National Environmental Research Institute
University of Aarhus · Denmark

NERI Technical Report No. 649, 2007

Annual Danish Emission Inventory Report to UNECE

Inventories from the base year of the protocols to year 2005

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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 due by 15 February 2007. The report contains information on Denmark's emission inventories regarding emissions of (1) SO_X for the years 1980-2005, (2) NO_X, CO, NMVOC and NH_3 for the years 1985-2005; (3) Particulate matter: TSP, PM_{10}, $PM_{2.5}$ for the years 2000-2005, (4) Heavy Metals: Pb, Cd, Hg, As, Cr, Cu, Ni, Se and Zn for the years 1990-2005, and (5) Polyaromatic hydrocarbons (PAH): Benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene and indeno(1,2,3-cd)pyrene for the years 1990-2005. Further, the report contains information on background data for emissions inventory.

Keywords: Emission Inventory; Emissions; Projections; UNECE; EMEP; 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; Benzo(a)pyrene, Benzo(b)fluoranthene.

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Summary

I Background information on emission inventories

Annual report

This report is Denmark's Annual Emissions Inventory Report due May 2007 to the UNECE-Convention on Long-Range Transboundary Air Pollution (LRTAP). The report contains information on Denmark's inventories for all years from the base years of the protocols to 2005.

The gases reported under the LRTAP Convention are SO_2, NO_X, NMVOC, CO, NH_3, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn, dioxins/furans, PAHs, TSP, $PM_{2.5}$ and PM_{10}.

The annual emission inventory for Denmark is reported in the Nomenclature for Reporting (NFR) format as requested in the reporting guidelines. The complete set of NFR files are provided in the report.

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 is, as far as possible, the same as the National Inventory Report to UNFCCC.

This report and the NFR tables are available to the public on the National Environmental Research Institute's homepage

(http://www.dmu.dk/1_Viden/2_Miljoetilstand/3_luft/4_adaei/default_en.asp).

Responsible institute

The National Environmental Research Institute (NERI), Aarhus University, is responsible for the annual preparation and submission to the UNECE-LRTAP Convention of the Annual Danish Emissions Report and the inventories in the NFR format in accordance with the guidelines. NERI 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.

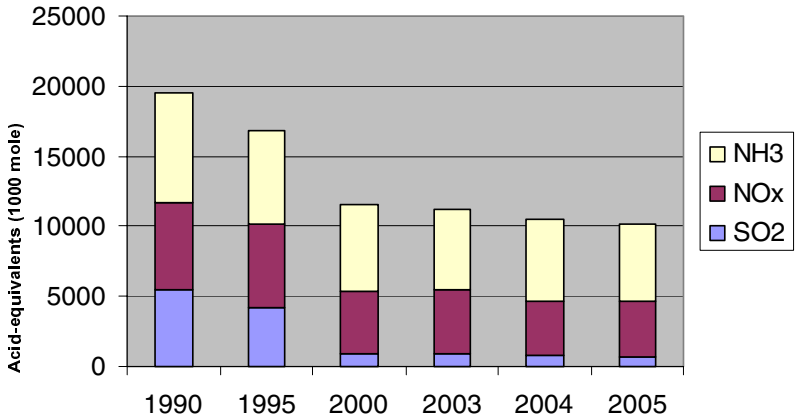
II Trends in emissions

Acidifying gases

Figure S.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 2005, the most important acidification factor in Denmark was ammonia nitrogen and the relative contributions

for SO_2, NO_X and NH_3 were 7 %, 40 % and 53 %, respectively. However, regarding long-range transport of air pollution, SO_2 and NO_X are still the most important pollutants.

Figure S.1 Emissions of NH_3, NO_X and SO_2 in acid equivalents.



SO_2

The main part of the SO_2 emission originates from combustion of fossil fuels, i.e. mainly coal and oil, in public power and district heating plants. From 1980 to 2005, the total emission decreased by 95 %. The large reduction is largely due to installation of desulphurisation plant 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 36 % of the total emission. Also emissions from industrial combustion plants, non-industrial combustion plants and other mobile sources are important. National sea traffic (navigation and fishing) contributes with about 12 % of the total SO_2 emission. This is due to the use of residual oil with high sulphur content.

NO_X

The largest sources of emissions of NO_X are other mobile sources followed by road transport 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 2005, 35 % of the Danish emissions of NO_X stems from road transport, national navigation, railways and civil aviation. Also 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 public power plants and district heating plants have decreased by 61 % from 1985 to 2005. In the same period, the total emission decreased by 36 %. The reduction is due to the increasing use of catalyst cars and installation of low-NO_X burners and denitrifying units in power and district heating plants.

NH_3

Almost all atmospheric emissions of NH_3 result from agricultural activities. Only a minor part originates from road transport. This part is, however, increasing due to increasing use of catalyst cars. The major part of the emission from agriculture stems from livestock manure (79 %) and the largest losses of ammonia occur during the handling of the manure

in stables and in field application. Other contributions come from crops (15 %), use of mineral fertilisers (6 %), sewage sludge used as fertiliser and ammonia used for treatment of straw (less than 1 %). The total ammonia emission decreased by 36 % from 1985 to 2005. This is due to the active national environmental policy efforts of the past twenty years.

Other air pollutants

NMVOC

The emissions of NMVOC originate from many different sources and can be divided into two main groups: incomplete combustion and evaporation. Road vehicles and other mobile sources such as national navigation vessels and off-road machinery are the main sources of NMVOC emissions from incomplete combustion processes. Road transportation vehicles are still the main contributor, even though the emissions have declined since the introduction of catalyst cars in 1990. The evaporative emissions mainly originate from the use of solvents. The emissions from the energy industries have increased during the nineties due to the increasing use of stationary gas engines, which have much higher emissions of NMVOC than conventional boilers. The total anthropogenic emissions have decreased by 31 % from 1985 to 2005, largely due to the increased use of catalyst cars and reduced emissions from use of solvents.

CO

Transport is responsible for the dominant share of the total CO emission. Also other mobile sources and non-industrial combustion plants contribute significantly to the total emission of this pollutant. The drop in the emissions seen in 1990 was a consequence of a law forbidding the burning of agricultural waste on fields. The emission decreased further by 21 % from 1990 to 2005, largely because of decreasing emissions from road transportation.

PAHs

The present emission inventory for PAH (poly aromatic hydrocarbons) includes the four PAHs reported to UNECE: benzo(a)py-rene, benzo(b)fluoranthene, benzo(k)fluoranthene and indeno-(1,2,3-cd) pyrene. The most important sources of the PAH emission are combustion of wood in the residential sector and road transportation. The increasing emission trend is due to increasing combustion of wood in the residential sector.

Particulate Matter

The particulate matter (PM) emission inventory has been reported for the years 2000-2005. 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 sources are the residential sector (64 %), road traffic (15 %) and other mobile sources (7 %). For the latter, the most important source is off-road vehicles and machinery in the agricultural-/forestry sector (54 %). For the road transport sector, exhaust emissions account for the major part (77 %) of the emissions.

The largest TSP emission sources are the agricultural sector and the residential sector. 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 45 % of the TSP emission from road transport.

Heavy metals

In general, the most important sources of heavy metal emissions are combustion of fossil fuels and waste. The heavy metal emissions have decreased substantially in recent years. The reductions span from 10 % to 95 % for Cu and Pb, 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). The large reduction in the Pb emission is due to a gradual shift towards.

III Recalculations and Improvements

In general, considerable work is being carried out to improve the inventories. New investigations and research carried out in Denmark and abroad are, as far as possible, included as the basis for the emission estimates and included as data in the inventory databases. Furthermore, the updates of the EMEP/CORINAIR guidebook and the work in the Task Force on Emission Inventories and its expert groups are followed closely in order to be able to incorporate the best scientific information as the basis for the inventories. Further important references in this regard are the IPCC guidelines and IPCC good practice guidance.

Implementation of new results in inventories is made in a way so that improvements better reflect Danish conditions and circumstances. In improving the inventories, care is taken to consider implementation of improvements for the whole time-series of inventories, to promote consistency. Such efforts lead to recalculation of previously submitted inventories.

The most important recalculations for the various sectors are mentioned below.

Energy

Stationary Combustion

The national energy statistics has been updated for the years 2000-2004. This has resulted in increased emissions for the residential sector due to an increase in the estimated wood consumption in residential plants. The emission factors for NMVOC, PM, PAH and dioxin have been updated for the residential sector.

Mobile sources

NO_x

The largest changes are for road transport, military, national sea transport and agriculture.

Road transport: The 1985-2004 emission inventories have been updated with new emission factors (COPERT IV) and mileage information (Danish Vehicle Inspection and Maintenance Programme). The COPERT IV emission factors are derived from the European research project ARTEMIS, which has conducted new emission measurements and simulations of emission factors for road transport vehicles. It is important to note that ARTEMIS includes measurements for Euro I-IV engines and moreover incorporates the so-called engine cycle beating effect.

Military: Emission factors derived from the new road transport simulations have caused some changes in the emissions from 1985-2004.

National sea transport: A new research project has given new knowledge, and the following changes have therefore been made to the national inventory which affects the emission results:

1) Updated emission factors from 1985-2004

2) The residual fuel use amount from the fishery sector in the national energy statistics has been moved to the national sea transport category, in the 1985-2004 period

Agriculture: Updated stock information for tractors and harvesters 2001-2004, has given a fuel use and emissions increase for these years.

NMVOC

The largest changes are for road transport and agriculture.

Road transport: The emission factor and mileage updates have given a slight emission change for NMVOC from 1985-2004.

Military: Emission factors derived from the new road transport simulations have caused minor changes in the emissions from 1985-2004.

Agriculture: Updated stock information for tractors and harvesters 2001-2004, has given a fuel use and emissions increase for these years.

SO_2 and NH_3

No changes of significance have occurred.

Industrial processes

SO_2 emissions from a sulphur recovery plant in sector 'Chemical Industry' have been included as process emissions.

The estimated SO_2 and NO_x emissions from cement production have been updated for the years 2002 to 2004.

Solvent

A survey based on new methodologies results in new NMVOC emission estimates. Revisions have been made regarding use of pentane and styrene in the plastic industry, use and emission factors of glycolethers, use and emission factor of tetrachloroethylene and reassignment of some product groups from degreasing to paints.

Agriculture

Small changes for emissions from the agricultural sector have taken place. This change reflects an increased emission from 1990-2005 by less than ± 2 % compared to previous emission inventory. The change is alone related to updated data and is not a result of changes in the methodology.

Based on the newly introduced chapter in the EMEP-CLRTAP emission inventory guidebook chapter B1100, the particulate emission from animal husbandry has been recalculated. As a result of the recalculation, the total particulate emission from animal husbandry has decreased by 2 % in 2000 and 11 % in 2005 compared to previous emission inventory due to lower emission factor for cattle and swine. In previous inventory a specific emission factor is used for all swine. The guidebook introduce emission factor for subcategories as sows, piglets and slaughtering pigs. The situation is the same for cattle and poultry.

Sammenfatning

I Baggrund for emissionsopgørelser

Årlig rapport

Denne rapport er Danmarks årlige rapport om emissionsopgørelser sendt til UNECE-konventionen om langtransporteret grænseoverskridende luftforurening (LRTAP) i maj 2007. Rapporten indeholder oplysninger om Danmarks opgørelser for alle år fra basisårene for protokollerne til 2005.

Gasserne der rapporteres til LRTAP-konventionen er SO_2, NO_X, NMVOC, CO, NH_3, As, Cd, Cr, Cu, HG, Ni, Pb, Se, Zn, dioxiner/furaner, PAH, TSP, $PM_{2,5}$ og PM_{10}.

Den årlige emissionsopgørelse for Danmark rapporteres i det format (NFR) som angivet i retningslinierne for rapportering. Det fuldkomne sæt af NFR-filer er inkluderet i rapporten.

Emnerne behandlet i rapporten er: Udvikling i emissioner, beskrivelse af hver NFR-kategori, usikkerheder, rekalkulationer, planlagte forbedringer og procedure for kvalitetssikring og -kontrol. Strukturen i rapporten er, så vidt muligt, den samme som den nationale emissionsopgørelsesrapport sendt til FN's konvention om klimaændringer (UNFCCC).

Denne rapport og NFR-tabellerne er tilgængelige for offentligheden på DMU's hjemmeside.

(http://www.dmu.dk/1_Viden/2_Miljoetilstand/3_luft/4_adaei/default_en.asp)

Ansvarligt institut

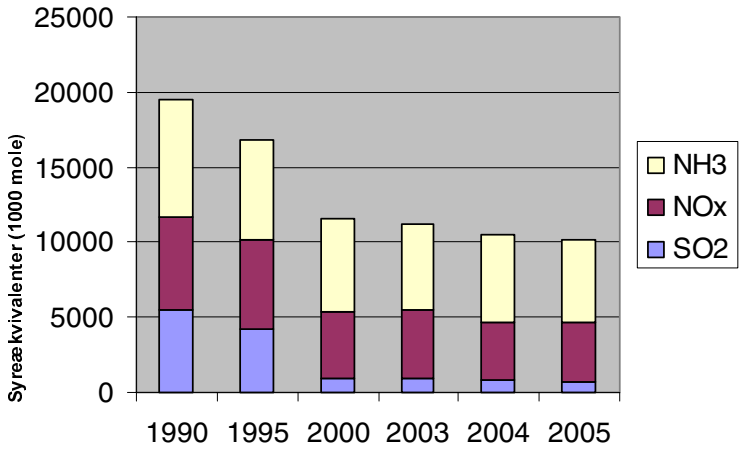
Danmarks Miljøundersøgelser (DMU), Aarhus Universitet er ansvarlig for udarbejdelse af den årlige danske emissionsrapport og opgørelserne i NFR-format i overensstemmelse med retningslinierne samt rapportering til UNECE-LRTAP-konventionen. DMU deltager i møder under UNECEs arbejdsgruppe for emissionsopgørelser og –fremskrivninger samt ekspertpaneler, hvor parter i konventionen udarbejder retningslinier og metoder for emissionsopgørelserne.

II Udviklingen i emissioner

Forsurende gasser

Figur S.1 viser emissionen af danske forsurende gasser opgjort i syreækvivalenter. I 1990 var det relative bidrag af syreækvivalenter næsten ens for de tre gasarter. I 2005 var ammoniak den vigtigste forsurende faktor i Danmark og de relative bidrag for SO_2, NO_X og NH_3 var på hen-

holdsvis 7 %, 40 % og 53 %. Med hensyn til langtransporteret luftforurening er det dog stadig SO_2 og NO_X, der er de største kilder.



Figur S.1 Emissioner af NH_3, NO_X og SO_2 i syreækvivalenter.

SO_2

Hovedparten af SO_2-emissionerne stammer fra forbrænding af fossile brændsler, dvs. primært kul og olie, på kraftværker, kraftvarmeværker og fjernvarmeværker. Fra 1980 til 2005 er det totale udslip reduceret med 95 %. Den store reduktion er primært opnået gennem installation af afsvovlingsanlæg og brug af brændsler med lavt svovlindhold på kraftværker og fjernvarmeværker. Trods den store reduktion er disse værker kilde til 36 % af det samlede udslip. Også emissioner fra industrielle forbrændingsanlæg, ikke-industrielle forbrændingsanlæg og andre mobile kilder er væsentlige bidragsydere til emissionen. National søfart (sejlads og fiskeri) bidrager med omkring 12 % af den totale SO2-emission. Dette skyldes brug af fuelolie med et højt svovlindhold.

NO_X

Den største kilder til emissioner af NO_X er andre mobile kilder efterfulgt af vejtransport og forbrænding i energisektoren (hovedsageligt kraftværker og fjernvarmeværker). Transportsektoren er den sektor, der bidrager mest til udledningen af NO_X og i 2005 stammede 35 % af de danske NO_X-emissioner fra vejtransport, national sejlads, 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 61 % fra 1985 til 2005. I sammen periode er den totale emission faldet med 36 %. Reduktionen skyldes øget brug af katalysatorer i biler og installation af lav-NO_X-brændere og de-NO_X-anlæg på kraftværker og fjernvarmeværker.

NH_3

Stort set alle atmosfæriske emissioner af NH_3 stammer fra aktiviteter i landbruget. Kun en mindre del skyldes vejtransport. Denne del er dog stigende pga. den øgede brug af biler med katalysator. Hovedparten af emissionen fra landbruget stammer fra husdyrgødning (79 %) og de største tab af ammoniak optræder under håndtering af gødningen i stalden og under spredning på marken. Andre bidrag kommer fra afgrøder (15 %), brug af kunstgødning (6 %), slam fra rensningsanlæg brugt som

gødning og ammoniak brugt til behandling af halm (mindre end 1 %). Den totale ammoniakemission er faldet 36 % fra 1985-2004. Dette er et resultat af den nationale miljøpolitik, der er ført gennem de seneste 20 år.

Anden luftforurening

NMVOC

Emissionen af NMVOC stammer fra mange forskellige kilder og kan opdeles i to hovedgrupper: Ufuldstændig forbrænding og fordampning. Hovedkilderne til NMVOC-emissioner fra ufuldstændig forbrændingsprocesser er 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 brugen af opløsningsmidler. Emissionerne fra energisektoren er steget igennem 90'erne pga. øget brug af stationære gasmotorer, som har meget højere emissioner af NMVOC end konventionelle kedler. De totale menneskeskabte emissioner er faldet med 31 % fra 1985 til 2005, primært som følge af øget brug af biler med katalysator og reducerede emissioner fra brug af opløsningsmidler.

CO

Selvom biler med katalysator blev introduceret i 1990, er vejtransport stadig årsag til den største del af den totale CO-emission. Også andre mobile kilder og ikke-industrielle forbrændingsanlæg bidrager betydeligt til den totale emission af denne gas. Faldet i emissioner set i 1990 var en konsekvens af loven, der forbyder markafbrænding. Emissionen faldt med 21% fra 1990 til 2005 hovedsageligt pga. faldende emissioner fra vejtransport.

PAH'er

Den nuværende emissionsopgørelse for PAH (polycycliske aromatiske hydrocarboner) inkluderer de fire PAH'er der rapporteres til LRTAP-konventionen: Benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene og indeno(1,2,3-cd)pyrene. De vigtigste kilder til emission af PAH er forbrænding af træ i husholdningerne samt vejtransport. De stigende emissioner skyldes øget forbrænding af træ i husholdningerne.

Partikler

Emissionsopgørelsen for partikler (Particulate Matter, forkortet PM) er blevet rapporteret for årene 2000-2005. Opgørelsen inkluderer den totale emission af partikler TSP (Total Suspended Particles), 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 (64 %), vejtrafik (15 %) og andre mobile kilder (7 %). For den sidstes vedkommende er offroad køretøjer samt landbrugs- og skovbrugsmaskiner de vigtigste kilder (54%). I transportsektoren tegner udstødningsemissioner sig for størstedelen (77 %).

De største kilder til TSP-emission er landbrugssektoren og husholdningerne. 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 45 % af TSP-emissionen fra transport.

Tungmetaller

Generelt er de vigtigste kilder til emissioner af tungmetaller forbrænding af fossile brændsler og affald. Emissionerne af tungmetaller er faldet betydeligt de seneste år. Reduktionerne spænder fra 10 % til 95 % for henholdsvis Cu og Pb. 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.

III Rekalkulationer 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/CORINAIR-retningslinjerne for emissionsopgørelser nøje med henblik på at indarbejde de bedste videnskabelige informationer som basis for opgørelserne. Andre vigtige kilder er IPCCs retningslinier (IPCC Guidelines og IPCC Good Practice Guidance).

Opgørelserne opdateres løbende med ny viden, således opgørelserne bedst mulig afspejler danske forhold. Ved forbedringer lægges vægt på, at opdateringer omfatter hele tidsserier for at sikre konsistente data. Disse tiltag medfører rekalkulation af tidligere indberettede opgørelser. De vigtigste rekalkulationer for de forskellige sektorer er nævnt i nedenstående.

Stationære forbrændingsanlæg

Den seneste officielle energistatistik er implementeret i opgørelsen. Dette har især betydet en øget emission fra husholdningssektoren pga. en stigning i brændeforbruget. Derudover er der kun tale om mindre ændringer.

Emissionsfaktorerne for NMVOC, PM, PAH og dioxin for afbrænding af træ i husholdninger er blevet opdateret på baggrund af ny viden omkring teknologiudviklingen indenfor sektoren.

Transport

NO_x

De største ændringer er udført indenfor vejtrafik, militær og national søtransport.

Vejtrafik: Nye emissionsfaktorer (COPERT IV) samt opdaterede tal for trafikarbejde (Periodisk bilsyn) er brugt i opgørelserne for 1985-2004. COPERT IV emissionsfaktorerne stammer fra det fælles-europæiske forskningsprojekt ARTEMIS, der har udført nye emissionsmålinger og simuleret nye emissionsfaktorer for vejtrafikkens køretøjer. Det under-

streges at ARTEMIS har lavet målinger på Euro I-IV motorer og derudover inkluderer den såkaldte cycle-beating effect for tunge køretøjer.

Militær: Visse emissionsændringer er sket fra 1985-2004 på baggrund af nye afledte emissionsfaktorer for vejtrafik.

National søtransport: Et nyt forskningsprojekt har givet ny viden, og følgende ændringer er udført, der påvirker de samlede emissioner:

1) Emissionsfaktorer er opdateret fra 1985-2004, og 2) forbruget af tung olie indenfor fiskeri i Energistyrelsens energistatistik 1985-2004 er overført til national søtransport.

Landbrug: Energi- og emissionsændringer er gjort for 2001-2004 på basis af opdaterede bestandstal for traktorer og mejetærskere.

NMVOC

De største ændringer er sket for vejtrafik og landbrug.

Vejtrafik: Opdateringen af emissionsfaktorer og trafikarbejde har givet mindre emissionsændringer fra 1985-2004.

Militær: De nye afledte emissionsfaktorer fra vejtrafik har givet mindre emissionsændringer fra 1985-2004.

Landbrug: Energi- og emissionsændringer er gjort for 2001-2004 på basis af opdaterede bestandstal for traktorer og mejetærskere.

SO_2 og NH_3

Kun ubetydelige ændringer er sket.

Industri

SO_2 emissioner fra et svovl behandlings anlæg i sektoren 'Chemical Industry' er inkluderet som procesemissioner.

SO_2 og NO_x emissioner fra cement produktion er blevet opdateret for årene 2002 til 2004.

Opløsningsmidler

En ny undersøgelse har resulteret i nye estimater for NMVOC emissionen. Rekalkulationen omfatter brug af pentan og styren i plastikindustrien samt brug af og emissionsfaktorer for glycolethere og tertrachloroethylene. Desuden er der sket en omgruppering af visse produkter fra affedtning til maling.

Landbrug

Der er fortaget få opdateringer i beregningen af NH_3-emissionen 1985 - 2004. Ændringen har en effekt på den totale i ammoniak emission på mindre end ± 2 % i forhold til det som er angivet ved sidste afrapportering (se afsnit 6.7). Ændringerne skyldes alene opdateringer af data og skyldes således ikke ændringer i beregningsmetoden.

På baggrund af opdatering i EMEP-CLRTAP emission Inventory Guidebook foreligger der nu retningslinier for beregning af partikelemissionen fra stalde med kvæg, svin, fjerkræ og heste (kapitel B1100). Emissionen beregnes på baggrund af den tid hvor dyrene er opstaldet. Genberegningen baseret på guidelines betyder en lavere partikelemission fra husdyrstalde end hidtil beregnet – 2 % lavere i 2000 og 11 % lavere i 2004 som følge af lavere emissionsfaktorer for kvæg og svin. Tidligere anvendtes en emissionsfaktor for alle svin, mens der i guidelines er angivet flere emissionsfaktorer for forskellige underkategorier - dvs. der skelnes mellem søer, smågrise og slagtesvin. Det samme gør sig gældende for kvæg og fjerkræ.

1 Introduction

1.1 Background information on emission inventories

1.1.1 Annual report

According to the Guidelines for Estimating and Reporting Emission Data/2002/7 prepared by the Task Force on Emission Inventories and Projections, countries party to the UNECE-Convention on Long-Range Transboundary Air Pollution are required annually to submit an informative report to the Secretariat.

This report is Denmark's Annual Emissions Inventory Report due May 2007. The report contains information on Denmark's inventories for all years from the base years of the protocols to 2005.

The annual emission inventory for Denmark is reported in the Nomenclature for Reporting (NFR) format as requested in the reporting guidelines. The complete sets of NFR files are available in Annex 1.

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 is, as far as possible, the same as the National Inventory Report to UNFCCC.

This report and NFR tables are available to the public on NERI's homepage (http://www.dmu.dk/1_Viden/2_Miljoetilstand/3_lu-ft/4_adae-i/default_en.asp).

1.2 A description of the institutional arrangement for inventory preparation

The National Environmental Research Institute (NERI), Aarhus University, is responsible for the annual preparation and submission to the UNECE-LRTAP Convention of the Annual Danish Emissions Report, and the inventories in the NFR Format in accordance with the guidelines. NERI 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.

The work concerning the annual emissions inventory is carried out in cooperation with other Danish ministries, research institutes, organisations and companies:

Danish Energy Authority, The Ministry of Economic and Business Affairs:
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, The Ministry of the Environment. Database on waste and emissions of the F-gases.

Statistics Denmark, The Ministry of Economic and Business Affairs. Statistical yearbook, sales statistics for manufacturing industries and agricultural statistics.

The Faculty of Agriculture Sciences, Aarhus University. Data on use of mineral fertiliser, feeding stuff consumption and nitrogen turnover in animals.

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

Danish Centre for Forest, Landscape and Planning, University of Copenhagen. Background data for Forestry and CO_2 uptake by forest.

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

Danish Railways, The Ministry of Transport and Energy. Fuel-related emission factors for diesel locomotives.

Danish companies. Audited green accounts and direct information gathered from producers and agency enterprises.

Formerly, the provision of data was on a voluntary basis, but more formal agreements are now prepared.

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 NERI. The databases are in Access format and handled with software developed by the European Environmental Agency and NERI. 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 1.6), the data structure for data processing support the pathway from collection of raw data to data compilation, modelling and final reporting.

For each submission, databases and additional tools and submodels are frozen 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 NERI, for which obligations apply to NERI, as a governmental institute. In this journal system, correspondence, both in-going and out-going, is regis-

tered, 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 (Pulles et al., 1999) and for reporting the software tool is developed by NERI. Data files and programme files used in the inventory preparation process are listed in Table 1.1.

