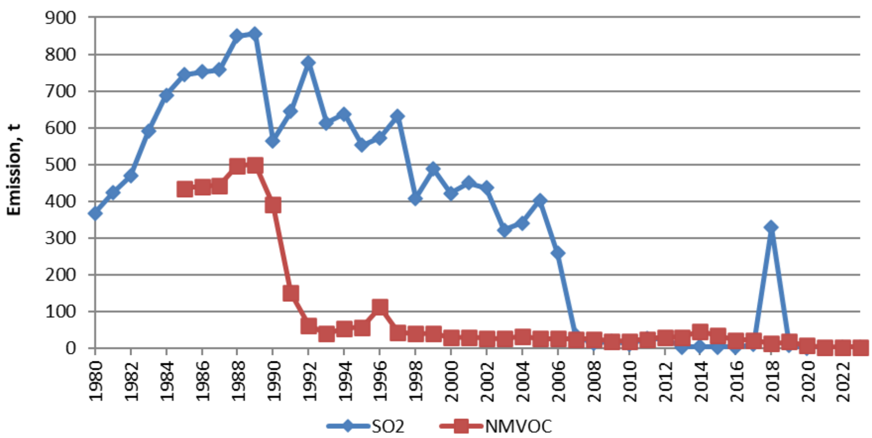

Figure 4.3.3 Emissions of SO_2 and NMVOC from pesticide production.

4.3.6 Production of tar products

One Danish factory (Koppers) situated in Nyborg produces tar products. The following category is covered:

- Production of tar products

The following pollutants are relevant for the production process of tar products:

- SO_2
- NMVOC
- Hg
- PAH: Benzo(a)pyrene

Methodology

Koppers is a chemical plant that refines coal tar. The main products of the company are coal tar pitch, carbon black feedstock, creosote oil and naphthalene.

The production takes place in closed system and the storage tanks that are run at vacuum to keep releases to the surroundings to a minimum. (Koppers, 2014).

Activity data are known for 2002-2023 (Koppers, 2017a and 2024) and estimated using surrogate data (Statistics Denmark, 2024) for previous years. The emissions are based on measured emissions reported in the environmental reports from the company (Koppers, 2017a, 2017b and 2024). Where no emissions are reported, these are calculated using implied emission factors.

Activity data

Activity data for production of tar products are presented in Table 4.3.10 and Annex 3C-2.8 (also presents the surrogate data).

Table 4.3.10 Activity data for production of tar products, kt.

	1980	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Tar products	108	181	235	199	164	133	236	260	263	281	286

Emission factors

Calculated implied emission factors are presented in Table 4.3.11.

Table 4.3.11 Implied emission factors for production of tar products.

Pollutant	Unit	Value	Average of	Applied for
SO_2	t/kt	1.0	2002-2006	1980-2000
NMVOC	kg/kt	4.3	2002-2006	1985-2000
Hg	g/kt	30.7	2008-2012	1990-2007
Benzo(a)pyrene	g/kt	0.7	2005	1990-2011

Data measurements for benzo(a)pyrene are available also from 2018, emission factors for 2012-2017 are therefore estimated via interpolation (0.1-0.6 g/kt).

Emission trends

The SO_2 emission varies depending on the sulphur content in the raw tar. The NMVOC emission is fugitive, i.e. the emission is mainly associated with leakages, maintenance work and accidental releases. As such, there is no correlation between the SO_2 and NMVOC emission as the two pollutants are emitted through different processes from different sources. The Hg emission for the later years is based on measured emissions by the plant. The fluctuations are caused by differences in the raw material, differences in production conditions and variations in abatement efficiency.

Emissions are presented in Table 4.3.12 and Annex 3C-2.9.

Table 4.3.12 Emissions from production of tar products.

	Unit	1980	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
SO_2	Mg	108	181	235	199	212	105	153	14	13	84	3
NMVOC	Mg	-	0.8	1.0	0.9	0.9	1.2	0.9	2.2	4.8	1.3	0.1
Hg	kg	-	5.6	7.2	6.1	5.0	1.5	1.0	0.1	1.1	3.7	0.7
Benzo(a)pyrene	kg	-	0.12	0.16	0.14	0.11	0.09	0.07	0.001	0.001	0.001	0.0003

4.4 Metal production

4.4.1 Source category description

The processes within the sub-sector *Metal industry* (NFR 2C) in Denmark in relation to emission of non-greenhouse gas pollutants are:

- 2C1 Steel production
- 2C1 Iron production
- 2C3 Secondary aluminium production
- 2C5 Secondary lead production
- 2C7c Red bronze production

The time series for emission of SO_2, NMVOC, particulate matter, heavy metals, and POPs from *Metal production* is available in the NFR tables. Table 4.4.1 presents an overview of emissions from 2023.

Table 4.4.1 Overview of emissions from 2023.

	Total emission from Metal industries	Fraction of IPPU, %	Largest contributor in Metal industries	Emission from largest contributor	Fraction of Metal industries, %
SO_2	0.5 t	0.07	2C5 Lead production	0.5 t	100.0
NMVOC	4.8 t	0.02	2C1 Iron and steel production	4.8 t	100.0
TSP	208.5 t	3.1	2C1 Iron and steel production	204.8 t	98.2
HMs	2.7 t	33.2	Pb from 2C5 Lead production	1.5 t	53.4
POPs	0.05 kg	0.1	PCBs from 2C1 Iron and steel production	0.05 kg	92.3

In the NFR tables, steel production and iron production are summed into one category called “Iron and steel production”. This NFR sector 2C1 comprises three activities: An electric arc furnace (EAF) (until 2001/2002 and in 2005), rolling mills (from 2003) and grey iron foundries (whole time series). The most interesting activity from an emission perspective is the EAF. After the closing of the EAF, the site has since 2003 been used for rolling steel slabs imported from steelworks in other countries. This change in production results in large changes in activity data and emissions. In 2005, the EAF was shortly reopened, which explains the higher activity level this year.

Regarding the steelworks that use iron and steel scrap as raw material, the emissions to a large degree depend on the quality of the scrap. This fact may result in large annual variations for one or more of the heavy metals. This may also be the case for iron foundries, as they also use scrap as raw material, but they have not been subject to the same requirements to analyse emissions of heavy metals to air.

4.4.2 Steel production

The production of semi-manufactured steel products (e.g. steel sheets/plates and bars) is concentrated at one company: Det Danske Stålvalseværk A/S situated in Frederiksværk. After the closure of the primary production in 2002, the two rolling mills were divided in two companies called DanSteel and Duferco. The following categories are covered:

- Electric furnace steel plant
- Rolling mill

The following pollutants are relevant for the steel production processes:

- SO_2
- NO_x
- NMVOC
- CO
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn
- POPs: HCB, PCDD/F, PAHs, PCB

Methodology

The steelwork was closed down in January 2002 and then partly re-opened again in November 2002. The production of steel sheets/plates was reopened by DanSteel in 2003, the production of steel bars was reopened by DanScan Metal in March 2004, and the electro steelwork was reopened by DanScan Steel in January 2005. The production at DanScan Metal and Steel ceased in the last part of 2005 and in June 2006 DanScan Metal was taken over by Duferco; the electro steelwork (DanScan Steel) has still not been in operation since 2005. The timeline is presented in Figure 4.4.1.

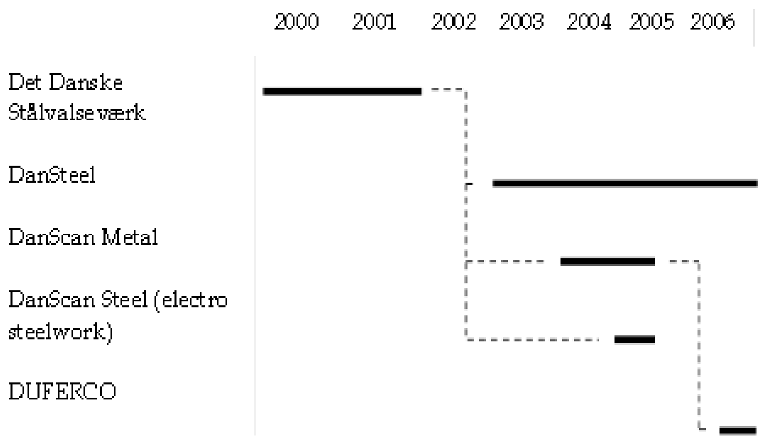

Figure 4.4.1 Timeline for production at the Danish steelwork.

Activity data

Statistical data on steel production activities are available in environmental reports from the single Danish plant (Det Danske Stålvalseværk, 2002) and the rolling mills factories (DanSteel, 2016 and Duferco, 2014, 2016) supplemented with other literature and personal contact with the plants (DanSteel, 2024 and Duferco, 2024); see Table 4.4.2 and Annex 3C-3.1.

Table 4.4.2 Overall mass flow for Danish steel production, kt.

		1980	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
Det Danske Stålvalseværk												
Raw material	Iron and steel scrap	-	-	-	657	680	-	-	-	-	-	-
Intermediate product	Steel slabs etc.	-	-	-	654	803	-	-	-	-	-	-
Product	Steel sheets	444	444	444	478	380	-	-	-	-	-	-
	Steel bars	170	170	170	239	251	-	-	-	-	-	-
	Products, total	614[1]	614[1]	614[1]	717	631	250[2]	-	-	-	-	-
Dansteel												
Raw material	Steel slabs	-	-	-	-	-	515	457	525	c	c	c
Product	Steel sheets	-	-	-	-	-	433	381	441	c	c	c
Duferco												
Raw material	Steel billets	-	-	-	-	-	-	141	137	c	c	c
Product	Steel bars	-	-	-	-	-	-	129	129	c	c	c

[1] Extrapolation.
[2] Assumed.
c Confidential.

The mass balances/flow sheets presented in the annual environmental reports do not for all years tell about the changes in the stock and therefore the balance cannot be completed.

Emission factors

The applied emission factors are presented in Table 4.4.3. Regarding the electric arc furnace the emissions for all other pollutants than TSP have been estimated by use of emission factor from literature.

Table 4.4.3 Emission factors for steel production.

	Unit	Electric Arc Furnace	Rolling Mill
SO_2	g/t	60[6]	-
NO_x	g/t	130[6]	-
NMVOC	g/t	46[6]	7[8]
CO	kg/t	1.7[6]	-
TSP	g/t	61-68[4]	2.5-11.1[4]
PM_{10}	g/t	80 % of TSP[6]	2.4-10.5[4]
$PM_{2.5}$	g/t	70 % of TSP[6]	1.5-6.6[4]
BC	g/t	0.36 % of $PM_{2.5}$[6]	0.36 % of $PM_{2.5}$[7]
As	mg/t	15[6]	-
Cd	mg/t	10-80[2]	0.1-0.4[4]
Cr	mg/t	100[6]	-
Cu	mg/t	20[6]	-
Hg	mg/t	50-400[6,2]	-
Ni	g/t	0.4-1.4[2]	0.004-0.010[4]
Pb	g/t	1.0-5.0[2]	0.005[5]
Se	g/t	0.02[7]	-
Zn	g/t	3.6-19.0[6,2]	0.005[5]
HCB	mg/t	3.2[3]	-
PCDD/F	µg/t	3.0[6]	-
Total 4 PAHs	g/t	0.48[1,6]	-
PCB	mg/t	2.5[3]	-

[1]Divided by four for an estimate of the individual pollutants, [2]Illerup et al. (1999), [3]Nielsen et al. (2013), [4]Implied emission factor, [5]DCE judgement, [6]EMEP/EEA (2023) 2.C.1 Table 3-15 Tier 2 EAF no abatement, [7]EMEP/EEA (2023) 2.C.1 Table 3-1 Tier 1, [8]EMEP/EEA (2023) 2.C.1 Table 3-22 Tier 2 hot rolling mills.

Emission trends

Emissions from the electro steelwork and rolling mills are presented in Table 4.4.4 and Annex 3C-3.2.

Table 4.4.4 Emissions from the electro steelwork and rolling mills.

	Unit	1980	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
SO_2	t	37	37	43	38	15	-	-	-	-	-	-
NO_x	t	-	80	93	82	33	-	-	-	-	-	-
NMVOC	t	-	32	37	33	19	6.1	6.9	6.8	8.1	8.1	8.1
CO	t	-	1.0	1.2	1.1	0.4	-	-	-	-	-	-
TSP	t	-	141	153	95	72	45.4	52.9	44.3	55.8	55.6	53.7
PM_{10}	t	-	71	82	33	15	3.0	5.4	3.4	4.2	4.1	4.2
$PM_{2.5}$	t	-	62	72	29	12	2.5	4.0	2.7	3.2	3.1	3.1
BC	t	-	0.22	0.26	0.10	0.05	1.11	1.11	1.13	1.04	0.99	0.87
As	kg	-	9.2	10.8	9.5	3.8	-	-	-	-	-	-
Cd	kg	-	39	22	16	7.1	0.8	0.8	0.9	0.8	0.7	0.7
Cr	kg	-	61	72	63	25	-	-	-	-	-	-
Cu	kg	-	12	14	13	5.0	-	-	-	-	-	-
Hg	kg	-	246	143	63	13	-	-	-	-	-	-
Ni	kg	-	757	430	252	104	2.8	1.7	2.1	1.8	1.8	1.9
Pb	kg	-	2967	1720	669	268	1.9	2.2	2.5	2.8	2.8	3.0
Se	kg	-	12	14	13	5.0	-	-	-	-	-	-
Zn	kg	-	11492	6547	3085	902	3.0	3.3	3.6	3.8	3.8	3.8
HCB	kg	-	2.0	2.3	2.0	0.8	-	-	-	-	-	-
PCDD/F	g	-	12.0	7.5	0.5	0.8	-	-	-	-	-	-
Benzo(b)flouranthene	kg	-	74	86	76	30	-	-	-	-	-	-
Benzo(k)flouranthene	kg	-	74	86	76	30	-	-	-	-	-	-
Benzo(a)pyrene	kg	-	74	86	76	30	-	-	-	-	-	-
Indeno(1,2,3-c,d)pyrene	kg	-	74	86	76	30	-	-	-	-	-	-
PCB	kg	-	1.5	1.8	1.6	0.6	-	-	-	-	-	-

Due to the change in production process in the beginning of the 00's, the emissions (and even more so the implied emission factors) change drastically from 2001 to 2002 and from 2002 to 2003. Please refer to Figure 4.4.1 and Table 4.4.2 (Annex 3C-3.1).

4.4.3 Iron production

Multiple grey iron foundries exist in Denmark, producing a wide range of products like e.g. cast-iron pipes, central heating boilers and flywheels. The following category is covered:

- Grey iron foundries

The following pollutants are relevant for the iron production process:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn
- POPs: HCB, PCB

Methodology

There are about 15 grey iron producers in Denmark, most of these are small producing only 10-1000 tonnes per year. The emissions from iron foundries are based on yearly production statistics from Statistics Denmark (2024), emission measurements (implied emission factors) and standard emission factors.

Activity data

Statistical data on production in grey iron foundries are available from Statistics Denmark (2024) for the entire time series. The activity data are presented in Table 4.4.5 and Annex 3C-3.3.

Table 4.4.5 Activity data, iron foundries, kt.

	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Grey iron foundries	104.9	100.5	108.0	107.2	86.5	96.2	83.5	104.6	104.2	100.1

Emission factors

The applied emission factors are presented in Table 4.4.6.

Table 4.4.6 Emission factors for grey iron foundries.

	Unit	Grey iron foundries	Reference
TSP	g/t	2000	CEPMEIP[1]
PM_{10}	g/t	600	CEPMEIP[1]
$PM_{2.5}$	g/t	90	CEPMEIP[1]
BC	% of $PM_{2.5}$	10	EMEP/EEA (2023)[2]
As	g/t	0.3	EMEP/Corinair (2007)[3]
Cd	g/t	0.1	EMEP/Corinair (2007)[3]
Cr	g/t	1.0	EMEP/Corinair (2007)[3]
Cu	g/t	1.0	EMEP/Corinair (2007)[3]
Hg	g/t	0.04	EMEP/Corinair (2007)[3]
Ni	g/t	0.3	EMEP/Corinair (2007)[3]
Pb	g/t	3.0	EMEP/Corinair (2007)[3]
Se	g/t	0.01	EMEP/Corinair (2007)[3]
Zn	g/t	5.0	EMEP/Corinair (2007)[3]
HCB	mg/t	0.04	Nielsen et al. (2013).
PCB	mg/t	0.5	Nielsen et al. (2013).

[1]CEPMEIP & EMEP/Corinair 2007, SNAP 030303, Table 8.1, [2]2.C.2, SNAP 040302 Ferroalloys, Table 3-1, [3]SNAP 030303, Table 8.1.

Emission trends

Emissions from grey iron foundries are presented in Table 4.4.7 and Annex 3C-3.4.

Table 4.4.7 Emissions from grey iron foundries.

	Unit	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
TSP	t	210	201	216	214	173	192	167	209	208	200
PM_{10}	t	63	60	65	64	52	58	50	63	63	60
$PM_{2.5}$	t	9	9	10	10	8	9	8	9	9	9
BC	t	0.9	0.9	1.0	1.0	0.8	0.9	0.8	0.9	0.9	0.9
As	kg	31	30	32	32	26	29	25	31	31	30
Cd	kg	10	10	11	11	9	10	8	10	10	10
Cr	kg	105	100	108	107	86	96	83	105	104	100
Cu	kg	105	100	108	107	86	96	83	105	104	100
Hg	kg	4.2	4.0	4.3	4.3	3.5	3.8	3.3	4.2	4.2	4.0
Ni	kg	31	30	32	32	26	29	25	31	31	30
Pb	kg	315	301	324	322	259	289	250	314	313	300
Se	kg	1.0	1.0	1.1	1.1	0.9	1.0	0.8	1.0	1.0	1.0
Zn	kg	524	502	540	536	432	481	417	523	521	501
HCB	g	4.2	4.0	4.3	4.3	3.5	3.8	3.3	4.2	4.2	4.0
PCB	g	52	50	54	54	43	48	42	52	52	50

4.4.4 Secondary aluminium production

Only one Danish producer of secondary aluminium exists; "Stena Aluminium". The following category is covered:

- Secondary aluminium production

The following pollutants are relevant for the secondary aluminium production:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: Cd, Pb
- POPs: HCB, PCDD/F, PCB

Methodology

Secondary aluminium industries were identified from a list of companies with the relevant environmental approvals acquired from the Danish Environmental Agency. All producers were contacted when necessary to determine if they use scrap aluminium in their production. The only secondary aluminium producer (called Stena Aluminium) closed in the end of 2008.

Activity data

The activity data are known from the company's environmental reports (Stena Aluminium, 2008) for 1996-2008 and are presented in Table 4.4.8 and Annex 3C-3.5.

Table 4.4.8 Activity data for secondary aluminium production, kt.

	1990[1]	1995[1]	2000	2005	2006	2007	2008
Stena Aluminium	30.2	30.2	32.9	23.4	31.3	35.1	36.2

1990-1995: Calculated average of 1996-2000.

Emission factors

Emission factors for the production of secondary aluminium are presented in Table 4.4.9.

Table 4.4.9 Emission factors for secondary aluminium production.

Pollutant	Unit	Value	Source
TSP	kg/t	0.12	Average IEF (1998-2000)
PM_{10}	% of TSP	70.0	EMEP/EEA (2023)[1]
$PM_{2.5}$	% of TSP	27.5	EMEP/EEA (2023)[1]
BC	% of $PM_{2.5}$	2.3	EMEP/EEA (2023)[1]
Cd	g/t	0.03	Average IEF (1998-2000)
Pb	g/t	0.15	Average IEF (1998-2000)
HCB	mg/t	20.0	Luglio (2006)
PCDD/F	mg/t	0.035	EMEP/EEA (2023)[1]
PCB	mg/t	3.4	Luglio (2006)

[1] 2.C.3 Aluminium production Table 3-4

Emission trends

Emissions from secondary aluminium production are available in Table 4.4.10 and Annex 3C-3.6.

Table 4.4.10 Emissions from secondary aluminium production.

	Unit	1990	1995	2000	2005	2006	2007	2008
TSP	t	3.6	3.6	3.9	2.8	3.8	4.2	4.3
PM_{10}	t	2.5	2.5	2.8	2.0	2.6	2.9	3.0
$PM_{2.5}$	t	1.0	1.0	1.1	0.8	1.0	1.2	1.2
BC	kg	23.0	23.0	25.0	17.8	23.8	26.7	27.5
Cd	kg	0.91	0.9	1.0	0.7	0.9	1.1	1.1
Pb	kg	4.5	4.5	4.9	3.5	4.7	5.3	5.4
HCB	kg	0.60	0.60	0.66	0.47	0.63	0.70	0.72
PCDD/F	g	1.1	1.1	1.2	0.8	1.1	1.2	1.3
PCB	kg	0.10	0.10	0.11	0.08	0.11	0.12	0.12

4.4.5 Secondary lead production

One Danish company producing secondary lead has been identified; Hals Metal. The following category is covered:

- Secondary lead production

The following pollutants are relevant for the secondary lead production:

- SO_2
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$
- Heavy metals: As, Cd, Hg, Pb, Zn
- POPs: HCB, PCDD/F, PCB

Methodology

Only one Danish company, called Hals Metal A/S, has been identified as producing secondary lead from scrap metal. In addition to Hals Metal, old lead tiles from castles, churches etc. are melted and recast on site during preservation of the many historical buildings in Denmark.

Hals Metal A/S has closed in 2021 but reopened in 2022 as part of a larger company; Rimeco.

Activity data

Activity data from Hals Metal is provided by the company (Hals Metal, 2024). A clause affected in 2002 meant that Hals Metal could no longer burn cables containing lead. The processing of cables was therefore stopped and the company's activity changed to melting. This transition resulted in a low activity in 2003. Because of the bankruptcy petition in 2021 and reopening in 2022, activities for these two years were lower than for the remaining timeseries.

The activity of recasting lead tiles is not easily found because it is spread out on many craftsmen and poorly regulated. However, an estimate by Lassen et al. (2004) stated that 200-300 tonnes lead tiles were recast in 2000. Since the building stock worthy of preservation is constant, it is considered reasonable to also let the activity of recasting of lead tiles be constant.

Activity data for secondary lead is shown in Table 4.4.11 and Annex 3C-3.7.

Table 4.4.11 Activity data for secondary lead production, t.

	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Hals Metal	540	750	540	691	635	745	194	97	24	78.6
Lead tiles	250	250	250	250	250	250	250	250	250	250
Total	790	1000	790	941	885	995	444	347	274	329

Emission factors

Emission factors are presented in Table 4.4.12. Measurements of SO_2, Hg, PCDD/F and PCB are available for Hals Metal for 2008-2010, these measurements are used to calculate plant specific emission factors. For Hg, the calculated implied emission factor (IEF) is also applied to the unabated production as a country specific emission factor. Hals Metal is a modern secondary lead production facility, and emission factors for "current technology" are therefore chosen for emission factors found in literature.

Table 4.4.12 Emission factors for secondary lead production.

		Current technology		Unabated	
Pollutant	Unit	Value	Reference	Value	Reference
SO_2	kg/t	6.4	Average IEF (2008-2010)	NA	
TSP	kg/t	0.012	Cusano et al., 2017, Table 5.13	14.8	EMEP/EEA (2023)[1]
PM_{10}	kg/t	0.010	Visschedijk et al. (2004)	11.8	EMEP/EEA (2023)[1]
$PM_{2.5}$	kg/t	0.005	Visschedijk et al. (2004)	8.8	EMEP/EEA (2023)[1]
As	g/t	0.09	Cusano et al., 2017, Table 5.13	47	EMEP/EEA (2023)[1]
Cd	g/t	0.03	Cusano et al., 2017, Table 5.13	15	EMEP/EEA (2023)[1]
Hg	g/t	0.46	Average IEF (2008-2010)	0.46	Average IEF (2008-2010)
Pb	g/t	2.3	Cusano et al., 2017, Table 5.13	5800	EMEP/EEA (2023)[1]
Zn	g/t	0.04	Cusano et al., 2017, Table 5.13[2]	35	EMEP/EEA (2023)[1]
HCB	µg/t	300	Luglio (2006)	300	Luglio (2006)
PCDD/F	µg/t	2.0	Average IEF (2008-2010)	8.0	EMEP/EEA (2023)[1]
PCB	µg/t	981	Average IEF (2008-2010)	3.2	EMEP/EEA (2023)[1]

[1] Chapter 2.C.5, Table 3-4, [2] Value for Ausmelt/ISASMELT

Emission trends

Emissions from secondary lead production are available in Table 4.4.13 and Annex 3C-3.8.

Table 4.4.13 Emissions from secondary lead production.

	Unit	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
SO_2	t	3.5	4.8	3.5	4.4	4.1	4.8	1.2	0.6	0.2	0.5
TSP	t	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
PM_{10}	t	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
$PM_{2.5}$	t	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
As	kg	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
Cd	kg	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Hg	kg	0.4	0.5	0.4	0.4	0.4	0.5	0.2	0.2	0.1	0.1
Pb	kg	1451	1452	1451	1452	1451	1452	1450	1450	1450	1450
Zn	kg	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
HCB	g	0.2	0.3	0.2	0.3	0.3	0.3	0.1	0.1	0.1	0.1
PCDD/F	mg	3.1	3.5	3.1	3.4	3.3	3.5	2.4	2.2	2.0	2.2
PCB	g	0.5	0.7	0.5	0.7	0.6	0.7	0.2	0.10	0.02	0.1

4.4.6 Red bronze production

The following category is covered:

- Allied metal manufacturing (Red bronze production)

The following pollutants are relevant for the red bronze production process:

- Heavy metals: Cd, Cu, Pb, Zn

Methodology

In Denmark casting of brass and bronze primarily occurs in clay bonded sand or chemically bonded sand with or without core. These production processes are usually used in small production and are suitable for series of 1-100 pcs, e.g. for prototypes, test series and small production series.

In addition, lost-wax precisions casting is used for e.g. sculptures and shell molding (aka. Croning casting) for large or medium-sized batches.

Products vary from valves and propellers to headstone ornaments and sculptures. The weight of these products are known to vary from 5 grams up to 2.5 tonnes.

Activity data

Activity data are estimated based on Statistics Denmark (2024), Illerup et al. (1999). Activity data are presented in Table 4.4.14 and Annex 3C-3.9.

Table 4.4.14 Activity data for red bronze production, kt.

	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Red bronze production	3.9	4.5	4.3	5.5	2.6	1.8	1.1	1.1	1.1	0.9

Emission factors

The applied emission factors are presented in Table 4.4.15 and are all referenced to Illerup et al. (1999).

Table 4.4.15 Emission factors for red bronze production.

Pollutant	Unit	Value
Cd	g/t	1
Cu	g/t	10
Pb	g/t	15
Zn	g/t	140

Emission trends

Emissions trends for Cd, Cu, Pb, and Zn from red bronze production are presented in Table 4.4.16 and Annex 3C-3.10.

Table 4.4.16 Emissions from red bronze production, kg.

	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Cd	3.9	4.5	4.3	5.5	2.6	1.8	1.1	1.1	1.1	0.9
Cu	39	45	43	55	26	18	11	11	11	9
Pb	58	67	65	82	39	28	17	16	17	14
Zn	545	630	603	769	368	258	157	148	159	132

4.5 Non-energy products from fuels and solvent use

4.5.1 Source category description

The processes within the sub-sector *Non-energy products from fuels and solvent use* (NFR 2D) in Denmark in relation to emission of other pollutants are:

- 2D3a, d, e, f, g, h, i NMVOCs used as solvents
- 2D3b Road paving with asphalt
- 2D3c Asphalt roofing

The creosote treatment of wood is not occurring in Denmark. It would require a special permission in order to use creosote for wood treatment in Denmark, no such permission has been granted.

After contact to the Danish refineries and the Danish Asphalt Industry Association, it is concluded that Denmark has no asphalt blowing activities.

4.5.2 NMVOC from solvents use

NMVOC emissions from solvent use are allocated in the following categories according to EMEP/EEA (2023):

- 2D3a Domestic solvent use including fungicides
- 2D3d Coating applications
- 2D3e Degreasing, included in 2D3f
- 2D3f Dry cleaning
- 2D3g Chemical products
- 2D3h Printing
- 2D3i Other solvent use

Only NMVOCs used as solvents are relevant for these categories. Solvents are chemical compounds that are used on a global scale in industrial processes and as constituents in final products to dissolve e.g. paint, cosmetics, adhesives, ink, rubber, plastic, pesticides, aerosols or are used for cleaning purposes, i.e. degreasing. NMVOCs are main components in solvents - and solvent use in industries and households is typically the dominant source of anthropogenic NMVOC emissions (UNFCCC, 2008; Pärt, 2005; Karjalainen, 2005). In industrial processes where solvents are produced or used, NMVOC emissions to air and as liquid can be recaptured and either used or destroyed. Solvent containing products are used indoor and outdoor and the majority of solvent sooner or later evaporate. A small fraction of the solvent ends up in waste or as emissions to water and may finally also contribute to air pollution by evaporation from these compartments. Emission inventories for solvents are based on model estimates, as direct and continuous emissions are only measured from a limited number of sources.

Methodology

The amount of solvent use attributing emissions in the industrial sectors and households are calculated using a model that is readily updated on a yearly basis.

The method is mainly based on the detailed approach and methodology described in EMEP/EEA (2023) and IPCC (2006), and emissions are calculated for industrial sectors and households for the stated NFR sectors, as well as for individual pollutants.

The emission modelling of solvents is done by estimating the amount of (pure) solvents consumed. All relevant solvents must be estimated, or at least those together representing more than 90 % of the total pollutant emission. (EMEP/EEA, 2023; IPCC, 2006).

The detailed method used in the Danish emission inventory for solvent use, represents a chemicals approach, where each pollutant is estimated separately. The sum of emissions of all estimated pollutants used as solvents equals the pollutant emission from solvent use.

For each pollutant or product a mass balance is formulated:

Consumption = *(production* + *import)* – *(export* + *destruction/disposal* + *hold-up)*

Data on production, import and export amounts of solvents and solvent containing products are collected from Statistics Denmark (2024), which contains detailed statistical information on the Danish society. Manufacturing and trading industries are committed to reporting production and trade figures to the Danish Customs & Tax Authorities in accordance with the Combined Nomenclature. Import and export figures are available from 1988 to present. Production figures are reported as "industrial commodity statistics by commodity group and unit" from 1990 to present.

Destruction and disposal of solvents, lower the pollutant emissions. In principle this amount must be estimated for each pollutant in all industrial activities and for all uses of pollutant containing products. At present the solvent inventory only considers destruction and disposal for a limited number of pollutants. For some pollutants it is inherent in the emission factor, and for others the reduction is specifically calculated from information obtained from the industry or literature.

Hold-up is the difference in the amount in stock in the beginning and at the end of the year of the inventory. No information on solvents in stock has been obtained from industries. As the inventory spans over several years, the offset in the use and production, import and export will balance over time.

In some industries the solvents are consumed in the process, e.g. in the graphics and plastic industry, whereas in the production of paints and lacquers the solvents are still present in the final product. These products can either be exported or used in the country. In order not to double count consumption amounts of pollutants it is important to keep track of total solvent use, solvents not used in products and use of solvent containing products. Furthermore, some pollutants may be represented as individual pollutants and also in chemical groups, e.g. "o-xylene", "mixture of xylenes" and "xylene". Some pollutants are better inventoried as a group rather than individual pollutants, due to missing information on use or emission for the individual pollutants. The Danish inventory considers single pollutants, with a few exceptions.

Activity data for pollutants are thus primarily calculated from the mass balance equation with input from Statistics Denmark. When Statistics Denmark holds no information on production, import and export or when more reliable information is available from industries, scientific reports or expert judgements the data can be adjusted or even replaced.

This applied method naturally causes fluctuations in the time series. Such are the conditions when using national statistical data, that it holds little to no information on interannual variations.

Pollutant list

The definitions of solvents and (NM)VOC that are used in the Danish emission inventory are as defined in the solvent directive (Directive 1999/13/EC) of the EU legislation: "Organic solvent shall mean any VOC which is used alone or in combination with other agents, and without undergoing a chemical change, to dissolve raw materials, products or waste materials, or is used as a cleaning agent to dissolve contaminants, or as a dissolver, or as a dispersion medium, or as a viscosity adjuster, or as a surface tension adjuster, or a plasticiser, or as a preservative". VOCs are defined as follows: "Volatile organic compound shall mean any organic compound having at 293.15 K a vapour pressure of 0.01 kPa or more or having a corresponding volatility under the particular condition of use".

This implies that some NMVOCs, e.g. ethylene glycol, that have vapour pressures just around 0.01 kPa at 20 °C, may only be defined as VOCs at use conditions with higher temperature. However, use conditions at elevated temperatures are typically found in industrial processes. Here the capture of solvent fumes is often efficient, thus resulting in small emissions (communication with industries).

The Danish list of NMVOCs comprises approx. 30 pollutants or pollutant groups representing more than 95 % of the total emission from solvent use, cf. Table 4.5.4.

Activity data

The used amounts of products (activity data) in Table 4.5.1 are derived from used amounts of pollutants by assessing the amount of pollutants that is comprised within products belonging to each of the categories. The complete time series is presented in Annex 3C-4.1.

Table 4.5.1 Activity data for NMVOCs used as solvents, kt.

		1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
2D3d	Coating applications	90.9	83.8	91.1	104.3	74.6	45.4	43.4	37.8	49.0	51.4
2D3f	Degreasing, dry cleaning and electronics	1.7	1.4	1.5	0.6	0.4	0.2	0.2	0.3	0.2	0.3
2D3g	Chemical products manufacturing or processing	413	408	575	588	751	641	524	522	647	611
2D3i	Other use of solvents and related activities	195	177	212	198	182	147	148	132	180	167
2D3h	Printing	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.4	0.3
2D3a	Domestic solvent use incl. fungicides	35.0	29.1	43.9	41.1	35.5	26.7	40.4	42.7	24.7	29.3

Emission factors

For each pollutant the emission is calculated by multiplying the consumption with the fraction emitted (emission factor), according to:

*Emission = consumption * emission factor*

The present Danish method uses emission factors that represent specific industrial activities, such as processing of polystyrene, dry cleaning etc. or that represent use categories, such as paints and detergents. Some pollutants have been assigned emission factors according to their water solubility. Higher hydrophobicity yields higher emission factors, since a lower amount ends in wastewater, e.g. ethanol (hydrophilic) and turpentine (hydrophobic).

Emission factors for solvents are categorised in four groups in ascending order: (1) Lowest emission factors in the chemical industry, e.g. lacquer and paint manufacturing, due to emission reducing abatement techniques and destruction of solvent containing waste, (2) Other processes in industry, e.g. graphic industry, have higher emission factors, (3) Non-industrial use, e.g. auto repair and construction, have even higher emission factors, (4) Diffuse use of solvent containing products, e.g. painting, where practically all the pollutant present in the products will be released during or after use.

For a given pollutant the consumed amount can thus be attributed with two or more emission factors; one emission factor representing the emissions occurring at a production or processing plant and one emission factor representing the emissions during use of a solvent containing product. If the chemical is used in more processes and/or is present in several products more emission factors are assigned to the respective chemical amounts.

Emission factors can be defined from surveys of specific industrial activities or as aggregated factors from industrial branches or sectors. Furthermore, emission factors may be characteristic for the use pattern of certain products. The emission factors used in the Danish inventory also rely on the work done in a joint Nordic project (Fauser et al., 2009).

The emission factors are listed in Table 4.5.2 and Annex 3C-4.2. They are based on the values in the Guidebook (EMEP/EEA, 2023) and adjusted on a country specific basis according to the assessment described above. For more details, please refer to the sector report Hjelgaard (2023).

Table 4.5.2 NMVOC emission factors for solvent use.

		Unit	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
2D3d	Coating applications	t/kt	59	60	63	60	56	59	60	59	57	61
2D3f	Degreasing, dry cleaning and electronics	t/kt	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2D3g	Chemical products manufacturing or processing	t/kt	21	20	17	12	8	8	9	10	7	7
2D3i	Other use of solvents and related activities	t/kt	119	119	112	111	90	108	99	103	105	111
2D3h	Printing	t/kt	40	40	42	40	34	39	39	40	39	39
2D3a	Domestic solvent use incl. fungicides	t/kt	151	145	157	155	145	140	151	127	143	144

Source allocation

The Danish Working Environment Authority (WEA) is administrating the registrations of chemicals and products to the Danish product register. All manufacturers and importers of products for occupational and commercial use are obliged to register. The following products are comprised in the registration agreement:

- Chemicals and materials that are classified as dangerous according to the regulations set up by the Danish Environmental Protection Agency (EPA).
- Chemicals and materials that are listed with a limit value on the WEA "limit value list".
- Materials, containing 1 % or more of a chemical, which is listed on the WEA "limit value list".
- Materials, containing 1 % or more of a chemical, which are classified as hazardous to humans or the environment according to the EPA rules on classification.

There are the following important exceptions for products, which do not need to be registered:

- Products exclusively for private use.
- Pharmaceuticals ready for use.
- Cosmetic products.

The Danish product register does therefore not comprise a complete account of used pollutants. Source allocations of exceptions from the duty of declaration are done based on information from trade organisations, industries and scientific reports.

The database Substances in Preparations in the Nordic Countries (SPIN) holds information on use of various pollutants in product and activities, i.e. Use Categories Nordic (UCN), and on use in industrial categories, i.e. according to the standard nomenclature for economic activities (NACE) system. UCN and NACE codes are allocated to specific SNAP and NFR codes based on a distribution key. The method of disaggregating the use amount for each pollutant from Statistics Denmark and allocating amounts to SNAP and NFR categories follows one of the following approaches:

1. Data from Statistics Denmark are used together with UCN and NACE information from SPIN together with the distribution key.
2. Data from Statistics Denmark are used together with an assignment of use amounts to SNAP categories. This assignment is set for a specific pollutant and may differ from information in the distribution key.
3. Instead of Statistics Denmark and SPIN data, branch specific data are used for amounts and distribution in categories.
4. A combination of the above.

As an example of this allocation, pesticides, herbicides and fungicides are comprised in the UCN categories in the SPIN database. Domestic uses are notated as e.g. “Biocides - pesticides for non-agricultural uses" and hence allocated to 2.D.3.a domestic solvent use including fungicides. There are more than 500 UCN codes included in the Danish model.

Use of spray cans

Emissions from use of spray cans include the propellant (propane and butane) and solvents. Propellants comprise, according to communication with “Aerosol Industriens Brancheforening” and FORCE (2009), approx. 33 vol-% (24 weight-%) of a can. According to Rambøll (2004) the remaining amount is solvents (VOCs), 71 weight-% for spray paint and 51 weight-% for cosmetics, and non-VOCs, 5 weight-% for spray paints and 25 weight-% for cosmetics. 3% of the Danish marked is spray paints. The rest is cosmetics, which comprises deodorants, hairspray and foam products. 90% of the use in Denmark is imported. It is assumed that approx. 5% remains in the can and is destroyed in waste handling. Based on these assumptions the total VOC emissions from use of spray cans in Denmark is 1.79 kt per year. This amount is assigned to all years as no detailed consumption trend is available. The specific compounds are propane and butane as propellants and ethanol, tert-butanol, acetone, butanone, butylacetate, ethylacetate, propanol, toluene and xylene as solvents.

Emissions from use of spray cans are allocated to NFR 2D3a Domestic solvent use and 2D3d Coating applications. For propane and butane, 20% of use is as propellant in 2D3d and 80% as propellant in 2D3a. For ethanol, a small fraction of the total use is as propellant and solvent in 2D3a, and for propylalcohol, butylacetate, xylene, acetone, ethylacetate, toluene, 1-butanol and butanone, small fraction of their uses are as solvent in 2D3a.

Emission trends

Table 4.5.3, Figure 4.5.1 and Annex 3C-4.3 show the emissions of NMVOC, where the used amounts of single pollutants have been assigned to specific products and NFR sectors. The general decrease from 1996 to present is an indication of increased implementation of NMVOC emission reducing measures in production facilities, and a general shift to water soluble and high solid products, in e.g. the graphics-, paint-, plastic- and auto paint and repair industries.

Table 4.5.3 NMVOC emissions from solvent use.

	Unit	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
2D3d Coating applications	kt	5.4	5.0	5.8	6.2	4.2	2.7	2.6	2.9	2.4	2.6
2D3f Degreasing and dry cleaning	t	0.09	0.07	0.08	0.03	0.02	0.01	0.01	0.01	0.01	0.01
2D3g Chemical products	kt	8.6	8.2	9.7	7.1	6.3	4.9	4.9	6.6	4.5	3.9
2D3i Other use of solvents	kt	23.2	21.1	23.7	22.0	16.4	15.9	14.7	18.6	16.7	17.2
2D3h Printing	t	9.0	8.0	9.7	7.3	6.4	9.7	10.0	15.0	16.0	15.4
2D3a Domestic solvent use incl. fungicides	kt	5.3	4.2	6.9	6.4	5.1	3.7	6.1	3.1	4.1	3.8
Total NMVOC	kt	42.4	38.5	46.1	41.7	32.1	27.2	28.3	31.2	27.8	27.6

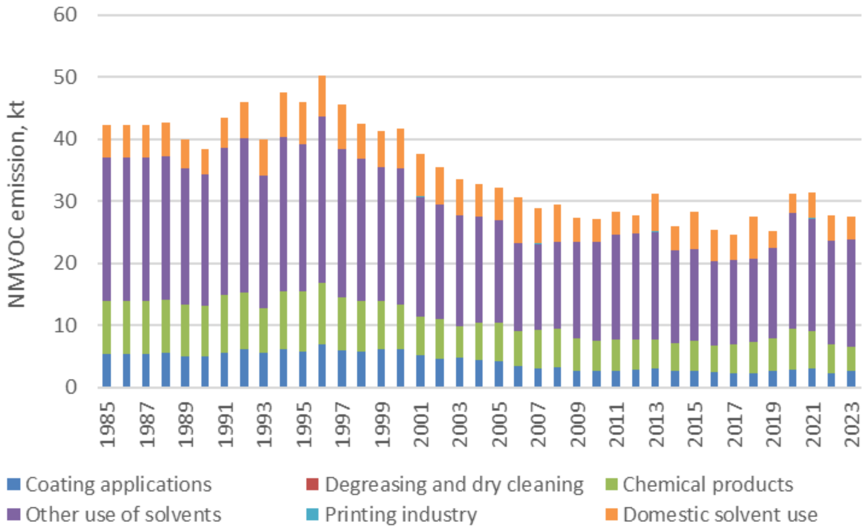

Figure 4.5.1 NMVOC emissions from solvent use, kt.

With the occurrence of Covid-19, the use of solvents (disinfectants) increased. The use amounts from Statistics Denmark are not specifically labelled as "hand sanitizers", nor are the UCN or NACE categories. The ethanol use amounts assigned to the categories "Domestic solvent use including fungicides" (NFR 2D3a) and "Other solvent use" (NFR 2D3i) should comprise the use of hand sanitizers (ethanol). The significant increase in 2D3i for the years 2020 and 2021 implies that the increased use of disinfectant is in fact included here. It is not possible to separate the domestic use of hand sanitiser in the activity data.

In Table 4.5.4 the emission for 2023 is split into individual pollutants. The most abundantly used solvents are ethanol and turpentine, or white spirit defined as a mixture of stoddard solvent and solvent naphtha and propylalcohol. Ethanol is used as solvent in the chemical industry and as windscreen washing agent. Turpentine is used as thinner for paints, lacquers and adhesives. Propylalcohol is used in cleaning agents in the manufacture of electrical equipment, flux agents for soldering, as solvent and thinner and as windscreen washing agent. Household emissions are dominated by propane and butane, which are used as aerosols in spray cans, primarily in cosmetics. For some pollutants the emission factors are precise but for others they are rough estimates. The division of emission factors into four categories implies that high emission factors are applicable for use of solvent containing products and lower emission factors are applicable for use in industrial processes.

Table 4.5.4 2023 NMVOC emissions of single pollutants or pollutant groups.

Pollutant	CAS no	Emissions, t
ethanol	64-17-5	12,323
turpentine (white spirit: stoddard solvent and solvent naphtha)	64742-88-7 8052-41-3	6,127
propyl alcohol	67-63-0	1,714
pentane	109-66-0	1,519
propylene glycol	57-55-6	1,409
acetone	67-64-1	974
cyanates	79-10-7	905
methanol	67-56-1	835
1-butanol	71-36-3	285
propane	74-98-6	282
butane	106-97-8	282
glycol ethers	110-80-5 107-98-2 108-65-6 34590-94-8 112-34-5 and others	157
phenol	108-95-2	141
xylenes	1330-20-7 95-47-6 108-38-3 106-42-3	117
butanone	78-93-3	83.5
butanoles	78-92-2 2517-43-3 and others	77.7
toluene	108-88-3	114
cyclohexanones	108-94-1	61,2
ethyl acetate	141-78-6	47.2
formaldehyde	50-00-0	43.4
ethylene glycol	107-21-1	40.2
styrene	100-42-5	32.9
butyl acetate	123-86-4	22.4
tetrachloroethylene	127-18-4	2.1
methyl bromide	74-83- 9	0.09
acrylic acid	79-10-7	0.08
Total		27,595

4.5.3 Road paving with asphalt

Road paving with asphalt is an activity that can be found all over the country and especially in relation to establishing new traffic facilities. The following category is covered:

- Road paving with asphalt

The following pollutants are relevant for road paving with asphalt:

- NMVOC
- CO
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC

The raw materials for construction of transport facilities are prepared at one of the plants located near the locality of application to limit the transport distance. The asphalt concrete is mixed and brought to the locality of application on a truck.

Methodology

Transport facilities are constructed by a number of different layers:

- a load bearing layer (e.g. course gravel)
- an adhesive layer (liquefied asphalt e.g. "cutback" asphalt or asphalt emulsion)
- a wearing coarse (e.g. hot mix asphalt concrete)

Different qualities of "cutback" asphalt (e.g. asphalt dissolved in organic solvents/petroleum distillates) and asphalt emulsion contains different kinds and amounts of solvent. Cutback asphalt contains 25-45%v/v solvent e.g. heavy residual oil, kerosene-type solvent, naphtha or gasoline solvent. Approximately 500.000 litre solvent evaporates annually from the use of "cutback" asphalt (Asfaltindustrien, 2003). This amount of solvent, which is added to the asphalt, is comprised in the solvent categories above with an emission factor of approximately unity. This means that NMVOC emissions from "cutback" asphalt in Road paving NFR 2D3b only include emissions from the asphalt fraction as quantified in Table 4.5.5.

Emissions are calculated as activity data multiplied with emission factors for all pollutants.

Activity data

The use amounts of asphalt for road paving have been compiled from production, import and export statistics of asphalt products in Statistics Denmark (2024) and are presented in Table 4.5.5 and Annex 3C-4.4.

Table 4.5.5 Activity data for asphalt in road paving, kt.

	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
Road paving with asphalt	2743	2535	3144	2933	3879	3005	3440	3833	4426	5299

Emission factors

Default emission and abatement factors are derived from EMEP/EEA (2023) and US EPA (2004).

Table 4.5.6 Emission factors for road paving with asphalt.

	Unit	Road paving with asphalt (incl. cutback)	Abatement factors[1], %
NMVOC	g/t	16	-
CO	g/t	120	-
TSP	g/t	50	99.6
PM_{10}	g/t	49	98.4
$PM_{2.5}$	g/t	6.6	98.4
BC	g/t	0.37	98.4

[1] The abatement factors have already been subtracted from the presented emission factors

Emission trends

Emissions from road paving with asphalt are presented in Table 4.5.7 and Annex 3C-4.5.

Table 4.5.7 Emissions from road paving with asphalt, t.

	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
NMVOC	44	41	50	47	62	48	55	61	71	85
CO	330	305	378	353	466	361	414	461	532	637
TSP	-	128	158	148	195	151	173	193	223	267
PM_{10}	-	125	155	144	191	148	169	189	218	261
$PM_{2.5}$	-	16.6	20.6	19.2	25.4	19.7	22.6	25.1	29.0	34.8
BC	-	0.95	1.18	1.10	1.45	1.12	1.29	1.43	1.66	1.98

4.5.4 Asphalt roofing

Asphalt roofing covers the following category:

- Asphalt roofing

The following pollutants are relevant for asphalt roofing:

- NMVOC
- CO
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC

Methodology

Emissions are calculated by multiplying activity data and emission factors.

Activity data

The used amounts of asphalt for roofing have been compiled from production, import and export statistics of asphalt products in Statistics Denmark (2024) and are available in Table 4.5.8 and Annex 3C-4.6.

Table 4.5.8 Activity data for asphalt roofing, kt.

	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
Asphalt roofing	55.7	56.1	57.0	88.5	69.6	43.9	47.0	60.0	48.3	50.4

Emission factors

Default emission and abatement factors are derived from EMEP/EEA (2023).

Table 4.5.9 Emission factors for asphalt roofing.

	Unit	Asphalt roofing	Abatement factors[1], %
NMVOC	g/t	130	-
CO	g/t	9.5	-
TSP	g/t	96	94
PM_{10}	g/t	24	94
$PM_{2.5}$	g/t	4.8	94
BC	mg/t	0.60	94

[1]The abatement factors have already been subtracted from the presented emission factors.

Emission trends

Emissions from asphalt roofing are presented in Table 4.5.10 and Annex 3C-4.7.

Table 4.5.10 Emissions from asphalt roofing.

	Unit	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
NMVOC	t	7.2	7.3	7.4	11.5	9.0	5.7	6.1	7.8	6.3	6.6
CO	t	0.53	0.53	0.54	0.84	0.66	0.42	0.45	0.57	0.46	0.48
TSP	t	-	5.4	5.5	8.5	6.7	4.2	4.5	5.8	4.6	4.8
PM_{10}	t	-	1.3	1.4	2.1	1.7	1.1	1.1	1.4	1.2	1.2
$PM_{2.5}$	t	-	0.27	0.27	0.42	0.33	0.21	0.23	0.29	0.23	0.24
BC	kg	-	0.034	0.034	0.053	0.042	0.026	0.028	0.036	0.029	0.030

4.6 Other product use

4.6.1 Source category description

The sub-sector *Other product use* (NFR 2G) covers the following processes relevant for the Danish inventories:

- 2G4 Use of fireworks
- 2G4 Use of tobacco
- 2G4 Use of shoes
- 2G4 Use of charcoal for barbeques
- 2G4 Paraffin wax use (Combustion of candles)

The time series for emission from *Other product use* is available in the NFR tables. Table 4.6.1 presents an overview of emissions from 2023.

Table 4.6.1 Overview of 2023 emissions from Other product use.

	Total emission from Other product use		Fraction of IPPU, %	Largest contributor in Other product use	Emission from largest contributor		Fraction of Other product use, %
SO_2	0.04	kt	6.3	Charcoal for barbeques	0.03	kt	64.6
NO_x	0.04	kt	59.8	Charcoal for barbeques	0.03	kt	71.8
NMVOC	0.05	kt	0.2	Charcoal for barbeques	0.03	kt	53.4
CO	2.43	kt	79.0	Charcoal for barbeques	1.90	kt	78.3
NH_3	0.02	kt	6.2	Use of tobacco	0.02	kt	95.9
TSP	0.41	kt	6.1	Use of fireworks	0.28	kt	68.6
HMs	5.39	t	65.9	Cu from use of fireworks	3.14	t	58.2
POPs	65.9	kg	99.9	PAH from charcoal for barbeques	64.5	kg	97.9

Emissions of Hg from product uses are a difficult area to assess. In Denmark, a lot of Hg, associated with uses in products, is collected annually and exported for disposal or reuse. In total, 2-4 tons of Hg are collected annually. In addition, some of the products containing Hg will end up in the regular waste stream and will be incinerated. The emissions from the incineration of waste are already included in the inventory as documented in the stationary combustion chapter. Considering the collection and the emissions already covered in the inventory, the emission estimate is considered accurate. No other data sources have been identified.

4.6.2 Use of other products

As listed above Table 4.6.1, this category includes the use of fireworks, tobacco, shoes, charcoal for barbeques and the use of paraffin wax candles.

The following pollutants are relevant for the other product use:

- SO_2
- NO_x
- NMVOC
- CO
- NH_3
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn
- POPs: HCB, PCDD/F, PAHs (benzo(a)pyrene, benzo(b)flouranthene, benzo(k)flouranthene, indeno(1,2,3-c-d)pyrene), PCBs

Methodology

Data on the used amounts of product are obtained from Statistics Denmark (2024), emission factors are primarily from international literature and guidelines.

For more information on what is included and descriptions of the trends, please refer to Hjelgaard (2023).

Activity data

Data on consumption of other products are presented in Table 4.6.2 and Annex 3C-5.1.

Table 4.6.2 Activity data for the use of other products.

	Unit	1980	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Fireworks	kt	1.0	1.3	3.0	4.9	3.7	5.4	5.8	4.2	5.0	7.1	7.1
Tobacco	kt	14.5	13.1	11.7	11.4	10.5	9.5	7.3	6.4	5.9	5.5	4.9
Shoes	million inhabitants	-	5.1	5.2	5.3	5.4	5.5	5.7	5.8	5.8	5.9	5.9
BBQs	kt	1.9	7.2	7.9	13.4	14.9	7.8	16.3	6.6	13.3	9.2	9.2
Paraffin wax	kt	-	7.4	9.1	16.9	34.4	35.3	24.4	20.4	23.5	20.9	20.9

Emission factors

The emission factor for fireworks for Pb was changed in 2000 and Hg and Pb, along with any compounds derived here from, were forbidden in 2003 and 2007, respectively. Emissions are therefore noted as not occurring for these years and forward.

Default emission factors are compiled from the scientific literature and are presented in Table 4.6.3.

Table 4.6.3 Emission factors for other product use.

Compound	Unit	Fireworks	Tobacco	Shoes	BBQs	Candles
SO_2	kg/t	1.94 (a)	0.40(e)		3.10 (i)	
NO_X	kg/t	0.26 (f)	1.80(f)		2.95 (j)[4]	
NMVOC	kg/t	-	4.84 (f)		2.95 (j)[4]	
CO	kg/t	6.90 (a)	55.10(f)		206.5 (j)[4]	10 (l)
NH_3	kg/t	-	4.15(f)		0.10 (e)	
TSP	kg/t	39.66 (b)	13.67(g)	0.75[5]	3.10 (i)	1.34 (m)
PM_{10}	kg/t	35.69 (b/f)	13.67(g)	NO	3.10 (i)	1.34
$PM_{2.5}$	kg/t	19.83 (b/f)	13.67(g)	NO	3.10 (i)	1.34
BC	% of $PM_{2.5}$	-	0.45 (f)		14.7 (e)	
As	g/t	1.33 (f)	0.16 (h)		0.10 (i)	
Cd	g/t	0.67 (c)	0.02(e)		0.04 (i)	
Cr	g/t	15.56 (f)	0.15 (h)		0.04 (e)	
Cu	g/t	444.4 (f)	0.35 (h)		0.15 (e)	
Hg	g/t	0.06 (f)[1]	0.01(e)		0.07 (i)	
Ni	g/t	30 (f)	0.03(e)		0.13 (i)	
Pb	g/t	2200 (d)[2]	0.64(e)		4.45 (i)	
		666.7 (c)[3]	-		-	
Se	g/t	-	0.01(e)		0.65 (i)	
Zn	g/t	260 (f)	1.61(e)		1.90 (e)	
HCB	mg/t	-	-		0.10 (e)	
PCDD/Fs	µg/t	-	0.10 (f)		10.50 (k)	0.027 (n)
Benzo(b)fluoranthene	g/t	-	0.05 (f)		2.14 (e)	
Benzo(k)fluoranthene	g/t	-	0.05 (f)		1.25 (e)	0.005 (m)
Benzo(a)pyrene	g/t	-	0.11 (f)		2.16 (e)	0.004 (m)
Indeno(1,2,3-cd)pyrene	g/t	-	0.05 (f)		1.46 (e)	0.001 (m)
PCB		-	-		0.13 (e)	

NO: Not occurring, NAV: Not available, [1]The emission of Hg from fireworks was banned in 2002, [2]1980-1999, [3]2000-2006, [4]Calculated from default uncontrolled combustion and a net calorific value of 30 MJ/kg, [5]Unit is g per inhabitant, (a) Van der Maas et al. (2010), (b) Klimont et al. (2002), (c) Passant et al. (2003), (d) Miljöförvaltningen (1999), (e) Emission factors for wood (111A) combustion in residential plants (1A4b i), SNAP 020200, the energy content used in the calculation is the average of wood pills and wood waste (16.1 GJ/t), (f) EMEP/EEA (2023), (g) Martin et al. (1997), (h) Finstad & Rypdal (2003), (i) Environment Australia (1999), (j) IPCC (1996), (k) Hansen (2000), (l) Hamins et al. (2005), (m) Fine et al. (1999), (n) Lau et al. (1997).

Emission trends

An excerpt of the calculated emissions from other product use is shown in Table 4.6.4. The full time series for all pollutants is available in Annex 3C-5.2.

Table 4.6.4 Excerpt of the emissions from other product use.

		Unit	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
NO_x	Fireworks	t	0.3	0.8	1.3	1.0	1.4	1.5	1.1	1.3	1.8	1.8
	Tobacco	t	23.7	21.1	20.6	18.9	17.2	13.2	11.5	10.6	10.0	8.8
	BBQ	t	21.2	23.3	39.4	44.0	23.1	48.1	19.3	39.4	27.1	27.1
	Total	t	45.1	45.2	61.2	63.9	41.7	62.8	31.9	51.3	38.9	37.8
CO	Fireworks	t	8.8	20.7	33.5	25.4	37.4	40.0	29.3	34.3	48.7	48.7
	Tobacco	t	723.6	646.2	629.0	577.3	524.9	403.9	351.2	325.3	305.7	269.5
	BBQ	t	1481.1	1630.3	2758.4	3082.0	1617.8	3367.3	1354.4	2755.6	1898.6	1898.6
	Paraffin wax	t	74.4	91.0	169.3	344.4	353.0	244.3	204.4	235.3	209.1	209.4
	Total	t	2288.0	2388.1	3590.1	4029.1	2533.2	4055.4	1939.3	3350.5	2462.0	2426.1
$PM_{2.5}$	Fireworks	t	25.4	59.4	96.3	73.1	107.5	114.8	84.2	98.6	139.9	139.9
	Tobacco	t	179.6	160.4	156.1	143.3	130.3	100.2	87.2	80.7	75.9	66.9
	BBQ	t	22.2	24.5	41.4	46.3	24.3	50.6	20.3	41.4	28.5	28.5
	Paraffin wax	t	10.0	12.2	22.7	46.2	47.3	32.7	27.4	31.5	28.0	28.1
	Total	t	237.2	256.5	316.5	308.7	309.4	298.4	219.1	252.2	272.3	263.3
Cu	Fireworks	kg	568.4	1332.3	2157.5	1637.1	2409.8	2573.8	1886.5	2209.7	3135.3	3135.3
	Tobacco	kg	4.6	4.2	4.0	3.7	3.4	2.6	2.3	2.1	2.0	1.7
	BBQ	kg	1.1	1.2	2.0	2.3	1.2	2.5	1.0	2.0	1.4	1.4
	Total	kg	574.2	1337.6	2163.6	1643.1	2414.3	2578.9	1889.8	2213.8	3138.6	3138.4
Hg	Fireworks	kg	0.1	0.2	0.3	-	-	-	-	-	-	-
	Tobacco	kg	0.08	0.07	0.07	0.06	0.06	0.04	0.04	0.04	0.03	0.03
	BBQ	kg	0.5	0.5	0.9	1.0	0.5	1.1	0.4	0.9	0.6	0.6
	Total	kg	0.6	0.8	1.2	1.0	0.6	1.1	0.5	0.9	0.6	0.6
Pb	Fireworks	kg	2813.9	6595.4	3236.7	2456.0	-	-	-	-	-	-
	Tobacco	kg	8.5	7.6	7.4	6.7	6.1	4.7	4.1	3.8	3.6	3.1
	BBQ	kg	31.9	35.1	59.4	66.4	34.9	72.6	29.2	59.4	40.9	40.9
	Total	kg	2854.3	6638.1	3303.5	2529.2	41.0	77.3	33.3	63.2	44.5	44.1
Zn	Fireworks	kg	332.6	779.5	1262.3	957.8	1409.8	1505.8	1103.7	1292.8	1834.3	1834.3
	Tobacco	kg	21.1	18.9	18.4	16.9	15.3	11.8	10.3	9.5	8.9	7.9
	BBQ	kg	13.6	15.0	25.4	28.4	14.9	31.0	12.5	25.4	17.5	17.5
	Total	kg	367.3	813.3	1306.0	1003.0	1440.1	1548.6	1126.4	1327.7	1860.7	1859.7
POPs	Tobacco	kg	3.2	2.9	2.8	2.6	2.3	1.8	1.6	1.5	1.4	1.2
	BBQ	kg	50.3	55.3	93.6	104.6	54.9	114.3	46.0	93.5	64.5	64.5
	Paraffin wax	kg	0.1	0.1	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2
	Total	kg	53.6	58.3	96.6	107.5	57.6	116.3	47.7	95.2	66.0	65.9

4.7 Other industry production

4.7.1 Source category description

The sub-sector *Other production* (NFR 2H) covers the following process relevant for the Danish inventories: 2H2 Food and beverages industry.

4.7.2 Food and beverages industry

The following categories are covered:

- Bread
- Wine
- Beer
- Spirits
- Sugar production
- Flour production
- Meat, fish etc. frying/curing
- Margarine and solid cooking fats
- Coffee roasting

The pollutant relevant for the food and beverages industry is NMVOC and particles.

Methodology

The emissions from production of foods and alcoholic beverages are generally estimated from production statistics (Statistics Denmark, 2024) and standard emission factors from the EMEP/EEA (2023).

Activity data for beer production from Statistics Denmark are supplemented with data from Danish Brewers' Association.

Activity data and particle emissions from flour production are available for 2007-2014 (and partly for 2004-2006), data for 2015-2023 are estimated using surrogate data.

Activity data

The production statistics for the relevant processes have been aggregated based on data from Statistics Denmark and presented in Table 4.7.1 and Annex 3C-6.1. The activity data for white wine includes the production of apple and pear cider and red wine includes other fruit wines.

Activity data for whisky production is estimated based on direct contact to the Danish distilleries.

Table 4.7.1 Production of foods and beverages.

		1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
Biscuits, cakes & other bakery prod.	kt	119	99	148	139	157	118	111	117	112	96
Bread (rye and wheat)	kt	193	190	231	244	257	245	208	186	182	177
Red wine	million l	12	10	5	5	1	4	1	2	2	2
White wine	million l	NO	3.2	0.5	0.9	3.1	18	10	10	4	3
Beer	million l	836	930	990	746	868	651	604	587	616	461
Malt whisky	million l	0.24	0.02	NO	NO	0.001	0.011	0.032	0.329	0.350	0.350
Grain whisky	million l	NO	NO	NO	NO	NO	0.003	0.008	0.330	0.350	0.350
Other spirits	million l	39	33	27	24	26	17	4	6	3	3
Sugar production	kt	533	506	444	443	503	262	468	421	443	398
Flour production	kt	-	180	182	210	175	140	239	438	440	473
Poultry curing	kt	4	11	14	24	35	54	64	75	85	76
Fish and shellfish curing	kt	35	52	31	44	41	73	69	60	57	49
Other meat curing	kt	531	448	464	393	361	303	211	173	185	196
Margarine and solid cooking fats	kt	222	161	144	123	109	105	100	82	83	80
Coffee roasting	kt	53	52	49	56	37	37	17	15	15	16

NO: not occurring

Emission factors

The emission factors used to calculate the NMVOC emissions from food and beverage production are shown in Table 4.7.2. Regarding refining of sugar, the default emission factor has been revised based on company specific measurements obtained from Nielsen (2011). TOC has been measured in order to solve odour issues. The emission of TOC has been used as indicator for NMVOC assuming a conversion factor at: 0.6 kg C/kg NMVOC.

It is assumed that Danish whisky is stored for six years.

The emission factor for particles from flour production is the calculated implied emission factor for 2004-2014 of 0.10-0.13 tonnes PM_{10} per kt flour produced.

Table 4.7.2 Emission factors for NMVOC emission from food and beverages production.

Production	Unit	Value	Reference
Bread (rye and wheat)	kg/t bread	4.5	EMEP/EEA (2023)
Biscuits, cakes and other bakery products	kg/t product	1	EMEP/EEA (2023)
Red wine	kg/m^3 wine	0.8	EMEP/EEA (2023)
White wine	kg/m^3 wine	0.35	EMEP/EEA (2023)
Beer	kg/m^3 beer	0.35	EMEP/EEA (2023)
Malt whisky	kg/m^3 alcohol	150	EMEP/EEA (2023)
Grain whisky	kg/m^3 alcohol	75	EMEP/EEA (2023)
Other spirits	kg/m^3 alcohol	4	EMEP/EEA (2023)
Sugar production	kg/t sugar	0.2	Nielsen (2011)
Meat, fish and poultry	kg/t product	0.3	EMEP/EEA (2023)
Margarine and solid cooking fats	kg/t product	10	EMEP/EEA (2023)
Coffee roasting	kg/t beans	0.55	EMEP/EEA (2023)

Emission trends

The emission trends for emission of NMVOC and particles from production of food and beverage are presented in Figure 4.7.1, Figure 4.7.2 and Annex 3C-6.2.

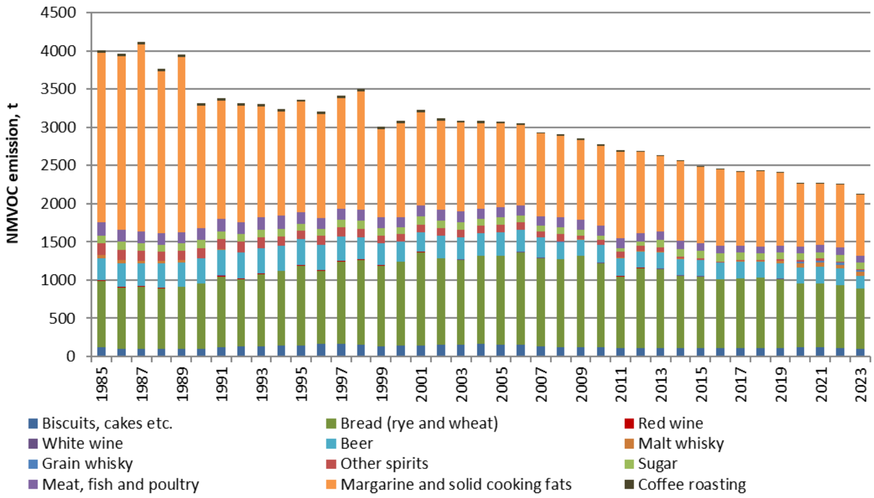

Figure 4.7.1 NMVOC emissions from the production of food and beverages, t.

The emission of NMVOC from production of food and beverage follows the activity as the same emission factors have been used for the entire period.

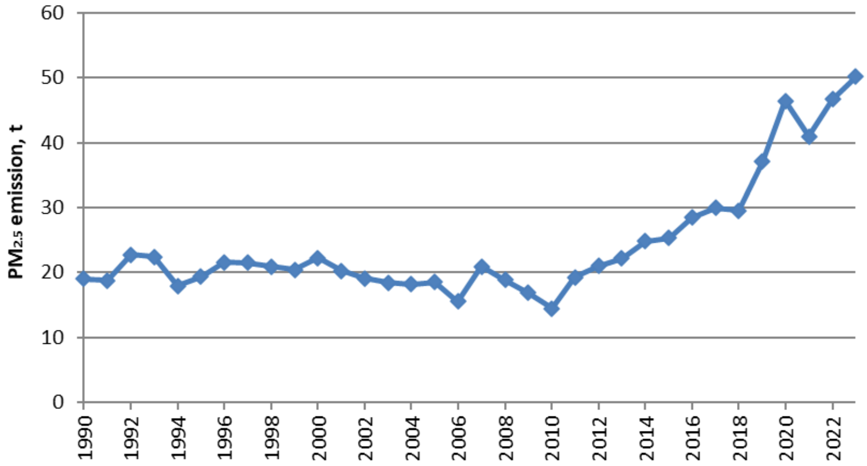

Figure 4.7.2 $PM_{2.5}$ emissions from the production of flour, t.

4.8 Wood processing

4.8.1 Source category description

The sub-sector *Wood processing* (NFR 2I) covers the production of wood products.

4.8.2 Wood processing

The following category is covered:

- Wood processing

The following pollutants are relevant for the wood processing industry:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$

Methodology

The emission of particles from production of wood products is estimated from production statistics (Statistics Denmark, 2024), standard emission factors from the EMEP/EEA (2023) and an assumption for the particle distribution TSP/PM_{10}/$PM_{2.5}$.

In addition to this, activity data from Statistics Denmark (m^3) are multiplied by a country specific density to gain the unit of kt wood product.

Activity data

The production data from Statistics Denmark (2024) are multiplied with the density 0.522 tonnes per m^3 for sawn wood and 0.538 tonnes per m^3 for wood-based panels. The densities are calculated from the carbon content of 0.261 and 0.269 tonnes C per m^3 for sawn wood and wood-based panels respectively (Schou et al., 2015) and the carbon fraction of 0.5 (KP Sup., 2013, Table 2.8.1). The resulting activity data are presented in Table 4.8.1 and Annex 3C-7.1.

Table 4.8.1 Activity data wood processing, kt.

	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Wood processing	341.8	440.2	455.8	348.6	411.8	431.4	432.3	389.4	413.6	405.4

Emission factors

The emission factors used to calculate the particle emissions from wood processing are shown in Table 4.8.2.

Table 4.8.2 Emissions factors for wood processing.

Pollutant	Unit	Value	Reference
TSP	t/kt	1	EMEP/EEA (2023)
PM_{10}	% of TSP	40	Expert judgement
$PM_{2.5}$	% of TSP	20	Expert judgement

Emission trends
The emission trends for particles are available in Table 4.8.3 and Annex 3C-7.2.

Table 4.8.3 Particle emissions from wood processing, t.

	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
TSP	341.8	440.2	455.8	348.6	411.8	431.4	432.3	389.4	413.6	405.4
PM_{10}	136.7	176.1	182.3	139.5	164.7	172.5	172.9	155.8	165.5	162.2
$PM_{2.5}$	68.4	88.0	91.2	69.7	82.4	86.3	86.5	77.9	82.7	81.1

4.9 Other production, consumption, storage, transportation or handling of bulk products

4.9.1 Source category description

The sub-sector *Other production, consumption, storage, transportation or handling of bulk products* (NFR 2L) covers the treatment of slaughterhouse waste (NFR 2L3).

4.9.2 Slaughterhouse waste

One company treats slaughterhouse waste: Daka with five departments located in Løsning, Randers, Lunderskov, Ortved, and Nyker. The following category is covered:

- Slaughterhouse waste

The following pollutant is relevant for the treatment of slaughterhouse waste:

- NH_3

Methodology
The raw materials for the processes are by-products from slaughterhouses, animals dead from accident or disease, and blood. The output from the processes are protein and fat products as well as animal fat, meat and bone meal.

The emissions from the processes are related to the consumption of energy, emissions of NH_3 and odour. The last-mentioned emissions are related to storage of the raw materials as well as to the drying process.

The emission of NH_3 from treatment of slaughterhouse waste has been calculated from an average emission factor based on measurements from the Danish plants (Daka, 2002; 2004) and activity data from Statistics Denmark (2024).

Activity data
The activity data for treatment of slaughterhouse waste are compiled from different sources. Due to changes in the company structure, environmental reports are only available for some years (1997-2009). Therefore, data from

Statistics Denmark are used in combination with blood meal data (partly estimated based on data from the environmental reports). The activity data are presented in Table 4.9.1 and Annex 3C-8.1.

Table 4.9.1 Activity data for treatment of slaughterhouse waste, kt.

	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
Meat/bone meal	134.4	128.8	197.0	156.0	164.1	104.6	98.5	115.1	111.7	93.8
Animal fat	11.1	72.1	54.2	71.3	89.5	75.3	54.0	40.8	55.1	46.5
Blood meal	11.0	11.0	11.0	11.4	10.2	7.5	7.5	7.5	7.5	7.5
Total	156.5	211.9	262.2	238.7	263.9	187.4	160.0	163.3	174.4	147.7

Emission factors

The emission of NH_3 from treatment of slaughterhouse waste has been calculated from an average emission factor based on measurements from the Danish plants (Daka, 2004). Measurements of NH_3 during the years 2002/3 from three locations (Lunderskov, Løsning and Randers) with different product mix have been included in the determination of an emission factor.

The weighted emission factors covering all the products within the sector have been estimated for 2000-2003 as 64-475 g per tonne product. The applied emission factor is the average 189 g per tonne product.

Emission trends

Emissions from the treatment of slaughterhouse waste are available in Table 4.9.2 and Annex 3C-8.2.

Table 4.9.2 Emissions from the treatment of slaughterhouse waste, t.

	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
NH_3	29.6	40.0	49.6	45.1	49.9	35.4	30.2	30.9	33.0	27.9

4.10 QA/QC and verification

Please refer to the sector specific reports Hjelgaard (2023).

4.11 Uncertainty estimates

The Danish uncertainty estimates are based on the simple “Approach 1”.

The uncertainty estimates are based on emission data for the base year (1990) and year 2023 as well as on uncertainties for activity data and emission factors for each of the NFR source categories.

Table 4.11.1 presents the calculated Approach 1 uncertainties for the IPPU sector.

Table 4.11.1 Approach 1 uncertainties for Industrial processes and product use. (NFR 2).

Pollutant	Uncertainty total emission %	Trend 1990-2022 %	Uncertainty trend %-age points
SO_2	142.60	-83.8	7.6
NO_x	83.92	-93.4	6.7
NMVOC	13.98	-29.5	6.9
CO	70.83	-77.7	38.1
NH_3	141.03	-48.5	79.7
TSP	589.19	-21.8	152.6
PM_{10}	234.70	-21.2	102.3
$PM_{2.5}$	119.58	-39.3	43.4
BC	105.84	-46.6	41.3
As	533.10	-66.9	162.0
Cd	485.33	-73.2	43.0
Cr	489.42	-13.5	227.8
Cu	291.69	344.8	664.9
Hg	738.53	-97.9	5.1
Ni	367.06	-71.3	239.6
Pb	186.85	-77.3	64.7
Se	390.20	-88.3	11.6
Zn	362.31	-80.7	149.4
HCB	719.52	-99.8	0.3
PCDD/F	156.44	-98.9	10.5
benzo(b)flouranthene	200.25	-77.8	184.7
benzo(k)flouranthene	200.25	-85.8	126.9
benzo(a)pyrene	200.25	-77.4	185.4
indeno(1,2,3-c,d)pyrene	200.25	-83.9	141.8
PCB	802.11	-96.3	5.8

4.12 Source specific recalculations and improvements

Table 4.12.1 presents the total IPPU recalculations from the previous submission to this submission, for chosen years is the time series. Table 4.12.2 presents the same recalculations for 2022 only, divided in subsectors.

Table 4.12.1 Total recalculations for industrial processes and product use, time series.

	Unit	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022
SO_2	t	-	-	-	-	-	-	-	-	-	-
NO_x	t	-	-	-	-	-	-	-	-	-	-
NMVOC	t	-	-	-	-	0.09	550.7	729.8	778.7	819.1	1110.1
CO	t	-	-	-	-	0.08	0.08	0.03	0.03	0.04	7.41
NH_3	t	-	-	-	-	-	-	-	-	-	-
TSP	t	-	-17.5	-24.6	-25.5	-19.7	-24.8	-22.1	46.8	20.1	96.6
$PM_{2.5}$	t	-	-3.5	-4.9	-5.1	-3.9	-5.0	-4.4	-2.0	-2.8	-5.5
Cd	kg	-	-	-	-	-	-	-	0.001	-0.20	-0.18
As	kg	-	-	-	-	-	-	1.3	-16.6	-27.5	-36.7
Hg	kg	-	-6.7	-8.7	-7.4	-6.1	-	-	-	-0.1	-0.1
Pb	kg	-	-	-	-	-	-	-	0.01	-5.9	-5.4
PCDD/F	mg	-	-	-	-	0.0002	0.0002	0.0001	0.0001	0.0001	-0.01
PAHs	kg	-	-	-	-	0.0001	0.0001	-0.09	-0.18	-0.18	-0.19

Table 4.12.2 Recalculations for the year 2022 for industrial processes and product use, subsectors.

		SO_2	NMVOC	CO	NH_3	$PM_{2.5}$	Cd	Hg	Pb	POPs
		t	t	t	t	t	kg	kg	kg	g
2A	**Mineral industry**	**-**	**-**	**-**	**-**	**0.33**	-		**-**	**-**
2A2	Lime production					-				-
2A3	Glass production	-	-	-	-	-	-		-	
2A5a	Quarrying and mining of minerals other than coal					-4.56				
2A5b	Construction and demolition					4.90				
2A5c	Storage, handling and transport of mineral products					0.0001				
2A6	Ceramics	-								-
2A6	Stone wool production	-	-	-	-	-				-
2B	**Chemical industry**	**-**	**0.02**		**-**	**-**		**-**		**-190.3**
2B10a	Catalysts/fertiliser production				-	-				
2B10a	Chemical ingredients		0.02							
2B10a	Pesticides	-	-							
2B10a	Tar products	-	-					-		-190.3
2C	**Metal industry**	**-**	**-**			**-0.16**	**-0.18**	**-0.07**	**-5.44**	**-0.98**
2C1	Iron and steel production		-			-0.16	-0.18	-0.07	-5.44	-0.98
2C5	Secondary lead production	-				-	-	-	-	-
2C7c	Allied metal production						-		-	
2D	**Non-energy products from fuels and solvent use**		**994.5**	**11.6**		**0.61**				
2D3a	Domestic solvent use including fungicides		849.5							
2D3b	Road paving with asphalt		1,5	11,6		0,63				
2D3c	Asphalt roofing		-0.7	-0.05		-0.02				
2D3d	Coating applications		-15.4							
2D3f	Dry cleaning		-9E-05							
2D3g	Chemical products		-174.6							
2D3h	Printing		1.0							
2D3i	Other solvent use		333.2							
2G	**Other product manufacture and use**	**-**	**-**	**-4.2**	**-**	**-0.6**	**-**	**-**	**-**	**-3.9**
2G4	Charcoal	-	-	-	-	-	-	-	-	-
2G4	Tobacco	-	-	-	-	-	-	-	-	-
2G4	Fireworks	-		-		-	-	-	-	
2G4	Paraffin wax use			-4.2		-0.6				-3.9
2H2	**Food and beverages industry**		115.6			**-**				
2I	**Wood processing**					**-5.7**				
2L	**Slaughterhouse waste**				**-**					

4.12.1 Mineral industry

Quarrying and mining of minerals other than coal

Statistical data for quarrying and mining for the inventory year, is not available in time for submission. Activity data for the inventory year is therefore kept constant on the same level as the latest historical year. This method results in a recalculation of the latest historical year in every annual submission, for this year's submission that means 2022.

The activity data for 2022 have decreased by 2.6 %; i.e. -4.6 tonnes $PM_{2.5}$.

Construction and demolition

Updated statistical data from Statistics Denmark result in changes in the activity data for 2018-2022. The resulting increase in $PM_{2.5}$ emissions is between

0.7 to 4.9 tonnes for the years 2018-2022; i.e. 0.5-4.8%, the largest recalculation is for 2022.

Storage, handling and transport of mineral products

A miniscule increase for 2022 is caused by recalculations for Ceramics (increase) and Other uses of soda ash (decrease). The recalculation for this source category is an increase in $PM_{2.5}$ emissions of just 0.1 kg (+0.003%) in 2022.

Other mineral products

For stone wool production, new measurements for As are available for the year 2023 for all production facilities. As these measurements are much lower than those for 2007-2015, a new methodology with new IEFs for As in the years 2015/2016-2022 is introduced in this year's inventory. The resulting recalculations are increases for 2015-2017 (1.3-12.9 kg) and decreases for 2018-2022 (1.1-36.1 kg), the largest changes are the decreases in 2021-2022.

4.12.2 Chemical industry

Production of chemical ingredients

A small increase in the activity data from Statistics Denmark, results in an increase of 0.02 tonnes NMVOC for 2022.

Production of tar products

New measurements are available for Hg, and emission factors are lowered with 55 % for 1990-2007 (5-9 kg Hg).

The previously calculated PAH emissions are replaced with measurements, resulting in decreases for 2012-2022 of 0.02 to 0.20 kg benzo(a)pyrene. The decrease is more than 98 % for 2018-2022.

4.12.3 Metal industry

Iron and steel production

An update to the cast iron activity data for 2021-2022 was made by Statistics Denmark for this year's submission. The recalculation results in decreases of 1.7-1.8 %.

Allied metal production

Activity data for 2020 increased slightly for this year's submission, because of an update to the national statistical data. The recalculation amounts to an increase of 1 g Cd and 15 g Pb (+0.1 %).

4.12.4 Non-energy products from fuels and solvent use

Asphalt

Activity data from Statistics Denmark were updated for 2006, 2008, 2010, 2014, 2016, 2018 and 2020-2022. The resulting recalculations are only significant for 2022, with -9.7 % for asphalt roofing and +2.2 % for road paving with asphalt.

Solvent use

Prior to this year's submission, Statistics Denmark made changes to their model for solvent use, affecting the years 2005-2022. Changes were made to all the solvent use source categories, resulting in increased emissions for all years 2005-2022. The changes in NMVOC emissions are +0.1 to +0.2 tonnes for 2005-2009 and +506 to +994 tonnes for 2010-2022 (2.1-3.7 % for 2010-2022).

4.12.5 Other product use

Paraffin wax use

Statistics Denmark has updated activity data for the years 2005-2022. Changes in activity data are increases of 0.01-0.04 % for 2005-2021 and a decrease of -2.0 % for 2022.

4.12.6 Other industry processing

Food and beverages industry

Activity data for coffee roasting (2005-2022), beer production (2021-2022), bread production (2022), biscuits production (2022), meat cooking (2022) and margarine and solid cooking fats (2021-2022) have been updated due to updates in the statistical data. The resulting NMVOC recalculations are increases of 1.2-5.0 kg in 2005-2020, +36 tonnes in 2021 (1.6 %) and +116 tonnes in 2022 (5.4 %).

4.12.7 Wood processing

The density of wood-based panels is updated to a country specific value in this year's submission. This results in a decrease of 10 % from wood-based panels for each year in the time series 1990-2022. The effect of this recalculation in the particle emissions from wood processing are decreases of 4.4-6.4 %, i.e. 3.0-5.7 tonnes $PM_{2.5}$.