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)	External report	I:\ROSPROJ\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: I:\ROSPROJ\LUFT_EMI\Inventory\AllYears\8_AllSectors\Level_3b_Processes	(exe + mdb)	manual input and Importer2CRF
3 process	Importer2CRF	Help tool	I:\ROSPROJ\LUFT_EMI\Inventory\AllYears\8_AllSectors\Level_3b_Processes	MS Access	CRF Reporter, Collec-tEr2CRFand excel files
3 process	CollectER2CRF	Help tool	I:\ROSPROJ\LUFT_EMI\Inventory\AllYears\8_AllSectors\Level_3b_Processes	MS Access	NERIRep
2 process	NERIRep	Help tool	Working path: I:\ROSPROJ\LUFT_EMI\DMURep	MS Access	CollectER databases; dk1972.mdb..dkxxxx.mdb
3 store					
2 process	CollectER	Management tool	Working path: local machine Archive path: I:\ROSPROJ\LUFT_EMI\Inventory\AllYears\8_AllSectors\Level_2b_Processes	(exe +mdb)	manual input
2 store	dk1972.mdb.dkxxxx.mdb	Datastore	I:\ROSPROJ\LUFT_EMI\Inventory\AllYears\8_AllSectors\Level_2a_Storage	MS Access	CollectER

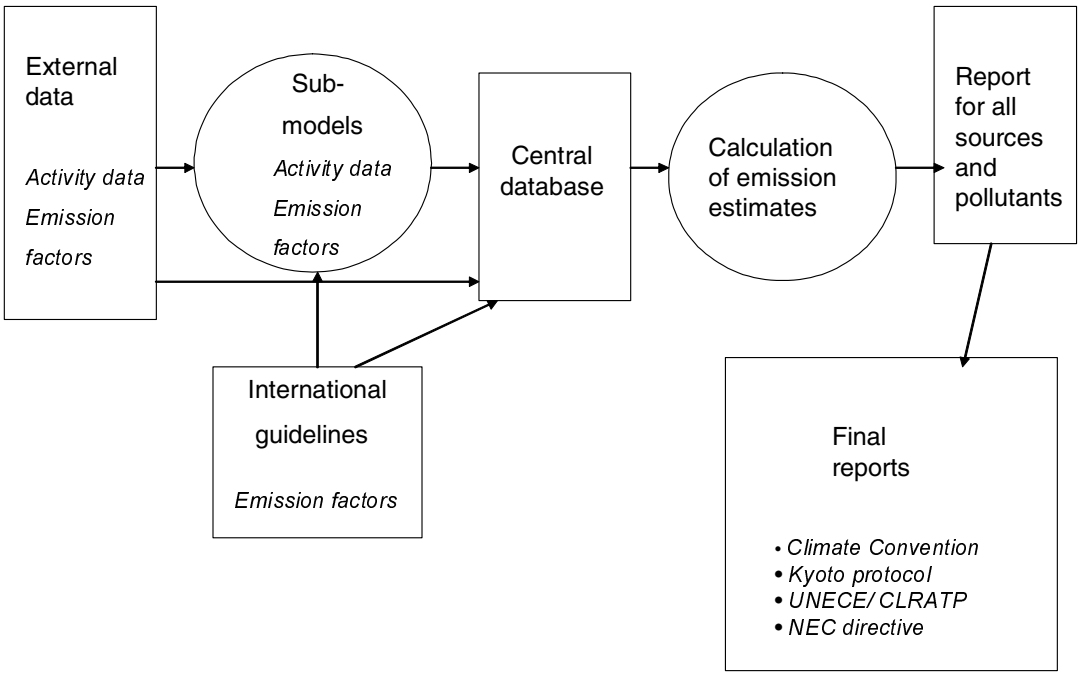


Figure 1.1 Schematic diagram of the process of inventory preparation.

1.4 Brief description of methodologies and data sources used

Denmark's air emission inventories are based on the Revised 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 1997), the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000) and the CORINAIR methodology. 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. 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 (EMEP/CORINAIR, 2004).

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.

The specific methodologies regarding Stationary Combustion Plants

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 CORINAIR system described in the Emission Inventory Guidebook (EMEP/CORINAIR, 2004). The inventory is based on activity rates from the Danish energy statistics and on emission factors for different fuels, plants and sectors.

The Danish Energy Authority aggregates fuel consumption rates in the official Danish energy statistics to SNAP categories.

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/CORINAIR 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 and municipal waste incineration plants are registered individually as large point sources and emission data from the actual plants are used. 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 and Annex 2A for further information on emission inventories for stationary combustion plants.

1.4.1 Fugitive emissions from oil (CRF Table 1.B.2. a)

Offshore activities

Emissions from offshore activities are estimated according to the methodology described in the Emission Inventory Guidebook (EMEP/CORINAIR, 2004). The sources include extraction of oil and gas, onshore oil tanks, and onshore and offshore loading of ships. The emission factors are based on the figures given in the guidebook except for in the case of onshore oil tanks where national values are used.

Oil Refineries – Petroleum products processing

The VOC emissions from petroleum refinery processes cover non-combustion emissions from feed stock handling/storage, petroleum products processing, product storage/handling and flaring. 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 and the energy statistics.

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

Natural gas transmission and distribution

Inventories of NMVOC emission from gas transmission and distribution are based on annual environmental reports from the Danish gas transmission company, DONG, and on a Danish inventory for the years 1999-2005 reported by the Danish gas sector (transmission and distribution companies).

Please refer to Chapter 3 for further information on fugitive emissions from fuels.

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 IPCC categories; 1A3b (Road transport), 1A2f (Industry-other), 1A3a (Civil aviation), 1A3c (Railways), 1A3d (Navigation), 1A4c (Agriculture/forestry/fisheries), 1A4b (Residential) and 1A5 (Other).

An internal NERI model with a structure similar to the European COPERT III emission model (Ntziachristos, 2000) 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 the Danish Road Directorate, 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 (Tier 2 approach).

For air traffic, the 2001, 2002 and 2003 estimates are made on a city-pair level, using flight data from the Danish Civil Aviation Agency (CAA-DK), 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, agriculture, forestry, industry, and household and gardening. 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 (Tier 2 approach).

The most thorough recalculations have changed the estimates for road transport, sea transport and fisheries. The recalculations influence the emission estimates for all emission components, and the emission factors of NO_x, NMVOC, CO, TSP, PM_{10} and $PM_{2.5}$ for the sectors: road (1A3b) Agriculture/forestry/fisheries (1A4c), Industry (1A2f), Residential (1A4b) and Navigation (1A3d).

For mobile sources in 2005, the uncertainty of the TSP and CO emissions were 47 and 52 %, respectively. The 2005 uncertainty estimates of SO_2, NO_x, NMVOC, PM_{10} and $PM_{2.5}$ lie between these two percentage values. The 1990-2005 uncertainties are 5 and 15 % for SO_2 and CO, and the trend uncertainties for NO_x, NMVOC, TSP, PM_{10} and $PM_{2.5}$ lie between these values. For NH_3, heavy metals and POPs, 2005 emissions have uncertainty levels of around 800 and 1 000 %. The emission trend uncertainties are significantly lower (except for NH_3) than their uncertainty levels – still, large fluctuations do exist between the calculated values for the different emission components. Apart from that for NH_3 (trend uncertainty of 3 475 %), the smallest and largest uncertainties are 7 (As) and 149 % (Cr).

Please refer to Chapter 3 and Annex 2B for further information on emissions from transport.

Specific methodologies regarding industrial processes

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.

1.4.3 Mineral products

The sub-sector includes production of cement, lime, container glass/glass wool, mineral wool, other production (consumption of limestone), and roofing and road paving with asphalt. The activity data as well as emission data are primarily based on information from environmental statements termed "Green National Accounts" (In Danish: "Grønne regnskaber") prepared by companies according to obligations under Danish law. 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.

1.4.4 Chemical industry

The sub-sector includes production of nitric acid, 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 "Green National Accounts" 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. Production of nitric acid ceased in the middle of 2004.

1.4.5 Metal production

The sub-sector includes production of steel sheets and bars, cast iron, aluminium, 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 "Green National Accounts", combined with information obtained by

contact with the companies. The activity data or the other processes are based on information from Statistics Denmark combined with Danish average emission factors and standard emission factors. The distribution of TSP between PM_{10} and $PM_{2.5}$ is based on European average data.

1.4.6 Other production

The sub-sector includes breweries. The activity data is obtained from Statistics Denmark and the emission factors are obtained from the IPCC guidelines.

Please refer to Chapter 4 for further information on industrial processes.

Specific methodologies regarding solvents (3)

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 according to product and with regard to the influence of product use on emissions. The procedure is to quantify the use of chemicals and estimate the fraction of the chemicals that is emitted as a consequence of use.

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 databases, from which a list of 427 single chemicals, a few groups and products are generated. For each of these a "use" amount in tonnes per year (from 1995 to 2005) is calculated. It is found that 44 different NMVOCs comprise over 95 % of the total use, and it is these 44 chemicals that are investigated further. The "use" amounts are distributed in industrial activities according to the Nordic SPIN (Substances in Preparations in Nordic Countries) database, where information on industrial use categories and products is available in a NACE coding system. The chemicals are also related to specific products. Emission factors are obtained from regulators or the relevant industry.

Outputs from the inventory are: a list where the 44 most predominant NMVOCs are ranked according to emissions to air; specification of emissions from industrial sectors and from households; contribution from each chemical to emissions from industrial sectors and households; tidal (annual) trend in NMVOC emissions, expressed as total NMVOC and single chemicals, and specified in industrial sectors and households.

Please refer to Chapter 5 for further information on emission inventories for solvents.

Specific methodologies regarding agriculture (4)

(NFR: 4B, 4D, 4F)

The emissions from the agricultural sector include emissions of ammonia and particulate matter. The emissions are registered in NFR tables 4B Manure Management and 4D Agricultural Soils. Table 4F Field Burning of Agricultural Wastes has only been completed until 1989, because burning of plant residue has been prohibited since 1990.

The calculations of the ammonia and PM emissions are based on the Emission Inventory Guidebook (EMEP/CORINAIR, 2004). In Denmark, a model-based system is applied for calculation of ammonia emissions, particulate matter and greenhouse gases. This model is called DIEMA (Danish Integrated Emission Model for Agriculture), and data on activity and emissions are collected, evaluated and discussed in close corporation with the the Faculty of Agriculture Sciences, Aarhus University and the Danish Agricultural Advisory Centre.

Livestock numbers and data concerning the land use and crop yield are based on the Agricultural Statistics published by Statistics Denmark (2005). The emission factors used to calculate the emissions are primarily based on information from the Faculty of Agriculture Sciences, Aarhus University and the Danish Agricultural Advisory Centre. Furthermore, activity data from the Danish Environmental Protection Agency and the Danish Plant Directorate are used.

Uncertainties for ammonia emissions from manure management and agricultural soils have been estimated. The estimated emissions for particulate matter are associated with very high uncertainties, which are estimated to be of several hundred percent. To ensure data quality, activity data and data for estimation of emission factors are collected and discussed in corporation with specialists and researchers at different institutes and research departments. This means that the emission inventories are continuously evaluated according to the latest knowledge and information. Furthermore, time-series of both emission factors and activity data are prepared, and considerable variations are checked and revised.

Please refer to Chapter 6 and Appendix 2C for further information on emission inventories for agriculture.

1.5 Information on the QA/QC plan including verification and treatment of confidential issues where relevant

In the Danish National Inventory Report to UNFCCC (Illerup et al., 2007), the plan for Quality Control (QC) and Quality Assurance (QA) for greenhouse gas emission inventories prepared by the Danish National Environmental Research Institute is outlined. The plan is in accordance with the guidelines provided by the UNFCCC (IPCC, 1997) and the "Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories" (IPCC, 2000). The ISO 9000 standards are also used as important input for the plan. The plan also, to some extent, includes the gases reported to the UNECE-LRTAP Convention.

1.6 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 2001).

The uncertainty estimates are based on emission data for the base year and year 2005, and on uncertainties for activity rates and emission factors for each of the main SNAP sectors. For particulate matter, the year 2000 is considered as the base year, but for all other pollutants the base year is 1990.

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 the sectors: stationary combustion, transport, industry and agriculture.

Table 1.2 Danish uncertainty estimates, 2005

Pollutant	Uncertainty Total emission [%]	Trend[2)] 1990[1)]-2005 [%]	Uncertainty Trend [%-age points]
SO_2	9	-88	±0.8
NO_x	32	-33	±5
NMVOC	32	-41	±13
CO	35	-21	±15
NH_3	28	-31	±18
TSP [1)]	275	+1.6	±64
As	134	-62	±11
Cd	331	-45	±110
Cr	188	-81	±28
Cu	726	-10	±200
Hg	219	-61	±43
Ni	155	-62	±13
Pb	266	-95	±37
Se	123	-64	±17
Zn	231	-26	±218
Benzo(b)fluoranthene	950	64	±33
Benzo(k)fluoranthene	948	168	±260
Benzo(a)pyrene	976	99	±35
Indeno(1,2,3-c,d)	968	72	±40

1. The base year for PM is 2000

2. Only including the emission sources for which uncertainty estimates have been estimated

1.7 General assessment of the completeness

The Danish emissions inventory due 15 February 2006 includes all sources identified by the EMEP/CORINAIR guidebook except the following:

1.7.1 Industrial processes

- Mineral products (NFR 2A): The inventory will be improved regarding completion of pollutants included. The methodology used for some of the pollutants from glass production is inconsistent and will be improved.
- Chemical industry (NFR 2B): The inventory covering the chemical industry is considered to be complete.
- Metal production (NFR 2C): The time-series will be completed. For especially secondary aluminium and zinc production, potential emissions of heavy metals will be investigated.
- Other production (NFR 2D): The time-series for emission of NMVOC from the production of beer is planned to be completed. Furthermore, production of bread and other food products are planned to be included.

1.7.2 Agriculture

The PM emission from stables will be included for the years 1985 to 1999.

It is planned to move the emission from sewage sludge used as fertiliser and applied on agricultural soils from NFR category 4.B13 – Manure Management "Other" to NFR category 4.D – Agricultural Soils.

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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 are apparent 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:

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

where 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 chalk content, acid deposition will be relatively easily neutralised.

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 2005, the most important acidification factor in Denmark was ammonia nitrogen and the relative contributions for SO_2, NO_X and NH_3 were 7 %, 40 % and 53 %, respectively. However, with regard to long-range transport of air pollution, SO_2 and NO_X are still the most important pollutants.

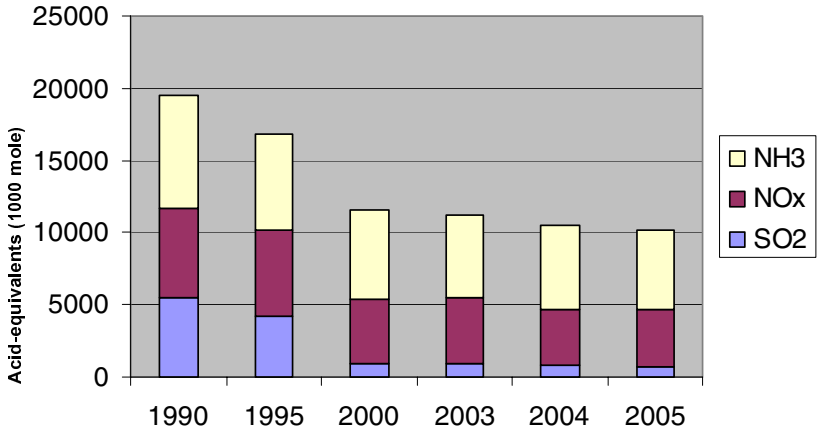


Figure 2.1 Emissions of NH_3, NO_X and SO_2 in acid equivalents

2.2 Description and interpretation of emission trends by gas

2.2.1 SO_2

The main part of the SO_2 emission originates from combustion of fossil fuels, i.e. mainly coal and oil, in public power and district heating plants. From 1980 to 2005, the total emission decreased by 95 %. The large reduction is largely due to installation of desulphurisation plant 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 36 % of the total emission. Also emissions from industrial combustion plants, non-industrial combustion plants and other mobile sources are important. National sea traffic (navigation and fishing) contributes with about 12 % of the total SO_2 emission. This is due to the use of residual oil with high sulphur content.

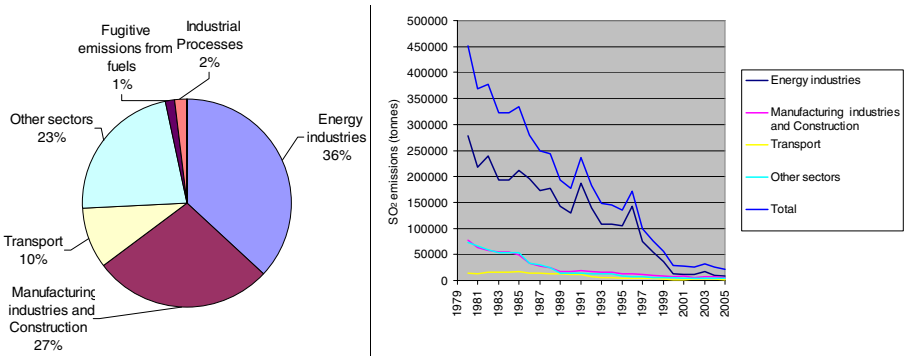


Figure 2.9 SO_2 emissions. Distribution according to the main sectors (2005) and time-series for 1990 to 2005.

2.2.2 NO_X

The largest sources of emissions of NO_X are other mobile sources followed by road transport 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 2005, 35% of the Danish emissions of NO_X stems from road transport, national navigation, railways and civil aviation. Also 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 public power plants and district heating plants have decreased by 61 % from 1985 to 2005. In the same period, the total emission decreased by 36%. The reduction is due to the increasing use of catalyst cars and installation of low-NO_X burners and denitrifying units in power and district heating plants.

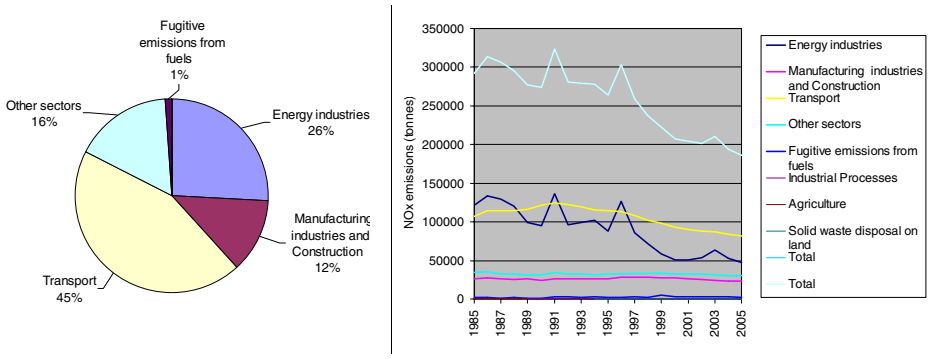


Figure 2.6 NO_X emissions. Distribution according to the main sectors (2005) and time-series for 1990 to 2005.

2.2.3 NH_3

Almost all atmospheric emissions of NH_3 result from agricultural activities. Only a minor fraction originates from road transport. This fraction is, however, increasing due to increasing use of catalyst cars. The major part of the emission from agriculture stems from livestock manure (79%) and the largest losses of ammonia occur during the handling of the manure in stables and in field application. Other contributions come from crops (15%), use of mineral fertilisers (6%), sewage sludge used as fertiliser and ammonia used for straw treatment (less than 1%). The total ammonia emission decreased by 36% from 1985 to 2005. This is due to the active national environmental policy efforts over the past twenty years. 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 application of livestock manure in winter, prohibition of broad-spreading of manure is prohibited, 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.

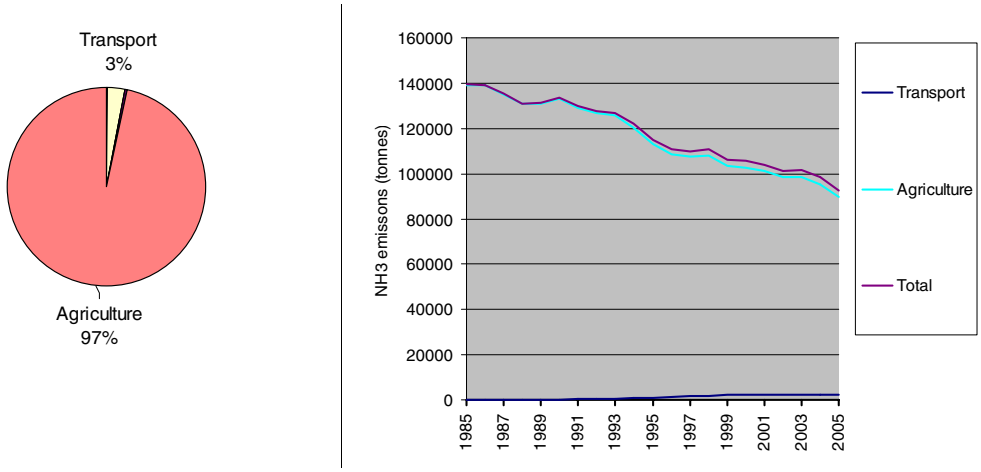


Figure 2.4 NH_3 emissions. Distribution on the main sectors (2005) and time-series for 1985 to 2005.

2.3 Other air pollutants

2.3.1 NMVOC

The emissions of NMVOC originate from many different sources and can be divided into two main groups: incomplete combustion and evaporation. Road vehicles and other mobile sources such as national navigation vessels and off-road machinery are the main sources of NMVOC emissions from incomplete combustion processes. Road transportation vehicles are still the main contributors, even though the emissions have declined since the introduction of catalyst cars in 1990. The evaporative emissions mainly originate from the use of solvents. The emissions from the energy industries have increased during the nineties due to the increasing use of stationary gas engines, which have much higher emissions of NMVOC than conventional boilers. The total anthropogenic emissions have decreased by 31 % from 1985 to 2005, largely due to the increased use of catalyst cars and reduced emissions from use of solvents.

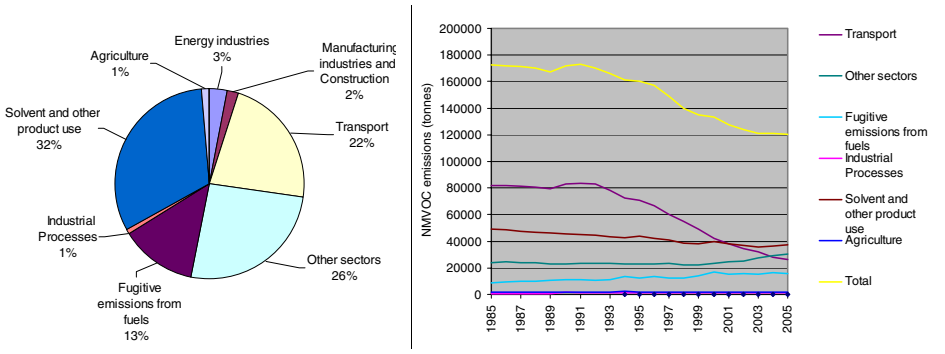


Figure 2.8 NMVOC emissions. Distribution according to the main sectors (2005) and time-series for 1990 to 2005.

2.3.2 CO

Transport is responsible for the dominant share of the total CO emission. Also other mobile sources and non-industrial combustion plants contribute significantly to the total emission of this pollutant. The drop in the emissions seen in 1990 was a consequence of a law forbidding the burning of agricultural waste on fields. The emission decreased further by 21 % from 1990 to 2005, largely because of decreasing emissions from road transportation.

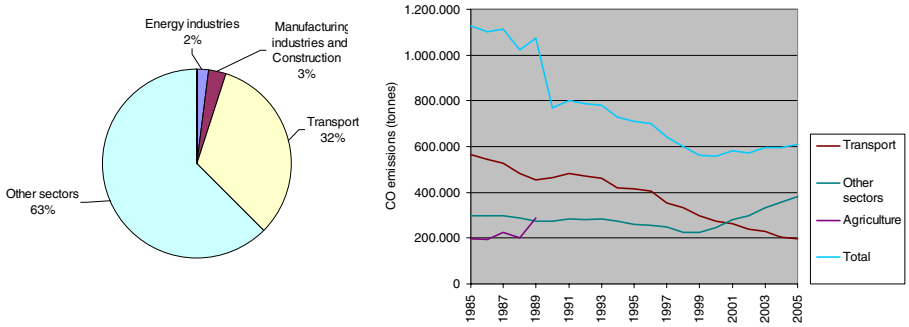


Figure 2.7 CO emissions. Distribution according to the main sectors (2005) and time-series for 1990 to 2005.

2.3.3 PAHs

The present emission inventory for PAH (polyaromatic hydrocarbons) includes the four PAHs reported to UNECE: benzo(a)pyrene, benzo(b)-fluoranthene, benzo(k)fluoranthene and indeno(1,2,3-cd) pyrene. The most important sources of PAH emissions are combustion of wood in the residential sector and road transportation. The increasing emission trend is due to increasing combustion of wood in the residential sector.

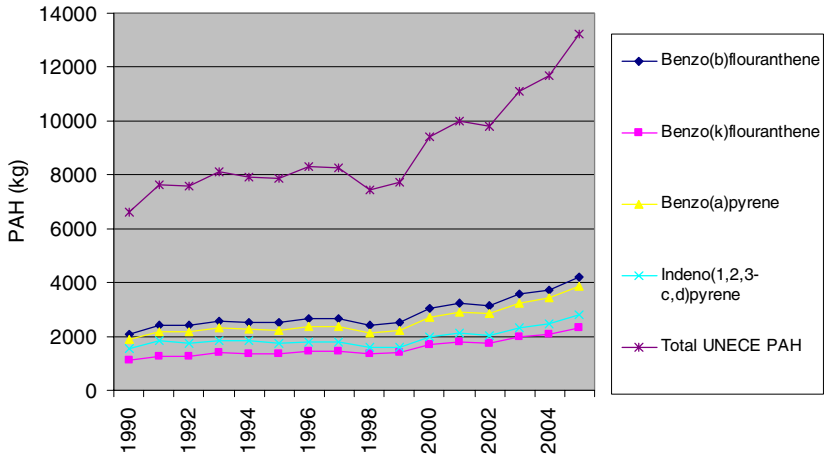


Figure 2.7 PAH emissions. Time-series for 1990 to 2005.

2.3.4 Particulate Matter

The particulate matter (PM) emission inventory has been reported for the years 2000-2005. 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 sources are the residential sector (64 %), road traffic (15 %) and other mobile sources (7 %). For the latter, the most important source is off-road vehicles and machinery in the agricultural-/forestry sector (54 %). For the road transport sector, exhaust emissions account for the major part (77 %) of the emissions.

The largest TSP emission sources are the agricultural sector and the residential sector. 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 45 % of the TSP emission from road transport.

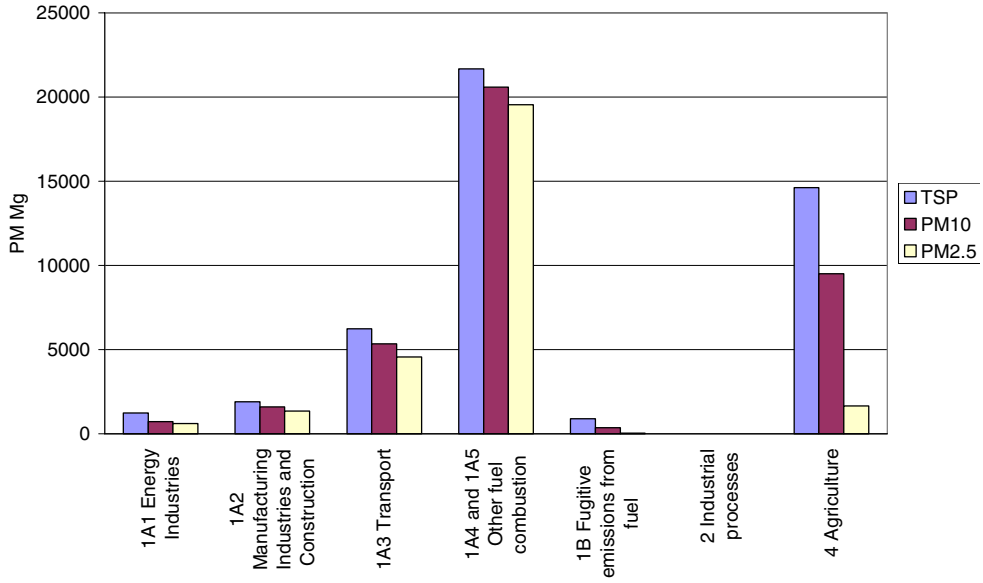


Figure 2.8 PM emissions for 2005.

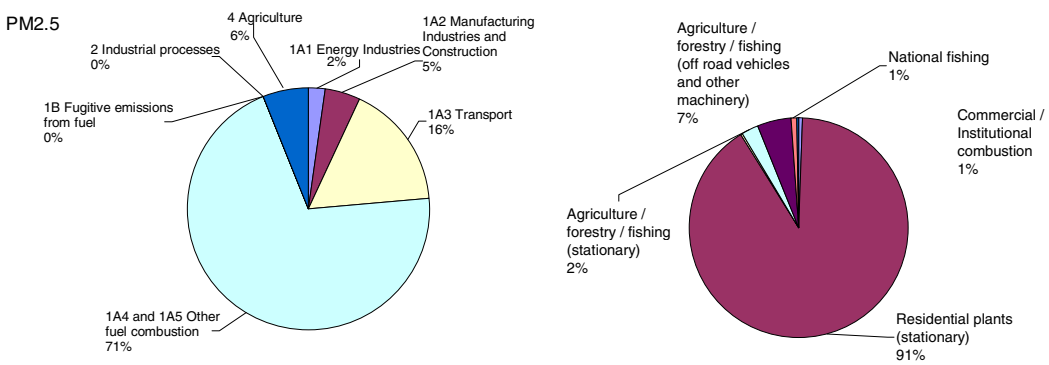


Figure 2.9 $PM_{2.5}$ emissions. Distribution by main sector and on sub-sectors for other fuels combustion for 2005.

Heavy metals

In general, the most important sources of heavy metal emissions are combustion of fossil fuels and waste. The heavy metal emissions have decreased substantially in recent years. The reductions span from 10% to

95% for Cu and Pb, 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). The large reduction in the Pb emission is due to a gradual shift towards unleaded gasoline, the latter being essential for catalyst cars.

Tabel 2.1 Emissions of heavy metals.

(Kg)	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
1990	1504	1139	6326	10239	3339	25244	122074	4470	35449
2005	568	623	1200	9247	1291	9507	5582	1623	26211
Reduction in %	62	45	81	10	61	62	95	64	26

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.

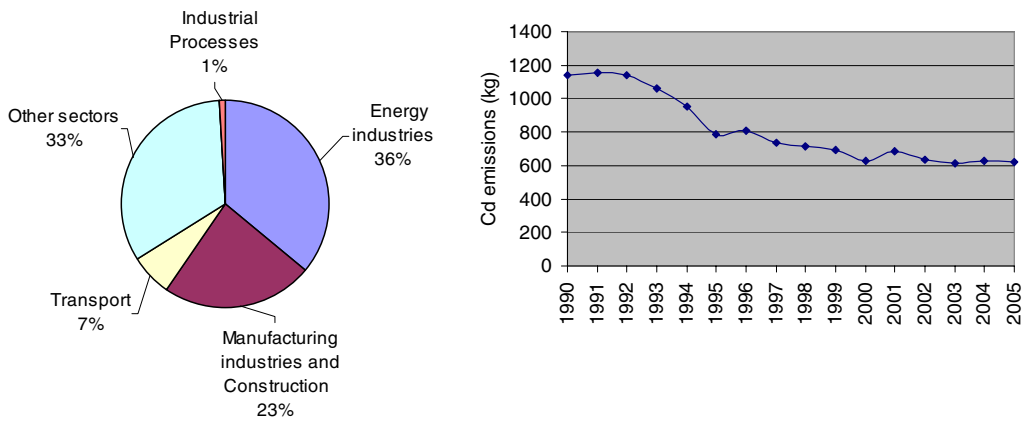


Figure 2.10 Cd emissions. Time-series for 1990 to 2005 and distribution by main sector for 2005.

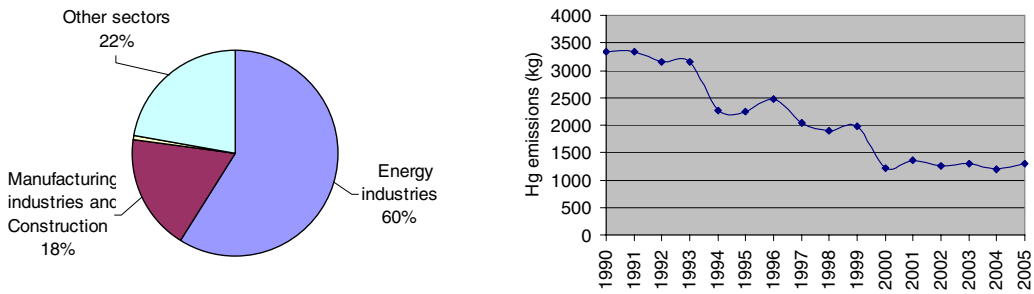


Figure 2.11 Hg emissions. Time-series for 1990 to 2005 and distribution by main sector for 2005.

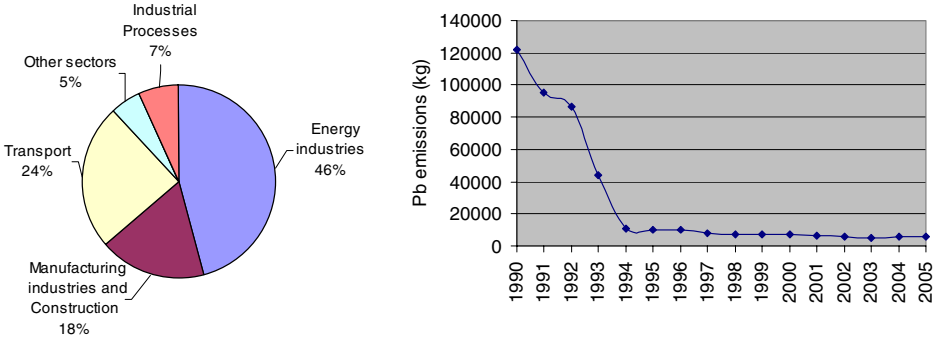


Figure 2.12 Pb emissions. Time-series for 1990 to 2005 and distribution by main sector for 2005.

3 Energy (NFR sector 1)

3.1 Overview of the sector

The energy sector is reported in three main chapters:

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

3.3 Transport (NFR sector 1A2, 1A3, 1A4 and 1A5)

3.4 Fugitive emissions (NFR sector 1B)

Although industrial combustion forms part of stationary combustion, detailed documentation for some of the specific industries is discussed in the industry chapters. The emissions are reported in NFR sector 1A2. Emissions from full fuel consumption in the industrial sector are included in the data presented in Chapter *3.2 Stationary Combustion*.

Table 3.1 shows detailed source categories for the energy sector and plant category in which the sector is discussed in this report.

Table 3.1 NFR source categories for the energy sector.

NFR id	NFR sector name	NERI documentation
1	Energy	Stationary combustion, Transport, Fugitive, Industry
1A	Fuel Combustion Activities	Stationary combustion, Transport, Industry
1A1	Energy Industries	Stationary combustion
1A1a	Electricity and Heat Production	Stationary combustion
1A1b	Petroleum Refining	Stationary combustion
1A1c	Solid Fuel Transf./Other Energy Industries	Stationary combustion
1A2	Fuel Combustion Activities/Industry (ISIC)	Stationary combustion, Transport, Industry
1A2a	Iron and Steel	Stationary combustion, Industry
1A2b	Non-Ferrous Metals	Stationary combustion, Industry
1A2c	Chemicals	Stationary combustion, Industry
1A2d	Pulp, Paper and Print	Stationary combustion, Industry
1A2e	Food Processing, Beverages and Tobacco	Stationary combustion, Industry
1A2f	Other (please specify)	Stationary combustion, Transport, Industry
1A3	Transport	Transport
1A3a	Civil Aviation	Transport
1A3b	Road Transportation	Transport
1A3c	Railways	Transport
1A3d	Navigation	Transport
1A3e	Other (please specify)	Transport
1A4	Other Sectors	Stationary combustion, Transport
1A4a	Commercial/Institutional	Stationary combustion
1A4b	Residential	Stationary combustion, Transport
1A4c	Agriculture/Forestry/Fishing	Stationary combustion, Transport
1A5	Other (please specify)	Stationary combustion, Transport
1A5a	Stationary	Stationary combustion
1A5b	Mobile	Transport
1B	Fugitive Emissions from Fuels	Fugitive
1B1	Solid Fuels	Fugitive
1B1a	Coal Mining	Fugitive
1B1a1	Underground Mines	Fugitive
1B1a2	Surface Mines	Fugitive
1B1b	Solid Fuel Transformation	Fugitive
1B1c	Other (please specify)	Fugitive
1B2	Oil and Natural Gas	Fugitive
1B2a	Oil	Fugitive
1B2a2	Production	Fugitive
1B2a3	Transport	Fugitive
1B2a4	Refining/Storage	Fugitive
1B2a5	Distribution of oil products	Fugitive
1B2a6	Other	Fugitive
1B2b	Natural Gas	Fugitive
1B2b1	Production/processing	Fugitive
1B2b2	Transmission/distribution	Fugitive
1B2c	Venting and Flaring	Fugitive
1B2c1	Venting and Flaring Oil	Fugitive
1B2c2	Venting and Flaring Gas	Fugitive
1B2d	Other	Fugitive

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

Table 3.2 SO_2, NO_X, NMVOC, CO and PM emission from the energy sector, 2005

	NO_X Gg NO_2	CO Gg	NMVOC Gg	SO_X Gg SO_2	TSP Mg	PM_{10} Mg	$PM_{2.5}$ Mg
1A1 Energy Industries	47.88	11.22	3.75	8.05	1253	734	609
1A2 Manufacturing industries and Construction	23.15	19.87	2.22	6.07	1903	1598	1352
1A3 Transport	82.05	197.38	26.12	2.10	6239	5334	4577
1A4 Other Sectors	29.19	381.40	30.47	4.88	21 627	20 552	19 498
1A5 Other	1.33	0.82	0.11	0.06	45	45	45
1B1 Fugitive Emissions from fuels, Solid Fuels	NA	NA	NA	NA	905	362	36
1B2 Fugitive Emissions from fuels, Oil and Natural gas	2.22	0.19	15.54	0.30	2	2	2
Energy, Total	185.82	610.88	78.21	21.46	31974	28628	26119

Table 3.3 HM emissions from the energy sector, 2005

	Pb Mg	Cd Mg	Hg Mg	As Mg	Cr Mg	Cu Mg	Ni Mg	Se Mg	Zn Mg
1A1 Energy Industries	2.55	0.23	0.72	0.29	0.54	0.65	3.29	0.71	14.41
1A2 Manufacturing industries and Construction	1.00	0.15	0.23	0.18	0.35	0.63	4.10	0.65	1.53
1A3 Transport	1.37	0.04	0.01	0.02	0.21	6.78	1.39	0.08	4.06
1A4 Other Sectors	0.23	0.21	0.27	0.07	0.10	1.00	0.68	0.19	4.53
1A5 Other	0.06	0.00	0.00	0.00	0.00	0.15	0.01	0.00	0.09
1B1 Fugitive Emissions from fuels, Solid Fuels	-	-	-	-	-	-	-	-	-
1B2 Fugitive Emissions from fuels, Oil and Natural gas	-	-	-	-	-	-	-	-	-
Energy, Total	5.21	0.62	1.23	0.57	1.20	9.20	9.46	1.62	24.61

Table 3.4 PAH emission from the energy sector, 2005

	benzo(a)-pyrene Mg	benzo(b)-fluoranthene Mg	benzo(k)-fluoranthene Mg	Indeno-(1,2,3-c,d)-pyrene Mg	Dioxin g I-Teq
1A1 Energy Industries	0.007	0.028	0.014	0.007	2.250
1A2 Manufacturing industries and Construction	0.029	0.097	0.020	0.010	0.171
1A3 Transport	0.051	0.071	0.078	0.061	0.277
1A4 Other Sectors	3.794	3.999	2.218	2.735	16.277
1A5 Other	0.000	0.001	0.001	0.000	0.001
1B1 Fugitive Emissions from fuels, Solid Fuels	-	-	-	-	-
1B2 Fugitive Emissions from fuels, Oil and Natural gas	-	-	-	-	-
Energy, Total	3.881	4.196	2.331	2.813	18.976

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

This chapter includes stationary combustion plants in the NFR sectors 1A1, 1A2 and 1A4. Further details of the inventories for stationary combustion are enclosed in Annex 2A.

3.2.1 Source category description

Emission source categories, fuel consumption data and emission data are presented in this chapter.

Emission source categories

In the Danish emission 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. Aggregation to the NFR sector codes is based on a correspondence list between SNAP and NFR enclosed in Annex 2A. Stationary combustion is defined as combustion activities in the SNAP sectors 01-03.

Stationary combustion plants are included in the emission source subcategories:

- 1A1 Energy, Fuel consumption, Energy Industries
- 1A2 Energy, Fuel consumption, Manufacturing Industries and Construction
- 1A4 Energy, Fuel consumption, Other Sectors

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 NFR sector codes have been applied unchanged, but some sector names have been changed to reflect the stationary combustion element of the source.

Fuel consumption

In 2005 total fuel consumption for stationary combustion plants was 531 PJ of which 424 PJ was fossil fuels.

Fuel consumption distributed on the stationary combustion subsectors is shown in Figure 3.1 and Figure 3.2. The majority – 57 % - of all fuels is combusted in the sector, *Public electricity and heat production.* Other sectors with high fuel consumption are *Residential* and *Industry*.

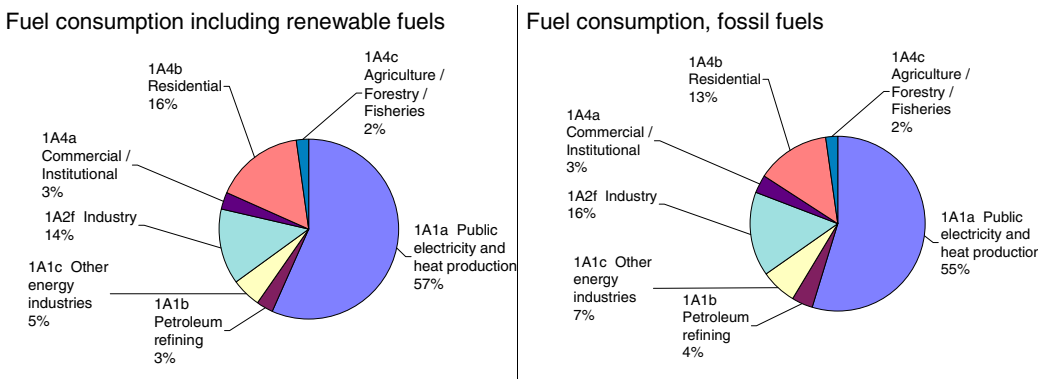


Figure 3.1 Fuel consumption rate of stationary combustion, 2005 (based on DEA 2006a)

Coal and natural gas are the most utilised fuels in stationary combustion plants. Coal is mainly used in power plants and natural gas is used in power plants and decentralised CHP plants, as well as in industry, district heating and households.

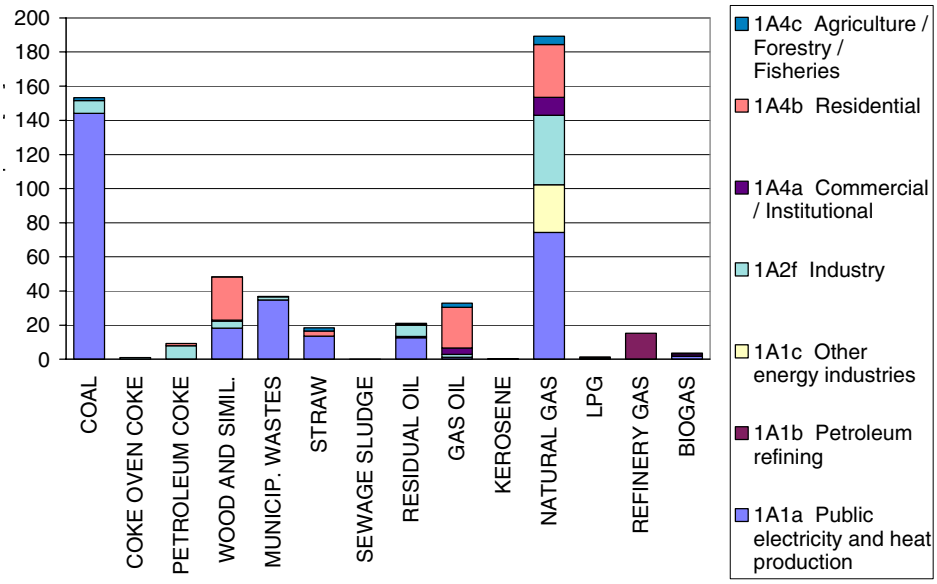


Figure 3.2 Fuel consumption in stationary combustion plants 2005 (based on DEA 2006a).

Fuel consumption time-series for stationary combustion plants are presented in Figure 3.3. Total fuel consumption increased by 6.6 from 1990 to 2005, while fossil fuel consumption decreased by 4.9%. The consumption of natural gas and renewable fuels has increased since 1990, whereas coal consumption has decreased.

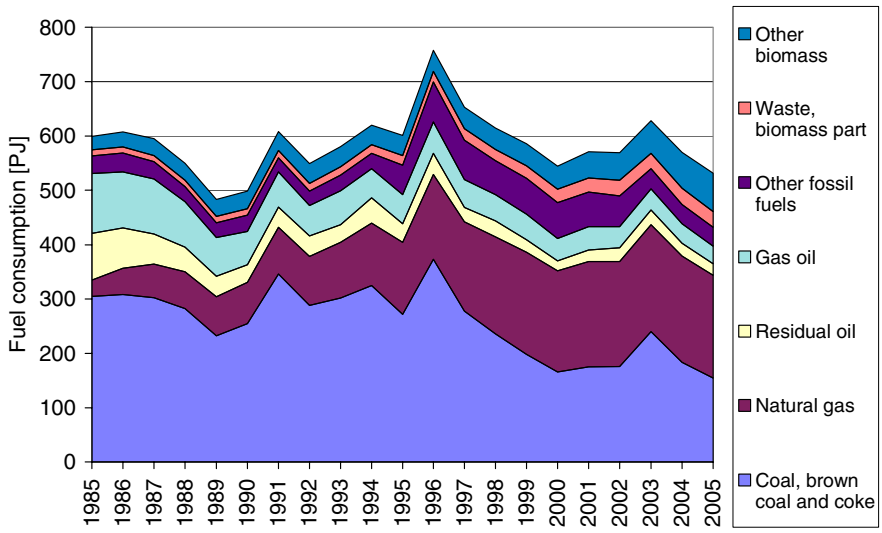


Figure 3.3 Fuel consumption time-series, stationary combustion (based on DEA 2006a)

The fluctuations in the time-series for fuel consumption are mainly a result of electricity import/export activity, 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 emissions are illustrated and compared in Figure 3.4. In 1990 the Danish electricity import was large causing relatively low fuel consumption in Denmark's stationary combustion plants, whereas the fuel consumption was high in 1996 due to a large electricity export. In 2005 the net electricity import was 4932 TJ in previous years there had been a net export. The electricity import in 2005 was the result of heavy rainfall in Norway and Sweden causing large hydropower production in both countries.

To be able to follow the national energy consumption, as well as for statistical and reporting purposes, the Danish Energy Authority produces a correction of the actual fuel consumption without random variations in electricity imports/exports and ambient temperature. This fuel consumption trend is also illustrated in Figure 3.4. The corrections are included here to explain the fluctuations in the emission time-series.

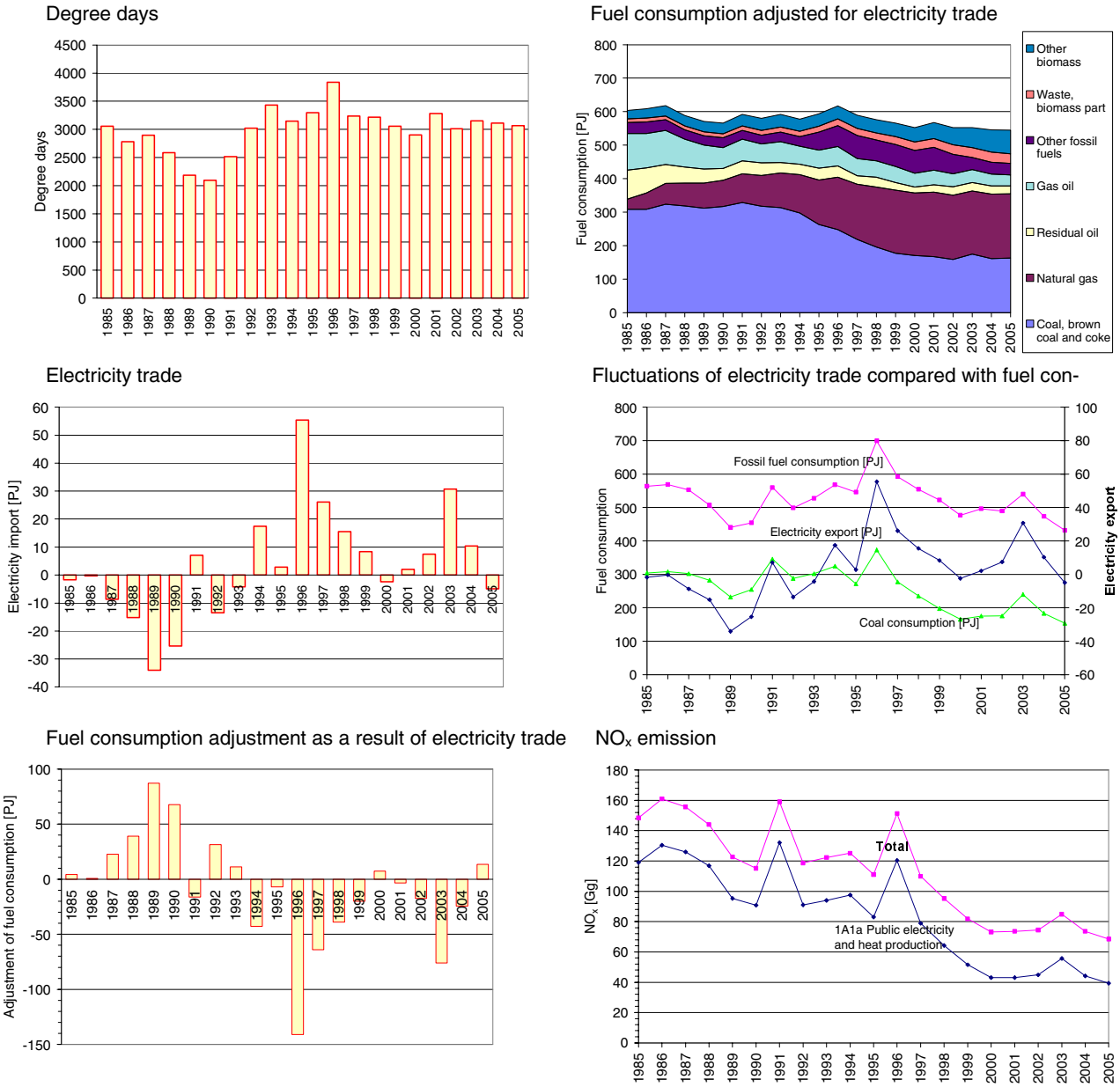


Figure 3.4 Comparison of time-series fluctuations for electricity trade, fuel consumption and NO_X emission (DEA 2006b).

3.2.2 Emissions

SO_2

In the 2005 inventory, stationary combustion is the most important emission source for SO_2 accounting for 84% of the total Danish emission. Table 3.5 shows the SO_2 emission inventory for the stationary combustion subsectors.

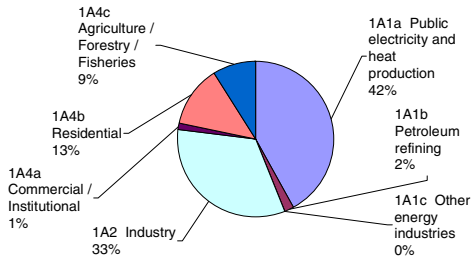
Electricity and heat production is the largest emission source accounting for 42 % of the emission. However, the SO_2 emission share is lower than the fuel consumption share for this sector, which is 57%. This is possible due to effective flue gas desulphurisation equipment installed in power plants combusting coal. The largest part (72%) of the emission in the subsector originates from power plants >300MW_{th}.

The SO_2 emission from *Industry* is 33%, a remarkably high emission share compared with fuel consumption. The main emission sources in the industrial sector are combustion of coal and residual oil, but emissions from the cement industry also represent a considerable emission source.

Time-series for the SO_2 emission from stationary combustion are shown in Figure 3.5. The SO_2 emission from stationary combustion plants decreased by 96% from 1980 and 85% from 1995. The large emission decrease is mainly a result of the reduced emission from *Electricity and heat production*, made possible due to installation of desulphurisation plant and due to the use of fuels with lower sulphur content.

Table 3.5 SO_2 emission from stationary combustion plants 2005 [1)]

SO_2	2005	
1A1a Public electricity and heat production	7716	Mg
1A1b Petroleum refining	325	Mg
1A1c Other energy industries	10	Mg
1A2 Industry	6045	Mg
1A4a Commercial / Institutional	260	Mg
1A4b Residential	2381	Mg
1A4c Agriculture / Forestry / Fisheries	1612	Mg
Total	18350	Mg



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

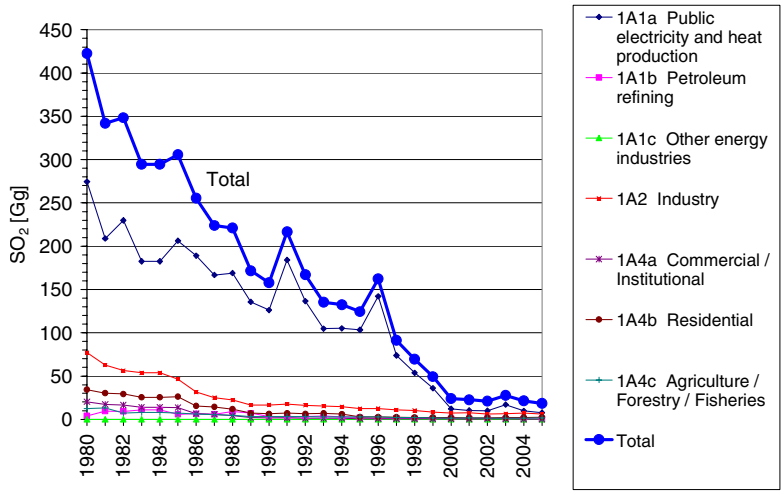


Figure 3.5 SO_2 emission time-series for stationary combustion

3.2.3 NO_X

Stationary combustion accounts for 37% of the total Danish NO_X emission. Table 3.6 shows the NO_X emission inventory for stationary combustion subsectors.

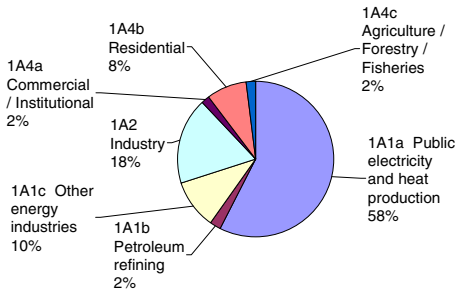
Electricity and heat production is the largest emission source, accounting for 58% of the emission from stationary combustion plants.

Industrial combustion plants are also an important emission source, accounting for 18 % of the emission. The main industrial emission source is cement production, accounting for 67 % of the emission.

Time-series for the NO_X emission from stationary combustion are shown in Figure 3.6. NO_X emissions from stationary combustion plants decreased by 54% from 1985 and 38% from 1995. The reduced emission is mainly a result of the reduced emission from *Electricity and heat production* due to installation of low-NO_X burners and selective catalytic reduction (SCR) units. The fluctuations in the time-series follow the fluctuations in *Electricity and heat production*, which, in turn, result from electricity trade fluctuations.