4.13 Source specific planned improvements

The following Table 4.13.1 lists the source specific planned improvements.

Table 4.13.1 List of planned improvements.

Main sector	Subsector	Improvement
2D Non-energy products from fuels and solvent use	2D3a, d, e, f, g, h, i NMVOCs used as solvents	A general re-evaluation and update of all aspects of the Danish solvent model is planned for next submission.
2D Non-energy products from fuels and solvent use	2D3f Dry cleaning (incl. degreasing)	Emissions from this source category are estimated using a constant emission factor. But, since both dry cleaning and degreasing are categories regulated by the solvent directive, it seems reasonable to assume that the emission factors would display a decreasing trend. The Danish solvent model is not currently able to reflect the effects of the solvent directive. Therefore, the solvent model will be updated to include the abatement technics that have been implemented to drycleaning and degreasing activities along with the solvent regulation. This planned improvement is based on a recommendation from the latest UNECE review.
2D Non-energy products from fuels and solvent use	2D3h Printing	It is observed that calculated emissions from printing activity are increasing significantly in the time series. This development goes against what would be expected due to the solvent regulation which was implemented with the solvent directive. The Danish solvent model is currently based on a static allocation of solvents into NFR categories. As it is unreasonable to assume that the allocation is unchanged during the time series 1985-2023, the Danish solvent model will be updated to include a variable allocation that takes into account both the effects of the solvent regulation and other significant developments in the solvent use sector. This planned improvement is based on a recommendation from the latest UNECE review.

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5 Agriculture

5.1 Overview of the sector

The agricultural sector includes emission from manure management (NFR 3B), agricultural soils (NFR 3D) that cover all fertilisation and N application, farm level operations and cultivated crops, field burning of agricultural residue (NFR 3F) and other (NFR 3I). Field burning of agricultural residue has been prohibited since 1989. However, as burning of straw occasionally takes place on fields with continuously cultivating seed grass or in cases where weather conditions result in surplus of straw in form of wet or broken bales, it is still included in the reporting. The only activity in 3I (other) is a minor contribution from ammonia (NH_3) treated straw.

The emission from the agricultural activities covers a range of pollutants. According to reporting obligations all main pollutants and particulate matter are reported on since at least 1990 (some since 1985) and the other pollutants since 2000. Only a minor contribution is from the group of other pollutants that e.g. include heavy metals and carbon monoxide (CO), which almost solely are due to field burning of agricultural residues.

Table 5.1 shows an overview of the sources within the agricultural sector and the relevant pollutants for each source.

Table 5.1 Overview of sources and pollutants.

NFR code	Emission source	Main pollutants				Particulate matter				Other				
		NO_x[a]	NMVOC	SO_x[b]	NH_3	$PM_{2.5}$	PM_{10}	TSP	BC	CO	HM[c]	POP[d]	HCB	PCB
3B	Manure management	x	x		x	x	x	x						
3Da	Agricultural soils	x	x		x									
3Dc	Farm-level agricultural operations					x	x	x						
3De	Cultivated crops		x		x									
3Df	Use of pesticides												x	
3F	Field burning of agricultural residues	x	x	x	x	x	x	x	x	x	x	x	x	x

[a] NO_x as NO_2
[b] SO_x as SO_2
[c] Heavy metals: As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn.
[d] dioxins and furanes (PCDD/F) and polycyclic aromatic hydrocarbons (PAH – benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoran-thene and indeno(1,2,3-cd)pyrene).

Table 5.2 shows the agricultural contribution of national emissions in 2023. The main part (95 %) of the NH_3 emission in Denmark is related to the agricultural sector, while the agricultural contribution of total suspended particles (TSP) and particulate matter (PM_{10} and $PM_{2.5}$) are 77 %, 38 % and 9 %, respectively. The agricultural share of non-methane volatile organic compounds (NMVOC) emission accounts for 46 % of the national total. These pollutants, which contribute with a high share of the national emission, are highlighted in overview sections 5.1.1, 5.1.2 and 5.1.3. The agricultural inventory also includes the nitrous oxides (NO_x) emission which contributes with 21 % of the national total. The agricultural part of the national total of SO_x emission is lower than 1 % and only relates to emission from field burning of agricultural residues.

Table 5.2 Agricultural share of the Danish national emission in 2023.

	NH_3	TSP	PM_{10}	$PM_{2.5}$	NMVOC	SO_X	NO_X
National total, kt	66	82	21	11	98	8	81
Agricultural total, kt	63	63	8	1	45	<1	17
Agricultural share, %	95	77	38	9	46	<1	21

5.1.1 Ammonia

The majority of the Danish NH_3 emission, corresponding to 95 %, originates from the agricultural sector. The remaining 5 % is mainly related to emission from transport. Figure 5.1 shows the distribution of NH_3 emission on the various sources from the agricultural sector for 2023. The main part of the agricultural emission is directly related to the livestock production by 39 % from manure management, 25 % from manure applied to soils and 4 % from grazing animals. Emissions from use of inorganic fertiliser and cultivated crops contribute with 18 % and 10 %, respectively. Emissions from NH_3-treated straw, field burning of agricultural residues and sewage sludge used as fertiliser amount to less than 2 % and other organic fertiliser to 1 %.

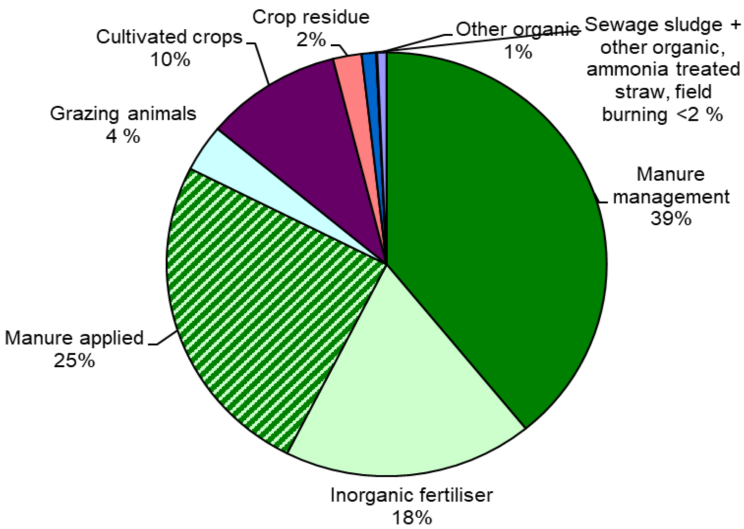

Figure 5.1 NH_3 emissions from the agricultural sector, 2023.

The NH_3 emission from the agricultural sector has decreased between 1985 and 2023 from 162.4 kt NH_3 to 63.0 kt NH_3, corresponding to a 61 % reduction (Figure 5.2). The emissions are also shown in Annex 3D-1. This significant drop in NH_3 emissions should be read in a conjunction of a very active national environmental policy designed to reduce the loss of nitrogen to the aquatic environment. A string of measures has been introduced through regulatory action plans, for example the NPO (Nitrogen, phosphor, organic matter) Action Plan (1986), Action Plans for the Aquatic Environment (1987, 1998, 2004), the Action Plan for Sustainable Agriculture (1991), the Ammonia Action Plan (2001) and the Agreement on Green Growth (2009 and 2010). Based on these action plans, legislative changes and actions has led to an optimization of manure as a resource.

Requirements on capacity of slurry storage and requirements on handling of manure during field application has led to a decrease in animal nitrogen excretion, improvement in use of nitrogen in manure and a decrease in the use of inorganic fertiliser and overall nitrogen application. A Danish environmental approval act for livestock holdings was acted in January 2007 and according to the act, farmers are required to apply for an environmental approval if the farmer wants to change or expand the livestock production facilities. In order to get environmental approval, farmers have to fulfil requirements concerning Best Available Technique (BAT) and specific environmental requirements on for example emissions of ammonia. The action plans have helped to reduce the overall NH_3 emission significantly and the Danish environmental approval act for livestock will continue to restrict emissions in the future.

From 2020 to 2021, a steep decrease in NH_3 emission from manure management is seen. This is mainly due to culling of all mink in Denmark, due to risk of spreading of SARS-CoV-2, during the COVID-19 pandemic. All animals were put down in the end of 2020. A general ban on mink breeding was established in 2021 and later extended until 31 December 2022, therefore continuously keeping emissions down in 2022. This also affects emissions from manure applied to soil. The further decrease in 2023 is due to decrease in number of swine and use of inorganic fertiliser.

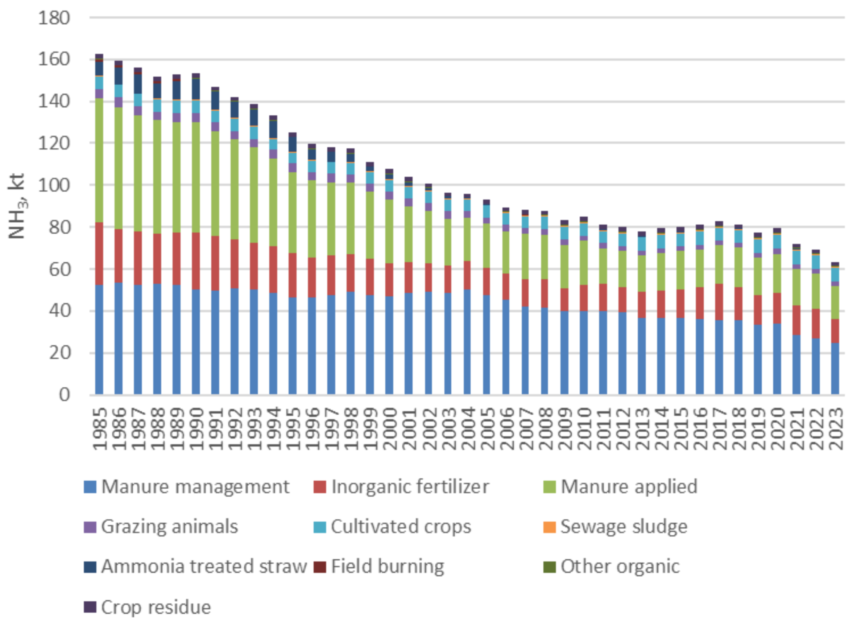

Figure 5.2 Total ammonia emission from the agricultural sector 1985 to 2023. See Annex 3D-1 for numbers.

The management of manure must be considered as the most important emission source for NH_3. Most of the emission originates from the production of swine and cattle, which contributed, respectively with 43 % and 43 % in 2023.

It is noteworthy that the overall emission from swine has decreased by 66 % from 1985 to 2023 despite a considerable increase in the swine production over the years. The most important reason for this is the improvement in feed efficiency, see section 5.3.2. Due to the large contribution from the swine production, the lower level of N-excretion from that sector has a significant influence on total agricultural NH_3 emissions.

Since 1985, changes in practice of manure application to the fields have taken place, which has reduced the emission from manure applied to soils. From the beginning of the 1990s, slurry has increasingly been spread using trailing hoses. From the late 1990s, the practice of slurry injection or mechanical incorporation into the soil has increased. This development is a consequence of a ban on broad spreading, but it is also a consequence of the general requirement to improve the utilisation of nitrogen in the manure - e.g. requirements that a larger part of the nitrogen in manure must be included in the farmer's nitrogen accounting. This has forced farmers to consider the manure as a fertiliser resource instead of a waste product.

Another emission source that has been reduced significantly is NH_3 treatment of straw, which since a ban in 2006 only takes place through legal dispensation in certain particularly wet areas.

5.1.2 Particulate matter

Investigations have shown that farmers, as well as livestock, are subject to an increased risk of developing lung and respiratory related diseases due to emissions of the particulate matter (PM) (Hartung and Seedorf, 1999). This is because the particles are able to carry bacteria, viruses and other organic compounds.

In the NFR, the emission of PM given as total suspended particulate (TSP) and PM of both 10 µm and 2.5 µm is reported for the years 1990 to 2023. The emission from the agricultural sector includes the emission of dust from manure management, field operations and field burning of agricultural residues.

TSP emission from the agricultural sector contributes with 77 % to the national TSP emission in 2023 and the agricultural emission shares for PM_{10} and $PM_{2.5}$ are 38 % and 9 % respectively. The majority (89 %) of the agricultural TSP emission originates from the field operations, while the emission from animal barns contributes with 11 % and field burning of agricultural residues, contributes with less than 1 % to in 2023.

The PM emission from agricultural activities, given in TSP, has decreased 14 % during the period from 1990 to 2023 (Figure 5.3) mainly due to decrease in the emission from field operations.

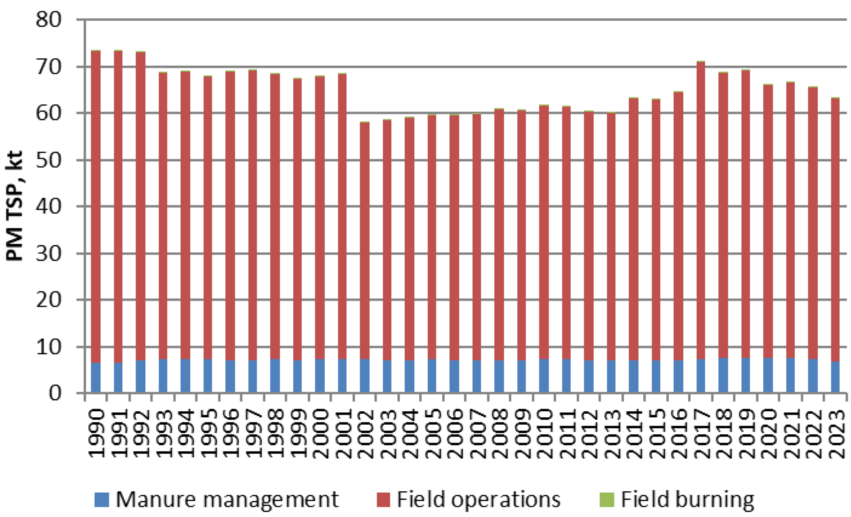

Figure 5.3 Emission of particulate matter (TSP) from the agricultural sector 1990 to 2023.

5.1.3 NMVOC

Emission of NMVOC from the agricultural sector includes the emission from manure management, manure applied to soil, grazing animals, cultivated crops and field burning of agricultural residues. NMVOC emission from the agricultural sector contributes with 46 % to the national NMVOC emission in 2023.

The majority (83 %) of the agricultural NMVOC emission originates from manure management, while the emission from manure applied to soil and cultivated crops contributes with 13 % and 4 %, respectively. Emission from grazing animals and field burning of agricultural residues, contributes with less than 1 % to in 2023.

The total emission of NMVOC from the agricultural sector has decreased by 41 % from 1985 to 2023, mainly due to decrease of emission from manure applied to soil.

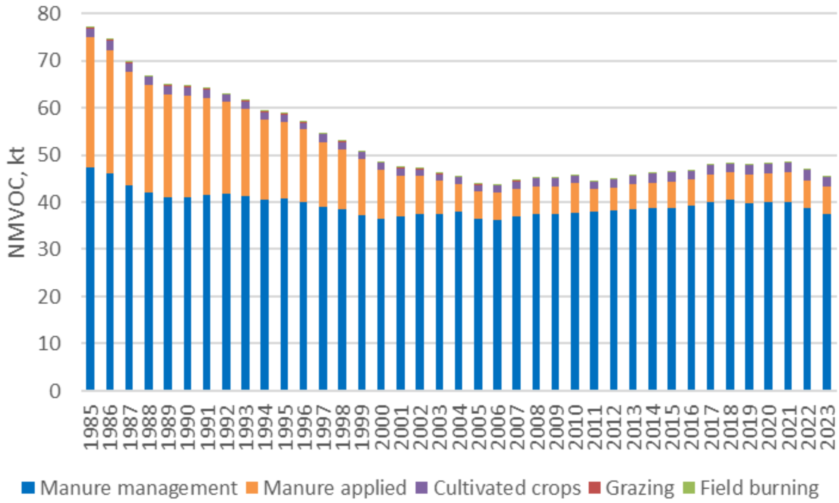

Figure 5.4 Emission of NMVOC from the agricultural sector 1990 to 2023.

5.2 Methods

As mentioned in the introduction, the emission calculation is based on the methodologies provided in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2023), the CORINAIR principle of calculating emissions as activities multiplied by emission factors as well as the 2006 IPCC Guidelines (IPCC, 2006).

5.2.1 Input data

The main part of the agricultural emission is related to livestock production and most of the data are based on country specific Danish standards when available. DCE – the Danish Centre for Environment and Energy, Aarhus University, which is responsible for the emission inventory, has established data agreements with the institutes and organisations to assure that the necessary data are available for timely completion of the emission inventory.

Activity data, emissions factors (EF) and additional values are collected, evaluated, and discussed in cooperation with Statistics Denmark, DCA - Danish Centre for Food and Agriculture, Aarhus University, SEGES Innovation (Agricultural Advisory Centre), the Danish Environmental Protection Agency, Agency for Green Transition and Aquatic Environment and Danish Agency for Agriculture and Fisheries. This means that both data and methods used are evaluated continuously according to the latest knowledge and information from relevant research institutions as well as industry advisory services and stakeholders.

Table 5.3 shows the sources of data input from the different institutes applied in the inventory aside from general standard factors from the EMEP/EEA. The specific data in terms of activity data and emission factors is described in more detail in the chapter section for each emission source (5.3 Manure management, 5.4 Agricultural soils, 5.5 Field burning of agricultural residues and 5.6 NH_3 treated straw).

Table 5.3 List of the main organisations and institutes involved in generating data applied in the emission inventory.

References	Abbreviation	Data / information
Statistics Denmark - Agricultural Statistics (www.dst.dk/en.aspx)	DSt	- livestock production - milk yield - slaughtering data - export of live animals - poultry - agricultural area and distribution of crop types - crop yield
Danish Centre for Food and Agriculture, Aarhus University	DCA	- N-excretion from livestock production - feed, amount and composition - N-content in crops - NH_3 emission factors, barn, storage, application of manure - grazing days for cattle, sheep and goats
SEGES innovation (www.segesinnovation.dk/)	SEGES	- barn type (1985-2004) - number of horses - grazing situation - manure application time and methods - estimation of extent of field burning of agricultural residue - acidification of slurry
Danish Environmental Protection Agency (www.mst.dk)	DEPA	- sewage sludge used as fertiliser - industrial waste used as fertiliser (1985-2004)
Danish Agency for Agriculture and Fisheries	LFST	- inorganic fertiliser consumption and types
Agency for Green Transition and Aquatic Environment	SGAV	- livestock production, sheep, goats, ostrich from CHR (central livestock register) - farmers N accounts - barn type (from 2005) - industrial waste used as fertiliser (from 2005) - reduction factors for NH_3 reducing technology in barns
The Danish Energy Agency (www.ens.dk)	DEA	- amount of energy produced in biogas plants - used biomass in biogas plants

Numbers from Statistics Denmark (DSt) are publish on DSt webpage and DCE collect the data every year from there. Data for exported live animals are received by mail.

Danish standards relating to feeding consumption, manure type in different barn types, nitrogen content in manure, etc. called the Danish Manure Normative System or as referred to in Danish 'Normtalsystemet'. Previously, the standards were updated and published every third or fourth year. From year 2001, DCE receives updated data annually directly from DCA in the form of spreadsheets, which contains numbers for N and amount of manure excretion ex animal, ex barn and ex storage. This means that different normative figures are applied to different years in the historical inventory. The system and standards have been described and published in English in Poulsen & Kristensen (1998), and in Danish in Poulsen et al (2001) and Børsting et al (2021). From 2004, the standards are uploaded and made publicly available every year at http://anis.au.dk/forskning/sektioner/husdyrernaering-og-fysiologi/normtal/. The published numbers cover all N excretion ex animal and the N and amount of manure excretion ex storage.

SEGES Innovation (SEGES) are responsible for registration of all horses in Denmark, so DCE receive estimation on number of horses from SEGES by mail. Further has SEGES a range of farm data, which are used to update information on manure application time and methods, every third to fifth year by request from DCE.

Data for sewage sludge are collected from public reports made by Danish Environmental Protection Agency (DEPA) yearly. Agency for Green Transition and Aquatic Environment (SGAV) collect data from the farmer's nitrogen accounts. These are made available for DCE and are used to estimate the distribution of animals in barn types and application of industrial waste used as fertiliser. Danish Agency for Agriculture and Fisheries (LFST) also make a yearly public report with sales statistics for inorganic fertilisers. From the Danish Energy Authority (DEA) DCE yearly receive by mail information on energy production and biomass used in biogas plants. The energy production is also published on DEA's webpage.

5.2.2 Integrated Database model for Agricultural emissions (IDA)

The emissions from the agricultural sector are calculated in a comprehensive agricultural model complex called IDA (Integrated Database model for Agricultural emissions). The model complex is designed in a relational database system (MS Access). Input data are annually updated and stored in tables in one database called IDA_Backend and the calculations are carried out as queries in another linked database called IDA. The model, as shown in Figure 5.5, is implemented as the central step in the data and calculation process, and used to calculate emissions of air pollutants NH_3, PM, NO_x, CO, NMVOC, SO_2, heavy metals, dioxin, PAH, HCB, PCB as well as greenhouse gases (N_2O, CH_4 and CO_2). Thus, the same activity data is used for both the air pollutants and the greenhouse gases and there is a direct link between the NH_3 emission and the emission estimation of N_2O.

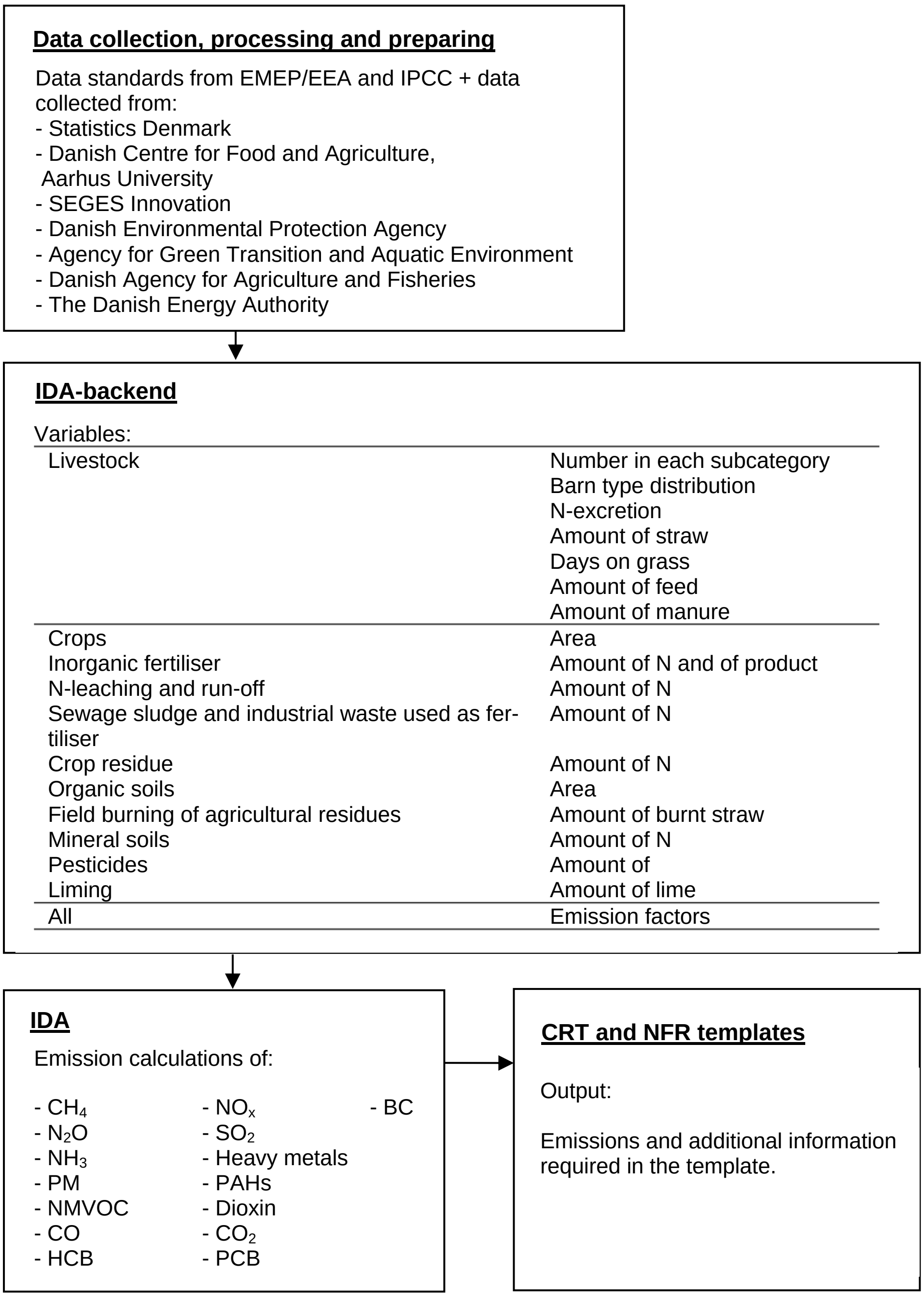

Figure 5.5 Overview of the data process for calculation of agricultural emissions in IDA (Integrated Database model for Agricultural emissions).

IDA includes 42 different livestock categories, divided on weight class and age. Each of these subcategories is subdivided according to barn system and manure type, which results in a total of 300 different combinations of subcategories and barn type (see Table 5.4). In IDA the emissions are calculated from each of these subcategories and then aggregated in accordance with the livestock categories given in the NFR.

It is important to point out that changes in the overall emission and the implied emission factor over the years, are not only a result of changes in the number of animals, but also depend on changes in the allocation of subcategories in the NFR format, changes in feed consumption, changes in barn type and changed practices with regard to the handling of livestock manure in relation to storage and application.

Buffalos, camels, lamas, mules and donkeys are not farmed above a negligible threshold in Denmark and therefore no emission estimates from these animal categories are reported.

Table 5.4 Livestock categories and subcategories.

NFR 3B	Animal categories	Animal types included in the category	No. of sub-categories in IDA, animal type/barn system/manure type
3B 1a	Dairy Cattle[1]	Dairy Cattle	40
3B 1b	Non-dairy Cattle[1]	Calves (<½ year), heifers, bulls and suckling cattle	129
3B 2	Sheep	Sheep and lambs	2
3B 3	Swine	Sows, weaners and fattening pigs	52
3B 4d	Goats	Adult + kids (meet, dairy and mohair)	3
3B 4e	Horses	Weight classes <300 kg, 300 - 499 kg, 500 - 700 kg, >700 kg	4
3B 4gI-gIV	Poultry	Hens, pullet, broilers, turkey, geese, ducks, ostrich and pheasant	61
3B 4h	Other	Fur bearing animals (incl. mink) and deer	9

1) For all cattle categories, large breed and jersey cattle are distinguished from each other in the subcategories.

5.3 Manure management

For the sector manure management (3B1-4), the handling of manure in barn and storage facilities, the emissions of NH_3, PM, NMVOC and NO_x are estimated. They are all calculated based on the same basic activity data, described in the following section.

5.3.1 Activity data

Animals

Table 5.5 shows the development in livestock production in the animal categories used in the inventory from 1985 to 2023. The number of animals corresponds to average annual production (AAP), which means the number of animals that are present on average within the year (EMEP/EEA, 2023). See Annex 3D Table 3D-2 for number of animals allocated on subcategories.

Most data on livestock production are based on the Agricultural Statistics published by DSt based on an annual census. For most of the cattle subcategories, the number given in the annual Agricultural Statistics 'HDYR1' can be used directly. However, in order to calculate number of animals and report in AAP, the number of produced weaners, fattening pigs and bulls are estimated based on Agricultural Statistics 'ANI5' (pigs) and 'ANI4' (bulls), because the total production cycle for these animals is less than one year and the 'HDYR1' only reports the average herd size at any given time throughout the year. The same is the case for broilers, ducks and geese were Agricultural Statistics 'ANI6' combined with information on export of living animals are used. This also allows direct correlation with N-excretion data from the normative figures that are given per produced animal. Estimation of number of hens are based on egg production from Agricultural Statistics 'ANI8' combined with normative figures for eggs per hen.

Only farms larger than five hectares are included in the annual census from Statistics Denmark. Especially horses, goats and sheep are placed on small farms, which mean that the number of animals given in the Agricultural Statistics is not representative and underestimates the actual animal population. Therefore, the number of sheep and goats is based on the Central Husbandry Register (CHR), which is the central register of farms and animals managed by the Ministry of Environment and Food of Denmark. From 2010, the annual census from DSt includes farms with more than 20 goats and sheep, but the CHR is considered as most reliable because the register includes all animals regardless of farm size. The number of horses is based on data from SEGES (Holm, 2024).

The number of deer and ostriches is also based on CHR because these are not included in the Agricultural Statistics. The number of pheasants is based on expert judgement from Department of Bioscience, Aarhus University and the Danish pheasant breeding association (Stenkjær, 2010, pers. comm.).

Since 1985, the production of swine, poultry and fur has increased significantly, fur only up until 2020. The fur production in Denmark was ceased in 2021 and 2022, since the 2020 Danish mink cull, where all animals were put down, due to the risk of spreading of the COVID-19 virus. The general increased in livestock is contrary to the production of cattle, which has decreased rather significantly while maintaining a steady level of milk production because of increasing milk yields per cow. The production of non-dairy cattle follows the same trend as dairy cattle, and the production of beef cattle is negligible in the Danish agricultural production.

Table 5.5 Livestock production 1985 to 2023 given in Average annual production (AAP), 1000 head - NFR 3B. See Annex 3D Table 3D-1 for number of animals allocated on subcategories.

NFR	Animal category	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
3B 1a	Dairy Cattle	896	753	702	636	564	568	561	567	564	557	547
3B 1b	Non-dairy cattle	1 721	1 486	1 388	1 232	1 006	1 003	991	932	924	914	895
3B 2	Sheep	99	230	202	279	316	278	210	200	196	190	186
3B 3	Swine	9 089	9 497	11 084	11 922	13 534	13 173	12 538	13 163	13 168	12 373	10 823
3B 4d	Goats[1]	8	7	7	8	11	16	11	10	10	10	11
3B 4e	Horses[1]	140	135	143	150	175	165	155	183	183	183	180
3B 4gI	Laying hens	5 577	5 696	6 088	4 935	5 168	5 248	5 765	7 385	7 398	7 175	6 192
3B 4gII	Broilers	8 490	9 802	12 585	16 047	11 905	12 836	11 122	13 950	14 056	15 237	15 652
3B 4gIII	Turkeys	308	238	456	456	518	463	275	319	209	186	220
3B 4gIV	Other poultry	1 822	1 600	1 563	1 374	1 509	1 510	1 447	1 620	1 379	1 477	1 602
3B 4h	Fur bearing Animals[1]	1 906	2 264	1 850	2 199	2 552	2 699	3 388	2 216	0	0	6
3B 4h	Deer	9	10	10	10	10	10	8	7	7	6	5

[1] In 2021 and 2022, NO, because of the 2020 Danish mink cull.

Grazing days

Number of days the animals are on grass are defined as days the animals are outside the barns, also called actual days on grass. For heifers, suckling cows, sheep, and goats are the feeding intake (intake of N) higher during grazing compared to the period in barn, this is called feeding days on grass. Feeding days on grass is a conversion of this higher feed intake on grass.

In the calculation of NH_3 and NOx emission feeding days on grass are used, while actual days on grass are used for the emission calculation of PM and NMVOC.

The number of estimated grazing days is based on information from SEGES and normative figures (Børsting et al., 2021) and for 2023 shown in Table 5.6 and for all years 1985-2023 in Annex 3D Table 3D-3.

Table 5.6 Livestock categories used in the emission inventory and the applied number of actual days on grass, 2023*

Livestock categories as given in NFR	Subcategories as given in the EMEP/EEA guidebook	Danish inventory	Grazing days	
			Actual days	Feeding days
Dairy Cattle	Dairy cattle	Dairy cattle	20	20
Non-Dairy Cattle	Calves	Calves < ½ year	0	0
	Beef cattle	Bulls	0	0
		Heifers	47	56
		Suckling cattle	184	224
Swine	Sows	Sows (incl. weaners until 6.7 kg)	0	0
		Sows (incl. weaners until 15 kg), organic production	195	195
	Weaners	Weaners (6.4-31 kg)	0	0
	Fattening pigs	Fattening pigs (31-115 kg)	0	0
Poultry	Laying hens	Laying hens	0	0
	Broilers	Broilers	0	0
	Turkeys	Turkeys	0	0
	Other poultry	Ducks	0	0
		Geese	0	0
Horses	Horses	Horses	183	183
Sheep	Sheep	Sheep and lambs	215	265
Goats	Goats	Meat and milk production	215	265
		Mohair production	203	265
Deer and pheasants	Deer and pheasants	Deer and pheasants	365	365

* Grazing days for all years (actual and feeding days) are show in Annex 3D Table 3D-3.

Barn system and extent of NH_3 reducing technologies

The barn system is a contributing factor in determining the basic NH_3 emissions as well as amount of N-excretion per head, as defined by the normative figures published by DCA. A systematic registration of the livestock barn types for all farms did not exist from 1985 to 2004 and the barn type distribution for these years is therefore based on estimates from the former Danish Agricultural Advisory Centre (now SEGES) (Rasmussen, 2006, pers. comm., Lundgaard, 2006, pers. comm.). From 2005, the distribution of barn system is based on information provided annually by the Agency for Green Transition and Aquatic Environment (SGAV), based on information in the fertiliser accounting system as registered by the farmers or farmer's consultants. The register is compulsory for all farmers that handle organic fertilisers containing more than 100 kg nitrogen per hectare or 1000 kg nitrogen combined or cultivate an area of more than 10 hectares with an N or P norm of more than 0 kg (SGAV, 2024a).

In Annex 3D, Table 3D-5, the distribution of barn type for all animal categories from 1985-2023 is listed.

The structural development in the agricultural sector as well as legislation on both environmental protection and animal welfare has an influence on the changes in barn type distribution. The trend in barn system for dairy cattle goes from older tied-up barns, which is replaced by bigger barns with loose-holding. In 1985, 85 % of the dairy cattle were kept in tied-up barns and in 2023, the share has been reduced to 3 %. In loose-holding systems, the cattle have more space and more straw bedding, and this increases the NH_3 emission per animal compared to the tied-up barns.

Use of NH_3 reducing technology in barns is to some extent implemented in the emission inventory. For the cattle production, the share of animals housed in systems with acidification of the manure is included and for the swine production, the share of animals in systems with acidification or cooling of the manure is estimated. For mink, share of barns with frequent removal of manure and for broilers barns with heat exchanger systems are estimated. NH_3 reducing technology is implemented for the years 2007-2023, starting year depending on the first documented use of the technology. The extent of the technologies is primarily based on data from the Environmental Approval Register from Agency for Green Transition and Aquatic Environment (SGAV) and specific industry distributers. See Annex 3D Chapter 3D-1 for further information on selection of technologies and data references documenting the estimation of NH_3 reducing technology in barn systems. Their applied varying reduction effects on the NH_3 emissions are presented in Table 5.10 in the section on emission factors. In Table 5.7a-d is shown the share of animals in barns with the different NH_3 reducing technology included in the inventory.

Table 5.7a Share of animals in barns with NH_3 reducing technology. Acidification, %.

	2007	2010	2015	2020	2021	2022	2023
Dairy cattle, large breed	0.1	0.9	3.4	2.7	2.2	2.2	2.2
Dairy cattle, Jersey	0.5	2.1	4.7	4.1	3.4	3.4	3.4
Heifers, large breed	0.04	0.1	0.4	0.5	0.4	0.4	0.4
Heifers, jersey	-	-	-	0.1	0.1	0.1	0.1
Bulls, large breed	-	1.3	2.7	1.1	-	-	-
Bulls, jersey	-	-	-	0.02	-	-	-
Fattening pigs	0.3	1.0	1.9	2.3	2.5	2.5	2.5
Weaners	0.6	1.1	1.4	1.5	1.4	1.4	1.4
Sows	0.3	1.1	2.1	1.9	2.4	2.4	2.4

Table 5.7b Share of animals in barns with NH_3 reducing technology. Cooling, %.

	2008	2010	2015	2020	2021	2022	2023
Fattening pigs	0.1	0.9	2.3	4.2	4.4	4.4	4.4
Weaners	0.0	0.9	3.7	5.2	5.1	5.1	5.1
Sows	0.4	1.6	6.1	9.5	10.2	10.2	10.2

Table 5.7c Share of animals in barns with NH_3 reducing technology. Frequent removal of manure, %.

	2010	2011	2012	2013	2014	2015	2016	2017-2023*
Mink	1.0	1.4	3.0	3.9	5.2	6.9	8.2	11.3

*In 2021-2022 no production of mink occurs.

Table 5.7d Share of animals in barns with NH_3 reducing technology. Heat exchanger, %.

	2012	2013	2014	2015	2016	2017-2023
Broilers	24	49	67	83	82	90

N-excretion

N-excretion for all animal subcategories is based on the Danish Manure Normative System (see also section 5.2.1), provided by DCA, Aarhus University

(Børsting et al., 2021, Børsting & Hellwing, 2024). Both total nitrogen excretion and the content of Total Ammoniacal Nitrogen (TAN) are estimated. For deer N-excretion rates are based on normative figures for goats and for pheasants and ostrich N-excretion rates are based the on normative figures for poultry.

The emission of NH_3 from manure management is calculated on the basis on nitrogen excreted from livestock. Most of the N excreted that is readily degradable and broken down to NH_4-N is found in the urine. The relationship between NH_4-N and total N will not remain constant over time but is impacted and can be improved by management of changes in feed composition and feed use efficiency. To be able to implement the effect of NH_3 reducing measures in the emission inventory, it is necessary to calculate the emission based on the TAN content. Since 2007, DCA has established Danish standards based on TAN for liquid manure, which is incorporated in the inventory. The emission for solid manure and deep litter is based on the total N excreted.

N-excretion for dairy cattle has increased from 1985 to 2023, due to increase in feed intake to substantiate increasing milk yield. For swine N-excretion has decreased due to a breeding of pigs with focus on a biological development and improvement in fodder efficiency. In Annex 3D Table 3D-4 is given the average N-excretion based on Total-N for each NFR livestock category from 1985 to 2023 (Table 3D-4a) and N-excretion based on TAN for 2007-2023 for selected subcategories (Table 3D-4b). These values include N excretion from grazing animals, where emission is included in the sector on agricultural soils, see section 5.4.5. Notice that each livestock category is an aggregated average of different subcategories (see Table 5.4).

Storage of manure

Livestock manure is managed and collected either as solid manure (solid and deep litter) or as liquid and slurry depending on barn system. It is assumed that a part of the deep litter is taken directly from the barn into the field is 65 % from cattle, 25 % from fattening pigs, 50 % from sows, 15 % from poultry, 5 % from hens and 15 % from mink (Kai et al, 2024a). The remaining part of the solid manure is deposited in stockpiles in the field until field application.

By law, all slurry tanks must be covered by a fixed cover (tent or concrete) or a full floating cover to reduce NH_3 emission. Birkmose, T. & Hørfarter, R. (2019) have estimated the amount of slurry tanks covered with tent cover in Denmark in 2018 by applying a web-based tool to machine learning. Information about the amount of slurry tanks covered with concrete lid in 2018 is given from the Danish Technological Institute ab a member of the supervisory body for slurry tanks (Anderson, 2019, pers. comm.). A survey has been made to estimate the amount of slurry tanks with either tent or concrete as fixed cover in the years 1985-2018 (Mikkelsen & Albrektsen, 2020). For full floating cover, it can be difficult to establish a natural full floating cover every day all year especially for tanks with pig slurry, but no data is available. In 2023, it is assumed that 5 % of the tanks with swine slurry and 2 % of tanks with cattle slurry are incompletely covered. Cover of slurry tanks for all years 1985-2023 are shown in Annex 3D Table 3D-6.

5.3.2 NH_3

Description

The NH_3 emission from manure management is estimated to 24.7 kt NH_3 in 2023, which represents a 53 % reduction since 1985 (Figure 5.6). NH_3 emission related to manure management contribute with 39 % of the agricultural emission and it mainly comes from the cattle and swine production. The reduced emission from swine production over time is due to an active environmental policy in combination with improvements within the genetic development and most importantly improvements of feed intake efficiency resulting in a lower N-excretion per head. In 1985, the nitrogen excretion for a fattening pig was estimated to 5.09 kg N (Poulsen & Kristensen, 1998). In 2023, that figure was considerably lower at 2.56 kg N per fattening pig produced (Børsting & Hellwing, 2024). In 2023 the number of swine has also decreased. The emission from cattle has decreased as a consequence of a reduced number of cattle.

The emission from "other" cover mink, sheep, goats, and horses and varies over the years, which is mainly due to variation in the number of produced mink and in 2021 and 2022 due to the closing of the production of mink in the end of 2020 emission from "other" decreases significantly.

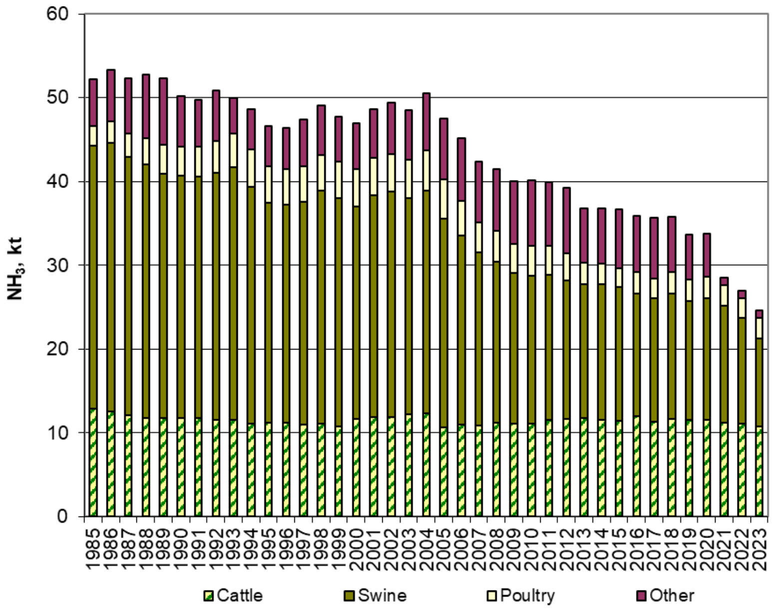

Figure 5.6 NH_3 emission from manure management 1985 to 2023.

Methodological issues

NH_3 emission from manure management covers emission from barns and storage. The emission calculation is based on activity data for each animal subcategory given as the amount of N excreted multiplied with the emission factors, both given in the normative figures (Børsting & Hellwing., 2024, Børsting et al., 2021).

Equation for calculation NH_3 from manure management:

$$Emi\ NH_{3,manman} = Emi\ NH_{3,barn} + Emi\ NH_{3,storage} \quad \text{Eq. (5.1)}$$

Where:

Emi $NH_{3,\ manman}$	= emission of NH_3 from manure management
Emi $NH_{3,\ barn}$	= emission of NH_3 from barn (Eq.5.2)

Emi $NH_{3,\ storage}$	= emission of NH_3 from storage (Eq. 5.3)

Equation for calculation NH_3 from barn:

$$Emi\ NH_{3,barn} = n_i \cdot \left(1 - \frac{grazing\ days}{365}\right) \cdot Nex_{animal} \cdot Tech_j \cdot RE_j \cdot EF_h \qquad \text{Eq. (5.2)}$$

Where:

Emi $NH_{3,\ barn}$	= emission of NH_3 from barn
n_i	= number of animals in *i* subcategory
Grazing days	= feeding days on grass, days per year [1]
$Nex_{animals}$	= N-excretion, N ex Animal
$Tech_j$	= share of NH_3 reducing technology for *j* technology
RE_j	= emission reduction factor for *j* technology (Table 5.10)
EF_h	= emission factor barn, for the specific barn and manure type (Table 5.8)

Equation for calculation NH_3 from storage:

$$Emi\ NH_{3,storage} = \left(n_i \cdot \left(1 - \frac{grazing\ days}{365}\right) \cdot Nex_{barn} \cdot Tech_j + a_j\right) \cdot EF_s \qquad \text{Eq. (5.3)}$$

Where:

Emi $NH_{3,\ storage}$	= emission of NH_3 from storage
n_i	= number of animals in *i* subcategory
Grazing days	= feeding days on grass, days per year [1]
Nex_{barn}	= N-excretion, N ex Barn
$Tech_j$	= share of NH_3 reducing technology for *j* technology
a_j	= amount of nitrogen retained in the manure due to *j* technology
EF_s	= emission factor storage, for the specific manure type (Table 5.9)

Activity data

See section 5.2.1

Emission factor - Barn

The emission from barns is determined by several different conditions that depends on barn type and the different kinds of manure management systems placed in these barns. Danish Centre for Food and Agriculture - DCA, Aarhus University has carried out several emission surveys and estimated emission coefficients for each type of barns, updated recently for 2024/2025 (Kai et al., 2024b) where all emission factors are available. The calculations and assumptions are described and explained in, Poulsen et al. (2001) and Børsting et al. (2021). Table 5.8 shows the emission factors for the most important animal categories; dairy cattle and fattening pigs in different barn systems. For the slurry and liquid manure TAN emission factors is given (TAN ex animal) and for solid and deep litter manure N ex animal is given. From the numbers in the table, it is evident that the emission factor generally is higher for N excreted in manure from fattening pigs.

[1] Actual days on grass are the number of days that animal is outside. Feeding days on grass is higher than actual days on grass due to a higher feed intake (intake of N) during grazing compared to the period in barns. Feeding days on grass is a conversion of this higher feed intake on grass.

Table 5.8 NH_3 emission factors in different barn systems 2023 – dairy cattle and fattening pigs.

Barn and manure system	Manure type	NH_3 emission	NH_3 emission
		Pct. NH_3-N of N ex Animal	Pct. NH_3-N of TAN ex Animal
Dairy cattle (all breeds)			
Tied-up	Solid manure	5.0	
	+ Liquid		6.0
Tied-up	Slurry		6.0
Loose-holding with beds, slatted floor	Slurry		13.5
Loose-holding with beds, slatted floor, scrapes	Slurry		13.5
Loose-holding with beds, solid floor	Slurry		20.0
Loose-holding with beds, drained floor	Slurry		10.4
Deep litter (all)	Deep litter	6.0	
Deep litter, slatted floor	Deep litter	6.0	
	+ Slurry		13.5
Deep litter, slatted floor, scrapes	Deep litter	6.0	
	+ Slurry		12.0
Deep litter, solid floor, scrapes	Deep litter	6.0	
	+ Slurry		20.0
Fattening pigs			
Full slatted floor	Slurry		24.0
Partly slatted floor (50-75% solid floor)	Slurry		13.0
Partly slatted floor (25-49% solid floor)	Slurry		17.0
Solid floor	Solid manure	15.0	
	+ Liquid		27.0
Deep litter	Deep litter	15.0	
Partly slatted and drained floor	Slurry		21.0
Partly slatted floor and partly deep litter	Deep litter	15.0	
	+ Slurry		18.0

Emission factor – Storage

The manure systems are divided in four types of manure: Liquid manure (primarily urine), slurry, solid manure and deep litter. Emission factors for liquid manure are based on factors given in Kai et al. (2024a). For slurry the emission factors are based on Hansen et al. (2008) and estimated as a weighted average for covered (tent, concrete, full floating) and uncovered storage (see section 5.3.1). Share of cover of slurry tanks for all years 1985-2023 are shown in Annex 3D Table 3D-6.

Emission factor for solid manure is estimated as a weighted factor for covered and uncovered manure heaps. Based on expert judgment it is assumed that 50 % of the heaps are covered. The emission factors for covered and uncovered solid manure are based on Hansen et al. (2008). Emission factor for storage of deep litter is based on Kai et al. (2024a), where direct application to the field is taken into account.

Table 5.9 shows the emission factors used for storage.

Table 5.9 NH_3 emission factors for storage, 2023.

Animal category		Liquid manure	Slurry	Solid manure	Deep litter
		Loss of NH_3-N in %			
		of TAN ex barn	of TAN ex barn	of N ex barn	of N ex barn
Cattle		2.2	3.4	4.0	1.05
Swine	Fattening pigs and weaners	2.2	2.7	19.0	9.75
	Sows		2.7	19.0	6.5
Poultry	Hens, pullet and ostrich		2.0[a]	7.5	4.75
	Broilers, geese and ducks				6.8
	Turkeys				8.0
Fur bearing animals			2.7	11.5	6.8
Sheep/goats					3.0
Horses					3.0
Biogas treated			5.6		

[a] Loss of NH_3-N in % of N ex barn.

From 2005, storage of deep litter should be covered by law (BEK, 2002), which has resulted in a reduction of the emission factor for storage of deep litter for cattle from 8.75 % to 1.75 % NH_3-N of N ex Barn.

Emission reduction factor

The effect and use of the NH_3 reducing technologies; acidification, cooling of slurry, frequent removal of manure and heat exchanger in barns, have been implemented in the emission calculations.

Table 5.10 show the emission reduction factors used in the emission calculations. The reduced emission factor applied to acidified slurry, frequent removal of manure and heat exchanger is based on the values acknowledged in the List of Environmental Technologies, which is managed by SGAV (SGAV, 2024b). The list includes technologies, which through tests have documented reliable effects on NH_3 and/or odour emissions according to specific industry standards. The List of Environmental Technologies is continuously adjusted and updated due to new emission reducing technology being adopted to the list or due to implementation of latest knowledge, which can result in change of previously set reduction factors.

The reduction factor for cooling of slurry is based on the average reduction factors in the Environmental Approval Register. If farmers plan to increase the livestock production and build or restore livestock barns, then a reduction of ammonia emission is required by law. The farmers must apply for an Environmental Approval for livestock farming whit information for how to reach the reduction, and for approximately 20 % of the approval, the emission reducing technology in barns chosen.

Table 5.10 Emission reduction factors for environmental technologies for manure management in barn systems.

	Emission reduction factor, %
Acidification in barn, cattle	33[a]
Acidification in barn, swine	64[a]
Cooling of slurry, swine	20[b]
Frequent removal of manure, mink	27[a]
Heat exchanger, broilers	28[a]

[a] Based on values in the Environmental Technologies List (SGAV, 2024b).
[b] Average value based on the Environmental Approval Register (DEPA, 2018).

Implied emission factor

Table 5.11 shows the implied emission factors (IEF) for each NFR livestock category from 1985 to 2023. The implied emission factors express the average emission of NH_3 from barn and storage combined per AAP (annual average population) per year for the entire group of subcategories within each main NFR animal category. The implied emission factors are changing from year to year depending on a combination of several factors, such as:

- change in number of animals in certain subcategories changing the distribution within the main category,
- changes in feed or feed intake impacting N-excretion,
- changes in barn distribution
- extent or share of environmental technologies in use

For dairy cattle, the implied emission factor has increased from 1985 to 2023, and this is due to increase in feed intake and milk production per cow, which has increased the N-excretion. For most of the other animal categories, the implied emission factor has decreased from 1985 to 2023, which is mainly the result of measures in relation to the environmental Action Plans mentioned in the overview of the sector. Strict requirements to obtain improvements in utilisation of nitrogen in feed and manure have resulted in reduction of N-excretion for some livestock categories and especially for fattening pigs. Similarly increased shares of manure management systems with approved environmental technologies have contributed to lower implied emission factors, with a significant impact e.g. on broilers.

Table 5.11 Implied emission factor, manure management 1985 to 2023, kg NH_3 per AAP per year.

NFR	Animal category	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
3B 1a	Dairy cattle	9.08	10.00	10.00	11.46	13.90	13.39	13.62	13.90	13.38	13.44	13.28
3B 1b	Non-dairy cattle	2.73	2.89	2.99	3.54	2.79	3.51	3.89	3.97	3.96	3.89	3.86
3B 2	Sheep	0.44	0.44	0.44	0.44	0.44	0.40	0.40	0.40	0.40	0.40	0.40
3B 3	Swine	3.45	3.04	2.38	2.12	1.84	1.34	1.27	1.10	1.06	1.02	0.98
3B 4d	Goats	1.09	1.09	1.09	1.09	1.05	0.98	1.01	1.00	1.00	1.00	1.00
3B 4e	Horses	5.44	5.34	4.80	4.84	4.84	4.34	4.34	4.80	4.80	4.80	4.80
3B 4gI	Laying hens	0.15	0.20	0.25	0.27	0.34	0.27	0.22	0.20	0.20	0.20	0.22
3B 4gII	Broilers	0.15	0.20	0.18	0.17	0.21	0.15	0.08	0.06	0.06	0.05	0.06
3B 4gIII	Turkeys	0.49	0.51	0.65	0.63	0.64	0.51	0.55	0.55	0.54	0.53	0.55
3B 4gIV	Other poultry	0.10	0.10	0.14	0.11	0.08	0.03	0.02	0.02	0.01	0.01	0.003
3B 4h	Other*	2.47	2.28	2.16	2.13	2.44	2.55	1.82	1.84	NO	NO	1.63

* NO in 2021 and 2022 due to closing of the production of mink.

The emission from urine and dung deposited by grazing animals is included in the emission from agricultural soils (NFR – 3Da3) described in chapter section 5.4.5.

Emissions

The NH_3 emission from manure management is estimated to 24.7 kt NH_3 in 2023 (Table 5.12). From 1985 to 2023, the emission of NH_3 from manure management has been reduced by 53 % (see also Figure 5.4). As mentioned in the overview Chapter 5.1.1 this development is mainly due to implementation of a number of action plans to reduce nitrogen losses from the agricultural production. Furthermore, the closing of the mink production in the end of 2020 and decrease in the production of swine contributes to the most recent reductions.

In 2023, cattle production contributes with 43 % of the total emission from manure management and the swine production contributes with 43 %. The number of cattle has decreased as a result of a growth in milk yield. The production of fattening pigs has increased over the years. However, despite this development the emission from swine is still decreasing. This is due to a breeding of pigs with focus on a biological development and improvement in fodder efficiency. Thus, the N-excretion for fattening pigs has decreased from 5.09 kg per pig per year in 1985 to 2.56 in 2023.

The emission from other poultry decreases from 2005 to 2010. This is due to a change in the proportions of different types of poultry within the sector. Other poultry includes ducks, geese, pheasants and ostrich, and because of a huge decrease in the number of ducks and ostrich from 2006 to 2007 the emission decreases and the IEF decreases as well because the share of emission changes.

Table 5.12 Emission of NH_3 from manure management 1985 to 2023, kt NH_3.

NFR	Animal category	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
3B 1a	Dairy cattle	8.14	7.53	7.03	7.29	7.84	7.61	7.64	7.88	7.55	7.49	7.27
3B 1b	Non-dairy cattle	4.71	4.29	4.14	4.36	2.80	3.52	3.85	3.70	3.66	3.56	3.45
3B 2	Sheep	0.04	0.10	0.09	0.12	0.14	0.11	0.08	0.08	0.08	0.08	0.07
3B 3	Swine	31.36	28.92	26.33	25.31	24.91	17.61	15.87	14.53	13.92	12.64	10.56
3B 4d	Goats	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01
3B 4e	Horses	0.76	0.72	0.68	0.73	0.85	0.72	0.67	0.88	0.88	0.88	0.86
3B 4gI	Laying hens	0.86	1.17	1.51	1.35	1.76	1.44	1.24	1.48	1.49	1.42	1.37
3B 4gII	Broilers	1.24	1.99	2.31	2.68	2.52	1.89	0.90	0.89	0.85	0.82	0.91
3B 4gIII	Turkeys	0.15	0.12	0.29	0.29	0.33	0.23	0.15	0.18	0.11	0.10	0.12
3B 4gIV	Other poultry	0.19	0.16	0.22	0.15	0.12	0.05	0.03	0.02	0.01	0.01	0.01
3B 4h	Other*	4.73	5.19	4.02	4.71	6.26	6.90	6.19	4.10	NO	NO	0.02
3B	Total	52.19	50.21	46.64	46.99	47.54	40.08	36.64	33.74	28.57	27.00	24.65

*NO in 2021 and 2022 due to closing of the production of mink.

Figure 5.7 shows the percentage distribution of the NH_3 emission from barn, storage and application of manure (see Annex 3D Table 3D-7 for numbers). The main part of the reduction in NH_3 emission from agriculture has taken place in connection with the application of manure in fields, due to changes in manure application practice, which is further described in Chapter 5.4.2. There has also been a reduction in emissions associated with storage of manure, which is a result of improvement in coverage of slurry tanks. As a consequence of this development, the percentage of emission from barns are increased from 31 % in 1985 to 47 % in 2023.

The possibilities for further NH_3 reduction will likely be focused on measures in barns by applying various technological solutions either as new technology becomes available or as higher share of the production implements existing solutions. The reduction effect of air cleaning systems is not taken into account in the Danish inventory because improvement in the documentation of share of the production which has implemented this is still needed. Slurry acidification and cooling of slurry in barns, frequent removal of manure in fur barns and heat exchanger in broiler barns is taken into account in the emission estimates reported. For the emissions from manure application to the field acidification either in the storage just prior to application or during application is considered and included.

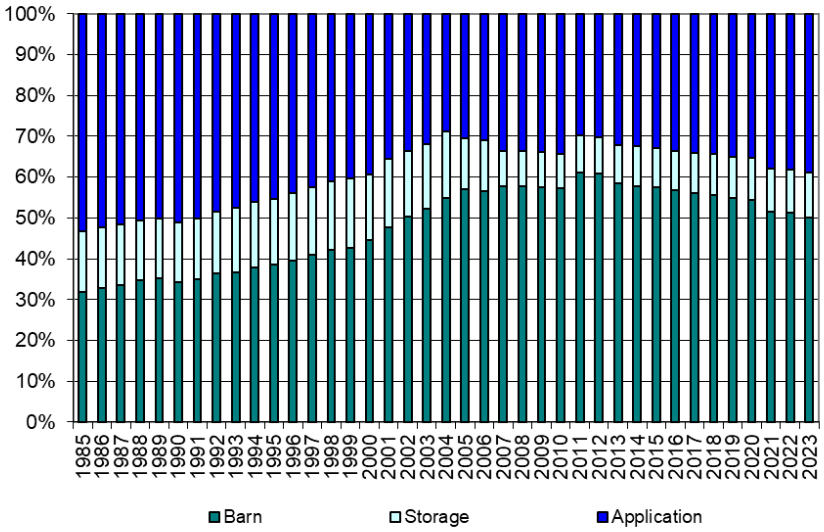

Figure 5.7 The percentage distribution of the NH_3 emission in manure management 1985-2023.

As shown in Figure 5.8 the emission of NH_3 from different manure types has changed over the years. Due to changes in barn types more manure is handled as slurry in 2023 than in 1985 and share of emissions from slurry increase from 1985 to around 2012, from where the share of emission from slurry decreases again. This is due to increase in NH_3 reducing technology as this is mainly used for slurry.

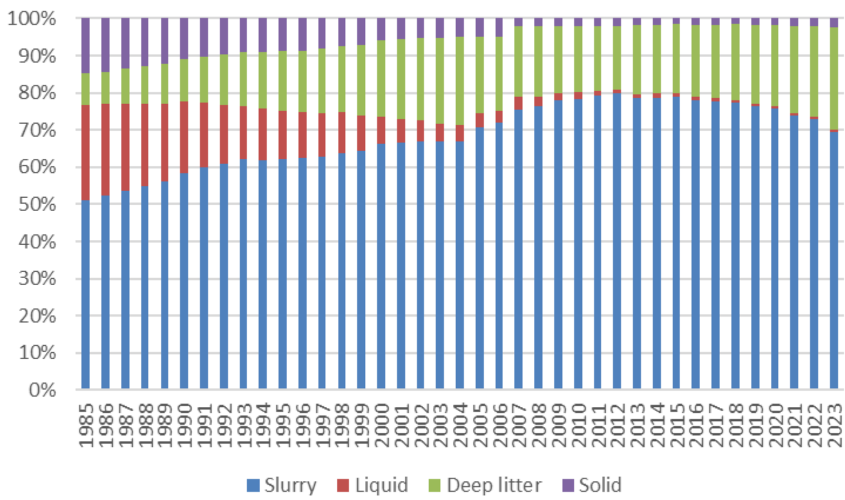

Figure 5.8 The percentage distribution of the NH_3 emission in manure type 1985-2023.

5.3.3 PM

Description

PM emitted from manure management relates to dust from livestock barn systems.

In 2023, the PM emission from barns, given as total suspended particles (TSP), is estimated to 6.65 kt, which correspond to 11 % of the emission of TSP from the agricultural sector. Of the 6.65 kt TSP, 51 % relates to swine production. The emission from cattle and poultry contributes with 21 % and 27 %, respectively and the remaining animals contribute with less than 1 %.

Methodological issues

The estimation of PM emission is based on the EMEP/EEA guidebook (2023) and includes primary particles in the form of dust from barns. The inventory includes PM emission from all animal categories except from ostriches because no emission factors are available. The number of grazing days (actual days on grass) is taken into account as a share of the year where the animals are outside and subtracted in the emission calculation, because the PM emission from grazing animals is considered as negligible. For deer and pheasants, which are outside all year no emission of PM is expected.

Some animal categories are divided into subcategories and for some categories (if applicable) a distinction is made between solid and slurry-based barn systems. The PM emission calculation is based on the annual average population (AAP) and the time the animal is housed.

Activity data

See section 5.3.1.

Emission factor

Emission factors for TSP, PM_{10} and $PM_{2.5}$ are based on the EMEP/EEA guidebook (EMEP/EEA, 2023). The same emission factors are used for all years. Estimation of TSP is based on the transformation factors between TSP and PM_{10} as given in the EMEP/EEA emission inventory guidebook (2023). For cattle the emission factors vary between solid and slurry-based systems, where slurry in general has higher emissions than solids. The available emission factors for swine do not distinguish between type of manure management system.

Table 5.13 Emission factors for particle emission from animal manure barn systems.

Livestock category	Barn system	Emission factor PM10	PM2.5	TSP	Transformation factor PM10 to TSP
		kg per AAP per year			
Cattle:					
Dairy cattle	Slurry	0.83	0.54	1.81	0.46
	Solid	0.43	0.28	0.94	0.46
Calves < ½ year	Slurry	0.15	0.10	0.34	0.46
	Solid	0.16	0.10	0.35	0.46
Beef cattle	Slurry	0.32	0.21	0.69	0.46
	Solid	0.24	0.16	0.52	0.46
Heifer[1)]	Slurry	0.49	0.32	1.07	0.46
	Solid	0.30	0.19	0.64	0.46
Suckling cattle[2)]	Slurry	0.32	0.21	0.69	0.46
	Solid	0.24	0.16	0.52	0.46
Swine:					
Sows	Slurry	0.17	0.01	0.62	0.27
	Solid[3]	0.17	0.01	0.62	0.27
Weaners	Slurry	0.05	0.00	0.27	0.19
	Solid[3]	0.05	0.00	0.27	0.19
Fattening pigs	Slurry	0.14	0.01	1.05	0.13
	Solid[3]	0.14	0.01	1.05	0.13
Poultry:					
Laying hens	Solid	0.04	0.003	0.19	0.21
Broilers	Solid	0.02	0.002	0.04	0.50
Ducks	Solid	0.14	0.02	0.14	1.00
Geese	Solid	0.24	0.03	0.24	1.00
Turkeys	Solid	0.11	0.02	0.11	1.00
Horses	Solid	0.22	0.14	0.48	0.46
Sheep	Solid	0.06	0.02	0.14	0.40
Goats	Solid	0.06	0.02	0.14	0.40
Fur bearing animals	Solid	0.008	0.004	0.02	0.45

1) Average of "calves" and "dairy cattle".
2) Assumed the same value as for "Beef cattle".
3) Same as slurry-based systems.

Emissions

Figure 5.9 shows the PM emission, given in TSP for the main animal categories in the period 1990 to 2023. It is seen that the main part of the emission originates from swine barns. See Annex 3D Table 3D-8 for the PM emission, given in TSP, PM_{10} and $PM_{2.5}$ for all NFR categories. In the period 1990 to 2023, the total agricultural emission of TSP from barns has increased by 1%. The changes in the emission are mainly affected by the production of swine and poultry.

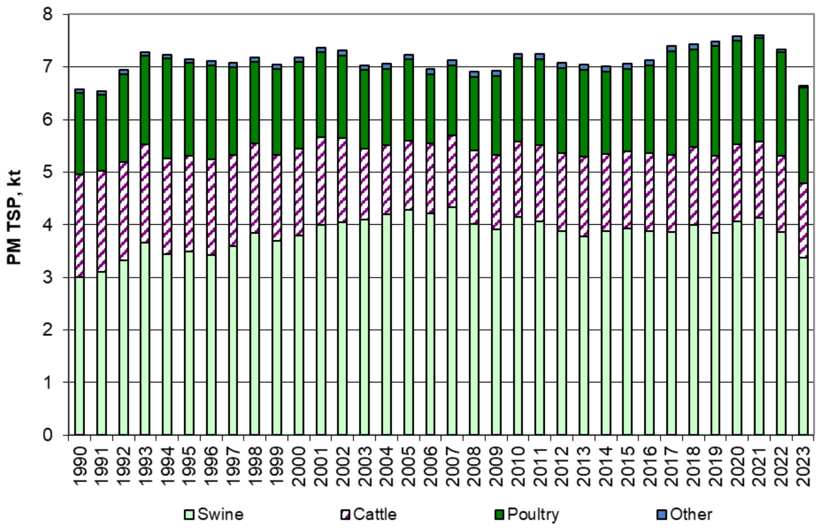

Figure 5.9 PM emission from barns 1990 – 2023 distributed between main livestock categories, in kt TSP.

5.3.4 NMVOC

Description

The emission of non-methane volatile organic compounds (NMVOC) from manure management contributes with 83 % of the agricultural NMVOC emission in 2023 and is mainly related to the cattle production. NMVOC emissions are estimated from all animal categories.

Methodological issues

The estimation of NMVOC emission is based on the EMEP/EEA guidebook (2023) Tier2 approach. NMVOC emissions from animal husbandry comes from feed, degradation of feed in the rumen and from undigested fat, carbohydrate, and protein decomposition in the rumen and in the manure**.** The estimation includes NMVOC from silage storage and the feeding table if silage is used for feeding, because silage is a major source of NMVOC emissions. Furthermore, the estimation includes emission from livestock in barn systems and outdoor manure stores. Emission of NMVOC from manure application and grazing animals are reported in sector 3Da2a (manure applied to soil) and 3Da3 (urine and dung deposited by grazing animals), respectively.

Activity data

The NMVOC emission is estimated on the number of animals, share of time spend in barn/on grass (time on grass in Table 5.6), gross energy feed intake for cattle (Annex 3D Table 3D-19), volatile solids (VS) for other animal categories (Annex 3D Table 3D-20) and the fraction of silage in the feed (Table 5.14). Gross energy intake and VS content are estimated based on normative figures for energy intake and amount of manure excretion, respectively. Fraction of silage is based on expert judgement and information on feed composition for the livestock categories.

The number of animals is given as the average annual population (AAP) – see Table 5.5 in section 5.3.1 on activity data.

Table 5.14 Fraction of silage in the feed, in percentage.

	Fraction of silage in feed, %
Dairy Cattle	1
Non-Dairy Cattle	1
Sheep	0.5
Goats	0.5
Horses	0.5
Swine	0
Laying hens	0
Broilers	0
Turkeys	0
Other poultry	0
Other	0

Emission factor

NMVOC emission factors recommended in EMEP/EEA Guidebook 2023 Table 3-11 (cattle) and Table 3-12 (other animals) is used (Table 5.15).

The same emissions factors are used during all years, which mean that changes of the emission over time only depends on changes in animal production, feed practices or changes in grazing days.

Table 5.15 NMVOC emission factors (EMEP/EEA Guidebook 2023).

	EF NMVOC silage feeding	EF NMVOC barn
	Kg NMVOC per MJ feed intake	
Dairy Cattle	0.0002002	0.0000353
Non-Dairy Cattle	0.0002002	0.0000353
	Kg NMVOC per kg VS excreted	
Sheep	0.010760	0.001614
Swine – sows		0.007042
Swine – other		0.001703
Goats	0.010760	0.001614
Horses	0,010760	0.001614
Laying hens		0.005684
Broilers		0.009147
Turkeys		0.005684
Other poultry		0.005684
Fur bearing animals		0.005684

Emissions

The development of NMVOC emission from 1985 to 2023 shows a decrease from 47 kt to 38 kt with the highest fall in the beginning of the period (Figure 5.10). The greatest part of the emission originates from cattle. Emission from dairy cattle is almost unaltered from 1985-2023 because while the number of dairy cattle has decreased has the feed intake increased. The emission from non-dairy cattle decreases due to decease in number of animals.

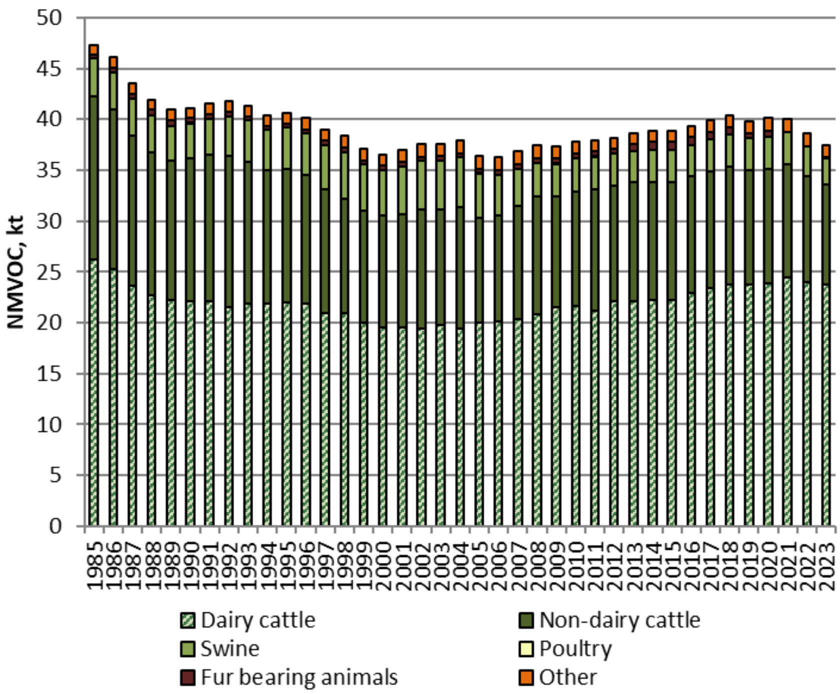

Figure 5.10 Emission of NMVOC from manure management, 1990-2023, in kt NMVOC.

5.3.5 NO_X

Description

The estimate of NO_x from manure management has been calculated and in 2022 sums up to 0.72 kt, which is a 4 % contribution out of the total agricultural NO_x emission in 2023. The primary emission source in manure management is from the poultry production. Most of the agricultural NO_x emissions are from manure applied to soil and inorganic fertiliser.

Methodological issues

The estimation of NO_x emission is based on the EMEP/EEA guidebook (2023) Tier1 approach.

Activity data

The Tier 1 approach is based on number of animals given as the average annual population (AAP) and manure type. The number of AAP is showed in Table 5.5. In Annex 3D Table 3D-5 are the distribution in barn systems and types of manure for all animal categories for all years 1985-2023.

Emission factor

The applied emission factors for estimation of NO_x emission from manure management is listed in Table 5.16. Some of the manure from the mink production is handled as slurry, but no EF for slurry from fur bearing animals is mentioned in the Guidebook. Therefore, the same emissions factor is used for both slurry and solid systems.

Table 5.16 NO_x emission factors (EMEP/EEA Guidebook 2023), kg NO_2 per AAP.

NFR code	Livestock	slurry	solid
3B 1a	Dairy cows	0.01	0.752
3B 1b	Non-dairy cattle	0.003	0.217
3B 2	Sheep		0.012
3B 3	Sows	0.005	0.471
3B 3	Sows, outdoor		0
3B 3	Fattening pigs	0.002	0.017
3B 4d	Goats		0.012
3B 4e	Horses		0.25
3B 4gi	Laying hens	0.014	0.0001
3B 4gii	Broilers		0.027
3B 4giii	Turkeys		0.027
3B 4giv	Ducks		0.022
3B 4giv	Geese		0.005
3B 4h	Fur bearing animals	0.001*	0.001

* Used the same EF as given for solid manure.

Emissions

The NO_x emission from 1990 to 2023 has decreased significantly from 0.91 kt NO_x to 0.72 kt NO_x corresponding to a 21 % reduction. The emission depends on number of animals and manure type and the decrease is mainly related to changes from solid based systems to slurry-based systems for both dairy cattle and swine production. Thus, the share of animals in systems with solid manure was 23 % in 1990 and dropped to 11 % in 2023. Poultry contributes with the main part of the emission and the emission from poultry increases from 1990-2023 due to increase in number of animals.

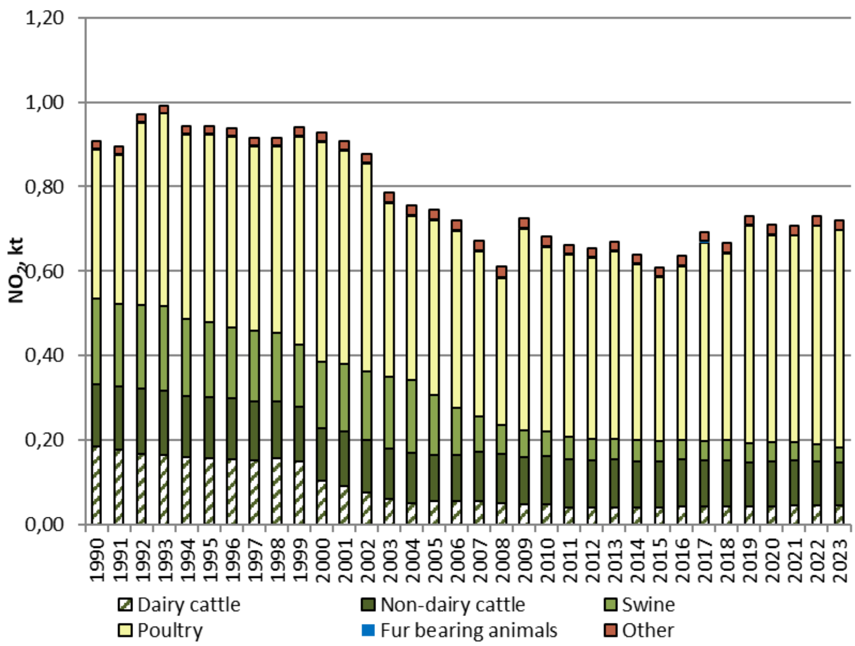

Figure 5.11 NO_x emission from manure management 1990–2023 in kt, distributed between main anil categories.

5.4 Agricultural soils

Denmark is an intensely cultivated nation and at present, the farmed area covers about 60 % of the total land area in Denmark. In recent decades, the farmed area has decreased, being replaced by built-up areas for industry or residential purposes, roads, forest, and nature habitats. The emission sources related to the cultivation of the agricultural soils (NFR 3D) covered here are: inorganic N-fertilisers (3Da1), animal manure, sewage sludge and other organic fertilizers applied to soils (3Da2a-c), urine and dung from grazing animals (3Da3), farm level agricultural operations (3Dc), cultivated crops (3De) and use of pesticides (3Df). All emission subcategories are described with specific sections on methodological issues, activity data, emission factors and emissions. Where relevant emissions of NH_3, NO_x, NMVOC and PM are estimated.

5.4.1 Inorganic N-fertilisers

Description

For the sector inorganic N-fertiliser (3Da1) the emission of NH_3 and NO_x are estimated. No methodology is available for estimating NMVOC and PM emissions.

The emission of NH_3 from inorganic fertiliser contributes in 2023 with 18 % of the emission from the agricultural sector. The emission of NO_x contributes in 2023 with 47 % of the emission from the agricultural sector.

Methodological issues

The emission calculation of NH_3 from inorganic fertiliser is based on the consumption of fertiliser of different types and their respective emission factors taken from the EMEP/EEA Guidebook (2023). In Table 5.17 are shown emission factors and the consumption of each type for 2023, see next section on activity data. See Annex 3D Table 3D-9 for the background assumptions on N content for the different fertiliser types.

The calculation on emission of NO_x is based on the total consumption of N in inorganic N-fertiliser and the emission factor given by EMEP/EEA (2023) of 0.04 kg NO_2 per kg N in the fertiliser, as there is no differentiation between fertiliser types.

Table 5.17 Inorganic N-fertiliser consumption 2023 and related NH_3 emission factors.

Fertiliser type	NH_3 Emission factor[1], Kg NH_3-N pr kg N	Consumption[2], kt N
Pure ammonium nitrate	0.025	3.12
Ammonium nitrate with/without sulfur	0.025	108.40
Ammonium nitrate-urea solutions	0.084	4.72
Urea	0.163	8.16
Calcium ammonium nitrate	0.025	13.88
Calcium and boron calcium nitrate	0.087	0.20
Ammonium sulphate	0.087	6.77
Ammonium sulphate nitrate	0.087	2.55
Liquid ammonia	0.017	3.16
Liquid nitrogen	0.084	3.97
NPK-fertiliser	0.087	34.92
NK fertiliser	0.025	0.89
Other NP fertiliser types	0.087	3.89
Other fertiliser with N	0.025	0.77
Diammonphosphate	0.087	0.00
Other[3]	0.048	1.95
Total consumption of N in inorganic N fertiliser		197.35

[1] EMEP/EEA (2023) weighted value of 79 % normal pH and 21 % high pH. See Annex 3D Table 3D-9 for assumptions on fertiliser types. EF is converted to NH_3-N.
[2] Sales statistics and fertiliser accounts from Danish Agency for Agriculture and Fisheries and Agency for Green Transition and Aquatic Environment, 2024. The fertiliser types of magnesium fertiliser and nitrogenous calcium cyanamide are also included in the sales statistics, but no NH_3 is emitted from these fertilisers.
[3] For other fertiliser without specified emission factors, the implied emission factor across all other fertiliser types is used. The IEF, varies from year to year, see Table 5.18.

Activity data

The amount of nitrogen (N) applied to soil by use of inorganic N fertiliser is estimated from sales statistics managed by the Danish Agency for Agriculture and Fisheries (LFST, 2023). As part of the annual QA/QC procedure, the sale statistics is compared with the consumption registered directly by farmers or their consultants in the Danish fertiliser N accounts controlled by Agency for Green Transition and Aquatic Environment (SGAV). The comparison indicates a difference for all years 2009-2022 and especially a significant difference for 2016, 2018 and 2020-2022 (Figure 5.12). For the years 2009-2016 and 2018, the comparison shows a higher consumption of fertilisers registered in the Danish fertiliser N accounts than in the sales statistics and thereby underestimate the amount of fertiliser, while in 2020-2022 the sales statistics have a higher amount of fertiliser. The difference in 2009-2016 is most likely caused by farmer's own import of inorganic fertilisers, which is confirmed by the LFST. It is allowed for the farmer to import fertiliser, if the consumption is related to own fields, but not for onward sale. The farmers have no interest in registering a to high estimate of their consumption of inorganic fertiliser, which indicates that the amount of applied N registered in the Danish fertiliser N accounts is more reliable for the years 2009-2016 and 2018. LFST and SGAV is aware of the situation with farmers import, and in the for years since 2017, the sales statistics include more companies selling inorganic N fertiliser, which can explain why these numbers have again increased. For 2023 no sales statistics are available.

For inventory purposes the data with the highest number in the specific year is applied in the calculation. This means that for the years 1985-2008, 2017 and 2019-2021, the use of inorganic N fertiliser is based on the sales statistics and for 2009-2016, 2018 and 2023 it is based on the fertiliser accounts. Distribution on fertiliser types is not available in the fertiliser accounts therefore are the distribution from the sales statistics for given year used. For 2018, a high uncertainty is indicated for the sales estimates (Skade, 2020, pers. Comm.) and distribution is therefor based on the distribution in 2017. For 2023 where no sales statistics are available the distribution is based on the distribution in 2022.

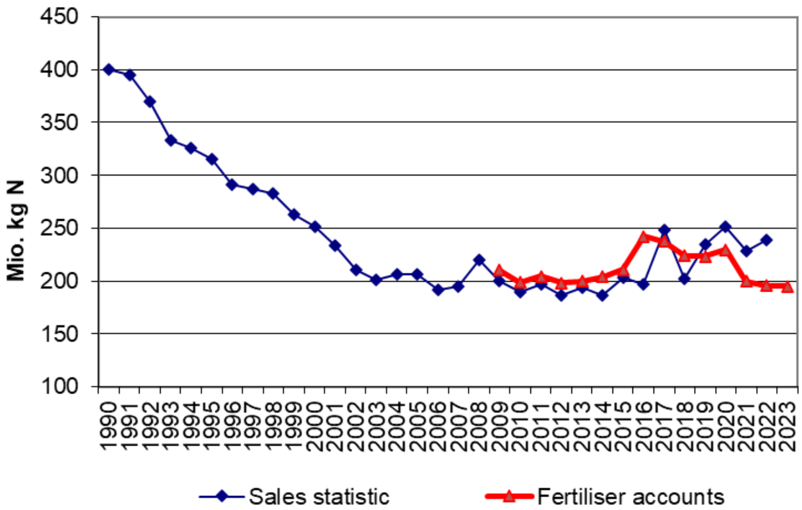

Figure 5.12 N applied from inorganic N fertiliser, sales statistic, and N fertiliser account.

Emission factor

Emission factors for both NH_3 and NO_x are based on the values given in EMEP/EEA guidebook (EMEP/EEA, 2023) and the same emission factors are used for all years 1985-2023.

Studies (Hutchings & Sommer, 2020) have shown that 21 % of the Danish agricultural area have a soil pH > 7 (high pH), and therefore the emission factors estimated as a weighted value of 79 % EF for normal soil pH and 21 % EF for high pH given in EMEP/EEA (2023). See Table 5.17 for the weighted NH_3 emission factors. For NO_x are used the EMEP/EEA (2023) emission factor of 0.04 kg NO_2 per kg N in the fertiliser for all years.

The implied emission factor for NH_3 from inorganic fertilisers shown in Table 5.18 as dependent on annual consumption and share of various types of fertilisers. This implied emission factor, is used for the fertiliser type "Other".

Table 5.18 Implied emission factor for NH_3-N from inorganic N-fertiliser, 1985-2023.