Table 3.6 NO_X emission from stationary combustion plants 2005 [1)]

	2005	
1A1a Public electricity and heat production	39367	Mg
1A1b Petroleum refining	1513	Mg
1A1c Other energy industries	6998	Mg
1A2 Industry	12482	Mg
1A4a Commercial / Institutional	1075	Mg
1A4b Residential	5762	Mg
1A4c Agriculture / Forestry / Fisheries	1309	Mg
Total	68506	Mg



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

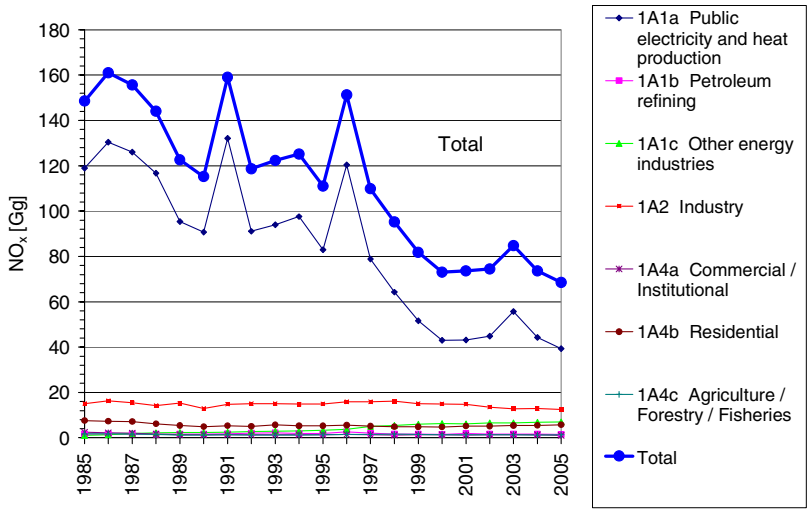


Figure 3.6 NO_X emission time-series for stationary combustion

3.2.4 NMVOC

Stationary combustion plants account for 20% of the total Danish NMVOC emission. Table 3.7 shows the NMVOC emission inventory for the stationary combustion subsectors.

Residential plants are the largest emission source accounting for 72 % of the total emission from stationary combustion plants. For residential

plants, NMVOC is mainly emitted from wood and straw combustion, see Figure 3.7.

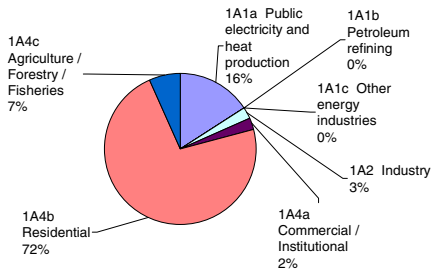
Electricity and heat production is also a considerable emission source, accounting for 16 % of the total emission. Lean-burn gas engines have a relatively high NMVOC emission factor and are the most important emission source in this subsector. The gas engines are either natural gas or biogas fuelled.

Time-series for the NMVOC emission from stationary combustion are shown in Figure 3.8. The emission has increased by 69% from 1985 and 37% from 1995. The increased emission is mainly a result of the increased use of lean-burn gas engines in CHP plants.

The emission from residential plants was 79% higher in 2005 than in 1990, but the NMVOC emission from wood combustion increased by 138% since 1990 due to increased wood consumption. However, the emission from straw combustion in farmhouse boilers has decreased over this period.

Table 3.7 NMVOC emission from stationary combustion plants 2005 [1)]

	2005	
1A1a Public electricity and heat production	3709	Mg
1A1b Petroleum refining	2	Mg
1A1c Other energy industries	42	Mg
1A2 Industry	600	Mg
1A4a Commercial / Institutional	569	Mg
1A4b Residential	17125	Mg
1A4c Agriculture / Forestry / Fisheries	1567	Mg
Total	23614	Mg



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

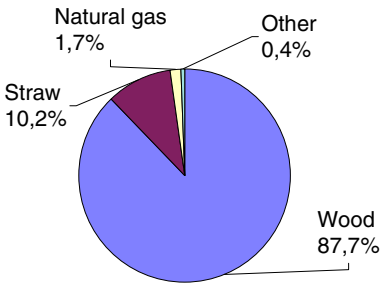


Figure 3.7 NMVOC emission from residential plants, 2005

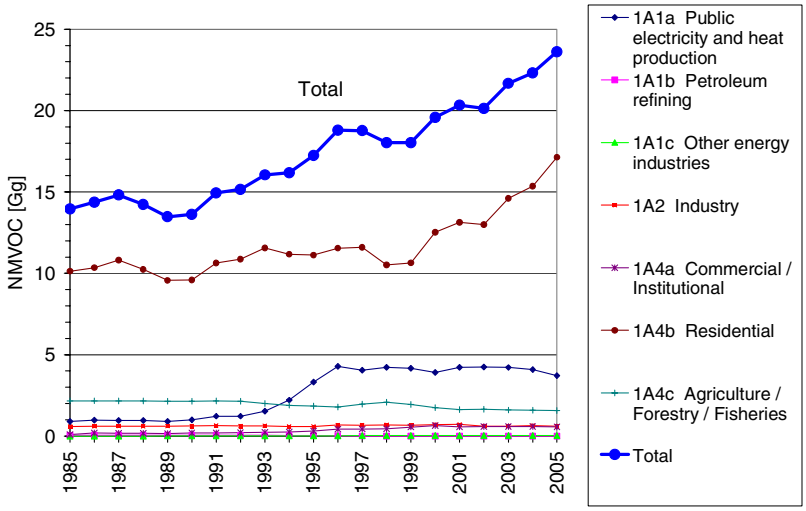


Figure 3.8 NMVOC emission time-series for stationary combustion

3.2.5 CO

Stationary combustion accounts for 45% of the total Danish CO emission. Table 3.8 presents the CO emission inventory for stationary combustion subsectors.

Residential plants represent the largest emission source, accounting for 88% of the emission. Wood combustion accounts for 94% of the emission from residential plants, see Figure 3.9. This is in spite of the fact that the fuel consumption share is only 30%. Combustion of straw also represents a considerable emission source, whereas the emission from other fuels used in residential plants is almost negligible.

Time-series for CO emission from stationary combustion are shown in Figure 3.10. The emission increased by 52% from 1985 and increased 45% from 1995. The time-series for CO from stationary combustion plants follows the time-series for CO emission from residential plants.

The consumption of wood in residential plants has increased by 180% since 1990 leading to an increase in the CO emission. The increase in CO emission from residential plants is lower than the increase in wood consumption, because CO emission from straw-fired farmhouse boilers has decreased considerably. Both the annual straw consumption in residential plants and the CO emission factor for farmhouse boilers have decreased.

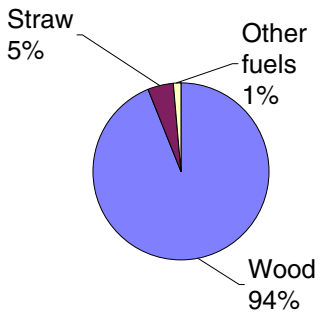
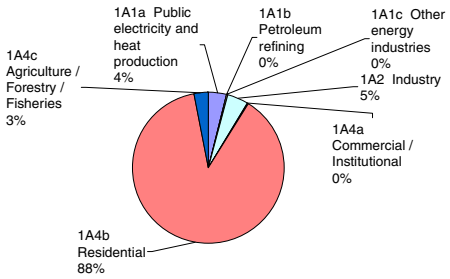


Figure 3.9 CO emission sources, residential plants, 2005

Table 3.8 CO emission from stationary combustion plants 2005 [1)]

	2005	
1A1a Public electricity and heat production	10789	Mg
1A1b Petroleum refining	223	Mg
1A1c Other energy industries	209	Mg
1A2 Industry	12373	Mg
1A4a Commercial / Institutional	952	Mg
1A4b Residential	240970	Mg
1A4c Agriculture / Forestry / Fisheries	8494	Mg
Total	274010	Mg



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

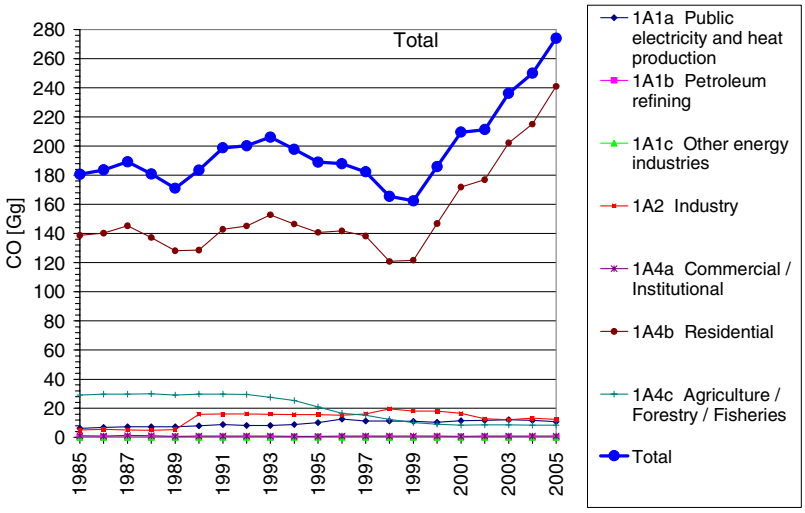


Figure 3.10 CO emission time-series for stationary combustion

3.2.6 PM

To date, PM emissions from stationary combustion, transport, agriculture and the industrial sector have been included in the Danish inventory. TSP from stationary combustion accounts for 48% of the total Danish emission. The emission shares for PM_{10} and $PM_{2.5}$ are 44% and 41%, respectively.

Table 3.9 shows the PM emission inventory for the stationary combustion subsectors. Residential plants represent the largest emission source, accounting for 91% of the $PM_{2.5}$ emission from stationary combustion plants.

Table 3.9 PM emission from stationary combustion plants, 2005

		TSP	PM_{10}	$PM_{2.5}$	
1A1a	Public electricity and heat production	1135	626	505	Mg
1A1b	Petroleum refining	114	107	103	Mg
1A1c	Other energy industries	3	2	1	Mg
1A2	Industry	900	596	350	Mg
1A4a	Commercial / Institutional	139	133	124	Mg
1A4b	Residential	19705	18676	17666	Mg
1A4c	Agriculture / Forestry / Fisheries	525	488	454	Mg
Total		**22522**	**20627**	**19203**	Mg

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

The primary sources of PM emissions are:

- Residential boilers, stoves and fireplaces combusting wood
- Farmhouse boilers combusting straw
- Power plants primarily combusting coal
- Coal and residual oil combusted in industrial boilers and processes

Furthermore, there are considerable emissions from:

- Residential boilers using gas oil
- Refineries

The PM emission from wood combusted in residential plants is the predominant source. Thus, 88% of the $PM_{2.5}$ emission from stationary combustion is emitted from residential wood combustion. This corresponds to 64% of the overall Danish emission. Wood combustion accounts for 96% of the $PM_{2.5}$ emission from residential plants in spite of the limited wood consumption share.

A literature review (Nielsen et al. 2003) and a Nordic Project (Sternhufvud et al. 2004) have demonstrated that the emission factor uncertainty for residential combustion of wood in stoves and boilers is extremely high.

Emission inventories for PM have only been reported for the years 2000-2005 and the emission level has not changed considerably over this period.

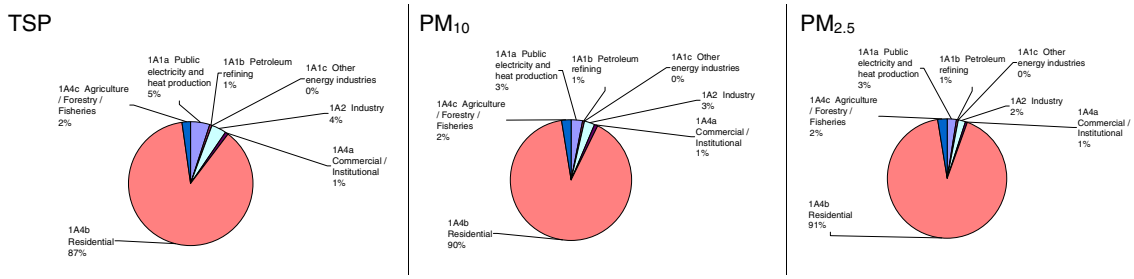


Figure 3.11 PM emission sources, stationary combustion plants, 2005

3.2.7 Heavy metals

Emission inventories for nine heavy metals are reported to the LRTAP Convention. Three of the metals are considered priority metals: Pb, Cd and Hg. The 2005 emissions are presented in Table 3.10.

Stationary combustion plants are the most important emission sources for heavy metals. For Cu, the emission share from stationary combustion plants is 11%, but for all other heavy metals the emission share is more than 68%.

The sectors *Electricity and heat production* and *Industry* have the highest emission shares. *Electricity and heat production* accounts for 67%, 38% and 59% of the emission of the priority metals Pb, Cd and Hg, respectively.

Table 3.10 Heavy metal emission from stationary combustion plants, 2005 [1)]

	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	
1A1a Public electricity and heat production	283	215	510	641	719	2808	2533	700	14405	kg
1A1b Petroleum refining	11	10	25	10	3	479	18	9	2	kg
1A1c Other energy industries	0	0	0	0	0	0	0	0	0	kg
1A2 Industry	183	142	337	151	227	4081	1000	647	1246	kg
1A4a Commercial / Institutional	8	8	10	13	21	83	16	19	204	kg
1A4b Residential	33	179	29	207	221	54	160	113	3735	kg
1A4c Agriculture / Forestry / Fisheries	19	13	33	21	23	502	41	21	80	kg
Total	**537**	**568**	**944**	**1043**	**1214**	**8008**	**3768**	**1510**	**19672**	**kg**

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

Time-series for heavy metal emissions are provided in Figure 3.12. Emissions of all heavy metals except Zn have decreased considerably since 1990. Table 3.11 shows the decrease of each heavy metal since 1990. Emissions have decreased despite increased incineration of municipal waste. This has been made 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 increasing Zn emission estimated in resent years might be a result of insufficient data for resent years.

Table 3.11 Decrease in heavy metal emission 1990-2005

Pollutant	Decrease since 1990
As	63%
Cd	46%
Cr	85%
Cu	71%
Hg	61%
Ni	63%
Pb	75%
Se	65%
Zn	-2%

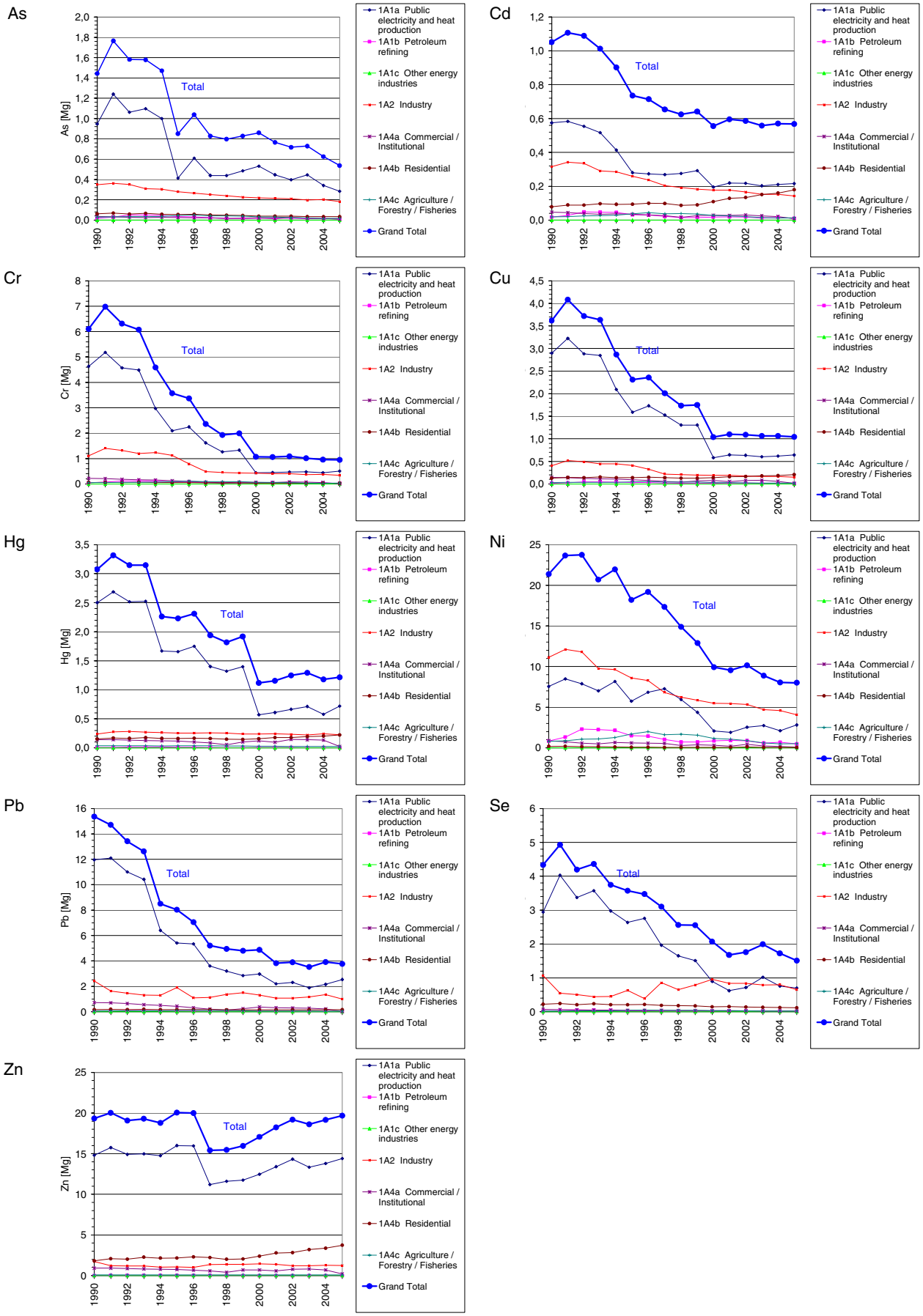


Figure 3.12 Heavy metal emission time-series, stationary combustion plants

3.2.8 PAH and dioxin

Emission inventories for 4 PAHs and for dioxin are reported to the LRTAP Convention. Stationary combustion plants account for more than 95% of the PAH emissions and for 73% of the dioxin emission in 2005.

Table 3.12 shows the PAH and dioxin emission inventory for the stationary combustion subsectors. Residential combustion is the largest emission source for both PAH and dioxin. Combustion of wood is the predominant source, accounting for more than 98% of the PAH emission in residential plants. The residential sector accounts for 77% of the dioxin emission from stationary combustion plants.

The increasing emission trend for PAH is a result of the increased combustion of wood in residential plants. The time-series for wood combustion in residential plants is also provided in Figure 3.14.

Dioxin emission decreased 61% since 1990 mainly due to installation of dioxin filters in MSW incineration plants. The emission from residential plants is increasing due to increased wood consumption in this sector.

Table 3.12 PAH emission from stationary combustion plants, 2005

	Benzo(a)-Pyrene (Mg)	Benzo(b)-fluoranthene (Mg)	Benzo(k)-fluoranthene (Mg)	Indeno(1,2,3-c,d)pyrene (Mg)	Dioxin [g I-Tec]
1A1a Public electricity and heat production	7	28	14	6	2,2
1A1b Petroleum refining	0	0	0	0	0,0
1A1c Other energy industries	0	0	0	0	0,0
1A2 Industry	26	91	14	7	0,2
1A4a Commercial / Institutional	120	158	52	85	0,4
1A4b Residential	3517	3666	2131	2402	14,4
1A4c Agriculture / Forestry / Fisheries	151	164	25	235	1,4
Total	**3822**	**4106**	**2237**	**2736**	**18,6**

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

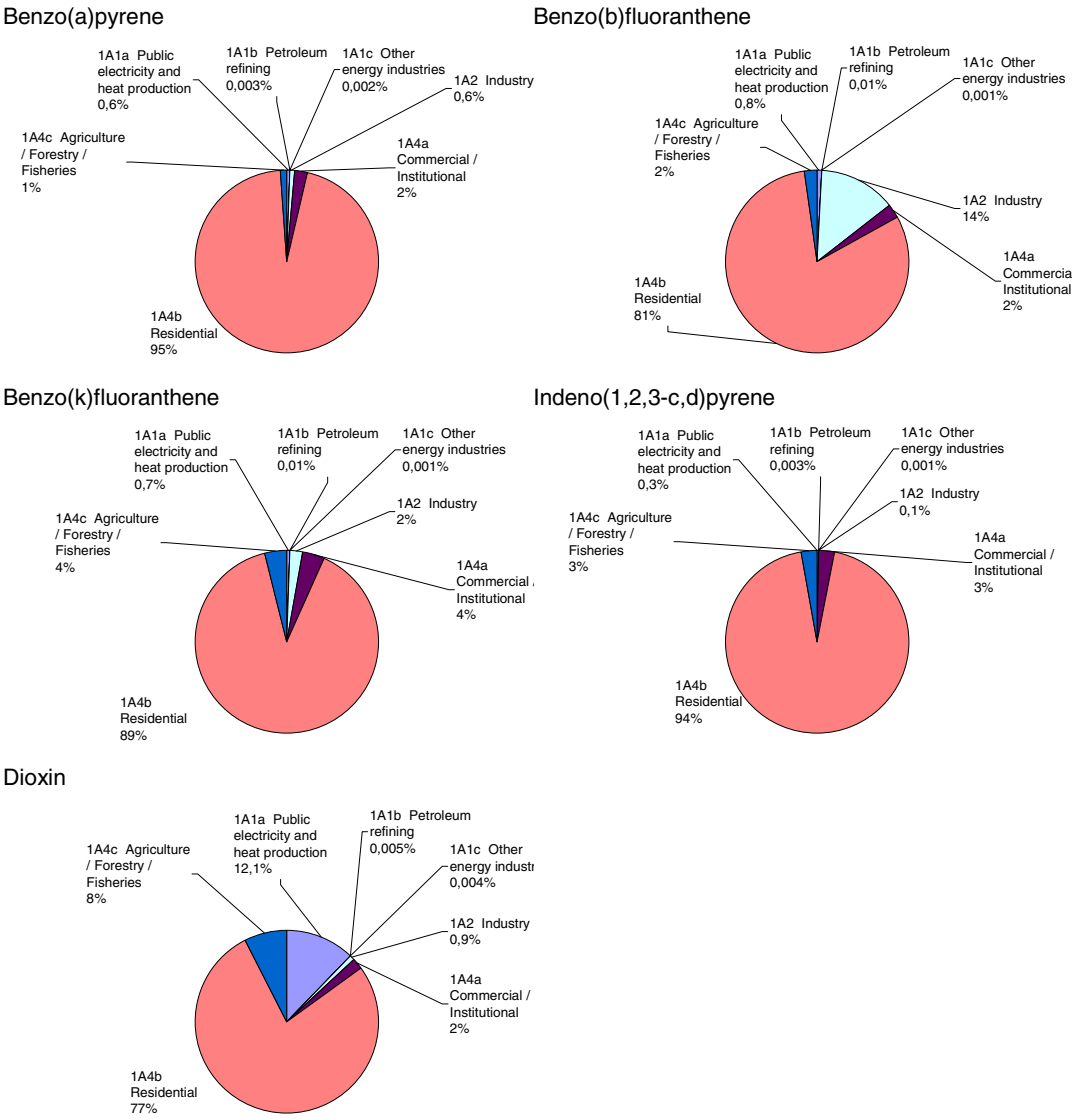


Figure 3.13 PAH emission sources, stationary combustion plants, 2005

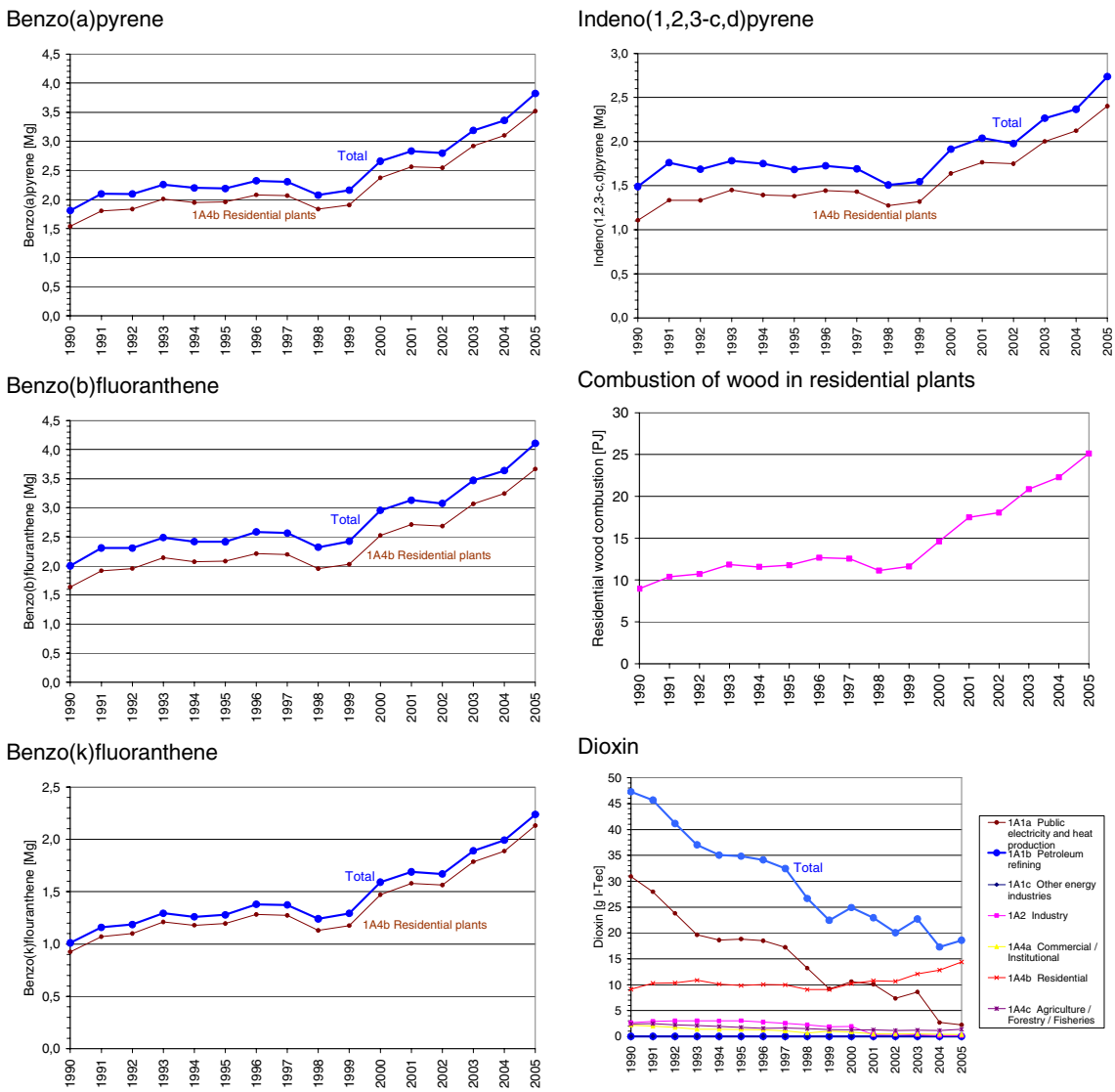


Figure 3.14 PAH emission time-series, stationary combustion plants. Comparison with wood consumption in residential plants.

3.2.9 Methodological issues

The Danish emissions inventory is based on the CORINAIR (CORe INventory on AIR emissions) system, which is a European programme for air emission inventories. CORINAIR includes the methodology structure and software for inventories. The methodology is described in the "EMEP/Corinair Emission Inventory Guidebook", 3rd edition, prepared by the UNECE/EMEP Task Force on Emissions Inventories and Projections (EMEP/Corinair 2004). Emission data are stored in an Access database, from which data are transferred to the reporting formats.