	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Implied emission factor NH_3-N, % of total N	6.17	5.61	5.48	5.10	5.25	5.04	5.35	4.90	5.02	4.83	4.83

Emissions

Figure 5.13 shows the development of NH_3 and NO_x emission from 1985-2023. Since 1985, there has been a significant decrease in the use of inorganic N-fertiliser. This is due to requirements to the utilisation of nitrogen in manure as outlined in various environmental action plans. Another explanation for the reduction of emission is a decrease in the use of urea, which has gone from up to 4 % in the nineties to less than 0.5 % of the total nitrogen in the latest years up to 2023. In 2022 the taxes for urea were lowered (Bitterhoff, 2023, pers. Comm.) and the use of urea have increased significantly (Table 5.17). From 2016, the emission of both NH_3 and NO_x has increased slightly, which is caused by an increase in consumption of inorganics fertilisers, because of the Agreement on a Food and Agricultural package adopted in December 2015 (MEFD, 2017). The purpose of the agreement was to establish better framework conditions for the agricultural production, to ensure opportunities for economic growth, in interaction with protection of nature and environment. It was decided to initiate a series of measures to decrease the N-leaching, and in combination with expected higher crop yield, a higher consumption level of inorganic fertilisers was allowed.

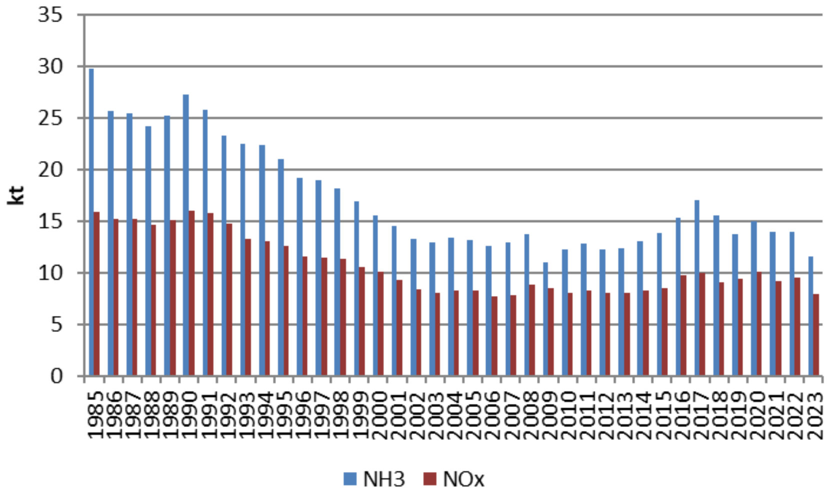

Figure 5.13 Emission of NH_3 and NO_x from inorganic N-fertiliser for 1985-2023, kt.

5.4.2 Animal manure applied to soils

Description

For the subsector, animal manure applied to soils (3Da2a) the emission of NH_3, NMVOC and NO_x are estimated. PM emission for field operations is reported under sector 3Dc farm level agricultural operations.

Emission of NH_3 from animal manure applied to soils contributes in 2023 with 25 % of the NH_3 emission from the agricultural sector. NMVOC contributes in 2023 with 13 % of the NMVOC emission from the agricultural sector. Emission of NO_x from animal manure applied to soils contributes in 2023 with 42 % of the NO_x emission from the agricultural sector.

Methodological issues

NH_3

To calculate emissions of NH_3 from animal manure applied to soils weighted emission factors are estimated and multiplied with TAN ex storage for liquid manure and N ex storage for solid manure for each animal type. The weighted emission factors are estimated based on background estimates of timing, application methods, application in growing crops or on bare soil, the time from application to ploughing and extent of acidification combined with the given annual climate conditions– see further description on NH_3 emission factor below.

NMVOC

Emission of NMVOC from manure applied to soil is based on Tier 2 method given in EMEP/EEA guidelines 2023 Chapter 3B Manure management but reported in sector 3Da2a. The emission factor is calculated by multiplying the NMVOC emission factor for barn systems with the relative ratio between the NH_3 emission related to application of manure and NH_3 emission from barn systems, as presented below:

$$EF_{NMVOC,appl.} = EF_{NMVOC,barn} \cdot \left(\frac{E_{NH3,appl.}}{E_{NH3,barn}}\right) \quad \text{Eq. (5.4)}$$

Where:

$EF_{NMVOC,\ appl.}$ = Emission factor for NMVOC from manure applied to soil
$EF_{NMVOC,\ barn}$ = Emission factor for NMVOC from barn (estimated in sector 3B)
$E_{NH3,\ appl.}$ = Emission of NH_3 from manure applied to soil
$E_{NH3,\ barn}$ = Emission of NH_3 from barn (estimated in sector 3B)

NO_x

The NO_x emission is calculated as the emission factor multiplied with N ex storage for each animal type.

Activity data

Based on the normative figures (Børsting & Hellwing, 2024) the amount of TAN ex storage for liquid manure and the amount of N ex storage for solid manure are given. See also section 5.3.1.

Activity data on manure application practices and the use of acidification and biogas is based on surveys from SEGES and Aarhus University and biogas registers made available from the Danish Energy Agency, as described further in the next section on emission factors.

Acidification of slurry just before application on the fields is a used environmental technology in Denmark and the development is a result of environmental requirements. By law if slurry is applied on grass fields or on bare soil without vegetation, the slurry must be either injected or treated with acid to lower the ammonia emission. The slurry acidified in barns is considered to have the acidification effect during application.

The amount of manure acidified in storage just prior or during application is estimated by SEGES for the years 2011-2016 (Hansen, 2017) and by Aarhus University for 2017 (Nyord & Mikkelsen, 2019), see Table 5.19. No information on acidification is available for 2018-2023, so the amount for 2017 is used for 2018-2023. It is mainly cattle manure, which is acidified in storage just prior or during application, but the shares generally declined in 2016 and 2017 after years of increase.

Table 5.19 Share of liquid manure acidified in barn, storage and just before application, 2008-2023.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017-2023
Share of cattle manure, %										
Barns	0.1	0.4	0.6	0.9	1.1	1.1	1.2	1.3	1.4	1.5
Storage	0	0	0	1.2	2.6	4.6	3.1	4.2	3.8	1.9
Just before application	0	0	0	1.1	2.5	4	7.4	8.8	8.3	7.5
Share of swine manure, %										
Barns	0.1	0.3	0.5	0.6	0.6	0.7	0.8	0,8	0.9	1.0
Storage	0	0	0	0.3	0.7	1.2	0.8	1	0.4	0.2
Just before application	0	0	0	0.4	0.8	1.3	2.5	2.9	1.5	1.3

Emission factor NH_3

The emission factors for slurry (all liquid manure) are based on background estimates of time of application, application methods, application in growing crops or on bare soil and the time from application to ploughing. The amount of manure being acidified in the barn, in storage just prior or during application is also considered. For manure acidified in barns a weighted emission factor is estimated, while the share of manure acidified in storage just prior or during application is incorporated in the weighted emission factor used for all slurry not acidified in barns or biogas treated.

In 2020, a survey was made by Birkmose (2020), which shows the share of manure applied to soil under the above-mentioned circumstances.

For each combination of timing, application methods, application in growing crops or on bare soil, the time from application to ploughing an emission factor have been estimated with the model ALFARM 2-model (Hafner et al., 2018, Hafner et al., 2019, Hafner et al., 2021). The emission factors are estimated for the decades 1980-1989, 1990-1999, 2000-2009 and 2010-2019 taking whether conditions for the different decades into account. For the years 2020-2023 are used the same emission factors as the decade 2010-2019. The ALFARM2-model is a semi-empiric model based on factual measurement of NH_3 emissions during application of manure. Specific emission factors are estimated for cattle and swine. For all other animals, the same emission factor as for cattle is used.

Annex 3D, Table 3D-10 to 3D-13 shows the distribution of manure under each combination of conditions applied and emission factors estimated by ALFARM2 for 2023 (decade 2010-2019). For solid manure, emission factors are based on the data and calculation method presented in Hansen et al (2008), also included in Annex 3D Table 3D-10 to 3D-13.

The weighted emission factors will vary from year to year depending on changes in the practice of application and emission factor for the decade. In Table 5.20 the weighted emission factors are shown for slurry untreated or acidified during storage and application, slurry acidified in barn, biogas treated slurry and for solid manure. The decrease in the emission factor for slurry (weighted untreated or acidified during storage and application) in the period from 2000-2005 is due to broad spreading of slurry being prohibited and for 2010-2015 is due to increasing implementation of acidification. For all years see Annex 3D Table 3D-14.

Table 5.20 Weighted emission factors for NH_3-N emission from application of manure, kg NH_3-N per kg TAN for slurry and kg NH_3-N per kg N for solid manure.

	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Slurry, weighted for untreated or acidified during storage and application											
Cattle*	47.74	46.08	36.79	28.21	11.81	12.35	10.53	10.21	10.21	10.21	10.21
Swine	24.44	25.44	18.97	16.15	11.13	11.18	9.58	9.61	9.61	9.61	9.61
Acidified slurry in barn											
Cattle	NO	NO	NO	NO	NO	12.35	16.32	16.32	16.32	16.32	16.32
Swine	NO	NO	NO	NO	NO	11.18	7.04	7.04	7.04	7.04	7.04
Biogas treated slurry	42.62	42.62	34.56	29.80	22.62	22.76	14.33	14.33	14.33	14.33	14.33
Solid manure	10.28	8.49	7.96	7.12	7.55	7.55	6.82	6.82	6.82	6.82	6.82

NO – not occurring.
* EF also used for all other animals than swine.

Emission factor NMVOC

The emission factor for NMVOC is estimated for each animal category and varies for all years due to changes in EF barn and the relative ratio between the NH_3 emission related to application of manure and NH_3 emission from barn systems.

Emissions factor NO_x

The emission factor for NO_x is based on EMEP/EEA guidebook (2023). The NO_x emission is estimated based on the Tier 1 emission factor at 0.04 kg NO_2 per kg N fertilised and is the same for all years in the inventory.

Emissions

The emission of NH_3 from manure applied to soils has decreased by 73 % from 1985 to 2023, due to the decrease of N excreted by animals and by changes in the way manure is handled during application. Based on the action plans various initiatives has been implemented and include for example the requirement for a minimum 9-months manure production storage capacity, that allows smarter timing of application, the requirement that solid manure applied to soil must be ploughed down within six hours, a ban on the application of manure in winter and broad. As a result, an increasing share of the slurry is injected or acidified, which results in a lower emission. The share of manure put through biogas plants and applied as digestate has increased significantly and pulls the result slightly in the other direction, increasing emissions. The emission in 2023 amounted to 15.7 kt NH_3.

NMVOC emission from manure applied to soil has decreased with 79 % from 1985 to 2023 and this is mainly due to the decrease in the ratio between emission of NH_3 from manure applied to soil and NH_3 emission from barn. The emission in 2023 amounted to 5.9 kt NMVOC.

Emission of NO_x from manure applied to soils has decreased by 19 % from 1985 to 2023 and this is mainly due to the mentioned decrease of N excreted. The NO_x emission in 2023 amounted to 7.2 kt.

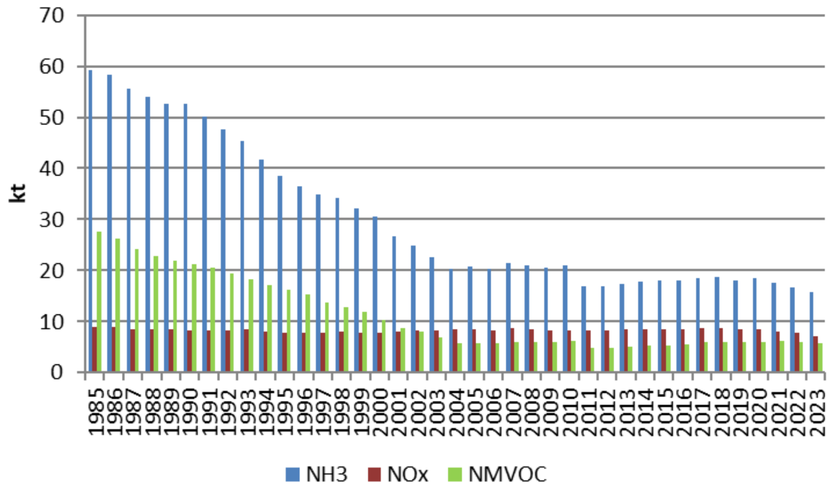

Figure 5.14 Emission of NH_3, NMVOC and NO_x from manure applied to soils, 1895-2023, kt NH_3, NO_x and NMVOC.

5.4.3 Sewage sludge applied to soils

Description

For the subsector, sewage sludge applied to soils (3Da2b) the emission of NH_3 and NO_x are estimated. No methodology is available for estimating NMVOC and PM emissions.

Emission of NH_3 and NO_x from sewage sludge applied to soils contributes in 2023 with 1 % of total NH_3 and NO_x from the agricultural sector.

Methodological issues

To estimate emissions of NH_3 and NO_x amount of N applied are multiplied with the emission factor.

Activity data

Information regarding the amount of sewage sludge applied on agricultural soil as fertiliser, is based on information from the Danish Environmental Protection Agency (DEPA), and covers the years 1987-2002, 2005, 2008-2009, 2013-2022 (latest DEPA, 2024). For 1985-1986 the amount of sewage sludge applied are based on expert judgement. In the intervening years, the amount of sewage sludge applied is interpolated and 2023 is based on an average of the years 2020-2022. The N-content for the years 1985-2002 varies and are based information in the reports from DEPA and expert judgement. For the years 2003-2019 it is assumed to be 4.75 kg N per kg dry matter (DEPA, 2009) and 6.0 kg N per kg dry matter for the years 2020-2022 (DEPA, 2022).

Table 5.21 Activity data used to estimate NH_3 and NO_x from sewage sludge, 1985-2023.

Data	Unit	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Amount of sludge applied on soil	Tonnes of dry matter	50 000	77 883	112 235	83 727	57 053	76 250	85 000	99 000	84 000	74 000	85 667
N-content	%	4.00	4.00	4.13	4.33	4.75	4.75	4.75	6.00	6.00	6.00	6.00
N applied on soil	Tonnes N	2 000	3 115	4 635	3 625	2 710	3 622	4 038	5 940	5 040	4 440	5 140

Emission factor

The emission factor for NH_3 emission from sewage sludge applied to soil is based on EMEP/EEA guidebook 2023 of 0.13 kg NH_3 per kg N applied.

The emission factor for NO_x is based on EMEP/EEA guidebook 2023 of 0.04 kg NO_2 per N applied.

Emissions

Estimated emission of NH_3 and NO_x from sewage sludge applied to soil is shown in Figure 5.15. The emission follows the amount of N applied, as the same emission factor are applied to all years and have increased slightly since 1985. The emission in 2023 amounted to 0.67 and 0.21 kt NH_3 and NO_x respectively.

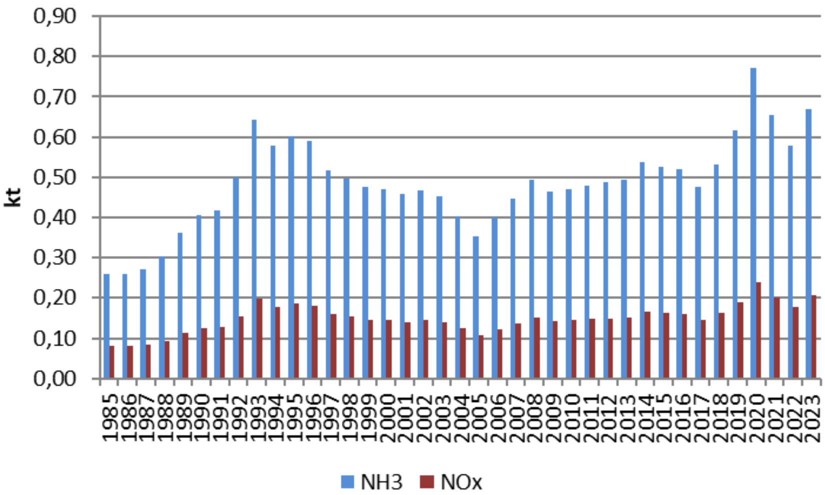

Figure 5.15 Emission of NH_3 and NO_x from sewage sludge, 1985-2023, kt.

5.4.4 Other organic fertilisers applied to soils

Description

For the subsector, other organic fertilisers applied to soils (3Da2c) the emission of NH_3, and NO_x are estimated. No methodology is available for estimating NMVOC and PM emissions. The category includes emission from industrial wastes, which is sludge from industries and 'other biomass' includes digestate from other types of biomass aside from manure treated in biogas plants, both applied to agricultural soils as fertiliser.

Methodological issues

The estimated on NH_3 and NO_x emission is calculated simply as the amount of N applied multiplied with the respective emission factors.

Activity data

Information about the amount of industrial waste applied on agricultural soil and the content of nitrogen is obtained from a series of reports published by the Danish Environmental Protection Agency. The recent official figures regarding the amount of sludge from the industrial waste are data covering until year 2001 (Petersen & Kielland, 2003). From 2005, the amount of N from sludge from industries is based on the information registered in the annual N fertiliser accounts controlled and made available by Agency for Green Transition and Aquatic Environment (SGAV). Amounts in 2002- 2004 are interpolated.

Amount of nitrogen applied to soil from biomass treated in biogas plants (other than manure) is based on the energy production in the biogas plants given in PJ and N per PJ, subtracting the amount of N from NH_3 emission at the biogas plant itself and the amount of N from manure. Production in PJ is given in the annual energy statistics provided by the Danish Energy Agency (DEA, 2024) and N per PJ is estimated as a standard value of 9.4 tonne N per PJ based on an average of N in feedstock and energy production in2016-2019. Amount of NH_3 emission from the feedstock at the biogas plants used for subtraction in the calculation is reported in the waste sector Chapter 6.2.2.

Table 5.22 Activity data used to estimate NH_3 and NO_x from other organic fertiliser applied to soils, 1985-2023. Tonnes N.

	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Industrial waste	1 500	1 529	4 445	5 147	2 359	3 401	4 455	5 283	5 425	5 800	5 148
Other biomass	2.69	6.62	12.29	21.02	30.07	36.80	55.78	192.19	238.08	263.50	289.16
N applied on soil	1 503	1 536	4 457	5 168	2 389	3 438	4 511	5 475	5 663	6 064	5 437

Emission factor

The emission factor for NH_3 emission from other organic fertilisers applied to soils is based on the EMEP/EEA guidebook 2023, at 0.08 kg NH_3 per kg N applied.

The emission factor for NO_x is based on the EMEP/EEA guidebook 2023, at 0.04 kg NO_2 per N applied.

Emissions

Emission of NH_3 and NO_x from other organic fertiliser is shown in Figure 5.16. The emission follows the amount of N applied and has increased since 1985 mainly due to increase in 'other biomass'. The emission in 2023 amounted to 0.43 and 0.22 kt NH_3 and NO_x respectively.

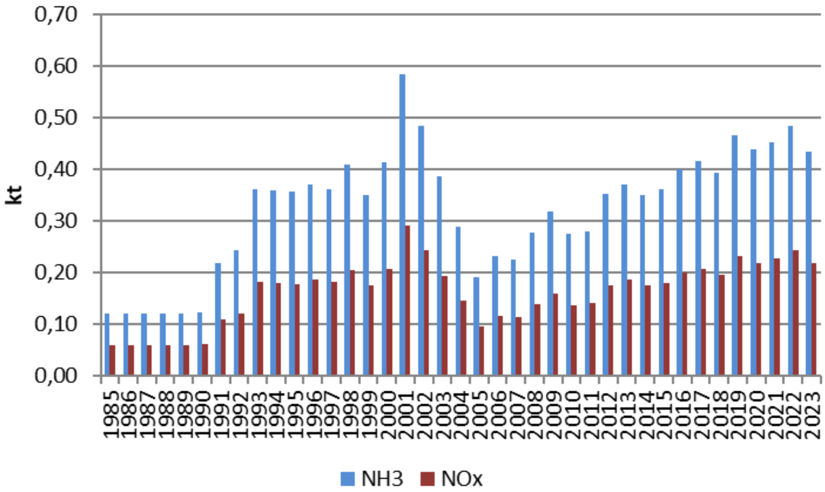

Figure 5.16 Emission of NH_3 and NO_x from other organic fertiliser, 1985-2023, kt.

5.4.5 Urine and dung deposited by grazing animals

Description

For the subsector, urine and dung deposited by grazing animals (3Da3) the emission of NH_3, NO_x and NMVOC are estimated. PM emission from grazing animals is considered as negligible.

Emission of NH_3 and NO_x from urine and dung deposit by grazing animals contributes in 2023 with 4 % and 4 %, respectively, of the emission from the agricultural sector.

NMVOC emission from urine and dung deposit by grazing animals contributes in 2023 with less than 1 %.

Methodological issues

NH_3

Emission of NH_3 from urine and dung deposited by grazing animals is based on N ex animal, for the number of feeding days on grass (see section 5.3.1) and the emission factor from EMEP/EEA Guidebook (2023). For the years 1985-2006 N ex animal and emission factors is based on total N, while for the years 2007-2023 N ex animal and emission factors for liquid manure is based on TAN. This is due to data for TAN ex animal from the normative figures are only available for the years 2007-2023 and only for liquid manure.

NO_x

Emission of NO_x from urine and dung deposited by grazing animals is as for NH_3 based on N ex animal, for the number of feeding days on grass (see section 5.3.1) and the emission factor from EMEP/EEA Guidebook (2023), but for NO_x emission it is based on N ex animal for all years because the emission factor is for N excreted.

NMVOC

Emission of NMVOC from urine and dung deposited by grazing animals is based on the Tier 2 method given in EMEP/EEA guidelines 2023 Chapter 3B Manure management but reported in sector 3Da3. The NMVOC emission is estimated on the number animals, the actual days on grass, gross energy for cattle and volatile solids (VS) for other animal categories.

Activity data

Number of animals and grazing days, both feeding and actual days are shown section 5.3.1. Number of animals in Table 5.5 and Annex 3D Table 3D-2 and for grazing days in Table 5.6 and Annex 3D Table 3D-3.

N deposit on grass based on TAN used for the calculation of NH_3 emission and based on total N used for NO_x emission are shown in Table 5.23.

Table 5.23 N deposit on grass, 1985-2023, kt N.

	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
N deposited for NH_3 emission[a]	40	37	35	34	26	17	14	14	14	14	13
N deposited for NO_x emission[b]	40	37	35	34	26	21	18	17	17	17	16

[a] 1985-2006 based on total N and 2007-2023 based on TAN.

[b] Based on total N all years 1985-2023.

For NMVOC, the activity data aside from number of animals and actual grazing days also include gross energy intake for cattle (Annex 3D Table 3D-19) and volatile solids (VS) for other animal categories (Annex 3D Table 3D-20). Gross energy intake and VS content are estimated based on normative figures for energy intake and amount of manure excretion, respectively.

Emission factor

NH_3

For cattle, swine, sheep, goats and horses, default emission factor from EMEP/EEA guidebook (2023) are used. For cattle and swine for the years 1985-2006, and for sheep, goats and horses for all years from 1985-2023, the emission factors are converted to total N by using proportion of TAN from EMEP/EEA guidebook (2023), see Table 5.24 below, as national data on TAN is not available. For deer, the same emission factor as for goats is applied. The emission factor for poultry is based on Misselbrook et al. (2000). Poultry droppings are more solid than urine from swine and cattle and therefore the droppings is staying on the top of the soil instead of soaking in to the soil. Emission from outdoor poultry is therefore considered to be higher than for swine (Jensen, 2019, pers. comm., Hansen, 2019, pers. comm.).

Table 5.24 Emission factors for NH3 emission from urine and dung deposited by grazing animals.

	Proportion of TAN[1]	EF default[1]	EF
		NH_3-N per TAN excreted	NH_3-N per total N excreted
Cattle	0.6	0.14[3]	0.084[4]
Swine	0.7	0.31[3]	0.217[4]
Sheep	0.5	0.09	0.045[5]
Goats	0.5	0.09	0.045[5]
Poultry	0.7		0.35[2]
Horses	0.6	0.35	0.21[5]

[1] EMEP/EEA guidebook (2023), Chapter 3B Table 3.9.
[2] Misselbrook et al. (2000). Used for the years 1985-2023.
[3] Used for the years 2007-2023.
[4] Used for the years 1985-2006.
[5] Used for the years 1985-2023.

NO_X

For the NO_x emission for all animal categories and all years, are the emission factor from the EMEP/EEA guidebook (2023) Chapter 3D Table 3.1 of 0.04 kg NO_2 per kg N used.

NMVOC

Default emission factors from EMEP/EEA guidebook (2023) (Chapter 3B Table 3.11 and 3.12) are used, see Table 5.25. For the animal categories without standard emission factors in the guidebook, no emission is estimated.

Table 5.25 Emission factor for NMVOC for urine and dung deposited by grazing animals (EMEP/EEA Guidebook 2023).

	EF NMVOC grazing
	Kg NMVOC per MJ feed intake
Dairy Cattle	0.0000069
Non-Dairy Cattle	0.0000069
	Kg NMVOC per kg VS excreted
Sheep	0.00002349
Swine – sows	
Swine – other	
Goats	0.00002349
Horses	0.00002349
Laying hens	
Broilers	
Turkeys	
Other poultry	
Fur bearing animals	

Emissions

The emission of NH_3, NO_x and NMVOC from urine and dung deposited by grazing animals has decreased by 50 %, 58 % and 68 %, respectively, from 1985 to 2023 and this is mainly due to a decrease in both number of dairy cattle and decrease in number days on grass for dairy cattle.

Table 5.26 Emission of NH_3, NO_X and NMVOC from urine and dung deposited by grazing animals, 1985-2023, kt.

	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
NH_3	4.53	4.17	3.99	3.91	3.16	2.57	2.28	2.39	2.35	2.34	2.26
NO_X	1.59	1.48	1.40	1.35	1.03	0.82	0.76	0.70	0.69	0.68	0.66
NMVOC	0.22	0.19	0.19	0.18	0.12	0.09	0.08	0.07	0.07	0.07	0.07

5.4.6 Farm-level agricultural operations including storage, handling and transport of agricultural products

Description

During agricultural operations such as soil cultivation, harvesting, cleaning, drying and transport emission of PM occur. In the EMEP/EEA guidebook are only method and emission factors for the farm-level agricultural operations (sector 3Dd) done in the field; that is soil cultivation, harvesting, cleaning and drying of the harvest.

The emission of PM as total suspended particles (TSP) from field operations contributes with 89 % of the total agricultural emission of TSP in 2023.

Methodological issues

The emission of PM from field operations is estimated based on the method given in EMEP/EEA Guidebook 2023 and calculated by the area of cultivated crops multiplied with number of operations and emission factor, for each crop type and type of operation.

Activity data

The areas of cultivated crops and number of operations for each crop type are used as activity data. The area of crops in hectares per crop type is estimated by Statistic Denmark in the statistic AFG5 (DSt, 2024) and the number of operations is based on budget estimates made by SEGES Innovation, the former Knowledge Centre for Agriculture (SEGES, 2024). Data are collected every third to fifth year.

See Annex 3D Table 3D-15 for hectares per cultivated crop and Annex 3D Table 3D-16a-16d for number of operations divided in soil cultivation, harvesting, cleaning and drying.

Emission factor

The emission factors used are given in Table 5.27 and they are based on the EMEP/EEA guidebook (EMEP/EEA, 2023) and van der Hoek (2007). The same emission factors are used for all years in the inventory.

Table 5.27 Emission factors for field operations, kg PM_{10}, kg $PM_{2.5}$ and TSP per ha.

PM_{10}	Soil cultivation	Harvesting	Cleaning	Drying
Wheat	0.25[a]	0.27[b]	0.19[a]	0.56[a]
Rye	0.25[a]	0.2[b]	0.16[a]	0.37[a]
Barley	0.25[a]	0.23[b]	0.16[a]	0.43[a]
Oat	0.25[a]	0.34[b]	0.25[a]	0.66[a]
Other arable	0.25[a]	0.26[c]	0.19[c]	0.51[c]
Grass	0.25[a]	0.25[a]	0[a]	0[a]
$PM_{2.5}$				
Wheat	0.015[a]	0.02[a]	0.009[a]	0.168[a]
Rye	0.015[a]	0.015[a]	0.008[a]	0.111[a]
Barley	0.015[a]	0.016[a]	0.008[a]	0.129[a]
Oat	0.015[a]	0.025[a]	0.0125[a]	0.198[a]
Other arable	0.015[a]	0.019[c]	0.009[c]	0.152[c]
Grass	0.015[a]	0.01[a]	0[a]	0[a]
TSP[d]				
Wheat	2.5	2.7	1.9	5.6
Rye	2.5	2	1.6	3.7
Barley	2.5	2.3	1.6	4.3
Oat	2.5	3.4	2.5	6.6
Other arable	2.5	2.6	1.9	5.1
Grass	2.5	2.5	0	0

[a] EMEP/EEA (2023).
[b] van der Hoek (2007).
[c] average of wheat, rye, barley and oat.
[d] PM_{10} multiplied by 10 (van der Hoek, 2007).

Emissions

The emission of PM_{10}, $PM_{2.5}$ and TSP is shown in Table 5.28. The emission of TSP has decreased 15 % from 1990 to 2023 due to a decrease in the area of cultivated crops and number of operations in the fields. A marked decrease is seen from 2001 to 2002 (see figure 5.3 in section 5.1.2) due to a decrease in number of soil cultivating treatments from 2001 to 2002 for many of the major crop types, such as wheat, barley, rye, oats, rape, fodder crops, grass and others (See Annex 3D Table 3D-16a-16d). This increases again from 2017 due to increase in number of soil cultivating treatments.

Table 5.28 Emissions of PM_{10}, $PM_{2.5}$ and TSP from farm and field operations, 1990-2023, tonnes.

	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
PM_{10}	6 681	6 082	6 058	5 231	5 438	5 599	5 851	5 884	5 827	5 659
$PM_{2.5}$	511	463	464	420	431	438	445	448	444	431
TSP	66 808	60 819	60 576	52 308	54 376	55 993	58 508	58 838	58 268	56 592

5.4.7 Cultivated crops

Description

For the sector, cultivated crops (3De) that cover emissions that arise from standing or cultivated crops the emission of NH_3 and NMVOC are estimated. No methodology is available for NO_x. PM emission are reported in sector 3Dd Farm-level agricultural operations including storage, handling and transport of agricultural products.

The Danish emission inventory includes NH_3 emission from crops, despite the relatively high uncertainties related to this emission source. Literature research shows that the volatilisation from crop types differs considerably across studies and depending on crop types. However, as for the emission ceiling given in the Gothenburg-Protocol and the EU NEC Directive the emission from crops as reported here is not taken into account.

Methodological issues

The emission for both NH_3 and NMVOC is calculated based on area of agricultural land with cultivated crops multiplied with the emission factors for each group of main crop types with available emission factors.

Activity data

Activity data on hectares per crop type are obtained from statistic AFG5 by Statistics Denmark (DSt), see Annex 3.D Table 3D-15.

Emission factor

NH_3

EF´s for crops are estimated to 2 % for crops and 0.5 % for grass based on a literary survey (Gyldenkærne and Albrektsen, 2009).

Table 5.29 EF used to estimate the emission of NH_3 from crops.

Crops	kg NH_3-N per ha
Cash crops, beets and silage maize	2
Grass/clover in rotation	0.5
Permanent grass	0.5
Set-a side	0

NMVOC

The calculation of the NMVOC emission is based on emission factors recommended in EMEP/EEA Guidebook 2023 Chapter 3D Table 3-5 for cultivation of wheat, rye, rape and grassland. A Tier 2 IEF is estimated corresponding to Danish yield level and dry matter content (DM) for these crop types. The emission from other crop types is not available in the Guidebook. However, the total NMVOC emission is estimated as the Tier 2 weighted IEF multiplied with the total cultivated area.

The NMVOC emission from cultivated crops is estimated to 1.90 kt in 2023 based on an IEF at 0.72 kg NMVOC per hectare and a cultivated area of 2 621 thousand hectares. The historic IEF varies annually from 0.51-0.82 kg NMVOC per hectare depending on the allocated extent of the four mentioned crop types. Higher allocation of rape and rye result in higher IEF due to a higher emission factor for these two crop types.

Table 5.30 Estimation of a Tier 2 NMVOC emission factor, 2023.

	EEA/EMEP, Emission factor	Fraction of year emitting	Total	Mean dry matter of crop	NMVOC EF	Cultivated area	NMVOC emission	Tier 2 DK
Crop	Kg NMVOC /kg DM		Kg/kg DM	kg DM/ha	Kg/ha	ha	Kg/ha	IEF, kg NMVOC/ha
Wheat	2.60E-08	0.3	6.82E-05	6 333	0.42	481 072	207 753	
Rye	1.41E-07	0.3	3.70E-04	4 760	2.02	107 602	189 587	
Rape	2.02E-07	0.3	5.30E-04	3 589	2.03	211 664	402 464	
Grass land*	1.03E-08	0.5	4.51E-05	5 894	0.30	479 415	127 485	
Total						1 279 753	927 290	0.72

*Grass (15 C) in Chapter 3D Table 3-5 in EMEP/EEA Guidebook 2023.

Emissions

Emissions of NH_3 and NMVOC are shown in Figure 5.17. Even though the area of agricultural annual crops has decreased the emission of NH_3 has increased by 6 % from 1985 to 2023 and the emission of NMVOC has increased by 1 %, due to changes in the distribution between crop types.

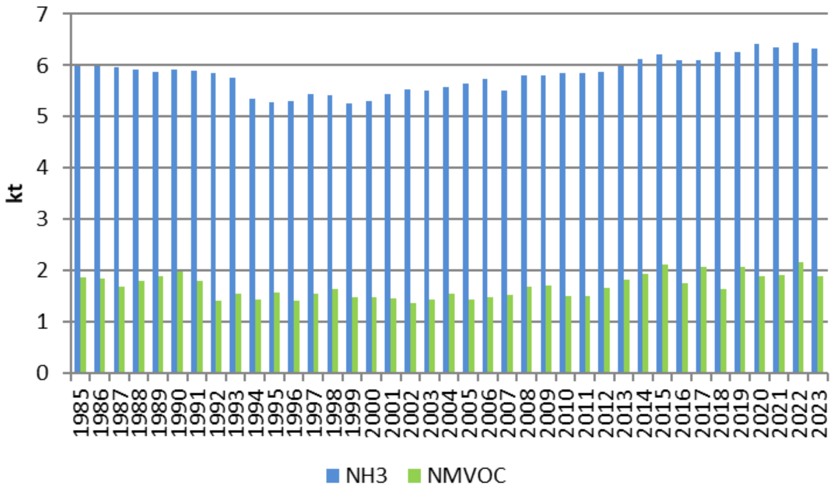

Figure 5.17 Emission of NH_3 and NMVOC from cultivated crops, 1985-2023, kt.

5.4.8 Crop Residue

Description

NH_3 emission from crop residues is a new emission source included in the EMEM/EEA Guidebook 2023 version. This emission is included for the first time in the Danish emission inventory and covered all years from 1985 to 2023. Crop residues are defined as those parts of the crop left on the soil surface following harvest and the ammonia emissions are related to the amount of N content of the residue left on the soil surface.

Methodological issues

The emission depending on the amount of N-content in crop residue above ground, which is estimated in the Danish greenhouse gas emission inventory (N-load). The N-content is estimated based on the Tier 1 methodology in the 2019 IPCC Guidelines. However, country specific estimates are used for crop yield and dry matter content. No estimates are given for vegetables in IPCC 2019 Refinement, therefore N-content in crop residues from vegetables are calculated based on data from Netherland (Ruijter and Huijsmans, 2019).

Besides the N-load the NH_3 emission also depending on how long time the crop residue is laying on the soil surface (F). Emission only takes place if the crop residues remain on the soil surface longer than three days after harvesting. For the first estimate calculation it is assumed that all crop residue laying longer than three days and thus contribute with NH_3 emission. For next submission laying time (F) separately for each crop residue will be considered.

Activity data

The N-content in crop residue above ground (N-load) given as kg N per hectare is calculated for each crop type. The cultivated area is based on information from Statistics Denmark and the total amount of N above ground is calculated in the Danish greenhouse emission inventory, where IPCC default values is used for slope, intercept and N-content per dry matter content (N_{AG}).

There exist no IPCC default values for vegetables. However, data for N-load for vegetables can be estimated based on values for N-content per dry matter content (N_{AG}) can be found in the Dutch paper (Ruijter and Huijsmans, 2019). Because the N-load values for vegetables are relatively high compared with other crop type it is considered as an important emission source in relation to the NH_3 emission. The Dutch data for vegetables is used in the Danish emission calculation, because production conditions between Danish and Dutch can be considered as comparable. For vegetables which is not listed in the Dutch paper, values for a similar vegetable are used. The Danish vegetables production is dominated by carrots, onions, peas for consumption, cabbage and lettuce, which contribute with approximately 70% of total. Table 5.31 shows the list of the crop types that contribute to NH_3 emissions.

Table 5.31 Values for N-load, 2023.

Above ground Residue	Cultivated area	Harvest	Dry matter fraction of harvest product (DRY)	Harvest	Slope	Intercept	Above-ground residue dry matter (AG_{DM})	Ratio of above-ground residue dry matter (R_{AG})	N content of above-ground residue (N_{AG}),	N in above ground residue (N-load)
	ha	M kg	kg DM/kg harvest	kg DM/ha		tonnes/ha	kg DM/ha	kg DM/kg DM	kg N/kg DM	kg N/ha
Potato	61 139	2 757	0.24	10 823	0.10	1.06	1 083	0.1	0.019	20.6
Alfalfa	480	16	0.21	7 000	0.29	0.00	2 030	0.3	0.027	54.8
Tubers	35 280	2 667	0.17	12 699	0.10	1.06	1 271	0.1	0.019	24.1
Non-N-fixing forages	21 453	264	0.41	5 040	0.30	0.00	1 512	0.3	0.015	22.7
N-fixing forages	21 453	264	0.34	4 179	0.30	0.00	1 254	0.3	0.027	33.9
Perennial grasses	167 654	3 161	0.25	792	0.30	0.00	238	0.3	0.015	3.6
Grass-clover mixtures, in rotation	361 030	9 017	0.25	6 255	0.30	0.00	1 877	0.3	0.025	46.9
Grass-clover mixtures, outside rotation	226 438	1 432	0.25	1 583	0.30	0.00	475	0.3	0.025	11.9
Vegetables	10 175						0.017-0.042*			0.8

* Data for N-content per dry matter content (N_{AG}) is based on values given in Ruijter and Huijsmans (2019) and varies between vegetable types.

Emission factor

The NH_3 emission factor given in the EEA/EMEP Guidebook is based on the paper from Ruijter and Huijsmans (2019), where a regression equation is provided on results from nine NH_3 measurements studies. Variables; N-concentration in crop residues (N_{AG}; N-content per dry matter) and laying time (F) is needed to estimate the NH_3 emission factor. The Dutch study shows that no NH_3 emission is expected if N_{AG} is lower than 0.0132 kg N per kg dry matter. Values for N_{AG} is based on the default values from IPCC 2019 Refinement, which shows that for cereal crops, maize and beans/pulses no NH_3 emission can be expected because the N_{AG} is lower than the limit of 0.0132 kg N per kg dry matter.

Table 5.32 NH_3 emission factors and NH_3 emission calculation, 2023.

	Area	Total N in residue above ground	N load	N content of above-ground residue (N_{AG})	Contributing fraction (F)	EF	Emission per ha	Emission
	ha	kg N	kg N/ha	kg N/kg DM		%	kg NH_3-N/ha	kt NH_3
Potato	61 139	1 258 515	20.6	0.019	1	2.37	0.49	0.04
Alfalfa	480	26 309	54.8	0.027	1	5.65	3.10	0.00
Tubers	35 280	851 953	24.1	0.019	1	2.37	0.57	0.02
Non-N-fixing forages	21 453	486 527	22.7	0.015	1	0.73	0.17	0.00
N-fixing forages	21 453	726 230	33.9	0.027	1	5.65	1.91	0.05
Perennial grasses	167 654	597 275	3.6	0.015	1	0.73	0.03	0.01
Grass-clover mixtures, in rotation	361 030	16 936 950	46.9	0.025	1	4.83	2.27	0.99
Grass-clover mixtures, outside rotation	226 438	2 688 987	11.9	0.025	1	4.83	0.57	0.16
Vegetables				0.017-0.042*				0.06
Total emission								1.33

* Data for N-content per dry matter content (N_{AG}) is based on values given in Ruijter and Huijsmans (2019) and varies between vegetable types.

Emissions

NH_3 emission depends on the N content above ground (N-load), which approximately follows development in area, but only approximately because N depends on yields in the individual years. Grass-clover and especially grass-clover in rotation is the main contributor and thus grass-clover covers 87 % of the total NH_3 emission in 2023.

From 1985 to 2023 the NH_3 emission has decreased, which is mainly driven by change in emission from grass-clover and mainly the fall in emission from grass-clover outside rotation. The main reason for lower emission from grass-clover outside rotation is due to more extensive cultivation of the fields, which lower the harvest yield. In attempt to reduce N-surplus to the environment (e.g. N-leaching), the farmers have the opportunity to use a varies of subsidy schemes for more extensive cultivation, where, for example, no fertilization or limited fertilization is allowed.

Table 5.33 NH_3 emission from crop residue, kt NH_3.

	1985	1990	1995	2000	2005	2010	2015	2020	2023
Potato	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.04
Alfalfa	0.02	0.05	0.05	0.04	0.03	0.04	0.02	0.01	0.00
Tubers	0.10	0.10	0.06	0.04	0.03	0.02	0.02	0.03	0.02
Non-N-fixing forages	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00
N-fixing forages	0.08	0.11	0.18	0.23	0.13	0.10	0.09	0.09	0.05
Perennial grasses	NO	NO	0.02	0.02	0.02	0.00	0.00	0.00	0.01
Grass-clover mixtures, in rotation	1.22	1.19	1.06	1.15	1.25	1.62	1.40	1.40	0.99
Grass-clover mixtures, outside rotation	0.56	0.58	0.52	0.44	0.39	0.38	0.49	0.27	0.16
Vegetables	0.12	0.10	0.08	0.06	0.05	0.06	0.06	0.07	0.06
Total emission	2.13	2.15	2.02	2.02	1.92	2.25	2.11	1.91	1.33

5.4.9 Use of pesticides

Description

A range of pesticides is used in the Danish agricultural sector and some of them contain Hexachlorobenzene (HCB), even though pure HCB used as pesticide is banned in EU as a part of the Stockholm Convention. HCB is a persistent organic pollutant, which is toxic to human and animal health but is used as the active substance in certain pesticides.

The emission of HCB from use of pesticides (sector 3Df) contributes with 11 % of the Danish total HCB emission in 2023.

Methodological issues

Emission of HCB from use of pesticides is based on amount of effectual substance used multiplied with the emission factors for each type of pesticides from the EMEP/EEA Guidebook 2023.

Activity data

A range of pesticides are used in Denmark. In the period from 1990 to 2023, six types of active substance containing HCB have been identified. These are atrazine, chlorothalonil, clopyralid, lindane, picloram and simazine. Data on amounts of effectual substance used in Denmark are collected from Danish Environmental Protection Agency (DEPA), see Table 5.34. The use of atrazine and lindane stopped in 1994 and the use of chlorothalonil and simazine ceased in 2000 and 2004, respectively.

Table 5.34 Amounts of active substance used in pesticides in Denmark, 1990-2023, kg.

	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023*
Atrazine	91 294	-	-	-	-	-	-	-	-	-
Chlorothalonil	10 512	10 980	7 340	-	-	-	-	-	-	-
Clopyralid	16 461	22 587	7 446	5 874	9 122	10 229	3 102	3 396	3 130	3 130
Lindane	8 356	-	-	-	-	-	-	-	-	-
Picloram	-	-	-	-	723	328	2 265	3 775	4 466	4 466
Simazine	30 234	19 865	23 620	-	-	-	-	-	-	-

*Same as 2022, due to lack of data.

Emission factor

Default emission factors from the EMEP/EEA Guidebook 2023 are used in the calculation of the emissions, see Table 5.35.

Table 5.35 Emission factors for HCB from pesticides, 1990-2023, g per tonnes.

	1990	1995	2000	2005	2010-2023
Atrazine	2.5	-	-	-	-
Chlorothalonil	300	300	40	-	-
Clopyralid	2.5	2.5	2.5	2.5	2.5
Lindane	100	-	-	-	-
Picloram	-	-	-	-	50
Simazine	1	1	1	-	-

- Not used in the given year in Denmark.

Emissions

Table 5.36 shows the emission of HCB from the use of pesticides for the years 1990-2023. The emission has decreased significantly from 1990 to 2023 due to a decrease in use of pesticides containing HCB following attention and legislation to phase out use of the chemical. See also Table 5.34 on specific substances. An increase is seen from 2016 to 2017, due to an increase in use of picloram.

Table 5.36 Emission of HBC from use of pesticides, 1990-2023, kg.

	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Pesticides	4.29	3.37	0.34	0.01	0.06	0.04	0.12	0.20	0.23	0.23

5.5 Field burning of agricultural residues

5.5.1 Description

Field burning of agricultural residues (3F) has been prohibited in Denmark since 1990 and may only take place in connection with production of grass seeds on fields with repeated grass seed production and in cases of wet or broken bales of straw.

A long range of emissions are included under the NFR category 3F: NH_3, NO_x, CO (carbon monoxide), NMVOC, SO_2, PM, BC (black carbon), heavy metals, dioxin, PAHs, HCB and PCB. The emission of NH_3, NO_x, NMVOC and TSP from field burning contributes in 2023 with less than 1 % of the agricultural emission of those pollutants. PM_{10} and $PM_{2.5}$ from field burning contributes with 1 % and 8 % of the agricultural PM_{10} and $PM_{2.5}$ emission. In 2023 the emission of BC, CO, SO_2, heavy metals, dioxin and PCB from field burning contribute with up to 2 % of the total national emission of those, while the emission of PAHs and HCB contribute with around 1-6 % of the national emission. From 1989 to 1990, all emissions decrease significantly due to the ban on field burning.

5.5.2 Methodological issues

Emissions from field burning of agricultural residues are calculated based on the amount of burnt straw given in tonnes dry matter and emission factors given in the EMEP/EEA guidebook (EMEP/EEA, 2023). See equation below:

$$E_{i,j} = A_j \cdot d_j \cdot Cf \cdot EF_i \qquad \text{Eq. (5.5)}$$

Where:

$E_{i,j}$ = Emission of pollutant *i*, kg
A_j = Amount of burnt residue *j*, kg
d_j = dry matter content of *j*, %
Cf = Combustion factor, %
EF_i = Emission factor for pollutant *i*, g per kg dry matter (see Table 5.37)

Types of burnt residue *j* are straw from grass seed production and from bales of wet straw. For straw from grass seed production, the dry matter content (d_j) is 20 % and for other straw it is 85 % (Møller et al, 2005) and the combustion factor for both is set by the guidebook at 90 % (EMEP/EEA, 2023).

5.5.3 Activity data

The amount of burnt straw from the grass seed production is estimated as 15-20 % of the total amount produced. The amount of burnt bales of wet straw is estimated as 0.1 % of total amount of straw. Both estimates are based on expert judgement by SEGES (Feidenhans'l, 2009, pers. comm.). The produced amounts are based on data from Statistics Denmark (DSt); grass seed production from the statistic FRO and straw from the statistic HAML1. See Annex 3D Table 3D-17 for activity data on burned amounts of both.

5.5.4 Emission factors

For most of the pollutants the default emission factors from the EMEP/EEA guidebook (EMEP/EEA, 2023) are used, but for PAH, HCB and PCB the emission factors are based on Jenkins (1996), Hübner (2001) and Black et al. (2012), respectively – see Table 5.37.

Table 5.37 EF for pollutants from field burning of agricultural residues.

Pollutant	EF	Unit
NO_x[1]	2.3	g/kg DM
CO[1]	66.7	g/kg DM
NMVOC[1]	0.5	g/kg DM
SO_x[1]	0.5	g/kg DM
NH_3[1]	2.4	g/kg DM
TSP[1]	5.8	g/kg DM
PM_{10}[1]	5.7	g/kg DM
$PM_{2.5}$[1]	5.4	g/kg DM
BC[1]	0.5	g/kg DM
PCDD/F[1]	500	ng TEQ/t
Pb[1]	0.11	mg/kg DM
Cd[1]	0.88	mg/kg DM
Hg[1]	0.14	mg/kg DM
As[1]	0.0064	mg/kg DM
Cr[1]	0.08	mg/kg DM
Ni[1]	0.052	mg/kg DM
Se[1]	0.02	mg/kg DM
Zn[1]	0.56	mg/kg DM
Cu[1]	0.073	mg/kg DM
Benzo(a)pyrene[2]	0.41	mg/kg DM
benzo(b)fluoranthene[2]	1.14	mg/kg DM
benzo(k)fluoranthene[2]	0.48	mg/kg DM
Indeno(1,2,3-cd)pyrene[2]	0.67	mg/kg DM
HCB (broken bales)[3]	0.003	g/tonnes
HCB (seed production)[3]	0.002	g/tonnes
PCB (broken bales)[4]	3	ng TEQ/t
PCB (seed production)[4]	0.05	ng TEQ/t

[1] EMEP/EEA (2023) Chapter 3F Table 3-1.
[2] Jenkins (1996).
[3] Hübner (2001).
[4] Black et al. (2012).

5.5.5 Emissions

All emission from field burning have decreased more than 90 % in the period from1985 to 2023, with the main reductions happening from 1985 to 1990 due to the ban of general field burning. See Annex 3D Table 3D-18 for emissions of all pollutants 1985 to 2023.

5.6 Agriculture other

The only emission source included in the Danish NFR sector 3I Agricultural other is NH_3 treated.

5.6.1 NH_3 treated straw

Description

Emission from NH_3 treated straw cover NH_3 from when NH_3 is used for conservation of straw for feeding. As for the emission ceiling given in the Gothenburg-Protocol and the EU NEC Directive the emission from NH_3 treated straw is not taken into account.

Methodological issues

Emissions are calculated as NH_3–N used for treatment of straw multiplied with a country specific emission factor.

Activity data

Information on NH_3 used for treatment of straw used to be collected directly from the suppliers, but from 2021 Agency for Green Transition and Aquatic Environment collect these data and make them available for the inventory. NH_3 treated straw has been prohibited since 2006, but each year exemptions are given in some areas due to particularly wet weather conditions.

Table 5.38 NH_3 treated straw 1985 to 2023, t NH_3-N.

	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Tonnes NH_3-N	8 300	12 936	8 421	3 131	329	200	200	200	306	104	9

Emission factor

Earlier investigations show that up to 80-90% of the supplied NH_3 (given in NH_3-N) can be lost as emissions (Andersen et al., 1999). However, the emissions can be reduced, particularly if the right dose is used. Based on expert judgement from the analysis (Andersen et al., 1999) the emission factor for all years in the inventory is set to 65 % of the applied NH_3-N.

Emissions

The development and reduction of the emission of NH_3 from NH_3-treated straw is shown in Figure 5.18.

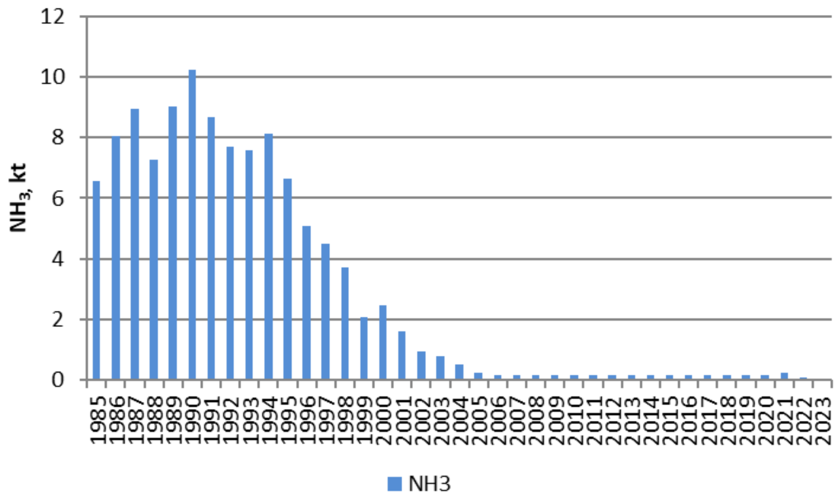

Figure 5.18 Emission of NH_3 from NH_3-treated straw, 1985-2023.

5.7 Uncertainties

Table 5.40 shows the estimated uncertainties for activity data and the emission factor for each pollutant along with the combined uncertainties and total uncertainties of results per pollutant. The provided uncertainties are sometimes based on expert assessments and may not necessarily apply to all sub-elements within a specific emission source. For several sources, this involves a complex assessment since neither activity data, nor the final emission factor is derived from a single dataset, as described in the following sections. When uncertainty estimates are provided by the data source, such as the EMEP/EEA guidebook, these are implemented.

The uncertainty analyses are conducted following Approach 1, as described in the IPCC "Guidelines for national greenhouse gas inventories" (2006), Volume 1, Chapter 31. Approach 1 is a simple and straightforward method for uncertainty analysis that relies on error propagation. Through error propagation it is assumed that there is an overlap between the different uncertainties, reducing the aggregated uncertainty at a higher level than the individual uncertainties alone. Approach 1 also assumes that data is normally distributed and works best with low uncertainties. Previously, more detailed work was done on uncertainty calculations related to the inventory using Approach 2 (Fauser et al., 2011)., which prescribes Monte Carlo simulations and is better suited for data with high uncertainties and different distributions (e.g., log-normal distribution). However, the results based on Approach 2 did not differ significant different from Approach 1 and thus an Approach 2 calculation is no longer carried out due to resource constraints.

5.7.1 NH_3

3B Manure management

It is defined that activity for manure management covers both the number of animals and barn type. The allocation of animals on different barn types determines if the manure is handled as slurry or solid manure.

The number of animals for the most important animal categories is estimated by Statistic Denmark. The uncertainties for the most important livestock categories are relatively low e.g. for swine and cattle the uncertainties are estimated to 1.3 % and 0.9 %, respectively. The uncertainty is higher for less important animal groups for the emissions, e.g. fur bearing animals (3.4 %), poultry, horses and sheep (10.4 %). The uncertainty for number of animals overall is estimated by Statistics Denmark to 2 %. The allocation of barn system is based on information from the farm nitrogen fertilizer budgets handled and controlled by the Agency for Green Transition and Aquatic Environment. Almost all farmers have to submit the information annually and the uncertainty is evaluated as relatively low.

The uncertainty for the activity data is thus a combination of low uncertainty in animal numbers and a relatively low uncertainty for barn type, which is assessed to result in an overall uncertainty of 5 %.

The uncertainty for the emission factor covers nitrogen excretion, grazing days and NH_3 emission factors from both barn and during storage of the manure. The Danish Normative System for animal excretions is based on data from SEGES Innovation, which is the central office for all Danish agricultural industry advisory services and DCA, Aarhus University. The database contains data on diet composition, feed utilisation and production parameters like milk yield, daily gain, pigs per litter, egg production, etc. The data represent more than 50 % of all dairy herds, and a higher proportion of all dairy cows. For slaughter calves' data represented about 60 % of the slaughtered animals. The swine values were based on 700.000 sows equivalent to 70 % of all sows, and the data from fattening pigs were based on 8.7 million pig equivalents to about 60 % of all pigs slaughtered in Denmark (Børsting, 2024). For poultry 80-90 % of the production and approximately 100 % of the fur production was covered. With the very large proportion of the cattle, swine and poultry farms yielding data to the database these data are considered to be very representative for Danish animal production. In the normative standards (Børsting & Hellwing, 2024) uncertainty values are indicated for emission measurements in barns and varies from 15 -25 %.

Regarding the uncertainties for the emission factor, it similarly has to be included that the emission comes from three different places in the livestock production; from manure in barn, from stored manure and from application of manure. The uncertainties for emission measurements in barn, which are the starting point for the normative standards varies from 15 -25 % (Poulsen et al., 2001). However, there is no specified uncertainty estimates for emission factors for storage and application of manure. The overall uncertainty value for NH_3 emission factor for manure management is assumed to be approximately 25 %.

3Da1 Inorganic fertilisers

The activity data for the emission from inorganic N-fertiliser depends on the amount of sold fertiliser and the N-content for each fertiliser type, which is based on information provided annually by Danish Agency for Agriculture and Fisheries. Uncertainty is considered to be low and set to 3 %, based on expert judgement.

No uncertainty values for the emission factor are given in the EMEP/EEA guidebook or the data set from the Danish Agency for Agriculture and Fisheries. An uncertainty value of 25 % is estimated based on an expert judgement. Some uncertainty in connection with reporting the consumption og inorganic fertilisers is unavoidable, but because of the registration itself and the control linked to the registration, this will in some extend ensure that data should be trustworthy. Serious registration errors will typically be revealed by trend analysis.

3Da2a Animal manure applied to soils

Besides the number of animals, the uncertainty for activity data covers N-excretion, grazing days and the NH_3 emission from barn and storage. It is assumed that the most important variables are the number of animals, which has a low uncertainty 2 %. However, the uncertainty is also affected by the other variables, which have a higher uncertainty estimate. Thus, the uncertainty for the activity data is assumed at around 15 %.

The emission factor uncertainty depends on the uncertainty regarding the information on application time, application technics and plant cover. The uncertainty of these is estimated to 25 %.

3Da2b Sewage sludge applied to soils

From 2005 and onwards, the amount of N applied from wastewater treatment is based on the fertiliser accounts controlled by the Danish Environmental Protection Agency, see also section 5.3.1. The uncertainty for the activity data is assumed to be 15 %.

The emission factor depends on the application of time, application technic and the climate conditions and the uncertainty is assumed relatively high – and set to 50 %.

3Da2d Other organic fertilisers applied to soils

The uncertainty is estimated to be at the same level as for sewage sludge applied to soils.

3Da3 Urine and dung deposited by grazing animals

The overall uncertainty for the activity is estimated to 5 %. Besides the number of animals, the uncertainty depends on number of grazing days.

Regarding the uncertainty for the emissions factor, this depends on the N excretion and the climate conditions as temperature, wind and precipitation. The uncertainty value is estimated to 25 %.

3Da4 Crop residue

The activity data for calculation of NH_3 emission from crop residues is mainly depending on the estimation of N-content in crop residues above ground. This emission is based on the same calculation as provided in the greenhouse gas emission inventory, where the uncertainty estimate is assumed to 25 %, which also is used in the current emission inventory. The NH_3 emission factor is based on a regression equation provided on basis of the Dutch paper covering NH_3 measurements from nine studies (Ruijter and Huijsmans (2019). The uncertainty value for the emission factors is assumed to 135 %

3De Cultivated crops

The activity data covers the cultivated area, which is based on data from Statistics Denmark. For the major crops, the uncertainty is relatively low – e.g. winter wheat it is 1.1 %. The overall uncertainty for the activity is estimated to 2 %. Knowledge concerning the emission is relatively limited and therefore the uncertainty of the emission factors is assumed to be 50 %.

3F Field burning of agricultural residues

An uncertainty of 25 % for the activity for field burning of agricultural residues is used. The uncertainty is a combination of the uncertainty for area of grass for seed production, which has a low uncertainty, amount of burned straw and yield, which have a high uncertainty. The uncertainties for the emission factor are based on the EMEP/EEA Guidebook (EMEP/EEA, 2023) and Jenkins et al. (1996), Hübner (2001) and Black et al. (2012).

3I Agriculture other

Under NFR category 3I emissions from NH_3 treated straw are reported. NH_3 treated straw was until 2006 commonly used as cattle feed. By law in 2006, the NH_3 treatment of straw was banned. However, in exceptionally wet weather conditions exemptions are given in some areas. The activity depends on the amount of ammonia used in the second half of the year, because it is expected that ammonia bought proposed the crop season will be used for NH_3 treated straw and is based on information from the Agricultural Agency. The uncertainty value is assumed to be 20 %. The uncertainty level for the emission factor is assumed to be 50 %.

5.7.2 PM

Uncertainty estimates on the activity data are estimated to 7 %. Besides the number of animals and barn type, also uncertainty related to the crop production cycles plays a role.

The activity data covers the cultivated crops and number of operations for each crop type. The area cultivated with each crop type is estimated by Statistic Denmark and the number of operations is based on budget estimates made by Knowledge Centre for Agriculture. The uncertainty of both is assumed to be 10 %.

The uncertainties for the PM emission factors have considered to be very high and especially for animal husbandry and manure management. The uncertainty estimates regarding the PM emission factors for manure management and farm level agricultural operations are based on the EMEP/EEA guidebook and set to 300 %.

5.7.3 Other pollutants

For both the NO_x and NMVOC emission, the activity data is based on the same input and data sources as mentioned in NH_3 chapter and therefore the same uncertainty estimates are used.

The uncertainty for the NO_x and NMVOC emission factors is based on expert judgment and is considered to be very high; 100 - 500 % based on the on the EMEP/EEA guidebook.

Emission of BC, CO, SO_2, heavy metals, dioxin, PAHs, HCB and PCB from the agricultural sector originates from field burning of agricultural residues. The uncertainty for activity data for these emissions is set to 25 % as a combination of the uncertainty for crop production, which is low and the uncertainty of the amount of burned straw, which is high. The uncertainties for the emission factors are based on EMEP/EEA guidebook. All uncertainties for field burning are relatively high.

The uncertainty for activity data for the emission of HCB from pesticides are estimated to 5 % and the uncertainty for the emission factor is relatively high at.

Table 5.39 Estimated uncertainty associated with activities and emission factors for the agricultural sector, 2023.

Compound	NFR sector	Emission	Activity data, %	Emission factor, %	Combined Uncertainty, %	Total Uncertainty, %
NH_3, kt	3.B Manure management	24.65	5	25	25	14
	3.Da1 Inorganic fertilisers	11.58	3	25	25	
	3.Da2a Animal manure applied	15.74	15	25	29	
	3.Da2b Sewage sludge applied	0.67	15	50	52	
	3.Da2c Other organic fertiliser	0.43	15	50	52	
	3.Da3 Deposited by grazing	2.26	5	25	25	
	3Da4 Crop residues applied	1.33	25	135	137	
	3.De Cultivated crops	6.32	2	50	50	
	3.F Field burning	0.04	25	50	56	
	3.I Agriculture other	0.01	20	50	54	
TSP, kt	3.B Manure management	6.65	7	300	300	270
	3.Dc Farm-level agri. operations	56.59	10	300	300	
	3.F Field burning	0.09	25	50	56	
PM_{10}, kt	3.B Manure management	2.29	7	300	300	228
	3Dc Farm-level agri. operations	5.66	10	300	300	
	3.F Field burning	0.09	25	50	56	
$PM_{2.5}$, kt	3.B Manure management	0.54	7	300	300	197
	3Dc Farm-level agri. operations	0.43	10	300	300	
	3.F Field burning	0.08	25	50	56	
NMVOC, kt	3 B Manure management	37.50	2	300	300	252
	3.Da2a Animal manure applied	5.86	15	300	300	
	3.Da3 Deposited by grazing	0.07	15	300	300	
	3.De Cultivated crops	1.90	5	500	500	
	3.F Field burning	0.01	25	100	103	
NO_x, kt	3.B Manure management	0.72	5	100	100	253
	3.Da1 Inorganic fertilisers	7.89	3	400	400	
	3.Da2a Animal manure applied	7.13	15	400	400	
	3.Da2b Sewage sludge applied	0.21	15	400	400	
	3.Da2c Other organic fertiliser	0.22	15	400	400	
	3.Da3 Deposited by grazing	0.66	5	400	400	
	3.F Field burning	0.04	25	25	35	
HCB, kg	3Df Use of pesticides	0.23	5	500	500	367
HCB, kg	3.F Field burning	0.13	25	500	501	
PCB, kg	3.F Field burning	<0.001	25	500	501	501
SO_2, kt	3.F Field burning	0.01	25	100	103	103
BC, kt	3.F Field burning	0.01	25	100	103	103
CO, kt	3.F Field burning	1.03	25	100	103	103
Pb, Mg	3.F Field burning	0.00	25	50	56	56
Cd, Mg	3.F Field burning	0.014	25	100	103	103
Hg, Mg	3.F Field burning	0.002	25	200	202	202
As, Mg	3.F Field burning	0.0001	25	100	103	103
Cr, Mg	3.F Field burning	0.00	25	200	202	202
Cu, Mg	3.F Field burning	0.001	25	200	202	202
Ni, Mg	3.F Field burning	0.001	25	200	202	202
Se, Mg	3.F Field burning	0.000	25	100	103	103
Zn, Mg	3.F Field burning	0.009	25	200	202	202
Dioxin, g I-Teq	3.F Field burning	0.03	25	500	501	501
Benzo(a)pyrene, Mg	3.F Field burning	0.01	25	500	501	501
Benzo(b)fluoranthen, Mg	3.F Field burning	0.02	25	500	501	501
Benzo(k)fluoranthen, Mg	3.F Field burning	0.01	25	500	501	501
Indeno(1,2,3 cd)pyrene, Mg	3.F Field burning	0.01	25	500	501	501

5.8 Quality assurance and quality control (QA/QC)

A general QA/QC and verification plan for the agricultural sector is continuously under development and will be improved and developed as deficiencies are identified and corrected. The objectives for the quality planning, as given in the CLRTAP Emission Inventory Guidebook, which is closely related to the IPCC Good Practice Guidance, are to improve the transparency, consistency, comparability, completeness, and confidence.

To ensure consistency a procedure for internal quality check is provided. Input of external data is checked, and certain time series have been prepared for both the activity data, the emission factors and implied emission factors, 1985 - 2023. The annual change for each emission source on activity is checked for significant differences and if necessary, explained. Considerable variation between years can reveal miscalculations or changes in methods. All checks of all activity data, emission factors, implied emission factors and other important key parameters are provided and archived in excel spread sheet format.

Activity data and emission factors are collected and discussed in cooperation with specialists and researchers at different institutes and research departments. Consequently, both data and methods are evaluated continuously according to latest knowledge and information. A more detailed description of quality assurance and quality control is given in Denmark´s National Inventory Document 2024 (Nielsen et al, 2024)- submitted under the United Nations Framework Convention on Climate Change (https://unfccc.int/sites/default/files/resource/Denmark%27s%20National%20Inventory%20Document%202024.pdf).

5.9 Recalculations

Compared with the previous submission (submission 2024) some changes and updates have caused historical changes in the NH_3, NO_x NMVOC and PM emissions, see Table 5.40. These changes cause increase in NMVOC and NO_x emission for all years (1985-2022) and both increase and decrease for the total NH_3 emission all years (1895-2022) and PM emission for the years (1990–2022).

Table 5.40 Changes in historical NH_3, NO_x NMVOC and PM emission in the agricultural sector compared to NFR reported last year.

NH_3 emission, kt NH_3	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022
2024 submission	166.60	156.85	127.65	109.01	93.98	85.19	80.84	80.52	72.92	70.64
2025 submission	162.36	153.17	125.17	107.70	93.08	84.96	80.16	79.35	71.99	69.47
Difference, %	-2.55	-2.35	-1.94	-1.20	-0.95	-0.28	-0.84	-1.44	-1.28	-1.66

NO_x emission, kt NO_x	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022
2024 submission	28.94	26.96	23.27	20.52	18.75	18.14	18.60	20.51	19.08	19.15
2025 submission	28.94	26.96	23.27	20.52	18.75	18.22	18.69	20.56	19.12	19.15
Difference, %	0.00	0.00	0.00	0.01	0.01	0.45	0.47	0.25	0.20	0.04

NMVOC emission, kt	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022
2024 submission	77.22	64.59	58.73	48.45	43.77	45.62	46.40	48.12	48.25	46.67
2025 submission	77.22	64.59	58.73	48.45	43.77	45.62	46.40	48.13	48.31	46.87
Difference, %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.43

PM emission, kt TSP		1990	1995	2000	2005	2010	2015	2020	2021	2022
2024 submission		75.02	69.70	69.64	61.47	63.97	62.04	64.23	64.32	63.49
2025 submission		73.45	68.05	67.84	59.63	61.70	63.13	66.20	66.54	65.71
Difference, %		-2.09	-2.37	-2.59	-2.99	-3.56	1.76	3.06	3.44	3.49

5.9.1 NH_3

A range of changes is made for the emission of NH_3, and this has decreased the overall emission from agriculture with 0.1-2.6 % for the years 1985-2008, 2010-2013 and 2015-2022. In 2009 and 2014 the emission is increased 0.1 % compared to submission 2024. Recalculations for the subcategories are mentioned below. The main explanatory factors are changes related to 3Da1 Inorganic N-fertilisers, and the new source 3Da4 Crop residues applied to soils.

3B Manure management

For emissions from manure management, some changes have been made, and it decreases the emissions in 2005-2009 by up to 0.01 % and increases the emission by up to 0.4 % in 2012-2022 compared to submission 2024.

The effect of heat exchange in barns for broilers has been decreased from 30 % to 28 % due to updated information of the reduction factor (SGAV, 2024b). This affects the emission for the years 2012-2022.

For the barn type boxes with sloping bedded floor the manure type has been changed from slurry to deep litter, because this better match the type of manure (Kai, 2024). This affects the emission for the years 2005-2009.

Changes in number of fattening pigs (2021-2022) and number of bulls (2018, 2021-2021) has been made due to updated data.

3Da1 Inorganic N-fertilisers

The emission factors given in EMEP/EEA Guidebook 2023 are given in kg NH_3 per kg N, by a mistake it has been used as NH_3-N in the calculations. To correct this, the emission factors from EMEP/EEA Guidebook 2023 are to this year's submission therefore converted to NH_3-N.

For the years (2009-2016, 2018) the total amount of N from inorganic N fertiliser are based on the Danish fertiliser N accounts, while in remaining years the total amount of N is based on sales statistics. For the years with data from the sales statistics are estimated that 1 % are used in private gardens. This is not included in the data from the Danish fertiliser N accounts. So, for the years 2009-2016 and 2018 1 % of N given in the Danish fertiliser N accounts are added.

The emission of NH_3 from inorganic N fertiliser are reduced by 17-18 % for all years 1985-2022.

3Da2a Animal manure applied to soils

Emission from animal manure applied to soils has been recalculated for the years 2005-2009 and 2012-2022 due to range of changes, which decreases the emission for the years 2005-2009, 2012-2013 and 2015-2020 with less than 0.02 % and increase the emission in 2014 with 3 % and for the years 2021-2022 with 0.2-0.3 %.

For 2014 an error in the emission factor for swine slurry applied to soil have been corrected.

The effect of heat exchange in barns for broilers has been decreased from 30 % to 28 % due to updated information of the reduction factor (SGAV, 2024b). This affects the amount of N applied to soil and thereby the emission for the years 2012-2022.

For the barn type boxes with sloping bedded floor the manure type has been changed from slurry to deep litter, because this better match the type of manure (Kai, 2024). Therefore, the emission factor for manure from these barns are changed and this affects the emission for the years 2005-2009.

Changes in number of fattening pigs (2021-2022) and number of bulls (2018, 2021-2021) has been made due to updated data.

3Da2b Sewage sludge applied to soils

A recalculation of NH_3 is made for the years 2018-2022 due to updated values from statistics, increasing emissions with 1-21 % in 2018-2021 and decreases the emission with 12 % in 2022.

3Da2c Other organic fertilisers applied to soils

The amount of N from other organic fertiliser from biomass from the biogas production are affected of the emission of NH_3 from the biogas production site, where emissions are reported in the waste sector. A recalculation has been made in the waste sector for all years which gives changes for N applied as fertiliser in the agricultural sector.

No recalculations of emission from sludge from industries.

Emission from other sources is increased for all years (1985-2022) by 0.04-0.9 %.

3Da3 Urine and dung deposited by grazing animals

The emission of NH_3 from grazing animals has been recalculated for the years 2007-2009 and 2021-2022. The emission decreases by 0.1 % in 2007-2009 and increases by 0.01 % in 2021-2022.

For 2007-2009 the change of manure type for animals in boxes with sloping bedded floor changes the emission factor for manure deposited during grazing. The manure type has for these barns been changed from slurry to deep litter, because this better match the type of manure (Kai, 2024).

Changes in emission for 2021-2022 is due to changes in number of organic fattening pigs made due to updated data.

3Da4 Crop residues applied to soils
In the EMEP/EEA Guidebook 2023 method for NH_3 emission from crop residues are included. This have now been included in the Danish inventory and contribute with around 1 100-2 000 tonnes NH_3 per year for all years 1985-2022.

3De Cultivated crops
No recalculations.

3F Field burning of agricultural residues
Recalculations have been made for the year 2022 due to updated activity data from Statistics Denmark, resulting in a negligible decrease of 0.2 %.

3I Agriculture other
No recalculations.

5.9.2 NO_x

Emission of NO_x has been recalculated for the years 1985-2022 and increases the emission up to 0.6 % in 1985-2021 and decreases the emission with 0.001 % in 2022. Recalculations for the subcategories are mentioned below.

3B Manure management
For the emission of NO_X recalculations are seen for 1990-2022 which increases the emission with 0.01-0.5 %. This is mainly due to correction of an error in the calculation for barns with biogas treated manure. The changes in manure type for the barn type boxes with sloping bedded and changes in number of animals - fattening pigs in 2021-2022 and bulls 2018 and 2020-2022 - also affect the emission of NO_X.

3Da1 Inorganic N-fertilisers
For the years (2009-2016, 2018) the total amount of N from inorganic N fertiliser are based on the Danish fertiliser N accounts, while in remaining years the total amount of N is based on sales statistics. For the years with data from the sales statistics are estimated that 1 % are used in private gardens. This is not included in the data from the Danish fertiliser N accounts. So, for the years 2009-2016 and 2018 1 % of N given in the Danish fertiliser N accounts are added. This result in an increase in the emission of NO_X of 1 %.

3Da2a Animal manure applied to soils
Emission from animal manure applied to soils has been recalculated for the years 2005-2009 and 2012-2022. The changes increase the emission with less than 0.001 % for the years 2005-2009 due to the changes in manure type for the barn type boxes with sloping bedded. For 2012-2020 change in the effect of heat exchange in barn for broilers mentioned above decrease the emission from manure applied by up to 0.004 %. For 2021-2022 the emission increase by 0.3 % mainly due to change in number of animals.

3Da2b Sewage sludge applied to soils
A recalculation of NO_X is made for the years 2018-2022 due to updated values from statistics, increasing emissions with 1-21 % in 2018-2021 and decreases the emission with 12 % in 2022.

3Da2c Other organic fertilisers applied to soils
The amount of N from other organic fertiliser from biomass from the biogas production are affected of the emission of NH_3 from the biogas production site, where emissions are reported in the waste sector. A recalculation has been made in the waste sector for all years which gives changes for N applied as fertiliser in the agricultural sector.

No recalculations of emission from sludge from industries.

Emission from other sources is increased for all years (1985-2022) by 0.04-0.9 %.

3Da3 Urine and dung deposited by grazing animals
Changes in emission of NO_X from grazing animals is seen for 2021-2022, this is due to changes in number of organic fattening pigs made due to updated data.

3F Field burning of agricultural residues
Recalculations have been made for the year 2022 due to updated activity data from Statistics Denmark (Statistics Denmark, 2024).

5.9.3 NMVOC

Recalculations of NMVOC has given changes in the emission for the years 2005-2009 and 2012-2022 of less than 0.5 % compared with submission 2024. Recalculations for the subcategories are mentioned below.

3B Manure management
For emission of NMVOC from manure management are seen recalculations for the years 2005-2009, 2012-2022. The emission of NMVOC is affected by changes in NH_3 emission. The emission decreases in 2005-2009, 2012-2017 and 2019 with less than 0.01 %. In 2018 and 2020 the emission increases with less than 0.01 % and in 2021-2022 increases with 0.03-0.04 %. The changes are due changes in manure type for the barn type boxes with sloping bedded floor and changes in number of animals - fattening pigs in 2021-2022 and bulls 2018 and 2020-2022. Furthermore, are there changes in NH_3 emission for broilers.

3Da2a Animal manure applied to soil
Emission of NMVOC from manure applied to soil are recalculated for the years 2005-2009 and 2012-2022. The emission decreases less than 0.01 % for the years 2005-2006 and increases 0.02 % in 2007-2009 due to changes in manure type for the barn type boxes with sloping bedded floor. In 2012-2013 and 2015-2020 the emission changes with less than 0.001 % due changes in NH_3 emission for broilers and change in number of bulls (2018 and 2020). In 2014 NMVOC emission increases 2 % due to an error corrected for the NH_3 emission for manure applied to soil. For 2021-2022 the emission increases with 0.1 % due to changes in number of bulls and fattening pigs.

3Da3 Urine and dung deposited by grazing animals
No recalculations.

3De Cultivated crops

The emission of NMVOC from cultivated crops increases with 2-9 % in 2021-2022 due to updated data on yield from Statistics Denmark (Statistics Denmark, 2024).

3F Field burning of agricultural residues

Recalculations have been made for the year 2022 due to updated activity data from Statistics Denmark (Statistics Denmark, 2024).

5.9.4 PM

Emission of PM is recalculated for all years 1990-2022 and it has changed the emission of PM_{10}, $PM_{2.5}$ and TSP. Recalculations for the subcategories are mentioned below.

3B Manure management

Emission of PM has been recalculated for the years 2005-2009, 2018 and 2020-2022. In 2005-2009 due to changes in manure type for the barn type boxes with sloping bedded floor and in 2018 and 2020-2022due to changes in number of bulls (2018, 2020-2022) and fattening pigs (2021-2022). The emission decreases with less than 0.01 % in 2005-2009 and increases with up to 0.03 % in 2018 and 2020-2022.

3Dc Farm-level agricultural operations

A review of the data for number of operations in the fields have been made, which lead to changes in mainly numbers for soil cultivations. This decreases the emission in 1990-2013 by 2-4 % and increases the emission by 1-5 % in 2014-2022.

3F Field burning of agricultural residues

Recalculations have been made for the year 2022 due to updated activity data from Statistics Denmark (Statistics Denmark, 2024).

5.9.5 HCB

The emission of HCB for 2022 has been recalculated due changes in for both pesticides and field burning. The changes increase the total emission of HCB from agriculture with 9 %.

3Df Use of pesticides

Recalculations of HCB from use of pesticides have been recalculated for 2022. For submission 2024 of NFR no data were available for the use of pesticides in 2022, and the use were set to the same level as in 2021. Now data for the use of pesticides for 2022 are available and the emission is recalculated. This increases the emission of HCB from use of pesticides with 17 %.

3F Field burning of agricultural residues

Recalculations have been made for the year 2022 due to updated activity data from Statistics Denmark (Statistics Denmark, 2024).

5.10 Planned improvements

Reduction of emission because of using NH_3 reducing technologies as acidification, cooling of slurry, heat exchanger (broilers) and frequent removal of manure (mink) in barns, has been implemented in the emission inventory.

Other NH_3 reducing technologies will be considered as soon as activity data and NH_3 reduction potential is available and documented. The remaining relevant NH_3 reducing technologies could be using of air scrubbers in swine barn or frequent removal of manure for hen's barn.

The Danish normative system for N-excretion and NH_3 emission is planned to be extended, to also include carbon and CH_4 emission and in this work the N-excretion through the system will also be evaluated. The project is expected to finish in 2027. When results are available, they will be incorporated in the Danish emission inventory as far as possible.

In calculation of NH_3 emission from crop residues an F-factor is needed, which reflects how long time the crop residue is laying on the soil surface, because emission only takes place if the crop residues remain on the soil surface longer than three days after harvesting. For the first estimate calculation it is assumes that all crop residue laying longer than three days and thus contribute with NH_3 emission. For next submission the F-factor must be estimated for each crop residue.

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6 Waste

6.1 Overview of the sector

The waste sector consists of the following five main NFR categories:

- Solid waste disposal (NFR 5A)
- Biological treatment of solid waste (NFR 5B)
- Incineration and open burning of waste (NFR 5C)
- Wastewater treatment and discharge (NFR 5D)
- Other waste (NFR 5E)

Table 6.1.1 below shows the relevant NFR codes for the waste sector and an indication of which sources are included in the Danish inventories.

Table 6.1.1 Overview of NFR sectors.

NFR code	SNAP name	Included
5A	Managed Waste Disposal on Land	Yes
5A	Unmanaged Waste Disposal Sites	NO
5A	Other	NO
5B1	Compost production	Yes
5B2	Biogas production	Yes
5C1a	Incineration of domestic or municipal wastes	NO*
5C1bi	Incineration of industrial wastes	NO*
5C1bii	Incineration of hazardous waste	NO*
5C1biii	Incineration of clinical waste	NO*
5C1biv	Sewage sludge incineration	NO*
5C1bv	Incineration of corpses and carcasses	Yes
5C2	Open burning of wastes	NE
5D2	Industrial wastewater treatment and effluent	Yes
5D1	Domestic wastewater treatment and effluent	Yes
5D3	Other wastewater handling	NO
5E	Other waste: Accidental fires	Yes

NO: Not occurring, NE: Not estimated (negligible), *Incineration with energy recovery is not included in the waste sector, please refer to Chapter 3.2 for information on energy production.

Incineration of waste (municipal, industrial, clinical, and hazardous) in Denmark is done with energy recovery and therefore the emissions are included under the relevant sectors under NFR sector 1A. The documentation for waste incineration is included in Chapter 3.2 Stationary combustion.

Sludge from wastewater treatment plants is only spread on agricultural land. Emissions that derive from this activity are included in Chapter 5.

6.2 Solid waste disposal

Major emissions from landfills are emissions of greenhouse gases. Particulate matter (PM) emissions are emitted from waste handling and small quantities of NMVOC and NH_3 may be released as well. This report includes emissions of NMVOC, TSP, PM_{10} and $PM_{2.5}$. NH_3 is acknowledged by the EMEP/EEA air pollutant emissions inventory guidebook (EEA, 2023) as applicable, but no default or country specific emission factor is available. For information on greenhouse gasses emissions (i.e. CH_4), please refer to Nielsen et al. (2024).

Methodology

Emissions of NMVOC are estimated using the Tier 1 methodology from EEA (2023), while PM emissions from waste handling at solid waste disposal sites are calculated according to the Tier 3 emission modelling and use of facility data as described in EEA (2023).

For a more comprehensive description on landfills in Denmark over time and the regulatory framework, please refer to Hjelgaard and Nielsen (2023).

Activity data

For the purpose of calculating particulate matter emissions from operations associated with depositing waste at landfills, the annual amount of deposited waste at solid waste disposal sites was applied, while for the calculation of the emissions of NMVOC, the CH_4 emission at the Danish landfills was applied as activity data. Figure 6.2.1 illustrates the total deposited amounts of waste and the methane emissions; these data are also presented in Annex Table 3E-1.1.

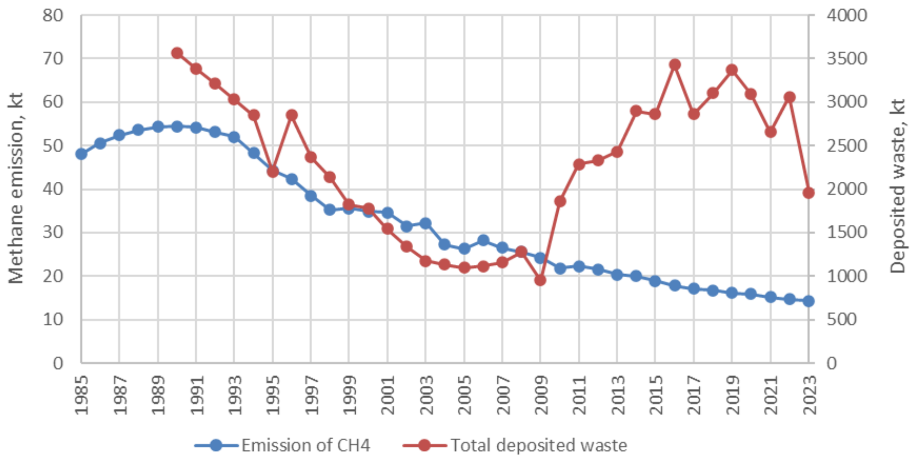

Figure 6.2.1 Activity data for calculating NMVOC and PM emissions from solid waste disposal sites.

Emission factors

For NMVOC, the default Tier 1 value of 3.6 kg per tonne methane is applied (EEA, 2023). For the particle emissions, the emission factors are derived following the Tier 3 methodology (EEA, 2023) using equation 6.2.1:

$$E = k(0.0016)\frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \quad \text{Eq. 6.2.1}$$

where *k* is the particle size multiplier, *U* is the average wind speed where Denmark uses the country specific value of 4.7 m/s based on daily Danish measurements in the period 2011-2023 (Annex Table 3E-1.2), and *M* is the moisture content for municipal solid waste, which was set equal to the default value of 11 % (EEA, 2023). An overview of parameters and resulting emission factors, *E*, are provided in Table 6.2.1.

Table 6.2.1 Input parameters to Equation 6.2.1 and resulting emission factor values for TSP, PM_{10} and $PM_{2.5}$.

Parameter	Description	Unit	Value
*M**	Moisture content	%	11
*U***	Mean wind speed, 2011-2023	m/s	4.7
	TSP		0.74
*K**	PM_{10}		0.35
	$PM_{2.5}$		0.053
	E(TSP)	g/t	0.29
E	E(PM_{10})	g/t	0.14
	E($PM_{2,5}$)	g/t	0.02

*default values from EEA (2023), Part B, 5.A SWDS, Chapter 4.3, pages 7-8.

**Annex Table 3E-1.2.

Emissions

Table 6.2.2 shows the total national emissions from waste handling at solid waste disposal sites. The full time series is shown in Annex Table 3E-1.3.

Table 6.2.2 National emissions from waste handling at solid waste disposal sites.

	Unit	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
NMVOC	t	172.9	196.1	159.4	125.6	94.6	78.5	68.1	57.4	52.7	51.4
TSP	t		1.03	0.64	0.52	0.32	0.54	0.83	0.90	0.89	0.57
PM_{10}	t		0.50	0.31	0.25	0.15	0.26	0.40	0.43	0.43	0.27
$PM_{2.5}$	t		0.07	0.05	0.04	0.02	0.04	0.06	0.06	0.06	0.04

The NMVOC emissions follow the decreasing methane emissions and are therefore also decreasing throughout the time series. Organic waste is not generally deposited in Denmark in modern times, but since methane emissions are calculated according to the first order decay model, methane emissions from organic waste deposited decades ago still occur. For more information on the methane emissions, please refer to Hjelgaard and Nielsen (2023).

For particulate emissions, the emissions fluctuate with the total amount of waste landfilled, a big part of which is soil, sand and stone that varies greatly from year to year.

6.3 Biological treatment of solid waste

This sector covers two activities: composting and anaerobic digestion at biogas facilities. These are described in more detail below.

6.3.1 Compost production

This section covers the biological treatment of solid organic waste called composting. Pollutants that are emitted during composting are CO and NH_3. In addition, CH_4 and N_2O emissions are covered by Nielsen et al. (2024) and are not included in the present report.

Methodology

Emissions from composting have been calculated according to a Tier 2 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,
- And, use of raw compost.

Composting facilities are categorised in three types. Type 1, treating organic waste mixed with garden waste or other organic waste, Type 2, treating only garden waste and Type 3, treating garden waste mixed with sludge and/or other organic waste.

Table 6.3.1 Composting facilities distributed as the different types.

	1997	2001	2017
Type 1	16	16	9
Type 2	99	123	150
Type 3	11	10	10
Total	126	149	169

According to Petersen & Hansen (2003), 92 % of Danish composting facilities consist entirely of windrow composting. Windrows are a simple technology composting method with access to only natural air. It is assumed that all facilities can be considered using windrow composting.

Composting is performed with simple technology in Denmark; this implies that temperature, moisture, and aeration are not consistently controlled or regulated. Temperature is measured but not controlled, moisture is regulated by watering the windrows in respect to weather conditions and aeration is assisted by turning the windrows (Petersen & Hansen, 2003).

During composting, a fraction of the degradable organic carbon (DOC) in the waste material is converted into CO. Even though the windrows are occasionally turned to support aeration, anaerobic sections are inevitable and will cause emissions of CH_4. In the same manner, aerobic biological digestion of N leads to emission of N_2O and NO_x, while the anaerobic decomposition leads to the emission of NH_3 (IPCC, 2006).

The category "use of raw compost" covers the use of garden waste for soil improvement in agriculture. Part of the garden waste that enters the Danish composting sites, is sold to farmers before composting. The raw compost (i.e. finely divided garden waste) is typically collected in large piles from spring till autumn. These piles are not monitored, watered, or aerated. Raw compost is then spread on the fields and ploughed into the soil. As this practise has no fertilising effect, there are no obligations for registration of this practise by the farmer. There is also no central registration of garden waste sold before composting by the composting sites, only incoming amounts. Work was done in the recent years, to improve the knowledge on this practice. DEPA (2022) and a following (unpublished) survey provides data on the activity data and DEPA (2023a) improves knowledge on practises and emission factors for the handling of raw compost in agriculture. No significant difference in the emission factors from the temporary storage and regular composting was found, and all though activity data for garden waste is divided into garden waste for composting and raw compost, the emission factors applied for these two categories are the same. As the greenhouse gasses emitted from raw compost are emitted during the temporary storage (where anaerobic conditions occur), and not on the fields, emissions from this practise are included in this chapter.

Activity data

All Danish waste treatment plants are obligated to statutory registration and reporting of all waste entering the plants. All waste streams are weighed, categorised with a waste type and a type of treatment, and registered to the national waste data system. For 1995-2009, Denmark used the ISAG waste information system, but since 2010, registration of waste data has gone into the ADS reporting system. Data from the ADS database is however not applied for 2010, as this first data year is clearly incomplete. Activity data for home composting and the share of garden waste (raw compost) used for soil improvement on agricultural fields are estimated separately.

Activity data for each composted waste type are presented in Table 6.3.2, and for the whole time series, in Figure 6.3.1 and Annex Table 3E-2.1.

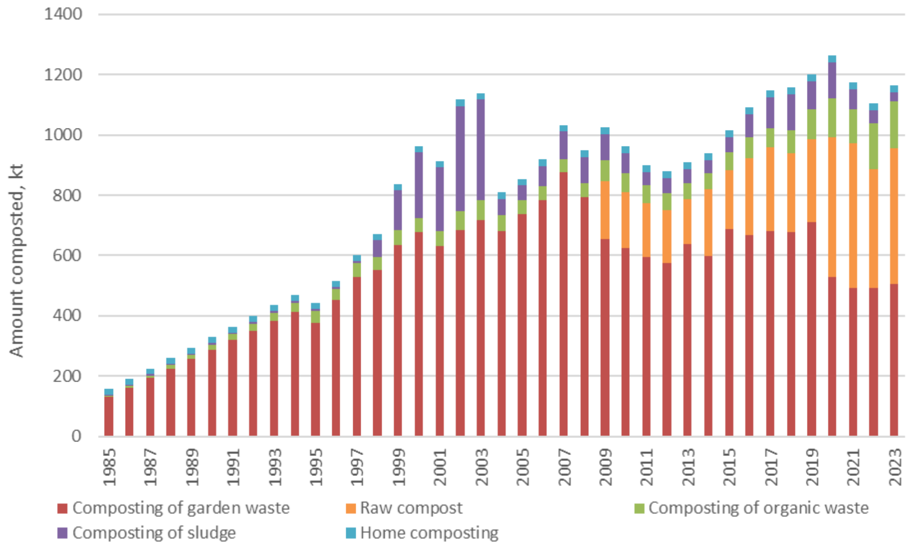

Figure 6.3.1 Trends in the national amount of composted waste, these data are also shown in Table 6.3.2.

Table 6.3.2 Activity data composting, kt.

	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
Composting of garden waste	130	288	376	677	737	626	687	530	492	507
Raw compost	NO	NO	NO	NO	NO	184	196	462	394	447
Composting of organic waste	5	16	40	47	45	64	60	129	152	158
Composting of sludge	4	5	7	218	50	65	49	118	42	29
Home composting	19	20	21	21	22	23	23	24	24	24
Total	158	329	444	963	854	961	1015	1263	1104	1166

NO: Not occurring

Garden waste

Activity data for garden waste for the years 1995-2009 are collected from the Danish waste statistics (DEPA, 2023b).

The ISAG activity data (1995-2009) for composting of garden waste include wood chipping. Compost data for garden waste provided by Petersen (2001) and Petersen & Hansen (2003) show that for 1997-2001, wood chipping accounts for about 3 % of the total chosen waste statistics activity data for garden waste. Activity data for garden waste for the years 1985-1994 are estimated by extrapolating the trend.

Activity data for 2011-2023 for composting of garden waste are available from DEPA (2024a). Activity data for 2010 are interpolated between 2009 and 2011.

Raw compost

To determine how much garden waste is used for soil improvement, a survey was carried out during 2023 by the Danish EPA. The respondents correspond to 25%-38% (average 30%) of the total garden waste handled commercially and it was found that this practice is only relevant for the years since 2009.

Between 19 % (2013) and 50% (2021) of garden waste was found to be used in agriculture and not composted at composting sites. The appliance of raw compost in agriculture is generally higher in 2020-2022 (44-50%) than in 2009-2019 (19-29%). For 2023, the average share from 2020-2022 of 47 % is used.

Organic waste

Activity data for composting of organic waste from households and other sources for the years 1995-2009 are collected from the Danish waste statistics (DEPA, 2023b).

Activity data for 2011-2023 are available from DEPA (2024a) and data for 2010 are interpolated between 2009 and 2011.

The amount of organic waste composted in the years 1985-1994 is estimated using surrogate data. The number of facilities treating organic waste is known for the years 1985-2001, and the average amount of organic waste composted per facility is known for the years 1995-2001 (2.6-3.8 kt per facility per year). The following Table 6.3.3 shows the number of composting sites divided in the three types, where type 1 is mainly receiving source separated organic waste, type 2 receives only garden waste, while type 3 receives garden waste in combination with other organic waste types (Petersen, 2001 and Petersen & Hansen, 2003).

Table 6.3.3 Number of composting facilities in the years 1985-2001.

Facility type	1985	1987	1989	1991	1993	1995	1996	1997	1998	1999	2000	2001
Type 1	**2**	**3**	**4**	**6**	**8**	13	14	13	14	13	11	9
Type 2	**6**	**14**	**22**	**54**	**86**	113	108	99	102	111	115	123
Type 3	**0**	**0**	**0**	**2**	**3**	9	9	11	10	10	7	10
Total	**8**	**17**	**26**	**62**	**97**	136	133	123	130	139	138	142

Type 1 waste treatment sites normally include biogas-producing facilities, but these have been excluded in this table.

Sludge

Activity data for the years 1995-2009 and 2011-2021 are collected from the Danish waste statistics (DEPA, 2023b). For sludge, activity data in the period 1988-1994 were interpolated based on sludge known to be composted in 1987 (DEPA, 1999) and 1985-1986 is set equal to 1987. 2010 is interpolated between 2009 and 2011. Composting data for 2022-2023 were collected from DEPA (2024a).

The Danish legislation on sludge (MIM, 2006) was implemented in the summer of 2003. This stated that composted sludge must only be used as a fertilizer on areas not intended for growing foods of any kind for at least 2-3 years. This restriction caused the amount of composted sludge to drop drastically from 2003 to 2004.

Home composting

The last waste category involved in composting is home composting of garden waste and vegetable waste. The activity data for this category are known from Petersen & Kielland (2003) to be 21.4 kt in 2001. It is assumed that the following estimates made by Petersen & Kielland (2003) are valid for all years in the time series.

- 28 % of all residential buildings with private gardens (including summer cottages) are actively contributing to home composting.
- 14 % of all multi-dwelling houses are actively contributing to home composting.
- On average, 50 kg waste per year will be composted at every contributing residential building.
- On average, 10 kg waste per year will be composted at every contributing multi-dwelling house.

Multi-dwelling houses include apartment buildings. It is quite un-common for people in these types of buildings to compost their bio waste and the average amount of composted waste is therefore lower despite the higher number of residents. The total number of occupied residential buildings, summer cottages and multi-dwelling houses are gathered from Statistics Denmark (2024) for the entire time series.

Emission factors

The emissions from composting strongly depend on both the composition of the treated waste and on process conditions such as aeration, mechanical agitation, moisture control and temperature pattern (Amlinger et al., 2008).

Emission factors for carbon monoxide, *EF(CO),* and ammonia, $EF(NH_3)$, are generally calculated using the following two equations:

$$EF(CO) = E(CO\text{-}C) \cdot 28/12 \cdot DOC \cdot f_{degraded} \cdot (1 - f_{moisture}) \cdot 1000 \text{ kg/t} \qquad \text{Eq. 6.3.1}$$

$$EF(NH_3) = E(NH_3\text{-}N) \cdot 17/14 \cdot N_{tot} \cdot (1 - f_{moisture}) \cdot 1000 \text{ kg/t} \qquad \text{Eq. 6.3.2}$$

where the emission factors are provided in units of kg per tonne wet weight (ww) bio-waste, *E(CO-C)* is the CO emission (% CO-C in dry weight (dw) degraded C), 28/12 is the molecular weight ratio between CO and C, *DOC* is the content of degradable organic carbon (% DOC in dw bio-waste), $f_{degraded}$ is the fraction of *DOC* that are degraded during the composting process, $f_{moisture}$ is the moisture content in the composted waste, $E(NH_3\text{-}N)$ is the NH_3 emission (% NH_3 –N in dw total N), 17/14 is the molecular weight ratio between NH_3 and N and N_{tot} is the total N content in the dw waste.

The factors used to calculate the emission factors, and the calculated emission factors are presented in Table 6.3.4. More information on the specific applied values is given for each composting type below the table.

Table 6.3.4 CO and NH_3 emission factors for composting.

	Unit	Garden waste	Organic waste	Sludge	Home composting
DOC	of dw	49%[1]	38%[1]	50%[1]	47%[1]
$f_{degraded}$	-	56%[2]	56%[2]	57.5%[3]	56%[2]
N_{tot}	of dw	2%[1]	-	4%[4]	2%[1]
$f_{moisture}$	-	60%[1]	60%[1]	72.5%[3]	73.5%[5]
CO	kg/t ww	0.87[6]	0.68[6]	0.63[6]	0.06[6]
NH_3	kg/t ww	0.64[6]	0.24[7]	0.01[3]	0.41[6]

[1]IPCC (2006), [2]Andersen et al. (2010a), [3]DEPA (2013), [4]Jensen et al. (2015), [5]Andersen et al. (2010b), [6]Boldrin et al. (2011), [7]EEA (2019).

Garden waste

Boldrin et al. (2011, Table 4) provides *E(CO-C)* and *E(N_2O–N)* emission factors of 0.34% CO-C in dw degraded C and 6.6% NH_3-N in dw total N for central composted garden waste. The *EF(CO)* emission factor is calculated using Equation 6.3.1, the DOC value of 49% in dw (IPCC, 2006, Vol. 5, Ch. 2, Table 2.4), a $f_{degraded}$ of 56% (Andersen et al., 2010a, page 717) and the default IPCC moisture content of 60% IPCC (2006, Vol. 5, Ch. 4, Table 4.1). The *EF(NH_3)* emission factor is calculated using Equation 6.3.2 and default values for moisture and N_{tot} from IPCC (2006, Vol. 5, Ch. 4, Table 4.1).

Organic waste

Since little information is available about composting of “organic waste”, the emission factor value for NH_3 is set equal to the default EEA (2019) value of 0.24 kg NH_3 per tonne ww organic waste.

For CO, the emission factor is calculated using Equation 6.3.1, the *E(CO-C)* for garden waste (Boldrin et al., 2011, Table 4), the $f_{degraded}$ from Andersen et al. (2010a, page 717) of 56% and the default values for DOC (IPCC, 2006, Vol. 5, Ch. 2, Table 2.4, Food waste) and $f_{moisture}$ (IPCC, 2006, Vol. 5, Ch. 4, Table 4.1).

Sludge

The *EF(CO)* value for sludge composting is calculated using Equation 6.3.1 and the *EF(NH_3)* using Equation 6.3.2.

The default DOC value of 50% DOC in dw sludge (IPCC, 2006, Vol. 5, Ch. 2.3.2) is applied along with a fraction of degraded carbon of 57.5%, which is the average value of the reported 50% of DOC for anaerobic digested sludge and 65% for secondary (non-digested) sludge (DEPA, 2013, page 177).

The nitrogen content of sludge, N_{tot}, is equal to 4% of the dw sewage sludge (Jensen et al., 2015).

The dry matter content of sludge before composting is in the range of 20-30 % and set equal to an average value of 27.5 % for digested and non-digested sludge (DEPA, 2013, page 177).

The *E(CO-C)* value of 0.34% CO-C in dw degraded C in garden waste (Boldrin et al., 2011, Table 4) is chosen for sludge, as no better data is available. The *E(NH_3-N)* value of 0.15% NH_3-N of N loss is known from DEPA (2013, page 177). According to Equation 6.3.2, *E(NH_3-N)* should be in the unit of % NH_3–N in dw total N, and the available *E(NH_3-N)* of 0.15% is therefore multiplied with the N-loss of 55 % of the total N content in sludge (DEPA, 2013, page 177).

As a result, an *EF(CO)* value 0.63 kg CO per tonne ww sludge is applied. *EF(NH_3)* is calculated as 0.01 kg NH_3 per tonne ww sludge.

Home composting

The DOC value of 47% in dw that is applied for home composting is calculated from IPCC (2006, Vol. 5, Ch. 2, Table 2.4) standard values, by assuming a mix of 80 % garden waste and 20 % food waste.

A $f_{degraded}$ value of 56% value from Andersen et al. (2010a, page 177) is applied for home composting, along with the default N_{tot} of 2% in dw from IPCC (2006, Vol. 5, Ch. 4, Table 4.1).

The moisture content in waste that is home composted is set as the calculated average of measured values from Andersen et al. (2010b, Table 1); i.e. 73.5% (range 63.8-78.9%).

The *E(CO–C)* and *E(NH_3-N)* values for home composting are 0.04% and 6.3% in dw respectively (Boldrin et al. 2011, Table 4).

Emissions

Table 6.3.5 show the total national emissions from composting. The full time series is shown in Annex Table 3E-2.2.

Table 6.3.5 National emissions from composting, tonnes.

	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
CO	120	266	360	760	705	790	841	1027	903	958
NH_3	92	196	259	455	492	543	590	677	614	659

6.3.2 Biogas production

Emissions from biogas production are divided and reported in different sectors according to waste type and method.

Emissions from the combustion of biogas regardless of the origin are included in the energy sector and are allocated to the appropriate subsector in the Danish energy statistics. See this IIR Chapter 3, Energy.

NH_3 emissions from livestock manure processed in biogas facilities and afterwards spread on agricultural soils are included in the agricultural sector in Chapter 5.

Emissions in this section include emissions of NH_3 from feedstock (not livestock manure) stored at the biogas facility before and after the anaerobic digestion.

Methodology

Calculations are based on the Tier 1 methodology given in EEA (2019).

Data regarding the amount of N from feedstock delivered to biogas facilities is available for the years since 2015. The data are based on data registration covering the main part of all biogas plants, it is called the BIB – register (Biomass Input to Biogas production), managed by the Danish Energy Agency (DEA).

For the entire time series, the data for amount of N from feedstock delivered to the biogas production are calculated based on the relation between the amount of N in feedstock delivered and the total energy production produced at the biogas facilities for the years 2016-2019. The average amount of N per PJ is estimated to be 9.4 tonnes N per PJ. The total energy production from biogas facilities for all years is based on the Energy Statistics (DEA, 2024).

Activity data

In 1985, the energy production produced at the biogas facilities is estimated by DEA to 294 TJ. Based on the assumptions mentioned above, this corresponds to 2.8 tonnes N delivered to the biogas production plants. In 2023, the energy production is increased to 31.6 PJ and the amount of slurry delivered to the biogas facilities is 297.3 tonnes N. Time series for the energy production at biogas facilities and amount of N in feedstock are shown in Table 6.3.6 and Annex Table 3E-2.3.

Table 6.3.6 Energy production from biogas facilities and amount of N in feedstock.

	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
Energy production, PJ	0.3	0.7	1.3	2.3	3.3	4.0	6.1	21.0	28.8	31.6
Total N, tonnes	2.8	6.8	12.6	21.6	30.9	37.8	57.4	197.6	271.0	297.3

Emission factor

The emission factor for Tier 1 given in Table 3.1 in Chapter 5.B.2 Biological treatment of waste – anaerobic digestion at biogas facilities in EEA (2019) is 0.0275 kg NH_3-N per kg N in feedstock. This corresponds to 0.0334 kg NH_3 per kg N in feedstock.

Emission

The emission of NH_3 from storage of feedstock to biogas production is presented in Table 6.3.7. For all years of the time series, see Annex Table 3E-2.3. The emission is increasing due to increase in the production of biogas.

Table 6.3.7 Emission of NH_3 from storage and separation of feedstock to biogas production, t.

	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
Emission NH_3	0.09	0.23	0.42	0.72	1.03	1.26	1.92	6.60	9.05	9.05

6.4 Waste incineration

Incineration of municipal, industrial, clinical and hazardous waste takes place with energy recovery; therefore, the emissions are included in the relevant subsectors under NFR sector 1A. For documentation, please refer to Chapter 3.2. Flaring offshore and in refineries are included under NFR sector 1B2c, for documentation please refer to Chapter 3.4. No flaring in chemical industry occurs in Denmark.

6.4.1 Human cremation

The incineration of human corpses is a common practice in Denmark that is performed on an increasing percentage of the deceased. All Danish crematoria use optimised and controlled cremation facilities, with temperatures reaching 800-850 °C, secondary combustion chambers, controlled combustion air flow and regulations for coffin materials.

However, the emissions of especially Hg caused by cremations can still contribute to a considerable part of the total national emissions. In addition to the most frequently discussed emissions of Hg and PCDD/Fs (dioxins and furans), are the emissions of compounds like SO_2, NO_x, NMVOC, CO, other heavy metals (As, Cd, Cr, Cu, Ni, Pb, Se, Zn), particulate matter, HCB, PAHs and PCBs.

Crematoria are usually located within cities, close to residential areas and normally, their stacks are relatively low. Therefore, environmental and human exposure is likely to occur as a result of emissions from cremation facilities.

Methodology

During the 1990s, all Danish crematoria were rebuilt to meet new standards. This included installation of secondary combustion chambers and in most cases, replacement of old primary combustion chambers (Schleicher et al., 2001). All Danish crematoria are therefore performing controlled incinerations with a good burn-out of the gases, and a low emission of pollutants.

Following the development of new technology, the emission limit values for crematoria were lowered again in January 2011. These new standards were originally expected from January 2009 but were postponed two years for existing crematoria.

Table 6.4.1 shows a comparison of the emission limit values from February 1993 and the new standard limits.

Table 6.4.1 Emission limit values mg per Nm^3 at 11 % O_2.

Component	1993 standard*	2011 standard**
Total dust	80	10
CO	50	50
Hg	No demands	0.1
Other demands:		
Stack height	3 m above rooftop	3 m above rooftop
Temperature in stack	Minimum 150 °C	Minimum 110 °C
Flue gas flow in stack	8 – 20 m/s	No demands
Temperature in after burner	850 °C	800 °C
Residence time in after burner	2 seconds	2 seconds
Odour	The crematory must not cause noticeable odour in the surroundings	The crematory must not cause odour nuisance outside the crematory perimeter, that is significant according to the supervisory authority

*Schleicher et al., 2001; **Schleicher & Gram, 2008.

To meet the new standards, some crematoria have been rebuilt to larger capacity while others are closed (KM, 2006). In 2023, there were 19 operating crematoria in Denmark, some with multiple furnaces. In 2010, there were 31 operating crematoria (DKL, 2024).

Crematoria that are not closed are equipped with flue gas cleaning (bag filters with activated carbon). The use of air pollution control devices and activated carbon, for the removal of Hg will also reduce the flue gas concentration of dioxins, PAHs and odour. Existing knowledge on the reduction efficiencies justifies are presented in Schleicher & Gram (2008).

Around half of the Danish crematoria are currently connected to the district heating system and in addition, a few crematoria produce heat for use in their own buildings. The bag filter cleaning system requires that the flue gas is cooled down to 125-150 °C, and the cheapest way to do so is to use the surplus heat in the district heating system (DKL, 2009). The heat contribution from crematoria is negligible compared to the total district heat production and is not part of the Danish energy statistics.

Activity data

Table 6.4.2 shows the time series of total number of deceased persons (Statistics Denmark, 2024), number of cremations and the fraction of cremations in relation to the total number of deceased (DKL, 2024). Annex Table 3E-3.1 presents data for the entire time series.

Table 6.4.2 Data human cremations.

	1980	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
Nationally deceased	55939	58378	60926	63127	57998	54962	54368	52555	54645	59435	58384
Cremations	33986	36705	40991	43847	41651	40758	42050	43238	46910	51435	50493
Cremation fraction, %	60.8	62.9	67.3	69.5	71.8	74.2	77.3	82.3	85.8	86.5	86.5

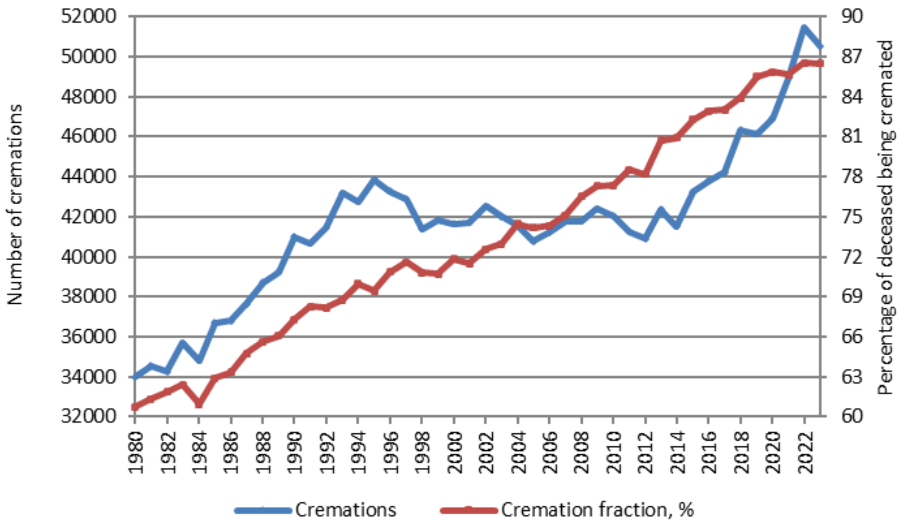

Figure 6.4.1 Illustration of the development in cremations (DKL 2024), where the number of cremations is shown at the left Y-axis. The right Y-axis shows the percentage of deceased being cremated. Data for 1980-1983 are estimated values, for details on the estimation, see Annex Table 3E-3.1.

Even though the total number of annual cremations is fluctuating, the cremation percentage has been steadily increasing since 1984.

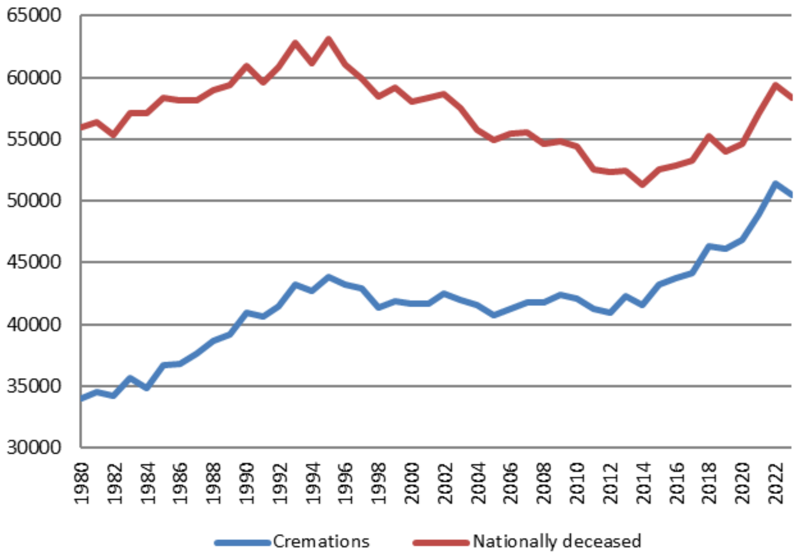

Figure 6.4.2 Trends of the activity data for cremation of human corpses and the number of deceased persons.

Figure 6.4.2 presents the trend of the number of deceased persons together with the activity data for human cremation. The figure shows a direct connection between the number of deceased and the activity of human cremation, as the two trends are quite similar. Figure 6.4.2 also shows the effect of the increasing fraction of cremations per deceased, as the number of cremations is not decreasing along with the number of deceased. The percentage of the deceased being cremated has increased from 67 % in 1990 to 86 % in 2023 as shown in Figure 6.4.1, Table 6.4.2 and Annex Table 3E-3.1.

Emission factors

For crematoria, emissions are calculated by multiplying the total number of cremations by the emission factors. The emission factors are gathered from literature and are based on the measurements performed in countries that are comparable with Denmark. By comparable is meant countries that use similar incineration processes, similar cremation techniques including support fuel and have a similar composition of sources to lifetime exposure, lifetimes and coffins.

Table 6.4.3 lists the emission factors in the period 1980-2010 and their respective references. As mentioned earlier, 2011 is year one after installation of bag filters with activated carbon at all Danish crematoria, causing the emission factors for particles, heavy metals, PAHs and PCDD/Fs to decrease significantly (Schleicher & Gram, 2008).

Table 6.4.3 Emission factors for human cremation with references.

Pollutant name	Unit	Emission factor	Reference
SO_2	kg/body	0.113	Santarsiero et al., 2005
NO_X	kg/body	0.825	Santarsiero et al., 2005
NMVOC	kg/body	0.013	EEA, 1996
CO	kg/body	0.010	Schleicher et al., 2001
TSP	kg/body	0.039	Webfire, 2012
PM_{10}	kg/body	0.035	Webfire, 2012
$PM_{2.5}$	kg/body	0.031	Webfire, 2012
As	g/body	0.014	Webfire, 2012
Cd	g/body	0.005	Webfire, 2012
Cr	g/body	0.014	Webfire, 2012
Cu	g/body	0.012	Webfire, 2012
Hg	g/body	1.12	Kriegbaum and Jensen, 2005
Ni	g/body	0.017	Webfire, 2012
Pb	g/body	0.030	Webfire, 2012
Se	g/body	0.020	Webfire, 2012
Zn	g/body	0.160	Webfire, 2012
HCB	mg/body	0.152	Toda, 2006
PCDD/F	µg I-TEQ/body	0.350	Schleicher et al., 2001
Benzo(b)flouranthene	µg/body	7.21	Webfire, 2012
Benzo(k)flouranthene	µg/body	6.44	Webfire, 2012
Benzo(a)pyrene	µg/body	13.20	Webfire, 2012
Indeno(1,2,3-c-d)pyrene	µg/body	6.99	Webfire, 2012
PCBs	mg/body	0.414	Toda, 2006

The average body weight of cremated corpses is assumed to be 65 kg.

Flue gas cleaning efficiencies are based on measurements performed at Danish crematoria and expert judgements, and set equal to 99 % for PCDD/Fs, particles, PAHs and heavy metals. These abatement efficiencies are implemented from 2011. For all other pollutants, the emission factors are as listed in Table 6.4.3.

It has not been possible to find data for ammonia. Ammonia might appear in lesser amounts but will most likely be converted to NO_X at the high incineration temperatures.

There might for some emission factors be included a small part of the support fuel (natural gas) if the measurements were taken early in the burning process. This would then be a double counting since fuel for cremation is reported under NFR code 1A4a, commercial and institutional. However, this potential double counting is considered negligible.

Emissions

Table 6.4.4 shows the total emissions from selected years. To view the entire time series 1980-2023, see Annex Table 3E-3.2.

Emissions from human cremations have decreased strongly for the pollutants TSP, PM_{10}, $PM_{2.5}$, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn, PCDD/Fs and PAHs from 2010 to 2011 because of the installation of bag filters with activated carbon.

Table 6.4.4 Total national emissions from human cremations.

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
SO_2	t	3.8	4.1	4.6	4.9	4.7	4.6	4.7	4.9	5.3	5.8	5.7
NO_X	t		30.3	33.8	36.2	34.4	33.6	34.7	35.7	38.7	42.4	41.7
NMVOC	t		0.5	0.5	0.6	0.5	0.5	0.5	0.6	0.6	0.7	0.7
CO	t		0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5
TSP	t			1.6	1.7	1.6	1.6	1.6	0.02	0.02	0.02	0.02
PM_{10}	t			1.4	1.5	1.4	1.4	1.5	0.02	0.02	0.02	0.02
$PM_{2.5}$	t			1.3	1.4	1.3	1.3	1.3	0.01	0.01	0.02	0.02
As	kg			0.6	0.6	0.6	0.6	0.6	0.01	0.01	0.01	0.01
Cd	kg			0.2	0.2	0.2	0.2	0.2	0.002	0.002	0.003	0.003
Cr	kg			0.6	0.6	0.6	0.6	0.6	0.01	0.01	0.01	0.01
Cu	kg			0.5	0.5	0.5	0.5	0.5	0.01	0.01	0.01	0.01
Hg	kg			45.9	49.1	46.6	45.6	47.1	0.5	0.5	0.6	0.6
Ni	kg			0.7	0.8	0.7	0.7	0.7	0.01	0.01	0.01	0.01
Pb	kg			1.2	1.3	1.3	1.2	1.3	0.01	0.01	0.02	0.02
Se	kg			0.8	0.9	0.8	0.8	0.8	0.01	0.01	0.01	0.01
Zn	kg			6.6	7.0	6.7	6.5	6.7	0.1	0.1	0.1	0.1
HCB	g			6.2	6.6	6.3	6.2	6.4	6.6	7.1	7.8	7.7
PCDD/F	mg I-TEQ			14.3	15.3	14.6	14.3	14.7	0.2	0.2	0.2	0.2
benzo(b)flouranthene	g			0.3	0.3	0.3	0.3	0.3	0.003	0.003	0.004	0.004
benzo(k)flouranthene	g			0.3	0.3	0.3	0.3	0.3	0.003	0.003	0.003	0.003
benzo(a)pyrene	g			0.5	0.6	0.5	0.5	0.6	0.01	0.01	0.01	0.01
indeno(1,2,3-c-d)pyrene	g			0.3	0.3	0.3	0.3	0.3	0.003	0.003	0.004	0.004
PCB	g			17.0	18.1	17.2	16.9	17.4	17.9	19.4	21.3	20.9

6.4.1 Animal cremation

The incineration of animal carcasses in animal crematoria follows much the same procedure as human cremation. Animal crematoria use similar two chambered furnaces and controlled incineration. However, animal carcasses are burned in special designed plastic (PE) bags rather than coffins. Emissions from animal cremation are similar to those from human cremation, with the exception of Hg, which mainly stems from amalgam tooth fillings.

Animal cremations are performed in two ways, individually where the owner often pays for receiving the ashes in an urn or collectively which is most often the case with animal carcasses that are left at the veterinarian.

Open burning of animal carcasses is illegal in Denmark and is not occurring and small-scale incinerators are not known to be used at Danish farms. Livestock that is diseased or in other ways unfit for consumption is disposed of through rendering plants, incineration of livestock carcasses is illegal, and these carcasses are therefore commonly used in the production of fat and soap at Daka Bio-industries.

The only animal carcasses that are approved for cremation in Denmark are deceased pets and animals used for experimental purposes, where the incineration must take place at a specialised animal crematorium. There are four animal crematoria in Denmark but one of these is situated at a waste incineration company in northern Jutland called AVV. The specially designed cremation furnaces are at this location connected to the flue gas cleaning equipment of the municipal waste incineration plant with energy recovery and the emission from the cremations are therefore included in the annual inventory from AVV. Consequently, this crematorium is included in Chapter 3.2 Stationary combustion. Therefore, only three animal crematoria are included in this sector.

Animal by-products are regulated under the EU commission regulation no. 142/2011. This states that animal crematoria must be approved by the authority and comply either with the EU directive (2010/75/EC) (EC, 2010) on waste incineration or with Regulation (EC) No. 1069/2009 (EC, 2009).

Methodology

The incineration of animal carcasses is, as the incineration of human corpses, performed in special incineration chambers. All Danish animal crematoria have primary combustion chambers with temperatures around 850 ºC and secondary combustion chambers with temperatures around 1100 ºC. The support fuel used at the Danish facilities is natural gas.

Emissions from pet cremations are calculated for SO_2, NO_x, NMVOC, CO, particles, heavy metals (As, Cd, Cr, Cu, Ni, Pb, Se, Zn), HCB, dioxins/furans, PAHs and PCBs. For the pollutants SO_2, NO_x, NMVOC, CO, particles, As, Se and POPs, emissions are estimated by using the same emission factors as for human cremation.

Activity data

Activity data for animal cremation are gathered directly from the animal crematoria. There is no national statistics available on the activity from these facilities. The precision of activity data therefore depends on the information provided by the crematoria.

The following Table 6.4.5 lists the four Danish pet crematoria, their foundation year and provides each crematorium with an id letter.

Table 6.4.5 Animal crematoria in Denmark.

Id	Name of crematorium	Founded in
A	Dansk Dyrekremering ApS	May 2006
B	Ada's Kæledyrskrematorium ApS	Unknown, existed in more than 40 years, assumed 1980
C	Kæledyrskrematoriet	2006
D	Kæledyrskrematoriet v. Modtagestation Vendsyssel I/S	-

Crematorium D is situated at the AVV municipal waste incineration site and the emissions from this site are, as previously mentioned, included in the annual emission reporting from AVV and consequently included in the energy sector in this report as waste incineration with energy recovery. Therefore, only crematoria A-C are considered in this chapter.

Table 6.4.6 lists the activity data for crematoria A-C. The entire dataset for 1980-2023 is available in Figure 6.4.3 and Annex Table 3E-3.3.

Table 6.4.6 Activity data. Source: direct contact with all Danish crematoria.

	1980	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
Total, t	50	100	150	200	443	762	1449	1119	995	960	786

Crematorium B delivered exact annual activity data for the years 1998-2023. They were not certain about the founding year but believe to have existed since the early 1980es. It is assumed that crematorium B was founded on January 1st, 1980, and activity data for 1980-1997 must therefore be estimated.

Statistical data describing the national consumption for pets including food and equipment for pets were evaluated as surrogate data. These statistical data show an increase of consumption of 6 % from 1998 to 2000, in the same period the amount of cremated animal carcasses increased with 89 % and no correlation seems to be present. Since there are no other available data about pets, it is concluded that there are no surrogate data available.

It is not possible to extrapolate data linearly back to 1980 because the activity, due to the steep increase, in this case would become negative from 1993 and back in time.

The activity data for animal cremation for the period of 1980-1997 are estimated by expert judgement. The estimated data are shown in Table 6.4.6, Figure 6.4.3 and Annex Table 3E-3.3.

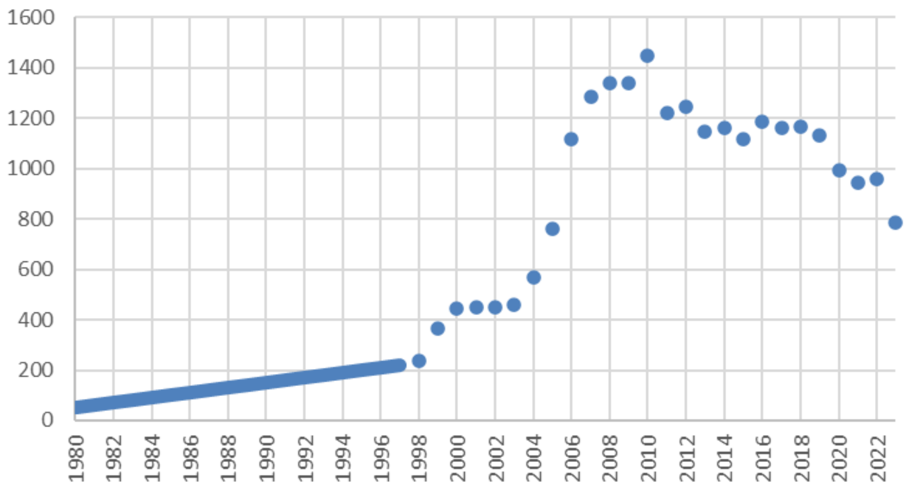

Figure 6.4.3 The amount of animal carcasses cremated, in tonnes. Data from 1998-2023 are delivered by the crematoria and is exact; these data are marked as points. Data from 1980-1997 are estimated and are shown as the thick line in the figure.

Emission factors

Concerning the incineration of animal carcasses in animal crematoria there is not much literature to be found. EEA (2019) only provides emission factors for open burning of carcasses, which is not useful for the Danish practice.

Chen et al. (2004) is found useful for describing the heavy metal emissions of Cd, Cr, Cu, Ni, Pb and Zn from Danish animal crematoria.

The emission factors of the remaining pollutants SO_2, NO_x, NMVOC, CO, particles, As, Se, HCB, PCDD/F, PAHs and PCBs are collected from the literature search on human cremation, and it is assumed that human corpses and animal carcasses are similar in composition for this purpose. Emission factors from human cremation are recalculated to match the activity data for animal cremation, emission per tonnes.

No data were available for the emission of Hg in animal cremations. The Hg emission factor for human cremation is not transferable to animal cremations, because the Hg emission from human cremations primarily stems from tooth fillings.

Table 6.4.7 lists the emission factors and their respective references.

Table 6.4.7 Emission factors for animal cremation with references, per tonnes.

Pollutant	Unit	Emission factor	Source
SO_2	kg	1.74*	Santarsiero et al, 2005
NO_X	kg	12.69*	Santarsiero et al, 2005
NMVOC	kg	0.20*	EEA, 1996
CO	kg	0.15*	Schleicher et al., 2001
TSP	kg	0.59*	Webfire, 2012
PM_{10}	kg	0.53*	Webfire, 2012
$PM_{2.5}$	kg	0.47*	Webfire, 2012
As	g	0.21*	Webfire, 2012
Cd	g	0.01	Chen et al., 2004
Cr	g	0.07	Chen et al., 2004
Cu	g	0.02	Chen et al., 2004
Ni	g	0.06	Chen et al., 2004
Pb	g	0.18	Chen et al., 2004
Se	g	0.30*	Webfire, 2012
Zn	g	0.19	Chen et al., 2004
HCB	mg	2.33*	Toda, 2006
PCDD/F	µg I-TEQ	5.40*	Schleicher et al., 2001
Benzo(b)flouranthene	mg	0.11*	Webfire, 2012
Benzo(k)flouranthene	mg	0.10*	Webfire, 2012
Benzo(a)pyrene	mg	0.20*	Webfire, 2012
Indeno(1,2,3-c-d)pyrene	mg	0.11*	Webfire, 2012
PCB	mg	6.36*	Toda, 2006

* Emission factors from human cremations.

Emissions

For the incineration of animal carcasses, emissions are calculated by multiplying the number of incinerated animals by the emission factors.

Emissions are summarised in Table 6.4.8, while emissions for the full time series are shown in Annex Table 3E-3.4.

Table 6.4.8 Emissions from animal cremation.

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
SO_2	t	0.09	0.17	0.26	0.35	0.77	1.32	2.51	1.94	1.73	1.67	1.36
NO_X	t		1.27	1.90	2.54	5.62	9.67	18.39	14.20	12.63	12.18	9.98
NMVOC	t		0.02	0.03	0.04	0.09	0.15	0.29	0.22	0.20	0.19	0.16
CO	t		0.02	0.02	0.03	0.07	0.12	0.22	0.17	0.15	0.15	0.12
TSP	t			0.09	0.12	0.26	0.45	0.86	0.66	0.59	0.57	0.47
PM_{10}	t			0.08	0.11	0.24	0.41	0.77	0.60	0.53	0.51	0.42
$PM_{2.5}$	t			0.07	0.09	0.21	0.36	0.69	0.53	0.47	0.46	0.37
As	kg			0.03	0.04	0.09	0.16	0.30	0.23	0.21	0.20	0.16
Cd	kg			0.002	0.002	0.004	0.01	0.01	0.01	0.01	0.01	0.01
Cr	kg			0.01	0.01	0.03	0.05	0.10	0.08	0.07	0.07	0.06
Cu	kg			0.003	0.004	0.009	0.02	0.03	0.02	0.02	0.02	0.02
Ni	kg			0.01	0.01	0.03	0.05	0.09	0.07	0.06	0.06	0.05
Pb	kg			0.03	0.04	0.08	0.14	0.26	0.20	0.18	0.17	0.14
Se	kg			0.05	0.06	0.13	0.23	0.44	0.34	0.30	0.29	0.24
Zn	kg			0.03	0.04	0.08	0.14	0.28	0.21	0.19	0.18	0.15
HCB	g			0.35	0.47	1.03	1.78	3.38	2.61	2.32	2.24	1.83
PCDD/F	mg			0.81	1.08	2.39	4.11	7.82	6.04	5.37	5.18	4.24
benzo(b)flouranthene	g			0.02	0.02	0.05	0.08	0.16	0.12	0.11	0.11	0.09
benzo(k)flouranthene	g			0.01	0.02	0.04	0.08	0.14	0.11	0.10	0.10	0.08
benzo(a)pyrene	g			0.03	0.04	0.09	0.15	0.29	0.23	0.20	0.19	0.16
indeno(1,2,3-c-d)pyrene	g			0.02	0.02	0.05	0.08	0.16	0.12	0.11	0.10	0.08
PCB	g			0.95	1.27	2.82	4.85	9.22	7.12	6.33	6.11	5.00

6.5 Wastewater handling

According to the 2023 EMEP/EEA Guidebook wastewater handling can be a source for emissions of NMVOC, NH_3, particles and heavy metals. For the current submission, Denmark has estimated the NMVOC emission from wastewater handling as default emission factors are not available for other pollutants. Latrines are not used in Denmark.

6.5.1 Methodology

A Tier 2 approach from EEA (2023) is applied for the calculation of NMVOC emissions from wastewater treatment. The emission factor is the same for the Tier 1 and Tier 2 methodologies, but the relevant activity data for a Tier 2 is applied, i.e. are the amount of wastewater handled. The amount of wastewater handled is available from the "Point sources" report series for 1992-2023 from DEPA (2024b). Activity data for 1985-1991 are estimated from 1992-1994 data.

6.5.2 Activity data

Activity data for wastewater handling is the volume of wastewater handled as provided in Table 6.5.1, the full time series are shown in Annex Table 3E-4.1.

Table 6.5.1 Amount of wastewater treated in Denmark, million m^3/yr.

	1985	1990	2000	2005	2010	2015	2020	2022	2023
Influent wastewater at municipal WWTPs	788	757	825	701	683	767	693	613	607
Wastewater treated at industrial WWTPs*	86	88	74	62	54	49	40	43	40
Total influent wastewater	874	846	899	763	737	816	733	656	647

*set equal to the amount of reported effluent wastewater from separate industries.

6.5.3 Emission factor

The EMEP/EEA Guidebook contains a default NMVOC emission factor for wastewater handling of 15 mg NMVOC per m^3 wastewater treated at Tier 1 and Tier 2 (EEA, 2023).

6.5.4 Emissions

Emissions are summarised in Table 6.5.2, while emissions for the full time series are shown in Annex Table 3E-4.2.

Table 6.5.2 NMVOC emissions from wastewater handling, t/yr.

	1985	1990	2000	2005	2010	2015	2020	2022	2023
Municipal WWTPs	11.8	11.4	12.4	10.5	10.2	11.5	10.4	9.2	9.1
Industrial WWTPs	1.3	1.3	1.1	0.9	0.8	0.7	0.6	0.6	0.6
Total NMVOC emissions	13.1	12.7	13.5	11.4	11.1	12.2	11.0	9.8	9.7

6.6 Other waste

This category is a catch all for the waste sector. Emissions in this category could stem from e.g. sludge spreading, accidental fires and other combustion without energy recovery.

6.6.1 Sludge spreading

Sludge from wastewater treatment plants is only spread out in the open with the purpose of fertilising agricultural land. Emissions that derive from this activity are included in Chapter 5.

6.6.2 Accidental fires

This category covers emissions from fires in buildings, vehicles and containers, these fires are collectively called accidental fires, although they are in practice not always accidental. Emissions from accidental fires are categorised under the NFR category 5E Other waste. Pollutants that are emitted from building fires include SO_2, NO_x, NMVOC, CO, particles, heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn), PCDD/F and PAHs.

Methodology

Emissions are calculated by multiplying the activity data of either mass or area, with selected emission factors.

In January 2005, it became mandatory for the local authorities to register every rescue assignment in the *online data registration- and reporting system called* ODIN (www.odin.dk). ODIN is developed and run by the Danish Emergency Management Agency (DEMA, 2007). The new system took a few years to refine, this means that Denmark has very detailed and reliable data on accidental fires since 2007.

The raw activity data for accidental fires are given by ODIN (DEMA, 2024). These raw data are detailed registrations of the time of the fire, the location of the fire, the object(/s) concerned, the cause of the fire, the fire progress at arrival, and the number of and type of jet tubes used in the firefighting work. A database model is produced, to translate these detailed data into mass or area burned.

The model calculates emissions from 18 different object types individually, e.g. detached buildings, apartment buildings, combined harvesters, ships, passenger cars/light duty vehicles etc.

The numbers of fires are then calculated into full scale equivalent fires (FSE). The types and number of jet tubes used for the fire extinguishing is used to evaluate if the fire should be considered small (5 % of mass or area combusted), medium (30 %), large (75 %) or full (100 %).

For each of the 12 vehicle types and containers, the numbers of FSE fires are then multiplied with an average mass, e.g. 12 kg per bicycle, 5 tonnes per tractor, 1.5 tonnes per caravan, 1 tonne per container etc. It is assumed that all the different vehicle types lead to similar emissions. Container fires cover all types of containers, from small residential garbage containers to large shipping containers.

For each of the five building types, the numbers of FSE fires are multiplied with the average area, e.g. 130 m^2 per undetached building, 500 m^2 per industrial building, 20 m^2 per additional building etc.

Different emission factors are available for vehicle fires, container fires, residential building fires and non-residential fires. The calculated mass of combusted vehicle is therefore summed, and the same for residential building area and non-residential building area, reducing the number of fire types from 18 to four.

Activity data

The number of FSE fires are calculated by the emission model for the years since 2007.

The numbers of total registered fires are known from DEMA for the years 1989-2023 and the numbers of actual fires, i.e. excluding false alarms, are known for the years 2016-2023. It is assumed that the average number of false alarms in 2016-2021 can be applied for 1989-2015. The number of actual fires for 1989-2015 is used as surrogate data to calculate mass and area of accidental fires for these historic years. The 1980-1988 data are estimated as average values for 1989-1999.

Table 6.6.1 shows the activity data. The total occurrence of actual fires and the full time series is presented in Annex Table 3E-5.1.

Table 6.6.1 Activity data.

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2020	2022	2023
Burnt residential area	$1000m^2$	152	152	144	166	146	140	140	126	128	120	117
Burnt non-residential area	$1000m^2$	222	222	211	242	213	205	188	183	170	177	159
Burnt container mass	t	348	348	329	378	332	320	239	278	421	318	298
Burnt vehicle mass	t	3159	3159	2994	3436	3020	2910	2943	2769	2735	2931	1932

Emission factors

The emission factors are produced from different measurements and assumptions from literature and expert judgements. When possible, emission factors are chosen that represent conditions that are comparable to Denmark. By comparable is meant countries that have similar building traditions, with respect to the materials used in building structure and interior.

In the process of selecting the best available emission factors for the calculation of the emissions from Danish accidental building fires, a range of different sources has been studied. Unfortunately, it is difficult to do an interrelated comparison of the different sources because they all establish emission factors on different assumptions and many of these assumptions are not fully accounted for.

Emission factors are not available for different vehicle types, whereas it is assumed that all the different vehicle types lead to similar emissions.

Table 6.6.2 lists the emission factors that were chosen as the best reliable and their respective references.

Table 6.6.2 Emission factors for accidental fires.

		Vehicle fires	Container fires	Residential building fires	Non-residential building fires
	Unit	per t	per t	per m^2	per m^2
SO_2	kg	5.0[a]	2.4[b]	1.6[b]	0.8[b]
NO_x	kg	2.0[c]	3.0[d]	0.5[d]	0.2[d]
NMVOC	kg	8.5[a]	2.1[b]	2.3[d]	1.1[d]
CO	kg	63.0[a]	42.0[d]	6.4[d]	3.1[d]
TSP	kg	38.0[a]	23.2[e]	1.2[f]	0.5[f]
PM_{10}	kg	38.0[a]	23.2[e]	1.1[f]	0.5[f]
$PM_{2.5}$	kg	38.0[a]	23.2[e]	1.1[f]	0.5[f]
BC	kg	-	-	0.11[f]	0.05[f]
As	g	0.26[a]	0.22[e]	0.0003[f]	0.0001[f]
Cd	g	1.70[a]	0.14[e]	0.02[f]	0.01[f]
Cr	g	3.80[a]	0.21[e]	0.03[f]	0.02[f]
Cu	g	27.0[a]	0.48[e]	0.009[f]	0.004[f]
Hg	g	-	0.14[e]	0.001[f]	0.0004[f]
Ni	g	2.8[a]	-	0.003[f]	0.001[f]
Pb	g	820[a]	0.07[e]	0.04[f]	0.02[f]
Se	g	-	-	0.001[f]	0.0003[f]
Zn	g	3200[a]	-	0.74[f]	0.34[f]
PCB	µg	-	-	0.09[f]	0.04[f]
PCDD/F	mg	0.04[g]	1.1[b]	0.02[g]	0.01[g]
Benzo(b)fluoranthene	g	16.2[c]	1.9[d]	0.29[d]	0.14[d]
Benzo(k)fluoranthene	g	16.2[c]	0.7[d]	0.10[d]	0.05[d]
Benzo(a)pyrene	g	14.7[c]	1.2[d]	0.18[d]	0.09[d]
Indeno(1,2,3-cd)pyrene	g	23.3[c]	1.3[d]	0.20[d]	0.09[d]
HCB	µg	-	-	7.2[f]	3.3[f]

[a] Lönnermark & Blomqvist (2006), [b] Blomqvist et. al (2002), [c] Lemieux et. al (2004), [d] NAEI (2009), [e] EEA (2023) 5.E for detached building fires but scaled after Danish combusted mass data, [f] EEA (2019) 1.A.4 Small combustion Table 3.6 Tier 1 wood, using the Danish calorific value of 14.7 GJ/t wood and building mass data from Blomqvist et al (2002) and building interior mass from Persson & Simonson (1998), [g] Hansen (2000).

The SO_2 emission factors for building fires are derived based on the typical amount of gypsum in buildings based on Blomqvist et al. (2002) together with an emission factor from Persson & Simonson (1998). The sources provide emission factors in emission per fire, but by using the average building area also provided in the sources, we can derive an emission per area emission factor.

Some emission factors from literature for building fires are given in mass emission per mass burned. For the calculation of these emission factors to a unit that matches the activity data, the material mass in the building structure and the material mass in the interior from Blomqvist et al. (2002) and Persson & Simonson (1998) respectively are applied. The total building masses are calculated using an average weight loss rate of 12.4 % (Persson and Simonson, 1998) and data for the amount of combustible material in the building structure itself (Blomqvist et al., 2002) and the amount of combustible interior (Persson and Simonson, 1998).

Emissions

Table 6.6.3 shows the total emissions from building fires. The entire time series 1980-2023 is shown in Annex Table 3E-5.5, the annex also presents the emissions from the four accidental fire types individually.

Table 6.6.3 Emissions from accidental fires.

	Unit	1990	1995	2000	2005	2010	2015	2020	2022
SO_2	t	416.4	478.9	421.3	404.7	390.7	364.0	356.2	350.0
NO_x	t	119.5	137.4	120.9	116.1	112.1	104.5	102.7	100.8
NMVOC	t	587.3	675.6	594.3	570.9	551.9	513.7	503.0	494.2
CO	t	1771.9	2037.8	1792.6	1722.2	1667.5	1555.5	1529.3	1508.5
TSP	t	400.9	460.9	405.4	389.7	379.6	355.6	352.3	352.2
PM_{10}	t	387.4	445.4	391.7	376.6	367.0	343.8	340.8	340.9
$PM_{2.5}$	t	378.9	435.5	383.1	368.3	359.0	336.3	333.6	333.7
BC	t	26.4	30.4	26.7	25.7	24.8	23.0	22.5	22.0
As	kg	0.9	1.1	0.9	0.9	0.9	0.8	0.9	0.9
Cd	kg	9.7	11.1	9.8	9.4	9.3	8.7	8.6	8.8
Cr	kg	19.5	22.4	19.7	18.9	18.8	17.6	17.3	17.9
Cu	kg	83.1	95.4	83.8	80.8	81.5	76.7	75.8	81.0
Hg	kg	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2
Ni	kg	9.1	10.4	9.2	8.8	8.9	8.4	8.3	8.8
Pb	kg	2464.5	2828.4	2486.0	2395.4	2422.0	2279.2	2250.5	2411.6
Se	kg	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
Zn	kg	9759.5	11200.7	9844.8	9485.6	9584.6	9018.3	8903.6	9529.3
HCB	g	1.7	2.0	1.8	1.7	1.6	1.5	1.5	1.4
PCDD/F	g	5.3	6.1	5.3	5.1	4.9	4.6	4.7	4.5
Benzo(b)fluoranthene	kg	119.9	137.8	121.2	116.5	114.5	107.1	105.5	107.2
Benzo(k)fluoranthene	kg	73.6	84.5	74.3	71.5	71.1	66.7	65.8	68.4
Benzo(a)pyrene	kg	89.2	102.5	90.1	86.7	85.6	80.1	78.9	80.9
Indeno(1,2,3-cd)pyrene	kg	118.7	136.4	119.9	115.4	114.4	107.2	105.7	109.2
PCB	g	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

6.6.3 Other

Other combustion sources include open burning of yard waste and bonfires.

Due to the cold and wet climatic conditions in Denmark wildfires very seldom occur. Controlled field burnings and the occasional wildfires are categorised under the sectors Agriculture and Land Use. Land Use Change and Forestry (LULUCF), respectively.

In Denmark, the open burning of private yard waste is under different restrictions according to the respective municipality. These restrictions involve what can be burned but also the quantity, and how, when and where; or in some cases a complete ban is imposed. The burning of yard waste is not allowed within urban areas (DEPA, 2011). There is no registration of private waste burning and the activity data on this subject are impossible to estimate, additionally, no emission factors are available in the EMEP/EEA Guidebook. Citizens are generally encouraged to compost their yard waste or to dispose of it through one of the many waste disposal/recycling sites, which is free of charge and hence there is no incentive for back yard burning.

The occurrence of bonfires at midsummer night and in general are likewise not registered. Therefore, it has not been possible to obtain activity data and consequently bonfires are not included in this inventory.

Burning at an industrial scale does not occur, and therefore the guidance in the 2019 EMEP/EEA Guidebook ("The average amount of waste burned for arable farmland is therefore estimated to be 25 kg/hectare") is not relevant for Danish conditions as no waste burning occur in connection with farming. The EMEP/EEA Guidebook states that "For small scale waste incineration, the national annual quantity of agricultural waste incinerated is required". This number is impossible to estimate as there are no obligations for private citizens to report these activities nor any requirements for municipalities or other authorities to monitor or collect data for backyard burning.

6.7 Uncertainties and time series consistency

This section covers the uncertainty estimates.

6.7.1 Input data

The waste amounts for solid waste disposal are registered in a national database held by the Danish EPA and assessed to be of high quality resulting in the adoption of an uncertainty for reported waste amounts of 10 %.

The uncertainty of the activity data for composting is higher for the earliest years in the time series. Overall for the entire time series, the level of uncertainty is set at 20 %. Activity data for biogas production is an estimated N content in the feedstock; the uncertainty for this activity is set to 20 %.

The uncertainty of the number of human cremations is miniscule. However, for the purpose of the calculation it has been set to 1 %. The uncertainty of the activity data from animal cremations is also minimal for the most recent years (1998-2023) but is increasing back in time (to 200 % in 1980). The uncertainty is set to 40 % for all years.

The activity data uncertainty for wastewater handling is 30 % for all years for both domestic- and industrial wastewater handing.

The uncertainty of the total number of accidental fires is very small, but the division into building and transportation types and also the calculation of full-scale equivalents will lead to some uncertainty, partly caused by the category “other”. The uncertainty for accidental fire activity data is therefore set to 20 % for all years. The uncertainty is however lowest for the most recent years (2008-2023) (Authors expert judgement).

Table 6.7.1 lists the uncertainties for activity data in the waste sector.

Table 6.7.1 Estimated uncertainty rates for activity data.

	Solid waste disposal	Compost-ing	Biogas production	Human cremation	Animal cremation	Wastewater handling	Accidental fires
Activity data uncertainty. %	10	20	20	1	40	30	20

The uncertainties for emission factors in the waste sector and at the present level of available information are listed in Table 6.7.2. The uncertainties are assumed valid for all years 1990-2023.

Table 6.7.2 Estimated uncertainty rates for emission factors, %.

Pollutant	Solid waste disposal	Composting	Biogas production	Human cremation	Animal cremation	Wastewater handling	Building fires	Container fires	Vehicle fires
SO_2				100	100		300	300	500
NO_x				150	150		500	500	500
NMVOC	200			100	300	300	500	300	500
CO		100		150	150		500	500	500
NH_3		100	75						
TSP	500			500	300		500	500	500
PM_{10}	500			500	300		500	500	500
$PM_{2.5}$	500			500	300		500	500	500
BC							500		
As				700	700		500	500	500
Cd				700	500		500	500	500
Cr				700	500		500	500	500
Cu				700	500		500	500	500
Hg				150			500	500	
Ni				700	500		500		500
Pb				600	500		500	500	500
Se				700	700		500		
Zn				700	500		500		500
HCB				500	500		500		
PCDD/F				300	300		200	300	200
B(b)f[1]				1 000	1 000		500	500	500
B(k)f[2]				1 000	1 000		500	500	500
B(a)p[3]				1 000	1 000		500	500	500
I(1,2,3-cd)p[4]				1 000	1 000		500	500	500
PCB				1 000	1 000		500		

[1] Benzo(b)fluoranthene, [2] Benzo(k)fluoranthene, [3] Benzo(a)pyrene, [4] Indeno(1,2,3-cd)pyrene.

6.7.2 Uncertainty results

The Tier 1 uncertainty estimates for the waste sector are calculated from 95 % confidence interval uncertainties. Results are shown in Table 6.7.3.

Table 6.7.3 Tier 1 uncertainty results for waste.

Pollutant	2023 emission	Total emission uncertainty. %	Trend 1990-2023. %	Trend Uncertainty %-age points
SO_2	332.1 t	285.3	-21.2	21.3
NO_x	144.8 t	309.1	-6.7	57.1
NMVOC	520.1 t	425.2	-34.7	52.8
CO	2326.3 t	270.0	14.1	143.0
NH_3	668.8 t	100.5	240.1	95.0
TSP	301.2 t	385.2	-25.4	25.7
PM_{10}	290.3 t	382.4	-25.5	25.9
$PM_{2.5}$	283.3 t	380.7	-25.5	26.0
BC	20.8 t	500.4	-94.5	22.3
As	0.8 kg	353.6	-47.5	153.2
Cd	6.9 kg	351.5	-30.1	29.7
Cr	13.8 kg	351.7	-31.2	29.8
Cu	54.0 kg	483.9	-35.4	18.0
Hg	0.8 kg	152.9	-98.4	1.8
Ni	6.0 kg	452.4	-38.6	37.4
Pb	1592.1 kg	498.0	-35.4	18.2
Se	0.4 kg	469.9	-62.6	251.5
Zn	6324.1 kg	489.4	-35.2	18.0
HCB	10.8 g	368.1	30.8	103.9
PCDD/F	4.2 g	182.9	-20.8	20.5
benzo(b)flouranthene	87.5 kg	365.3	-27.0	28.1
benzo(k)flouranthene	51.1 kg	361.4	-30.6	26.4
benzo(a)pyrene	64.0 kg	353.9	-28.3	28.5
indeno(1,2,3-c,d)pyrene	83.6 kg	353.4	-29.6	27.7
PCB	25.9 g	829.1	44.5	284.2

6.8 QA/QC and verification

A list of QA/QC tasks are performed directly in relation to the emissions from the waste sector part of the Danish emission inventories. The following procedures are carried out to ensure the data quality:

- Checking of time series in the NFR and SNAP source categories. Considerable changes are controlled and explained
- Comparison with the inventory of the previous year. Any major changes are verified
- A manual log table is applied to collect information about recalculations
- Some automated checks have been prepared for the emission databases
- Check of units for fuel rate and emission factors
- Additional checks on database consistency.

The QC work will continue in future years.

6.8.1 Data deliveries

Table 6.8.1 lists the external data deliveries used for the waste emission inventory. Further, the table holds information on the contacts at the data delivery companies.

Table 6.8.1 List of external data sources.

Category	Data description	Activity data. emission factors or emissions	Reference	Contact(s)	Data agreement/ Comment	http. file or folder name
Solid waste disposal	Waste deposition	Activity data	Danish Environmental Protection Agency	Maja Hornung Thorndahl	Personal contact	
Composting	Waste composted	Activity data	Danish Environmental Protection Agency	Maja Hornung Thorndahl	Personal contact	
Home composting	Number of homes	Activity data	Statistics Denmark		Public access	www.statistikbanken.dk
Biogas production	Energy statistics	Activity data	Danish Energy Agency		Public access	https://ens.dk
Human cremation	Annual number of cremated persons	Activity data	Association of Danish Crematories		Public access	www.dkl.dk
Human cremation	Population statistics	Activity data	Statistics Denmark		Public access	www.statistikbanken.dk, BEF4
Animal cremation	Annual number of cremated carcasses	Activity data	Ada's Kæledyrskrematorium and Dansk Dyrekremering	Søren Sørensen	Personal contact	
Animal cremation	Annual number of cremated carcasses	Activity data	Kæledyrs-krematoriet	Annette Laursen	Personal contact	
Wastewater handling	Report series: *"Point sources"*	Activity data	Danish Environmental Protection Agency	Thomas Frank-Gopolos	Personal contact	
Accidental fires	Categorised fires	Activity data	The Danish Emergency Management Agency		Public access	https://statistikbank.brs.dk
Composting	Waste categories for composting	Activity data	Waste Statistics (Affaldsstatistik) (DEPA, 2023b)		Public access	https://www.ads.mst.dk/Default.aspx

6.9 Source-specific recalculations and improvements

Some recalculations have been made. See details for each emission sector below.

6.9.1 Solid waste disposal on land

For this year's submission, activity data has changed for 2010-2022 due to updates done by DEPA. The modelled CH_4 emissions - and thereby also NMVOC emissions, are reduced for 2011-2022 (0.1-2.1 tonnes NMVOC, i.e. 0.1-3.2%).

New data for average windspeed in Denmark results in increased particle emissions. TSP is increased by 222%, PM_{10} by 250% and $PM_{2.5}$ is increased by 200% for all years in the time series. As the total amount of deposited waste is reduced for 2010-2013 and increased for 2014-2022, the effect of the increased average windspeed is slightly counteracted for 2010-2013 and amplified for 2014-2022. The change in $PM_{2.5}$ emissions are 0.01-0.05 tonnes for each year in the time series.

6.9.2 Biological treatment of solid waste

Composting

Since last year's submission, activity data has changed for 2010-2022 due to updates done by DEPA and Statistics Denmark affecting all composting categories.

The resulting overall recalculation for sub-category 5.B.1 is between -51.1 tonnes CO (-5.4 %) in 2022 and +70.4 tonnes CO (+8.5 %) in 2016, and between -27.1 tonnes NH_3 (-4.2 %) in 2022 and +27.4 tonnes NH_3 (+4.6 %) in 2016.

Anaerobic digestion at biogas facilities

Emissions have been recalculated for all years 1985-2022 due to correction of an error. Correcting the N per PJ factor from 7.5 to 9.4 results in increases in the NH_3 emission. Increases are largest where the gas production is largest, i.e. most recent years. The resulting recalculation affect the entire time series between +0.02 tonnes NH_3 (+24%) in 1985 and +1.8 tonnes NH_3 (+25%) in 2022.

6.9.3 Waste incineration and open burning

An error in the activity data for human cremation for 1998 and 1999 was corrected. The error of -268 persons (-0.6%) and -440 persons (-1.0%) for the two years respectively, results in recalculations for all calculated pollutants of -0.6 % in 1998 and -1.0 % in 1999.

There are no recalculations for animal cremation.

6.9.4 Wastewater treatment and discharge

For this year's submission, NMVOC emissions were included for 1985-1989.

Smaller recalculations in the NMVOC emission also occur for 1999-2020 due to roundings in the activity data. The resulting recalculations are -0.03 kg NMVOC to +0.02 kg NMVOC, i.e. less than 0.01 % per year.

6.9.5 Other

Prior to this year's submission, smaller updates in the activity data from DEMA were provided for 2017-2019 and 2021-2022.

Emissions of BC, Se, HCB and PCB are new from accidental fires in this year's submission. And Ni and Zn are new additions from accidental building fires but were already included for vehicle fires.

An error was corrected for NMVOC from container fires, resulting in the emission factor to increase a factor three from 0.7 kg per tonne to 2.1 kg per tonne. But since container fires is a small contribution to the overall emissions from accidental fires, this correction only results in increases of 0.3-0.6 tonnes NMVOC (0.05-0.12 %).

6.10 Source-specific planned improvements

There are currently no planned improvements for this sector.

6.11 References

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7 Other and natural emissions

Denmark only reports emissions of NH_3 from dogs and cats in the NFR category "Other" (NFR 6).

Regarding natural emissions, volcanoes do not occur in Denmark and hence the category is reported as NO (Not Occurring).

Emissions from forest fires are for most years negligible but have not been estimated. Any other natural emissions, to be reported under NFR category 11C, have also not been estimated.

7.1 Description

A calculation method and emission factors are in EMEP/EEA Guidebook (2023) given for emission of NH_3 from pets. In the Danish inventory emission from dogs and cats are estimated and reported in sector 6A Other. Emission from horses are reported in sector 3 Agriculture.

7.2 Methodological issues

The method given in EMEP/EEA Guidebook (2023) are used.

7.3 Activity data

The number of dogs and cats are based on information's from the European Pet Food Federation (2024). Number is given for 2000, 2010, 2012, 2014 and 2016-2022. For dogs are the number of animals for the years 1985-1999 based on a linear trend and for 2001-2009 the numbers are based on interpolation. For cats are the number of animals for the years 1985-1999 and 2001-2009 based on a polynomial trend. For the years 2011, 2013 and 2015 the numbers are based on interpolation. No information is given for 2023 therefore are the numbers set at the same level as in 2022.

Table 7.1 Number of dogs and cats, unit 1 000.

	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Dogs	503	517	532	546	563	580	592	607	610	643	643
Cats	557	593	623	646	663	673	684	670	680	698	698

7.4 Emission factor

The emission factors given in EMEP/EEA Guidebook (2023) are used, 0.13 and 0.74 kg NH_3 per AAP for cats and dogs, respectively.

7.5 Emissions

Emission of NH_3 is shown in Table 7.2. The emissions are increasing from 1985 to 2023 due to increase in number of animals.

Table 7.2 Emission of NH_3, kt.

	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023
Dogs	0.37	0.38	0.39	0.40	0.42	0.43	0.44	0.45	0.45	0.48	0.48
Cats	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09

7.6 References

EMEP/EEA air pollutant emission inventory guidebook. 2023: Available at: https://www.eea.europa.eu/publications/emep-eea-guidebook-2023 (Feb. 2025).

European Pet Food Federation. 2024: European pet population and market data 2022. https://europeanpetfood.org/about/statistics/

8 Recalculations and Improvements

8.1 Recalculations

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

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

In improving the inventories, care is taken to consider implementation of improvements for the whole time series of inventories to make it consistent. Such efforts lead to recalculation of previously submitted inventories. This submission includes recalculated inventories for the whole time series. The recalculations are shown in Table 8.1 below. The table shows the difference between the latest and the previous submission, i.e. a positive number indicates an increase in emission.

Table 8.1 Recalculations by selected pollutants and main sectors.

NO_x, kt	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022
Stationary combustion		0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.08	-0.09
Mobile combustion	-1.13	-0.45	0.02	1.00	0.32	-0.18	-0.23	-0.19	-0.24	0.53
Fugitive emissions from fuels										
Industrial processes										
Agriculture	0.00	0.00	0.00	0.00	0.00	0.08	0.09	0.04	0.03	0.00
Waste									0.00	0.00
Total	-1.13	-0.45	0.02	1.00	0.33	-0.10	-0.15	-0.15	-0.29	0.44

NMVOC, kt	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022
Stationary combustion		0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.02	-0.04
Mobile combustion	-0.76	-0.41	-0.44	-0.37	-0.37	-0.19	-0.06	-0.05	-0.04	-0.05
Fugitive emissions from fuels	0.00	0.01	0.01	0.00	0.00	-0.83	-1.88	-2.92	-3.13	-18.98
Industrial processes					0.00	0.55	0.73	0.78	0.82	1.11
Agriculture					0.00		0.00	0.00	0.06	0.20
Waste	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	-0.75	-0.41	-0.43	-0.37	-0.37	-0.48	-1.22	-2.20	-2.33	-17.76

SO_2, kt	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022
Stationary combustion		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01
Mobile combustion	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fugitive emissions from fuels										
Industrial processes										
Agriculture										0.00
Waste									0.00	0.00
Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

NH_3, kt	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022
Stationary combustion							0.00	0.00	0.00	0.00
Mobile combustion	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02
Fugitive emissions from fuels										
Industrial processes										
Agriculture	-4.24	-3.68	-2.48	-1.31	-0.89	-0.24	-0.68	-1.16	-0.94	-1.17
Waste	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	-0.03
Total	-4.24	-3.68	-2.48	-1.31	-0.91	-0.25	-0.68	-1.15	-0.93	-1.22

TSP, kt	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022
Stationary combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02
Mobile combustion	NR	0.07	0.12	0.15	0.06	0.01	0.00	-0.01	-0.01	-0.01
Fugitive emissions from fuels	NR									
Industrial processes	NR	-0.02	-0.02	-0.03	-0.02	-0.02	-0.02	0.05	0.02	0.10
Agriculture	NR	-1.56	-1.65	-1.80	-1.84	-2.28	1.09	1.96	2.21	2.22
Waste	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	NR	-1.51	-1.56	-1.68	-1.79	-2.29	1.06	2.00	2.22	2.29

PM_{10}, kt	1985	1990	1995	2000	2005	2010	2015	2020	2021	2022
Stationary combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01
Mobile combustion	NR	0.06	0.11	0.13	0.05	0.00	-0.01	0.00	0.00	0.00
Fugitive emissions from fuels	NR									
Industrial processes	NR	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.01	0.00	0.03
Agriculture	NR	-0.16	-0.17	-0.18	-0.18	-0.23	0.11	0.20	0.23	0.23
Waste	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	NR	-0.10	-0.07	-0.06	-0.14	-0.23	0.09	0.21	0.22	0.24

Continued

$PM_{2.5}$, kt	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2021**	**2022**
Stationary combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01
Mobile combustion	NR	0.05	0.09	0.11	0.04	0.00	-0.01	0.00	-0.01	0.00
Fugitive emissions from fuels	NR									
Industrial processes	NR	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	-0.01
Agriculture	NR	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	0.01	0.01	0.01
Waste	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	NR	0.04	0.08	0.09	0.03	-0.02	-0.01	0.00	0.00	0.00

BC, kt	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2021**	**2022**
Stationary combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mobile combustion	NR	0.02	0.04	0.06	0.02	0.00	-0.01	0.00	0.00	0.00
Fugitive emissions from fuels	NR									
Industrial processes	NR					0.00		0.00	0.00	0.00
Agriculture	NR									0.00
Waste	NR	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02
Total	NR	0.05	0.07	0.08	0.05	0.02	0.01	0.02	0.02	0.02

CO, kt	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2021**	**2022**
Stationary combustion		0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.09	-0.19
Mobile combustion	-5.11	-1.29	-3.44	-3.38	-3.62	-1.96	-0.69	-0.69	-0.46	-0.54
Fugitive emissions from fuels										
Industrial processes					0.00	0.00	0.00	0.00	0.00	0.01
Agriculture										0.00
Waste						0.00	0.03	0.03	0.02	-0.05
Total	-5.11	-1.29	-3.44	-3.38	-3.62	-1.96	-0.67	-0.67	-0.53	-0.77

Pb, t	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2021**	**2022**
Stationary combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mobile combustion	NR	0.11	0.13	0.16	0.09	0.05	0.04	0.04	0.05	0.19
Fugitive emissions from fuels	NR									
Industrial processes	NR							0.00	-0.01	-0.01
Agriculture	NR									0.00
Waste	NR								0.00	0.00
Total	NR	0.11	0.13	0.16	0.09	0.05	0.04	0.04	0.05	0.18

Cd, t	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2021**	**2022**
Stationary combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mobile combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fugitive emissions from fuels	NR									
Industrial processes	NR							0.00	0.00	0.00
Agriculture	NR									0.00
Waste	NR								0.00	0.00
Total	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Hg, t	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2021**	**2022**
Stationary combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mobile combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fugitive emissions from fuels	NR									
Industrial processes	NR	-0.01	-0.01	-0.01	-0.01				0.00	0.00
Agriculture	NR									0.00
Waste	NR								0.00	0.00
Total	NR	-0.01	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00

Continued

PCDD/F, g I-TEQ	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2021**	**2022**
Stationary combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01
Mobile combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fugitive emissions from fuels	NR									
Industrial processes	NR				0.00	0.00	0.00	0.00	0.00	0.00
Agriculture	NR									0.00
Waste	NR								0.00	0.01
Total	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01

HCB, t	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2021**	**2022**
Stationary combustion	NR						0.00	0.00	0.00	0.00
Mobile combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fugitive emissions from fuels	NR									
Industrial processes	NR								0.00	0.00
Agriculture	NR									0.03
Waste	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03

BaP, t	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2021**	**2022**
Stationary combustion	NR	0.00	0.00			0.00	0.00	0.00	0.00	0.00
Mobile combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fugitive emissions from fuels	NR									
Industrial processes	NR				0.00	0.00	0.00	0.00	0.00	0.00
Agriculture	NR									0.00
Waste	NR								0.00	0.00
Total	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

PCBs, t	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2021**	**2022**
Stationary combustion	NR						0.00	0.00	0.00	0.00
Mobile combustion	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fugitive emissions from fuels	NR									
Industrial processes	NR								0.00	0.00
Agriculture	NR									0.00
Waste	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	NR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

NR = Not Reported. This notation key is used for years preceding the base year of the relevant protocol.

0.00 indicates that the recalculation is between -0.0049 and 0.0049.

The reasoning for the recalculations performed is to be found in the sectoral chapters of this report. For sector specific planned improvements please also refer to the relevant sectoral chapters.

8.2 Improvements

Improvements are continuously made to the extent that resources allow. Priority is given to key categories with a significant impact on the national total emissions.

Improvements are most often initiated by the inventory team, but improvements can also be caused by recommendations through national or international reviews.

8.2.1 Improvements in response to the review process

In 2017, there was the first review under the National Emission Ceilings Directive. The review formulated a number of recommendations for the Danish inventory mostly related to transparency. This review has been followed up annually since with additional reviews focussing on following up on the outcome of the previous reviews and additional focus areas. The recommendations contained in the latest review report[1], recommendations due for the next reporting of gridded and LPS data and the responses by Denmark as to the current state of implementation are provided in Table 8.2.

[1] https://environment.ec.europa.eu/topics/air/reducing-emissions-air-pollutants/emissions-inventories_en

Table 8.2 Recommendations form the 2024 review under the NECD and recommendations related to gridded and LPS reporting and responses by Denmark.