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 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 2005, 75 stationary combustion plants are specified as large point sources. These point sources include:

- Power plants and decentralised CHP plants (combined heat and power plants)
- Municipal waste incineration plants
- Large industrial combustion plants
- Petroleum refining plants

The criteria for selection of point sources consist of the following:

- All centralised 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 or above and a significant fuel consumption
- All waste incineration plants included in the Danish law "Bekendtgørelse om visse listevirksomheders pligt til at udarbejde grønt regnskab".
- Industrial plants
    - With an installed effect of 50 MW or above and significant fuel consumption.
    - With a significant process-related emission.

The fuel consumption of stationary combustion plants registered as large point sources is 341 PJ (2005). This corresponds to 64% of the overall fuel consumption for stationary combustion.

Further details on large point sources are shown in Annex 2A. The number of large point sources registered in the databases increased from 1990 to 2005. In the emission databases for the years before 1990, only one large point source was registered.

If plant-specific emission factors are not available, general area source emission factors are used. Plant-specific emission data are obtained from:

- Annual environmental reports
- Annual plant-specific reporting of SO_2 and NO_X from power plants >25MW_e prepared for the Danish Energy Authority due to a Danish legislatory requirement
- Emission data reported by Elsam and E2, the two major electricity suppliers
- Emission data reported from industrial plants

Annual environmental reports for the plants include a considerable number of emission datasets. Emission data from annual environmental

reports are, in general, based on emission measurements, but some emissions have potentially been calculated from general emission factors.

Area sources

Fuels not combusted in large point sources are included as sector-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 below.

Activity rates, fuel consumption

The fuel consumption rates are based on the official Danish energy statistics prepared by the Danish Energy Authority. The Danish Energy Authority aggregates fuel consumption rates to SNAP sector categories (DEA 2006a). Some fuel types in the official Danish energy statistics are added to obtain a less detailed fuel aggregation level, see Annex 2A. The calorific values on which the energy statistics are based are also enclosed in Annex 2A.

The fuel consumption of the NFR sector *1A2 Manufacturing industries and construction* (corresponding to SNAP sector *03 Combustion in manufacturing industries)* is not disaggregated into specific industries in the NERI emission database. To date, disaggregation into specific industries has only been estimated for reporting to the Climate Convention. Disaggregation for LRTAP Convention reporting is planned in the future.

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 628 TJ) is added to the apparent consumption of petroleum coke and the emissions are included in the inventory.

The Danish Energy Authority (DEA) compiles a database for the fuel consumption of each district heating and power-producing plant, based on data reported by plant operators. The fuel consumption of large point sources specified in the Danish emission database refers to the DEA database (DEA 2006c).

The fuel consumption of area sources is calculated as total fuel consumption minus fuel consumption of large point sources.

Emissions from non-energy use of fuels have not been included in the Danish inventory. The Danish energy statistics include three fuels used for non-energy purposes: bitumen, white spirit and lube oil. The fuels used for non-energy purposes add up to about 2% of the total fuel consumption in Denmark.

In Denmark, all municipal 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)*.

Fuel consumption data are presented in Chapter 3.2.1.2.

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 international guidebooks: EMEP/Corinair guidebook (EMEP/Corinair 2004) and the IPCC reference manual (IPCC 1996).

A complete list of emission factors for 2005, time-series for emission factors and detailed references are enclosed in Annex 2A. The area source emission factors in 2005 for SO_2, NO_X, NMVOC and CO are shown in Table 3.13.

Table 3.13 SO_2, NO_X, NMVOC and CO emission factors 2005

Fuel	NFR sector	SNAP	SO_2 [g/GJ]	NO_X [g/GJ]	NMVOC [g/GJ]	CO [g/GJ]
COAL	1A1a	010101, 010102, 010103	41	127	1.5	10
COAL	1A1a, 1A2f, 1A4c	010202, 010203, 0301, 0203	574	95	15	10
COAL	1A4b	0202	574	95	15	2 000
BROWN COAL BRI.	1A4b	0202	574	95	15	2 000
COKE OVEN COKE	1A2f	0301	574	95	15	10
COKE OVEN COKE	1A4b	0202	574	95	15	2 000
PETROLEUM COKE	1A2f	0301	605	95	1.5	61
PETROLEUM COKE	1A4a, 1A4b, 1A4c	0201, 0202, 0203	605	50	1.5	1 000
WOOD AND SIMIL.	1A1a	010102, 010103, 010104	1.74	69	3.3	79
WOOD AND SIMIL.	1A1a	010105	25	130	48	50
WOOD AND SIMIL.	1A1a, 1A2f	010202, 010203, 0301, 030102, 030103	25	130	48	240
WOOD AND SIMIL.	1A4a, 1A4c	0201, 020105, 0203	25	130	600	240
WOOD AND SIMIL.	1A4b	0202	25	120	598	9 000
MUNICIP. WASTES	1A1a	010102, 010103, 010104, 010105	23.9	124	0.98	7.4
MUNICIP. WASTES	1A1a, 1A2f, 1A4a	010203, 030102, 0201, 020103	67	164	9	10
STRAW	1A1a	010102, 010103	47.1	131	0.8	63
STRAW	1A1a, 1A2f, 1A4c	010202, 010203, 030105, 020302	130	153	50	325
STRAW	1A4b, 1A4c	0201, 0203	130	153	600	4 000
RESIDUAL OIL	1A1a	0101, 010101, 010102, 010103, 010104, 010105	283	127	3	15
RESIDUAL OIL	1A1a, 1A4a, 1A4b, 1A4c	010202, 010203, 0201, 0202, 0203, 020302	344	142	3	30
RESIDUAL OIL	1A1b	010306	537	142	3	30
RESIDUAL OIL	1A2f	0301, 030102, 030103	344	130	3	30
RESIDUAL OIL	1A2f	030104	344	130	3	15
RESIDUAL OIL	1A2f	030105	344	130	3	100
RESIDUAL OIL	1A4c	020304	344	142	3	100
GAS OIL	1A1a	0101, 010101, 010102	23	249	1.5	15
GAS OIL	1A1a, 1A2f	Gas turbines: 010104, 030104	23	350	2	15
GAS OIL	1A1a, 1A1c, 1A2f, 1A4a, 1A4c	Engines: 010105, 010205, 010505, 030105, 020105, 020304	23	700	100	100
GAS OIL	1A1a	010103	23	65	1.5	15
GAS OIL	1A1a, 1A1b, 1A2f	010202, 010203, 010306, 0301, 030102, 030103, 030106	23	65	1.5	30
GAS OIL	1A4a, 1A4c	0201, 020103, 0203	23	52	3	30
GAS OIL	1A4b	0202	23	52	3	43
KEROSENE	all	all	5	50	3	20
FISH & RAPE OIL	1A1a	010103	1	220	1.5	15
FISH & RAPE OIL	1A1a	010202, 010203	1	65	1.5	15
FISH & RAPE OIL	1A2f, 1A4c	030105, 020304	1	700	100	100
ORIMULSION	1A1a	010101	12	86	3	15
NATURAL GAS	1A1a	0101, 010101, 010102	0.3	97	2	15
NATURAL GAS	1A1a, 1A2f, 1A4a, 1A4c	Gas turbines: 010104, 030104, 020104, 020303	0.3	124	1.4	6.2
NATURAL GAS	1A1a, 1A1c, 1A2f, 1A4a, 1A4b, 1A4c	Gas engines: 010105, 010205, 010505, 030105, 020105, 020204, 020304	0.3	168	117	175
NATURAL GAS	1A1a, 1A2f	010103, 010202, 010203, 0301, 030103, 030106	0.3	42	2	28
NATURAL GAS	1A1c	010504	0.3	250	1.4	6.2
NATURAL GAS	1A4a, 1A4c	0201, 020103, 0203	0.3	30	2	28
NATURAL GAS	1A4b	0202, 020202	0.3	30	4	20
LPG	1A1a, 1A2f	010203, 0301	0.13	96	2	25
LPG	1A4a, 1A4c	0201, 0203	0.13	71	2	25
LPG	1A4b	0202	0.13	47	2	25
REFINERY GAS	1A1b	010304	1	170	1.4	6.2
BIOGAS	1A1a, 1A2f, 1A4a, 1A4c	010102, 010103, 010203, 0301, 0201, 020103, 0203	25	28	4	36
BIOGAS	1A1a, 1A1c, 1A2f, 1A4a, 1A4c	Gas engines: 010105, 010505, 030105, 020105, 020304	19.2	540	14	273
BIOGAS	1A2f	030102	25	59	4	36

Most country-specific emission factors refer to:

- Danish legislation
- A emission measurement programme for decentralised CHP plants
- Other Danish research reports
- Calculations based on plant-specific emissions from a considerable number of power plants
- Calculations based on plant-specific emissions from a considerable number of municipal waste incineration plants

SO_2 and NO_X emissions from large point sources are often plant specific i.e. based on emission measurements. Emissions of CO, NMVOC, PM and heavy metals are also plant specific in some cases.

Some of the area source emission factors for power plants and municipal waste CHP plants take into account that large plants are included in the inventory as large point sources with plant-specific emission data. Thus, some area source emission factors are default values which assume that the remaining fuel consumption is combusted in smaller units with less effective flue gas cleaning. The area source emission factors are, therefore, not necessarily average values for these plant categories.

3.2.10 Uncertainties and time-series consistency

Time-series for fuel consumption and emission are shown and discussed in Chapter 3.2.1.2 and 3.2.1.3.

Methodology

The applied methodology for uncertainty estimates refers to Pulles & Aardenne (2001). 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 the year 2005 as well as on uncertainties for fuel consumption and emission factors for each of the main SNAP sectors. For particulate matter, 2000 is considered to be the base year, but for all other pollutants the base year is 1990. The applied uncertainty estimates for activity rates and emission factors are default values referring to Pulles & Aardenne 2001. The uncertainty for PM is, however, estimated by NERI. The default uncertainty estimates for emission factors are given in letter codes representing an uncertainty range. It has been assumed that the uncertainty estimates were in the lower end of the range for all sources and pollutants. The values applied for emission factors are listed in Table 3.14. The uncertainty for fuel consumption in stationary combustion plants was assumed to be 2%.

Table 3.14 Uncertainty values for emission factors [%].

SNAP sector	SO_2	NO_X	NMVOC	CO	PM	HM	PAH
01	10	20	50	20	50	100	100
02	20	50	50	50	500	1 000	1 000
03	10	20	50	20	50	100	100

Results

Uncertainty estimates include uncertainty regarding the total emission as well as uncertainty relating to the trend. The estimated uncertainties for stationary combustion emission inventories are shown in Table 3.15. Detailed calculation sheets are shown in Annex 2A.

The total emission uncertainty is 7% for SO_2, 16% for NO_X, 42% for NMVOC and 46% for CO. For PM, heavy metals, except Pb, and PAH, the uncertainty estimate is greater than 100%.

Table 3.15 Danish uncertainty estimates, 2005

Pollutant	Uncertainty Total emission [%]	Trend 1990-2005 [%]	Uncertainty Trend [%-age points]
SO_2	7	-88	±0.7
NO_X	16	-41	±2.6
NMVOC	42	+73	±10
CO	46	+49	±5
TSP [1)]	452	+33	±27
PM_{10} [1)]	468	+32	±33
$PM_{2.5}$ [1)]	475	+33	±27
As	130	-63	±11
Cd	356	-46	±116
Cr	101	-85	±5
Cu	239	-71	±43
Hg	227	-61	±45
Ni	103	-63	±3
Pb	93	-75	±4
Se	120	-65	±14
Zn	217	+2	±60
Benzo(b)fluoranthene	971	+66	±7
Benzo(k)fluoranthene	987	+186	±86
Benzo(a)pyrene	991	+101	±6
Indeno(1,2,3-c,d)	995	+74	±14

1. The base year for PM is year 2000

3.2.11 Source specific QA/QC and verification

A QA/QC plan is implemented. A thorough description can be found in Denmark's National Inventory Report (Illerup et al. 2007a)

The QC includes:

- Checking of time-series in the IPCC and SNAP source categories. Considerable changes are controlled and explained.
- Comparison with the inventory of the previous year. Any major changes are verified.
- Total emission, when aggregated to IPCC and LRTAP reporting tables, is compared with totals based on SNAP source categories (control of data transfer).
- A manual log table in the emission databases is applied to collect information about recalculations.

- The IPCC reference approach validates the fuel consumption rates and CO_2 emissions of fuel combustion. Fuel consumption rates and CO_2 emissions differ by less than 1.6% (1990-2005). The reference approach is further discussed in annex 2A.
- The emission from each large point source is compared with the emission reported the previous year.
- Some automated checks have been prepared for the emission databases:
  - Check of units for fuel rate, emission factor 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
- Most emission factor references are now incorporated in the emission database, itself.
- Annual environmental reports are kept for subsequent control of plant-specific emission data.
- QC checks of the country-specific emission factors have not been performed, but most factors are based on work from companies that have implemented some QA/QC work. The two major power plant owners / operators in Denmark: E2 and Elsam both obtained the ISO 14001 certification for an environmental management system. Danish Gas Technology Centre and dk-Teknik[1] both run accredited laboratories for emission measurements.

3.2.12 Source specific recalculations

Improvements and recalculations since the 2006 emission inventory include:

- Update of fuel rates according to the latest energy statistics. The update included the years 1980-2004.
- Emission factors for NMVOC, TSP, PM10, PM2.5 & PAH for residential wood combustion has been updated as time-series based on new research

3.2.13 Source specific planned improvements

The planned improvements of the inventory include:

1) Improved documentation for emission factors
   Reporting of and references for the applied emission factors have been improved in the current year and will be further developed in future inventories.
2) QA/QC and validation
   The QA/QC and validation of the inventories for stationary combustion will be further expanded as part of the ongoing work that for the Danish inventory as a whole. The work is documented in Denmark's National Inventory Report (Illerup et al. 2007a)
3) Uncertainty estimates

[1] Now FORCE

Uncertainty estimates are based mainly on default uncertainty levels for activity rates and emission factors. More country-specific uncertainty estimates will be incorporated in future inventories.

4) Other improvements
HM emission factors should be compared with new Danish legislation and updated if necessary.

3.3 Transport and other mobile sources (NFR sector 1A2, 1A3, 1A4 and 1A5)

The emission inventory basis for mobile sources is fuel use 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) 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/CORINAIR Emission Inventory Guidebook. However, for railways, measurements specific to Denmark are used.

In the Danish emission 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 UN-ECE Conventions is based on a correspondence list between SNAP and NFR classification codes shown in Table 3.16 below (mobile sources only).

Table 3.16 SNAP – NFR correspondence table for transport

SNAP classification	NFR classification
07 Road transport	1A3b Transport-Road
0801 Military	1A5 Other
0802 Railways	1A3c Railways
0803 Inland waterways	1A3d Transport-Navigation
080402 National sea traffic	1A3d Transport-Navigation
080403 National fishing	1A4c Agriculture/forestry/fisheries
080404 International sea traffic	1A3d Transport-Navigation (international)
080501 Dom. airport traffic (LTO < 1000 m)	1A3a Transport-Civil aviation
080502 Int. airport traffic (LTO < 1000 m)	1A3a Transport-Civil aviation (international)
080503 Dom. cruise traffic (> 1000 m)	1A3a Transport-Civil aviation
080504 Int. cruise traffic (> 1000 m)	1A3a Transport-Civil aviation (international)
0806 Agriculture	1A4c Agriculture/forestry/fisheries
0807 Forestry	1A4c Agriculture/forestry/fisheries
0808 Industry	1A2f Industry-Other
0809 Household and gardening	1A4b Residential

Military transport activities (land and air) refer to the NFR sector Other (1A5), while the Transport-Navigation sector (1A3d) comprises national sea transport (ship movements between two Danish ports) and small boats and pleasure craft. The working machinery and equipment in industry is grouped in Industry-Other (1A2f), while agricultural and forestry machinery is accounted for in the Agriculture/forestry/fisheries (1A4c) sector together with fishing activities.

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.

Fuel consumption

Table 3.17 Fuel use (PJ) for domestic transport in 2005 in NFR sectors

NFR ID	Fuel use (PJ)
Industry-Other (1A2f)	13.0
Civil Aviation (1A3a)	1.9
Road (1A3b)	165.3
Railways (1A3c)	3.1
Navigation (1A3d)	7.3
Residential (1A4b)	4.1
Ag./for./fish. (1A4c)	21.3
Military (1A5)	3.7
Total	219.6

Table 3.17 shows the fuel use for domestic transport based on DEA statistics for 2005 in NFR sectors. The fuel use figures in time-series 1990-2005 are given in Annex 2.B.14 (NFR format) and are shown for 1990 and 2005 in Annex 2.B.13 (CollectER format). Road transport has a major share of the fuel consumption for domestic transport. In 2005 this sector's fuel use share is 75%, while the fuel use shares for Agriculture/forestry/fisheries and Industry-Other are 10 and 6%, respectively. For the remaining sectors the total fuel use share is 9%.

From 1985 to 2005, diesel and gasoline fuel use has increased by 39% and 25%, respectively, and in 2005 the fuel use shares for diesel and gasoline were 60% and 37%, respectively (Figures 3.15 and 3.16). Other fuels only have a 3% share of the domestic transport total. Almost all gasoline is used in road transportation vehicles. Gardening machinery and recreational craft are merely small consumers. Regarding diesel, there is considerable fuel use in most of the domestic transport 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.

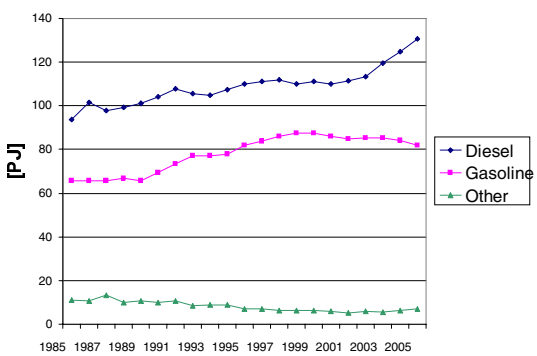


Figure 3.15 Fuel consumption per fuel type for domestic transport 1985-2005

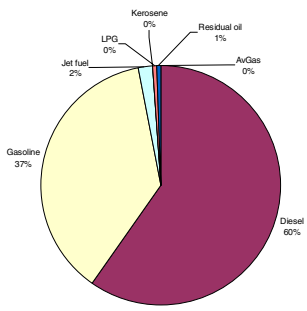


Figure 3.16 Fuel use share per fuel type domestic transport in 2005

Road transport

As shown in Figure 3.17, the energy use for road transport increased until 2000, where a small fuel use decline can be noted. From 2002 onwards, fuel consumption increases. The fuel use development is due to a slight decrease in the use of gasoline fuels from 1999 onwards combined with a steady growth in the use of diesel. Within subsectors, passenger cars represent the most fuel-consuming vehicle category, followed by heavy-duty vehicles, light duty vehicles and 2-wheelers, in decreasing order (Figure 3.18).

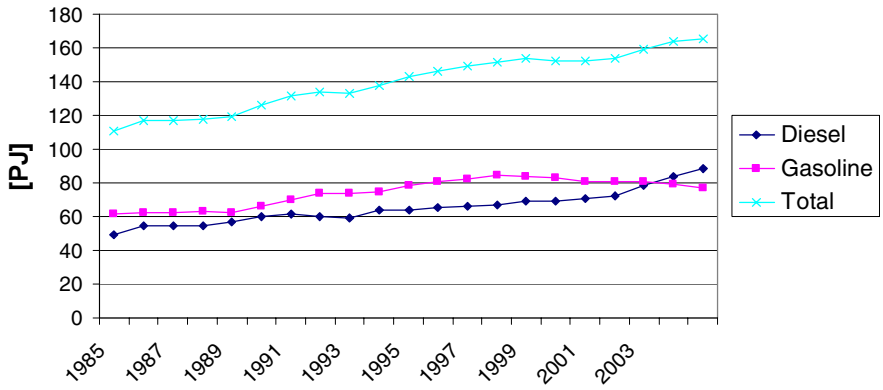


Figure 3.17 Fuel consumption per fuel type and as totals for road transport 1985-2005

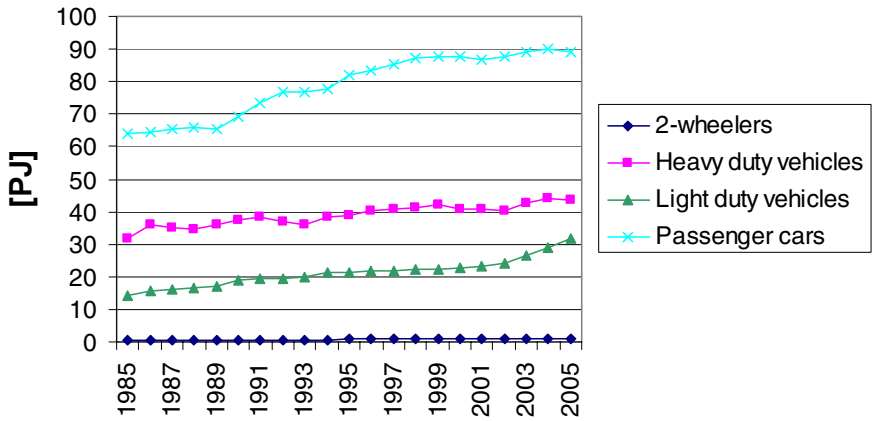


Figure 3.18 Total fuel consumption per vehicle type for road transport 1985-2005

As shown in Figure 3.19, fuel consumption for gasoline passenger cars dominates the overall gasoline consumption trend. The development in diesel fuel consumption in recent years (Figure 3.20) is characterised by increasing fuel use for diesel passenger cars and light duty vehicles, while the fuel use for trucks and buses (heavy-duty vehicles), since 1999, has fluctuated. The sudden increase in fuel consumption for heavy-duty vehicles in 2003 is, however, significant.

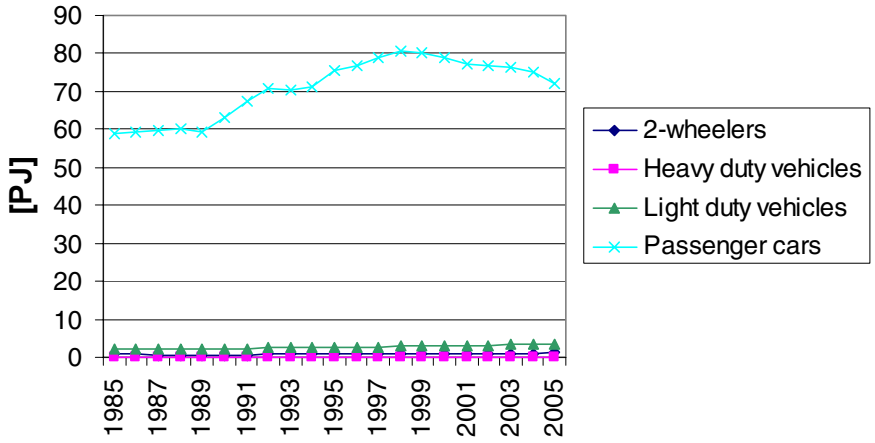


Figure 3.19 Gasoline fuel consumption per vehicle type for road transport 1985-2005

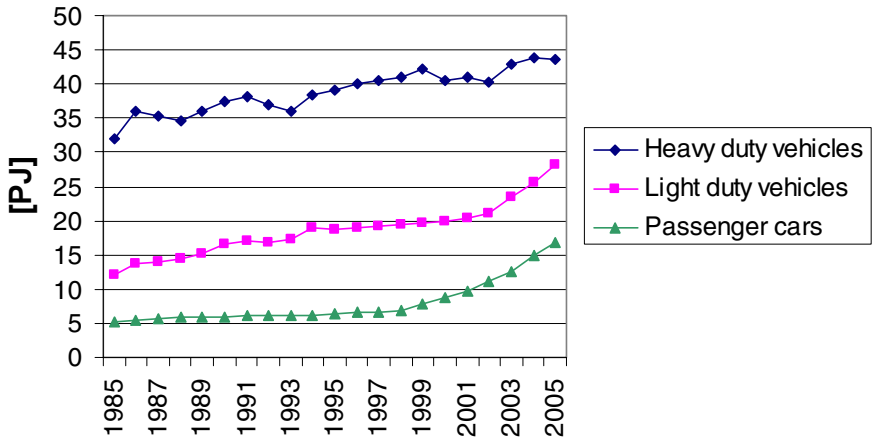


Figure 3.20 Diesel fuel consumption per vehicle type for road transport 1985-2005

In 2005, fuel consumption shares for gasoline passenger cars, heavy-duty vehicles, diesel light duty vehicles, diesel passenger cars and gasoline light duty vehicles were 44, 26, 17, 10 and 2%, respectively (Figure 3.21).

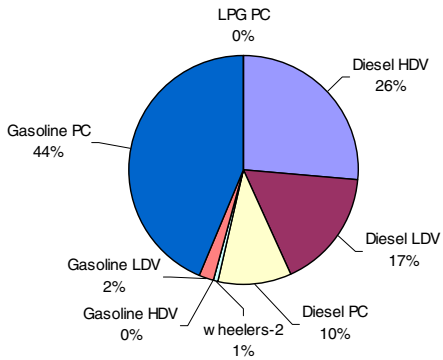


Figure 3.21 Fuel use share (PJ) per vehicle type for road transport in 2005

Other mobile sources

It must be noted that the fuel use 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 use in-

formation, and fuel use totals are subsequently estimated from activity data and fuel use factors. For 2005 no new stock information has been gathered for the machinery types in household and gardening and for recreational craft, and thus the 2004 total stock information is repeated for this year.

As seen in Figure 3.22, classified according to NFR the most important sectors are Agriculture/forestry/fisheries (1A4c), Industry-other (mobile machinery part of 1A2f) and Navigation (1A3d). Minor fuel consuming sectors are Civil Aviation (1A3a), Railways (1A3c), Other (military mobile fuel use: 1A5) and Residential (1A4b).

The 1985-2005 time-series are shown per fuel type in Figures 3.23-3.26 for diesel, gasoline, residual oil and jet fuel, respectively.

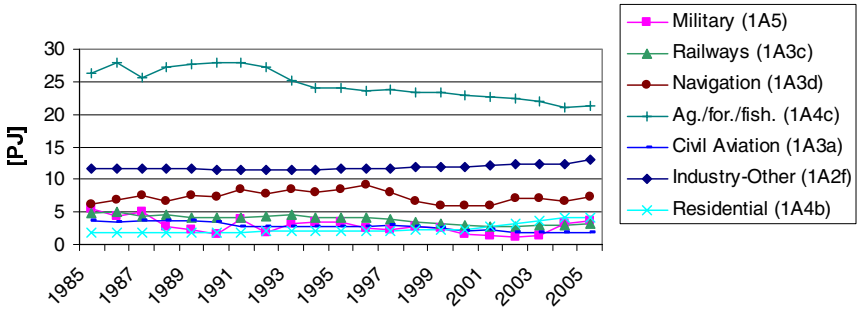


Figure 3.22 Total fuel use in NFR sectors for other mobile sources 1985-2005

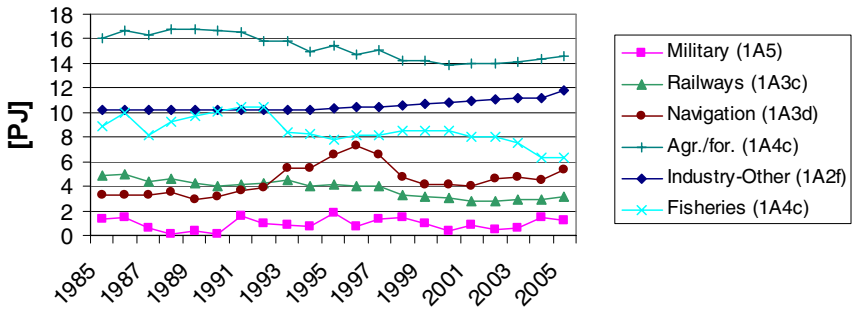


Figure 3.23 Diesel fuel use in NFR sectors for other mobile sources 1985-2005

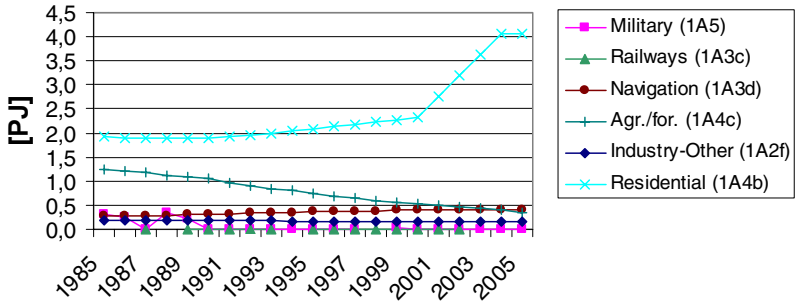


Figure 3.24 Gasoline fuel use in NFR sectors for other mobile sources 1985-2005

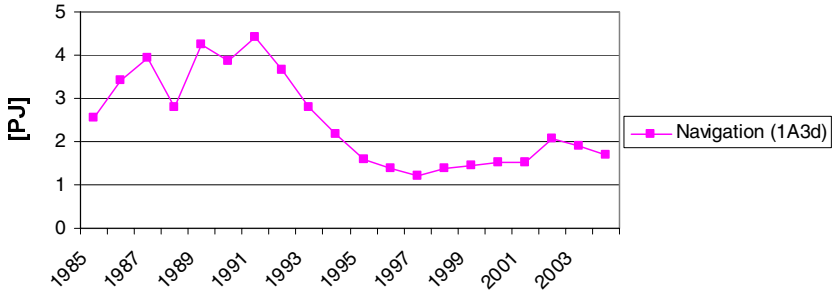


Figure 3.25 Residual oil fuel use in NFR sectors for other mobile sources 1985-2005

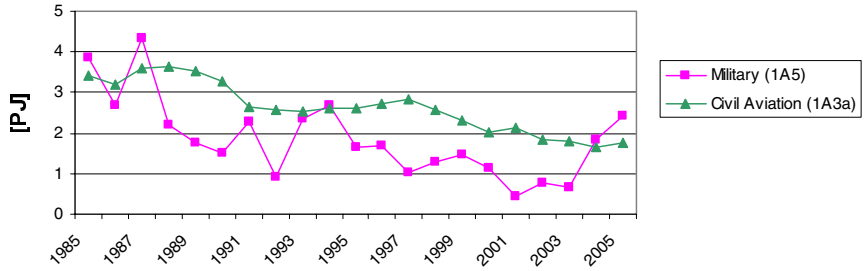


Figure 3.26 Jet fuel use in NFR sectors for other mobile sources 1985-2005

In terms of diesel, the fuel use decreases for agricultural machines until 2000, due to fewer numbers of tractors and harvesters. After that, the increase in the engine sizes of new sold machines has more than outbalanced the trend towards smaller total stock numbers. The fuel use for industry has increased from the beginning of the 1990's, due to an increase in the activities for construction machinery. For fisheries, the development in fuel use reflects the activities in this sector.

The Navigation sector comprises national sea transport (fuel use between two Danish ports) and recreational craft. For the latter category, fuel use has increased significantly from 1985 to 2004 due to the rising number diesel-fuelled private boats. For national sea transport, diesel fuel use shows some fluctuations over the same time period. However, for 1997 and 1998, a sudden decline in fuel use 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 use and the emissions for this transport sector. The fuel used (and associated emissions) to produce electricity is accounted for in the stationary source part of the Danish inventories.

The largest gasoline fuel use is found for household and gardening machinery in the Residential (1A4b) sector. Especially from 2001-2004, a significant fuel use increase is apparent due to considerable growth in the machinery stock. The decline in gasoline fuel use for Agriculture/forestry/fisheries (1A4c) is due to the gradual phasing out of gasoline-fuelled agricultural tractors.

The considerable variations from one year to another in military jet fuel use 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 use. Civil aviation has decreased since the building of the Great Belt Bridge, both in terms of number of flights and total jet fuel use.

In terms of residual oil there has been a substantial decrease in the fuel use for sea vessels. The fuel use decline is most significant from 1991-1997.

Bunkers

The residual oil and diesel oil fuel use 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 use drop in 2002 is explained by the recession in the air traffic sector due to the events of September 11, 2001 and structural changes in the aviation business.

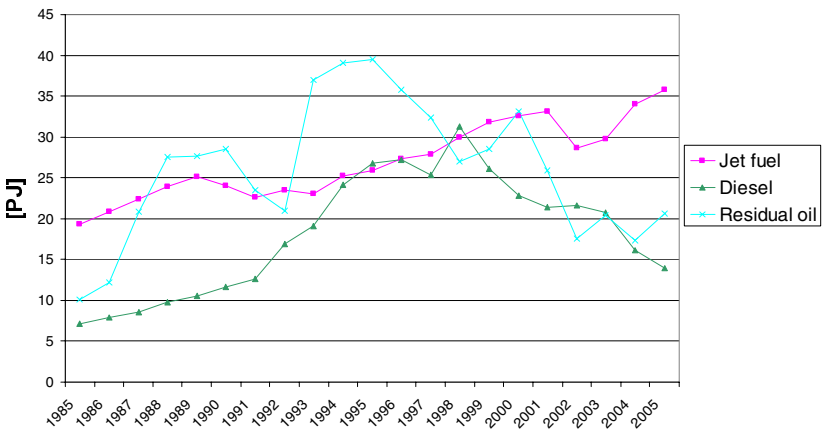


Figure 3.27 Bunker fuel use 1985-2005

Emissions of SO_2, NO_X, NMVOC and CO

In Table 3.18 the SO_2, NO_X, NMVOC and CO emissions for road transport and other mobile sources are shown for 2005 in NFR sectors. The emission figures in the time-series 1985-2005 are given in Annex 2.B.14 (NFR format) and are shown for 1990 and 2005 in Annex 2.B.13 (CollectER format).

From 1985 to 2005, the road transport emissions of NMVOC, CO and NO_X emissions have decreased by 70, 66 and 26%, respectively (Figures 3.29-3.31). The highest CO, NO_X and NMVOC emissions occur in 1991, after which the emissions drop by 60, 36 and 70%, respectively, until 2005.

For other mobile sources, the emissions of NO_X decreased by 3% from 1985 to 2005 and for SO_2 the emission drop is as much as 79%. In the same period, the emissions of NMVOC have declined by 8%, whereas the CO emissions have increased by 1% (Figures 3.33-3.36).

Table 3.18 Emissions of SO_2, NO_X, NMVOC and CO in 2005 for road transport and other mobile sources

NFR ID	SO_2 [tons]	NO_X [tons]	NMVOC [tons]	CO [tons]
Industry-Other (1A2f)	28	10664	1620	7497
Civil Aviation (1A3a)	43	579	165	858
Railways (1A3c)	1	3724	235	648
Navigation (1A3d)	1975	9645	1394	7802
Residential (1A4b)	2	327	8727	115088
Ag./for./fish. (1A4c)	628	20713	2483	15899
Military (1A5)	57	1332	113	821
Total other mobile	2733	46985	14737	148612
Road (1A3b)	77	68105	24325	188071
Total mobile	28	10664	1620	7497

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 3.28). 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 2005 shares for SO_2 emissions and fuel use for passenger cars, heavy-duty vehicles, light-duty vehicles and 2-wheelers are the same in each case: 53, 27, 19 and 1%, respectively (Figure 3.32).

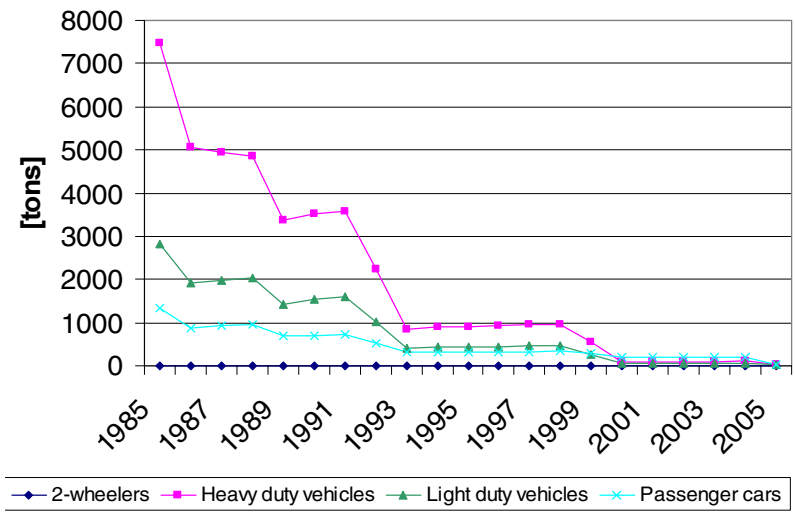


Figure 3.28 SO_2 emissions (tonnes) per vehicle type for road transport 1985-2005

Historically, the emission totals of NMVOC and CO have been very dominated by the contributions coming from private cars, as shown in Figures 3.30-3.31. 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 II and III private cars (introduced in 1997 and 2001, respectively).

In the case of NO_x, the real traffic emissions for heavy duty vehicles do not decline follow the reductions as intended by the EU emission legislation. This is 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 switches to a fuel efficient engine running mode, thus leading to increasing NO_x emissions.

In 2005, the emission shares for heavy-duty vehicles, passenger cars, light-duty vehicles and 2-wheelers were 52, 33, 15 and 0%, respectively, for NO_X; 6, 67, 7 and 20%, respectively, for NMVOC; and 4, 81, 7 and 8%, respectively, for CO (Figure 3.32).

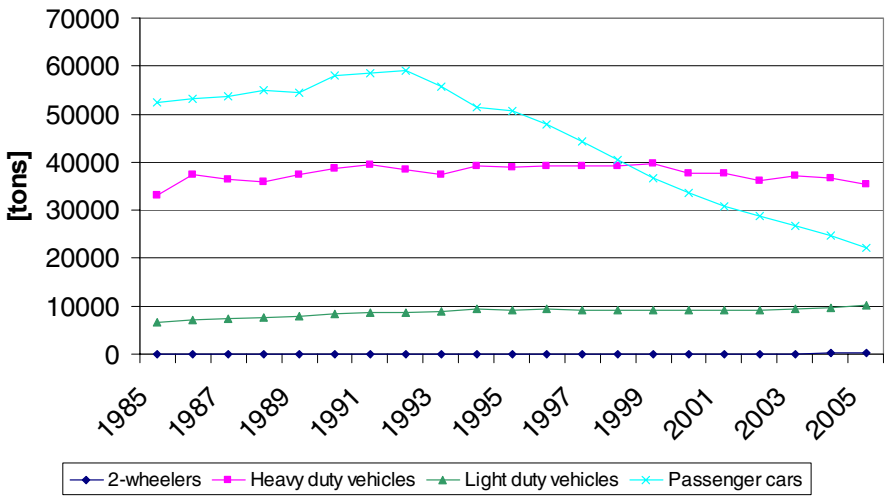


Figure 3.29 NO_X emissions (tonnes) per vehicle type for road transport 1985-2005

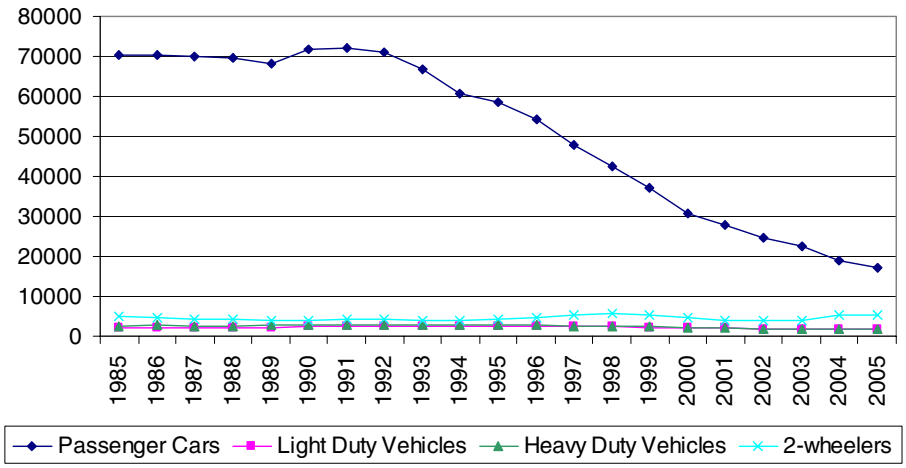


Figure 3.30 NMVOC emissions (tonnes) per vehicle type for road transport 1985-2005

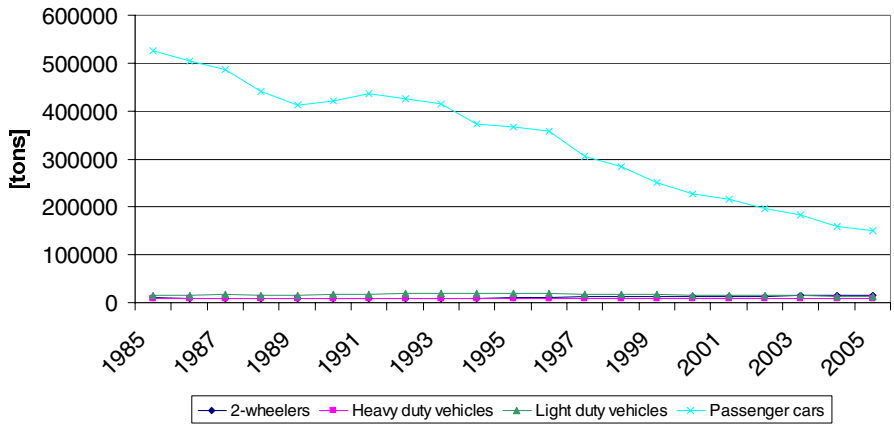


Figure 3.31 CO emissions (tonnes) per vehicle type for road transport 1985-2005

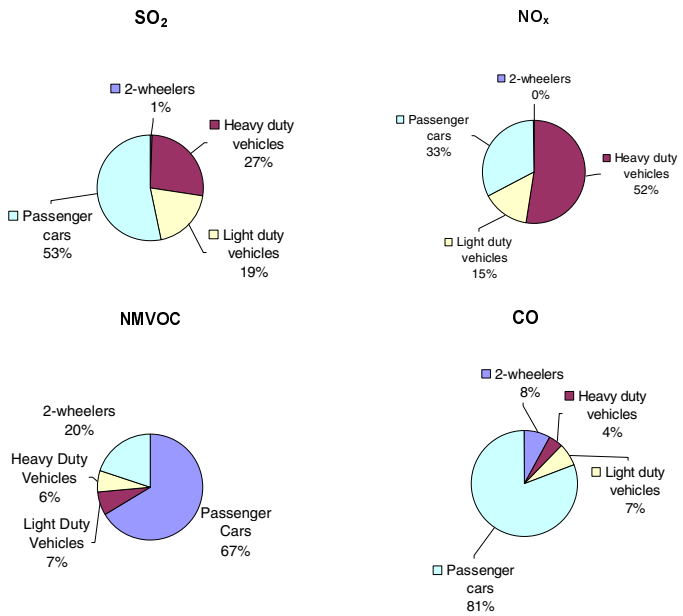


Figure 3.32 SO_2, NO_X, NMVOC and CO emission shares per vehicle type for road transport in 2005

Other mobile sources

SO_2 emissions decrease significantly from 1985 to 1996, as shown in Figure 3.33. The lowering is due to a decrease in the use of residual oil by ships in Navigation (1A3d) and a reduction in sulphur content for marine gas oil in Navigation (1A3d) and Fisheries (1A4c), and sulphur content reductions for diesel used by, among others, Railways (1A3c) and non-road machinery in Agriculture/forestry (1A4c) and Industry (1A2f).

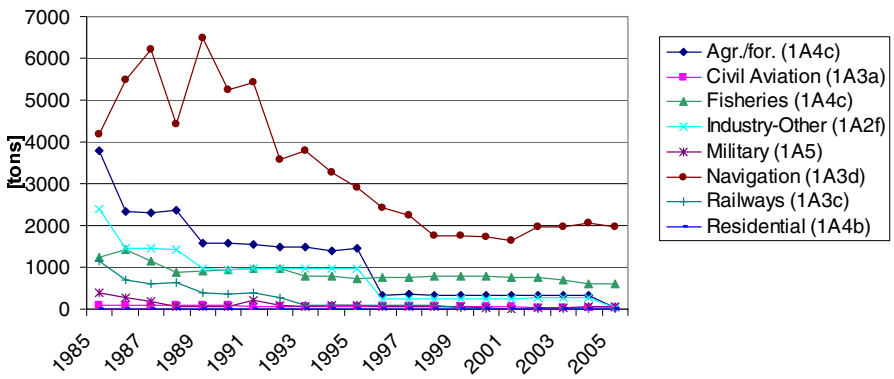


Figure 3.33 SO_2 emissions (k-tonnes) in NFR sectors for other mobile sources 1985-2005

In general, the emissions of NO_X, NMVOC and CO from diesel-fuelled working equipment and machinery in agriculture, forestry and industry have decreased slightly since the end of the 1990s due to gradually strengthened emission standards given by the EU emission legislation directives.

NO_X emissions mainly come from diesel machinery, and the most important sources are Agriculture/forestry/fisheries (1A4c), Industry (1A2f),

Navigation (1A3d) and Railways (1A3c), as shown in Figure 3.34. The 2005 emission shares are 43, 23, 21 and 8%, respectively (Figure 3.37). Minor emissions come from the sectors, Civil Aviation (1A3a), Military (1A5) and Residential (1A4b).

The NO_X emission trend for Navigation, Fisheries and Agriculture is determined by fuel use fluctuations for these sectors, and the development of emission factors. For ship engines the emission factors tend to increase for new engines until mid 1990's. 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. For agricultural machines, there have been somewhat higher NO_x emission factors for 1991-stage I machinery, and an improved emission performance for stage I and II machinery since the late 1990s.

The emission development for industry NO_x is the product of a slight fuel-use increase from 1985 to 2005 and a development in emission factors as explained for agricultural machinery. For railways, the gradual shift towards electrification explains the declining trend in diesel fuel use and NO_X emissions for this transport sector until 2001.

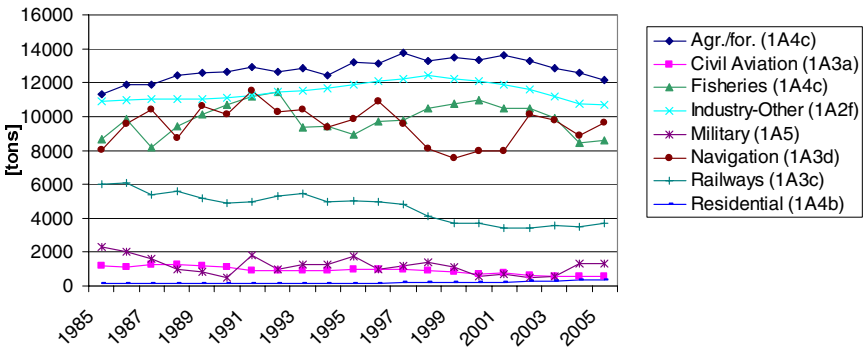


Figure 3.34 NO_X emissions (tonnes) in NFR sectors for other mobile sources 1985-2005

The 1985-2005 time-series of NMVOC and CO emissions are shown in Figures 3.35 and 3.36 for other mobile sources. The 2005 sector emission shares are shown in Figure 3.37. For NMVOC, the most important sectors are Residential (1A4b), Agriculture/forestry/fisheries (1A4c), Industry (1A2f) and Navigation (1A3d), with 2005 emission shares of 59, 17, 11 and 9%, respectively. The same four sectors also contribute with most of the CO emissions in the same consecutive order; the emission shares are 77, 11, 5 and 5%, respectively. Minor NMVOC and CO emissions come from Railways (1A3c), Civil Aviation (1A3a) and Military (1A5).

For NMVOC and CO, the significant emission increases for the residential sector 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 Navigation decrease due to

the gradually phase-out of the 2-stroke engine technology for recreational craft. The main reason for the significant 1985-2005 CO emission decrease for Agriculture/forestry/fisheries is the phasing out of gasoline tractors.

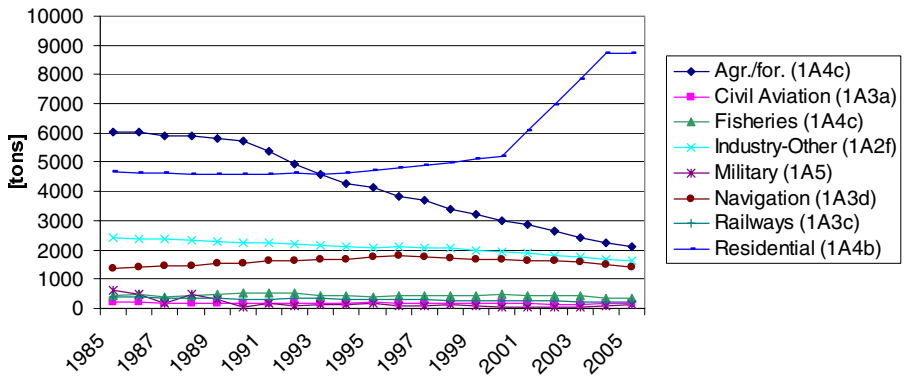


Figure 3.35 NMVOC emissions (tonnes) in NFR sectors for other mobile sources 1985-2005

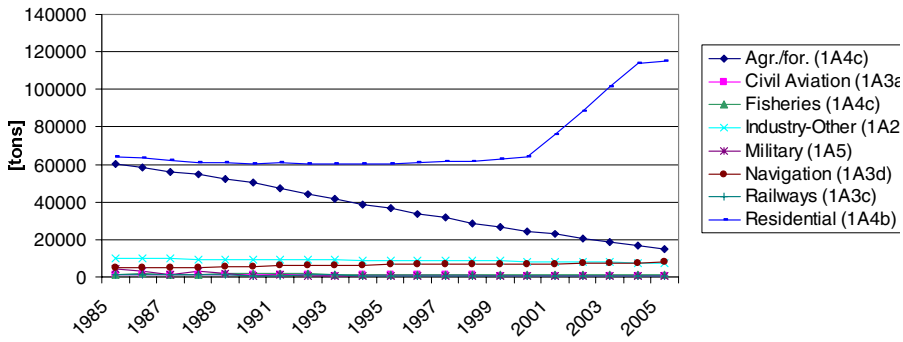


Figure 3.36 CO emissions (tonnes) in NFR sectors for other mobile sources 1985-2005

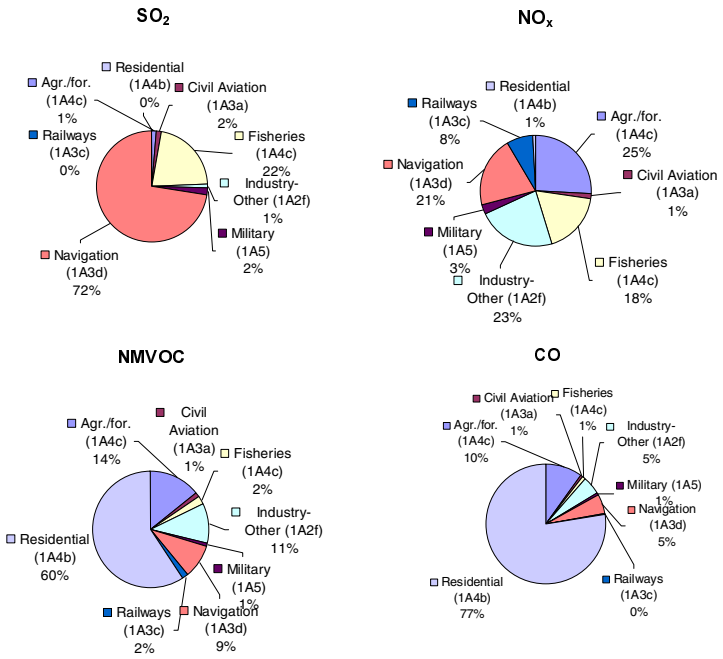


Figure 3.37 SO_2, NO_X, NMVOC and CO emission shares for other mobile sources in 2005

Particulate matter (PM)

The Danish emission inventories comprise the exhaust emission estimates of particulate matter (PM) for all mobile sources. In addition, the inventories include the non-exhaust PM emissions coming from road transport brake and tyre wear, and road abrasion.

In Table 3.19, the TSP, PM_{10} and $PM_{2.5}$ emissions for road transport and other mobile sources are shown for 2005 in NFR sectors. The emission figures (exhaust only) in the time-series for the period 1985-2005 are given in Annex 2.B.13 (NFR format). Exhaust PM emissions are also shown for 1990 and 2005 in Annex 2.B.13 (CollectER format), while 2005 non-exhaust emission figures are shown in Annex 2.B.14.

From 1985 to 2005, road transport PM emissions (exhaust only) decreased by 30% (from Figure 3.38). The highest emissions occur in 1991, after which the emissions drop by 40%, until 2005. The TSP emissions for other mobile sources decrease by 50% from 1985 to 2005 (from Figure 3.40).

Table 3.19 Emissions of TSP, PM10 and PM2.5 in 2005 from road transport and other mobile sources

NFR Sector	TSP [tonnes]	PM_{10} [tonnes]	$PM_{2.5}$ [tonnes]
Industry-Other (1A2f)	1002	1002	1002
Civil Aviation (1A3a)	3	3	3
Railways (1A3c)	124	124	124
Navigation (1A3d)	433	430	429
Residential (1A4b)	87	87	87
Ag./for./fish. (1A4c)	1170	1168	1167
Military (1A5)	45	45	45
Total other mobile	2864	2859	2857
Road exhaust (1A3b)	3124	3124	3124
Road brake wear	593	581	231
Road tyre wear	913	548	383
Road abrasion	1049	525	283
Total Road non-exhaust	2555	1653	898
Total Road	5679	4777	4022
Total Mobile	5988	5983	5981

PM emissions from exhaust

Exhaust particulate emissions from road transportation vehicles are well below $PM_{2.5}$. The largest emission contributor in 2005 was light duty vehicles (42%) followed by heavy-duty vehicles (33%), passenger cars (23%) and 2-wheelers (2%), as shown in Figure 3.39.

The emissions from light- and heavy-duty vehicles have significantly decreased since the mid-1990s due to gradually stricter EURO emission standards. The environmental benefit of introducing diesel private cars with lower particulate emissions since 1990 is more or less outbalanced by an increase in sales of new vehicles in recent years (Figure 3.38).