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Response by Denmark
DK-1A1b-2024-0001	Yes	1A1b Petroleum refining, SO_2, 2021, 2022	For category 1A1b Petroleum refining, for the pollutant SO_2, for the years 2021 to 2022 the TERT notes that there is a lack of transparency regarding a relatively large year to year change in emissions. This does not relate to an over- or under-estimate of emissions. In response to a question raised during the review, Denmark explained that emissions are due to variation in operation in the refining sector and although a large year to year change, reflect variation in refinery operation and relate to a shutdown and startup of one refinery. The TERT recommends that Denmark provide commentary to explain this issue and any other relatively large year to year variations in emissions in the next submission.	No	The explanation has been added in Chapter 3.2.5
DK-1A4bi-2024-0001	No	1A4bi Residential: Stationary, NH_3, 1990-2022	For category 1A4bi Residential: Stationary for NH_3 for years 1990-2022, the TERT notes that there is large variation in wood use across the time series and a lack of transparency regarding how activity data have been allocated between a range of biomass technology types. This does not relate to an over- or under-estimate of NH3 emissions. In response to a question raised during the review, Denmark explained that wood activity is from national energy statistics and that technology classes were developed from a 2021 study which was based on various inputs including developments in legislation and surveys of households and the residential heating industry. Activity is allocated using a model which accounts for the different classes of appliance but activity use is scaled to total wood use in energy statistics which can mean that a large change in total energy statistics is reflected in energy allocated to individual appliance types. The TERT recommends that Denmark include commentary to explain the technology classes used for wood fuel, reasons for historic change in appliance fuel use and review the residential model for energy allocation to separate (for example) activity changes due to annual variation in weather and other factors such as scrappage schemes or new appliance installations, in the next submission.	No	The information is included in Chapter 3.2.7, Residential wood combustion. This chapter is 15 pages and includes a reference to the methodology report for residential combustion. However, a reference to this chapter will be added in IIR Chapter 3.2.5 1A4b i Residential plants. In addition, further comments to the residential plant time series (including NH_3) will be added in Chapter 3.2.5.
DK-LPS-E-2021-0001	NA	E Solvents, 2019	The TERT noted that for the year 2019, emissions are reported for NFR code 2D3g Chemical Products in the national inventory but not for GNFR code E_Solvents in the LPS submission. The TERT would expect emissions to be reported for this GNFR given that emissions are reported for these source categories in the national inventory. In response to the review Denmark explained that the inventory for solvents is based on a top-down approach which means that the inventory methodology is not compatible with using information from individual plants, as highlighted this in the IIR Chapter 10.4. The TERT recommends that Denmark consider developing an approach which enables reporting of emissions in GNFR sector E_Solvents, particularly for the 3 large plants identified in Table 10.3 of the IIR.	No	Denmark disagrees with this recommendation. Denmark is currently using a higher tier method to estimate NMVOC emissions from solvent use. This method is not compatible with reporting for single point sources. There is no basis in the reporting guidelines or the directive for the TERT to recommend that Denmark changes it current higher tier methodology.
DK-GRID-GEN-2021-0001	NA	General, NOX, NH3, NMVOC, Cd, Pb, PCDD/F, CO, 2019	The TERT notes with reference to Annex V submitted in 2021, that there are a number of locations (grid cells) where gridded and LPS data are inconsistent. The TERT had compared gridded emissions for each grid cell with LPS emissions (allocated to the respective grid cell), where several inconsistencies were found, i.e. cases where LPS emissions exceeded gridded emissions. In response to a question raised during the review, Denmark explained that the Danish gridding model are based on the national 1 km x 1 km grid (DKN) and for reporting purposes, the emissions are allocated to the 0.1 degree x 0.1 degree EMEP grid (EMEP). The allocation is done using weighting factors for the share of area of each DKN grid cell allocated in relevant EMEP cells. In the 2021 submission, the allocation is done for the total emissions including LPS emission. Hence, in cases where a given LPS is located in a DKN cell, which overlap more EMEP cells, the LPS emissions are split to these EMEP cells. This method will be changed in the next submission, so that LPS emissions are excluded from the	No	This has been implemented in the 2025 reporting.

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Response by Denmark
			area-weighted allocation and added afterwards to ensure that the total LPS emissions are allocated to the correct EMEP cell.. The TERT recommends that for the next submission, Denmark changes the process for reporting on the EMEP grid as outlined to avoid any inconsistencies between the LPS reporting and the gridded reporting and that the process for generating the gridded reporting is explained in chapter 11 of the IIR.		

9 Gridded emissions

The gridded emissions were last reported on 1 May 2021 and an updated dataset of gridded emissions will be reported on 1 May 2025. The information contained in this chapter is consistent with the information in the 1 May 2025 reporting. The next submission is planned for 1 May 2029.

This chapter include descriptions on input data, methodology and results of the Danish gridded emissions for the year 2023. A detailed methodological description is given in Plejdrup et al. (2021).

The gridded emissions are consistent with the national total emissions reported in the NFR template submitted 15 February 2025 and includes all emissions, i.e. including LPS emissions. The gridded emissions incorporate the LPS emissions so full consistency is ensured. For further information on the LPS emissions, please refer to Chapter 10.

9.1 Background for reporting

According to the UNECE Convention on Long-Range Transboundary Air Pollution parties are obligated to report gridded emissions.

In December 2013, the Executive Body for the Convention on Long-range Transboundary Air Pollution adopted new reporting guidelines, which include requirement of four-year reporting of gridded emissions from 2017. The new reporting guidelines have been implemented for gridded emissions.

In the 2025 reporting cycle Denmark report gridded emissions for the year 2023. The mandatory reporting of gridded emissions includes the following 13 pollutants: NO_x, NMVOC, SO_x, NH_3, $PM_{2.5}$, PM_{10}, BC, CO, Pb, Cd, Hg, PCDD/PCDF (dioxins/furans), PAHs (benzo(b)flouranthene, benzo(k)flouranthene, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene), HCB and PCBs. The reporting includes GNFR sectoral emissions as well as national total emissions disaggregated to the standard EMEP grid with a resolution of 0.1 degree x 0.1 degree. Table 9.1 lists the categories (sectors) used for reporting gridded emission data based on the Danish inventories.

Table 9.1 GNFR categories and corresponding NFR categories and SNAP categories in the Danish gridded emission inventory.

GNFR	NFR	SNAP	Note
A_PublicPower	1A1a	0101, 0102	
B_Industry	1A1b, 1A1c, 1A2a, 1A2c, 1A2d, 1A2e, 1A2f, 1A2gviii, 2A1, 2A2, 2A3, 2A5a, 2A5b, 2A5c, 2A6, 2B10a, 2B7, 2C1, 2C5, 2C7c, 2D3b, 2D3c, 2H2, 2I, 2L	0103, 0105, 0301, 0303, 0304, 0306, 0307, 0308, 0309, 0310, 0311, 0312, 0313, 0314, 0315, 0316, 0320, 0402, 0403, 0404, 0405, 0406	
C_OtherStationaryComb	1A4ai, 1A4bi, 1A4ci	0201, 0202, 0203	
D_Fugitive	1B1a, 1B2ai, 1B2aiv, 1B2av, 1B2b, 1B2c	0401, 0501, 0502, 0503, 0505, 0506, 0902	
E_Solvents	2D, 2D3a, 2D3d, 2D3f, 2D3g, 2D3h, 2D3i, 2G	0601, 0602, 0603, 0604, 0605, 0606	
F_RoadTransport	1A3bi, 1A3bii, 1A3biii, 1A3biv, 1A3bv, 1A3bvi, 1A3bvii	0701, 0702, 0703, 0704, 0705, 0706, 0707, 0708	
G_Shipping	1A3dii	080402	
H_Aviation	1A3ai(i), 1A3aii(i)	080501, 080502	
I_Offroad	1A2gvii, 1A3c,1A4aii, 1A4bii, 1A4cii, 1A4ciii, 1A5b	0801, 0802, 0803, 080403, 0806, 0807, 0808, 0809, 0811	
J_Waste	5A, 5B1, 5B2, 5C1bv, 5D, 5D1, 5D2, 5E	0904, 0909, 0910, 0911, 091	
K_AgriLivestock	3B1a, 3B1b, 3B2, 3B3, 3B4d, 3B4e, 3B4gi, 3B4gii, 3B4giii, 3B4giv, 3B4h	*	
L_AgriOther	3Da1, 3Da2a, 3Da2b, 3Da2c, 3Da3, 3Da4, 3Dc, 3De, 3Df 3F, 3I	*	
M_Other	6A	1107	
N_Natural			NO
O_AviCruise	1A3ai(ii), 1A3aii(ii)	080503, 080504	
P_IntShipping	1A3di(i)	080404	
z_Memo			NO

* The Danish national emission inventory system for agriculture builds on NFR categories and not SNAP categories as is the case for the remaining sectors in the Danish emission inventory system.

The Guidelines used for this reporting are included in UNECE (2015). The methodology in Danish emission gridding model SPREAD follows the EMEP/EEA Guidebook (EEA, 2019). The gridded emission data in the 2025 reporting will be made available at the EIONET Central Data Repository homepage:

https://cdr.eionet.europa.eu/dk/un/clrtap

Further, a detailed methodological description is given in Plejdrup et al. (2021).

9.2 Methods and data for disaggregation of emission data

A national model for high-resolution spatial distribution of emissions to air, the SPREAD model, has been developed at Department of Environmental Science, Aarhus University. SPREAD includes all sources and pollutants in the Danish emission inventory system, and generates emissions on a resolution of 1 km x 1 km.

SPREAD covers the area defined by the Exclusive Economic Zone (EEZ) and the national border. Denmark is geographically the peninsula of Jutland and 443 named islands and islets, of which approximately 72 are inhabited. The country is in Scandinavia neighbouring the sea (the Baltic Sea, Skagerrak, Kattegat and the North Sea) as well as Germany, which Jutland are adjacent to the south (Figure 9.1).

The spatial emission distribution is carried out on the most disaggregated level possible and therefore SPREAD includes many distribution keys related to single sources, subcategories or sectors. Gridded emissions reported to UNECE LRTAP are based on the results from SPREAD, aggregated on the 0.1 degree x 0.1 degree EMEP grid.

The spatial distribution in SPREAD is based on several national geographical data sets. As the model is very complex and include many spatial data, only the most important input data and methodology descriptions are included in the IIR report. For a more detailed description, please refer to Plejdrup et al. (2021).

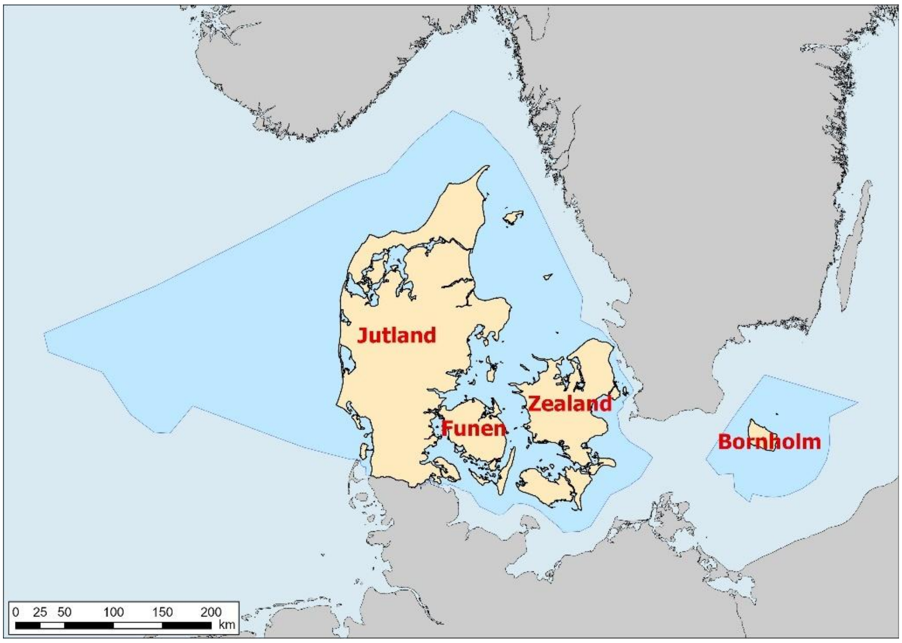


Figure 9.1 Map of Denmark including names of regions and the Exclusive Economic Zone.

9.2.1 The SPREAD model

The distribution in SPREAD is made on SNAP category level to assure the most accurate distribution of the emissions. It has been aimed to use the most disaggregated SNAP level (SNAP 3 level) but for some categories and sectors SNAP 2 or SNAP 1 level has been applied in the distribution model, due to a lack of detailed geographical information. An exception is the agricultural sector, as this sector is not treated on SNAP level in the Danish inventory system. Instead, the agricultural data processing is carried out for the relevant NFR categories, and the same approach is applied in SPREAD. The SPREAD model is prepared to be applicable for the mandatory reporting of gridded emissions under CLRTAP.

Emissions from all Large Point Sources (LPS) are treated separately in SPREAD. LPSs represent emissions at all SNAP 1 categories except solvents (SNAP 06), road traffic (SNAP 07) and agriculture. Point Sources, for which the fuel consumption is known at plant level, but emissions are calculated using standard emission factors, are included as point sources with an exact location in SPREAD.

General methodology

The distribution of emissions in the Danish emission inventory is carried out in an integrated MS SQL and MS Access database system and in the geographical information system (GIS) ArcGIS.

The methodology applied in the part of the distribution carried out in GIS is shortly described in this chapter. The description is made for Non-Metallic Minerals as a case, as this distribution is rather simple.

The emission inventory for Non-Metallic Minerals covers both point sources and area sources. Emissions from point sources are allocated to the coordinates for the individual plants included in the Danish inventory system and are not relevant in relation to the GIS procedure. Emissions from area sources are calculated from production statistics and the resulting emissions are national totals as allocation of the sources (non-metallic minerals plants) is not possible with the available data. Instead, a proxy for the distribution is applied, in this case the location of industrial areas as given in the national topographic map KORT10 by the National Survey and Cadastre (Figure 9.2). The map of industrial areas is not reflecting differences in the location for different industries but only holds industrial buildings (referred to as the industrial area as the buildings are treated as areas rather than units). The map is a shape file, and the industrial areas are polygons.

Figure 9.2 Segment around Avedoere (close to Copenhagen) of the map of industrial areas (KORT10).

As SPREAD gives emissions on 1 km x 1 km, the map of industrial areas must be combined with the Danish 1 km x 1 km Grid Net. The grid is an orthogonal coordinate system, and the cells are defined and named by their lower left corner coordinates. The grid net map is a shape file, and the grid cells are polygons (Figure 9.3).

Figure 9.3 Segment around Avedoere in Copenhagen of the map of the Danish 1 km x 1 km grid net (KORT10).

To be able to distribute the emissions on 1 km x 1 km it is necessary to split the industrial polygons between the grid cells and thereby be able to calculate the industrial area in each grid cell (Figure 9.4). These functionalities are available in GIS, in this case ArcGIS. The split is made using the intersect tool, and afterwards the areas are applied to each cell using the Calculate Area function.

Figure 9.4 Segment around Avedoere in Copenhagen of the map of industrial areas and the Danish 1 km x 1 km grid net (KORT10).

The remaining part of the emission distribution for Non-Metallic Minerals is carried out in a database. The share of the national emissions that should be allocated to each grid cell is calculated as the industrial area of the cell divided by the total industrial area. The same distribution key is applied for all pollutants.

In the case of the Non-Metallic Minerals only one map is combined with the grid, but more maps or layers can be combined to make a distribution key. This is the case e.g. for emissions from organic soils in the agricultural sector, where the distribution key is based on a map of organic soils, a map of the agricultural fields and the Danish Grid Net. Some area sources are distributed to line features, e.g. emissions from road traffic. In these cases, the lines are split into segments by intersection with the 1 km x 1 km grid net. The emission in each grid cell is calculated as the national emission multiplied by the length of the line segment(s) in the cell and divided by the total length of the line feature.

For some sources the same distribution key can be applied for more or all years, while other sources demand a separate distribution key for each year. For Non-Metallic Minerals the distribution key can be applied for more years, as the dataset is not available on annual basis. Further, the industrial area does not change much from year to year. In other cases, the distribution keys must be set up on annual basis as large changes occur from year to year. This is the case e.g. for agricultural soils and for plants with annual emissions data and or fuel consumption data in the energy sector and the industrial sector.

National geographical data

Many national geographical data sets are implemented in the SPREAD model in preparation of the various distribution keys. The data sets are listed in Table 9.2 with specification of data owner and a short description of the content of each data set.

Table 9.2 Non-exhaustive list of geographic data applied in the emission gridding.

Data owner	Data set	Contents
The National Survey and Cadastre	Topographic map	Geo-referenced basic map layers on administrative units, Land cover, territorial borders, coastline and infrastructure.
The National Agency for Enterprise and Construction	Central Dwelling and Building Register (Danish abbreviation BBR)	Geo-referenced information on dwellings and buildings
The Directorate for Food, Fisheries and Agri Business	The Central Husbandry Register (CHR)	Information on stock of livestock at farm level
	The General Agricultural Register (GLR)	Information on agricultural farms and crops on field level
Ministry of food, agriculture and fisheries	The Fertilizer and Husbandry Register (Danish abbreviation GHI)	Information on manure and fertiliser amounts on farm level
	The Land Parcel Identification System (LPIS)	Geo-referenced data on agricultural land parcels, including field IDs for fields located in the parcels
The Central Business Register	Central Business Register (Danish abbreviation CVR)	Geo-referenced information on businesses with a CVR number, e.g. farms
Centre for Integrated Register-based Research (CIRRAU)	The Civil Registration System (Danish abbreviation CPR)	Geo-referenced information on population on address level
The Department of Environmental Science, Aarhus University	National road and traffic database	Geo-referenced traffic load on the Danish road network
The Danish Energy Agency	Energy producer accountings	Geo-referenced information on fuel consumption for district heating and/or power producing plants
	The regional inventory	Regional inventory of energy consumption for heating for oil boilers, natural gas boilers and solid fuel installations on municipality level
	Off-shore oil/gas facilities	Map of oil and gas production facilities in the North Sea
The Danish Chimneysweeper Association	Small combustion appliances (SFL)	Location and types of small combustion appliances in Denmark
DCE - Danish Centre for Environment and Energy	Large Point Sources (LPS)	Geo-referenced information on power plants, large industrial plants and offshore installations
Danish Petroleum association	Service stations	Geo-referenced information on addresses for all Danish service stations
The Danish Road Directorate	Road construction	Map of major and minor road construction work
Aarhus University	The Danish land use matrix (LUM)	Geo-referenced data on agricultural areas and forest areas
Energinet.dk	Measurement and regulator stations	Geo-referenced information on location of measurement and regulator stations in the Danish natural gas transmission network
The Danish Forest and Nature Agency	Military training terrain	Geo-referenced information on military training terrains
The Danish Environmental Protection Agency	Information system for waste and recycling (Danish abbreviation ISAG)	Data on waste treatment companies on address level
The Danish Nature Agency	Waste water treatment	Annual BI5 data per wastewater treatment plant
Statistics Denmark	Employment statistics	Annual number of employed by region and industry
The Danish Road Directorate	Road construction projects	Map of larger road construction projects

9.3 Gridded emission data

In this section selected maps of gridded emissions are presented, all referring to the year 2023. The selected maps in the figures 9.5 to 9.10 illustrate the emissions included in the national total in the NFR table (all emissions excluding Civil Aviation - Domestic and International Cruise, and International Maritime Navigation). All figures illustrate the sum of all included GNFR sectors. The Danish high resolution gridded emissions are aggregated on the 0.1 degree x 0.1 degree EMEP grid for reporting to CLRTAP. The share of each 1 km x 1 km grid cell located in the relevant EMEP grid cells are calculated and the aggregated emissions are calculated as the weighted sum of emissions in the 1 km x 1 km grid cells intersecting each EMEP grid cell being partial or fully part of the Danish Exclusive Economic Zone, EEZ. On the 0.1 degree x 0.1 degree aggregated level spatial patterns from the major sectors are visible for different pollutants, but the high resolution results in SPREAD provides even more detailed data.

9.3.1 NOx

The major GNFR source to NO_x emissions is F_RoadTransport followed by L_AgriOther, I_Offroad, A_PublicPower and B_Industry contributing 24 %, 20 %, 14 %, 12 % and 11 %, respectively. The pattern of the gridded NO_x emissions reflects the major road network located in the eastern part of Jutland and across Funen and Zealand to Copenhagen. The large emission from agricultural soils is causing a large 'background emission' that obscures the spatial pattern somewhat. Further, large emissions from PublicPower and Industry are seen around the major cities. Part of the fugitive emissions is located offshore, due to extraction of oil and gas on the North Sea. See Figure 9.5.

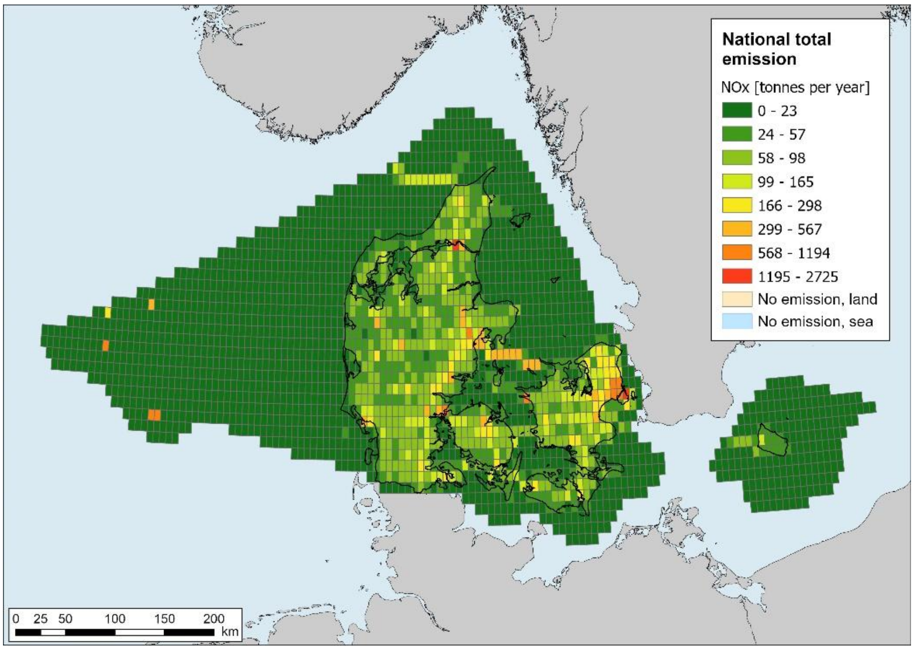


Figure 9.5 National total gridded emissions excluding civil aviation and international navigation of NO_x for the year 2023.

9.3.2 NMVOC

The major source of NMVOC is K_AgriLivestock followed by E_Solvents, C_OtherStationaryComb, L_AgriOther, D_Fugitive and F_RoadTransport contributing 38 %, 28 %, 8%, 8 %, 5 %, and 4 %, respectively. Emissions from Solvents, OtherStationaryComb and Offroad are to a large degree allocated according to population density, location of one-storey settlements and to addresses with woodstoves. Part of the fugitive emissions is located offshore due to extraction of oil and gas on the North Sea. See Figure 9.6.

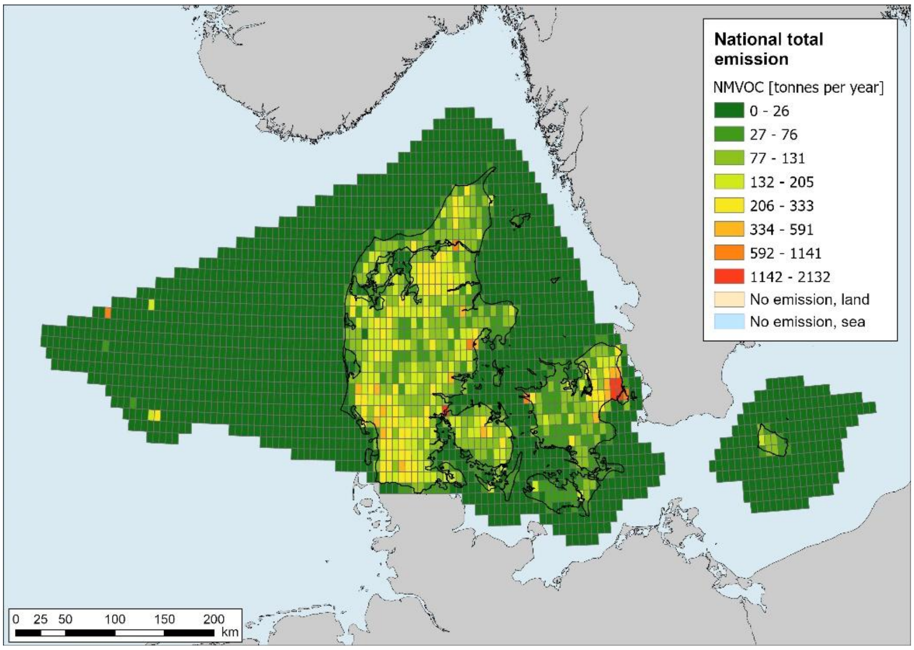


Figure 9.6 National total gridded emissions excluding civil aviation and international navigation of NMVOC for the year 2023.

9.3.3 SO_2

The major sources of SO_2 are B_Industry, A_PublicPower and D_Fugitive followed by C_Other StationaryComb contributing 26 %, 26 %, 23 %, and 12 %, respectively. Even though the SO_2 emission has decreased over the years due to implementation of techniques for reduction of sulphur in the flue gas, it still produces a distinct pattern reflecting the location of large power plants in Denmark. The allocation of emissions from Industry reflects the location of many CHP plants not reported as LPS due to no plant specific emission factors. SO_2 emissions from Fugitive is mainly from refineries. The main source to SO_2 emissions from OtherStationaryComb is strawfired plants in agricultural and residential buildings.

For the ferries operating between Copenhagen and Bornholm and routes to Greenland and the Faroe Islands part of the route is outside the Danish EEZ. The emissions from all these ferries are included in Shipping and distributed on the part of the route line located inside the Danish EEZ. This leads to an aggregation of the emissions in few EMEP cells, and thereby artificial high emissions at the part of the route inside the EEZ. See Figure 9.7.

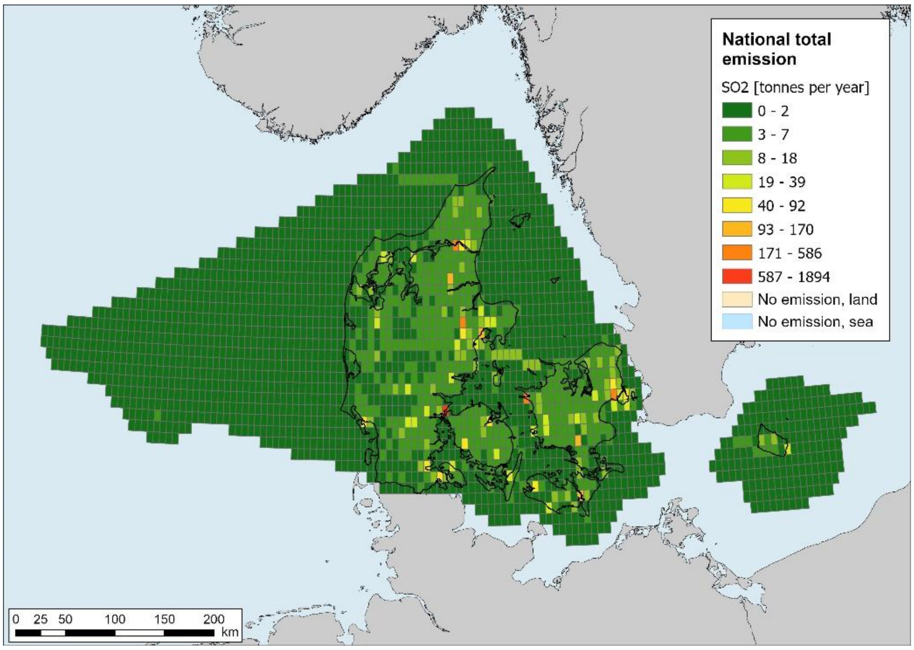


Figure 9.7 National total gridded emissions excluding civil aviation and international navigation of SO_2 for the year 2023.

9.3.4 NH_3

The agricultural sector is by far the major contributor to the NH_3 emission. 58% of the national emissions excluding civil aviation and international navigation derive from L_AgriOther and another 38 % from K_AgriLivestock. Emission of NH_3 is mainly related to livestock farming and especially to manure management and its application to soil. Emissions are distributed according to very detailed data on animals and fields, and the geographical pattern is in good agreement with the localisation of the major Danish livestock farming in Jutland. See Figure 9.8.

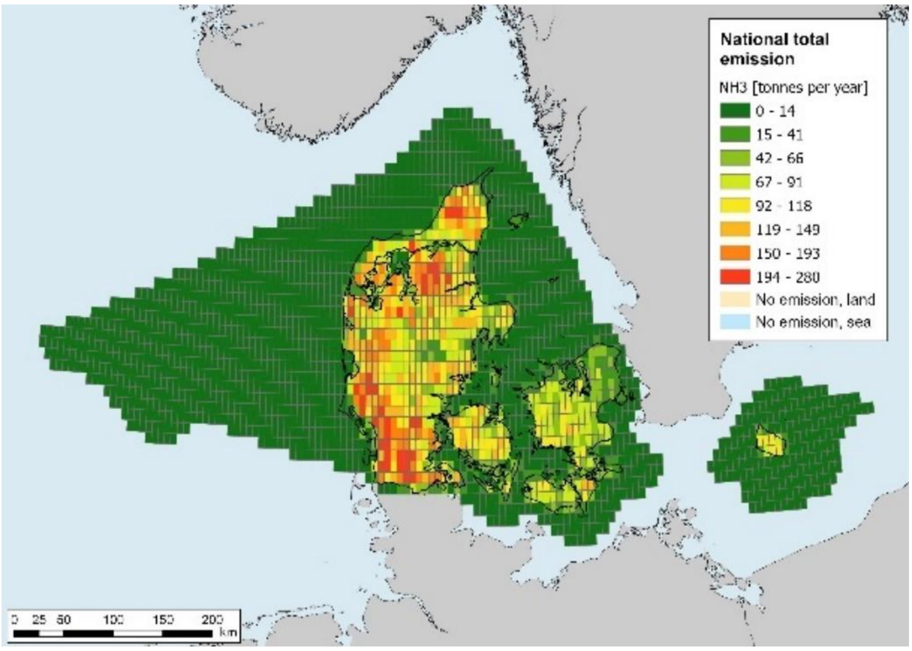


Figure 9.8 National total gridded emissions excluding civil aviation and international navigation of NH_3 for the year 2023.

9.3.5 $PM_{2.5}$

The major source of $PM_{2.5}$ emissions is C_OtherStationaryComb contributing 59 %. RoadTransport is the second largest source contributing 10 % of the $PM_{2.5}$ emission. Residential wood combustion is an important source in OtherStationaryComb. Emissions from OtherStationaryComb are allocated based on detailed information from the Danish chimney sweepers association. See Figure 9.9.

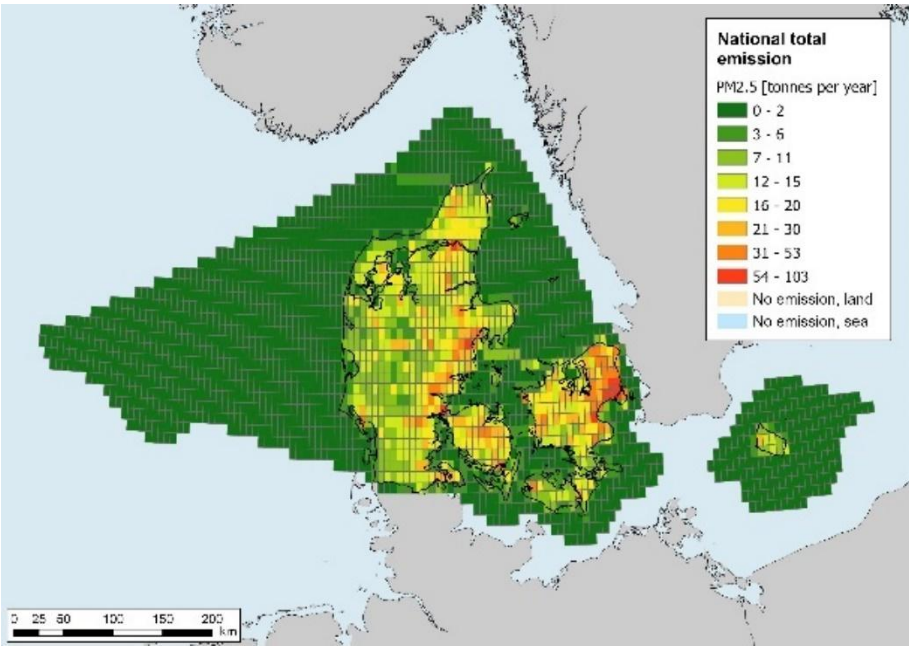


Figure 9.9 National total gridded emissions excluding civil aviation and international navigation of $PM_{2.5}$ for the year 2023.

9.3.6 Benzo(a)pyrene

The major source to emissions of benzo(a)pyrene (BaP) in Denmark is C_OtherStationaryComb contributing 87 %. Hereof the all-important source is residential wood combustion Emissions from OtherStationaryComb are allocated based on detailed information from the Danish chimney sweepers association. See Figure 9.10.

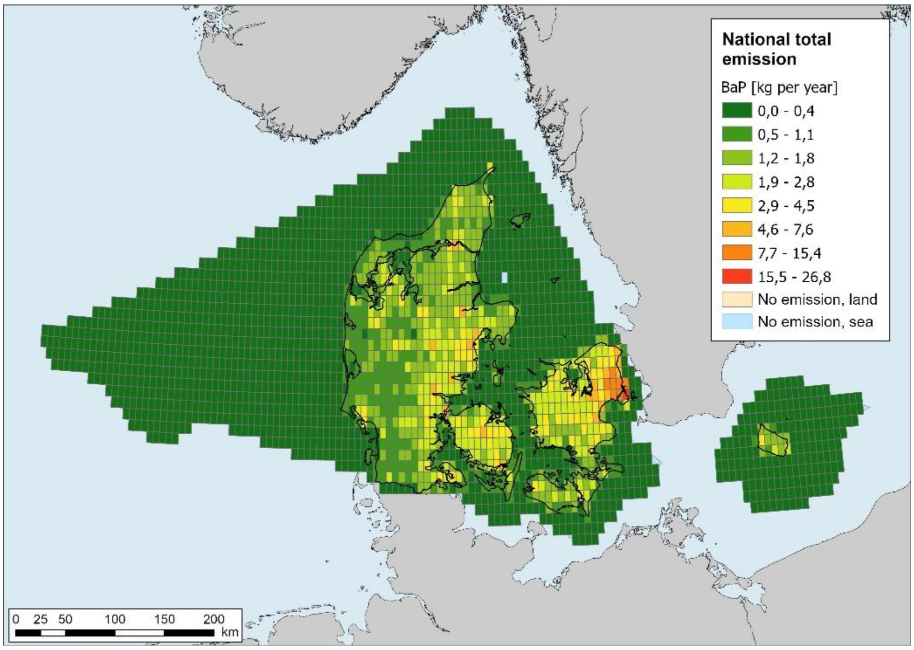


Figure 9.10 National total gridded emissions excluding civil aviation and international navigation of benzo(a)pyrene for the year 2023.

9.4 References

EEA, 2019: EMEP/EEA air pollutant emission inventory guidebook - 2019 Available at:
https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (10-01-2023).

Plejdrup, M.S., Nielsen, O.-K., Gyldenkærne, S. & Bruun, H.G. 2021: Spatial high-resolution distribution of emissions to air – SPREAD 3.0. Aarhus University, DCE – Danish Centre for Environment and Energy. In prep.

UNECE, 2015: Guidelines for Reporting Emissions and Projections Data under the Convention on Long-range Transboundary Air Pollution (ECE/EB.AIR/128). Available at:
https://unece.org/fileadmin/DAM/env/documents/2015/AIR/EB/English.pdf (10-01-2023).

10 Large Point Sources

Reporting of large point sources (LPS) is mandatory every four years. The next deadline is 1 May 2025. The information in this chapter is consistent with the data submission made on 1 May 2025.

The Danish emission inventory makes use of point source data, where emissions are available at point source level, either through annual measurements or established plant-specific emission factors. The definition of point sources in the inventory differs from e.g. the PRTR definition. Under PRTR, large pig and poultry producing sites are considered as point sources. However, as these facilities do not have any annual measurements or site-specific measurements, they do not fall within the definition of a point source in the inventory. For that reason, there are no agricultural farms included in the LPS reporting. The data reported under the PRTR is calculated by the emission inventory team and as such the methodology is consistent and the result would not differ, if it were included as LPS.

Another difference between the PRTR reporting and the LPS reporting is for solvent use. The Danish inventory is based on a top-down approach for a number of specific solvents; see Chapter 4 for further information. As companies usually does not disclose the specific solvents used in the production it is not possible to harmonise the inventory methodology with data reported under PRTR. It should also be noted that PRTR reporting only consists of an emission value with no supporting documentation. The specific differences between the datasets are discussed in Chapter 10.4.

10.1 Reported LPS emissions

The Danish LPS inventory consists of many facilities. The general rule of thumb for including a facility as LPS is that plant-specific information should be available so that the emission estimate is more accurate than if the facility was handled as part of a group, i.e. as an area source. In the Danish LPS inventory, all CHP plants with a capacity of more than 25 MW_e are included. The same with all waste incineration plants and refineries. For industrial point sources, there is no fixed definition other than the before mentioned that plant-specific data need to be available and the emissions should not be insignificant. A graphical illustration of the Danish LPS in 2023 (without considering pollutant thresholds) is provided in Figure 10.1.

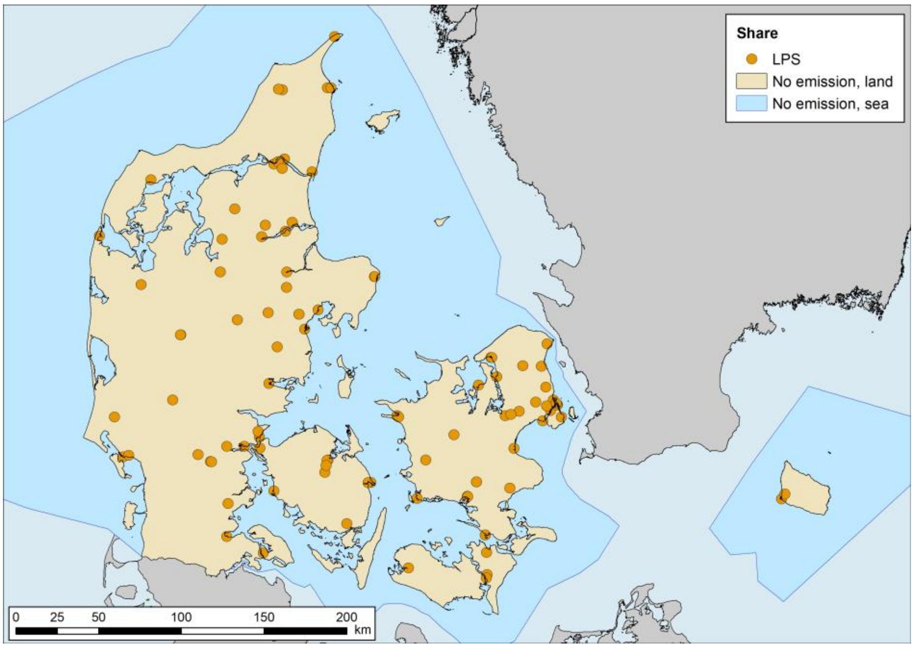


Figure 10.1 Location of Danish LPS in 2023.

In many cases, a LPS consists of multiple parts, e.g. a power plant can have multiple boilers. In some cases, they will have different stacks (and sometimes of different heights) and in other cases the flue gas from multiple boilers are emitted using the same stack, sometimes with separate channels in the stack.

The LPS reporting does not cover the full range of pollutants covered by the inventory as only a subset is required in the reporting guidelines (UNECE, 2023). The pollutants included and the threshold value for reporting is shown in Table 10.1.

Table 10.1 List of pollutants and threshold values.

Pollutant	Threshold (kg/year)
SO_x	150 000
NO_x	100 000
CO	500 000
NMVOCs	100 000
NH_3	10 000
$PM_{2.5}$	50 000
PM_{10}	50 000
Pb	200
Cd	10
Hg	10
PAHs	50
PCDD/F	0.0001
HCB	10
PCBs	0.1

The relatively high threshold values mean that for the majority of pollutants, only very few Danish LPS exceed the threshold values.

Emissions are reported for a LPS, only if the emission exceeds the threshold value listed in Table 10.1. The emission is calculated on a part level. However, the whole plant is considered in the reporting, e.g. in case of a power plant, with three boilers with individual stacks, where the emission for one part exceeds the threshold, but for the other two parts emissions are below all three parts are included in the reporting. If a boiler has a different stack height class then it will be reported even though the emission will be below the threshold.

The number of LPS reported for each pollutant for 2023 are shown in Table 10.2. It is seen that NO_x is the pollutant where most Danish LPS exceeds the threshold. However, for the heavy metals and persistent organic pollutants, there are very few or none LPS exceeding the threshold.

Table 10.2 Number of LPS exceeding the threshold value in 2023.

Pollutant	Number
SO_x	5
NO_x	26
CO	4
NMVOCs	4
NH_3	5
$PM_{2.5}$	0
PM_{10}	1
Pb	3
Cd	1
Hg	0
PAHs	1
PCDD/F	4
HCB	0
PCBs	0

10.2 Consistency with the emission inventory

The underlying purpose of the LPS reporting is to provide improved input for air quality modelling; as such, the reporting of LPS data only makes sense if they are consistent with the emission inventory. In the Danish inventory, the LPS emissions are an integrated part of the national emission inventory. For example, the fuel consumption used in LPS is subtracted from the national energy statistics and the residual fuel amount is considered as area source consumption. In cases where a plant does not report an emission for one year, an emission is calculated using an emission factor to ensure a consistent time-series.

The need for consistency is also, why PRTR emissions are not automatically considered LPS emissions in the inventory.

10.3 Use of LPS data in gridded emissions

The full LPS dataset in the Danish emission database system is used in the spatial distribution of emissions. The thresholds used for LPS reporting are not used and all LPS emissions are considered when gridding emissions. For more information, please see Chapter 9 and Plejdrup et al. (2021).

10.4 Comparison with PRTR data

As mentioned previously, there are a number of important differences between PRTR data and the inventory. This is especially the case for agriculture and solvents, where PRTR includes facilities as point sources that are not considered LPS in the Danish inventory, due to the reasons outlined previously on the consistency with the inventory.

PRTR only includes emissions of PM_{10} and not $PM_{2.5}$, while there is a reporting requirement for LPS emissions of both.

The data used for comparison with the inventory data are collected from a website hosted by the Danish Environmental Protection Agency (DEPA, 2021). The data used were correct as of 1 January 2025.

Some specific examples on facilities reporting emissions above the threshold in the PRTR, yet are not included in the Danish LPS inventory or reporting are provided in Table 10.3 with the reason for the exclusion.

Table 10.3 List of PRTR facilities not included in the LPS reporting.

Facility	Pollutant	Reason
Novo Nordisk A/S	NMVOC	The emission relates to use of solvents. This is not compatible with the Danish emission inventory methodology.
AarhusKarlshamn Denmark A/S	NMVOC	The emission relates to use of solvents. This is not compatible with the Danish emission inventory methodology.
AMCOR FLEXIBLES HORSENS	NMVOC	The emission relates to use of solvents. This is not compatible with the Danish emission inventory methodology.

In addition to the mentioned facilities in Table 10.3, all agricultural facilities are excluded, as they are not considered as point sources in the inventory.

10.5 References

DEPA, 2025: Miljøoplysninger (Environmental information). Website of the Danish EPA collecting environmental reporting from companies used for the PRTR reporting. Available at: https://dma.mst.dk/prtr/offentlig

Plejdrup, M.S., Nielsen, O.-K., Gyldenkærne, S. & Bruun, H.G. 2021: Spatial high-resolution distribution of emissions to air – SPREAD 3.0. Aarhus University, DCE – Danish Centre for Environment and Energy, 186 pp. Scientific Report from DCE – Danish Centre for Environment and Energy. (In press).

UNECE, 2023: Guidelines for Reporting Emissions and Projections Data under the Convention on Long-range Transboundary Air Pollution. ECE/EB.AIR/150/Add.1. Available at: https://www.ceip.at/fileadmin/inhalte/ceip/1_reporting_guidelines2014/ece_eb.air_150_add.1_2305250e__1_.pdf

11 Projections

Reporting of projections is mandatory every two years. The information in this chapter is consistent with the data submission made on 15 March 2025.

Projections of emissions are carried out by DCE periodically. The most recent projection was made in 2022, projecting the emissions of NO_x, SO_2, NMVOC, NH_3, TSP, PM_{10}, $PM_{2.5}$ and BC to 2040. This projection is reported to the EU and UNECE on 15 March 2025. This projection was based on the historic inventory until 2022 reported to the EU and UNECE on 15 February 2024. The projections therefore do not reflect recalculations in the historic emissions as reported in this report.

Recalculations have occurred with varying impact on the national total emissions across all sectors and pollutants. These recalculations will have an impact on the projections when the projections are updated, expectedly in 2026.

The total projected emissions for these pollutants for 2025, 2030, 2035 and 2040 are shown in the table below together with the historic emissions for 2005 and 2020 (as reported in 2024). The general methodology is based on the methodologies used in the emission inventory as documented in this report.

Table 11.1 2005 and 2020 emissions and projected emissions for 2025, 2030, 2035 and 2040, tonnes.

Pollutant	2005	2020	2025	2030	2035	2040
SO_2	26,293	8,772	7,743	6,644	5,948	5,605
NO_x	205,785	92,158	74,879	56,277	46,782	42,153
NO_x*	187,069	71,682	57,325	39,143	29,694	25,115
NMVOC	160,956	109,129	99,902	95,681	91,542	88,780
NMVOC*	117,197	61,013	53,363	49,309	45,574	42,993
NMVOC**	140,935	85,235	75,901	71,966	68,002	65,378
NH_3	98,882	83,394	70,736	67,771	65,581	62,709
$PM_{2.5}$	21,445	12,166	9,922	8,382	7,099	6,059
BC	3,756	1,770	1,396	1,101	875	682

* Excluding manure management and agricultural soils.

** Including adjustment for dairy cattle.

The detailed results of the projection are available online at: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/air-pollutants/projection/

11.1 Trend by Pollutant

11.1.1 Nitrogen oxides, NO_X

The largest sources of NO_x are road transport, agriculture, energy industries and non-road mobile machinery in agriculture and fishing, accounting for 26 %, 22 %, 15 % and 9 % of the NO_x emission in 2020, respectively.

The NO_x emission is expected to decrease by 39 % from 2020 to 2030 and by 54 % from 2020 to 2040. The decrease is mainly related to road transport and other mobile sources due to the introduction of stricter demands at EU level (new EURO norms).

NO_x emissions from manure management and agricultural soils are not part of the reduction commitment under the revised NEC Directive. This is due to the fact that methodologies were only recently included in the EMEP/EEA Guidebook, that the emissions from mineral fertiliser are very high and that this source was not included at the time when the reduction commitments were established.

Compared to 2005, the emission is projected to be 72.7 % lower in 2030, but 79.1 % lower when excluding emissions from animal husbandry, manure management and agricultural soils.

11.1.2 Sulphur dioxide, SO_2

The largest sources of SO_2 emissions are manufacturing industries and energy industries accounting for 27 % and 21 % respectively of the national SO_2 emission in 2020.

The SO_2 emission is expected to decrease by 24.3 % from 2020 to 2030 and by 36.1 % from 2020 to 2040. The emissions are projected to decrease mainly from combustion in power plants, district heating plants and non-industrial plants. This decrease is due to decreased overall fuel consumption.

Compared to 2005, the emission is projected to be 74.7 % lower in 2030.

11.1.3 Non methane volatile organic compounds, NMVOC

The largest sources of emissions of NMVOC are agriculture followed by industrial processes, small combustion, fugitive emissions from fuels and transport. These sources account for 44 %, 30 %, 8 %, 7 % and 5 %, respectively, of the total NMVOC emission in 2020.

The NMVOC emission is expected to decrease by 12.3 % from 2020 to 2030 and by 18.6 % from 2020 to 2040. The largest decrease in emission is expected for residential plants but substantial decreases in emissions are also expected for road transport, other mobile sources, agriculture and industrial processes.

NMVOC emissions from manure management and agricultural soils are not part of the reduction commitment under the revised NEC Directive. This is due to the fact that methodologies were only recently included in the EMEP/EEA Guidebook, that the emissions from animal husbandry and manure management are very high and that this source was not included at the time when the reduction commitments were established.

Under the UNECE, Denmark has an accepted adjustment for dairy cattle based on this being a new source.

Compared to 2005, the emission is projected to be 40.6 % lower in 2030, but 57.9 % lower when excluding emissions from animal husbandry, manure management and agricultural soils. The corresponding reduction including the effect of the adjustment is 48.9 %.

11.1.4 Ammonia (NH_3)

The dominant source of emissions of NH_3 is agriculture accounting for about 97 % of the total emission. The remaining 3 % is mainly emissions from small combustion, transport and composting. The largest sources are animal manure applied to soils followed by swine, mineral fertiliser, dairy cattle and crops.

The NH_3 emission is expected to decrease by 18.7 % from 2020 to 2030 and by 24.8 % from 2020 to 2040. The largest decrease in emission is expected for manure management especially swine mainly due to implementation of emission reducing technology in the animal housing systems.

Additionally, all mink in Denmark were culled towards the end of 2020 due to fear of COVID-19 mutations and the keeping of mink was banned in 2021 and 2022. It must therefore be assumed that mink production will not resume the same scale and emissions and therefore will be significantly lower from 2023 onwards.

Compared to 2005, the emission is projected to be 31.4 % lower in 2030.

11.1.5 Particulate matter with diameter less than 2.5 µm - PM2.5

The single major source of the $PM_{2.5}$ emission is non-industrial combustion, mainly wood combustion in residential plants, which accounted for 51% of the national $PM_{2.5}$ emission in 2020. Other important sources are road transport, agriculture and other mobile sources with 9 %, 6 % and 6 %, respectively.

The $PM_{2.5}$ emission is expected to decrease by 31.1 % from 2020 to 2030 and by 50.2 % from 2020 to 2040. The emission reduction is mainly due to a decreasing emission from residential plants caused by the continued phase-in of new technologies with lower emissions.

Compared to 2005, the emission is projected to be 60.9 % lower in 2030.

11.1.6 Black carbon, BC

The single major source of the BC emission is small-scale combustion, mainly biomass combustion in residential and agricultural plants, which accounted for 55 % of the national BC emission in 2020. Other important sources are transport and agricultural machinery with 21 % and 7 %, respectively.

The BC emission is expected to decrease by 37.8 % from 2020 to 2030 and by 61.5 % from 2020 to 2040. The emission reduction is mainly due to decreasing emissions from transport and other mobile sources, due to lower emission limit values for particulate matter and residential plants due to decreased wood consumption.

11.2 Stationary combustion

Annual emissions are available for the years until 2022, while the presented emissions for other years are projections.

The combustion of fossil fuels is one of the most important sources of emission of SO_2, NO_x, NMVOC and PM. This chapter covers all sectors, which use fuels for energy production, with the exception of mobile combustion. Table 11.2.1 shows the sector categories used and the relevant classification.

Table 11.2.1 Sectors included in stationary combustion.

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

In Denmark, all waste incineration is utilised for heat and power production. Thus, incineration of waste is included as stationary combustion in the NFR Energy sector (source categories *1A1*, *1A2* and *1A4)*.

11.2.1 Methodology

Stationary combustion plants are included in the CRF emission sources 1A1 Energy Industries, 1A2 Manufacturing Industries and 1A4 Other sectors.

The methodology for emission projections is, just as the Danish emission inventory for stationary combustion plants, based on the CORINAIR system described in the EMEP/CORINAIR Guidebook (EMEP-/CORINAIR, 2002). The projections are based on official activity rates forecast from the Danish Energy Agency (DEA) and on emission factors that are either emission factors for 2022 or projected emission factors for different fuels, plants and sectors. For each of the fuels and categories (sector and e.g. type of plant), a set of general emission factors has been determined. References for the 2022 emission factors are included in Chapter 3.2 and annex 3A and the projected emission factors that differ from the historic emission factors are discussed in Chapter 11.2.5.

Some of the large plants, such as power plants and waste incineration plants are registered individually as large point sources. Projected data for fuel consumption and emission are included for these plants. Projected fuel consumption refers to RAMSES, which is a plant specific projection of fuel consumptions estimated by the DEA as part of the energy projection. Projected plant specific emission factors are either based on 2022 emission data from annual environmental reports/PRTR data or projected emission factors provided by plant owners.

11.2.2 Model description

The software used for the energy model is Microsoft Access 2013, which is a Relational Database Management System (RDBMS) for creating databases. The database is called the 'Projection 2023-2040' and the overall construction of the database is shown in Figure 3.1 and Figure 3.2.

The model consists of input data collected in tables containing fuel consumption and emission factors for combustion plants larger than 25 MW_e and combustion plants smaller than 25 MW_e. 'Area' and 'Point' in the model refer to small and large combustion plants, respectively. In Table 11.2.2, the names and the content of the tables are listed.

Table 11.2.2 Tables in the 'Projection 2023-2040' database.

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

From the data in these tables, a number of calculations and unions are created by means of queries. The names and the functions of the queries used for calculating the total emissions are shown in Table 11.2.3.

Table 11.2.3 Queries for calculating the total emissions.

Name	Function
EmissionArea	Calculation of the emissions from small combustion plants.
	Input: tblActArea and tblEmfArea
EmissionPoint	Calculation of the emissions from large combustion plants.
	Input: tblActPoint and tblEmfPoint
EmissionAll	Union of EmissionArea and EmissionPoint

Based on some of the queries a number of summation queries are available in the 'Projection 2023-2040' database. Output from the summation queries is in the form of Excel Pivot tables.

Table 11.2.4 Summation queries.

Name	Output
xlsBrændselsforbrug fordelt på snap_Crosstab	Query containing total fuel consumptions for SNAP groups and years
xlsBrændselsforbrug fordelt på fuel_Crosstab	Query containing fuel consumptions for each fuel and years
xls_Brændselsforbrug fordelt på fuel punkt-kilder_Crosstab	Query containing fuel consumptions for large combustion plants for each fuel and years
xlsEmissionAll	Query containing emissions for SNAP groups, pollutants and years
xlsEmissionArea	Query containing emissions for small combustion plants for SNAP groups, years and pollutants
xlsEmissionPoint	Query containing emissions for large combustion plants for SNAP groups, years and pollutants

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

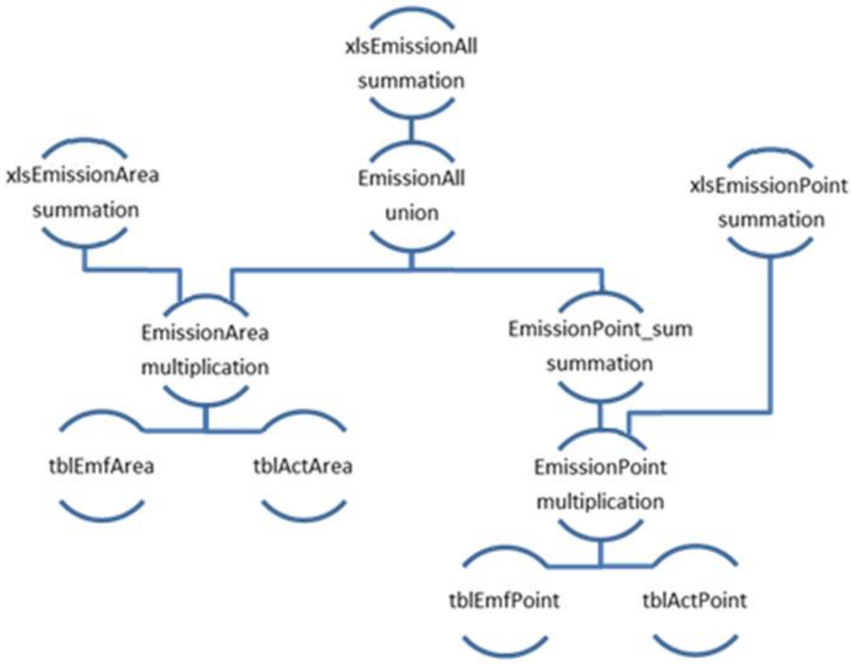


Figure 11.2.1 Overall construction of the database and calculation of emissions.

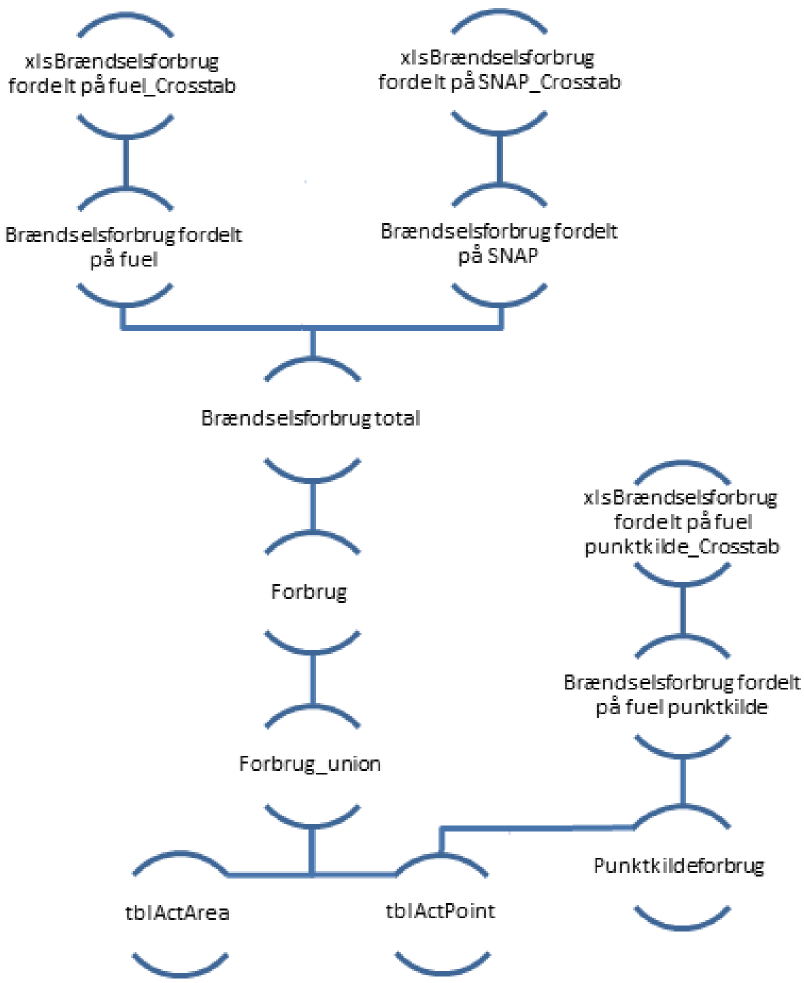


Figure 11.2.2 Overall construction of the database and calculation of fuel consumptions.

11.2.3 Activity data

The fuel consumption data in the model are based on the general projection of the energy consumption by the Danish Energy Agency (DEA, 2024a).

Fuel consumption data distributed according to fuel types is shown in Table 11.2.5 and Figure 11.2.3.

The most important fuel is wood and wood pellets followed by natural gas in the first years of the projection period. It can also be seen that coal is significantly reduced to a very low level.

The projection of the future energy consumption is highly dependent on the development in fuel prices as well as structural changes in the Nordic electricity market.

Table 11.2.5 Fuel consumption for stationary combustion, TJ.

	2023	2025	2030	2035	2040
Natural gas	54655	47735	18268	16777	16092
Wood and simil.	74366	79199	64218	59451	51495
Wood pellets	65654	63256	34821	16029	14428
Biogas	6532	6515	4605	3712	2840
Municipal waste - biogenic	20396	20132	18756	15200	15309
Steam Coal	13600	13026	1957	1583	1259
Fossil waste	24845	21940	22040	17670	17779
Refinery gas	15949	14455	10403	10385	10346
Gas oil	13979	9748	3727	1829	989
Bio Natural gas	25445	28987	34489	29900	24225
Petroleum coke	6617	5297	3749	3137	2877
Agricultural waste	21955	22636	17514	14893	14185
Residual oil	2584	2115	1157	894	759
LPG	3319	2642	1545	1195	1078
Kerosene	6	4	2	1	1
Total	349902	337686	237253	192657	173663

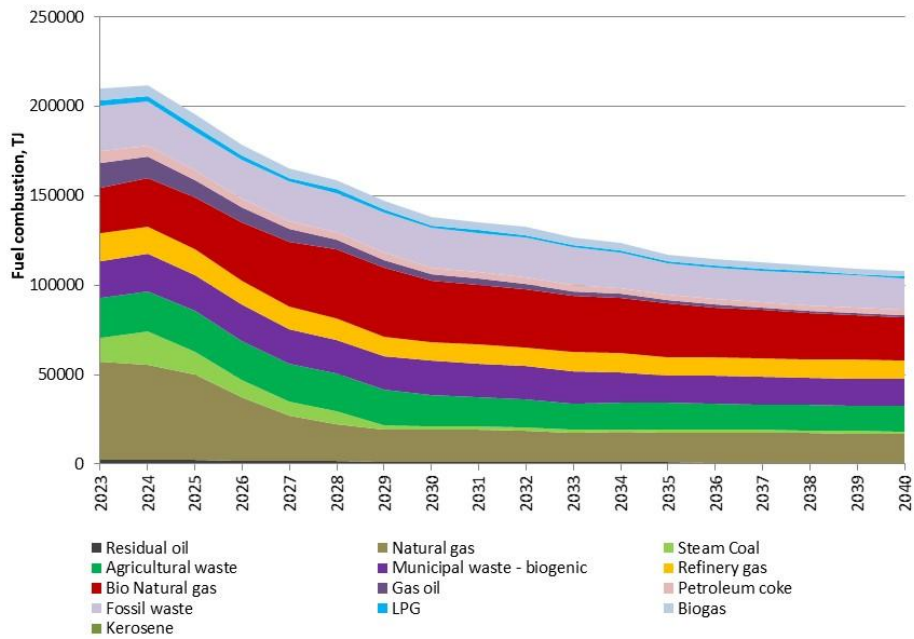


Figure 11.2.3 Fuel consumption distributed according to fuel type.

The sectors consuming the most fuel are public power, residential plants, manufacturing industries, off-shore and district heating.

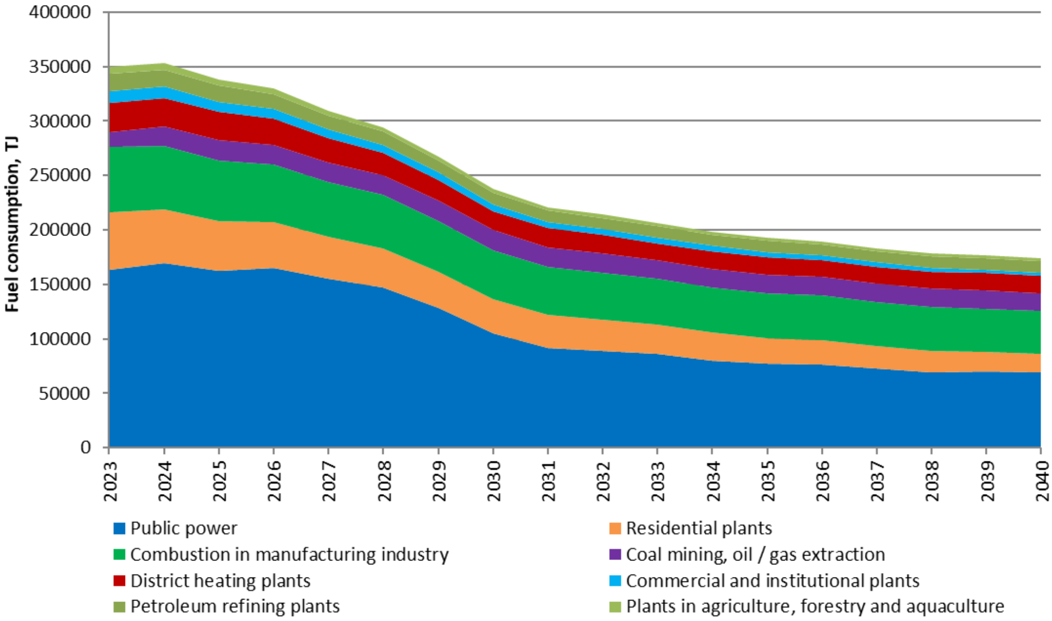


Figure 11.2.4 Fuel consumption distributed by sector.

For a description of the models used in the energy projections, please refer to the Danish Energy Agency (DEA, 2024b).

11.2.4 Emission factors

The emission factors are assumed equal to the emission factors applied for 2022 in the latest emission inventory (Nielsen et al., 2024). The projection of the energy consumption is not disaggregated to technologies, and thus in some cases, the emission factors have been aggregated based on the technology distribution in 2022.

For residential wood combustion, the same emission factors have been applied for each technology. However, a time series have been estimated for implementation of new boilers and stoves, see Chapter 3.2.

In addition, the projected emission factors take into account:

- The decreasing NO_x emission factor for small gas boilers < 120 kW (Schweitzer & Kristensen, 2014)
- The decreasing NO_x emission factor gas boilers above 120 kW (Schweitzer & Kristensen, 2015)
- Decreasing emission factors for CO, NMVOC, TSP, PM_{10}, $PM_{2.5}$ and BC based on new legislation for straw combustion (Brændeovnsbekendtgørelsen[1], 2022)
- Plant specific emission data for cement production in 2022.

11.2.5 Emissions

NO_x

The estimated NO_x emissions are shown in Figure 11.2.6.

[1] Bekendtgørelse om regulering af luftforurening fra fyringsanlæg til fast brændsel under 1 MW, Bekendtgørelse 199 af 04-02-2022

The total NO_x emission decreases slowly throughout the time-series following closely the overall fuel consumption. The increase in 2023/2024 is driven by an increase in emissions from gas extraction, due to the restart of one gas field after renovation in the North Sea and hence lower production in preceding years.

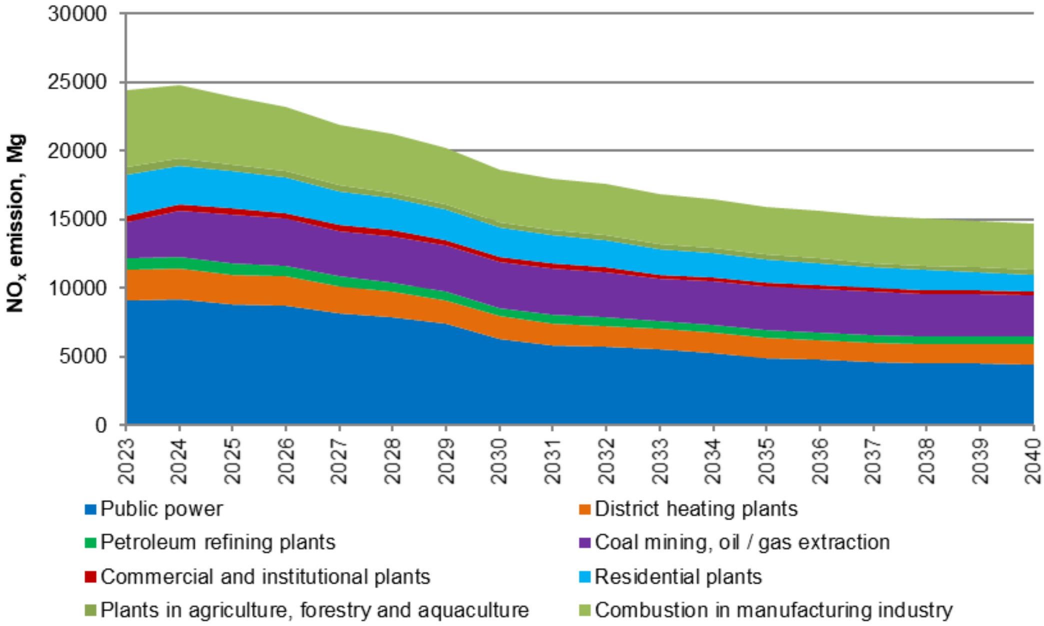


Figure 11.2.6 Projected NO_X emissions by sector.

SO_2

The estimated SO_2 emission is shown in Figure 11.2.7.

The total SO_2 emission decreases slightly throughout the projection period due to lower fuel consumption, e.g. for coal and residual oil.

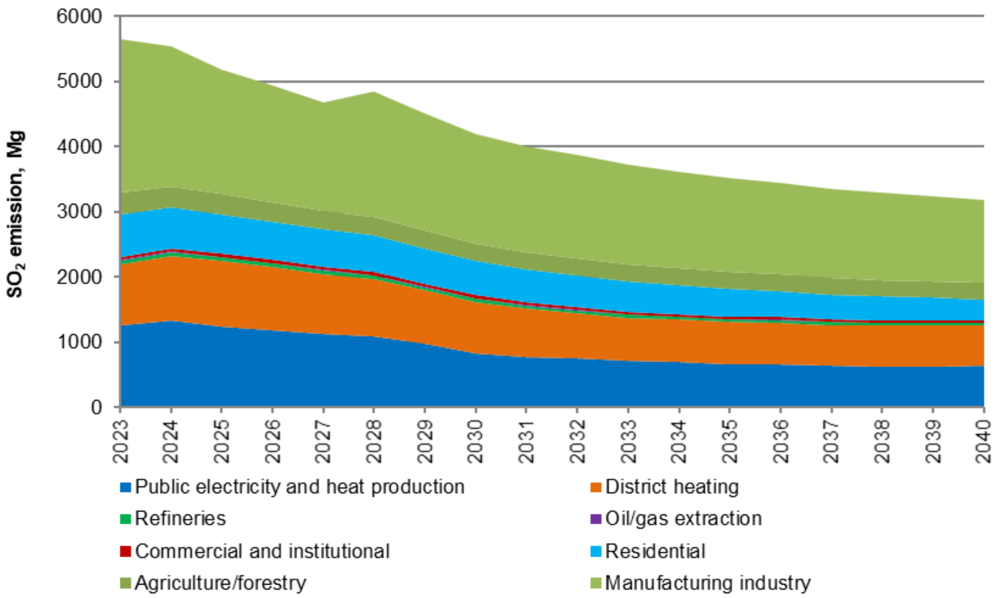


Figure 11.2.7 Projected SO_2 emissions by sector.

NMVOC

The estimated NMVOC emission is shown in Figure 11.2.8.

From 2023 to 2040, the NMVOC emission is projected to decrease due to a lower emission from wood combustion in residential plants. This is due to the replacement of old wood stoves and boilers with new technologies that have considerably lower emissions.

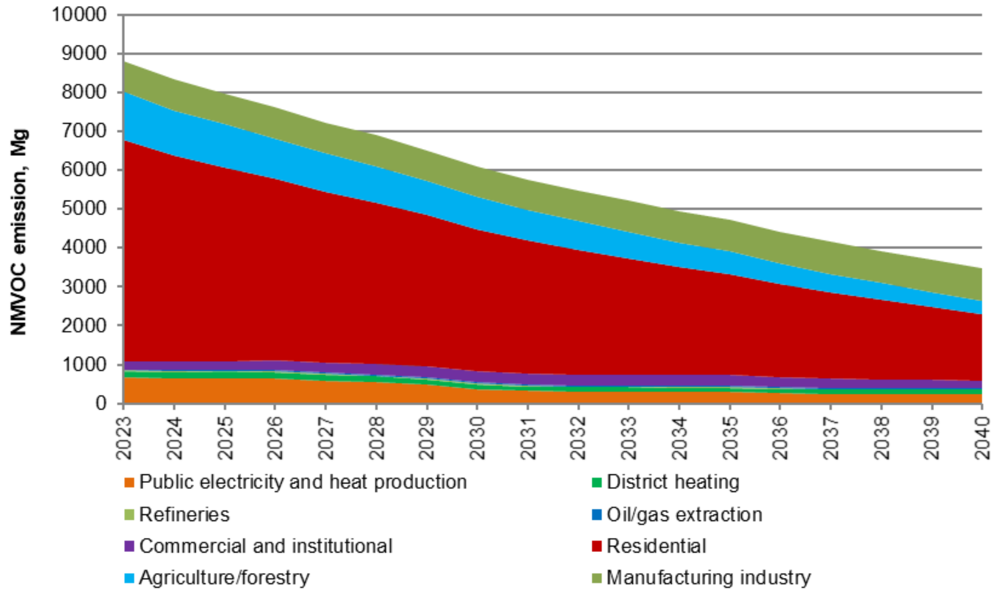


Figure 11.2.8 Projected NMVOC emissions by sectors.

$PM_{2.5}$

The estimated $PM_{2.5}$ emissions are shown in Figure 11.2.9.

The $PM_{2.5}$ emission has increased in the historic years (until 2007) due to increasing wood combustion in residential plants. However, from 2023 to 2040 the $PM_{2.5}$ emission is expected to decrease due to lower emissions from wood combustion in residential plants. This is due to the replacement of old wood stoves and boilers with new technologies that have considerably lower emissions.

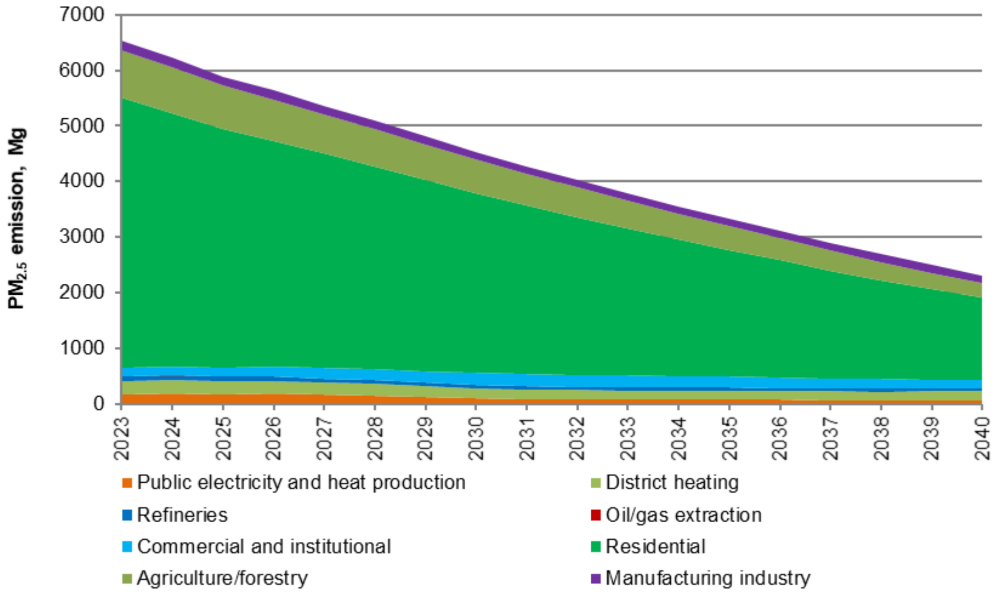


Figure 11.2.9 Projected $PM_{2.5}$ emissions by sector.

Black Carbon

The estimated black carbon (BC) emissions are shown in Figure 11.2.10.

The BC emission has increased in the historic years due to increasing wood combustion in residential plants. However, from 2021 to 2040 the BC emission is expected to decrease due to lower emissions from wood combustion in residential plants. The residential sector will account for around 69 % for the entire projection period.

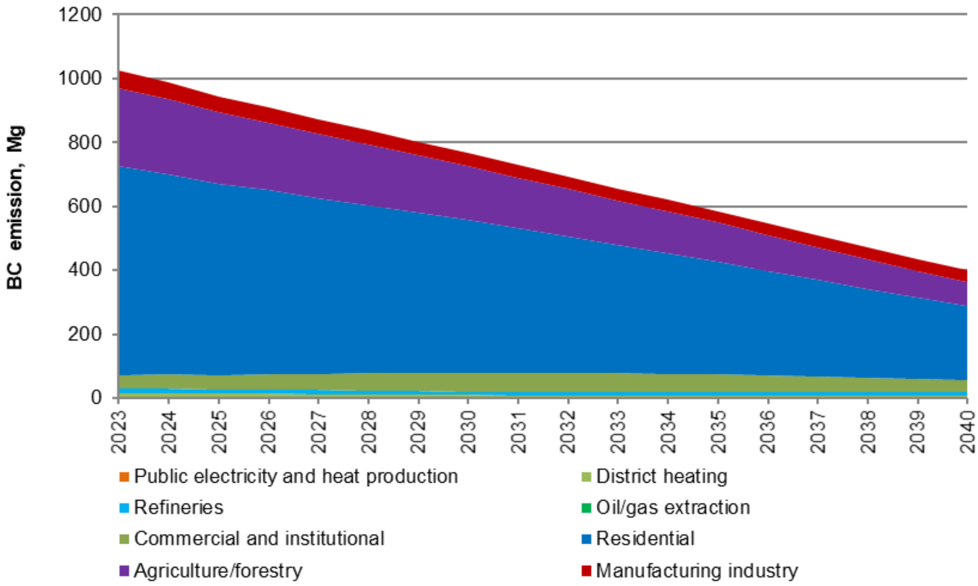


Figure 11.2.10 Projected BC emissions by sector.

11.2.6 References

DEA, 2024a: Projection of national energy consumption. May 2024.

DEA, 2024b: Denmark's Energy and Climate Outlook 2024. Baseline Scenario Projection Towards 2030 With Existing Measures (Frozen Policy). Available at: https://www.kefm.dk/klima/klimastatus-og-fremskrivning/klimastatus-og-fremskrivning-2024 (17-02-2025). (In Danish).

Brændeovnsbekendtgørelsen, 2022: Bekendtgørelse om regulering af luftforurening fra fyringsanlæg til fast brændsel under 1 MW, Bekendtgørelse 199 af 04/02/2022.

Nielsen, O-K., Plejdrup, M.S., Winther, M., Mikkelsen, M.H., Nielsen, M., Gyldenkærne, S., Fauser, P., Albrektsen, R., Hjelgaard, K.H. & Bruun, H.G. 2024: Annual Danish Informative Inventory Report to UNECE. Emission inventories from the base year of the protocols to year 2022. Aarhus University, DCE – Danish Centre for Environment and Energy, 628 pp. Scientific Report No. 595. Available at: https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Videnskabelige_rapporter_500-599/SR595.pdf

Schweitzer & Kristensen, 2014: Evaluation of the NO_x emissions of the Danish population of gas boilers below 120 kW, Project report, October 2014, DGC.

Schweitzer & Kristensen, 2015: Evaluation of the NO_x emissions of the Danish population of gas boilers above 120 kW, Project report, October 2015, DGC.

11.3 Mobile combustion

The air pollutant emission projections for road transport and other mobile sources include the emissions of SO_2, NO_x, NMVOC, $PM_{2.5}$ and BC.

The DEMOS (Danish Emission model system for Mobile Sources) model developed at DCE, Aarhus University, is used to calculate the emission 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 most recent emission projections being described in this chapter was made in February 2024. The projections use the historical year 2022 as a basis for the forecasted activity data such as fleet and mileage data for road transport, stock and activity data for non-road machinery, aircraft type specific flight data for aviation and ferry specific sailing data for navigation. Fuel consumption forecast data used in the emission projections are the official national fuel consumption projections provided by the Danish Energy Agency (Denmark's Energy and Climate Outlook – DECO24), see DEA (2024).

A prerequisite for the air pollutant emissions projections is that the model structure and calculation principles are the same and the input data for activities and fuel consumption equals the data used in the greenhouse gas emission projections prepared for the Danish Ministry for Climate, Energy and Utilities.

The usage of the DECO24 fuel consumption data in specific subsectors and fuel types necessitates the use of model energy balances. In the energy balance the model estimated fuel consumption and emissions are adjusted per fuel type to account for all fuel sales in the projections. This fuel balance adjustment principle has the largest impacts on the modelled results for non-road machinery.

By the end of the forecast period the difference between model fuel estimates and DECO24 fuel sales projections become relatively large for non-road diesel in the agriculture/forestry, industry and commercial/institutional sub sectors. In addition, for non-road gasoline no fuel is included in DECO24 for the commercial/institutional sector. Instead, all gasoline fuel sales are included under residential in DECO24.

As a result, from the fuel proportion and allocation differences for these above-mentioned subsectors, the stock and activity data shown in the next section 11.3.1 do not fully explain the emission development shown in section 11.3.4.

11.3.1 Methodology

Road transport

For road transport, the calculations are made with the DEMOS-Road model using the European COPERT 5 model methodology (EMEP/EEA, 2023). The methodology includes fuel consumption and emissions for operationally hot engines, taking into account gradually stricter emission standards and emission degradation due to catalyst wear. Furthermore, the emission effects of cold-start and evaporation are simulated.

A thorough description of the COPERT 5 based calculation methodology is given in paragraph 3.3.2.

The calculated fuel consumption in DEMOS-Road must equal the projected fuel sale totals by fuel type according to the UNFCCC and UNECE emissions reporting format. The projected fuel sales for road transport comes from the DECO24 energy projections. A thorough description of the fuel balance calculation is given in paragraph 3.3.2.

Air traffic

In DEMOS-Aviation, the historical jet fuel sales from DEA are annually split into landing and take-off (LTOs < 3000 ft) and cruise (> 3000 ft) for domestic and international flights. The fuel split is made based on the calculated fuel consumption for flights from Danish airports, using number of flights per aircraft type, origin and destination airport, representative aircraft types and corresponding fuel consumption factors as input for the calculations.

The fuel split for the latest historical year (2022) is used to split the forecasted total jet fuel sales from DECO24 in the projection years into LTO (national total) and cruise (international total) as prescribed by the UNECE inventory reporting rules. The latest historical year is used as key for the fuel split due to lack of specific prognosis data for flight traffic.

Fuel related emission factors for LTO and cruise for the latest historical year are also derived from DEMOS-Aviation, and subsequently the emissions for national aviation (LTO) and international aviation (cruise) are calculated in each case as the product of the forecasted fuel consumption and the fuel related emission factors.

A thorough description of the DEMOS-Aviation model, historical flight activity data, representative aircraft types and fuel consumption and emission factors is given in paragraph 3.3.3.

Non-road working machinery and recreational craft

The DEMOS-NRMM model estimates the fuel consumption and emissions for non-road machinery in agriculture, forestry, industry, commercial/institutional and residential as well as recreational craft. The fuel consumption and emissions are calculated in the model as the product of the number of engines, annual working hours, average rated engine size, load factors and fuel consumption/emission factors per engine size class and emission level.

Different approaches are used to project machinery stock and activity data for various non road machinery types in the forecast.

For tractors and harvesters, the total amount of GWh's produced are assumed to be constant in the projection period, and this together with an engine size/age/sector fleet distribution for 2022 held constant in the forecast period defines the future activity for these machinery types.

For many of the other most important types of non-road equipment (e.g. building and construction machinery, gasoline working machinery) the machinery stock is projected in the model by assuming that annual machinery new sales in the forecast years equals the average of the later historical year's new sales, and by using machinery scrappage curves as a function of engine age.

For diesel and gasoline engines, the deterioration effects (due to engine ageing) are included in the emission calculation equation by using deterioration factors according to engine type, size, age, lifetime, and emission level. For diesel engines before Stage IIIB, IV and V, transient operational effects are also taken into consideration by using average transient factors.

For more details regarding the DEMOS-NRMM calculation procedure please refer to paragraph 3.3.3 and Winther (2023).

A thorough description of the machinery types in DEMOS-NRMM, stock data, engine size and load factors, annual working hours and fuel consumption and emission factors are also given in paragraph 3.3.3 and Winther (2023).

As explained in the beginning of this chapter, model energy balances are used for the different fuel types and subsectors in DEMOS-NRMM to account for all fuel sales in the DECO24 fuel sales projections.

National sea transport and fisheries

For Danish ferries, fuel consumption and emissions are calculated as the product of the number of round trips, sailing time per round trip, engine size, load factor, and fuel consumption/emission factors. The ferry traffic (number of round trips per ferry route) remains unchanged in the projections due to lack of forecast data for ferry traffic. For each ferry, engine replacement is assumed to occur every 30 years, thus enabling the selection of engine build year specific fuel consumption and emission factors as input for the emission projection calculations.