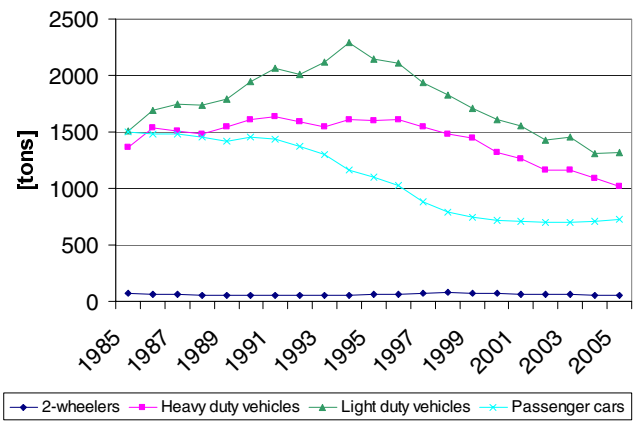


Figure 3.38 Exhaust particulate emissions ($PM_{2.5}$) in tonnes from 1985-2005 for road transport

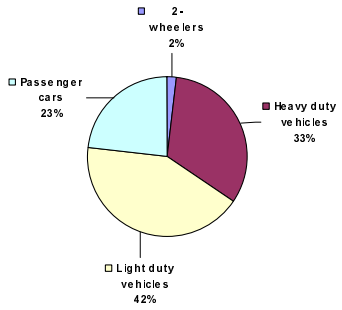


Figure 3.39 Exhaust particulate emission ($PM_{2.5}$) shares for road transport in 2005

As shown in Figure 3.41, for other mobile sources the largest TSP contributors in 2005 are Agriculture/forestry/fisheries (1A4c), Industry (1A2f) and Navigation (1A3d), with emission shares of 41, 35 and 15%, respectively. The remaining sectors: Railways (1A3c), Civil aviation

(1A3a), Military (1A5) and Residential (1A4b) represent only minor emission sources.

The 1985-2005 TSP emissions for navigation and fisheries are determined by the fuel use fluctuations in these years, and the development of the emission factors, which to a major extent is a function of the fuel sulphur content. As for NO_x, the emission development for Agriculture/forestry is determined by the generally decreasing total diesel fuel use and gradually reducing emission factors over the time period.

The TSP emission development for industrial non-road machinery is the product of a slight fuel use increase from 1985 to 2005 and a development in emission factors, as explained for agricultural machinery. The TSP emission explanations for railways are the same as for NO_x (Figure 3.40).

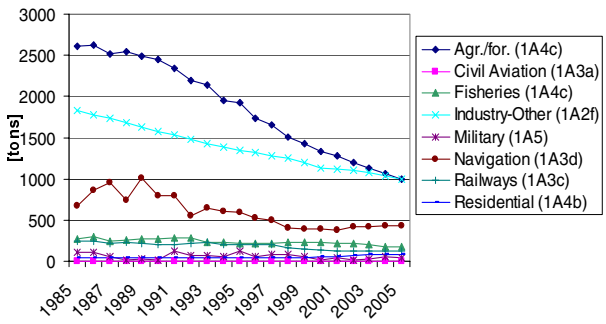


Figure 3.40 Exhaust particulate emissions (TSP) in tonnes from 1985-2005 for other mobile sources

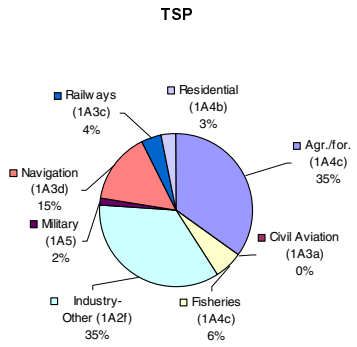


Figure 3.41 Exhaust particulate emissions (TSP) shares for other mobile sources in 2005

Non-exhaust PM

The respective source category distributions for TSP, PM_{10} and $PM_{2.5}$ emissions are identical for each of the non-exhaust emission type's brake wear, tyre wear and road abrasion, and, hence, only the PM_{10} distributions are shown in Figure 3.42. For brake and tyre wear, passenger cars caused the highest emissions in 2005, followed by light-duty vehicles, trucks, buses and 2-wheelers. Trucks cause higher road abrasion emissions than light-duty vehicles, but apart from this, the size order of emission sources is the same as for brake and tyre wear.

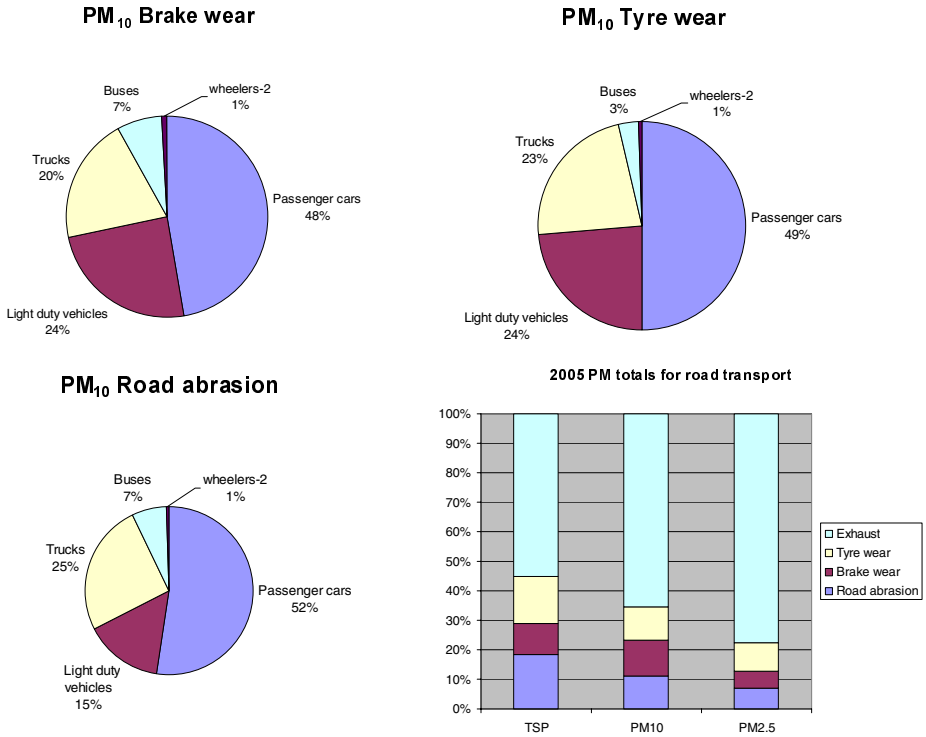


Figure 3.42 Brake and tyre wear and road abrasion PM_{10} emission shares and PM exhaust/non-exhaust distributions for road traffic in 2005

The exhaust emission shares of total road transport TSP, PM_{10} and $PM_{2.5}$ are 55, 65 and 78%, respectively, in 2005. For brake and tyre wear and road abrasion the TSP shares are 10, 16 and 18%, respectively. The same three sources have PM_{10} shares of 12, 11 and 11%, respectively, and $PM_{2.5}$ shares of 6, 10 and 7%, 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.

Heavy metals

In Table 3.20, the heavy metal emissions for road transport and other mobile sources are shown for 2005 in NFR sectors. The emission figures in the time-series 1990-2005 are given in Annex 2.B.14 (NFR format) and are shown for 1990 and 2005 in Annex 2.B.13 (CollectER format).

The heavy metal emission factors (except Pb) are taken from the EMEP/CORINAIR guidebook and are constant throughout the 1990-2005 period. Consequently, emission development follows the trends in fuel use. The road transport emissions have increased by 31% from 1990 to 2005. For Pb, however, there has been an almost 100% emission decline, due to the phasing out of leaded gasoline fuels in 1994 (Figure 3.44). For other mobile sources, emissions generally decrease throughout the time period and the phasing out of lead is also the reason for the 79% decline in Pb emissions from other mobile sources. Here, household and gardening equipment and recreational craft are the the main gasoline fuel consumers. In addition, from 1990 to 2005, gasoline fuel use almost reached zero for agricultural tractors. The 59% decline in Ni emissions is due to lower residual fuel use in navigation.

Table 3.20 Heavy metal emissions in 2005 for road transport and other mobile sources

NFR Sector	As [kg]	Cd [kg]	Cr [kg]	Cu [kg]	Hg [kg]	Ni [kg]	Pb [kg]	Se [kg]	Zn [kg]
Industry-Other (1A2f)		3	14	474		20	0	3	279
Civil Aviation (1A3a)	0	0	2	72	0	3	1297	0	42
Railways (1A3c)		1	4	125		5		1	73
Navigation (1A3d)	23	2	13	79	6	1114	18	35	117
Residential (1A4b)		1	5	158		7	3	1	93
Ag./for./fish. (1A4c)	7	5	23	600	7	35	15	33	423
Military (1A5)	0	1	4	146	0	6	59	1	86
Total other mobile	31	13	65	1654	13	1189	1392	74	1113
Road (1A3b)		38	191	6505		268	53	38	3826
Total mobile	31	51	256	8159	13	1457	1444	112	4940

As shown in Figure 3.43, the road transport emissions of Cd, Cr, Cu and Zn account for around two thirds of the total for all mobile sources in 2005. No road transport emissions occur for As and Hg. Instead, the emissions of these species come from the use of marine diesel oil and residual oil in fisheries and navigation. The latter sector also contributes with a high emission of Ni (from residual oil), whereas the Se emission comes from agriculture/forestry/fisheries, road transport and navigation, in almost equal shares.

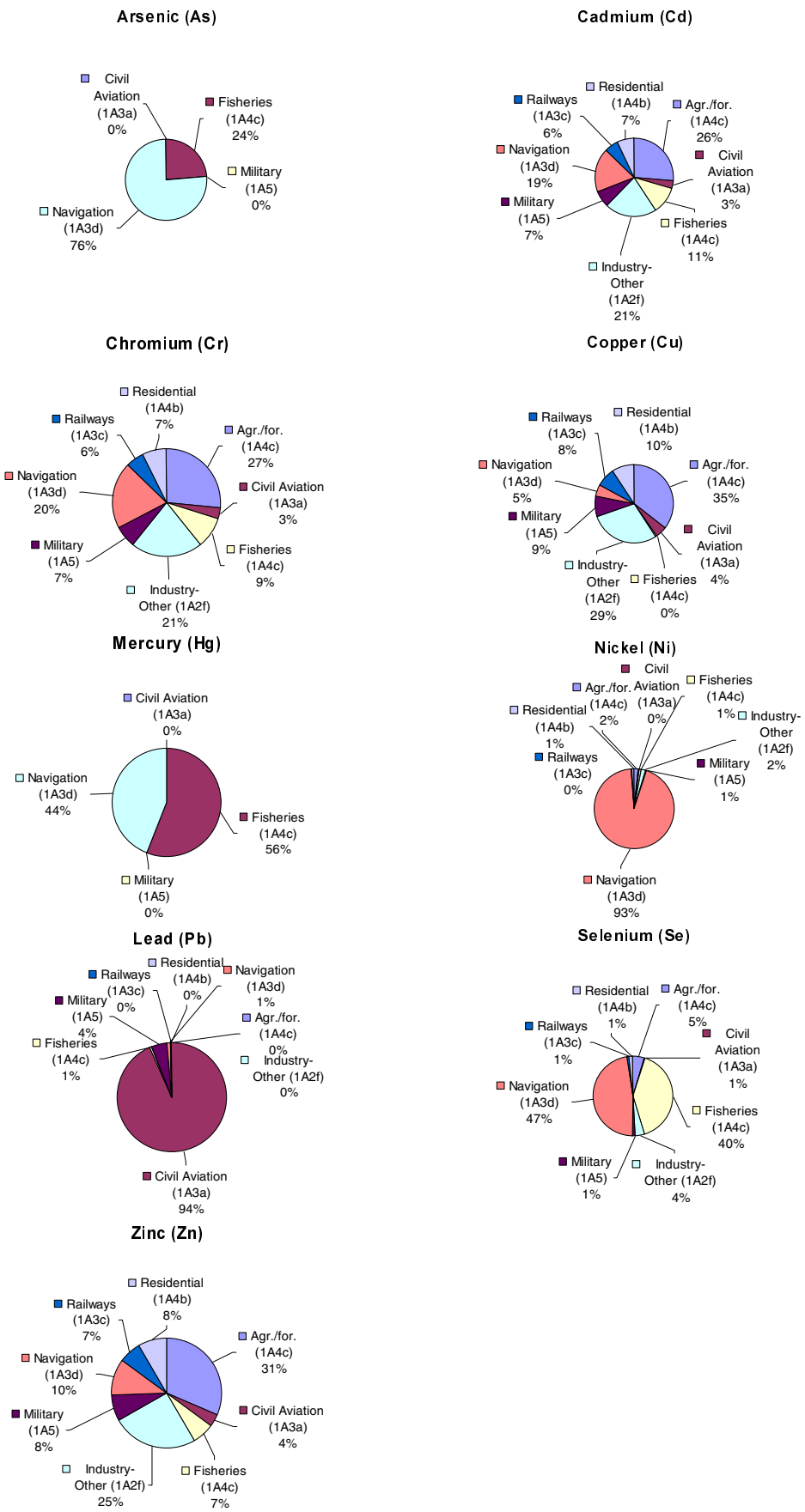


Figure 3.43 Heavy metal emission shares for road transport and other mobile sources in 2005

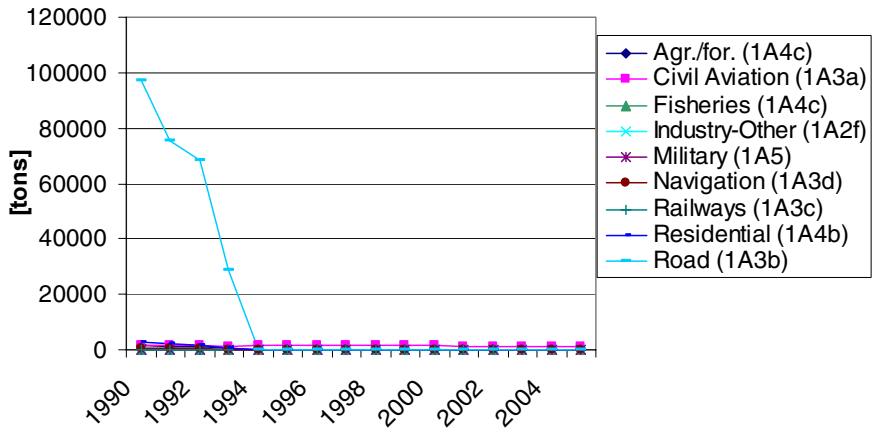


Figure 3.44 Pb emissions (kg) in NFR sectors for road transport and other mobile sources 1990-2005

Dioxin and PAH

In Table 3.21, the dioxin and PAH emissions for road transport and other mobile sources are shown for 2005 in NFR sectors. The emission figures in the time-series 1990-2005 are given in Annex 2.B.14 (NFR format) and are shown for 1990 and 2005 in Annex 2.B.13 (CollectER format).

Table 3.21 Dioxin and PAH emissions in 2005 for road transport and other mobile sources

NFR ID	Dioxins/ Furans	Flouranthene	Benzo(b) flouranthene	Benzo(k) flouranthene	Benzo(a) pyrene	Benzo(g,h,i) perylene	Indeno (1,2,3-c,d) pyrene
	[g]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]
Industry-Other (1A2f)	0	52	6	6	3	6	3
Civil Aviation (1A3a)	0	0	0	0	0	0	0
Railways (1A3c)	0	4	1	1	0	0	0
Navigation (1A3d)	0	46	4	2	1	7	6
Residential (1A4b)	0	18	1	0	0	3	1
Ag./for./fish. (1A4c)	0	112	12	9	5	16	11
Military (1A5)	0	6	1	1	0	1	0
Total other mobile	0	238	24	19	10	32	22
Road (1A3b)	0	671	66	75	50	95	55
Total mobile	0	909	90	94	60	128	77

For mobile sources, road transport displays the largest emission of dioxins and PAH (Figure 3.45). The dioxin emission share for road transport is 50% of all mobile emissions in 2005, whereas Agriculture/forestry/fisheries and Navigation have smaller shares of 22 and 19%. For the different PAH components, road transport shares are around two thirds or more 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.

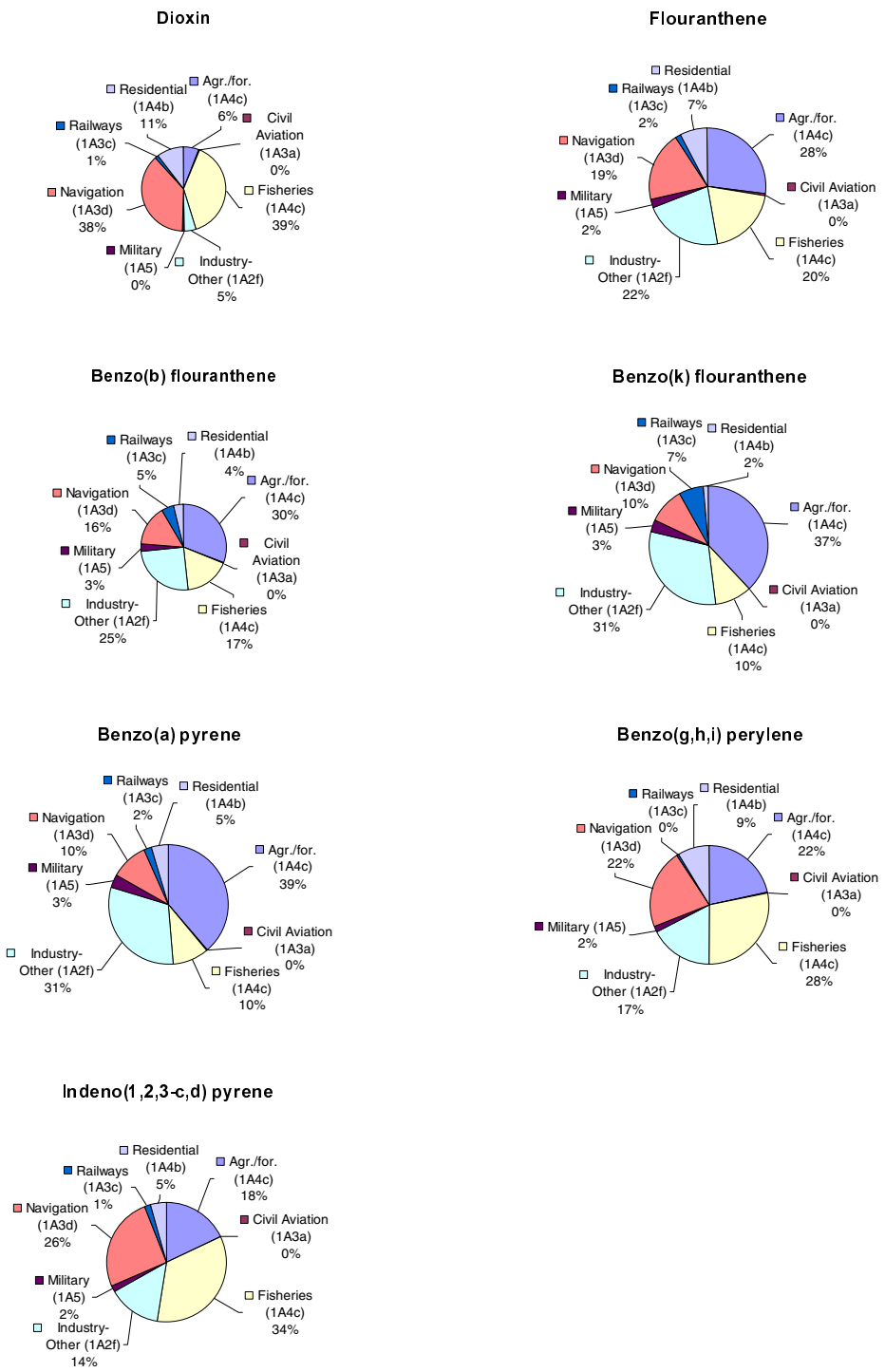


Figure 3.45 Dioxin and PAH emission shares for road transport and other mobile sources in 2005

Bunkers

The most important emissions from bunker fuel use (fuel use for international transport) are SO_2, NO_X and CO_2 (and TSP, not shown). However, compared with the Danish national emission total (all sources), the greenhouse gas emissions from bunkers are small. The bunker emission totals are shown in Table 3.22 for 2005, split into sea transport and civil aviation. All emission figures in the 1985-2005 time-series are given in

Annex 2.B.16 (NFR format). In Annex 2.B.13, the emissions are also given in CollectER format for the years 1990 and 2005.

Table 3.22 Emissions in 2005 for international transport and national totals

NFR sector	SO_2 [tonnes]	NO_X [tonnes]	NMVOC [tonnes]	CH_4 [tonnes]	CO [tonnes]	CO_2 [k-tonnes]	N_2O [tonnes]
Navigation int. (1A3d)	36,544	62,825	2,005	6,615	2,636	166	36,544
Civil Aviation int. (1A3a)	822	11,037	469	1,914	2,575	89	822
International total	37,367	73,862	2,474	8,529	5,211	255	37,367

The differences in emissions between navigation and civil aviation are much larger than the differences in fuel use (and derived CO_2 emissions), and display a poor emission performance for international sea transport. In broad terms, the emission trends shown in Figure 3.46 are similar to the fuel-use development. Minor differences occur for navigation (SO_2, NO_X and CO_2) due to varying amounts of marine gas oil and residual oil, and for civil aviation (NO_X) due to yearly variations in LTO/aircraft type (earlier than 2001) and city-pair statistics (2001 onwards).

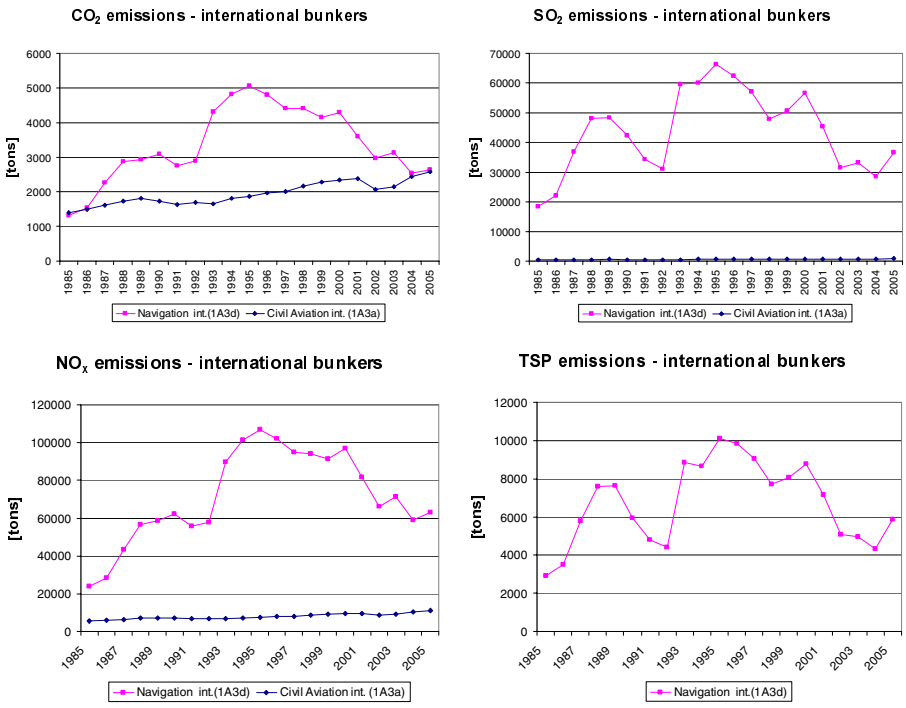


Figure 3.46 CO_2, SO_2, NO_X and TSP emissions for international transport 1985-2005

3.3.2 Methodological issues

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

Methodology and references for Road Transport

For road transport, the detailed methodology is used to make annual estimates of the Danish emissions, as described in the EMEP/CORINAIR Emission Inventory Guidebook (EMEP/CORINAIR, 2003). The actual

calculations are made with a model developed by NERI, using the European COPERT III model methodology, and updated fuel use and emission factors from the latest version of COPERT - COPERT IV. The latter model approach is explained in (EMEP/CORINAIR, 2003). In COPERT, fuel use 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 III fleet classification, all present and future vehicles in the Danish fleet are grouped into vehicle classes, sub-classes and layers. The layer classification is a further division of vehicle sub-classes into groups of vehicles with the same average fuel use and emission behaviour, according to EU emission legislation levels. Table 3.23 gives an overview of the different model classes and sub-classes, and the layer level with implementation years are shown in Annex 2.B.1.

Table 3.23 Model vehicle classes and sub-classes, trip speeds and mileage split

			Trip speed [km/h]			Mileage split [%]		
Vehicle classes	Fuel type	Engine size/weight	Urban	Rural	Highway	Urban	Rural	Highway
PC	Gasoline	< 1.4 l.	40	70	100	35	46	19
PC	Gasoline	1.4 – 2 l.	40	70	100	35	46	19
PC	Gasoline	> 2 l.	40	70	100	35	46	19
PC	Diesel	< 2 l.	40	70	100	35	46	19
PC	Diesel	> 2 l.	40	70	100	35	46	19
PC	LPG		40	70	100	35	46	19
PC	2-stroke		40	70	100	35	46	19
LDV	Gasoline		40	65	80	35	50	15
LDV	Diesel		40	65	80	35	50	15
Trucks	Gasoline		35	60	80	32	47	21
Trucks	Diesel	3.5 – 7.5 tonnes	35	60	80	32	47	21
Trucks	Diesel	7.5 – 16 tonnes	35	60	80	32	47	21
Trucks	Diesel	16 – 32 tonnes	35	60	80	19	45	36
Trucks	Diesel	> 32 tonnes	35	60	80	19	45	36
Urban buses	Diesel		30	50	70	51	41	8
Coaches	Diesel		35	60	80	32	47	21
Mopeds	Gasoline		30	30	-	81	19	0
Motorcycles	Gasoline	2 stroke	40	70	100	47	39	14
Motorcycles	Gasoline	< 250 cc.	40	70	100	47	39	14
Motorcycles	Gasoline	250 – 750 cc.	40	70	100	47	39	14
Motorcycles	Gasoline	> 750 cc.	40	70	100	47	39	14

New total mileage data for passenger cars, light duty trucks, heavy duty trucks and buses produced by the Danish vehicle inspection programme is used for the years 1985-2004. For 2005, the information for 2004 is used, due to lack of data.

The new Danish mileage data is distributed into annual mileage per first registration year for the different vehicle categories in the inventory, by using the baseline vehicle stock and annual mileage information obtained from the Danish Road Directorate (Ekman, 2005). Fleet numbers

in total vehicle categories for 2005 has been obtained from the Danish Road Directorate (Ekman, 2006), and data are split into vehicle categories-first registration years, by using the 2004 distribution matrix.

The data set from Ekman (2005) which underpinned the Danish 2004 emission inventory, covers data for the number of vehicles and annual mileage per first registration year for all vehicle sub-classes, and mileage split between urban, rural and highway driving, and the respective average speeds. Additional data for the moped fleet and motorcycle fleet disaggregation information is given by the National Motorcycle Association (Markamp, 2006).