The fuel consumption for other national sea transport is calculated per fuel type as the total fuel consumption from DECO24 minus the bottom-up estimated fuel consumption for ferries. The emission factors per fuel type for other national sea transport is selected as a rolling 30 year-average (average engine lifetime) in the individual forecast years.

For fisheries, fuel consumption and emissions are calculated for each fishing trip as the product of vessel engine size, engine load factor, hours at sea and fuel consumption/emission factors. To account for all fuel sold, the bottom-up calculated fuel consumption and emission results in the model are scaled with the ratio between fuel sales and model-based bottom-up fuel consumption.

Please refer to paragraph 3.3.3 for more details regarding the calculations for national sea transport and fisheries.

Railways

The emissions from railways are calculated as the product of average fuel-related emission factors for the future railway machinery provided by Danish Railways (Mølgård, 2023) and total fuel consumption from the DECO24 (see also paragraph 3.3.3).

Military

The emissions from military equipment is calculated in each forecast year as the product of fuel consumption and fuel related emission factors. For land based equipment (gasoline and diesel) average fuel based emission factors derived from road transport results is used. For jet fuel the emission factors come from EMEP/EEA (2023), see also paragraph 3.3.3.

11.3.2 Activity data

Road transport

Corresponding to the COPERT fleet classification, all present and future vehicles in the Danish traffic fleet are grouped into vehicle classes, sub-classes and layers, as explained in paragraph 3.3.2. For each vehicle sub-class and first registration year, fleet and annual mileage projection data are provided by DTU Transport (Jensen, 2023).

The trends in vehicle numbers and total mileages per EU layer are shown in the Figures 11.3.1 and 11.3.2 for the 2024-2040 periods. The latter figure clearly shows how vehicles complying with the gradually stricter EU emission levels (EURO 5/V, Euro 6/VI, Euro 6d-TEMP and Euro 6d) are introduced into the Danish motor fleet in the forecast period.

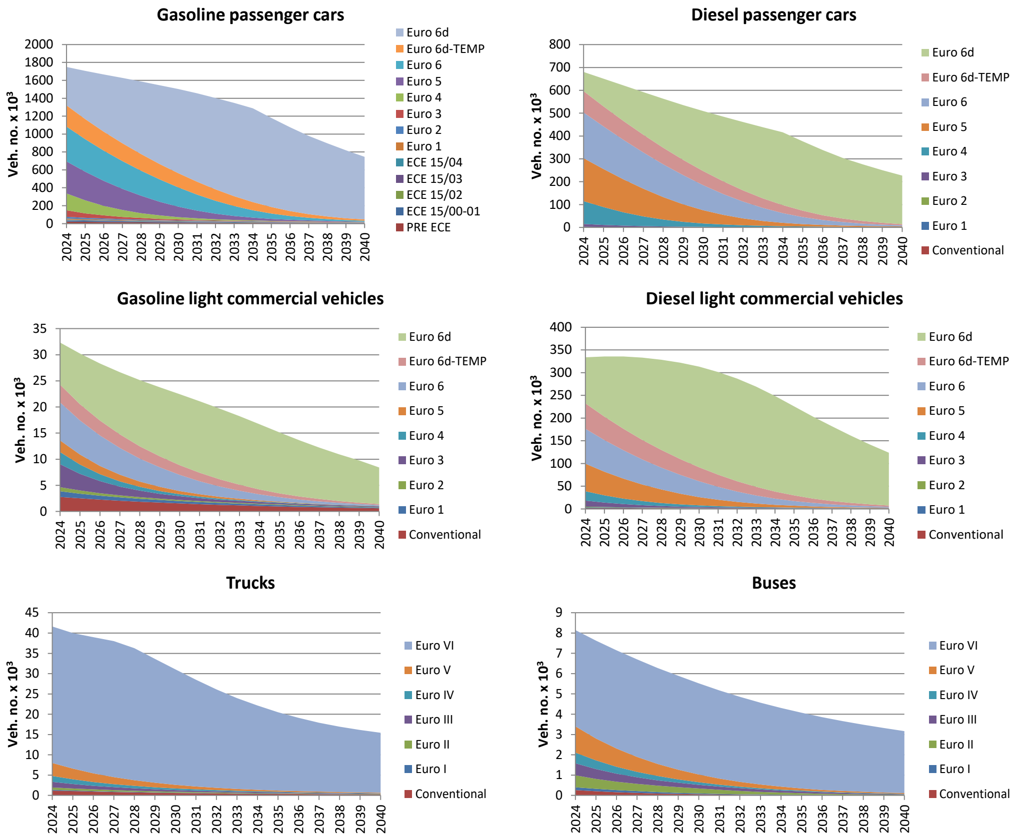
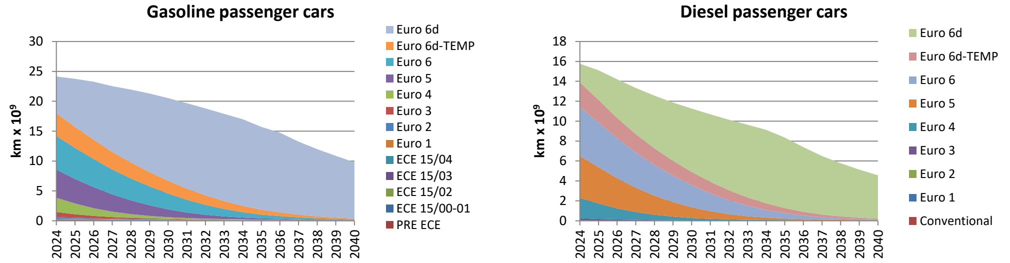


Figure 11.3.1 Layer distribution of vehicle numbers per vehicle type in 2024-2040.



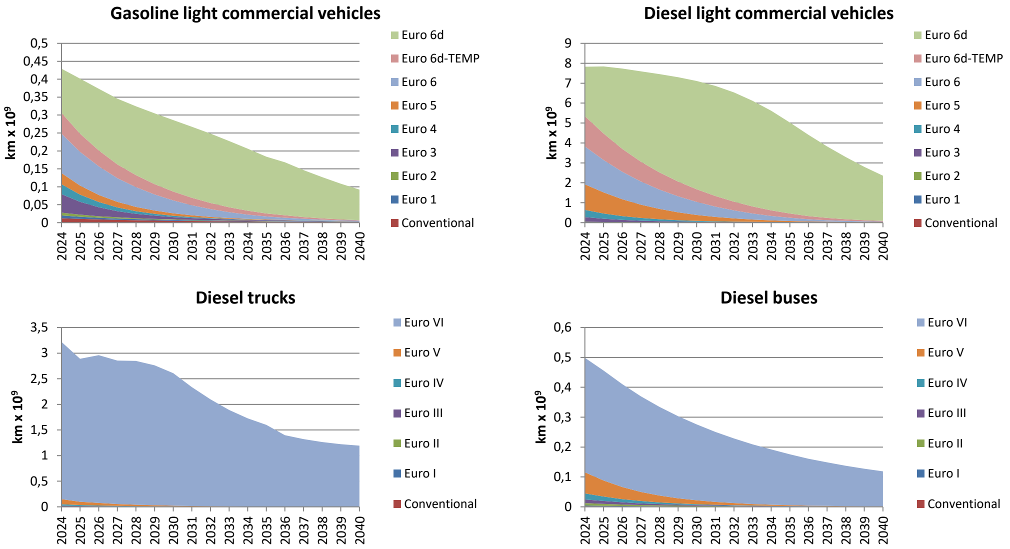


Figure 11.3.2 Layer distribution of total mileage per vehicle type in 2024-2040.

Agriculture

The predominant part of the fuel consumption and emissions from non-road agricultural sources is associated with the use of tractors and harvesters.

For tractors and harvesters, the machinery stock is projected in the model in the following way. In a first step, the fleet number distribution into engine age and engine size for the last historical year is used to estimate a first unadjusted fleet for the projection years. This enables the calculation of an unadjusted total power output (GWh) for each of the projection years.

Next, it is assumed that the total power output (GWh) in each projection year is the same as the total power output in the last historical year. Finally, the unadjusted fleet is estimated by scaling the engine age and size specific fleet numbers equally with the ratio between the total power output for last historical year and the total power output for the projection year in question.

For agriculture, the projection of the total number of agricultural tractors and harvesters and average engine sizes from 2024-2040 are shown in Figure 11.3.3. In the historical years, there has been a decrease in the total number of tractors and harvesters and an overall increase in the average engine size. The trend towards decreasing number and increasing average engine sizes continues in the projection periods.

Figure 11.3.3 also shows the total stock of tractors and harvesters, and total kWh power output split into emission layers from 2024-2040. The annual working hours are highest for new machinery, and hence the share of total kWh power output becomes higher than number share for the most modern technologies in the projection periods.

The stock and activity data shown in this paragraph for non-road agriculture underpins the bottom-up calculations made in DEMOS-NRMM. Hence, the data developments only partly explain the emission development shown in section 11.3.4. As explained in the beginning of this chapter, fuel balance adjustments are made to the bottom-up model results to account for all fuel sales projected in DECO24.

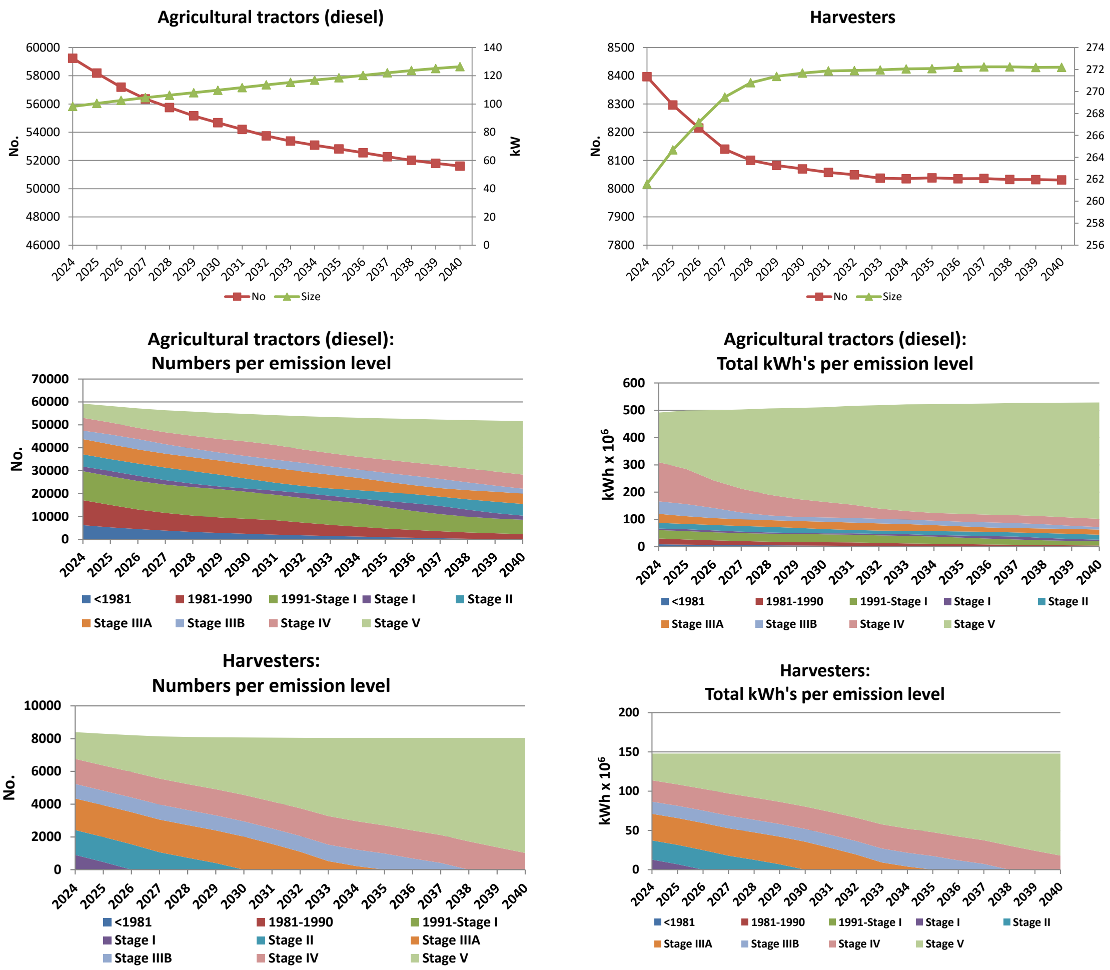


Figure 11.3.3 Total number of tractors and harvesters, average engine sizes, and numbers and kWh power output per emission level from 2024-2040.

Industry

The most important machinery types for industrial non road are different types of diesel fuelled building and construction machinery (e.g. excavators/loaders, dump trucks), fork lifts and tractors.

In DEMOS-NRMM, the most important types of building and construction machinery and forklifts are subdivided into a large number of engine sizes (see paragraph 3.3.3) that corresponds with the grouping of annual new sales provided by the Association of Danish Agricultural Machinery Dealers and the Association of Producers and Distributors of Fork Lifts in Denmark.

The machinery stock is projected in the model by assuming that annual machinery new sales in the forecast years equals the average of new sales in the four latest historical years, and by using machinery scrappage curves as a function of engine age (see paragraph 3.3.3). For tractors used in industry, the machinery stock is projected as explained for agricultural tractors.

The number of machinery and total kWh power output from 2024-2040 are shown in Figure 11.3.4 split into emission layers for the most important types of building and construction machinery and forklifts. For the most modern technologies the shares of total kWh power output are higher than fleet shares throughout the forecast period, due to more annual working hours for new machinery.

The stock and activity data shown in this paragraph for non-road industry underpins the bottom-up calculations made in DEMOS-NRMM. Hence, the data developments only partly explain the emission development shown in section 11.3.4. As explained in the beginning of this chapter, fuel balance adjustments are made to the bottom-up model results to account for all fuel sales in the DECO24 projections.

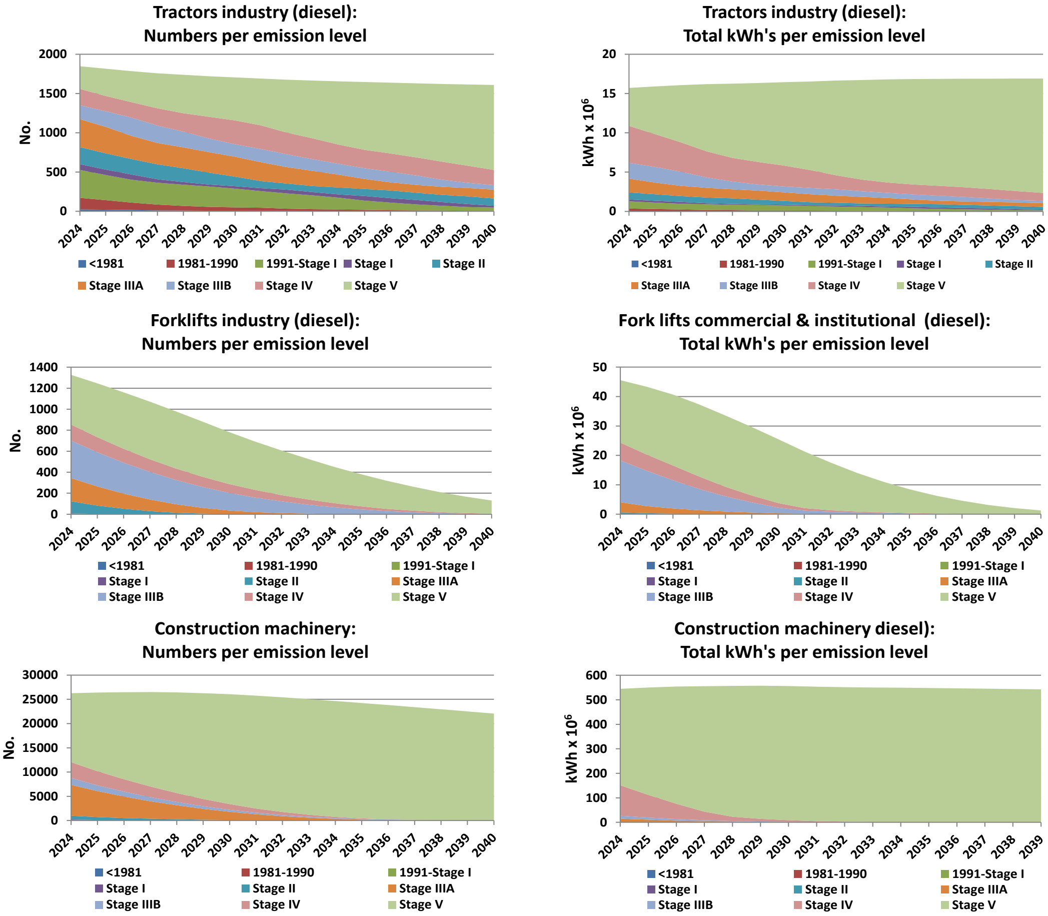


Figure 11.3.4 non-road industry: Number of diesel fuelled construction machinery (most important types), tractors and forklifts and total kWh power output, split into emission levels from 2024-2040.

Residential and commercial/institutional

Some of the most important diesel fuelled non road machinery types in the commercial and institutional sector are forklifts and tractors.

For tractors used in the commercial and institutional sector, the machinery stock is projected as explained for agricultural tractors. For forklifts used in the commercial and institutional sector, the machinery stock is projected as explained for industrial forklifts.

The number of machinery and total kWh power output from 2024-2040 are shown in Figure 11.3.5 split into emission layers for forklifts and tractors used in the commercial and institutional sector. For the most modern technologies the shares of total kWh power output are higher than fleet shares throughout the forecast period, due to more annual working hours for new machinery.

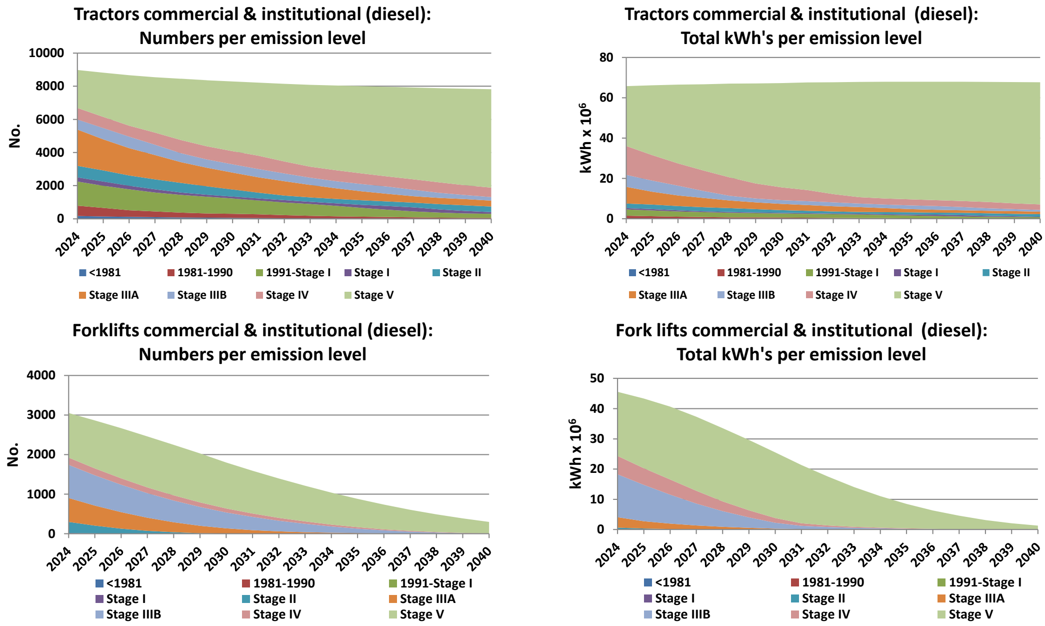


Figure 11.3.5 Non-road commercial and institutional: Number of diesel fueled tractors and fork lifts and total kWh power output, split into emission levels from 2024-2040.

The most important household and gardening machinery types in the residential and commercial/institutional sectors are gasoline-fuelled riders, lawn movers, shrub clearers and trimmers, chain saws and hedge cutters.

As a basis for the fleet projections in the DEMOS-NRMM, annual new sales data are used for the most important household and gardening machinery types provided by the Association for Industrial Technics, Tools and Automation. The machinery stock is projected in the model by assuming that annual machinery new sales in the forecast years equals the average of new sales in the five latest historical years, and by using machinery scrappage curves as a function of engine age (see paragraph 3.3.3). New sales of gasoline fuelled machinery are expected to gradually phase out and be fully replaced by battery electric machinery towards 2030 for hedge cutters, trimmers, blowers, cutters, 2035 for vertical cutters and 2040 for lawn mowers and chain saws. This technology shift is included in the projected sales figures used in the model.

The total stock development from 2024-2040 for the most important household and gardening machinery types is shown in Figure 11.3.6 split into 2-stroke and 4-stroke machinery for Residential (1.A.4b) and Commercial/Institutional (1.A.4.a).

For the same stock division, the emission layer distribution is also shown in Figure 11.3.7. The penetration of the most modern Stage V technology occur faster for working machinery in Commercial/Institutional (1.A.4.a) compared with Residential (1.A.4.b), due to the shorter maximum life times for the working equipment used by professionals.

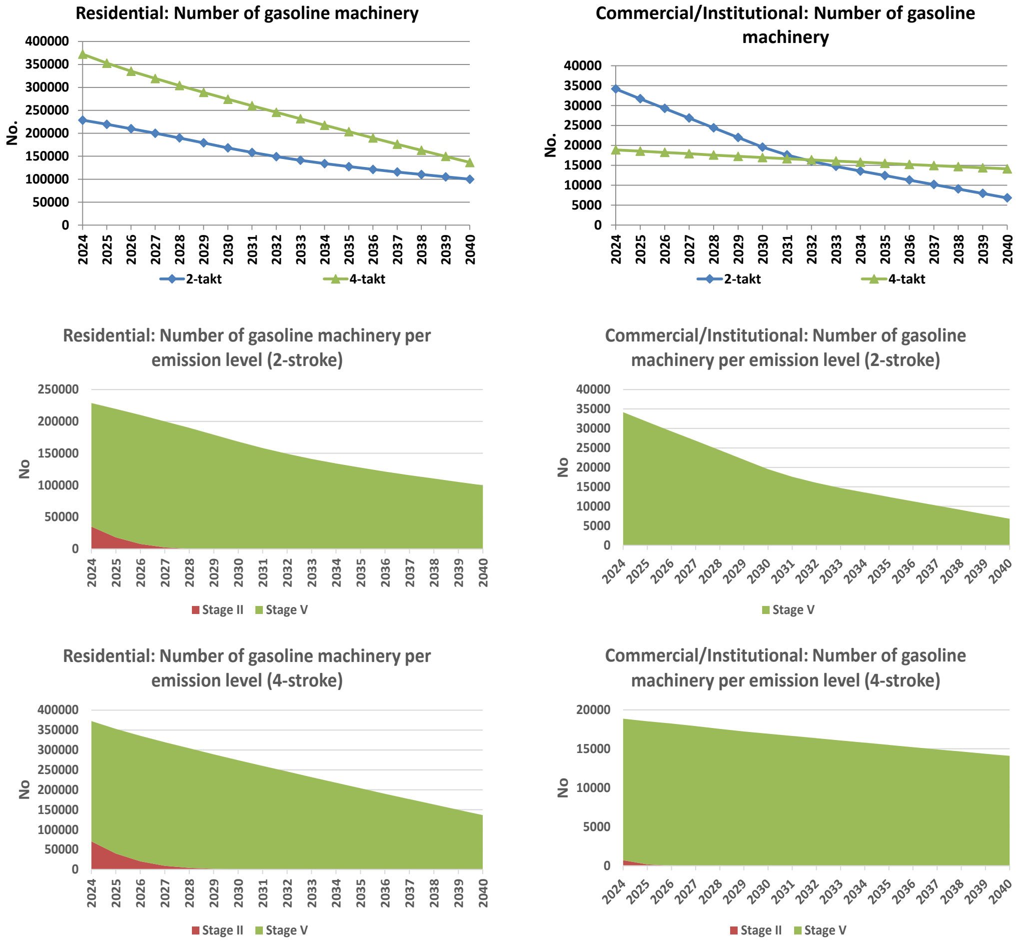


Figure 11.3.6 Number of gasoline fuelled working machinery (most important types) from 2024-2040, split into 2-stroke/4-stroke engines and emission levels for residential and commercial/institutional.

Figure 11.3.7 shows the total number of kWh's produced from 2024-2040 for the most important household and gardening machinery types, split into 2-stroke and 4-stroke machinery for Residential (1.A.4b) and Commercial/Institutional (1.A.4.a).

Although the number of machines in commercial/institutional are much smaller than the number of residential machinery, the total kWh power output is quite similar for 2-stroke machinery (although significantly decreasing for commercial/institutional engines), and approximately three times higher in the case of 4-stroke machinery. The reason is that annual working hours is much higher, and engines (in kW) are generally larger for professional equipment compared with private machinery.

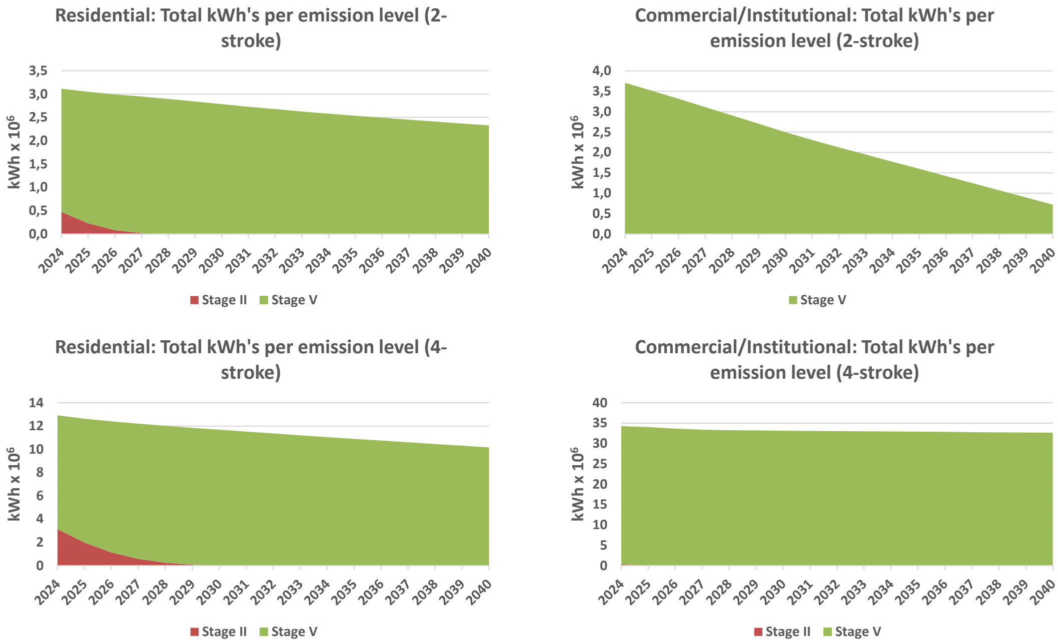


Figure 11.3.7 Number of kWh's produced for gasoline-fuelled working machinery (most important types) from 2024-2040, split into 2-stroke/4-stroke engines and emission levels for residential and commercial/institutional.

The stock and activity data shown in this paragraph for gasoline fueled non road working machinery underpins the bottom-up calculations made in DEMOS-NRMM. The data developments are not able to explain the emission development shown in section 11.3.4. As explained in the beginning of this chapter, fuel balance adjustments are made to the bottom-up model results in order to account for all fuel sales in the DECO24 projections.

In DECO24, no gasoline fuel (expected to be used by non-road machinery) is included in the commercial/institutional sector. Instead, all gasoline fuel sales are included under residential in DECO24.

The change in sectoral allocation and the difference in the levels of fuel consumption and emissions for gasoline non-road residential and commercial/institutional will be very visible in the time series in the shift from historical years to forecast years.

National sea transport, fisheries and recreational craft

The fuel activity data for national sea transport (diesel and heavy fuel oil) in the projections is composed by the sum of fuel consumption for the sectors "national sea transport" and "Greenland/Faroe Islands maritime" in the Danish energy forecast (DEA, 2022).

The diesel fuel activity data for recreational craft in the projections is estimated with the DEMOS-NRMM model (see also paragraph 3.3.3). During the preparation of DECO24 DEA subtracts the latter diesel fuel consumption from the road transport sector total (see also paragraph 3.3.3).

The gasoline and bio ethanol fuel activity data for recreational craft in the projections is estimated with the DEMOS-NRMM model (see also paragraph 3.3.3). During the preparation of DECO24 DEA subtracts the latter gasoline and bio ethanol fuel consumption from the road transport sector total (see also paragraph 3.3.3).

The fuel activity data used for national sea transport, fisheries and recreational craft in the projections are shown in Figure 11.3.8.

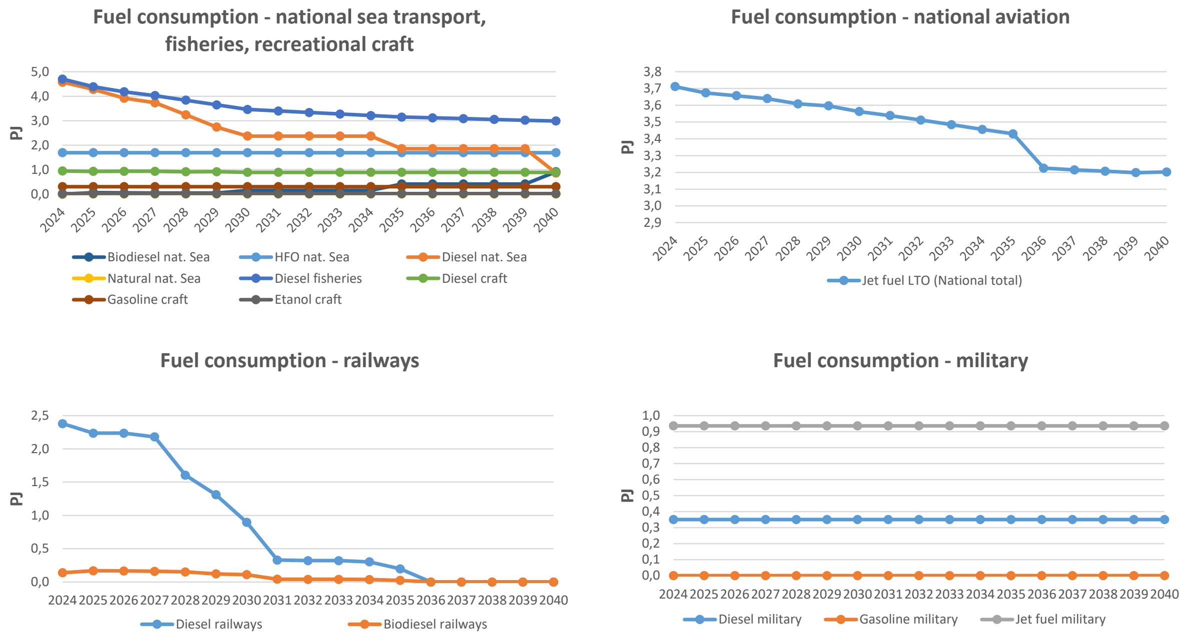


Figure 11.3.8 Fuel consumption for national sea transport, fisheries, recreational craft, aviation, railways and military from 2024-2040.

Air traffic

The basis activity data for aviation shown consist of the fuel consumption figures from DECO24 split into domestic and international aviation.

The DEMOS-Aviation model divides the DECO24 fuel consumption forecast figures into LTO (Landing and Take Off: Flight activities below 3.000 ft) and cruise (flight activities above 3.000 ft), for domestic and international flights respectively, based on the DEMOS-Aviation model fuel consumption distribution for the latest historical year (2022).

Subsequently for each year in the projection period, the total fuel sum is calculated for LTO. The LTO fuel sum (shown in Figure 11.3.8), defined as the national total for aviation according to the UNECE inventory reporting rules, constitute the fuel activity data for national aviation in the projections.

A thorough description of the DEMOS-Aviation model, historical flight activity data, representative aircraft types and fuel consumption and emission factors is given in paragraph 3.3.3.

Railways

The diesel fuel activity data for railways used in the projections from 2024-2040 comes from DECO24. The railways activity data used in the projections for 2024-2040 are shown in Figure 11.3.8.

Military

The diesel and gasoline fuel consumption data for land based military activities and jet fuel consumption for military aviation activities comes from DECO24. The military activity data used in the projections for 2024-2040 are shown in Figure 11.3.8.

11.3.3 Emission factors

The fuel consumption and emission factors used in the Danish emission inventories for road transport comes from the COPERT 5 model and are thoroughly explained in paragraph 3.3.2.

The fuel consumption and emission factors used in the Danish emission inventories and projections for other mobile sources comes from numerous sources and they are described in the previous paragraph 11.3.2 and in paragraph 3.3.3.

Table 11.3.1 shows the aggregated fuel related emission factors (g/GJ) for SO_2, NO_x NMVOC, $PM_{2.5}$ and BC for road transport and other mobile sources in Denmark in 2024, 2025, 2030, 2035 and 2040.

Table 11.3.1 Aggregated fuel related SO_2, NO_x NMVOC, $PM_{2.5}$ and BC emission factors (g/GJ) for road transport and other mobile sources in Denmark in 2024, 2025, 2030, 2035 and 2040.

	Category	2024	2025	2030	2035	2040
SO_2	Industry - Other (1A2g)	0,45	0,45	0,44	0,44	0,43
	Civil Aviation nat. (1A3a)	22,99	22,37	20,23	17,28	15,08
	Road - Cars (1A3bi)	0,41	0,41	0,41	0,41	0,40
	Road - Light duty trucks (1A3bii)	0,39	0,38	0,37	0,37	0,37
	Road - Heavy duty vehicles (1A3biii)	0,56	0,55	0,53	0,54	0,54
	Road - Motorcycles and mopeds (1A3biv)	0,51	0,51	0,51	0,52	0,52
	Railways (1A3c)	0,44	0,44	0,42	0,42	#DIV/0!
	Navigation (1A3d)	27,43	27,58	23,99	24,48	25,71
	Comm./Inst. (1A4a)	0,47	0,47	0,46	0,46	0,45
	Residential (1A4b)	0,43	0,43	0,43	0,43	0,43
	Agriculture/forestry/fisheries (1A4c)	16,28	15,50	13,29	13,62	13,63
	Other (1A5b, military mobile)	16,84	16,84	16,84	16,84	16,84
	Other (1A5b, recreational craft)	34,90	34,76	34,38	34,37	34,37
	Navigation int. (1A3d)	47,53	47,53	47,53	47,53	47,53
	Civil Aviation int. (1A3a)	22,99	22,46	21,04	17,93	15,13
NO_x	Industry - Other (1A2g)	182,5	175,3	159,0	154,7	152,4
	Civil Aviation nat. (1A3a)	315,8	314,7	314,8	314,7	316,5
	Road - Cars (1A3bi)	100,8	91,5	51,7	30,7	25,0
	Road - Light duty trucks (1A3bii)	217,2	192,5	108,5	73,5	60,0
	Road - Heavy duty vehicles (1A3biii)	70,3	64,6	41,3	37,3	34,7
	Road - Motorcycles and mopeds (1A3biv)	133,7	130,5	118,7	109,8	104,3
	Railways (1A3c)	407,2	407,2	407,2	407,2	#DIV/0!
	Navigation (1A3d)	1310,6	1287,9	1158,9	896,0	797,1
	Comm./Inst. (1A4a)	219,1	208,0	165,7	134,0	110,2
	Residential (1A4b)	77,9	75,8	71,1	68,3	65,0
	Agriculture/forestry/fisheries (1A4c)	487,7	452,3	365,8	312,4	275,2
	Other (1A5b, military mobile)	219,9	217,4	203,0	195,1	192,0
	Other (1A5b, recreational craft)	506,4	489,0	415,4	401,3	401,3
	Navigation int. (1A3d)	1577,5	1525,8	1264,2	1022,3	774,6
	Civil Aviation int. (1A3a)	340,8	340,8	340,8	340,8	341,2
NMVOC	Industry - Other (1A2g)	29,5	28,6	26,5	25,9	25,6
	Civil Aviation nat. (1A3a)	19,7	17,9	17,8	17,5	17,6
	Road - Cars (1A3bi)	17,7	15,6	8,9	6,4	6,2
	Road - Light duty trucks (1A3bii)	4,2	3,2	1,2	0,8	0,8
	Road - Heavy duty vehicles (1A3biii)	3,7	3,7	3,7	4,1	4,4
	Road - Motorcycles and mopeds (1A3biv)	807,9	758,2	569,6	492,8	458,3
	Railways (1A3c)	23,0	23,0	23,0	23,0	#DIV/0!
	Navigation (1A3d)	62,6	62,9	63,4	63,7	61,8
	Comm./Inst. (1A4a)	29,7	28,5	24,5	21,4	19,3
	Residential (1A4b)	2012,1	1954,0	1732,3	1553,3	1354,4
	Agriculture/forestry/fisheries (1A4c)	43,7	42,5	39,2	38,0	36,9
	Other (1A5b, military mobile)	18,9	18,8	18,6	18,6	18,7
	Other (1A5b, recreational craft)	158,1	154,0	141,9	139,6	139,6
	Navigation int. (1A3d)	65,6	65,8	66,7	67,2	67,7
	Civil Aviation int. (1A3a)	3,7	3,7	3,7	3,7	3,7
$PM_{2.5}$	Industry - Other (1A2g)	9,2	7,8	3,5	2,5	2,5
	Civil Aviation nat. (1A3a)	2,2	2,2	2,2	2,2	2,2
	Road - Cars (1A3bi)	0,8	0,7	0,3	0,1	0,1
	Road - Light duty trucks (1A3bii)	1,3	1,0	0,4	0,2	0,2
	Road - Heavy duty vehicles (1A3biii)	1,0	0,9	0,6	0,6	0,6
	Road - Motorcycles and mopeds (1A3biv)	12,5	11,8	8,9	8,1	7,8
	Railways (1A3c)	3,9	3,9	3,9	3,9	#DIV/0!
	Navigation (1A3d)	38,9	39,8	47,9	50,3	55,5
	Comm./Inst. (1A4a)	11,5	9,9	5,7	4,4	3,4
	Residential (1A4b)	40,9	41,0	41,3	41,3	41,5
	Agriculture/forestry/fisheries (1A4c)	18,1	17,1	14,4	12,3	10,9
	Other (1A5b, military mobile)	1,2	1,2	1,0	0,9	0,9
	Other (1A5b, recreational craft)	31,9	29,3	17,0	14,6	14,6
	Navigation int. (1A3d)	49,9	50,2	51,3	52,0	52,6
	Civil Aviation int. (1A3a)	3,4	3,4	3,4	3,4	3,4

Continued						
BC	Industry - Other (1A2g)	6,8	5,8	2,5	1,7	1,6
	Civil Aviation nat. (1A3a)	0,8	0,8	0,8	0,8	0,8
	Road - Cars (1A3bi)	0,5	0,5	0,1	0,0	0,0
	Road - Light duty trucks (1A3bii)	0,9	0,7	0,2	0,1	0,1
	Road - Heavy duty vehicles (1A3biii)	0,5	0,4	0,2	0,1	0,1
	Road - Motorcycles and mopeds (1A3biv)	2,2	2,1	1,7	1,5	1,5
	Railways (1A3c)	2,5	2,5	2,5	2,5	#DIV/0!
	Navigation (1A3d)	3,9	4,0	4,4	4,4	4,5
	Comm./Inst. (1A4a)	7,8	6,6	3,6	2,7	2,1
	Residential (1A4b)	2,0	2,1	2,1	2,1	2,1
	Agriculture/forestry/fisheries (1A4c)	8,0	7,5	6,2	4,8	4,0
	Other (1A5b, military mobile)	0,8	0,7	0,5	0,4	0,4
	Other (1A5b, recreational craft)	11,4	10,5	5,9	5,0	5,0
	Navigation int. (1A3d)	3,1	3,1	3,1	3,1	3,1
	Civil Aviation int. (1A3a)	1,2	1,2	1,2	1,2	1,2

11.3.4 Emissions

Table 11.3.2 shows the total fuel consumption and emissions of SO_2, NO_x NMVOC, $PM_{2.5}$ and BC for road transport and other mobile sources in Denmark in 2024, 2025, 2030, 2035 and 2040.

Table 11.3.2 Total fuel consumption and emissions of SO_2, NO_x NMVOC, $PM_{2.5}$ and BC for road transport and other mobile sources in Denmark in 2024, 2025, 2030, 2035 and 2040.

	Category	2024	2025	2030	2035	2040
Energy	Industry - Other (1A2g)	8,7	8,8	8,6	8,1	7,3
	Civil Aviation nat. (1A3a)	3,7	3,7	3,6	3,4	3,2
	Road - Cars (1A3bi)	87,5	85,3	70,8	53,6	32,5
	Road - Light duty trucks (1A3bii)	25,5	25,1	21,3	13,9	6,5
	Road - Heavy duty vehicles (1A3biii)	29,4	25,9	20,4	11,3	7,7
	Road - Motorcycles and mopeds (1A3biv)	0,8	0,8	0,8	0,8	0,8
	Railways (1A3c)	2,5	2,4	1,0	0,2	0,0
	Navigation (1A3d)	6,3	6,0	4,2	4,0	3,5
	Comm./Inst. (1A4a)	0,7	0,6	0,4	0,2	0,2
	Residential (1A4b)	0,5	0,5	0,5	0,5	0,5
	Agriculture/forestry/fisheries (1A4c)	13,8	13,5	12,5	11,1	10,5
	Other (1A5b, military mobile)	1,3	1,3	1,3	1,3	1,3
	Other (1A5b, recreational craft)	1,3	1,3	1,2	1,2	1,2
	Navigation int. (1A3d)	20,6	20,6	20,6	20,6	20,6
	Civil Aviation int. (1A3a)	26,9	26,5	25,8	24,8	24,0
SO_2	Industry - Other (1A2g)	4	4	4	4	3
	Civil Aviation nat. (1A3a)	85	82	72	59	48
	Road - Cars (1A3bi)	36	35	29	22	13
	Road - Light duty trucks (1A3bii)	10	10	8	5	2
	Road - Heavy duty vehicles (1A3biii)	16	14	11	6	4
	Road - Motorcycles and mopeds (1A3biv)	0	0	0	0	0
	Railways (1A3c)	1	1	0	0	0
	Navigation (1A3d)	172	167	101	97	89
	Comm./Inst. (1A4a)	0	0	0	0	0
	Residential (1A4b)	0	0	0	0	0
	Agriculture/forestry/fisheries (1A4c)	225	210	166	151	143
	Other (1A5b, military mobile)	22	22	22	22	22
	Other (1A5b, recreational craft)	44	44	42	42	42
	Navigation int. (1A3d)	980	980	980	980	980
	Civil Aviation int. (1A3a)	618	596	542	446	363
NO_x	Industry - Other (1A2g)	1589	1535	1369	1250	1111
	Civil Aviation nat. (1A3a)	1172	1156	1121	1080	1014
	Road - Cars (1A3bi)	8829	7804	3660	1648	814
	Road - Light duty trucks (1A3bii)	5544	4839	2313	1023	392
	Road - Heavy duty vehicles (1A3biii)	2067	1674	844	420	267
	Road - Motorcycles and mopeds (1A3biv)	106	103	93	86	84
	Railways (1A3c)	1025	979	410	90	0
	Navigation (1A3d)	8220	7778	4903	3560	2770
	Comm./Inst. (1A4a)	149	128	58	29	17
	Residential (1A4b)	41	40	37	36	34
	Agriculture/forestry/fisheries (1A4c)	6727	6123	4574	3467	2895
	Other (1A5b, military mobile)	283	280	261	251	247
	Other (1A5b, recreational craft)	646	616	507	490	490
	Navigation int. (1A3d)	32516	31451	26058	21073	####
	Civil Aviation int. (1A3a)	9162	9036	8776	8469	8185
NMVOC	Industry - Other (1A2g)	257	250	228	209	187
	Civil Aviation nat. (1A3a)	73	66	63	60	56
	Road - Cars (1A3bi)	1550	1333	632	342	202
	Road - Light duty trucks (1A3bii)	108	81	25	11	6
	Road - Heavy duty vehicles (1A3biii)	109	96	75	46	34
	Road - Motorcycles and mopeds (1A3biv)	639	601	447	385	369
	Road – Evaporation (1A3bv)	1246	1198	999	805	606
	Railways (1A3c)	58	55	23	5	0
	Navigation (1A3d)	392	380	268	253	215
	Comm./Inst. (1A4a)	20	17	9	5	3
	Residential (1A4b)	1053	1023	907	813	709
	Agriculture/forestry/fisheries (1A4c)	602	576	490	422	389
	Other (1A5b, military mobile)	24	24	24	24	24
	Other (1A5b, recreational craft)	202	194	173	170	170
	Navigation int. (1A3d)	1353	1357	1374	1386	1395

Continued						
	Civil Aviation int. (1A3a)	100	98	95	92	88
$PM_{2.5}$	Industry - Other (1A2g)	80	68	31	20	18
	Civil Aviation nat. (1A3a)	8	8	8	7	7
	Civil Aviation nat. tyre & brake (1A3a)	2	2	2	2	2
	Road - Cars (1A3bi)	70	62	18	7	4
	Road - Light duty trucks (1A3bii)	32	25	8	3	2
	Road - Heavy duty vehicles (1A3biii)	30	24	13	7	5
	Road - Motorcycles and mopeds (1A3biv)	10	9	7	6	6
	Railways (1A3c)	10	9	4	1	0
	Railways Non-exhaust (1A3c)	183	183	183	183	183
	Navigation (1A3d)	244	240	202	200	193
	Comm./Inst. (1A4a)	8	6	2	1	1
	Residential (1A4b)	21	21	22	22	22
	Agriculture/forestry/fisheries (1A4c)	250	232	180	136	114
	Other (1A5b, military mobile)	2	1	1	1	1
	Other (1A5b, recreational craft)	41	37	21	18	18
	Navigation int. (1A3d)	1029	1035	1057	1072	1083
	Civil Aviation int. (1A3a)	91	89	87	84	81
BC	Industry - Other (1A2g)	59	51	21	13	12
	Civil Aviation nat. (1A3a)	3	3	3	3	3
	Road - Cars (1A3bi)	46	42	10	3	1
	Road - Light duty trucks (1A3bii)	24	18	5	2	1
	Road - Heavy duty vehicles (1A3biii)	14	10	4	1	1
	Road - Motorcycles and mopeds (1A3biv)	2	2	1	1	1
	Railways (1A3c)	6	6	3	1	0
	Navigation (1A3d)	25	24	19	18	16
	Comm./Inst. (1A4a)	5	4	1	1	0
	Residential (1A4b)	1	1	1	1	1
	Agriculture/forestry/fisheries (1A4c)	111	102	77	53	42
	Other (1A5b, military mobile)	1	1	1	1	1
	Other (1A5b, recreational craft)	15	13	7	6	6
	Navigation int. (1A3d)	64	64	64	64	64
	Civil Aviation int. (1A3a)	33	32	31	30	29

Road transport

Figure 11.3.8 shows the projections of fuel consumption and emissions per vehicle category for road transport from 2024-2040.

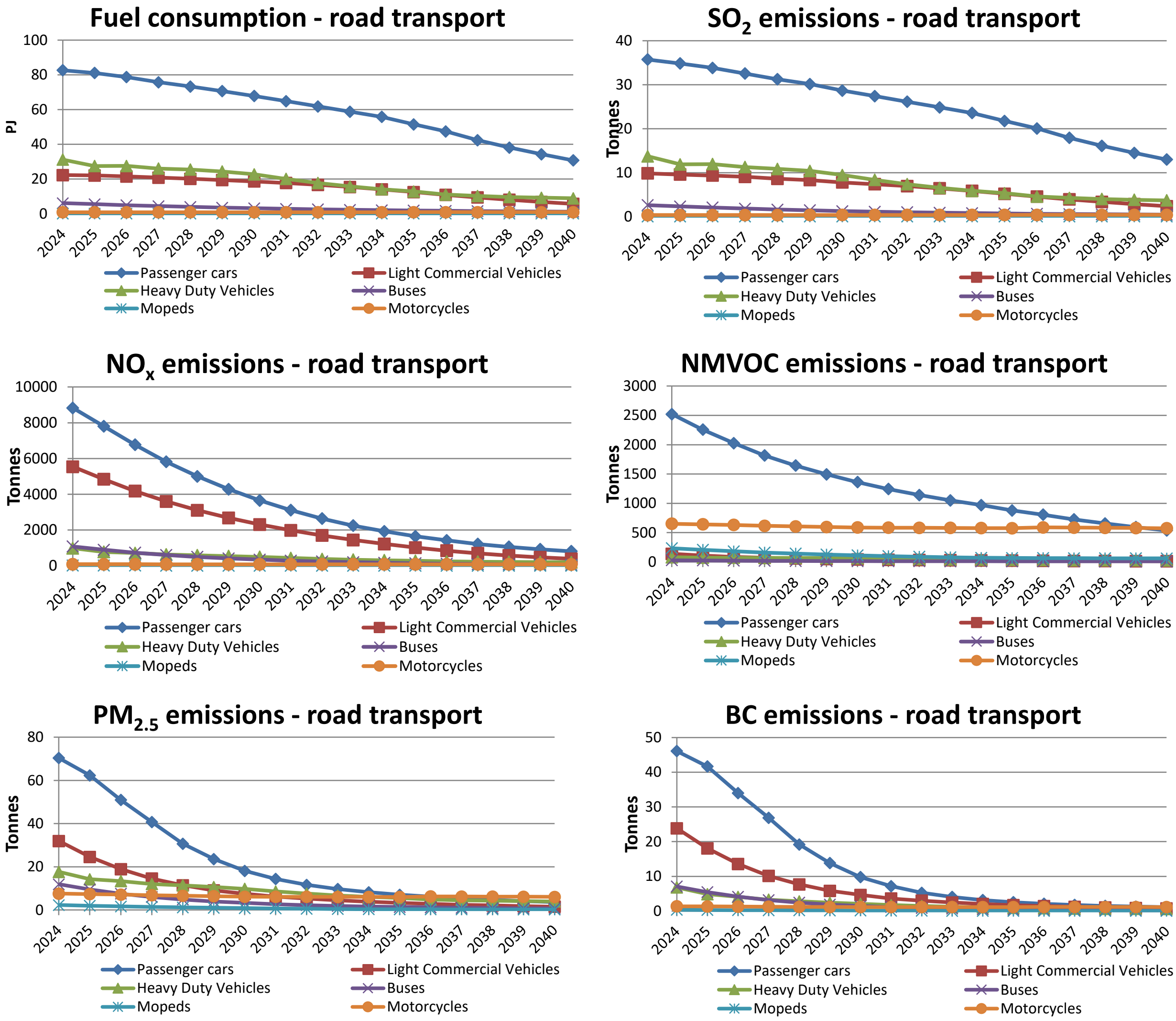


Figure 11.3.8 Fuel consumption, NO_X, SO_2, NMVOC, $PM_{2.5}$ and BC emissions from 2024-2040 for road traffic.

From 2024 to 2040 the fuel consumption and SO_2 emissions decrease for passenger cars and light commercial vehicles due to the increasing number of electric vehicles and plug in hybrids expected to enter the fleet during the forecast period (not shown). The largest fuel consumption and SO_2 emissions shares are calculated for passenger cars in the forecast period, followed by heavy-duty vehicles, light duty vehicles, buses and two-wheelers in decreasing order. The sulphur content of gasoline and diesel is 10 ppm, and hence the development of the total SO_2 emissions follow the trend in total fuel consumption.

The majority of the NMVOC emission from road transport comes from gasoline passenger cars (Figure 11.3.8). The NMVOC emission is projected to decrease around 79 % from 2024 to 2040 for passenger cars, explained by the introduction of gradually more efficient catalytic converters for gasoline cars and a very pronounced decrease in the total mileage driven for gasoline cars during the projection period (Figure 11.3.2) due to the gradual electrification of the passenger car fleet during the projection period.

In terms of $PM_{2.5}$ and BC the total exhaust emission is expected to decline by 89 % and 95 %, respectively, from 2024 to 2040, in particular due to the introduction of diesel particulate filters (DPF) for Euro 5 and 6 cars/vans, and Euro VI trucks/buses and the gradual electrification of the vehicle fleet during the projection period. The largest emission source is passenger cars, followed by light duty vehicles. Emission reductions are generally higher for BC than for $PM_{2.5}$ due to the very efficient removal of BC by the DPF technology.

The NO_X emission for road transport declines by 91 % from 2022 to 2040. For cars and vans the expected emission reductions (91 % and 93 %, respectively) are large due to the introduction of Euro 6d diesel cars and vans associated with very small NO_x emissions, and the gradual electrification of the fleet of passenger cars and vans during the projection period. For trucks and buses, the relative emission declines of 79 % and 94 %, respectively, are also quite significant during the forecast period, due to the automatic fleet turnover towards Euro 6 vehicles and the increasing number of electric vehicles entering the fleet in the projection period.

Other mobile sources

Figure 11.3.9 shows the projections of fuel consumption and emissions for other mobile sources from 2024-2040.

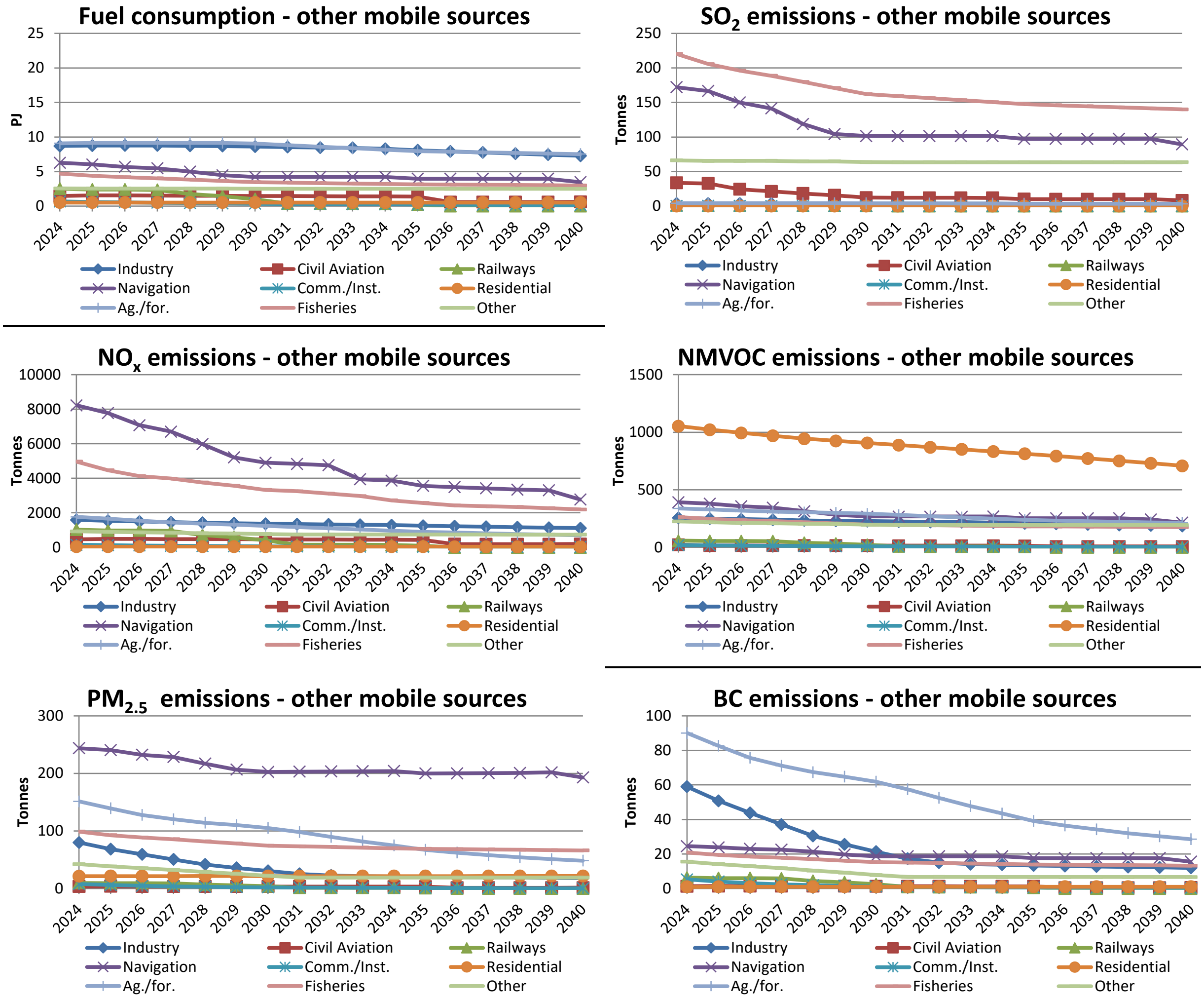


Figure 11.3.9 Fuel consumption, NO_X, SO_2, NMVOC, $PM_{2,5}$ and BC emissions from other mobile sources 2024-2040.

From 2024 to 2040 the total fuel consumption decreases by 29 % for other mobile sources. The emissions of SO_2, decrease by 37 %. For other mobile sources the emissions of NO_x, NMVOC, $PM_{2.5}$ and BC decreased by 57 %, 35 %, 34 % and 64 %, respectively.

The development in fuel consumption is forecasted by the DEA in DECO24. Agriculture/forestry/fisheries is by far the largest fuel consumption source followed by industry and navigation. Rather small fuel consumption totals are noted for railways, civil aviation, other (military and recreational boats), residential and commercial/institutional.

The SO_2 emissions for other mobile sources are insignificant except for sea-going vessels. However, for navigation and fisheries, the reduction of the sulphur content in heavy fuel oil used in the Baltic and North Sea SO_x emission control areas (SECAs) has had a major emission impact from 2015.

Gasoline working machinery in residential is the largest source of emissions of NMVOC. For this sector, the projected NMVOC emission reductions are due to the phasing in of the most stringent stage V emission technology (figure 11.3.5) for some types of equipment. For agriculture/forestry, the gradually stricter emission standards for diesel engines (figure 11.3.3) will cause the NMVOC emission to decrease during the forecast period.

For $PM_{2.5}$, navigation is the largest emission source for the other mobile sector. For agriculture/forestry high $PM_{2.5}$ emissions are, however, calculated in the beginning of the forecast period. The $PM_{2.5}$ emissions from navigation and fisheries rely on the fuel consumption development (Figure 11.3.7 and Figure 11.3.9) and the sulphur content of the fuels used. For the latter sectors, the $PM_{2.5}$ emissions are significant due to the relatively high sulphur content of marine fuels compared to the fuel types used by other mobile sources.

The $PM_{2.5}$ emissions from agriculture/forestry and industry decrease substantially throughout the forecast period due to the introduction of particulate filters for diesel engines > 19 kW, in compliance with the Stage V emission standards. Particulate filters are very efficient removers of BC, explaining the large BC emission decreases for agriculture/forestry and industrial machinery shown in Figure 11.3.9.

For NO_x, navigation is by far the largest emission source for the other mobile sector, followed by fisheries. For agriculture/forestry, industry, navigation, fisheries and railways, substantial NO_x emission improvements are expected during the forecast period due to the penetration of cleaner engine technologies, in compliance with future emission standards. Rather small NO_x emissions are calculated for railways, civil aviation, residential, commercial/institutional and other.

11.3.5 References

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11.4 Fugitive emissions from fuels

The projection of fugitive emissions from fuels includes sources related to exploration, production, refining, storage, handling, and transport of fuels. The projection includes emissions of

- SO_2 from oil and gas exploration, sulphur recovery in oil refineries and flaring of oil and gas,
- NO_X from flaring of oil and gas,
- particulate matter (PM) from storage of coal, exploration of oil and gas, and flaring of oil and gas, and
- NMVOC from refining of oil, extraction of oil and gas, storage and transport of oil and gas, post-meter emissions, venting of gas, and flaring of oil and gas.

The following chapters describe the methodology, activity data, emission factors and emissions in the projection.

11.4.1 Methodology

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

Activity data are based on Denmark's Energy and Climate Outlook (DEA, 2024), including official forecasts on fuel consumption and offshore production and flaring of oil and natural gas.

Emission factors are based on international guidelines (EMEP/EEA, 2019; IPCC, 2006, 2019) or are country-specific based on data for one or more of the historical years. For a number of sources, the emissions are given in annual reports, e.g. environmental reports, self-regulation reports and green accounts, and these are adopted in the Danish emission inventory and used as basis for the projection.

11.4.2 Activity data

Prognosis of oil and gas production

The prognosis for the production of oil and gas and for flaring (DEA, 2024) is shown in Figure 10.4.1. The prognosis includes production from existing fields and new fields based on existing technology, technological resources (estimated additional production due to new technological initiatives) and prospective resources (estimated production from new discoveries). Further, the projected production includes flaring in upstream oil and gas production.

The prognosis for production of oil and gas shows a significant increase from 2023 to 2025, due to the reopening of the Tyra platform. The overall trend shows a decrease from 2025 to 2040.

According to Denmark's Energy and Climate Outlook (DEA, 2024), the flaring amounts are expected to increase from 2023 to 2024, decrease 2024 to 2025, followed by a more levelled out trend showing small increase 2025-2040. Flaring related to exploration of oil and gas is not included in the oil and gas projection, and therefore this activity is not included in the projection.

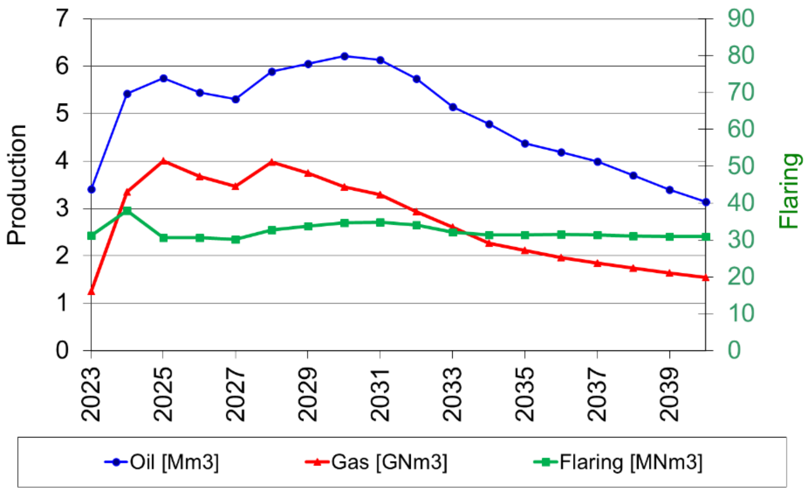

Figure 10.4.1 Prognosis for the production of oil and gas and flaring in offshore oil and gas production (DEA, 2024).

The DEA prognosis of the production of oil and gas are used in projection of a number of sources; production of oil and natural gas, emissions from the crude oil terminal, onshore and offshore loading of ships, and flaring in upstream oil and gas production.

The same methodology is applied to estimate activity data for these sources, where the amount in the projection year is estimated as the amount in the latest historical year multiplied by the share of the oil production in the projection year and the latest historical year. Equation 10.4.1 shows the estimation methodology for onshore loading.

Eq. 10.4.1 Formula for estimating onshore loading amount in projection year p

$$OL_p = OL_h \times \frac{OP_p}{OP_h}$$

where OL = onshore loading, OP = oil production, p = projection year and h = latest historical year

Prognosis of energy consumption

The prognosis of energy consumption (DEA, 2024) is applied in the projection of fugitive emissions from fuels. The annual prognosis of consumption of natural gas as a total for all sectors is used as proxy to project transmission of natural gas.

Emissions from transmission and distribution of natural gas and town gas show variations from year to year, because of varying extent of leakages due to maintenance and accidental excavations. To include these unpredictable events, the emissions from transmission and distribution of natural gas and town gas are estimated as the average emissions in the latest five historical years scaled to the annual total natural gas consumption from the energy consumption prognosis by the DEA (2024).

Summarised gasoline and coal consumptions for all sectors are used as proxy activity data to project emissions from service stations and storage of solid fuels, respectively.

Large point sources

The sector fugitive emissions from fuels cover only few large point sources (LPS). These are the two Danish refineries and the natural gas storage and treatment plants. Fugitive emissions from refineries are related to three sources: 1) fugitive losses from tanks, pipes, valves etc., 2) sulphur recovery, and 3) flaring. Projections of emissions from these sources are associated with large uncertainties, as the emissions are not related to the production amounts or other predictable parameters. Fugitive losses are dependent of the number and character of leakages and the maintenance conditions. SO_2 emissions form sulphur recovery show large annual variations due to interruptions of the sulphur recovery system. When the sulphur recovery plant does not work optimally, the gas is lead to the flare, which results in larger SO_2 emissions from the flare. In the energy consumption prognosis, the rates for refinery gas consumption and flaring in refineries are assumed constant. To be consistent with this approach, the emissions in the latest historical year are applied for all projection years.

Fugitive emissions from the natural gas storage and treatment plants are very limited and owe to flaring and venting. The amounts of natural gas that is vented and flared vary from year to year, and the emissions in the projection years are estimated as the average emission in the last five historical years. Following, the same emission is applied for all projection years.

11.4.3 Emission factors

Emission factors from the EMEP/EEA Guidebook (EMEP/EEA, 2019) are used to estimate emissions from exploration of oil and gas, and offshore flaring in oil and gas production.

For offshore loading of ships, the tier 1 emission factors for ships with VRU from the 2019 IPCC Refinery (IPCC, 2019) is used in the projection.

The NMVOC emission factors for onshore loading in historical years are based on data from the harbour terminal. The emission factor for the latest historical year is used in the projection. NMVOC emissions from the crude oil terminal in the projection period are estimated as the emission in the latest historical year scaled to the annual oil production. The NMVOC emission factors for the projection years are listed in Table 10.4.1.

The emission factor for service stations are the summarised emission factors for reloading of tanker trucks and refuelling of cars based on the EMEP/EEA Guidebook (EMEP/EEA, 2019). The NMVOC emission factor for service stations is listed in Table 10.4.1.

Table 10.4.1 NMVOC emission factors for the projection years.

Source	EF	Unit	Reference
Ships offshore	0.16	Mg /10^3 m3 oil loaded	EMEP/EEA, 2019
Ships onshore	9.508	g/Mg oil loaded	A/S Dansk Shell - Havneterminalen, 2023
Service stations	541	g/Mg gasoline	EMEP/EEA, 2019*

**Modified to 70% abatement according to Danish act for conditions occurring in practice.*

Emission factors for offshore flaring are listed in Table 10.4.2. The SO_2 emissions are calculated using a country specific SO_2 emission factor for Danish natural gas. The emission factor for NO_x is based on a survey by the Danish Environmental Protection Agency (Danish EPA, 2008). Emission factors for NMVOC and PM are based on the EMEP/EEA Guidebook (2019).

Table 10.4.2 SO_2, NO_x and PM emission factors for offshore flaring.

Pollutant	EF	Unit	Reference
SO_2	0.019	g/Nm3	EMEP/EEA, 2019
NO_x	1.230	g/Nm3	Danish EPA, 2008
NMVOC	1.530	g/Nm3	EMEP/EEA, 2019
TSP	0.039	g/Nm3	EMEP/EEA, 2019
PM_{10}	0.039	g/Nm3	EMEP/EEA, 2019
$PM_{2.5}$	0.039	g/Nm3	EMEP/EEA, 2019
BC	0.0009	g/Nm3	EMEP/EEA, 2019

Emissions of particulate matter (PM) from coal storage are estimated by the emission factors from the Coordinated European Particulate Matter Emission Inventory Program, CEPMEIP (Visschedijk et al., 2004). The emission factors are listed in Table 10.4.3. The emission factor for black carbon (BC) is estimated based on the TSP EF and the C content in other bituminous coal according to IPCC (2006).

Table 10.4.3 Emission factors for PM emissions from coal storage.

Pollutant	EF	Unit	Reference
TSP	15	g/Mg	Visschedijk et al., 2004
PM_{10}	13	g/Mg	Visschedijk et al., 2004
$PM_{2.5}$	4	g/Mg	Visschedijk et al., 2004
BC	10	g/Mg	Visschedijk et al., 2004; IPCC, 2006

The NMVOC emissions from the oil terminal, covering storage and handling of crude oil, are given in annual reports for the crude oil terminal from Danish Oil Pipe A/S (Boesen, 2023). Emissions from storage tanks at the oil terminal are provided annually by Danish Oil Pipe A/S. During 2009 new emission reducing technologies (degassing unit) were installed at the crude oil terminal, leading to a significant decrease of the emissions. Estimation of emissions from the oil terminal in the projection years is based on the average emission factor for the latest five historical years and the activity data for the latest historical year scaled to the annual oil production given in the oil and gas production prognosis (DEA, 2024).

A similar approach has been applied for transmission and distribution of natural gas and distribution of town gas. The emissions in the projection years are estimated as the average emission in the latest five historical years scaled according to the annual gas consumption given in the energy consumption prognosis (DEA, 2022). Emissions from refineries (processes and flaring) are kept constant at the level in the latest historical year in agreement with the approach in the energy consumption prognosis.

Post-meter emissions in the projection are estimated as the average emission for the last five historical years scaled according to the annual gas transmission (post-meter emissions in industry and power plants) and distribution (post-meter emissions in the commercial and residential sector). Post-meter emissions from gas-burning vehicles are estimated as the average for the latest five historical years.

Emissions from venting in gas storage plants and flaring in the gas treatment plant are calculated as the average emission of the last five historical years, and consequently no emission factors have been used to estimate projected emissions.

11.4.4 Emissions

Tables and figures in this section show data for selected historical years (1990, 2000, 2005, 2010, 2015 and 2020), the latest historical year as in this projection (2022), the first year of the projection period (2023), and every fifth projection year (2025-2040).

The SO_2 emissions (Figure 10.4.2) are high in the first years of the time series, mainly for refineries, due to the presence of a third refinery. SO_2 emissions from refineries show large annual fluctuations due to unpredictable circumstances and therefore the projected emissions must be expected to have large uncertainties. By using a five-year mean, part of the annual variations is taken into account.

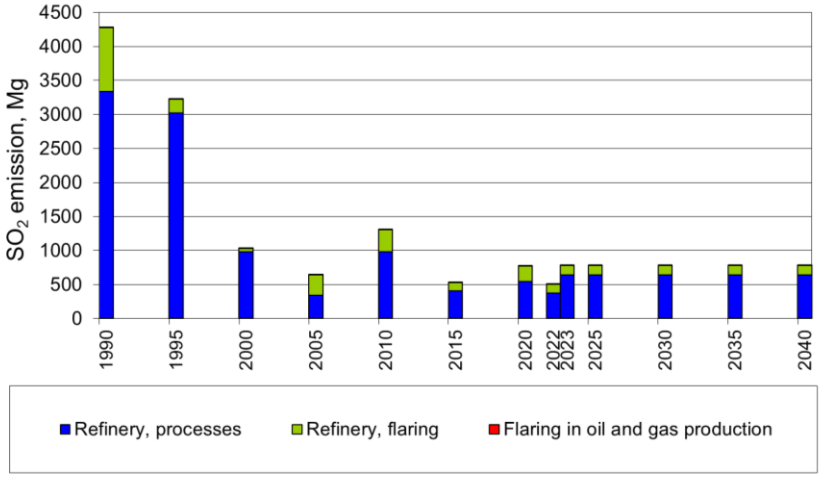

Figure 10.4.2 SO_2 emissions for selected historical years (1990-2022) and projection years (2023-2040).

Projected SO_2 emissions are listed in Table 10.4.4. The major source is refinery processes followed by flaring in refineries and flaring in oil and gas production, the latter being of only minor importance.

Table 10.4.4 Projected SO_2 emissions for selected historical years (1990-2022) and projection years (2023-2040).

NFR code	Source	1990	2000	2005	2010	2015	2020	2022	2023	2025	2030	2035	2040
		Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
1B2a iv	Refinery, processes	3335	981	347	981	406	548	374	646	646	646	646	646
1B2c	Refinery, flaring	943	51	296	326	126	224	134	138	138	138	138	138
1B2c	Flaring in oil and gas production	2.1	4.8	3.5	2.3	1.7	0.9	0.6	0.6	0.6	0.7	0.6	0.6

The only source to emissions of NO_x in the fugitive sector is flaring, which occur in refineries, offshore in oil and gas production, at the gas treatment plant and in gas transmission and distribution (Figure 10.4.3). Emissions of NO_x peaked around year 2000 and have been decreasing until 2022 due to the decreasing trend for offshore flaring.

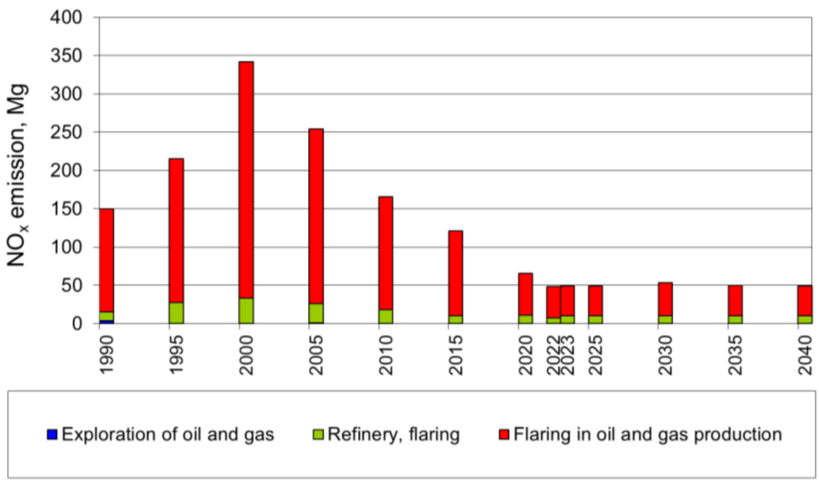

Figure 10.4.3 NO_x emissions for selected historical years (1990-2022) and projection years (2023-2040).

The most important source is offshore flaring in oil and gas production, which account for 96 % in year 1992, 85 % in 2022 and 79 % in 2040 of the total fugitive NOx emissions. Table 10.4.5 lists NO_x emissions for selected historical and projection years. Emissions from flaring in oil and gas extraction include offshore flaring and flaring in gas storage and treatment plants. Exploration of oil and gas is not included in the projection, as activity data are not available and due to the unpredictability of this source.

Table 10.4.5 Projected NO_x emissions for selected historical years (1990-2022) and projection years (2023-2040).

NFR code	Source	1990	2000	2005	2010	2015	2020	2022	2023	2025	2030	2035	2040
		Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
1B2a i	Exploration of oil and gas	3.56	0.07	0.88	0	0.04	0	0	0	0	0	0	0
1B2c	Refinery, flaring	12	34	26	18	11	11	7	10	10	10	10	10
1B2c	Flaring in oil and gas production	134	309	228	148	110	55	41	39	39	44	39	39

The fugitive sector is an important source of NMVOC emissions. In 2022, the sector accounted for 5 % of the national total NMVOC emission when not taking the exceptional emissions from the Nord Stream leakages in 2022 into account. The major fugitive NMVOC sources are onshore and offshore activities in oil and gas production, refinery processes, and service stations (Figure 10.4.4). In the later historical years and in the projection years, refinery processes are the major single source. As mentioned, fugitive emissions from refineries are highly unpredictable and only very few measurements are available as basis for the emission estimation. Improvement of the emission estimation and projection for refinery processes require more measurements at the refineries.

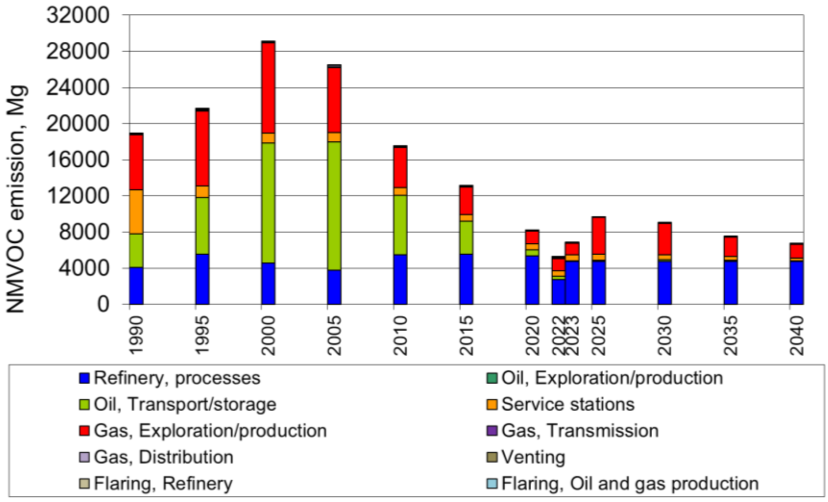

Figure 10.4.4 NMVOC emissions for selected historical years (1990-2022) and projection years (2023-2040).

Emissions of NMVOC are listed in Table 10.4.6. Emissions from offshore activities for oil and gas, from onshore activities for oil, and from flaring in oil and gas production fluctuate in the projection years according to the oil and gas production prognosis. These sources have a decreasing trend in the projection years. Emissions from service stations, gas transmission and distribution, and post-meter emissions follow the prognosis for consumption of gasoline and natural gas, respectively. Emissions from service stations decrease significantly in the early historical years, followed by a more constant level from 1996 onwards. Consumption of natural gas are decreasing in the projection period, leading to decreasing NMVOC emissions. Venting occurs due to safety reasons in connection with construction work, inspection and maintenance, and fluctuates in an unpredictable way. The emissions are constant in the projection period, as an average of the emissions in the latest five historical years.

Table 10.4.6 Projected NMVOC emissions for selected historical years (1990-2022) and projection years (2023-2040).

NFR code	Source	1990 Mg	2000 Mg	2005 Mg	2010 Mg	2015 Mg	2016 Mg	2017 Mg	2020 Mg	2025 Mg	2030 Mg	2035 Mg	2040 Mg
1B2a iv	Refinery, processes	4072	4530	3742	5477	5556	5578	5633	5318	4745	4745	4745	4745
1B2a i	Oil, Exploration & production	0	0	0	0	0	0	0	0	0	0	0	0
1B2a i	Oil, Transport & Storage	3721	13308	14208	6597	3625	2914	2125	704	137	148	104	75
1B2a v	Service stations	4856	1119	1031	851	721	707	711	638	626	553	428	264
1B2b	Gas, Exploration & production	6104	9985	7234	4418	3040	3002	3180	1402	4076	3520	2155	1572
1B2b	Gas, Transmission	31	25	41	41	45	44	44	14	10	0	0	0
1B2b	Gas, Distribution	113	105	167	122	95	83	86	70	34	6	6	5
1B2c	Venting	0	0	0	0	0	0	0	0	0	0	0	0
1B2c	Flaring, Refinery	11	17	19	20	15	16	16	13	13	13	13	13
1B2c	Flaring, Oil & gas production	0	0	0	0	0	0	0	0	0	0	0	0

* Offshore loading of ships was not occurring until 1999.

The major fugitive source of PM and BC emissions is coal storage, while emissions from flaring are of only minor importance especially regarding BC (Figure 10.4.5, Figure 10.4.6, Table 10.4.7 and Table 10.4.8). Emissions from coal storage follow the trend of the annual coal consumption, which is decreasing for the projection years.

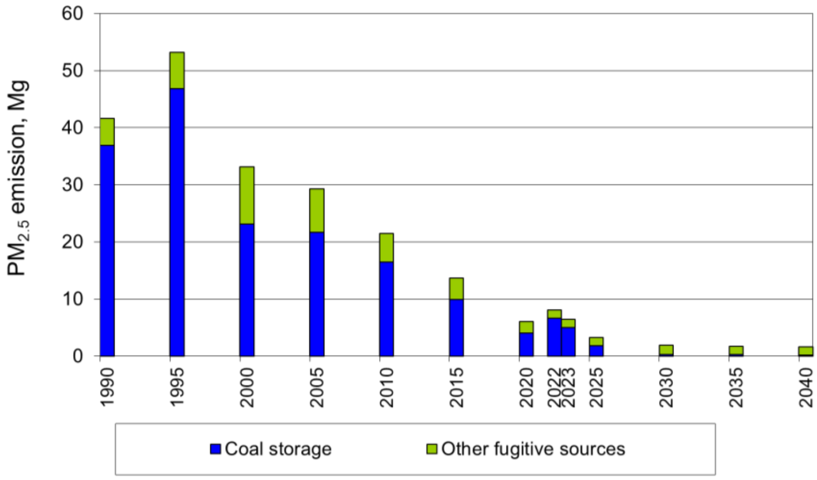

Figure 10.4.5 $PM_{2.5}$ emissions for selected historical years (1990-2020) and projection years (2021-2040).

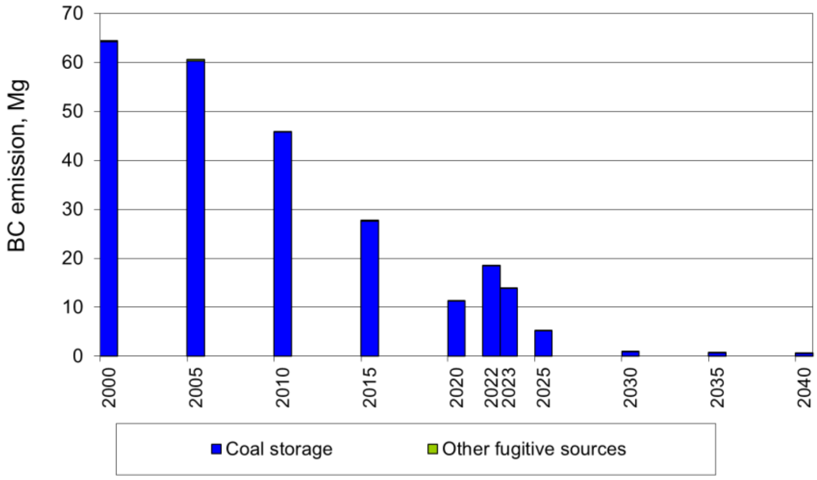

Figure 10.4.6 BC emissions for selected historical years (1990-2022) and projection years (2023-2040).

Table 10.4.7 Projected $PM_{2.5}$ emissions for selected historical years (1990-2022) and projection years (2023-2040).

NFR code	Source	1990	2000	2005	2010	2015	2020	2022	2023	2025	2030	2035	2040
		Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
1B1a	Coal storage	37	23	22	16	10	4	7	5	2	0	0	0
1B2a + 1B2b	Exploration of oil and gas	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1B2c	Refinery, flaring	0.4	0.3	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
1B2c	Flaring in oil and gas production	4.3	9.8	7.2	4.7	3.5	1.7	1.3	1.2	1.2	1.4	1.2	1.2

Table 10.4.8 Projected BC emissions for selected historical years (1990-2022) and projection years (2023-2040).

NFR code	Source	1990	2000	2005	2010	2015	2020	2022	2023	2025	2030	2035	2040
		Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
1B1a	Coal storage	103	64	60	46	28	11	18	14	5	1	1	1
1B2a + 1B2b	Exploration of oil and gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1B2c	Refinery, flaring	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
1B2c	Flaring in oil and gas production	0.1	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

11.4.5 References

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11.5 Industrial processes and product use

Industrial processes and product use (IPPU) covers a large range of sources, some with very limited contributions to the total national emissions and some with significant contributions to overall emissions.

For some source categories, it is not possible to distinguish between energy and process related emissions e.g. cement production. These sub-sectors are included in the chapter on stationary combustion.

The source categories are grouped into sub-categories 2A Mineral industry, 2B Chemical industry, 2C Metal industry, 2D Non-energy products from fuels and solvent use, 2G Other product manufacture and use, 2H Other, 2I Wood processing and 2L Other production. The source categories included in the projections from IPPU are:

- 2A2 Lime production – TSP, PM_{10}, $PM_{2.5}$, BC
- 2A3 Glass production – SO_2, TSP, PM_{10}, $PM_{2.5}$, BC
- 2A3 Glass wool production – NMVOC, NH_3, CO, TSP, PM_{10}, $PM_{2.5}$, BC
- 2A5a Quarrying and mining of minerals other than coal – TSP, PM_{10}, $PM_{2.5}$
- 2A5b Construction and demolition – TSP, PM_{10}, $PM_{2.5}$
- 2A5c Storage, handling and transport of mineral products – TSP, PM_{10}, $PM_{2.5}$
- 2A6 Brickworks – SO_2
- 2A6 Production of expanded clay products – SO_2
- 2A6 Stone wool production – NMVOC, NH_3, CO, TSP, PM_{10}, $PM_{2.5}$, BC
- 2B10a Catalyst production – NO_x, NH_3, TSP, PM_{10}, $PM_{2.5}$, BC
- 2B10a Chemical ingredients production – NMVOC
- 2B10a Pesticide production – SO_2, NMVOC
- 2B10a Production of tar products – SO_2, NMVOC
- 2C1 Steel production – NMVOC, TSP, PM_{10}, $PM_{2.5}$, BC
- 2C1 Iron production – TSP, PM_{10}, $PM_{2.5}$, BC
- 2C5 Lead production – SO_2, TSP, PM_{10}, $PM_{2.5}$
- 2D3c Asphalt roofing – NMVOC, CO, TSP, PM_{10}, $PM_{2.5}$, BC
- 2D3b Road paving with asphalt – NMVOC, CO, TSP, PM_{10}, $PM_{2.5}$, BC
- 2D3a,d,f,g,h,i Solvent use – NMVOC
- 2G Use of charcoal for barbeques – SO_2, NO_x, NMVOC, NH_3, CO, TSP, PM_{10}, $PM_{2.5}$, BC
- 2G Use of fireworks – SO_2, NO_x, CO, TSP, PM_{10}, $PM_{2.5}$
- 2G Paraffin wax use – CO, TSP, PM_{10}, $PM_{2.5}$
- 2G Use of shoes – TSP
- 2G Use of tobacco – SO_2, NO_x, NMVOC, NH_3, CO, TSP, PM_{10}, $PM_{2.5}$, BC
- 2H2 Food and beverages production – NMVOC, TSP, PM_{10}, $PM_{2.5}$
- 2I Wood processing – TSP, PM_{10}, $PM_{2.5}$
- 2L Treatment of slaughterhouse waste – NH_3

11.5.1 Methodology

For most sub-sectors, no information is available to project emissions in a sophisticated manner. Therefore, in these cases the projection is done as the average of the three latest historical years. However, in the case of activities related to construction, growth factors for the projection time series are available (DEA, 2024), and in the case of use of shoes and use of tobacco, projections are calculated using population projections (Statistics Denmark, 2024) and historical trend respectively.

Projected growth values for the construction sector are applied when projecting emissions from:

- Glass wool production
- Stone wool production
- Quarrying and mining of minerals other than coal
- Construction and demolition
- Storage, handling and transport of mineral products
- Production of bricks, tiles and expanded clay products.

The growth factor time series is illustrated in Figure 11.5.1.

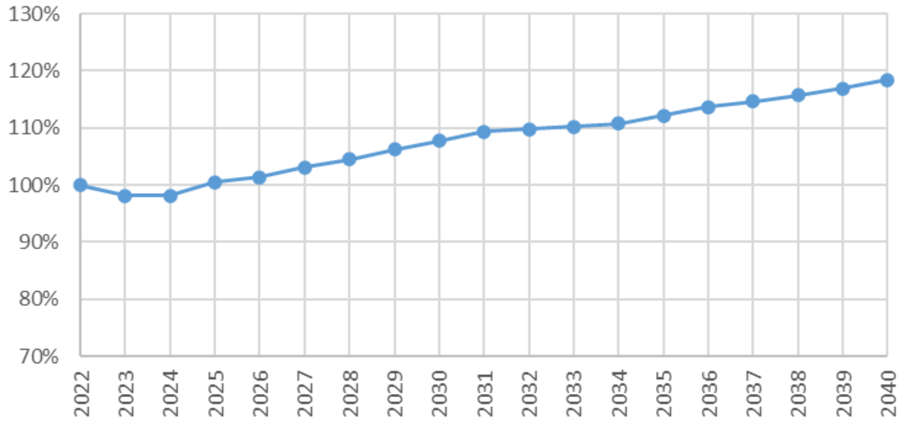

Figure 11.5.1 Expected development of the construction sector in relation to the 2022 level (DEA, 2024).

For the remaining sources (i.e. not construction related) the trends of the historical years are analysed, to ensure that there is not a significant increasing or decreasing trend that should be reflected in the projection. If such a trend is present, this is used in the projection, as is the case with the use of tobacco. When no convincing trend is present, the average value of the latest three historical years is applied. In cases where these years are not representable, other historical years are chosen, e.g. if they contain significant outliers, like the 2021-2022 NMVOC emission from solvent use, where the increased consumption of disinfectants during the Covid-19 pandemic, resulted in increased NMVOC emissions from solvent use of about 15%.

An exception to the projection methodology described above, is the emission from the use of shoes. This sub-sector is projected using the population projection from Statistics Denmark (2024).

11.5.2 Emissions

Overall projected emissions from the IPPU sector are presented in Table 11.5.1 below. Detailed emission data for each sector in IPPU (e.g. Mineral industries, Chemical industries, etc.) are available online (https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/projection) and not repeated here.

Table 11.5.1 Historical and projected emissions from IPPU.

	Unit	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
SO_2	kt	4.3	4.4	4.0	3.9	1.9	1.2	1.1	0.8	0.9	0.9	0.9
NO_x	kt	1.0	0.8	0.6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
NMVOC	kt	42.5	49.8	45.2	35.5	29.6	30.4	32.9	29.2	29.2	29.2	29.2
CO	kt	13.7	11.6	15.4	16.4	2.9	4.5	2.4	3.0	3.0	3.0	2.9
NH_3	kt	0.7	0.7	0.6	0.6	0.5	0.4	0.4	0.4	0.5	0.5	0.5
TSP	kt	-	-	9.1	9.1	8.8	5.5	6.1	6.2	6.5	6.7	7.0
PM_{10}	kt	-	-	3.7	3.5	3.3	2.3	2.5	2.5	2.7	2.7	2.8
$PM_{2.5}$	kt	-	-	1.3	1.0	0.8	0.7	0.7	0.8	0.8	0.8	0.8
BC	t	-	-	18.5	13.2	8.0	11.5	7.2	9.2	9.3	9.3	9.4

Emissions from the IPPU sector are not expected to change significantly in the years towards 2040.

SO_2 emissions from IPPU increases slightly from 2023-2040. In the same period, national emissions decrease, resulting in SO_2 emissions from IPPU to increase from 10% of national emissions in 2025 to 16% in 2040. The largest sources of SO_2 emissions from IPPU is production of bricks, tiles and expanded clay products (65-69%) and glass production (22-25%).

NO_x and NH_3 emissions from IPPU only make up 0.1% and 0.4-0.8% of the respective national emissions.

NMVOC emissions from IPPU amount to 29-33% of national emissions. 92% of NMVOC emissions from IPPU arise from solvent use.

2-4% of national CO emissions in 2023-2040 stem from the IPPU sector. The largest contributors to CO emissions in the IPPU sector are Burning of charcoal for barbeques (66-68%) and Road paving with asphalt (15-16%).

Regarding projected particle emissions, only 7-9% of national TSP emissions are caused by the IPPU sector in 2023-2040, but for $PM_{2.5}$ this number is 7-13%. There are 19 source categories contributing to $PM_{2.5}$ emissions in the IPPU sector, the largest being Quarrying and mining of minerals other than coal (19-22% of IPPU emissions), Construction and demolition (13-15%) and Use of fireworks (13-14%).

11.5.3 References

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11.6 Agriculture

The projection of air pollutants from the agricultural sector includes emission of ammonia (NH_3), particulate matter (PM) given as TSP, PM_{10} and $PM_{2.5}$, non-methane volatile organic compounds (NMVOC), sulphur dioxide (SO_2), nitrogen oxide (NO_X) and black carbon (BC).

The projection on emissions of air pollutants is regularly updated in line with new scientific knowledge, because of new emission sources, changes of emission factors or changes of the agricultural production conditions e.g. changes regarding the export market or the legislation and regulation. Some of the changes can lead to revision in the historical emission inventory as well and therefore, some deviations are apparent in comparison with the projection scenarios published in previous reports.

11.6.1 Methodology

The methodology used to estimate the projected emission is based on the same methodology as used in the annual emission inventories, which is described in the EMEP/EEA air pollutant emission inventory guidebook (EMEP, 2023). Thus, the same database setup is used, same estimation approach and principally the same emission factors. In cases where the future conditions will change, e.g. by implementation of emission reducing technology, an adjustment of the emission factor will follow.

11.6.2 Assumptions

The data used to in this projection is based on information from a range of agricultural related institutions and organisations. Data from the model AGMEMOD is used to project the trend in livestock production and agricultural area. AGMEMOD is managed by IFRO – Department of Food and Resource Economics, Copenhagen University. Projection of trend in housing of animals and implementation of ammonia reducing technology in housings is based on estimates from SEGES – the agricultural advisory centre.

Livestock

For cattle, swine, hens and broilers, the number of animals is based on the model AGMEMOD (Jensen, 2023) until 2040. For non-dairy cattle, the number of bulls and heifers are projected based on AGMEMOD combined with estimates from DCA (Kristensen and Lund, 2016), to make it convertible with the cattle categories used in the national inventory setup.

The production of horses, sheep, goats, turkeys, ducks, and geese is less important, because the contribution for these categories is relatively small compared to production of cattle, swine, and fur animals. Therefore, the number of animals is kept at the same level as in 2022. When it comes to fur bearing animals (mink) the situation changes dramatically compared with historic years. Because of the risk for developing a COVID-19 variant, the government required to destroy all fur animals, which supports the assumption of no Danish mink production in 2021-2022. The mink production can be continued from 2023, but it will be very difficult and costly to restart the mink production especially because of the loss of breeding animals, so the production is projected to be only 10 % of the production in 2020.

Figure 11.6.1 shows the projected trend in number of animals given in percent change compared to 2022. In Table 11.6.1 are the actual numbers shown. A decrease in number of cattle is expected up to 2040 due to expected development in milk production and for number of non-dairy cattle the trend is also expected to decrease as a spillover effect.

The number of swine decrease significantly from 2022 to 2023 mainly because the export of pork to China has decreased, because the production in China has been restored after the outbreak of swine fever in 2019. The consequences of swine fever are expected to fade out and the production of swine is expected to have a small increase and afterwards stagnate towards 2040. The number of sows is expected to decrease with 16 %, but due to expected increase in number of piglets per sow, number of weaners is only expected to decrease with around 6 %. Export of weaners is expected to increase towards 2040.

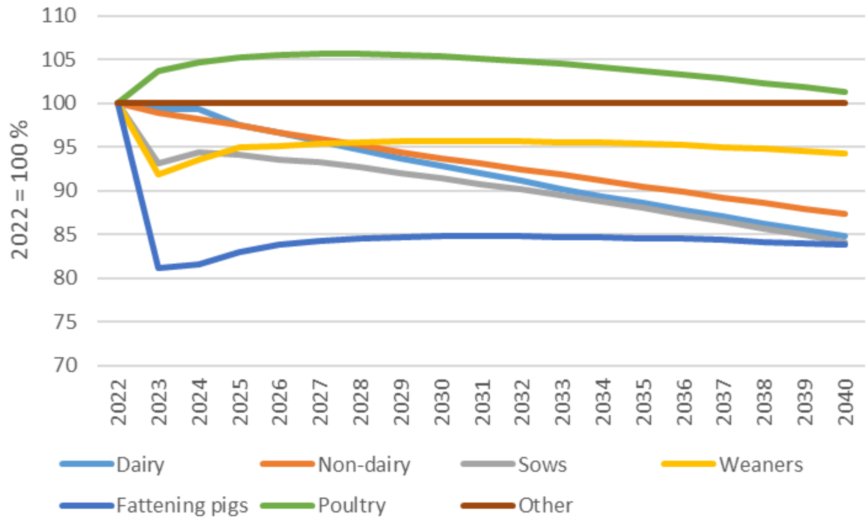

Figure 11.6.1 Trend of number of animals in 2022-2040 in relation to 2022.

Table 11.6.1 Projected number of animals, 1000 pc.

	2022	2023	2025	2030	2035	2040
Dairy cattle	557	553	543	517	493	473
Non-dairy cattle	1 087	1 075	1 059	1 018	983	948
Sows	975	907	918	891	858	820
Weaners (prod.)	32 447	29 819	30 784	31 020	30 932	30 566
Fattening pigs (prod.)	18 659	15 144	15 468	15 815	15 780	15 628
Poultry (prod.)	216	224	227	227	224	219
Mink	0	222	222	222	222	222
Other	277	277	277	277	277	277

Housing systems

Projection of distribution for cattle in different types of housing systems is provided by SEGES (2023). The estimates are for 2030 and 2040 and distribution for the years 2021-2029 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 2023.

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 during the COVID-19 pandemic. For the years 2023-2040 same distribution as for 2020 are used.

Table 11.6.2 Projected distribution on housing systems (*2022 are historic year).

	2022*	2023	2025	2030	2035	2040
Dairy cattle						
Tethered with urine and solid manure	1.0	0.9	0.8	0.6	0.0	0.0
Tethered with slurry	1.5	1.3	1.1	0.9	0.0	0.0
Loose-holding with beds, solid floor	16.7	15.9	15.0	14.2	10.0	6.0
Loose-holding with beds, slatted floor	43.7	41.5	39.3	37.1	26.0	26.0
Loose-holding with beds, slatted floor, scrape	21.2	20.4	19.7	18.9	15.0	15.0
Loose-holding with beds, solid floor with tilt	6.6	10.8	15.0	19.2	40.3	44.3
Deep litter (all)	6.7	6.6	6.5	6.4	6.0	6.0
Deep litter, long eating space, solid floor	0.6	0.7	0.8	0.9	1.5	1.5
Deep litter, slatted floor	1.2	1.2	1.1	1.1	0.8	0.8
Deep litter, slatted floor, scrape	0.8	0.8	0.7	0.7	0.4	0.4
Fattening pigs						
Partly slatted floor (50-75 % solid floor)	11.3	11.0	10.7	10.4	9.0	8.0
Partly slatted floor (25-49 % solid floor)	37.8	39.3	40.9	42.4	50.0	58.5
Solid floor	0.2	0.2	0.2	0.2	0.1	0.1
Deep litter	0.6	0.6	0.6	0.5	0.4	0.4
Partly slatted floor and partly deep litter	0.4	0.4	0.4	0.4	0.5	0.5
Partly slatted and drained floor	49.7	48.5	47.3	46.1	40.0	32.5
Broilers						
Broilers, (conv. 30 days)	1.6	1.5	1.5	1.4	1.0	1.0
Broilers, (conv. 32 days)	41.0	38.9	36.8	34.6	24.0	24.0
Broilers, (conv. 35 days)	45.3	42.8	40.2	37.7	25.0	25.0
Broilers, (conv. 40-45 days)	2.3	3.9	5.5	7.1	15.0	15.0
Broilers, barn (56 days)	7.9	10.7	13.4	16.2	30.0	30.0
Organic broilers (81 days)	1.9	2.3	2.7	3.1	5.0	5.0

NH_3 reducing technology

The technologies included in this projection is acidification of slurry, cooling of manure, air cleaning, frequent removal of manure (mink) and heat exchanger (broilers).

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

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

For cattle the only available technology in housings 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 SEGES (2023) and distribution of housings with air cleaning is based on Wiborg (2022).

Manure cooling is the most frequently used technology for the overall swine production, but 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 both cattle and swine are expected to 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.

Table 11.6.3 Percentage of total production of swine and cattle with NH_3 reducing technology in housings, %.

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	2022	2023	2025	2030	2035	2040
Dairy cattle	2	3	4	8	8	8
	3	4	5	8	8	8
Heifer	0	1	1	2	2	2
	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	2022	2023	2025	2030	2035	2040
Sows	0	2	3	5	3	0
Weaners	0	0	0	0	0	0
Fattening pigs	0	2	2	4	2	0

In 2022, almost 90 % of broiler housings have heat exchanger installed and it is expected that this increase to 100 % by 2030 (Jensen, 2021, Pers. Comm.). As mentioned, the mink production is not existing in 2021-2022, but a small production is expected from 2023 and is expected that 90 % of this will remove the manure 2 times weekly.

Projection of acidification during application of manure is based on 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 11.6.4 Percentage of total production of broilers and mink with NH_3 reducing technology in housings and percentage of acidification during application of manure, %.

Heat exchanger	2022	2023	2025	2030	2035	2040
Broilers	90	91	94	100	100	100
Removal of slurry - 2 times weekly	2022	2023	2025	2030	2035	2040
Mink	11	21	41	90	90	90
Acidification during application	2022	2023	2025	2030	2035	2040
Cattle manure	8	8	9	12	14	16
Swine manure	1	1	2	2	3	4

Reducing potential for NH_3 reducing technology

The List of Environmental Technologies managed by Danish Environmental Protection Agency (DEPA, 2023) includes a range of NH_3 reducing technologies, and for each technology is provided an average reducing effect for use of the technology. The listed factors for cooling and acidification of slurry, heat exchanging, and frequent removal of manure are used.

Assessment of the environmental approval register shows a high variation in the NH_3 reducing effects in practice for air cleaning, dependent on the conditions on the farm – e.g. the amount of air in housing which is cleaned etc. Based on the review of this reducing factors have been estimated.

In Table 11.6.5 are shown the reduction factors used.

Table 11.6.5 NH_3 reducing factors, %.

	Animal type	NH_3 reducing factors %
Cooling of manure	Swine	20*
Acidification of slurry in housings	Cattle	33*
	Swine	64*
Acidification of slurry during application	Cattle	49*
	Swine	40*
Air cleaning	Sows	61**
	Weaners	54**
	Fattening pigs	56**
Heat exchanger	Broilers	30*
Frequent removal of manure	Mink	27*

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

N-excretion

Development in N-excretion for dairy cattle and swine are based on projection made by Lund (2023) and Nørgaard & Hellwing (2023), respectively. For all other animal categories, N-excretion is set at the same level as in 2022.

N-excretion for dairy cattle (conventional farming) is expected to increase 14-16 % in 2040 due to increase in feed intake and increase in milk yield. For fattening pigs and weaners N-excretion is expected to decrease around 9-18 % mainly due to decrease in feed intake and an increase in feed efficiency.

Table 11.6.6 N-excretion, kg per year.

	2022	2023	2025	2030	2035	2040
Dairy cattle						
Large breed, conventional	160.8	162.2	165.1	171.0	177.0	183.1
Jersey, conventional	131.5	133.2	136.7	142.0	147.3	152.6
Large breed, organic		156.4	158.7	162.6	166.5	170.3
Jersey, organic		127.2	129.2	132.5	135.9	139.2
Swine						
Sows	23.2	23.3	23.6	23.3	23.0	22.6
Weaners	0.4	0.4	0.4	0.4	0.3	0.3
Fattening pigs	2.6	2.7	2.9	2.7	2.6	2.4

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).

Table 11.6.7 Agricultural land area in the projection, 1 000 ha.

	2022	2023	2025	2030	2035	2040
Agricultural land area	2 624	2 619	2 604	2 542	2 521	2 511

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 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 11.6.8 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 allocation of the main crop types towards 2040 are estimated by AGMEMOD (Jensen, 2023). For the crop types which is not mentioned by Jensen (2023) is assumed that the production is kept at the same level as the latest historical years.

Use of inorganic N-fertiliser

Use of inorganic fertiliser depends on the agricultural area and the amount of available nitrogen in animal manure and sewage sludge (amount of N in the farmers nitrogen fertiliser account). The use of inorganic fertiliser is also affected by the policy decision regarding no fertilisation of §3 areas and the three measure for increased area with perennial grass (Table 11.6.8), increase

N in soil due to increased area with cover crops and increased 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 enters into force from 1/7-2022.

The increasing interest and demand for reduction of loss of N-surplus to the aquatic environment and reduction of the air emission as well as the emission of greenhouse gases, a political agreement has been reached; Agreement on the Green Transition for Danish Agriculture (AGTDA, 2021). This agreement includes subsidy schemes and based on this, an increase in the area of perennial grass must be expected. 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 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 is 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 this average N-fertilisation the total N need 2023 is estimated to 387.6 kt N. The subtraction due to the policy decisions and assumption for these mention above the adjusted N quota is estimated to 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 11.6.9 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.

Field operations

The emission of PM from field operations is calculated by area of cultivated crops multiplied with number of operations and emission factor, for each crop type and type of operation. Operations are divided in soil cultivation, harvesting, cleaning, and drying. The projection of PM from field operations is based on a level equivalent to the average emission from the years 2018-2022 combined with the area.

11.6.3 Emissions

This projection covers the latest official Danish reporting, which includes historical emission until 2022. Thus, the projection comprises an assessment of the emissions from the agricultural sector from 2023 to 2040. Emission of the projected pollutants shown in Table 11.6.10 are all expected to decrease by 2-15 %.

Table 11.6.10 Projected emissions from the agricultural sector.

Tonnes	2022	2023	2025	2030	2035	2040	2022-2040	%
NH_3	70 640	68 057	68 246	65 447	63 496	60 846	-9 794	-14
NO_x	19 155	17 517	17 593	17 172	17 125	17 076	-2 079	-11
SO_2	10	8	8	8	8	8	-1	-15
NMVOC	46 666	46 158	46 548	46 379	45 976	45 796	-871	-2
$PM_{2,5}$	1 089	1 078	1 067	1 043	1 021	1 001	-88	-8
BC	10	8	8	8	8	8	-1	-15

NH_3 emission

NH_3 emission is expected to decrease by 9 800 t NH_3 in the period 2022 to 2040, corresponding to a decrease of 14 %. The emission from animal manure is expected to decrease by 6 600 t NH_3, corresponding to a decrease of 25 % compared to 2022. The decrease is due to a combination of decrease in number of animals, changes in distribution of animals in housings and implementation of NH_3 reducing technology.

For manure applied to soil a decrease in emission of 10 % is expected and this is mainly due to decrease in N from swine manure.

Emission from use of inorganic N-fertiliser is expected to decrease by 900 t NH_3 until 2040, corresponding to a decrease of 5 % compared to 2022. This is due to increase in area with low or no application of fertiliser and decrease in agricultural area. The emission from growing crops and other sources is expected to decrease by 4-7 %, caused by decrease of the agricultural area.

Table 11.6.11 Changes in NH_3 emission 2022-2040.

Tonnes NH_3	2022	2023	2025	2030	2035	2040	Difference 2022-2040	pct
Manure	26 903	25 557	25 688	23 957	22 443	20 278	-6 625	-25
Inorganic N-fertiliser	17 020	16 574	16 225	15 640	15 838	16 100	-920	-5
Manure applied to soil	16 678	16 103	16 545	16 207	15 655	14 996	-1 682	-10
Cultivated crops	6 429	6 258	6 223	6 075	6 025	5 999	-430	-7
Other*	3 609	3 564	3 565	3 568	3 534	3 473	-137	-4
Sum	70 640	68 057	68 246	65 447	63 496	60 846	-9 794	-14

* Sewage sludge, grassing, field burning, ammonia treated straw.

In Table 11.6.12 are shown the emission from manure in housings and storage for the period 2022-2040 distributed on animal categories. Emission of NH_3 from swine is expected to decrease by 36 % from 2022 to 2040, due to a combination of decrease in production of animals, lower N-excretion for weaners and fattening pigs and increase in implementation of NH_3 reducing technology.

Emission of NH_3 from dairy cattle is expected to decrease by 27 % from 2022 to 2040 due to a combination of decrease in number of animals, increase in organic production and changes in the distribution of housings, where it is assumed that systems with high NH_3 emission (solid floor) are replaced with systems with a lower NH_3 emission such (drained floor). Emission from non-dairy cattle is expected to decrease by 11 % mainly due to decrease in number of animals.

The mink production is closed in 2021 and 2022 and only expected to continue with very low production from 2023-2040, therefor a high decrease in the emission compared to before 2021, and the closing of the production, is expected. For poultry, the production and emission are assumed to decrease slightly.

Table 11.6.12 Changes in NH_3 emission from manure (housing and storage).

Tonnes NH_3	2022	2023	2025	2030	2035	2040	Difference 2022-2040	pct
Dairy cattle	7 487	7 330	7 079	6 409	6 276	5 434	-2 053	-27
Non-dairy cattle	3 561	3 528	3 380	3 400	3 290	3 171	-390	-11
Swine	12 552	10 934	11 447	10 410	9 205	8 073	-4 479	-36
Poultry	2 340	2 400	2 439	2 448	2 384	2 312	-28	-1
Mink	0	399	378	325	325	325	-	-
Other	964	964	964	964	964	964	0	0
Sum	26 903	25 557	25 688	23 957	22 443	20 278	-6 625	-25

PM emission

The emission of $PM_{2,5}$ is expected to decrease by 8 % in the period 2022-2040. Emission from animals is assumed to decrease due to decrease in number of animals and emission from field operations and field burning due to decrease in the agricultural area.

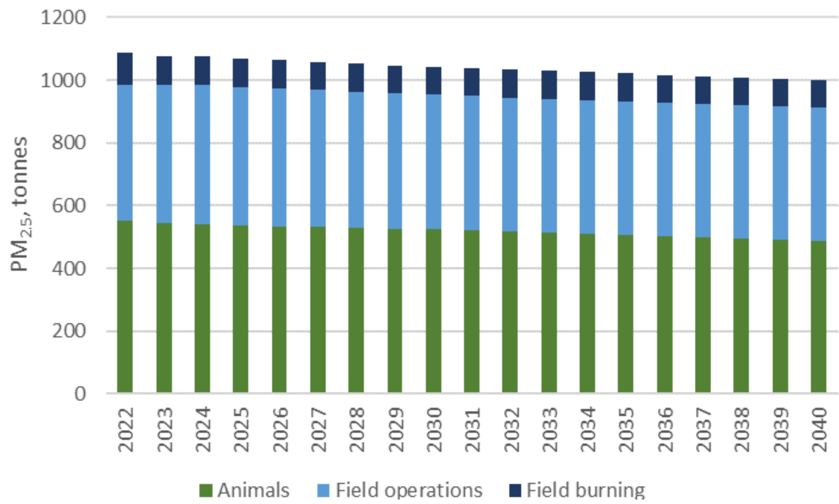

Figure 11.6.2 Projected $PM_{2,5}$ emission 2022-2040.

NMVOC emission

The NMVOC emission from the agricultural sector is expected to decrease by 2 %in the period from 2022 to 2040. Emission from manure management is expected to decrease, while emission from manure applied is expected to increase. The decrease in emission from manure management is mainly due to decrease in number of cattle and the increase in emission from manure applied is due to the ratio between NH_3 emission from housing and application.

Emission from crops is expected to decrease due to decrease in agricultural area.

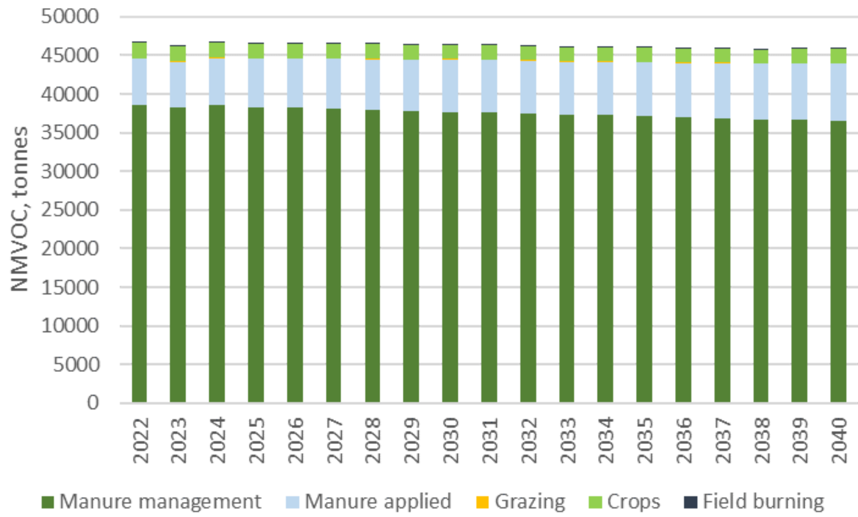

Figure 11.6.3 Projected NMVOC emission 2022-2040.

NO_x emission

NO_x emission is expected to decrease by 11 % in 2022-2040, where the main decrease is seen from 2022 to 2023. This is mainly due to decrease in emission from inorganic N-fertiliser and manure applied to soil. Use of inorganic N-fertiliser decreases due to increase of areas with low or no application of N and emission from manure applied decreases mainly due to decrease in N applied from swine.

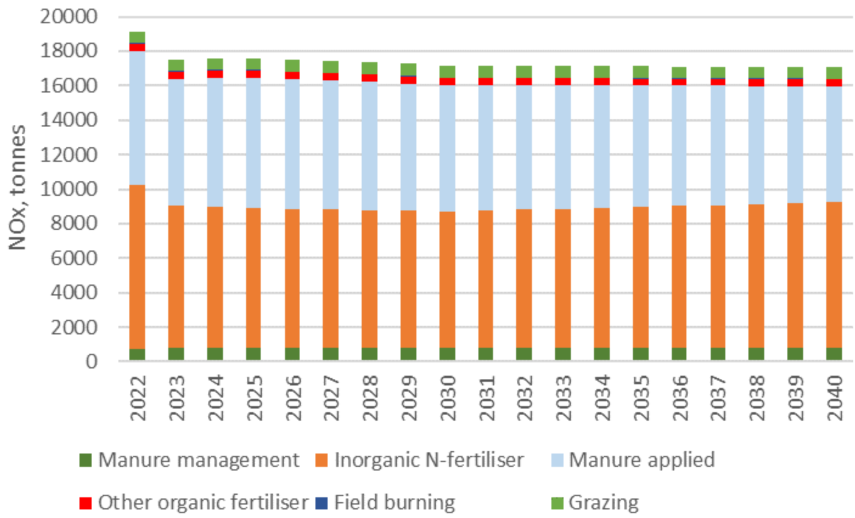

Figure 11.6.4 Projected NO_x emission 2022-2040.

SO_x and BC emission

The agricultural sector contributes with less than one percent of the national emission of SO_2 and BC. The agricultural emission of SO_2 and BC comes from field burning of agricultural residues. The projected emission is based on the average emission from 2018-2022 combined with the projection of the agricultural area. The emission is estimated to decrease due to decrease in agricultural area.

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11.7 Waste

Emission projections for the waste sector are performed individually for each of the included source categories:

- Solid waste deposit sites (SWDS) – NMVOC, TSP, PM_{10} and $PM_{2.5}$
- Composting – NH_3 and CO
- Biogas production – NH_3
- Cremation – SO_2, NO_x, NMVOC, CO, TSP, PM_{10} and $PM_{2.5}$
- Wastewater handling - NMVOC
- Accidental fires – SO_2, NO_x, NMVOC, CO, TSP, PM_{10} and $PM_{2.5}$

All waste incineration of municipal, industrial and hazardous waste in Denmark is done with energy recovery. Hence, the emissions from these activities are included under the stationary combustion part of both the emission inventory and the emission projection.

11.7.1 Methodology

The methods used in the emission projections follow the methodologies for the emission inventory as described in Chapter 6.

NMVOC emissions from SWDSs are estimated from the CH_4 emission. The CH_4 emission is calculated by means of a First Order Decay model equivalent to the IPCC Tier 2 methodology. The model calculations are performed using national statistics on landfill waste categories reported in the national waste statistics. Waste amount reported or estimated for the historical time series since 1940, are grouped into 10 degradable waste types with individual content of degradable organic matter and degradation kinetics expressed as half-lives. The CH_4 calculations are further described in the greenhouse gas projections report (Nielsen et al., 2024). The applied emission factor is the Tier 1 value of 3.6 t NMVOC per kt CH_4 (EMEP/EEA, 2023) for all projected years.

Particle emissions from SWDSs are estimated from the projected total amount of deposited waste from DEPA (2024) and the Tier 3 emission factors of 90, 40 and 7 g per kt for TSP, PM_{10} and $PM_{2.5}$ respectively.

Emissions from composting are projected individually for the four waste categories: garden waste, organic waste, sludge, and home composting. 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 (Chapter 6 of this report). It is therefore not possible to apply activity data projected by DEPA (2024) directly, but only as surrogate data. For organic waste and home composting, no further data are available, and emissions are therefore projected as the last three historical years.

NH_3 emission projections from anaerobic digestion at biogas facilities are calculated from the expected development of the biogas energy production (PJ) from the Danish Energy Agency (DEA, 2024) and the emission factor 0.25 tonnes NH_3 per PJ.

Emissions from cremations are projected from the latest three historical years and the national population projection from Statistics Denmark (2024).

Emissions from both wastewater handling and accidental fires are projected as the constant average emissions from the three latest historical years.

Regarding emission factors, these are kept constant throughout the time series 1990-2040, for more information on emission factors, please refer to Chapter 6 of this report.

11.7.2 Emissions

Overall projected emissions from the waste sector are presented in Table 11.7.1 below. Detailed emission data for each sub-sector in waste; SWDS, Biological treatment of waste (composting and biogas production), Waste incineration, Wastewater handling and Other (accidental fires), are available in the NFR tables online (https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/projection) and not repeated here.

Table 11.7.1 Historical and projected emissions from the waste sector.

	Unit	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
SO_2	kt	0.42	0.48	0.43	0.41	0.40	0.37	0.36	0.36	0.36	0.36	0.36
NO_x	kt	0.16	0.18	0.16	0.16	0.17	0.15	0.15	0.15	0.16	0.16	0.16
NMVOC	kt	0.80	0.85	0.73	0.68	0.64	0.60	0.57	0.56	0.56	0.55	0.55
CO	kt	2.04	2.40	2.55	2.43	2.46	2.37	2.53	2.58	2.63	2.64	2.64
NH_3	kt	0.20	0.26	0.46	0.49	0.54	0.58	0.66	0.74	0.77	0.76	0.77
TSP	kt	-	-	0.41	0.39	0.38	0.36	0.35	0.35	0.35	0.35	0.35
PM_{10}	kt	-	-	0.39	0.38	0.37	0.34	0.34	0.33	0.33	0.33	0.33
$PM_{2.5}$	kt	-	-	0.38	0.37	0.36	0.34	0.33	0.33	0.33	0.33	0.33

Emissions from the waste sector are not expected to change much in the years towards 2040.

98% of SO_2 emissions and 64-65% of NO_x emissions from the waste sector in 2023-2040 stem from accidental fires, the only other contributor to these pollutants is cremation of human corpses and animal carcasses.

The largest contributor to NMVOC emissions is also accidental fires (88-89%) with the second largest being SWDSs (9-10%).

CO emissions from the waste sector are made up 57-59% from accidental fires, 41-43% from biological treatment of waste and a miniscule contribution from waste incineration.

NH_3 emissions only arise from biological treatment of waste, where 98-99% is from composting.

99.8-99.9% of particle emissions from the waste sector in 2023-2040 arise from accidental fires.

11.7.3 References

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12 Adjustments

Decision 2012/3 of the Executive Body (UNECE, 2012a) decided that adjustments may be made under specific circumstances to the national emission inventories for the purpose of comparing the inventories with emission reduction commitments.

Under the revised NEC Directive (Directive 2016/2284/EU) Article V specifies flexibilities one of which is the possibility to establish adjusted emission inventories, where non-compliance with the national emission reduction commitments would result from applying improved emission inventory methods updated in accordance with scientific knowledge.

The circumstances under which an adjustment may be applied fall into three broad categories where:

- Emission source categories are identified that were not accounted for at the time when emission reduction commitments were set;
- Emission factors used to determine emissions levels for particular source categories for the year in which emissions reduction commitments are to be attained are significantly different than the emission factors applied to these categories when emission reduction commitments were set;
- The methodologies used for determining emissions from specific source categories have undergone significant changes between the time when emission reduction commitments were set and the year they are to be attained.

The supporting documentation required by Parties applying for an adjustment is set out in Decision 2012/12 (UNECE, 2012b) and in Annex IV Part 4 of Directive 2016/2284/EU and is summarised below.

A Party's/MS supporting documentation for an adjustment to its emission inventory or emission reduction commitments shall include:

- Evidence that the Party/MS exceeds its emission reduction commitments;
- Evidence of to what extent the adjustment to the emission inventory reduces the exceedance and possibly brings the Party/MS in compliance;
- An estimation of whether and when the reduction commitment is expected to be met based on emission projections without the adjustment, thereby using best available science;
- A full demonstration that the adjustment is consistent with one or more of the three broad categories above. Reference can be made, as appropriate, to relevant previous adjustments:
    - For new emission source categories:
        - Evidence that the new emission source category is acknowledged in scientific literature and/or the EMEP/EEA air pollutant emission inventory guidebook;
        - Evidence that this source category was not included in the relevant historic national emission inventory at the time when the emission reduction commitment was set;
        - Evidence that emissions from a new source category contribute to a Party being unable to meet its reduction commitments, support-

ed by a detailed description of the methodology, data and emission factors used to arrive at this conclusion;

- For significantly different emission factors used for determining emissions from specific source categories:
  - A description of the original emission factors, including a detailed description of the scientific basis upon which the emission factor was derived;
  - Evidence that the original emission factors were used for determining the emission reductions at the time when they were set;
  - A description of the updated emission factors, including detailed information on the scientific basis upon which the emission factor was derived;
  - A comparison of emission estimates made using the original and the updated emission factors, demonstrating that the change in emission factors contributes to a Party/MS being unable to meet its reduction commitments; and
  - The rationale for deciding whether the changes in emission factors are significant;
- For significantly different methodologies used for determining emissions from specific source categories:
  - A description of the original methodology used, including detailed information on the scientific basis upon which the methodology was based;
  - Evidence that the original methodology was used for determining the emission reductions at the time when they were set;
  - A description of the updated methodology used, including a detailed description of the scientific basis or reference upon which it has been derived;
  - A comparison of emission estimates made using the original and updated methodologies demonstrating that the change in methodology contributes to a Party/MS being unable to meet its reduction commitment; and
  - The rationale for deciding whether the change in methodology is significant.

12.1 Differences between UNECE and NECD

Under Directive 2016/2284/EU, the emissions of NO_x and NMVOC from animal husbandry and manure management (NFR category 3B) and crop production and agricultural soils (NFR category 3D) are excluded from the accounting as per Article 4, paragraph 3d of the Directive.

Under the amended Gothenburg Protocol (UNECE, 2013), emissions of NO_x from crop production and agricultural soils (NFR category 3D) are excluded from the accounting as per Annex II, footnote a to Table 3.

The differences in definitions on the emissions to be accounted leads to different compliance totals even in the absence of adjustments and can lead to a need for an adjustment under one reporting obligation without being needed for the other.

12.2 Accepted adjustments

Denmark applied for an adjustment under the UNECE in the 2022 submission that was approved (CEIP, 2022).

The adjustment pertains to NMVOC from Dairy Cattle (NFR 3B1a) on the basis that this is a new source compared to when the ERCs were set. In the 2009 version of the Guidebook (EEA, 2009), no default emission factors were available for NMVOC emissions from animal husbandry and manure management.

Table 122.1 NMVOC emissions with and without emissions from Dairy Cattle (NFR 3B1a).

Emissions, kt	2005	2020	2021	2022	2023
NMVOC	160.59	106.93	106.62	100.69	97.94
NMVOC from 3B1a	20.02	23.89	24.41	24.02	23.72
NMVOC excluding 3B1a	140.57	83.04	82.21	76.67	74.22
Accepted adjustment	-20.02	-23.89	-24.41	-24.02	-23.72

Table 122.2 NMVOC emission reductions with and without emissions from Dairy Cattle (NFR 3B1a).

Emission reduction, %	2020	2021	2022	2023	ERC, %
NMVOC	33.4	33.6	37.3	39.0	35
NMVOC from 3B1a	-19.3	-21.9	-20.0	-18.5	
NMVOC excluding 3B1a	40.9	41.5	45.5	47.2	35

The latest emission projection was done in 2024 and reported in 2025. This indicated that without an adjustment, Denmark would not meet the reduction target until 2023.

A detailed methodological description is provided in Chapter 5.3.4 and is only summarised here.

The estimation of NMVOC emission is based on the EMEP/EEA guidebook (2023) Tier 2 approach. The NMVOC emission is estimated on the number of animals, share of time spend in housing/on grass (time on grass in Table 5.6), gross energy for cattle (Annex 3D Table 3D-19), volatile solids (VS) for other animal categories (Annex 3D Table 3D-20) and fraction of silage in the feed (Table 5.14). The number of animals is given as the average annual population (AAP) – see Table 5.5.

NMVOC emission factors are used from the EMEP/EEA Guidebook (EEA, 2023) Table 3-11 (cattle) and Table 3-12 (other animals) is used, see Table 5.15. The same emissions factors are used for all years, which means that changes in the emission over time are caused by changes in animal production, feeding practice or grazing days.

Denmark applied for an adjustment under the UNECE in the 2024 submission that was approved (CEIP, 2024). The need for the additional adjustment was due to the high 2022 emissions caused by the Nord Stream leaks. However, as it was later decided that the emissions were not part of the Danish national total, these have been removed from the 2025 submission, and therefore there is no need for the adjustment for non-dairy cattle. This is therefore withdrawn.

12.3 Application for adjustment(s)

12.3.1 Gothenburg Protocol

No application for adjustment is made in this submission.

12.3.2 National Emission Ceilings Directive

No application for adjustment is made in this submission.

12.4 References

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https://unece.org/sites/default/files/2021-10/ECE.EB_.AIR_.114_ENG.pdf
(17-02-2025).

Annexes - overview

Annex 1 – Key category analysis

Denmark has carried out a key category analysis (KCA) level and trend assessment based on the NFR categories for all pollutants, i.e. no further disaggregation has been made. Denmark has applied Approach 1 based on the 2023 EMEP/EEA Guidebook and applied the recommended threshold value of 80 %. The results of the KCA for 2023 and the trend between 1990 and 2023 is presented in Table A1.1-A1.3 below.

Table A1.1 Categories identified as key based on emission level in 2023 and trend, main pollutants.

NFR	NO_x	NMVOC	SO_x	NH_3	$PM_{2.5}$	PM_{10}	TSP	BC	CO
1A1a Public electricity and heat production	L1, T1		L1, T1		L1	T1			L1
1A1b Petroleum refining			L1						
1A1c Manufacture of solid fuels and other energy industries	L1								
1A2e Stationary combustion in manufacturing industries and construction: Food processing, beverages and tobacco			L1, T1						
1A2f Stationary combustion in manufacturing industries and construction: Non-metallic minerals	L1		L1						
1A2gvii Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)					T1	T1	T1	L1, T1	L1
1A3bi Road transport: Passenger cars	L1, T1	T1			T1	T1	T1	T1	L1, T1
1A3bii Road transport: Light duty vehicles	L1				T1	T1	T1	T1	
1A3biii Road transport: Heavy duty vehicles and buses	L1, T1				T1	T1	T1	T1	
1A3bv Road transport: Gasoline evaporation		T1							
1A3bvi Road transport: Automobile tyre and brake wear					L1	L1, T1		L1	
1A3bvii Road transport: Automobile road abrasion					L1	L1			
1A3c Railways						T1			
1A3dii National navigation (shipping)	L1		T1		T1	T1			
1A4aii Commercial/institutional: Mobile									L1
1A4bi Residential: Stationary	L1	L1, T1	L1, T1		L1, T1	L1, T1	L1, T1	L1	L1, T1
1A4bii Residential: Household and gardening (mobile)									L1
1A4ci Agriculture/Forestry/Fishing: Stationary					L1, T1	L1, T1	T1	L1, T1	
1A4cii Agriculture/Forestry/Fishing: Off-road vehicles and other machinery		T1			T1	T1	T1	L1, T1	L1, T1
1A4ciii Agriculture/Forestry/Fishing: National fishing	L1								
1B2ai Fugitive emissions oil: Exploration, production, transport		T1							
1B2aiv Fugitive emissions oil: Refining / storage			L1						
1B2av Distribution of oil products		T1							
1B2b Fugitive emissions from natural gas (exploration, production, processing, transmission, storage, distribution and other)		T1							
2A5a Quarrying and mining of minerals other than coal						L1			
2A5b Construction and demolition						L1, T1	L1, T1		
2A6 Other mineral products (please specify in the IIR)			L1						
2B2 Nitric acid production					T1				
2D3a Domestic solvent use including fungicides		L1							
2D3d Coating applications		L1							
2D3g Chemical products		L1, T1							
2D3i Other solvent use (please specify in the IIR)		L1, T1							
2G Other product use (please specify in the IIR)					L1				
2H2 Food and beverages industry		L1							
3B1a Manure management - Dairy cattle		L1		L1	L1	L1			
3B1b Manure management - Non-dairy cattle		L1, T1		L1					
3B3 Manure management - Swine		L1		L1, T1		L1	T1		
3Da1 Inorganic N-fertilizers (includes also urea application)	L1, T1			L1, T1					
3Da2a Animal manure applied to soils	L1	L1, T1		L1, T1					
3Dc Farm-level agricultural operations including storage, handling and transport of agricultural products					L1	L1, T1	L1, T1		
3De Cultivated crops				L1					
3I Agriculture other (please specify in the IIR)				T1					
5E Other waste (please specify in IIR)			L1		L1				

In total, 43 NFR categories are identified as key for one or more main pollutants. Many of the categories within fuel combustion are identified as key categories based on the Approach 1 level assessment for one or multiple pollutants. Within fugitive emissions, refining and storage of crude oil has been identified as key together with oil exploration/production/transport, emissions from natural gas and distribution of oil products. For IPPU, the majority of identified categories are various types of solvent use for NMVOC. However, PM_{10} and $PM_{2.5}$ emissions from construction and demolition, PM_{10} from quarrying and mining as well as SO_2 emissions from other mineral products (production of bricks, tiles and expanded clay products) are also identified as key. In agriculture, the main animal types (cattle and swine) have been identified as key for NH_3 and in some cases also for PM. Application of mineral fertiliser and animal manure are key categories for NH_3 and NO_x. Other key categories within agriculture are farm level operations for PM, NH_3 treated straw (NFR 3I) and cultivated crops for NH_3. Finally, in the waste sector, the only category identified as key is other waste, which is emissions from accidental fires.

Table A1.2 Categories identified as key based on emission level in 2023 and trend, heavy metals.

NFR	Pb	Cd	Hg	As	Cr	Cu	Ni	Se	Zn
1A1a Public electricity and heat production	T1	L1, T1	L1, T1	L1, T1	L1, T1	T1	T1	L1, T1	T1
1A1b Petroleum refining		L1			L1			L1	
1A2e Stationary combustion in manufacturing industries and construction: Food processing, beverages and tobacco			L1	L1			L1, T1		
1A2f Stationary combustion in manufacturing industries and construction: Non-metallic minerals			L1	L1					
1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)							T1		
1A3bi Road transport: Passenger cars	T1	L1	L1						L1, T1
1A3bvi Road transport: Automobile tyre and brake wear	L1					L1, T1		L1	L1, T1
1A3c Railways					L1, T1		L1, T1		
1A3dii National navigation (shipping)				L1			L1, T1	L1	
1A4bi Residential: Stationary		L1, T1	L1		L1				L1, T1
1A4ciii Agriculture/Forestry/Fishing: National fishing								L1	
2A3 Glass production				T1				L1	
2C1 Iron and steel production			T1	L1					T1
2C5 Lead production	L1			L1					
2G Other product use (please specify in the IIR)				L1	L1		L1		
5E Other waste (please specify in IIR)	L1								L1

In total 16 NFR categories have been identified as key for one or more heavy metals. Most of the key categories for heavy metals are in the fuel combustion sector, but several categories in IPPU are also key for one or more heavy metals, see Table A1.2. Other waste (accidental fires) has also been identified as key for some heavy metals.

Table A1.3 Categories identified as key based on emission level in 2022 and trend, persistent organic pollutants.

NFR	PCDD/F	BaP	BbF	BkF	Ind	Total_PAH	HCB	PCBs
1A1a Public electricity and heat production	T1						L1, T1	L1, T1
1A3bi Road transport: Passenger cars				L1			L1	
1A3bii Road transport: Light duty vehicles							L1	
1A3biii Road transport: Heavy duty vehicles and buses							L1	
1A4bi Residential: Stationary	L1, T1	L1, T1	L1, T1	L1, T1	L1, T1	L1, T1	L1	L1
1A4ci Agricul-ture/Forestry/Fishing: Stationary		L1	L1	L1	L1	L1		
2C1 Iron and steel production	T1						T1	L1, T1
3Df Use of pesticides							L1, T1	
5C1bv Cremation								L1
5E Other waste (please specify in IIR)	L1		L1	L1	L1	L1		

In total, 10 NFR categories have been identified as key for one or more POPs. The only categories outside fuel combustion identified as key are iron and steel production, use of pesticides, cremation and other waste (accidental fires).

Annex 2 – Information on the energy balance

The official Danish energy balance is prepared by the Danish Energy Agency (DEA). The DEA is responsible for reporting of energy data to Eurostat and the IEA. DCE uses the energy balance as published by the DEA. However, some reallocations between sectors are made in connection with the bottom-up modelling done at DCE for different subsectors within transport and mobile sources. For a more in-depth discussion of the energy statistics, please see Annex 3A-9. For information on the reallocation of fuels, please see Chapter 3.3.

Annex 3 - Energy

Annex 3A - Stationary combustion

Annex 3A-1 Correspondence list for SNAP/NFR

Table 3A-1.1 Correspondence list for stationary combustion SNAP/NFR.

snap_id	snap_name	nfr_id_EA	nfr_name
010100	Public power	1A1a	Public electricity and heat production
010101	Combustion plants >= 300 MW (boilers)	1A1a	Public electricity and heat production
010102	Combustion plants >= 50 and < 300 MW (boilers)	1A1a	Public electricity and heat production
010103	Combustion plants < 50 MW (boilers)	1A1a	Public electricity and heat production
010104	Gas turbines	1A1a	Public electricity and heat production
010105	Stationary engines	1A1a	Public electricity and heat production
010200	District heating plants	1A1a	Public electricity and heat production
010201	Combustion plants >= 300 MW (boilers)	1A1a	Public electricity and heat production
010202	Combustion plants >= 50 and < 300 MW (boilers)	1A1a	Public electricity and heat production
010203	Combustion plants < 50 MW (boilers)	1A1a	Public electricity and heat production
010204	Gas turbines	1A1a	Public electricity and heat production
010205	Stationary engines	1A1a	Public electricity and heat production
010300	Petroleum refining plants	1A1b	Petroleum refining
010301	Combustion plants >= 300 MW (boilers)	1A1b	Petroleum refining
010302	Combustion plants >= 50 and < 300 MW (boilers)	1A1b	Petroleum refining
010303	Combustion plants < 50 MW (boilers)	1A1b	Petroleum refining
010304	Gas turbines	1A1b	Petroleum refining
010305	Stationary engines	1A1b	Petroleum refining
010306	Process furnaces	1A1b	Petroleum refining
010400	Solid fuel transformation plants	1A1c	Oil and gas extraction
010401	Combustion plants >= 300 MW (boilers)	1A1c	Oil and gas extraction
010402	Combustion plants >= 50 and < 300 MW (boilers)	1A1c	Oil and gas extraction
010403	Combustion plants < 50 MW (boilers)	1A1c	Oil and gas extraction
010404	Gas turbines	1A1c	Oil and gas extraction
010405	Stationary engines	1A1c	Oil and gas extraction
010406	Coke oven furnaces	1A1c	Oil and gas extraction
010407	Other (coal gasification, liquefaction)	1A1c	Oil and gas extraction
010500	Coal mining, oil / gas extraction, pipeline compressors	1A1c	Oil and gas extraction
010501	Combustion plants >= 300 MW (boilers)	1A1c	Oil and gas extraction
010502	Combustion plants >= 50 and < 300 MW (boilers)	1A1c	Oil and gas extraction
010503	Combustion plants < 50 MW (boilers)	1A1c	Oil and gas extraction
010504	Gas turbines	1A1c	Oil and gas extraction
010505	Stationary engines	1A1c	Oil and gas extraction
010506	Pipeline compressors	1A3e i	Pipeline transport
020100	Commercial and institutional plants	1A4a i	Commercial/institutional: Stationary
020101	Combustion plants >= 300 MW (boilers)	1A4a i	Commercial/institutional: Stationary
020102	Combustion plants >= 50 and < 300 MW (boilers)	1A4a i	Commercial/institutional: Stationary
020103	Combustion plants < 50 MW (boilers)	1A4a i	Commercial/institutional: Stationary
020104	Stationary gas turbines	1A4a i	Commercial/institutional: Stationary
020105	Stationary engines	1A4a i	Commercial/institutional: Stationary
020106	Other stationary equipment	1A4a i	Commercial/institutional: Stationary
020200	Residential plants	1A4b i	Residential: Stationary
020201	Combustion plants >= 50 MW (boilers)	1A4b i	Residential: Stationary
020202	Combustion plants < 50 MW (boilers)	1A4b i	Residential: Stationary
020203	Gas turbines	1A4b i	Residential: Stationary
020204	Stationary engines	1A4b i	Residential: Stationary
020205	Other equipment (stoves, fireplaces, cooking)	1A4b i	Residential: Stationary
020300	Plants in agriculture, forestry and aquaculture	1A4c i	Agriculture/Forestry/Fishing: Stationary
020301	Combustion plants >= 50 MW (boilers)	1A4c i	Agriculture/Forestry/Fishing: Stationary
020302	Combustion plants < 50 MW (boilers)	1A4c i	Agriculture/Forestry/Fishing: Stationary
020303	Stationary gas turbines	1A4c i	Agriculture/Forestry/Fishing: Stationary
020304	Stationary engines	1A4c i	Agriculture/Forestry/Fishing: Stationary
020305	Other stationary equipment	1A4c i	Agriculture/Forestry/Fishing: Stationary
030100	Comb. in boilers, gas turbines and stationary	1A2g viii	Other manufacturing industry
030101	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
030102	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
030103	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
030104	Gas turbines	1A2g viii	Other manufacturing industry
030105	Stationary engines	1A2g viii	Other manufacturing industry
030106	Other stationary equipment	1A2g viii	Other manufacturing industry

snap_id	snap_name	nfr_id_EA	nfr_name
030200	Process furnaces without contact (a)	1A2g viii	Other manufacturing industry
030203	Blast furnace cowpers	1A2a	Iron and steel
030204	Plaster furnaces	1A2g viii	Other manufacturing industry
030205	Other furnaces	1A2g viii	Other manufacturing industry
030400	Iron and Steel	1A2a	Iron and steel
030401	Combustion plants >= 300 MW (boilers)	1A2a	Iron and steel
030402	Combustion plants >= 50 and < 300 MW (boilers)	1A2a	Iron and steel
030403	Combustion plants < 50 MW (boilers)	1A2a	Iron and steel
030404	Gas turbines	1A2a	Iron and steel
030405	Stationary engines	1A2a	Iron and steel
030406	Other stationary equipment	1A2a	Iron and steel
030500	Non-Ferrous Metals	1A2b	Non-ferrous metals
030501	Combustion plants >= 300 MW (boilers)	1A2b	Non-ferrous metals
030502	Combustion plants >= 50 and < 300 MW (boilers)	1A2b	Non-ferrous metals
030503	Combustion plants < 50 MW (boilers)	1A2b	Non-ferrous metals
030504	Gas turbines	1A2b	Non-ferrous metals
030505	Stationary engines	1A2b	Non-ferrous metals
030506	Other stationary equipment	1A2b	Non-ferrous metals
030600	Chemical and Petrochemical	1A2c	Chemicals
030601	Combustion plants >= 300 MW (boilers)	1A2c	Chemicals
030602	Combustion plants >= 50 and < 300 MW (boilers)	1A2c	Chemicals
030603	Combustion plants < 50 MW (boilers)	1A2c	Chemicals
030604	Gas turbines	1A2c	Chemicals
030605	Stationary engines	1A2c	Chemicals
030606	Other stationary equipment	1A2c	Chemicals
030700	Non-Metallic Minerals	1A2f	Non-metallic minerals
030701	Mineral wool	1A2f	Non-metallic minerals
030702	Glass	1A2f	Non-metallic minerals
030703	Tile	1A2f	Non-metallic minerals
030704	Gas turbines	1A2f	Non-metallic minerals
030705	Stationary engines	1A2f	Non-metallic minerals
030706	Other non-metallic minerals	1A2f	Non-metallic minerals
030800	Mining and Quarrying	1A2g viii	Other manufacturing industry
030801	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
030802	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
030803	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
030804	Gas turbines	1A2g viii	Other manufacturing industry
030805	Stationary engines	1A2g viii	Other manufacturing industry
030806	Other stationary equipment	1A2g viii	Other manufacturing industry
030900	Food and Tobacco	1A2e	Food processing, beverages and tobacco
030901	Combustion plants >= 300 MW (boilers)	1A2e	Food processing, beverages and tobacco
030902	Combustion plants >= 50 and < 300 MW (boilers)	1A2e	Food processing, beverages and tobacco
030903	Combustion plants < 50 MW (boilers)	1A2e	Food processing, beverages and tobacco
030904	Gas turbines	1A2e	Food processing, beverages and tobacco
030905	Stationary engines	1A2e	Food processing, beverages and tobacco
030906	Other stationary equipment	1A2e	Food processing, beverages and tobacco
031000	Textile and Leather	1A2g viii	Other manufacturing industry
031001	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
031002	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
031003	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
031004	Gas turbines	1A2g viii	Other manufacturing industry
031005	Stationary engines	1A2g viii	Other manufacturing industry
031006	Other stationary equipment	1A2g viii	Other manufacturing industry
031100	Paper, Pulp and Print	1A2d	Pulp, Paper and Print
031101	Combustion plants >= 300 MW (boilers)	1A2d	Pulp, Paper and Print
031102	Combustion plants >= 50 and < 300 MW (boilers)	1A2d	Pulp, Paper and Print
031103	Combustion plants < 50 MW (boilers)	1A2d	Pulp, Paper and Print
031104	Gas turbines	1A2d	Pulp, Paper and Print
031105	Stationary engines	1A2d	Pulp, Paper and Print
031106	Other stationary equipment	1A2d	Pulp, Paper and Print
031200	Transport Equipment	1A2g viii	Other manufacturing industry
031201	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
031202	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry

snap_id	snap_name	nfr_id_EA	nfr_name
031203	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
031204	Gas turbines	1A2g viii	Other manufacturing industry
031205	Stationary engines	1A2g viii	Other manufacturing industry
031206	Other stationary equipment	1A2g viii	Other manufacturing industry
031300	Machinery	1A2g viii	Other manufacturing industry
031301	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
031302	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
031303	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
031304	Gas turbines	1A2g viii	Other manufacturing industry
031305	Stationary engines	1A2g viii	Other manufacturing industry
031306	Other stationary equipment	1A2g viii	Other manufacturing industry
031400	Wood and Wood Products	1A2g viii	Other manufacturing industry
031401	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
031402	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
031403	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
031404	Gas turbines	1A2g viii	Other manufacturing industry
031405	Stationary engines	1A2g viii	Other manufacturing industry
031406	Other stationary equipment	1A2g viii	Other manufacturing industry
031500	Construction	1A2g viii	Other manufacturing industry
031501	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
031502	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
031503	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
031504	Gas turbines	1A2g viii	Other manufacturing industry
031505	Stationary engines	1A2g viii	Other manufacturing industry
031506	Other stationary equipment	1A2g viii	Other manufacturing industry
031600	Cement production	1A2f	Non-metallic minerals
031601	Combustion plants >= 300 MW (boilers)	1A2f	Non-metallic minerals
031602	Combustion plants >= 50 and < 300 MW (boilers)	1A2f	Non-metallic minerals
031603	Combustion plants < 50 MW (boilers)	1A2f	Non-metallic minerals
031604	Gas turbines	1A2f	Non-metallic minerals
031605	Stationary engines	1A2f	Non-metallic minerals
031606	Other stationary equipment	1A2f	Non-metallic minerals
032000	Non-specified (Industry)	1A2g viii	Other manufacturing industry
032001	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
032002	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
032003	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
032004	Gas turbines	1A2g viii	Other manufacturing industry
032005	Stationary engines	1A2g viii	Other manufacturing industry
032006	Other stationary equipment	1A2g viii	Other manufacturing industry

Annex 3A-2 Fuel rate

Table 3A-2.1 Fuel consumption rate of stationary combustion plants 1990-2023, PJ.

Sum of Fuel_rate_PJ			Year									
fuel_type	**fuel_id**	**fuel_gr_abbr**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
SOLID	101A	Other solid fossil										
	102A	Coal	253.4	344.3	286.8	300.8	323.4	270.3	371.9	276.3	234.3	196.5
	103A	Fly ash (fossil)										
	106A	BKB	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
	107A	Coke oven coke	1.3	1.4	1.2	1.2	1.2	1.3	1.2	1.3	1.3	1.4
LIQUID	110A	Petroleum coke	4.5	4.4	4.3	5.7	7.5	5.3	5.9	6.0	5.3	6.8
	203A	Residual oil	32.1	37.0	37.3	32.5	46.6	33.3	38.1	26.7	29.5	23.0
	204A	Gas oil	73.5	76.8	67.3	73.1	64.2	64.3	67.9	61.1	57.8	56.8
	206A	Kerosene	5.1	1.0	0.8	0.8	0.7	0.6	0.5	0.4	0.4	0.3
	225A	Orimulsion						19.9	36.8	40.5	32.6	34.2
	303A	LPG	3.0	2.8	2.5	2.6	2.6	2.8	3.1	2.6	2.8	2.5
	308A	Refinery gas	14.2	14.5	14.9	15.4	16.4	20.8	21.4	16.9	15.2	15.7
GAS	301A	Natural gas	76.1	86.1	90.5	102.5	114.6	132.7	156.3	164.5	178.7	187.9
WASTE	114A	Waste	15.5	16.7	17.8	19.4	20.3	22.9	25.0	26.8	26.6	29.1
	115A	Industrial waste										
BIOMASS	111A	Wood	16.7	17.9	18.6	20.1	19.7	19.5	20.7	20.5	19.7	20.3
	117A	Straw	12.5	13.3	13.9	13.4	12.7	13.1	13.5	13.9	13.9	13.7
		Wood pellets	1.6	2.1	2.5	2.1	2.1	2.3	2.7	2.9	3.2	4.0
	215A	Bio oil	0.7	0.7	0.7	0.8	0.2	0.3	0.1	0.0	0.0	0.0
	309A	Biogas	0.8	0.9	0.9	1.1	1.3	1.8	2.0	2.4	2.7	2.7
	310A	Bio gasification gas					0.1	0.0	0.0	0.0	0.0	0.0
	315A	Biomethane										
Total			511.0	620.3	560.1	591.5	633.8	611.2	767.1	662.9	624.1	595.0

Sum of Fuel_rate_PJ			Year									
fuel_type	**fuel_id**	**fuel_gr_abbr**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
SOLID	101A	Other solid fossil										0.0
	102A	Coal	164.7	174.3	174.7	239.0	182.5	154.0	232.0	194.1	170.5	167.7
	103A	Fly ash (fossil)										
	106A	BKB	0.0	0.0	0.0	0.0					0.0	0.0
	107A	Coke oven coke	1.2	1.1	1.1	1.0	1.1	1.0	1.0	1.1	1.0	0.8
LIQUID	110A	Petroleum coke	6.8	7.8	7.8	8.0	8.4	8.1	8.5	9.2	6.9	5.9
	203A	Residual oil	18.0	20.2	24.8	27.3	23.5	21.1	25.4	19.3	15.3	14.2
	204A	Gas oil	50.0	52.2	47.1	47.1	44.0	40.0	35.3	30.9	30.4	32.5
	206A	Kerosene	0.2	0.3	0.3	0.3	0.2	0.3	0.2	0.1	0.1	0.1
	225A	Orimulsion	34.1	30.2	23.8	1.9	0.0					
	303A	LPG	2.4	2.1	2.0	2.1	2.1	2.1	2.2	1.9	1.7	1.5
	308A	Refinery gas	15.6	15.8	15.2	16.6	15.9	15.3	16.1	15.9	14.1	15.0
GAS	301A	Natural gas	186.1	193.8	193.6	195.9	195.1	187.4	191.1	171.0	173.0	165.7
WASTE	114A	Waste	29.8	31.3	33.3	35.1	35.3	35.8	37.8	38.9	40.1	38.1
	115A	Industrial waste	0.5	1.4	1.9	1.5	2.0	2.0	0.6	0.9	1.4	1.2
BIOMASS	111A	Wood	22.3	23.7	23.7	29.1	31.1	33.7	36.5	43.8	45.1	45.9
	117A	Straw	12.2	13.7	15.7	16.9	17.9	18.5	18.5	18.8	15.9	17.4
		Wood pellets	5.1	7.1	7.9	9.8	12.8	16.1	15.6	16.5	18.5	20.1
	215A	Bio oil	0.0	0.2	0.1	0.4	0.6	0.8	1.1	1.2	1.8	1.7
	309A	Biogas	2.9	3.0	3.4	3.6	3.7	3.8	3.9	3.9	3.9	4.2
	310A	Bio gasification gas	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3
	315A	Biomethane										
Total			**552.3**	**578.5**	**576.2**	**635.6**	**576.4**	**540.0**	**626.0**	**567.5**	**539.9**	**532.3**

Sum of Fuel_rate_PJ			Year									
fuel_type	**fuel_id**	**fuel_gr_abbr**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
SOLID	101A	Other solid fossil	0.0	0.0	0.0	0.0						
	102A	Coal	163.0	135.5	106.2	135.0	107.0	76.0	88.2	65.8	67.2	37.8
	103A	Fly ash (fossil)		0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0
	106A	BKB	0.0	0.0	0.0	0.0	0.0		0.0			
	107A	Coke oven coke	0.7	0.7	0.6	0.6	0.6	0.5	0.3	0.3	0.4	0.3
LIQUID	110A	Petroleum coke	5.1	6.5	6.7	6.1	6.6	6.6	7.6	7.9	6.9	7.7
	203A	Residual oil	12.8	7.8	7.2	5.5	4.5	4.2	4.1	4.1	3.2	3.0
	204A	Gas oil	31.8	25.5	21.7	20.0	13.1	13.9	14.0	12.1	13.5	10.4
	206A	Kerosene	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
	225A	Orimulsion										
	303A	LPG	1.6	1.5	1.7	1.6	1.3	1.8	2.1	2.3	2.3	2.3
	308A	Refinery gas	14.3	13.7	14.8	14.8	15.4	16.2	14.4	15.6	15.0	16.1
GAS	301A	Natural gas	185.7	157.3	147.1	139.3	119.3	120.6	122.5	116.5	113.1	105.5
WASTE	114A	Waste	37.2	37.1	36.1	35.9	37.1	37.7	37.8	38.1	37.1	38.4
	115A	Industrial waste	0.9	1.3	1.2	1.6	1.6	2.2	2.6	2.7	3.4	3.1
BIOMASS	111A	Wood	51.3	48.8	48.6	46.4	45.0	50.1	51.6	51.6	52.7	52.3
	117A	Straw	23.3	20.2	18.3	20.3	18.6	19.8	19.7	20.2	17.6	18.0
	122A	Wood pellets	29.9	30.0	33.2	35.0	36.3	36.5	44.3	57.4	55.2	53.3
	215A	Bio oil	2.0	0.8	1.1	0.9	0.7	0.6	0.3	0.2	0.2	0.1
	309A	Biogas	4.3	4.1	4.4	4.6	5.2	5.3	5.9	5.8	6.3	6.9
	310A	Bio gasification gas	0.2	0.3	0.4	0.1	0.4	0.5	0.5	1.0	1.4	1.5
	315A	Biomethane					0.3	1.0	3.1	5.2	7.1	9.4
Total			**564.3**	**491.3**	**449.5**	**467.6**	**413.2**	**393.6**	**419.0**	**407.0**	**402.8**	**366.5**

Sum of Fuel_rate_PJ			Year			
fuel_type	**fuel_id**	**fuel_gr_abbr**	**2020**	**2021**	**2022**	**2023**
SOLID	101A	Other solid fossil				
	102A	Coal	33.2	44.3	43.5	27.7
	103A	Fly ash (fossil)	0.0	0.1	0.1	0.0
	106A	BKB				
	107A	Coke oven coke	0.3	0.3	0.4	0.3
LIQUID	110A	Petroleum coke	7.9	6.9	7.3	4.0
	203A	Residual oil	3.1	2.7	3.1	2.1
	204A	Gas oil	9.5	11.6	16.8	12.8
	206A	Kerosene	0.0	0.0	0.0	0.0
	225A	Orimulsion				
	303A	LPG	2.3	2.7	3.4	3.6
	308A	Refinery gas	15.3	15.7	14.7	15.1
GAS	301A	Natural gas	85.3	85.6	61.2	58.1
WASTE	114A	Waste	38.2	37.4	37.0	36.3
	115A	Industrial waste	3.4	2.8	2.5	2.2
BIOMASS	111A	Wood	57.6	62.8	60.3	61.9
	117A	Straw	18.9	21.6	21.2	21.7
	122A	Wood pellets	47.2	66.2	47.1	43.9
	215A	Bio oil	0.1	0.2	0.1	0.2
	309A	Biogas	6.7	6.5	6.2	5.8
	310A	Bio gasification gas	1.6	1.7	1.7	1.9
	315A	Biomethane	13.5	19.6	22.5	25.7
Total			**344.2**	**388.7**	**349.0**	**323.1**

Table 3A-2.2 Detailed fuel consumption data for stationary combustion plants, PJ. 1990 – 2023.

This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Annex 3A-3 Default Lower Calorific Value (LCV) of fuels and fuel correspondence list

Table 3A-3.1 Time series for calorific values of fuels (DEA, 2024a).

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Crude Oil, Average	GJ per tonne	42.40	42.40	42.40	42.70	42.70	42.70	42.70	43.00	43.00	43.00
Crude Oil, Golf	GJ per tonne	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80
Crude Oil, North Sea	GJ per tonne	42.70	42.70	42.70	42.70	42.70	42.70	42.70	43.00	43.00	43.00
Refinery Feedstocks	GJ per tonne	41.60	41.60	41.60	41.60	41.60	41.60	41.60	42.70	42.70	42.70
Refinery Gas	GJ per tonne	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00
LPG	GJ per tonne	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00
Naphtha (LVN)	GJ per tonne	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50
Motor Gasoline	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
Aviation Gasoline	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
JP4	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
Other Kerosene	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
JP1	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
Gas/Diesel Oil	GJ per tonne	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70
Fuel Oil	GJ per tonne	40.40	40.40	40.40	40.40	40.40	40.40	40.70	40.65	40.65	40.65
Orimulsion	GJ per tonne	27.60	27.60	27.60	27.60	27.60	28.13	28.02	27.72	27.84	27.58
Petroleum Coke	GJ per tonne	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40
Waste Oil	GJ per tonne	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90
White Spirit	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
Bitumen	GJ per tonne	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80
Lubricants	GJ per tonne	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90
Natural Gas	GJ per 1000 Nm^3										
Natural Gas, North Sea	GJ per 1000 Nm^3										
Gas Works Gas	GJ per 1000 m^3	39.00	39.00	39.00	39.30	39.30	39.30	39.30	39.60	39.90	40.00
Liquefied Natural Gas	GJ per 1000 m^3							17.00	17.00	17.00	17.00
Electricity Plant Coal	GJ per tonne	25.30	25.40	25.80	25.20	24.50	24.50	24.70	24.96	25.00	25.00
Other Hard Coal	GJ per tonne	26.10	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Coke	GJ per tonne										
Brown Coal Briquettes	GJ per tonne	31.80	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30
Straw	GJ per tonne	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50
Wood Chips	GJ per m^3	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Wood Chips	GJ per tonne	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30
Firewood, Hardwood	GJ per m^3	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40
Firewood, Conifer	GJ per tonne	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60
Wood Pellets	GJ per tonne	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50
Wood Waste	GJ per tonne	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70
Wood Waste	GJ per m^3	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20
Biogas	GJ per 1000 m^3								23.00	23.00	23.00
Wastes	GJ per tonne	8.20	8.20	9.00	9.40	9.40	10.00	10.50	10.50	10.50	10.50
Bioethanol	GJ per tonne	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70
Liquid Biofuels	GJ per tonne	37.60	37.60	37.60	37.60	37.60	37.60	37.60	37.60	37.60	37.60
Bio Oil	GJ per tonne	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20

Continued		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Crude Oil, Average	GJ per tonne	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
Crude Oil, Golf	GJ per tonne	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80
Crude Oil, North Sea	GJ per tonne	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
Refinery Feedstocks	GJ per tonne	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70
Refinery Gas	GJ per tonne	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00
LPG	GJ per tonne	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00
Naphtha (LVN)	GJ per tonne	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50
Motor Gasoline	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
Aviation Gasoline	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
JP4	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
Other Kerosene	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
JP1	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
Gas/Diesel Oil	GJ per tonne	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70
Fuel Oil	GJ per tonne	40.65	40.65	40.65	40.65	40.65	40.65	40.65	40.65	40.65	40.65
Orimulsion	GJ per tonne	27.62	27.64	27.71	27.65	27.65	27.65	27.65	27.65	27.65	27.65
Petroleum Coke	GJ per tonne	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40
Waste Oil	GJ per tonne	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90
White Spirit	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
Bitumen	GJ per tonne	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80
Lubricants	GJ per tonne	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90
Natural Gas	GJ per 1000 Nm^3	40.15	39.99	40.06	39.94	39.77	39.67	39.54	39.59	39.48	39.46
Natural Gas, North Sea	GJ per 1000 Nm^3										
Gas Works Gas	GJ per 1000 m^3	17.01	16.88	17.39	16.88	17.58	17.51	17.20	17.14	15.50	21.29
Liquefied Natural Gas	GJ per 1000 m^3										
Electricity Plant Coal	GJ per tonne	24.80	24.90	25.15	24.73	24.60	24.40	24.80	24.40	24.30	24.60
Other Hard Coal	GJ per tonne	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	25.81	25.13
Coke	GJ per tonne	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30
Brown Coal Briquettes	GJ per tonne	18.30	18.30	18.30	18.30	18.30	18.30	18.30	18.30	18.30	18.30
Straw	GJ per tonne	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50
Wood Chips	GJ per m^3	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Wood Chips	GJ per tonne	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30
Firewood, Hardwood	GJ per m^3	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40
Firewood, Conifer	GJ per tonne	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60
Wood Pellets	GJ per tonne	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50
Wood Waste	GJ per tonne	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70
Wood Waste	GJ per m^3	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20
Biogas	GJ per 1000 m^3	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00
Wastes	GJ per tonne	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50
Bioethanol	GJ per tonne	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70
Liquid Biofuels	GJ per tonne	37.60	37.60	37.60	37.60	37.60	37.60	37.60	37.60	37.50	37.50
Bio Oil	GJ per tonne	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20

Continued		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Crude Oil, Average	GJ per tonne	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
Crude Oil, Golf	GJ per tonne	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80
Crude Oil, North Sea	GJ per tonne	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
Refinery Feedstocks	GJ per tonne	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70
Refinery Gas	GJ per tonne	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00
LPG	GJ per tonne	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00
Naphtha (LVN)	GJ per tonne	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50
Motor Gasoline	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
Aviation Gasoline	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
JP4	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
Other Kerosene	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
JP1	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
Gas/Diesel Oil	GJ per tonne	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70
Fuel Oil	GJ per tonne	40.65	40.65	40.65	40.65	40.65	40.65	40.65	40.65	40.65	40.65
Orimulsion	GJ per tonne	27.65	27.65	27.65	27.65	27.65	27.65	27.65	27.65	27.65	27.65
Petroleum Coke	GJ per tonne	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40
Waste Oil	GJ per tonne	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90
White Spirit	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
Bitumen	GJ per tonne	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80
Lubricants	GJ per tonne	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90
Natural Gas	GJ per 1000 Nm^3	39.46	39.51	39.55	38.99	39.53	39.64	39.63	39.66	39.59	38.81
Natural Gas, North Sea	GJ per 1000 Nm^3										
Gas Works Gas	GJ per 1000 m^3	21.35	21.37	19.30	19.31	20.20	19.80	20.28	20.80	20.82	20.80
Liquefied Natural Gas	GJ per 1000 m^3						26.50	26.50	26.50	26.50	26.50
Electricity Plant Coal	GJ per tonne	24.44	24.38	24.23	24.49	24.70	24.10	24.29	24.33	24.13	23.89
Other Hard Coal	GJ per tonne	24.44	24.38	24.23	24.49	24.70	24.10	26.10	26.88	26.64	24.17
Coke	GJ per tonne	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30
Brown Coal Briquettes	GJ per tonne	18.30	18.30	18.30	18.30	18.30	18.30	18.30	18.30	18.30	18.30
Straw	GJ per tonne	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50
Wood Chips	GJ per m^3	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Wood Chips	GJ per tonne	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30
Firewood, Hardwood	GJ per m^3	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40
Firewood, Conifer	GJ per tonne	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60
Wood Pellets	GJ per tonne	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50
Wood Waste	GJ per tonne	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70
Wood Waste	GJ per m^3	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20
Biogas	GJ per 1000 m^3	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00
Wastes	GJ per tonne	10.50	10.50	10.50	10.60	10.60	10.60	10.60	10.60	10.60	10.60
Bioethanol	GJ per tonne	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70
Liquid Biofuels	GJ per tonne	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50
Bio Oil	GJ per tonne	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20

Continued		2020	2021	2022	2023
Crude Oil, Average	GJ per tonne	43.00	43.00	43.00	43.00
Crude Oil, Golf	GJ per tonne	41.80	41.80	41.80	41.80
Crude Oil, North Sea	GJ per tonne	43.00	43.00	43.00	43.00
Refinery Feedstocks	GJ per tonne	42.70	42.70	42.70	42.70
Refinery Gas	GJ per tonne	52.00	52.00	52.00	52.00
LPG	GJ per tonne	46.00	46.00	46.00	46.00
Naphtha (LVN)	GJ per tonne	44.50	44.50	44.50	44.50
Motor Gasoline	GJ per tonne	43.80	43.80	43.80	43.80
Aviation Gasoline	GJ per tonne	43.80	43.80	43.80	43.80
JP4	GJ per tonne	43.80	43.80	43.80	43.80
Other Kerosene	GJ per tonne	43.50	43.50	43.50	43.50
JP1	GJ per tonne	43.50	43.50	43.50	43.50
Gas/Diesel Oil	GJ per tonne	42.70	42.70	42.70	42.70
Fuel Oil	GJ per tonne	40.65	40.65	40.65	40.65
Orimulsion	GJ per tonne	27.65	27.65	27.65	27.65
Petroleum Coke	GJ per tonne	31.40	31.40	31.40	31.40
Waste Oil	GJ per tonne	41.90	41.90	41.90	41.90
White Spirit	GJ per tonne	43.50	43.50	43.50	43.50
Bitumen	GJ per tonne	39.80	39.80	39.80	39.80
Lubricants	GJ per tonne	41.90	41.90	41.90	41.90
Natural Gas	GJ per 1000 Nm^3	36.70	36.62	37.41	38.03
Natural Gas, North Sea	GJ per 1000 Nm^3		40.94	41.65	38.54
Gas Works Gas	GJ per 1000 m^3	20.78	20.84	20.84	20.84
Liquefied Natural Gas	GJ per 1000 m^3	26.50	26.50	26.50	26.50
Electricity Plant Coal	GJ per tonne	24.09	23.96	23.75	23.49
Other Hard Coal	GJ per tonne	25.63	25.42	26.03	23.86
Coke	GJ per tonne	29.30	29.30	29.30	29.30
Brown Coal Briquettes	GJ per tonne	18.30	18.30	18.30	18.30
Straw	GJ per tonne	14.50	14.50	14.50	14.50
Wood Chips	GJ per m^3	2.80	2.80	3.13	3.13
Wood Chips	GJ per tonne	9.30	9.30	10.40	10.40
Firewood, Hardwood	GJ per m^3	10.40	10.40	10.40	10.40
Firewood, Conifer	GJ per tonne	7.60	7.60	7.60	7.60
Wood Pellets	GJ per tonne	17.50	17.50	17.50	17.50
Wood Waste	GJ per tonne	14.70	14.70	14.70	14.70
Wood Waste	GJ per m^3	3.20	3.20	3.20	3.20
Biogas	GJ per 1000 m^3	23.00	23.00	23.00	23.00
Wastes	GJ per tonne	10.60	10.60	10.60	10.60
Bioethanol	GJ per tonne	26.70	26.70	26.70	26.70
Liquid Biofuels	GJ per tonne	37.50	37.50	37.50	37.50
Bio Oil	GJ per tonne	37.20	37.20	37.20	37.20

Table 3A-3.2 Fuel category correspondence list, DEA, DCE and NFR.

Danish Energy Agency	DCE Emission database	IPCC fuel category
Other Hard Coal	Coal	Solid
Coke	Coke oven coke	Solid
Electricity Plant Coal	Coal	Solid
Brown Coal Briquettes	BKB	Solid
-	Other solid fossil	Solid
-	Fly ash fossil	Solid
Orimulsion	Orimulsion	Liquid
Petroleum Coke	Petroleum coke	Liquid
Fuel Oil	Residual oil	Liquid
Waste Oil	Residual oil	Liquid
Gas/Diesel Oil	Gas oil	Liquid
Other Kerosene	Kerosene	Liquid
LPG	LPG	Liquid
Refinery Gas	Refinery gas	Liquid
Gas Works Gas	Natural gas	Gas
Natural Gas	Natural gas	Gas
Straw	Straw	Biomass
Wood Waste	Wood	Biomass
Wood Pellets	Wood pellets	Biomass
Wood Chips	Wood	Biomass
Firewood	Wood	Biomass
Wastes, Renewable	Municipal wastes	Biomass
Biooil	Liquid biofuels	Biomass
Biogas	Biogas	Biomass
(Wood applied in gas engines)	Biomass gasification gas	Biomass
Bio methane	Biomethane	Biomass
Biogas distributed in the town gas grid	Biogas	Biomass
Wastes, Non-renewable	Fossil waste	Other fuel

Annex 3A-4 Emission factor time series

Table 3A-4.1 SO_2 emission factors time series, g per GJ for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.2 NO_x emission factors time series, g per GJ for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.3 NMVOC emission factors time series, g per GJ for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.4 CO emission factors time series, g per GJ for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.5 NH_3 emission factors time series, g per GJ for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.6 TSP emission factors, time series, g per GJ for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.7 PM_{10} emission factors, time series, g per GJ for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.8 $PM_{2.5}$ emission factors, time series, g per GJ for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.9 BC emission factors, time series, g per GJ for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.10 As emission factors time series, mg per GJ, for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.11 Cd emission factors time series, mg per GJ, for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.12 Cr emission factors time series, mg per GJ, for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.13 Cu emission factors time series, mg per GJ, for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.14 Hg emission factors time series, mg per GJ, for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.15 Ni emission factors time series, mg per GJ, for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.16 Pb emission factors time series, mg per GJ, for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.17 Se emission factors time series, mg per GJ, for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.18 Zn emission factors time series, mg per GJ, for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.19   PAH emission factors time series, µg pr GJ for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.20 HCB emission factors time series, ng per GJ for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.21 PCDD/F emission factors time series, ng per GJ for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Table 3A-4.22 PCB emission factors time series, ng per GJ for the years 1990 to 2023. This table is available at: https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luft-forurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Annex 3A-5 Implied emission factors for waste incineration plants and power plants combustion coal

Table 3A-5.1 Implied emission factors for municipal waste incineration plants 2023.

Pollutant	Implied emission factor	Unit
SO_2	4.7	g /GJ
NO_x	83	g / GJ
TSP	0.36	g / GJ
PM_{10}	0.35	g / GJ
$PM_{2.5}$	0.34	g / GJ
As	0.41	mg / GJ
Cd	0.36	mg / GJ
Cr	1.26	mg / GJ
Cu	1.12	mg / GJ
Hg	1.22	mg / GJ
Ni	2.94	mg / GJ
Pb	3.60	mg / GJ
Se	1.18	mg / GJ
Zn	2.69	mg / GJ

Table 3A-5.2 Implied emission factors for power plants combusting coal, 2023.

Pollutant	Implied emission factor	Unit
SO_2	11.8	g / GJ
NO_x	16.9	g / GJ
TSP	2.64	g / GJ
PM_{10}	2.29	g / GJ
$PM_{2.5}$	1.85	g / GJ
As	0.60	mg / GJ
Cd	0.06	mg / GJ
Cr	1.03	mg / GJ
Cu	0.43	mg / GJ
Hg	1.21	mg / GJ
Ni	0.99	mg / GJ
Pb	0.72	mg / GJ
Se	9.08	mg / GJ
Zn	1.41	mg / GJ

Annex 3A-6 Large point sources

Table 3A-6.1 Large point sources, 2023.

Large point sources
AffaldPlus+, Naestved Forbraendingsanlaeg
AffaldPlus+, Naestved Kraftvarmevaerk
Affaldplus+, Slagelse Forbr. and DONG Slagelse KVV
Affaldscenter aarhus - Forbraendsanlaegget
Affaldsforbraendingsanlaeg I/S REFA
Amagerforbraending
Amagervaerket
Ardagh Glass Holmegaard A/S
Asnaesvaerket
Avedoerevaerket
AVV Forbraendingsanlaeg
Bofa I/S
Centralkommunernes Transmissionsselskab F_berg
Cheminova
Dalum Kraftvarmevaerk
Danisco Grindsted Dupont
DanSteel
DTU
Duferco Danish Steel
Esbjergvaerket
Faxe Kalk
Fjernvarme Fyn, Centrum Varmecentral
Frederikshavn Affaldskraftvarmevaerk
Fynsvaerket
H.C.Oerstedsvaerket
Haldor Topsoee
Hammel Fjernvarmeselskab
Helsingoer Kraftvarmevaerk
Herningvaerket
Hilleroed Kraftvarmevaerk
Hjoerring Varmeforsyning
Horsens Kraftvarmevaerk
I/S Kara Affaldsforbraendingsanlaeg
I/S Kraftvarmevaerk Thisted
I/S Nordforbraending
I/S Reno Nord
I/S Reno Syd
I/S Vestforbraending
Koege Kraftvarmevaerk
Kolding Forbraendingsanlaeg TAS
Kommunekemi
Kyndbyvaerket
L90 Affaldsforbraending
LECA Danmark
Maricogen
Masnedoevaerket
Maabjergvaerket
Nordic Sugar Nakskov
Nordic Sugar Nykoebing
Nordjyllandsvaerket
Nybro Gasbehandlingsanlaeg
Odense Kraftvarmevaerk
Oestkraft
Randersvaerket Verdo
Rensningsanlaegget Lynetten
Rockwool A/S Doense
Rockwool A/S Vamdrup

Saint-Gobain Isover A/S
Shell Raffinaderi
Silkeborg Kraftvarmevaerk
Skaerbaekvaerket
Soenderborg Kraftvarmevaerk
Special Waste System
Statoil Raffinaderi
Studstrupvaerket
Svanemoellevaerket
Svendborg Kraftvarmevaerk
Viborg Kraftvarme
Vordingborg Kraftvarme
Aalborg Portland
AarhusKarlshamn Denmark A/S

Table 3A-6.2 Large point sources, aggregated fuel consumption in 2023.

nfr_id_EA	fuel_id	fuel_gr_abbr	Fuel, TJ
1A1a	102A	COAL	24356
	103A	SUB-BITUMINOUS	44
	111A	WOOD	28927
	114A	WASTE	35563
	117A	STRAW	5674
	122A	Wood Pellets	29877
	203A	RESIDUAL OIL	665
	204A	GAS OIL	443
	215A	BIO OIL	14
	301A	NATURAL GAS	3731
	303A	LPG	1
	309A	BIOGAS	99
	315A	BIONATGAS	2162
1A1a Total			131555
1A1b	203A	RESIDUAL OIL	0
	204A	GAS OIL	162
	301A	NATURAL GAS	597
	303A	LPG	0
	308A	REFINERY GAS	15055
	315A	BIONATGAS	346
1A1b Total			16160
1A1c	204A	GAS OIL	3
	301A	NATURAL GAS	323
	315A	BIONATGAS	0
1A1c Total			326
1A2a	204A	GAS OIL	0
	301A	NATURAL GAS	1194
	303A	LPG	1
	315A	BIONATGAS	692
1A2a Total			1887
1A2c	204A	GAS OIL	104
	301A	NATURAL GAS	634
	303A	LPG	11
	315A	BIONATGAS	367
1A2c Total			1116
1A2e	102A	COAL	62
	107A	COKE OVEN COKE	121
	111A	WOOD	642
	203A	RESIDUAL OIL	1371
	204A	GAS OIL	718
	215A	BIO OIL	100
	301A	NATURAL GAS	14
	303A	LPG	38
	309A	BIOGAS	93
	315A	BIONATGAS	8
1A2e Total			3168
1A2f	102A	COAL	2496
	107A	COKE OVEN COKE	160
	110A	PETROLEUM COKE	4001
	111A	WOOD	1910
	114A	WASTE	191
	115A	INDUSTR. WASTES	2224
	203A	RESIDUAL OIL	24
	204A	GAS OIL	82
	301A	NATURAL GAS	802
	303A	LPG	224
	315A	BIONATGAS	465
1A2f Total			12578
1A4a i	111A	WOOD	215
	114A	WASTE	0
	309A	BIOGAS	0
1A4a i Total			215
Grand Total			167005

Table 3A-6.3 Large point sources, plant specific emissions[1)].

Year	2023																				
nfr_id	lps_name	SO_2	NO_x	NMVOC	CO	NH_3	TSP	PM_{10}	$PM_{2.5}$	BC [2)]	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	PCDD/F	PCB
1A1a	AffaldPlus+, Naestved Forbraendings-anlaeg	x	x	x	x	x	x	x	x	x		x			x					x	
1A1a	Affaldplus+, Slagelse Forbr. and DONG Slagelse KVV	x	x		x	x	x	x	x	x		x			x					x	
1A1a	Affaldscenter aarhus - Forbraendsan-laegget	x	x				x	x	x	x					x					x	
1A1a	Affaldsforbraendingsanlaeg I/S REFA														x						
1A1a	Amagerforbraending	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	
1A1a	Amagervaerket	x	x			x	x	x	x	x	x	x	x	x	x	x	x		x		
1A1a	Asnaesvaerket	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x		
1A1a	Avedoerevaerket	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x		
1A1a	AVV Forbraendingsanlaeg	x	x		x		x	x	x	x		x			x					x	
1A1a	Bofa I/S	x	x		x						x	x	x	x	x	x	x			x	
1A1a	DTU		x		x																
1A1a	Esbjergvaerket	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x		
1A1a	Fjernvarme Fyn, Centrum Varmecen-tral		x																		
1A1a	Frederikshavn Affaldskraftvarmevaerk	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x			x	
1A1a	Fynsvaerket	x	x				x	x	x	x	x	x	x	x	x	x	x	x	x		
1A1a	H.C.Oerstedsvaerket		x	x	x																
1A1a	Herningvaerket	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x		
1A1a	Hilleroed Kraftvarmevaerk		x																		
1A1a	Horsens Kraftvarmevaerk		x			x														x	
1A1a	I/S Kara Affaldsforbraendingsanlaeg	x	x		x		x	x	x	x					x					x	
1A1a	I/S Nordforbraending		x																		
1A1a	I/S Reno Nord	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x
1A1a	I/S Reno Syd	x	x		x		x	x	x	x					x					x	
1A1a	I/S Vestforbraending	x	x		x		x	x	x	x	x	x	x	x	x	x	x			x	
1A1a	Koege Kraftvarmevaerk		x																		
1A1a	Kolding Forbraendingsanlaeg TAS	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	
1A1a	Kommunekemi	x	x	x	x		x	x	x	x											
1A1a	Kyndbyvaerket	x	x		x						x	x	x	x	x	x	x	x	x		
1A1a	L90 Affaldsforbraending	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x			x	
1A1a	Maabjergvaerket		x																		
1A1a	Nordjyllandsvaerket	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x		
1A1a	Odense Kraftvarmevaerk	x	x				x	x	x	x										x	
1A1a	Oestkraft	x	x				x	x	x	x											
1A1a	Silkeborg Kraftvarmevaerk		x																		
1A1a	Skaerbaekvaerket		x	x	x																

Year	2023																				
nfr_id	**lps_name**	**SO_2**	**NO_x**	**NMVOC**	**CO**	**NH_3**	**TSP**	**PM_{10}**	**$PM_{2.5}$**	**BC 2)**	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Zn**	**PCDD/F**	**PCB**
1A1a	Soenderborg Kraftvarmevaerk	x	x		x															x	
1A1a	Studstrupvaerket	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x		
1A1a	Svanemoellevaerket		x		x																
1A1a	Svendborg Kraftvarmevaerk	x	x		x		x	x	x	x	x	x	x	x	x	x	x			x	
1A1a	Viborg Kraftvarme		x																		
1A1a	Vordingborg Kraftvarme	x	x																		
1A1a	Dalum Kraftvarmevaerk	x	x				x	x	x	x											
1A1a	Randersvaerket Verdo	x	x				x	x	x	x											
1A1a	Hammel Fjernvarmeselskab	x	x		x		x	x	x	x					x					x	
1A1b	Shell Raffinaderi	x	x																		
1A1b	Statoil Raffinaderi	x	x																		
1A1c	Nybro Gasbehandlingsanlaeg		x																		
1A2a	DanSteel		x																		
1A2a	Duferco Danish Steel		x																		
1A2c	Cheminova																				
1A2c	Haldor Topsoee		x																		
1A2e	Nordic Sugar Nakskov	x	x																		
1A2e	Nordic Sugar Nykoebing	x	x				x	x	x	x											
1A2e	AarhusKarlshamn Denmark A/S	x	x				x	x	x	x											
1A2e	Danisco Grindsted Dupont		x																		
1A2f	Ardagh Glass Holmegaard A/S		x																		
1A2f	Faxe Kalk	x	x																		
1A2f	Rockwool A/S Doense	x	x												x		x				
1A2f	Rockwool A/S Vamdrup		x																		
1A2f	Saint-Gobain Isover A/S		x																		
1A2f	Aalborg Portland	x	x		x	x	x	x	x	x					x						
1A2f	LECA Danmark		x		x	x									x						
1A4a i	Rensningsanlaegget Lynetten	x	x		x		x	x	x	x		x			x		x			x	
Total		**2083**	**9568**	**28**	**6160**	**66**	**190**	**155**	**120**	**10**	**20**	**14**	**41**	**26**	**95**	**36**	**38**	**171**	**82**	**511**	**-**
Total emission from stationary combustion		4569	23305	9606	71082	986	7757	7307	7091	1024	111	493	1029	438	170	802	1399	327	17190	20346	298328
Share of total emission from stationary combustion based on plant specific data, %		46%	41%	0.3%	9%	6.7%	2%	2%	2%	1.0%	18%	2.8%	4%	6%	56%	5%	3%	52%	0.5%	2.5%	**-**

1) Emissions of the pollutants marked with “x” are plant specific. Emission of other pollutants is estimated based on emission factors. The total shown *in this table* only includes plant specific data.

2) Based on particle size distribution and BC fractions.

Annex 3A-7 Uncertainty estimates, 2023

Table 3A-7.1 Uncertainty estimates.

This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Annex 3A-8 Emission inventory 2023 based on SNAP sectors

Table 3A-8.1 Emission inventory 2023 based on SNAP sectors.

This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Annex 3A-9 Description of the Danish energy statistics

This description of the Danish energy statistics has been prepared by Denmark's National Environmental Research Institute, NERI (now DCE) in co-operation with the Danish Energy Agency (DEA) as background information to the Danish National Inventory Report (NIR).

The Danish energy statistics system

DEA is responsible for the Danish energy balance. Main contributors to the energy statistics outside DEA are Statistics Denmark and Danish Energy Association (before Association of Danish Energy Companies). The statistics is performed using an integrated statistical system building on an Access database and Excel spreadsheets.

The DEA follows the recommendations of the International Energy Agency as well as Eurostat.

The national energy statistics is updated annually and all revisions are immediately included in the published statistics, which can be found on the DEA homepage. It is an easy task to check for breaks in a series because the statistics is 100 % time-series oriented.

The national energy statistics does not include Greenland and Faroe Islands.

For historical reasons, DEA receive monthly information from the Danish oil companies regarding Danish deliveries of oil products to Greenland and Faroe Islands. However, the monthly (MOS) and annual (AOS) reporting of oil statistics to Eurostat and IEA exclude Greenland and Faroe Islands. For all other energy products, the Danish figures are also excluding Greenland and Faroe Islands.

Reporting to the Danish Energy Agency

The Danish Energy Agency receives monthly statistics for the following fuel groups:

- Crude oil and oil products.
    - Monthly data from 46 oil companies, the main purpose is monitoring oil stocks according to the oil preparedness system.
- Natural gas.
    - Fuel/flare from platforms in the North Sea.
    - Natural gas balance from the regulator Energinet.dk (National monopoly).
- Coal and coke.
    - Power plants (94 %).
    - Industry companies (4 %).
    - Coal and coke traders (2 %).
- Electricity.
    - Monthly reporting by e-mail from the regulator Energinet.dk (National monopoly).

- The statistics covers:
  - Production by type of producer.
  - Own use of electricity.
  - Import and export by country.
  - Domestic supply (consumption + distribution loss).
- Town gas (quarterly) from two town gas producers.
- The large central power plants also report monthly consumption of biomass.

Annual data includes renewable energy including waste. The DEA conducts a biannual survey on wood pellets and wood fuel. Statistics Denmark conducts biannual surveys on the energy consumption in the service and industrial sectors. Statistics Denmark prepares annual surveys on forest (wood fuel) & straw.

Other annual data sources include:

– DEA:
  - Survey on production of electricity and heat and fuels used.
  - Survey on end use of oil.
  - Survey on end use of natural gas.
  - Survey on end use of coal and coke.
– DCE (former NERI), Aarhus University.
  - Energy consumption for domestic air transport.
– Danish Energy Association (Association of Danish Energy companies).
  - Survey on electricity consumption.
– Ministry of Taxation.
  - Border trade.
– Centre for Biomass Technology.
  - Annual estimates of final consumption of straw and wood chips.

Annual revisions

In general, DEA follows the same procedures as in the Danish national account. This means that normally only figures for the last two years are revised.

Aggregating the energy statistics on SNAP level

The sectors used in the official energy statistics have been mapped to SNAP categories, used in the Danish emission database. DCE aggregates the official energy statistics to SNAP level based on a source correspondence table.

In cooperation between DEA and DCE, a fuel correspondence table has been developed mapping the fuels used by the DEA in the official energy statistics with the fuel codes used in the Danish national emission database. The fuel correspondence table between fuel categories used by the DEA, DCE and NFR is presented in Annex 3A-3.

The mapping between the energy statistics and the SNAP and fuel codes used by DCE can be seen in the table below.

Table 3A-9.1 Correspondence between the Danish national energy statistics and the SNAP nomenclature (only stationary combustion part shown).

Unit: TJ	End-use SNAP	Fuel (in Danish)	Fuel-code	Transformation 1980-1993 SNAP	Fuel-code
Foreign Trade					
- Border Trade					
- - Motor Gasoline					
- - Gas-/Diesel Oil					
- - Petroleum Coke	0202	Petrokoks	110A		
Vessels in Foreign Trade					
- International Marine Bunkers					
- - Gas-/Diesel Oil					
- - Fuel Oil					
- - Lubricants					
Energy Sector					
Extraction and Gasification					
- Extraction					
- - Natural Gas	010504	Naturgas	301A		
- Gasification					
- - Biogas, Landfill	091006	Biogas	309A		
- - Biogas, Other	091006	Biogas	309A		
Refineries					
- Own Use					
- - Refinery Gas	010306	Raffinaderigas	308A		
- - LPG	010306	LPG	303A		
- - Gas-/Diesel Oil	010306	Gas & Dieselolie	204A		
- - Fuel Oil	010306	Fuelolie & Spildolie	203A		
Transformation Sector					
Large-scale Power Units					
- Fuels Used for Power Production					
- - Gas-/Diesel Oil				0101	204A
- - Fuel Oil				0101	203A
- - Electricity Plant Coal				0101	102A
- - Straw				0101	117A
Large-Scale CHP Units					
- Fuels Used for Power Production					
- - Refinery Gas				0103	308A
- - LPG				0101	303A
- - Naphtha (LVN)				0101	210A
- - Gas-/Diesel Oil				0101	204A
- - Fuel Oil				0101	203A
- - Petroleum Coke				0101	110A
- - Orimulsion				0101	225A
- - Natural Gas				0101	301A
- - Electricity Plant Coal				0101	102A
- - Straw				0101	117A
- - Wood Chips				0101	111A
- - Wood Pellets				0101	111A
- - Wood Waste				0101	111A
- - Biogas, Landfill				0101	309A
- - Biogas, Others				0101	309A
- - Waste, Non-renewable				0101	114A
- - Wastes, Renewable				0101	114A
- Fuels Used for Heat Production					
- - Refinery Gas				0103	308A

Unit: TJ	End-use			Transformation 1980-1993	
	SNAP	Fuel (in Danish)	Fuel-code	SNAP	Fuel-code
- - LPG				0101	303A
- - Naphtha (LVN)				0101	210A
- - Gas-/Diesel Oil				0101	204A
- - Fuel Oil				0101	203A
- - Petroleum Coke				0101	110A
- - Orimulsion				0101	225A
- - Natural Gas				0101	301A
- - Electricity Plant Coal				0101	102A
- - Straw				0101	117A
- - Wood Chips				0101	111A
- - Wood Pellets				0101	111A
- - Wood Waste				0101	111A
- - Biogas, Landfill				0101	309A
- - Biogas, Other				0101	309A
- - Waste, Non-renewable				0101	114A
- - Wastes, Renewable				0101	114A
Small-Scale CHP Units					
- Fuels Used for Power Production					
- - Gas-/Diesel Oil				0101	204A
- - Fuel Oil				0101	203A
- - Natural Gas				0101	301A
- - Hard Coal				0101	102A
- - Straw				0101	117A
- - Wood Chips				0101	111A
- - Wood Pellets				0101	111A
- - Wood Waste				0101	111A
- - Biogas, Landfill				0101	309A
- - Biogas, Other				0101	309A
- - Waste, Non-renewable				0101	114A
- - Wastes, Renewable				0101	114A
- Fuels Used for Heat Production					
- - Gas-/Diesel Oil				0101	204A
- - Fuel Oil				0101	203A
- - Natural Gas				0101	301A
- - Coal				0101	102A
- - Straw				0101	117A
- - Wood Chips				0101	111A
- - Wood Pellets				0101	111A
- - Wood Waste				0101	111A
- - Biogas, Landfill				0101	309A
- - Biogas, Other				0101	309A
- - Waste, Non-renewable				0101	114A
- - Wastes, Renewable				0101	114A
District Heating Units					
- Fuels Used for Heat Production					
- - Refinery Gas				0103	308A
- - LPG				0102	303A
- - Gas-/Diesel Oil				0102	204A
- - Fuel Oil				0102	203A
- - Waste Oil				0102	203A
- - Petroleum Coke				0102	110A
- - Natural Gas				0102	301A
- - Electricity Plant Coal				0102	102A
- - Coal				0102	102A

Unit: TJ	End-use			Transformation 1980-1993	
	SNAP	Fuel (in Danish)	Fuel-code	SNAP	Fuel-code
- - Straw				0102	117A
- - Wood Chips				0102	111A
- - Wood Pellets				0102	111A
- - Wood Waste				0102	111A
- - Biogas, Landfill				0102	309A
- - Biogas, Sludge				0102	309A
- - Biogas, Other				0102	309A
- - Waste, Non-renewable				0102	114A
- - Wastes, Renewable				0102	114A
- - Fish Oil				0102	215A
Autoproducers, Electricity Only					
- Fuels Used for Power Production					
- - Natural Gas				0320	301A
- - Biogas, Landfill				0320	309A
- - Biogas, Sewage Sludge				0320	309A
- - Biogas, Other				0320	309A
Autoproducers, CHP Units					
- Fuels Used for Power Production					
- - Refinery Gas				0103	308A
- - Gas-/Diesel Oil				0320	204A
- - Fuel Oil				0320	203A
- - Waste Oil				0320	203A
- - Natural Gas				0320	301A
- - Coal				0320	102A
- - Straw				0320	117A
- - Wood Chips				0320	111A
- - Wood Pellets				0320	111A
- - Wood Waste				0320	111A
- - Biogas, Landfill				0320	309A
- - Biogas, Sludge				0320	309A
- - Biogas, Other				0320	309A
- - Fish Oil				0320	215A
- - Waste, Non-renewable				0320	114A
- - Wastes, Renewable				0320	114A
- Fuels Used for Heat Production					
- - Refinery Gas				0103	308A
- - Gas-/Diesel Oil				0320	204A
- - Fuel Oil				0320	203A
- - Waste Oil				0320	203A
- - Natural Gas				0320	301A
- - Coal				0320	102A
- - Wood Chips				0320	111A
- - Wood Waste				0320	111A
- - Biogas, Landfill				0320	309A
- - Biogas, Sludge				0320	309A
- - Biogas, Other				0320	309A
- - Waste, Non-renewable				0320	114A
- - Wastes, Renewable				0320	114A
Autoproducers, Heat Only					
- Fuels Used for Heat Production					
- - Gas-/Diesel Oil				0320	204A
- - Fuel Oil				0320	203A
- - Waste Oil				0320	203A
- - Natural Gas				0320	301A

Unit: TJ	End-use			Transformation 1980-1993	
	SNAP	Fuel (in Danish)	Fuel-code	SNAP	Fuel-code
- - Straw				0320	117A
- - Wood Chips				0320	111A
- - Wood Chips				0320	111A
- - Wood Waste				0320	111A
- - Biogas, Landfill				0320	309A
- - Biogas, Sludge				0320	309A
- - Biogas, Other				0320	309A
- - Waste, Non-renewable				0102	114A
- - Wastes, Renewable				0102	114A
Town Gas Units	030106	Naturgas	301A		
- Fuels Used for Production of District Heating	030106	Kul (-83) / Gasolie (84-)	102A / 204A		
Transport sector					
Military Transport					
- Aviation Gasoline					
- Motor Gasoline					
- JP4					
- JP1					
- Gas-/Diesel Oil					
Road					
- LPG					
- Motor Gasoline					
- Other Kerosene	0202	Petroleum	206A		
- Gas-/Diesel Oil					
- Fuel Oil					
Rail					
- Motor Gasoline					
- Other Kerosene					
- Gas-/Diesel Oil					
- Electricity					
Domestic Sea Transport					
- LPG					
- Other Kerosene					
- Gas-/Diesel Oil					
- Fuel Oil					
Air Transport, Domestic					
- LPG					
- Aviation Gasoline					
- Motor Gasoline					
- Other Kerosene	0201	Petroleum	206A		
- JP1					
Air Transport, International					
- Aviation Gasoline					
- JP1					
Agriculture and Forestry					
- LPG					
- Motor Gasoline					
- Other Kerosene	0203	Petroleum	206A		
- Gas-/Diesel Oil					
- Fuel Oil	0203	Fuelolie & Spildolie	203A		
- Petroleum Coke	0203	Petrokoks	110A		
- Natural Gas	0203	Naturgas	301A		
- Coal	0203	Kul	102A		

Unit: TJ	End-use			Transformation 1980-1993	
	SNAP	Fuel (in Danish)	Fuel-code	SNAP	Fuel-code
- Brown Coal Briquettes	0203	Brunkul	106A		
- Straw	0203	Halm	117A		
- Wood Chips	0203	Træ	111A		
- Wood Waste	0203	Træ	111A		
- Biogas, Other	0203	Biogas	309A		
Horticulture					
- LPG					
- Motor Gasoline					
- Gas-/Diesel Oil					
- Fuel Oil	0203	Fuelolie & Spildolie	203A		
- Petroleum Coke	0203	Petrokoks	110A		
- Natural Gas	0203	Naturgas	301A		
- Coal	0203	Kul	102A		
- Wood Waste	0203	Træ	111A		
Fishing					
- LPG					
- Motor Gasoline					
- Other Kerosene					
- Gas-/Diesel Oil					
- Fuel Oil					
Manufacturing Industry					
- Refinery Gas	0320	Raffinaderigas	308A		
- LPG					
- Naphtha (LVN)					
- Motor Gasoline					
- Other Kerosene	0320	Petroleum	206A		
- Gas-/Diesel Oil					
- Fuel Oil	0320	Fuelolie & Spildolie	203A		
- Waste Oil	0320	Fuelolie & Spildolie	203A		
- Petroleum Coke	0320	Petrokoks	110A		
- Natural Gas	0320	Naturgas	301A		
- Coal	0320	Kul	102A		
- Coke	0320	Koks	107A		
- Brown Coal Briquettes	0320	Brunkul	106A		
- Wood Pellets	0320	Træ	111A		
- Wood Waste	0320	Træ	111A		
- Biogas, Landfill	0320	Biogas	309A		
- Biogas, Other	0320	Biogas	309A		
- Wastes, Non-renewable	0320	Affald	114A		
- Wastes, Renewable	0320	Affald	114A		
- Town Gas	0320	Naturgas	301A		
Construction					
- LPG	0320	LPG	303A		
- Motor Gasoline					
- Other Kerosene	0320	Petroleum	206A		
- Gas-/Diesel Oil					
- Fuel Oil	0320	Fuelolie & Spildolie	203A		
- Natural Gas	0320	Naturgas	301A		
Wholesale					
- LPG	0201	LPG	303A		
- Motor Gasoline	0201	Petroleum	206A		
- Other Kerosene	0201	Gas & Dieselolie	204A		
- Gas-/Diesel Oil	0201	Fuelolie & Spildolie	203A		
- Petroleum Coke	0201	Petrokoks	110A		

Unit: TJ	End-use			Transformation 1980-1993	
	SNAP	Fuel (in Danish)	Fuel-code	SNAP	Fuel-code
- Natural Gas	0201	Naturgas	301A		
- Wood Waste	0201	Træ	111A		
Retail Trade					
- LPG	0201	LPG	303A		
- Other Kerosene	0201	Petroleum	206A		
- Gas-/Diesel Oil	0201	Gas & Dieselolie	204A		
- Fuel Oil	0201	Fuelolie & Spildolie	203A		
- Petroleum Coke	0201	Petrokoks	110A		
- Natural Gas	0201	Naturgas	301A		
Private Service					
- LPG	0201	LPG	303A		
- Other Kerosene	0201	Petroleum	206A		
- Gas-/Diesel Oil	0201	Gas & Dieselolie	204A		
- Fuel Oil	0201	Fuelolie & Spildolie	203A		
- Waste Oil	0201	Fuelolie & Spildolie	203A		
- Petroleum Coke	0201	Petrokoks	110A		
- Natural Gas	0201	Naturgas	301A		
- Wood Chips	0201	Træ	111A		
- Wood Waste	0201	Træ	111A		
- Biogas, Landfill	0201	Biogas	309A		
- Biogas, Sludge	0201	Biogas	309A		
- Biogas, Other	0201	Biogas	309A		
- Wastes, Non-renewable	0201	Affald	114A		
- Wastes, Renewable	0201	Affald	114A		
- Town Gas	0201	Naturgas	301A		
Public Service					
- LPG	0201	LPG	303A		
- Other Kerosene	0201	Petroleum	206A		
- Gas-/Diesel Oil	0201	Gas & Dieselolie	204A		
- Fuel Oil	0201	Fuelolie & Spildolie	203A		
- Petroleum Coke	0201	Petrokoks	110A		
- Natural Gas	0201	Naturgas	301A		
- Coal	0201	Kul	102A		
- Brown Coal Briquettes	0201	Brunkul	106A		
- Wood Chips	0201	Træ	111A		
- Wood Pellets	0201	Træ	111A		
- Town Gas	0201	Naturgas	301A		
Single Family Houses					
- LPG	0202	LPG	303A		
- Motor Gasoline					
- Other Kerosene	0202	Petroleum	206A		
- Gas-/Diesel Oil	0202	Gas & Dieselolie	204A		
- Fuel Oil	0202	Fuelolie & Spildolie	203A		
- Petroleum Coke	0202	Petrokoks	110A		
- Natural Gas	0202	Naturgas	301A		
- Coal	0202	Kul	102A		
- Coke	0202	koks	107A		
- Brown Coal Briquettes	0202	Brunkul	106A		
- Straw	0202	Halm	117A		
- Firewood	0202	Træ	111A		
- Wood Chips	0202	Træ	111A		
- Wood Pellets	0202	Træ	111A		
- Town Gas	0202	Naturgas	301A		

Unit: TJ	End-use			Transformation 1980-1993	
	SNAP	Fuel (in Danish)	Fuel-code	SNAP	Fuel-code
Multi-family Houses					
- LPG	0202	LPG	303A		
- Other Kerosene	0202	Petroleum	206A		
- Gas-/Diesel Oil	0202	Gas & Dieselolie	204A		
- Fuel Oil	0202	Fuelolie & Spildolie	203A		
- Petroleum Coke	0202	Petrokoks	110A		
- Natural Gas	0202	Naturgas	301A		
- Coal	0202	Kul	102A		
- Coke	0202	Koks	107A		
- Brown Coal Briquettes	0202	Brunkul	106A		
- Town Gas	0202	Naturgas	301A		

Annex 3A-10 QA/QC for stationary combustion

The quality work for the Danish GHG emission inventories is accounted for in *Quality manual for the Danish emission greenhouse gas inventory, Version 3* (Nielsen et al., 2020a). The quality manual outlines the quality work undertaken by the emission inventory group at the Department of Environmental Science, Aarhus University in connection with the preparation and reporting of the Danish greenhouse gas inventory.

The QA/QC defined in the Quality manual defines Critical control points and a Points of measurement. Some points of measurement are sector specific whereas others are general. Information on the Danish quality work is also included in NID Chapter 1.6. Sector specific QA/QC for stationary combustion is accounted for in this chapter.

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

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

Sector specific points of measurement

Table 3.2.43 lists the sector specific points of measurement and specification about the points of measurement for stationary combustion.

Table 3.2.43 List of sectoral points of measurement, and QC for stationary combustion.

Level	CCP	Id	Description		Stationary combustion QC
Data Storage level 1	1. Accuracy	DS.1.1.1	General level of uncertainty for every dataset including the reasoning for the specific values.	Sectoral	Uncertainties are estimated and references given in NID chapter 3.2.7.
	2. Comparability	DS1.2.1	Comparability of the emission factors/calculation parameters with data from international guidelines, and evaluation of major discrepancies.	Sectoral	In general, if national referenced emission factors differ considerably from IPCC Guideline values this is discussed in NID chapter 3.2.6. This documentation is improved annually based on reviews. At CRT level, a project has been carried out comparing the Danish inventories with those of other countries (Fauser et al., 2013).
	3.Completeness	DS.1.3.1	Ensuring that the best possible national data for all sources are included, by setting down the reasoning behind the selection of datasets.	Sectoral	A list of external data is shown and discussed below (Table 3.2.44).
	4.Consistency	DS.1.4.1	The original external data has to be archived with proper reference.	Sectoral	It is ensured that all original external data are archived. Subsequent data processing takes place in other spreadsheets or databases. The datasets are archived annually in order to ensure that the basic data for a given report are always available in their original form. All original data for stationary combustion are archived in the emission inventory archive: ST_ENVS-Luft-Emi/Inventory/(year)/1A1 1A2 and 1A4 Stationary combustion All original data for 1) the reference approach, 2) the comparison of EU ETS sum and CRT and 3) the comparison of Eurostat data and CRT are archived in the emission inventory archive: ST_ENVS-Luft-Emi/Inventory/(year)/1A Other Energy
	6.Robustness	DS.1.6.1	Explicit agreements between the external institution holding the data and AU, DCE about the conditions of delivery.	Sectoral	For stationary combustion, a data delivery agreement is made with the DEA. DCE and DEA have renewed the data delivery agreement in 2014.

Level	CCP	Id	Description		Stationary combustion QC
					Most of the other external data sources are available due to legislation. See Table 3.2.44.
	7.Transparency	DS.1.7.1	Listing of all archived datasets and external contacts.	Sectoral	A list of external datasets and external contacts is shown in Table 3.2.44 below.
Data Processing level 1	1. Accuracy	DP.1.1.1	Uncertainty assessment for every data source not part of DS.1.1.1 as input to Data Storage level 2 in relation to type and scale of variability.	Sectoral	Uncertainties are estimated and references given in NID chapter 3.2.7.
	2.Comparability	DP.1.2.1	The methodologies have to follow the international guidelines suggested by UNFCCC and IPCC.	Sectoral	The methodological approach is consistent with international guidelines. An overview of tiers is given in NID Chapter 3.2.5.
	3.Completeness	DP.1.3.1	Identification of data gaps with regard to data sources that could improve quantitative knowledge.	Sectoral	The energy statistics (the basic data sheet) is considered complete. Total fuel consumption is based on the energy statistics whereas other data sources are used for specification of technology, subsectors, plant specific data etc.
	4.Consistency	DP.1.4.1	Documentation and reasoning of methodological changes during the time series and the qualitative assessment of the impact on time series consistency.	Sectoral	The two main methodological changes in the time series; implementation of Energy Producers Survey (plant specific fuel consumption data) from 1994 onwards and implementation of EU ETS data from 2006 onwards are discussed in NID chapter 3.2.5.
	5.Correctness	DP.1.5.2	Verification of calculation results using time series.	Sectoral	Time series for activity data on SNAP and CRT source category level are used to identify possible errors. Time series for emission factors and the emission from CRT subcategories are also examined.
		DP.1.5.3	Verification of calculation results using other measures.	Sectoral	The IPCC reference approach validates the fuel consumption rates and CO_2 emission. Except for 2016, 2022, and 2023 both differ less than 2.0 % in 1990-2023. The reference approach is included in NID Chapter 3.4. The chapter gives an account of the differences between the national approach and the reference approach.
	7.Transparency	DP.1.7.1	The calculation principle, the equations used and the assumptions made must be described.	Sectoral	This is included in NID chapter 3.2.5.
		DP.1.7.2	Clear reference to dataset at Data Storage level 1.	Sectoral	This is included in NID chapter 3.2.5.
		DP.1.7.3	A manual log to collect information about recalculations.	Sectoral	A manual log is implemented in the emission database.

Level	CCP	Id	Description		Stationary combustion QC
Data Storage level 2	5.Correctness	DS.2.5.1	Check if a correct data import to level 2 has been made.	Sectoral	To ensure a correct connection between data on level 2 and level 1, different controls are in place, e.g. control of sums and random tests.
Data Storage level 4	4.Consistency	DS.4.4.3	The IEFs from the CRT are checked both regarding level and trend. The level is compared to relevant emission factors to ensure correctness. Large dips/jumps in the time series are explained.	Sectoral	Large dips/jumps in time series are discussed and explained in NID chapter 3.2.3 and 3.2.4.
	5. Correctness	DS.4.5.2	Check that additional information and information related to land-use changes has been correctly aggregated compared to the individual submissions of Denmark and Greenland.	Sectoral	(Not relevant for stationary combustion)

Table 3.2.44 List of external data sources for stationary combustion.

Dataset	Data reference	Contact(s)	Description	Years included	Data agreement/ Comment
Energy Producers Survey	The Danish Energy Agency (DEA)	Kaj Stærkind	Dataset for all plants producing electricity and district heating for the public grids. For each production unit, the dataset includes the consumption of each fuel, production of heat and electricity, technology and year of installation. The dataset is regarded as complete for fuel consumption since the plants are obliged to report the data to DEA.	1994 onwards	Data agreement 2014.
Gas consumption for gas engines and gas turbines 1990-1993	The Danish Energy Agency (DEA)	Kaj Stærkind	Historical dataset for gas engines and gas turbines. For the years 1990-1994, DEA has estimated consumption of natural gas and biogas in gas engines and gas turbines (DEA, 2003). Estimated fuel consumption data for 1990-1993 was based on engine specific data for year of installation and for fuel consumption in 1994. The 1994 data were based on the Energy Producers Survey. DCE assesses that the DEA estimate is the best available data for 1990-1993.	1990-1993	No data agreement. Historical data
Basic data	The Danish Energy Agency (DEA)	Carmela Moreno Jytte Boll Illerup Ali Zarnaghi	The Danish energy statistics. The dataset is applied for both the reference approach and the national approach. The spreadsheet from the Danish energy statistics (DEA) is used for the CO_2 emission calculation in accordance with the IPCC reference approach and is also the first dataset applied in the national approach.	1972 and 1975 onwards	Data agreement 2014. However, the dataset is also published as part of national energy statistics.
Energy statistics for industrial subsectors	The Danish Energy Agency (DEA)	Ali Zarnaghi	Disaggregation of the industrial fuel consumption. The data includes disaggregation of the fuel consumption for industrial plants. The dataset is estimated for the reporting to Eurostat. The data are included in the 2014 update of the agreement with DEA.		Included in data delivery agreement 2014.
Emission factors	See chapter regarding emission factors		Emission factors refer to a large number of sources. For specific references, see the Chapter 3.2.6 regarding emission factors. Some of the annually updated		Some of the annually updated CO_2 emission factors are based on EU ETS data, and thus included in the data delivery agreement with DEA.

Dataset	Data reference	Contact(s)	Description	Years included	Data agreement/ Comment
			CO_2 emission factors are based on EU ETS data, see below.		For other emission factors there is no formal data delivery agreement.
Annual environmental reports / environmental data / PRTR	Various plants		Emissions from plants defined as large point sources Some large plants are obligated to report annual environmental data including emission data to PRTR. In addition, some plants publish annual environmental reports. And finally, some plant owners non-compulsory report annual emission data to DCE.		No data agreement. Some plants are obligated to report data (DEPA, 2010b; DEPA, 2015) and data are published on the Danish EPA homepage.
EU ETS data	The Danish Energy Agency (DEA)	Rikke Brynaa Lintrup	Plant specific CO_2 emission factors and fuel consumption data. EU ETS data includes information on fuel consumption, heating values, carbon content of fuel, oxidation factor and CO_2 emissions. DCE receives the verified reports for all plants, which utilises a detailed estimation methodology. DCE's QC of the received data consists of comparing to calculation using standard emission factors as well as comparing reported values with those for previous years.		Plants are obligated by law. The availability of detailed information is part of the data agreement with DEA (2014 update).

Additional sector specific QC procedures

Some additional sector specific QC procedures are performed.

- Check of units for fuel rate, emission factors and plant-specific emissions.
- Check of emission factors for large point sources. Emission factors for pollutants that are not plant-specific should be the same as those defined for area sources.
- Additional checks on database consistency.
- Emission factor references are included in NID Chapter 3.2.6.
- Most country-specific emission factors are based on input from companies that have implemented some QA/QC work. The major power plant owner/operator in Denmark, Ørsted (former DONG Energy) has obtained the ISO 14001 certification for an environmental management system. The Danish Gas Technology Centre and Force Technology both run accredited laboratories for emission measurements.

Sector specific verification

The IPCC reference approach for CO_2 emission is the primary verification of the CO_2 emission from the energy sector. The reference approach for the energy sector is shown in NID Chapter 3.4.

In addition, as part of the EU review of the reported GHG emission data, EU performs for each member state a comparison of Eurostat energy data in terms of TJ with energy data provided in the CRT. The comparison has been performed in accordance with the Commission implementing regulation (EU) No 749/2014 of 30 June 2014 and with the IPCC Guidelines (2006). The latest comparison included comparisons of the reference approach (RA) and the sectoral approach (SA) for the years 2005 and 2008-2023. The comparison of fuel consumption data in CRT and energy statistics from Eurostat is shown in NID Annex 9 including explanation of the differences.

Finally, a verification of the Danish GHG emission inventories has been published by Fauser et al. (2013).

National external review for stationary combustion

The 2004, 2006, 2009, 2014, 2018 and 2021 updates of the sector report for stationary combustion have been reviewed by external experts (Nielsen & Illerup, 2004; Nielsen & Illerup, 2006; Nielsen et al., 2009, Nielsen et al., 2014; Nielsen et al., 2018; Nielsen, 2021). The national external review forms a vital part of the QA activities for stationary combustion.

The 2004, 2006, 2009, 2014, 2018 and 2021 updates of this report were reviewed by Jan Erik Johnsson from the Technical University of Denmark, Bo Sander from Elsam Engineering, Annemette Geertinger from FORCE Technology, Vibeke Vestergaard Nielsen, AU DCE, energy statistics experts from the Danish Energy Agency and Jytte Boll Illerup, The Danish Environmental Protection Agency.

Annex 1: Fleet data 1985-2023 for road transport (No. vehicles)

Annex 2: Mileage data 1985-2023 for road transport (km)

Annex 3: EU directive emission limits for road transportation vehicles

Annex 4: Basis fuel consumption and emission factors (g pr km) for conventional vehicles and PHEV (gasoline), fuel consumption factors for electric, PHEV (el) and hydrogen vehicles

Annex 6: Deterioration factors in 2023

Annex 7: Final fuel consumption factors (MJ/km) and emission factors (g/km) for conventional vehicles and PHEV (gasoline), fuel consumption factors for electric, PHEV (el) and hydrogen vehicles in 2023, for urban/rural/highway and weighted traffic

Annex 8: Fuel consumption (GJ) and emissions (tonnes) per vehicle category and as totals

Annex 9: Model consumption:Fuel sales derived fuel and emission adjustment factors

Annex 10-1: Correspondence table between actual aircraft type codes and representative aircraft types

Annex 10-2: LTO no. and average LTO fuel consumption and emission factors per representative aircraft type for domestic and international flights (Copenhagen and other airports)

Annex 10-3: No. of flights between Danish airports and airports in Greenland and Faroe Islands

Annex 10-4: Total distance flown (NM) and average cruise fuel consumption and emission factors per representative aircraft type for cruise flying

Annex 10-5: LTO times-in-modes (s) for the Danish airports

Annex 10-6: APU Engine mode specific fuel flows (kg/h), emission rates (kg/h or g/kg) and times-in-modes per aircraft type

Annex 11-1: Stock numbers per machine type for non road mobile machinery 1985-2023, grouped into sector, fuel type, engine type and engine size class

Annex 11-2: Engine size in kW (weighted by number) per machine type for non road mobile machinery 1985-2023, grouped into sector, fuel type, engine type and engine size class

Annex 11-3: Engine load factor (weighted by total engine kWh output) per machine type for non road mobile machinery 1985-2023, grouped into sector, fuel type, engine type and engine size class

Annex 11-4: Annual working hours (weighted by number) per machine type for non road mobile machinery 1985-2023, grouped into sector, fuel type, engine type and engine size class

Annex 11-5: Total annual working hours (1000 hours) per machine type for non road mobile machinery 1985-2023, grouped into sector, fuel type, engine type and engine size class

Annex 11-6: Total MWh per machine type for non road mobile machinery 1985-2023, grouped into sector, fuel type, engine type and engine size class

Annex 11-7: Stock data for recreational craft 1985-2023

Annex 12-1: Annual traffic data (no. of round trips) per route for Danish ferries 1990-2023

Annex 12-2: Annual traffic data (no. of round trips) per route per ferry for Danish ferries 1990-2023

Annex 12-3: Round trip shares per route per ferry for Danish ferries 1990-2023

Annex 12-4: Sailing time (single trip) per route per ferry for Danish ferries 1990-2023

Annex 12-5: Engine load factor (% MCR) per route per ferry for Danish ferries 1990-2023

Annex 12-6: Ferry service, ferry name, engine type, engine year, fuel type, main engine MCR (kW), aux. engine (kW), engine load factors (%), Number of round trips, Sailing time (mins), MWh produced, fuel consumption (tons and GJ), specific fuel consumption (g/kWh), SO2, NOx, NMVOC, CH4, VOC, CO, CO2, N2O, NH3, TSP, PM10, PM2.5 and BC emission factors for 2023 (g/kWh, g/GJ, g/kg fuel).

Annex 12-7: Specific fuel consumption, NOx, CO, VOC, NMVOC and CH4 emission factors (g pr kWh) per engine year for marine engines

Annex 12-8: Fuel consumption (PJ and tonnes), S-%, SO2 , NOx, NMVOC, CH4, CO, CO2, N2O, TSP, PM10, PM2.5 and BC emission factors (g/kg fuel and g/GJ) per fuel type for national sea transport, international sea transport and fisheries

Annex 12-9: Engine load adjustment functions for sfc, NOx, VOC, CO, N2O and TSP emission factors for marine engines

Annex 12-10: Hours at sea, engine load (%), MWh produced, fuel consumption (PJ), specific fuel consumption (g/kWh), SO2, NOx, NMVOC, CH4, VOC, CO, CO2, N2O, NH3, TSP, PM10, PM2.5 and BC emission factors (g/kWh, g/GJ, g/kg fuel) for Danish fishing vessels 1985-2023 distributed into overall length classes.

Annex 13-1: Train Litrakm, tonnes trainkm, engine type, fuel consumption (PJ or kWh), SO2, NOx, NMVOC, CH4, VOC, CO, CO2, N2O, NH3, TSP, PM10, PM2.5 and BC total emissions (exhaust, kg) and TSP, PM10, PM2.5, Cr, Cu and Ni total emissions (non exhaust, kg) for DSB, private railways, other railways and S-tog and Metro per litra type for the years 1985-2023.

Annex 14-1: Fuel sales figures from DEA, and further processed fuel consumption data suited for the Danish inventory

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Annex 17-1: Uncertainty estimates for greenhouse gases

Annex 17-2: Uncertainty estimates for emission components reported to the LRTAP Convention

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All annexes are available at:
https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Non-energy products from fuels and solvent use (NFR 2D)

Annex 3C-8.2:	Emissions from the treatment of slaughterhouse waste, t

All annexes are available online at:

https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Please note that data found via this link are updated annually. This means that data in the annexes always match the newest version of the Informative Inventory Report (IIR).

Annex 3D - Agriculture

Table 3D-1: Total NH_3 emissions from the agricultural sector. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values)

Table 3D-2: Number of animals allocated on subcategories. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values)

Table 3D-3: Grazing animals, number of on grass per year. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values)

Table 3D-4a: Nitrogen excretion rates in average, kg N per head per year. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation most recently submitted values)

Table 3D-4b: Nitrogen excretion given as TAN (Total Ammonia Nitrogen), kg N per head per year. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values)

Table 3D-5: Changes in barn type. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values)

Table 3D-6: Cover of slurry tanks. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values)

Table 3D-7: Emission of NH3 from animals (3B barn and storage, 3D manue applied to soil and grazing animals), kt NH3. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values)

Table 3D-8: PM emission from barns, Gg TSP, PM_{10} and $PM_{2.5}$. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values)

Table 3D-9 Assumptions for synthetic fertiliser.

EMEP/EEA fertiliser types[1]	Danish fertiliser types[2]
Anhydrous ammonia (AH)	Liquid ammonia
Ammonium nitrate (AN)	Pure ammonium nitrate Ammonium nitrate with/without sulphur Other N-fertiliser
Ammonium phosphates (MAP, DAP)	Diammonphosphate
Ammonium sulphate (AS)	Ammonium sulphate Ammonium sulphate nitrate
Calcium ammonium nitrate (CAN)	Calcium ammonium nitrate
NK mixtures	NK-fertiliser
NPK mixtures	NPK-fertiliser
NP mixtures	NP-fertiliser
Nitrogen solutions	Liquid nitrogen Ammonium-urea solutions
Other straight N compounds	Calcium and boron calcium nitrate
Urea	Urea

[1] EMEP/EEA emission inventory guidebook 2023, Table 3-2 EFs for NH_3 emissions from fertilisers.

[2] The fertiliser types magnesium fertiliser and nitrogenous calcium cyanamide are also included in the sales statistics from The Danish Agriculture Agency, but no NH_3 is emitted from these fertilisers.

Table 3D-10 Distribution and EF of untreated slurry applied to soil, 2023.

Application methods	Crop status	Time of application	Time before incorporation	Distribution[1], % Cattle	Distribution[1], % Swine	EF[2], % Cattle	EF[2], % Swine
Incorporated	-	March	0	8	8	1.6	1.8
	-	April	0	41	24	1.6	1.8
	+	March	0	9	2	12	9.7
	+	April	0	9	3	14	9.8
	+	Summer, grass	0	19	2	15	10
	-	Summer, before winter rape	0	1	3	1.6	1.8
	+	Autumn	0	2	1	15	10
Trailing hoses	+	March		3	14	22	14
	+	April		6	30	27	15
	+	May		2	9	30	15
	+	Summer		0	1	33	16
	-	Autumn		0	3	15	8.1
Broad spreading				NO	NO	NO	NO

[1] Birkmose (2020, 2023).

[2] Hafner et al (2021).

Table 3D-11 Distribution and EF of acidified slurry applied to soil, 2023.

Application methods	Crop status	Time of application	Time before incorporation	Distribution[1], %		EF, acidified in barn/storage		EF, acidified during application	
				Cattle	Swine	Cattle	Swine	Cattle	Swine
Trailing hoses	-	March	4 hours	0	20	3.1	2.2	4.7	3
	+	March		20	20	9.6	7	14	9.2
	+	April		20	40	13	8.2	18	10
	+	May		25	10	17	9.3	22	11
	+	Summer		30	0	22	10	27	12
	+	Autumn		5	10	19	9.9	25	12
Broad spreading	-			NO	NO	NO	NO	NO	NO

[1] Birkmose (2020).
[2] Hafner et al (2021).

Table 3D-12 Distribution and EF of biogas treated slurry applied to soil, 2023.

Application methods	Crop status	Time of application	Time before incorporation	Distribution[1], %	EF[2], %
Incorporated	-	March	0	6	2.6
	-	April	0	34	2.6
	+	March	0	6	16
	+	April	0	7	17
	+	Summer, grass	0	14	17
	-	Summer, before winter rape	0	2	2.6
	-	Autumn	0	1	2.6
Trailing hoses	+	March		7	28
	+	April		18	29
	+	May		4	30
	+	Summer		1	30
Broad spreading	-			NO	NO

[1] Birkmose (2020, 2023).
[2] Hafner et al (2021).

Table 3D-13 Distribution and EF of solid manure applied to soil, 2023.

Application methods	Crop status	Time of application	Time before incorporation	Distribution[1], %	EF[2], %
Broad spreading	-	Winter-spring	4 hours	66	5
	+	Winter-spring		7	16
	-	Spring-summer	4 hours	8	8
	+	Spring-summer		7	20
	-	Late summer-autumn	4 hours	12	3

[1] Birkmose (2020, 2023).
[2] Hansen et al (2008).

Table 3D-14: Weighted emission factors for NH3-N emission from application of manure, kg NH3-N per kg TAN for slurry and kg NH3-N per kg N for solid manure. See https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values).

Table 3D-15: Area of cultivated crops. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values).

Table 3D-16 a-d: Number of treatments. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values).

Table 3D-17: Activity data for field burning of agricultural residues. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values).

Table 3D-18: Emissions of pollutants from field burning of agricultural residues. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values).

Table 3D-19 Gross energy cattle, MJ per AAP per day. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values).

Table 3D-20 Volatile solids, kg VS per animal per day. See: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation (most recently submitted values).

Chapter 3D-1 NH_3 reducing technology in barns

Over the past fifteen years, is seen a growing interest in using technology to reduce the ammonia emission in livestock barns. In the inventory estimations are included reduction from cooling of manure in swine barns, acidification in cattle and swine barns, frequent removal of manure in mink barns and use of heat exchanger in barns with broilers.

The environmental technologies are closely related to the expansion of the livestock production. Due to the enlargement of the animal production, the farmer will be met by a statutory environmental requirement implemented in the Environmental Approval Act for Livestock Holdings (BEK no 1467 af 06/12/2018). For some farmers, the emission reducing technology will be chosen as an opportunity to reduce the ammonia emission. The farmers apply for an Environmental Approval for livestock farming and include information on, which environmental technologies are planned to be implemented to achieve the reduction of ammonia emission, as well as information regarding the expected reduction effect and the number of animals placed in the barn with the respective environmental technology. This Environmental Approvals Register for livestock farming is administrated by the Danish Environmental Protection Agency. This register also includes information on air cleaning system, but these data is not yet included in the inventory.

Information from the Environmental Approval Register is used to estimate the distribution of cooling of manure in swine barns (2008-2017) and frequent removal of manure in mink barns. Cooling of manure in swine barns for 2018-2023 are based on information from ConTerra (2022).

Estimation of distribution of barns with acidifications are based on information from the main distributor of acidification systems in Denmark.

Distribution of the use of heat exchanger in broiler barns is based on a combination of information from distributors of heat exchanger and subsidy schemes, which include subsidy to installation of heat exchangers.

Below is described the background for estimating the distribution of the included NH_3 reducing technologies in the Danish inventory.

Environmental Approval Register 2007-2016

DCE has received data sets for the Environmental Approval Register for livestock farming for the years 2007 – 2016 (DEPA, 2018), which are used to estimate the prevalence of ammonia emission technology in Danish livestock barns. However, it must be emphasized, that the data set covers the Environmental Approvals, which not in all cases necessarily has been implemented. It could be poor financial conditions or other circumstances, which lead to a situation, where the approval is not being realised. Therefore, the Register of Environmental Approvals for livestock farming is inserted in a database and combined with the Central Husbandry Register (CHR), which is the central register of farms and animals managed by the Ministry of Environment and Food of Denmark. It makes it possible to compare each approval with the actual development of the livestock production. In these cases where the CHR register show an expansion of the livestock production contemporary with the Environmental Approval, indicate that the approval is implemented. Around 20 % of all Environmental Approvals includes emission-reducing technologies in livestock barns.

The data set for Environmental Approval Register for the years 2007 – 2016 corresponds to approximately 1800 approvals, which includes emission reducing technologies solution in barns. Data processing showed that many farmers have applied more than one approval, which is caused by no realization of the first approval because of problems with e.g. financial conditions. In some cases, the second approval also could indicate a further expansion of the livestock production. Figure 3D-1 shows the percentage distribution of the different reducing technologies for the 1800 farms, and slurry cooling is the most frequently used technology. Particularly the pig production seems to be active regarding use of reducing technology and thus approval for swine accounts for 76 % of all farms, cattle for 17 % and poultry for the remaining 7 %.

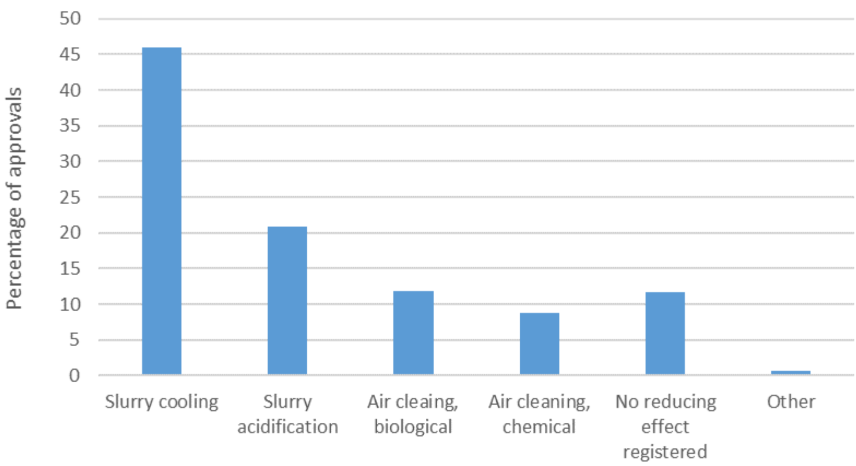

Figure 3D-1 Distribution of ammonia reducing technologies in barns, based on data from the Environmental Approval Register 2007 – 2016.

The review of Environmental Approval Register 2007-2016 indicate that slurry cooling seems to be the most common choose of reducing technology for the swine production, while the cattle production primarily uses slurry acidification.

Slurry cooling

Cooling of slurry only occur in swine barns. Cooling is not only an advantage for the environment, but also profitably due to the operational cost for energy use if the heat can be used in other production facilities – e.g. in piglet barns or farmhouse.

The estimation of distribution of slurry cooling for the years 2008-2017 is based on data from the Environmental Approval Register. Approximately 600 farmers have an approval, which include a barn system with slurry cooling. A sorting process of the data has been performed, to avoid double counting of approvals or avoid counting approvals, which in all probability has not been realized. This sorting process leads to the conclusion, that approximately 460 approvals is considered as implemented. Following assumption is taken into account during the sorting process:

- It is assumed, that the Environmental Approval is not implemented, if the production has not been increased, or increased by less than 10 %. This is based on the argument, that the farmer does not invest large costs for new technology, if no extension of the production take place.
- The extension of the animal production must occur within maximum four years after the approval date; otherwise, it is assumed that the approval is not realized.
- Based on the information from the distributors of slurry cooling system, it is assumed that farmers choose to implement slurry cooling system in relation to new barn buildings. Slurry cooling system can principally be established in existing building, but almost never take place in praxis.
- If CHR data shows a production increase above 10 % in year 2017, it is assumed that approvals for year 2014-2016 is realized.

Based on the 460 approvals (CHR numbers), which is considered as realized, the number of swine is summarized for each year, distinguished between three types of swine; fattening pigs, weaners, and sows. Table 3D-21 shows the estimated number of animals in 2008-2017, in barns with slurry cooling system. In 2008, 0.2 million swine is placed in barns with slurry cooling system increasing to 2.2 million swine in 2017.

Table 3D-21 Number of animals in barns with slurry cooling, based on the data from the Environmental Approval Register.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Fattening pigs	18 428	84 439	194 095	253 899	299 762	342 337	396 743	457 236	529 249	639 288
Weaners	0	124 205	259 149	368 078	512 387	686 390	889 685	1 175 157	1 410 678	1 713 473
Sows	4 140	9 476	17 578	22 899	31 075	42 590	51 514	62 638	69 166	75 294

For the years 2018-2022 the distribution of slurry cooling is based on information from ConTerra (2022).

Estimation of distribution of slurry cooling

In Table 3D-22 is the number of animals in barns with slurry cooling system, converted to the percentage of the total livestock production. It shows that slurry cooling most frequently take place in sow barns and for weaners, which confirm the profitably of using the heat in weaners barns. No data is available for 2022 and 2023, and therefore the slurry cooling system is kept at the same level as 2021.

Table 3D-22 Distribution of slurry cooling in barns, percentage of animals.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022*	2023*
Fattening pigs	0.1	0.4	0.9	1.2	1.5	1.7	2.0	2.3	2.7	3.4	3.7	3.9	4.2	4.4	4.4	4.4
Weaners	<0.0	0.4	0.9	1.2	1.7	2.3	2.9	3.7	4.4	5.3	5.3	5.2	5.2	5.1	5.1	5.1
Sows	0.4	0.9	1.6	2.2	3.1	4.4	5.0	6.1	6.9	7.4	8.1	8.8	9.5	10.2	10.2	10.2

* No data for 2022 and 2023 are available, therefore maintained the same level as year 2021.

Slurry cooling - NH_3 reducing potential

Reduction potential for the NH_3 emission due to slurry cooling in barns, is based on data from the Environmental Approvals. The approvals include information on NH_3 reduction factors for each farm depending on cooling system (temperature), the volume of air exchange in barns and pH level in manure regarding acidification. A weighted average of the NH_3 reduction factor is estimated to 19.6 %. The Environmental Technology List states a potential up to 34 % depending on barn type. The report from ConTerra (2022) confirms a reduction potential of 20 %.

Table 3D-23 Weighted average of NH_3 reduction emission factor for slurry cooling, based on the data from the Environmental Approval Register compared with the Environmental Technologies List, percentage.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average	**Tech list***
Cattle/swine	19.6	24.4	21.2	20.0	20.7	20.7	19.5	17.0	17.4	15.9	19.6	**20**

* Environmental Technologies List (SGAV, 2024) – the reduction unit is given as Watt per M2 (28 W/m^2 = 20 % reduction).

Acidification

Information on acidification in Danish livestock barns is based on information received from a distributor of acidification systems. Today, only one single company is the main distributor of acidification systems for barns in Denmark, from where DCE have received information regarding number of sold acidification systems (JH Agro A/S, 2022). The information included:

- Name and CHR number
- Type – cattle or swine
- Animal type – dairy cattle, heifer, bulls, sows, weaners and fattening pigs
- Year the system was put into service
- If the system is closed again, year the system was taken out of service
- If there is a service agreement
- If acid is received from JH Agro

Estimation of distribution of slurry acidification

Years the acidification systems are counted as active includes both the year it is put into service and the year it is taken out of service. For all farms (CHR number) with active systems number of animals and barn type are collected from the Danish fertiliser N accounts for the years 2009-2021.

The Danish fertiliser N accounts only go back to 2009, so information on number of animals for 2007 and 2008 are collected from CHR and type of barns is presume as given in the fertiliser account in 2009. For years with lack of information in the fertiliser accounts number of animals are interpolated.

The estimated number of animals in barns with acidification are shown in Table 3D-24.

Table 3D-24: Number of animals in barns with acidification

	2007	2008	2009	2010	2011	2012	2013	2014
Dairy cattle, large breed	551	1 311	3 371	4 587	6 451	11 038	14 427	15 833
Dairy cattle, jersey	350	359	926	1 595	2 340	3 354	3 540	3 752
Heifers, large breed	169	220	546	569	941	1 443	2 021	2 131
Heifers, jersey	-	-	-	-	-	-	-	-
Bulls, large breed	-	-	909	3 143	3 200	6 060	6 322	6 405
Bulls, jersey	-	-	-	-	-	1	1	
Sows	3 371	6 095	9 425	12 667	14 003	16 327	16 928	20 984
Fattening pigs	66 481	135 424	177 927	218 503	247 569	300 750	354 208	390 413
Weaners	152 315	197 691	241 033	314 336	290 369	305 240	326 843	378 523

	2015	2016	2017	2018	2019	2020	2021
Dairy cattle, large breed	16 089	17 306	17 321	17 120	14 462	13 324	10 385
Dairy cattle, jersey	3 824	4 166	3 298	3 374	3 284	3 378	2 871
Heifers, large breed	1 924	1 809	1 806	1 654	1 931	1 837	1 784
Heifers, jersey	-	-	34	77	42	39	76
Bulls, large breed	5 901	2 412	2 442	2 475	2 481	2 296	-
Bulls, jersey	-	-	-	-	-	1	-
Sows	21 667	23 566	21 589	21 349	21 184	20 095	24 577
Fattening pigs	387 080	442 096	391 384	382 939	486 239	490 252	515 277
Weaners	427 591	501 451	541 091	549 071	519 264	486 390	494 800

The number of animals in barns with acidification are converted to share of all animals. No data for 2022 and 2023 are available, therefore maintained the same level as year 2021.

Table 3D-25: Share of animals in barns with acidification, %.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021 - 2023
Dairy cattle, large breed	0.12	0.27	0.69	0.93	1.32	2.18	2.88	3.29	3.35	3.53	3.54	3.46	2.97	2.75	2.16
Dairy cattle, jersey	0.51	0.51	1.27	2.14	3.07	4.17	4.31	4.60	4.73	5.13	4.07	4.19	4.08	4.11	3.42
Heifers, large breed	0.04	0.05	0.13	0.13	0.22	0.32	0.43	0.47	0.43	0.42	0.42	0.40	0.47	0.46	0.45
Heifers, jersey	-	-	-	-	-	-	-	-	-	-	0.08	0.18	0.09	0.08	0.14
Bulls, large breed	-	-	0.38	1.32	1.27	2.74	2.87	3.02	2.71	1.11	1.11	1.12	1.18	1.13	-
Bulls, jersey	-	-	-	-	-	0.01	0.01	-	-	-	-	-	-	0.02	-
Sows	0.29	0.58	0.87	1.13	1.32	1.62	1.73	2.03	2.10	2.36	2.13	2.04	2.11	1.90	2.36
Fattening pigs	0.28	0.61	0.85	1.01	1.13	1.48	1.76	1.96	1.95	2.26	2.11	1.99	2.68	2.33	2.52
Weaners	0.55	0.71	0.86	1.08	0.97	1.03	1.10	1.24	1.36	1.55	1.68	1.65	1.59	1.46	1.44

Slurry acidification - NH_3 reducing potential

The Environmental Technologies List (SGAV, 2024) includes reduction factors for a series of NH_3 reduction technologies, among these a reduction factor by 33 % for acidification of cattle slurry and 64 % for acidification of swine slurry. These are used in the emission calculations.

Frequent removal of manure regarding mink barns

Frequent removal of manure reduces the emission of NH_3 from barns. A standard mink barns is defined as manure removal by once a week, while a frequent removal of manure minimum two times per week.

Estimation of distribution of frequent removal of manure

The Environmental Approval Register includes approvals for 89 farms (CHR numbers) with mink production in the period 2007-2016. However, the number of approvals is reduced to 60, because information regarding removal of manure (ones a week) and the design of manure system (slurry channel width), shows that 19 farms was considered as standard barn, with no further NH_3 reducing potential. For 2007-2009, no approvals are registered.

In Table 3D-26 are shown the number of mink (breeding females) registered in the Environmental Approval Register with frequent removal of manure for the years 2010-2017 and the percentage of the total production of mink. For 2018-2020 and 2023, no data is available and therefore the percentage of production with frequent removal of manure is considered at the same level (in percentage) as year 2017. In the end of 2020, the mink production was closed down and all animals put down, so no production in 2021 and 2022. The production has slowly started up in 2023 and frequent removal of manure is set at the same level (in percentage) as year 2017.

Table 3D-26 Number of breeding female mink in approvals with frequent removal of manure.

Approvals	2010	2011	2012	2013	2014	2015	2016	2017	2018[3]	2019[3]	2020 and 2023[3]
Number of mink[1], approval for the concerned year	27 360	11 920	49 087	32 499	51 365	61 635	33 099	119 926	-	-	
Total number of mink with frequent removal of manure	27 360	39 280	88 367	120 866	172 231	233 866	266 965	386 891	-	-	
Total number of breeding females, millions[2]	2.70	2.75	2.95	3.12	3.31	3.39	3.25	3.42	3.36	2.47	2.21
Percentage of production with frequent removal of manure	1.0	1.4	3.0	3.9	5.2	6.9	8.2	11.3	11.3	11.3	11.3

[1] Mink = breeding female.

[2] Production based on data from Danish Statistic.

[3] For 2018-2020 and 2023, no data is available. The percentage is maintained as year 2017.

Frequent removal of manure - NH_3 reducing potential

The Environmental Technologies List (SGAV, 2024) includes reduction factors for frequent removal of manure in mink barns, which are set to a 27 % NH_3 reduction.

Heat exchanger

Installation of heat exchanger in broiler barns have various positive effects; an economic cost saving for heat expense; quick drying of the bedding, which decreases the risk of NH_3 emission and better air quality in the barn, which is of benefit for both animals and humans.

Estimation of distribution of heat exchanger

Estimation of the use of heat exchanger in broiler barns is based on information from the largest distributor of heat exchanger system, which account for approximately 70 % of the marked (Rokkedahl Energy, 2019). DCE has received data for years 2012-2018. In addition to the information from the distributor, the estimation is also based on knowledge from subsidy schemes. Data is received from the Agency for Green Transition and Aquatic

Environment. The Danish farmers had the opportunity to apply for funding for activities, with replacing of old equipment to more modern technology, hereunder technology with ammonia reducing technology as heat exchanger, see Table 3D-27. Based on the data from the subsidy schemes, it is possible to register the number of farms, which have received confirmation of subsidy and also information of the animal production at these farms.

Both information from the distributor and the subsidy schemes pointed out the same development for the prevalence of heat exchanger.

It is concluded that the information based on the Environmental Approval Register is not reliable in the case of heat exchanger. Data registered in the approvals shows a very limited use of heat exchanger and this underestimate is undoubtedly due to the main reason for installation of heat exchanger is reduction of operational cost. Therefore, an installation of heat exchanger is not necessarily an act that occurs in connection with an expansion of the animal production, and thus not releases an environmental approval.

Table 3D-27 Subsidy schemes where subsidy for heat exchanger was possible.

Year	Subsidy schemes	Legislation
2015	Subsidy to investments in new green processes and technology in the main agriculture production	BEK no. 250 of 16. March 2015
2014	Subsidy to investments in green processes and technology in the main agriculture production	BEK no. 897 of 21. July 2014
2013	Subsidy to investments in new green processes and technology in the main agriculture production	BEK no. 569 of 31. May 2013
2012/2011	Subsidy to projects with investments in new green processes and technology in the main agriculture production	BEK no. 744 of 28. June 2011
2010	Subsidy to projects with investments in new green processes and technology in the main agriculture production	BEK no. 502 of 11. May 2010

Based on the data from the main distributor of heat exchanger and the data regarding the subsidy schemes, it is concluded that use of heat exchanger in broiler barns takes place from year 2012. Converted to the percentage of the total production in Denmark, the percentage of broiler production in barns with heat exchanger is estimated to 24 % in 2012 increasing to 90 % in 2018, Table 3D-28. For 2019-2023, no data is available and therefore the percentage of production with heat exchanger is considered at the same level (in percentage) as year 2018.

Table 3D-28 Distribution of heat exchangers in broiler barns.

Number of produced broilers, 1000 broilers	2012	2013	2014	2015	2016	2017	2018	2019[2]	2020[2]	2021[2]	2022[2]	2023[2]
Main distributor	24 246	27 639	17 433	14 785	1 834	3 875	999 000	-	-	-	-	
Other distributors	2 780	2 780	2 780	2 780	2 780	2 780	2 780	-	-	-	-	
Summed[1]	27 026	57 445	77 658	95 223	99 837	106 493	110 271	-	-	-	-	
Total number of produced broilers	112 459	117 341	115 997	114 738	121 185	118 102	122 768	124476	121008	118931	115198	118154
% of production	24	49	67	83	82	90	90	90	90	90	90	90

[1] Sum of number of broilers in barns with heat exchanger from the years before and the current year.

[2] For 2019-2023, no data is available. The percentage is maintained as year 2018.

Heat exchanger - NH_3 reducing potential

In the Environmental Technologies List (SGAV, 2024) is given a NH_3 reduction factor at 28 % for Rokkedahl heat exchanger, which is a product developed by the main distributor. Information from one of the other distributors of heat exchanger – Big Dutchman – shows a reduction factor of 29 % (LUFA Nord-West, 2012, Big Dutchman, 2019), which mean nearly at the same level as for the Rokkedahl product. A reduction factor of 28 % for all barns with heat exchanger are used.

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Annex 3E - Waste

All annexes are available online at:

https://envs.au.dk/en/om-instituttet-1/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/air-pollutants/supporting-documentation

Please note that data found via this link are updated annually. This means that data in the annexes always match the newest version of the Informative Inventory Report (IIR).

Annex 4 – Completeness and use of notation keys

Not estimated categories

The Danish air emission inventory is generally complete. However, some categories and/or pollutants are reported as NE (Not estimated).

Fugitive emissions from fuels

NMVOC emissions for 1B1a Fugitive Emission from Solid Fuels: Coal Mining and Handling are NE (Not Estimated) in accordance with the 2023 EMEP/EEA Guidebook.

Industrial processes

- Some pollutants from iron and steel production (Rolling mills and iron foundries) due to lack of emission factors.
- Some pollutants from aluminium production (secondary) due to lack of emission factors.
- Some pollutants from lead production (secondary) due to lack of emission factors.
- Some pollutants from other metal production due to lack of emission factors.
- Emissions of BC from construction and demolition are not estimated due to lack of emission factors.
- Emissions of PM and BC from secondary pulp and paper production have not been estimated due to lack of emission factors. There is no primary pulp and paper production in Denmark.
- Emissions of mercury from its use as a pure substance have not been estimated due to lack of activity data and emission factors.
- Emissions of PAH from road paving with asphalt and asphalt roofing have not been estimated.
- Emissions of CO from other chemical industry have not been estimated due to lack of emission factors.

Agriculture

- Emissions of PM from off-farm storage, handling and transport of bulk agricultural products have not been estimated, due to lack of emission factors.
- NO_x emissions from cultivated crops have not been estimated, due to lack of emission factors.

Waste

- Emissions of NH_3 and BC from solid waste disposal on land have not been estimated as no emission factors are available
- Emissions of NMVOC and particulate matter from composting have not been estimated due to lack of emission factors.
- Emissions of NMVOC from anaerobic digesters have not been estimated due to lack of emission factors.
- Emissions from small-scale waste burning have not been estimated. The emission factors in the EMEP/EEA Guidebook refers to burning of residues from tree pruning and similar that does not occur on any significant scale in Denmark. No activity data are available for bonfires, and similar activities.
- Black carbon emissions from cremations have not been estimated due to lack of emission factors.

- Technology specific emissions of NH_3 emissions from 5.D.1 latrines are not applicable to Denmark (i.e. not occurring). For 5.D.2 Wastewater treatment plants, NH_3 emissions are considered insignificant and no emission factors are available.
- The emission of NH_3, BC, selenium, PCBs and HCB from accidental fires has not been estimated due to lack of available emission factors.

Categories reported as IE (Included Elsewhere)

The table below indicates the categories where the notation key IE has been used in the reporting for some or all pollutants.

Table A3.1 List of categories reported as included elsewhere.

Category reported as IE	Emissions where emissions are included
1A5a Other stationary (including military)	1A4ai Commercial/institutional: Stationary
2A1 Cement production	1A2f Manufacturing industries and construction: Non-metallic minerals
2A2 Lime production	1A2f Manufacturing industries and construction: Non-metallic minerals
2A3 Glass production	1A2f Manufacturing industries and construction: Non-metallic minerals
2A6 Other mineral products	1A2f Manufacturing industries and construction: Non-metallic minerals
2C5 Lead production	1A2b Manufacturing industries and construction: Non-ferrous metals
2D3e Degreasing	2D3f Dry cleaning

Emissions from military stationary sources are not reported separately in the Danish energy statistics and hence it is not possible to report them separately. Emissions and fuel consumption are reported under commercial and institutional plants.

Emissions from cement production (2A1), lime production (2A2) and glass production (2A3) are included in manufacturing industries and construction (1A2f). For some or all pollutants, it is not possible to separate the process emissions from the energy related emissions.

For some pollutants in other categories, IE is also used. An example is solid fuels used in railways, this consumption is only for historic trains and no solid fuel consumption is reported in the energy statistics for railways. However, the coal consumption will be accounted for in the energy balance in a different sector. The specific reasons for instances of IE are explained in the sectoral chapters of the report.

Annex 5 – Summary Information on condensables included in PM emission estimates

The table below provides an overview of the NFR sectors and whether the condensable component of PM is included in the PM emission estimates. In cases, where emission factors from the EMEP/EEA Guidebook are used, no assessment has generally been made as to what the emission factors included in the EMEP/EEA Guidebook represent. The references for the PM emission factors used in the Danish inventory are included in the sectoral chapters of this report and will not be repeated here, due to the high level of detail.

The sectors listed below does not contain sources of fugitive particulate matter, as the issue of condensable and filterable particulate matter is only relevant with combustion related emissions.

NFR	Source/sector name	PM emissions: the condensable component is		EF reference and comments
		included	excluded	
1A1a	Public electricity and heat production		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A1b	Petroleum refining		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A1c	Manufacture of solid fuels and other energy industries		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A2a	Stationary combustion in manufacturing industries and construction: Iron and steel		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A2b	Stationary combustion in manufacturing industries and construction: Non-ferrous metals		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A2c	Stationary combustion in manufacturing industries and construction: Chemicals		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A2d	Stationary combustion in manufacturing industries and construction: Pulp, Paper and Print		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A2e	Stationary combustion in manufacturing industries and construction: Food processing, beverages and tobacco		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A2f	Stationary combustion in manufacturing industries and construction: Non-metallic minerals		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A2gvii	Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)			EMEP/EEA guidebook
1A2gviii	Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A3ai(i)	International aviation LTO (civil)			EMEP/EEA guidebook
1A3aii(i)	Domestic aviation LTO (civil)			EMEP/EEA guidebook
1A3bi	Road transport: Passenger cars			EMEP/EEA guidebook
1A3bii	Road transport: Light duty vehicles			EMEP/EEA guidebook
1A3biii	Road transport: Heavy duty vehicles and buses			EMEP/EEA guidebook
1A3biv	Road transport: Mopeds & motorcycles			EMEP/EEA guidebook
1A3c	Railways	✓		Danish National Railways
1A3di(ii)	International inland waterways	Not occurring		
1A3dii	National navigation (shipping)	✓		
1A3ei	Pipeline transport	Not applicable as no fuel combustion related to pipeline transport occurs in Denmark		
1A3eii	Other (please specify in the IIR)	Not occurring		
1A4ai	Commercial/institutional: Stationary		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A4aii	Commercial/institutional: Mobile			EMEP/EEA guidebook
1A4bi	Residential: Stationary	Wood	Other fuels	Please refer to Chapter 3.2, Table 3.2.29
1A4bii	Residential: Household and gardening (mobile)			EMEP/EEA guidebook
1A4ci	Agriculture/Forestry/Fishing: Stationary		X (or unknown)	Please refer to Chapter 3.2, Table 3.2.29
1A4cii	Agriculture/Forestry/Fishing: Off-road			EMEP/EEA guidebook

	vehicles and other machinery			
1A4ciii	Agriculture/Forestry/Fishing: National fishing			EMEP/EEA guidebook
1A5a	Other stationary (including military)	Included under 1A4ai		
1A5b	Other, Mobile (including military, land based and recreational boats)	✓		MWI
1B2c	Venting and flaring (oil, gas, combined oil and gas)		✓	EMEP/EEA guidebook
2A2	Lime production			EMEP/EEA (2016) - Unknown
2A3	Glass production			Container glass: EMEP/EEA (2023) - Unknown Glass wool: Environmental reports – Measurement method unknown
2C1	Iron and steel production			Electric arc furnace: Environmental reports – Measurement method unknown Rolling mills: Environmental reports – measurement method unknown & EMEP/EEA (2023) - Filterable Grey iron foundries: EMEP/Corinair 2007 - Unknown
2C5	Lead production			Abated: BREF (2017) - Unknown Unabated: EMEP/EEA(2023) - Filterable
2D3b	Road paving with asphalt		✓	EMEP/EEA (2023) - Filterable
2D3c	Asphalt roofing			EMEP/EEA (2023) - Unknown
2G	Other product use (please specify in the IIR)			Fireworks: Klimont Z. et al. (2002) - Unknown Barbeques: Environment Australia (1999) - Unknown Shoes: Sambat et al. (2001) Tobacco: Martin et al. (1997) - Filterable
3F	Field burning of agricultural residues			EMEP/EEA guidebook
5C1bv	Cremation			Human cremation: US EPA Webfire (2012) - Filterable Animal cremation: EMEP/EEA (2023) - Unknown
5E	Other waste (please specify in IIR)			Building fires: EMEP/EEA (2023) - Unknown Vehicle fires: Lönnermark et al. (2004) - Electrical low-pressure impactor

ANNUAL DANISH INFORMATIVE NVENTORY REPORT

Emission inventories from the base year of the protocols to year 2023. Submitted to the UNECE and the European Commission

This report is a documentation report on the emission inventories for Denmark as reported to the UNECE Secretariat under the Convention on Long Range Transboundary Air Pollution and the European Commission under the National Emission Ceilings Directive due by 15 March 2025. The report contains information on Denmark's emission inventories regarding emissions of (1) SO_X for the years 1980-2023, (2) NO_X, CO, NMVOC and NH_3 for the years 1985-2023, (3) Particulate matter: TSP, PM_{10}, $PM_{2.5}$ for the years 1990-2023, (4) Heavy Metals: Pb, Cd, Hg, As, Cr, Cu, Ni, Se and Zn for the years 1990-2023 (5) Polyaromatic hydrocarbons (PAH): Benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene and indeno(1,2,3-cd)pyrene, PCDD/F and HCB for the years 1990-2023. Further, the report contains information on background data for emissions inventory.

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