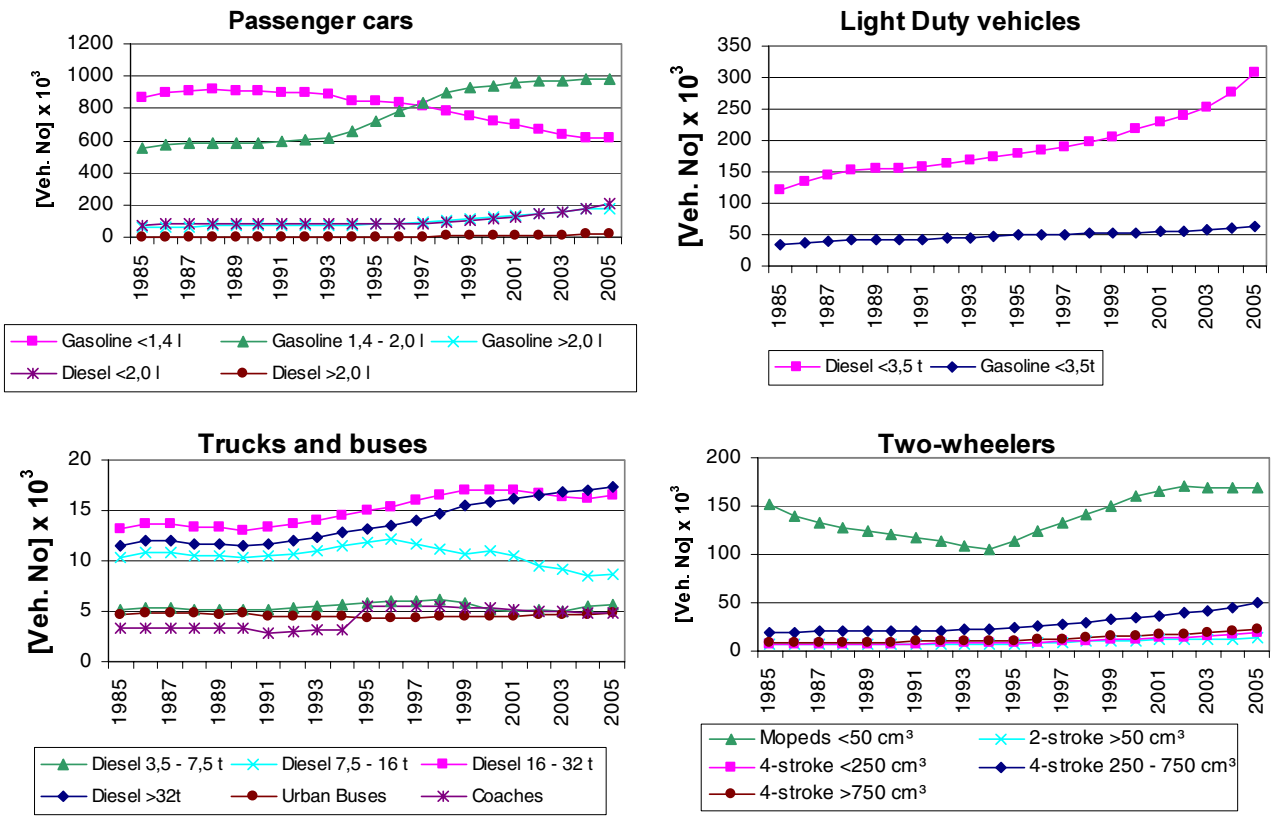


Figure 3.47 Number of vehicles in sub-classes in 1985-2005

The vehicle numbers per sub-class are shown in Figure 3.47. The engine size differentiation is associated with some uncertainty. The increase in the total number of passenger cars is mostly due to a growth in the number of gasoline cars with engine sizes between 1.4 and 2 litres (from 1990-2002) and an increase in the number of gasoline cars (>2 litres) and diesel cars (< 2 litres). In the later years, there has been a decrease in the number of cars with an engine size smaller than 1.4 litres.

There has been a considerable growth in the number of diesel light-duty vehicles from 1985 to 2005. The two largest truck sizes have also increased in numbers during the 1990s. From 2000 onwards, this growth has continued for trucks larger than 32 tonnes, whereas the number of trucks with gross vehicle weights between 16 and 32 tonnes has decreased slightly.

The number of urban buses has been almost constant between 1985 and 2005. The sudden change in the level of coach numbers from 1994 to 1995 is due to uncertain fleet data.

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. For motorcycles, the number of vehicles has grown in general throughout the entire 1985-2005 period. The increase is, however, most visible from the mid-1990s and onwards.

The vehicle numbers are summed up in layers for each year (Figure 3.48) by using the correspondence between layers and first year of registration:

$$N_{j,y} = \sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \quad (1)$$

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

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

$$M_{j,y} = \frac{\sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \cdot M_{i,y}}{\sum_{i=FYear(j)}^{LYear(j)} N_{i,y}} \quad (2)$$

Vehicle numbers and weighted annual mileages per layer are shown in Annex 2.B.1 and 3.B.2 for 1985-2005. The trends in vehicle numbers per layer are also shown in Figure 3.48. The latter figure shows how vehicles complying with the gradually stricter EU emission levels (EURO I, II, III etc.) have been introduced into the Danish motor fleet.

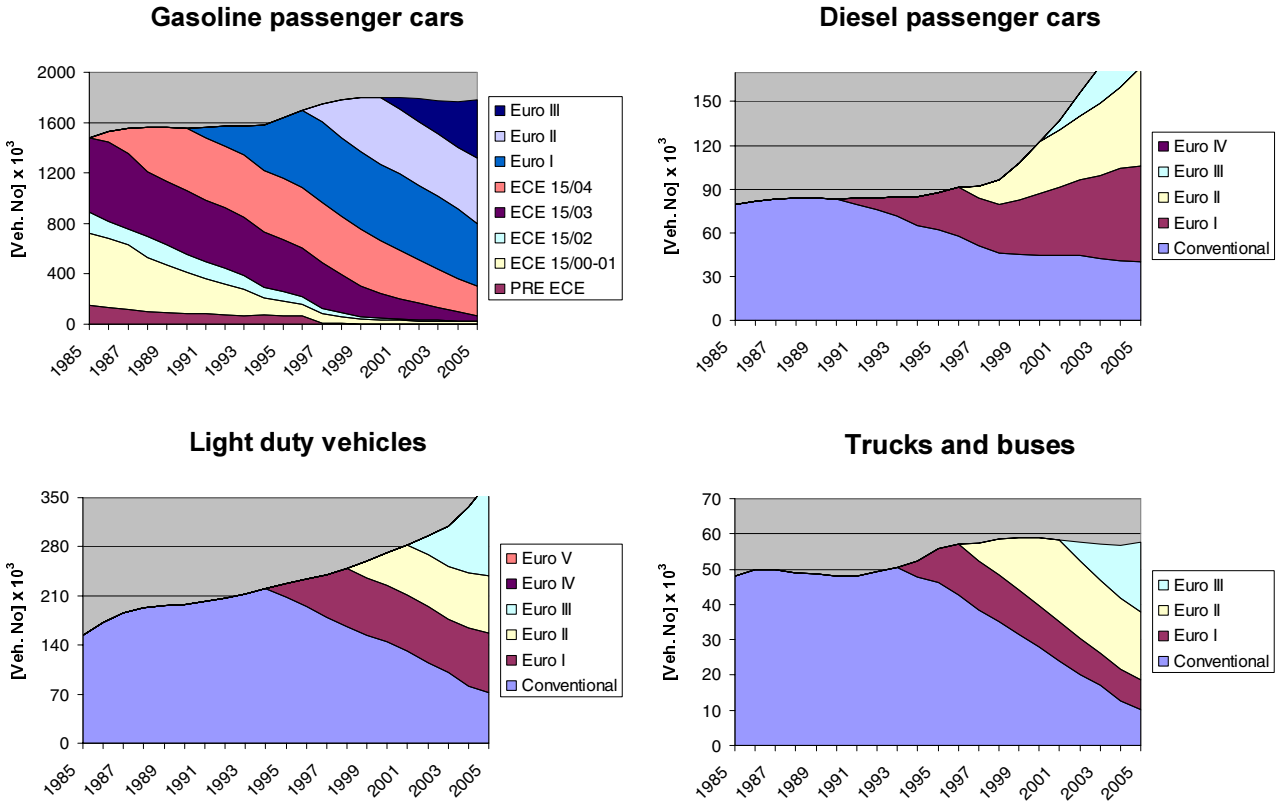


Figure 3.48 Layer distribution of vehicle numbers per vehicle type in 1985-2005

Emission legislation

For Euro 1-4 passenger cars and light duty trucks, the chassis dynamometer test cycle used in the EU for emission approval is the NEDC (New European Driving Cycle), see Nørgaard and Hansen (2004). The test cycle is also used also for fuel use 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 cycle2 (average speed: 19 km/h). The second part of the test is the run-through of the EUDC (Extra Urban Driving Cycle) test driving segment, simulating the fuel use under rural and highway driving conditions. The driving length of EUDC is 7 km at an average speed of 63 km/h. More information regarding the fuel measurement procedure can be found in the EU-directive 80/1268/EØF.

For NOx, VOC (NMVOC + CH4), CO and PM, the emissions from road transport vehicles have to comply with the different EU directives listed in Table 3.24. The emission directives distinguish between three vehicle classes according to vehicle reference mass[3]: Passenger cars and light duty trucks (<1305 kg), light duty trucks (1305-1760 kg) and light duty trucks (>1760 kg).The specific emission limits are shown in Annex 2.B.3.

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

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

Table 3.24 Simplified overview of the existing EU emission directives for road transport vehicles

Vehicle category	Emission layer	EU directive	First reg. year start
Passenger cars (gasoline)	PRE ECE		0
	ECE 15/00-01	70/220 - 74/290	1972[a]
	ECE 15/02	77/102	1981[b]
	ECE 15/03	78/665	1982[c]
	ECE 15/04	83/351	1987[d]
	Euro I	91/441	1991[e]
	Euro II	94/12	1997
	Euro III	98/69	2001
	Euro IV	98/69	2006
Passenger cars (diesel and LPG)		Conventional	0
	ECE 15/04	83/351	1987[d]
	Euro I	91/441	1991[e]
	Euro II	94/12	1997
	Euro III	98/69	2001
	Euro IV	98/69	2006
Light duty trucks (gasoline and diesel)		Conventional	0
	ECE 15/00-01	70/220 - 74/290	1972[a]
	ECE 15/02	77/102	1981[b]
	ECE 15/03	78/665	1982[c]
	ECE 15/04	83/351	1987[d]
	Euro I	93/59	1995
	Euro II	96/69	1999
	Euro III	98/69	2002
	Euro IV	98/69	2007
Heavy duty vehicles		Conventional	0
	Euro 0	88/77	1991
	Euro I	91/542	1994
	Euro II	91/542	1997
	Euro III	1999/96	2002
	Euro IV	1999/96	2007
	Euro V	1999/96	2010
Mopeds		Conventional	0
	Euro I	97/24	2000
	Euro II	2002/51	2004
Motor cycles		Conventional	0
	Euro I	97/24	2000
	Euro II	2002/51	2004
	Euro III	2002/51	2007

a,b,c,d: Expert judgement suggest 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 in 1991 (EU starting year: 1993).

In practice, the emissions from vehicles in traffic are different from the legislation limit values and, therefore, the latter figures are considered to be too inaccurate for total emission calculations. A major constraint is that the emission approval test conditions reflect only to a small degree

the large variety of emission influencing factors in the real traffic situation, such as cumulated mileage driven, engine and exhaust after treatment maintenance levels and driving behaviour.

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

For heavy-duty vehicles (trucks and buses), the emission limits are given in g/kWh and the measurements are carried out for engines in a test bench, using the EU ESC (European Stationary Cycle) and ETC (European Transient Cycle) test cycles, depending on the Euro norm and exhaust gas after-treatment system installed. A description of the test cycles is given by Nørgaard and Hansen, 2004). Measurement results in g/kWh from emission approval tests cannot be directly used for inventory work. Instead, emission factors used for national estimates must be transformed into g/km, and derived from a sufficient number of measurements which represent the different vehicle size classes, Euro engine levels and real world variations in driving behaviour.

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.

Fuel use and emission factors

Trip-speed dependent basis factors for fuel use and emissions are taken from the COPERT model using trip speeds as shown in Table 3.23. The factors are listed in Annex 2.B.4. For EU emission levels not represented by actual data, the emission factors are scaled according to the reduction factors given in Annex 2.B.5. For further explanation, see EMEP/CORINAIR (2003) or Illerup et al. (2002).

The fuel use and emission factors used in the Danish inventory come from the COPERT IV model. The scientific basis for COPERT IV is fuel use and emission information from the European 5th framework research projects ARTEMIS and Particulates. In cases where no updates are made for vehicle categories and fuel use/emission components, COPERT IV still uses COPERT III data; the source for these data are various European measurement programmes. In general the COPERT data are transformed into trip-speed dependent fuel use and emission factors for all vehicle categories and layers.

For passenger cars, real measurement results are behind the emission factors for Euro 1-4 gasoline vehicles and Euro 1-3 diesel vehicles (updated figures), and those earlier (COPERT III data). For light duty trucks the measurements represent Euro 1 and prior vehicle technologies from COPERT III. For mopeds and motorcycles, updated fuel use and emission figures are behind the conventional and Euro 1-3 technologies.

The experimental basis for heavy-duty trucks and buses is updated computer simulated emission factors for Euro 0-V engines. In COPERT IV the number of heavy duty vehicle categories has increased substantionally, and from the traffic data side is not possible to support all these new vehicle categories with consistent fleet and mileage data. Thus, the COPERT III vehicle size classification still remains as the Danish inventory basis for heavy duty vehicles.

However, in order to use the new COPERT IV fuel use and emission information, the decision is to calculate average fuel use and emission factors per technology level (Euro O-V) from COPERT IV. The average factors comprise the specific COPERT IV size categories in overlap with a given COPERT III size category. Next, these average COPERT IV factors are scaled with the ratio of fuel use factors between COPERT III and "average COPERT IV" in order to end up with vehicle sizes corresponding to COPERT III weight classes.

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.

Deterioration factors

For three-way catalyst cars the emissions of NO_X, NMVOC and CO gradually increase due to catalyst wear and are, therefore, modified as a function of total mileage by the so-called deterioration factors. Even though the emission curves may be serrated for the individual vehicles, on average, the emissions from catalyst cars stabilise after a given cut-off mileage is reached due to OBD (On Board Diagnostics) and the Danish inspection and maintenance programme.

For each forecast year, the deterioration factors (DF) are calculated per first registration year by using deterioration coefficients and cut-off mileages, as given in EMEP/CORINAIR (2003), for the corresponding layer. The deterioration coefficients are given for the two driving cycles: ”Urban Driving Cycle” (UDC) and ”Extra Urban Driving Cycle” (EUDC: urban and rural), with trip speeds of 19 and 63 km/h, respectively.

Firstly, the deterioration factors are calculated for the corresponding trip speeds of 19 and 63 km/h in each case determined by the total cumulated mileage less than or exceeding the cut-off mileage. The Formulas 3 and 4 show the calculations for the ”Urban Driving Cycle”:

$$UDF = U_A \cdot MTC + U_B \text{, MTC} < U_{MAX} \quad (3)$$

$$UDF = U_A \cdot U_{MAX} + U_B \text{, MTC} >= U_{MAX} \quad (4)$$

where UDF is the urban deterioration factor, U_A and U_B the urban deterioration coefficients, MTC = total cumulated mileage and U_{MAX} urban cut-off mileage.

In the case of trip speeds below 19 km/h the deterioration factor, DF, equals UDF, whereas for trip speeds exceeding 63 km/h, DF=EUDF. For trip speeds between 19 and 63 km/h the deterioration factor, DF, is found as an interpolation between UDF and EUDF. Secondly, the deterioration factors, one for each of the three road types, are aggregated into layers by taking into account vehicle numbers and annual mileage levels per first registration year:

$$DF_{j,y} = \frac{\sum_{i=FYear(j)}^{LYear(j)} DF_{i,y} \cdot N_{i,y} \cdot M_{i,y}}{\sum_{i=FYear(j)}^{LYear(j)} DF_{i,y} \cdot N_{i,y}} \quad (5)$$

where DF is the deterioration factor.

Emissions and fuel use for hot engines

Emissions and fuel-use results for operationally hot engines are calculated for each year and for layer and road type. The procedure is to combine fuel use and emission factors (and deterioration factors for catalyst vehicles), number of vehicles, annual mileage levels and the relvant road-type shares given in Table 3.23. For non-catalyst vehicles this yields:

$$E_{j,k,y} = EF_{j,k,y} \cdot S_k \cdot N_{j,y} \cdot M_{j,y} \quad (6)$$

Here E = fuel use/emission, EF = fuel use/emission factor, S = road type share and k = road type.

For catalyst vehicles the calculation becomes:

$$E_{j,k,y} = DF_{j,k,y} \cdot EF_{j,k,y} \cdot S_k \cdot N_{j,y} \cdot M_{j,y} \quad (7)$$

Extra emissions and fuel use for cold engines

Extra emissions of SO_2, NO_X, NMVOC, CH_4, CO, CO_2, PM and fuel consumption from cold start are simulated separately. In terms of cold start data no updates are made to the COPERT IV methodology, and the calculation approach is the same as in COPERT III. Each trip is associated with a certain cold-start emission level and is assumed to take place under 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 fraction of the total mileage driven with a cold engine (the β-factor) 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 2005, 2004, 2000-2003, 1990-1999 and 1980-1989 are given in Cappelen et al. (2006), Cappelen et al. (2005) and Cappelen (2004, 2000 and 2003). The cold:hot ratios are equivalent for gasoline fuelled conventional passenger

cars and vans and for diesel passenger cars and vans, respectively, see Ntziachristos et al. (2000). For conventional gasoline and all diesel vehicles the extra emissions become:

$$CE_{j,y} = \beta \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr - 1) \quad (8)$$

Where CE is the cold extra emissions, β = cold driven fraction, CEr = Cold:Hot ratio.

For catalyst cars, 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 future catalyst technologies. However, in order to comply with gradually stricter emission standards, the catalyst light-off temperature must be reached in even shorter periods of time for future EURO standards. Correspondingly, the β-factor for gasoline vehicles is reduced step-wise for Euro II vehicles and their successors.

For catalyst vehicles the cold extra emissions are found from:

$$CE_{j,y} = \beta_{red} \cdot \beta_{EUROI} \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr_{EUROI} - 1) \quad (9)$$

where β_{red} = the β reduction factor.

Evaporative emissions from gasoline vehicles

For each year, evaporative emissions of hydrocarbons are simulated in the forecast model as hot and warm running losses, hot and warm soak loss and diurnal emissions. For evaporation, no updates are made to the COPERT IV methodology, and the calculation approach is the same as in COPERT III. All emission types depend on RVP (Reid Vapour Pressure) and ambient temperature. The emission factors are shown in Ntziachristos et al. (2000).

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. In the model, hot and warm running losses occur for hot and cold engines, respectively. 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), the emission factors are only one tenth of the uncontrolled factors used for conventional gasoline vehicles.

$$R_{j,y} = N_{j,y} \cdot M_{j,y} \cdot ((1 - \beta) \cdot HR + \beta \cdot WR) \quad (10)$$

where R is running loss emissions and HR and WR are the hot and warm running loss emission factors, respectively.

In the model, hot and warm soak emissions for carburettor vehicles also occur for hot and cold engines, respectively. These emissions are calculated as number of trips (broken down into cold and hot trip numbers using the β-factor) times respective emission factors:

$$S_{j,y}{}^{C} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot ((1-\beta) \cdot HS + \beta \cdot WS) \quad (11)$$

where S^C is the soak emission, l_{trip} = the average trip length, and HS and WS are the hot and warm soak emission factors, respectively. Since all catalyst vehicles are assumed to be carbon canister controlled, no soak emissions are estimated for this vehicle type. Average maximum and minimum temperatures per month are used in combination with diurnal emission factors to estimate the diurnal emissions from uncontrolled vehicles $E^d(U)$:

$$E_{j,y}{}^{d}(U) = 365 \cdot N_{j,y} \cdot e^{d}(U) \quad (12)$$

Each year's total is the sum of each layer's running loss, soak loss and diurnal emissions.

Fuel use balance

The calculated fuel use in COPERT III must equal the statistical fuel sale and energy forecast totals from the Danish Energy Authority (DEA, 2006) according to the UNFCCC and UNECE emissions reporting format. The standard approach to achieve a fuel balance in annual emission inventories is to multiply the annual mileage with a fuel balance factor derived as the ratio between simulated and statistical fuel figures for gasoline and diesel, respectively. This method is also used in the present model.

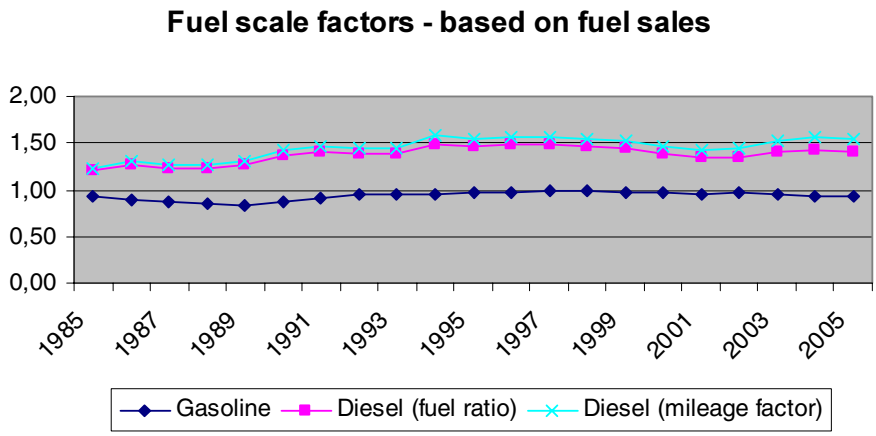


Figure 3.49 DEA:NERI Fuel ratios and diesel mileage adjustment factor based on DEA fuel sales data and NERI fuel consumption estimates

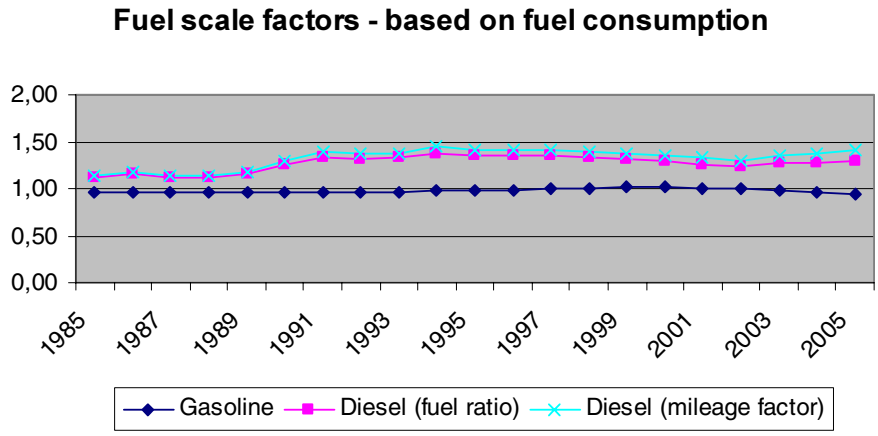


Figure 3.50 DEA:NERI Fuel ratios and diesel mileage adjustment factor based on DEA fuel consumption data and NERI fuel consumption estimates

In the figures 3.49 and 3.50 the COPERT IV:DEA gasoline and diesel fuel use ratios are shown for fuel sales and fuel consumption from 1985-2005. The fuel consumption figures are related to the traffic on Danish roads.

For gasoline vehicles all mileage numbers are equally scaled in order to obtain gasoline fuel equilibrium, and hence the gasoline mileage factor used is the reciprocal value of the COPERT IV:DEA gasoline fuel use ratio.

For diesel the fuel balance is made by adjusting the mileage for light and heavy-duty vehicles and buses, given that the mileage and fuel consumption factors for these vehicles are regarded as the most uncertain parameters in the diesel engine emission simulations. Consequently, the diesel mileage factor used is slightly higher than the reciprocal value of the COPERT IV:DEA diesel fuel use ratio.

From the Figures 3.49 and 3.50 it appears that the inventory fuel balances for gasoline and diesel would be improved, if the DEA statistical figures for fuel consumption were used instead of fuel sale numbers. The fuel difference for diesel is, however, still significant. The reasons for this inaccuracy are a combination of the uncertainties related to COPERT IV fuel use factors, allocation of vehicle numbers in sub-categories, annual mileage, trip speeds and mileage splits for urban, rural and highway driving conditions.

For future inventories it is intended to use improved fleet and mileage data and improved data for trip speed and mileage split for urban, rural and highway driving. The update of road traffic fleet and mileage data will be made as soon as this information is provided from the Danish Ministry of Transport and Energy in a COPERT IV model input format.

The final fuel use and emission factors are shown in Annex 2.B.6 for 1990-2005. The total fuel use and emissions are shown in Annex 2.B.7, per vehicle category and as grand totals, for 1990-2005 (and NFR format

in Annex 2.B.14). In Annex 2.B.13, fuel-use and emission factors as well as total emissions are given in CollectER format for 1990 and 2005.

In Table 3.25, the aggregated emission factors for SO_2, NO_X, NMVOC and TSP are shown per fuel type for Danish road transport.

Table 3.25 Fuel-based emission factors for SO_2, NO_X, NMVOC and TSP for road transport in Denmark (2005)

SNAP ID	Category	Fuel type	Mode	Emission factors[1] [g/GJ]			
				SO_2	NO_X	NMVOC	TSP
70101	Passenger cars	Diesel	Highway driving	0.47	321.22	9.19	35.44
70101	Passenger cars	Gasoline 2-stroke	Highway driving	2.28	288.90	2357.34	48.15
70101	Passenger cars	Gasoline conventional	Highway driving	0.46	1351.18	330.14	10.30
70101	Passenger cars	Gasoline catalyst	Highway driving	0.46	164.23	33.78	0.73
70101	Passenger cars	LPG	Highway driving	0.00	1151.70	187.09	10.06
70102	Passenger cars	Diesel	Rural driving	0.47	304.48	12.88	26.99
70102	Passenger cars	Gasoline 2-stroke	Rural driving	2.28	352.84	2476.82	41.51
70102	Passenger cars	Gasoline conventional	Rural driving	0.46	1160.77	450.72	11.50
70102	Passenger cars	Gasoline catalyst	Rural driving	0.46	125.17	37.05	0.69
70102	Passenger cars	LPG	Rural driving	0.00	1248.46	305.18	14.49
70103	Passenger cars	Diesel	Urban driving	0.47	280.04	29.26	42.68
70103	Passenger cars	Gasoline 2-stroke	Urban driving	2.28	51.89	4470.04	19.72
70103	Passenger cars	Gasoline conventional	Urban driving	0.46	633.21	875.52	11.06
70103	Passenger cars	Gasoline catalyst	Urban driving	0.46	157.79	234.40	0.79
70103	Passenger cars	LPG	Urban driving	0.00	614.22	437.11	11.68
70201	Light duty vehicles	Diesel	Highway driving	0.47	307.36	30.31	44.55
70201	Light duty vehicles	Gasoline conventional	Highway driving	0.46	1369.26	170.29	16.17
70201	Light duty vehicles	Gasoline catalyst	Highway driving	0.46	117.75	13.47	0.54
70202	Light duty vehicles	Diesel	Rural driving	0.47	324.37	33.77	40.70
70202	Light duty vehicles	Gasoline conventional	Rural driving	0.46	1188.86	262.59	15.25
70202	Light duty vehicles	Gasoline catalyst	Rural driving	0.46	103.60	18.94	0.45
70203	Light duty vehicles	Diesel	Urban driving	0.47	348.65	54.67	53.50
70203	Light duty vehicles	Gasoline conventional	Urban driving	0.46	622.77	707.71	8.80
70203	Light duty vehicles	Gasoline catalyst	Urban driving	0.46	115.90	128.04	0.44
70301	Heavy duty vehicles	Diesel	Highway driving	0.47	796.69	27.19	21.82
70301	Heavy duty vehicles	Gasoline	Highway driving	0.46	1037.78	474.61	55.35
70302	Heavy duty vehicles	Diesel	Rural driving	0.47	820.04	36.16	22.09
70302	Heavy duty vehicles	Gasoline	Rural driving	0.46	1141.55	820.40	60.88
70303	Heavy duty vehicles	Diesel	Urban driving	0.47	814.89	46.50	26.40
70303	Heavy duty vehicles	Gasoline	Urban driving	0.46	456.62	696.09	40.59
704	Mopeds	Gasoline		0.46	61.74	9904.83	151.62
70501	Motorcycles	Gasoline	Highway driving	0.46	247.99	1085.51	25.55
70502	Motorcycles	Gasoline	Rural driving	0.46	194.21	1330.24	31.44
70503	Motorcycles	Gasoline	Urban driving	0.46	107.05	1774.84	31.55

[1] References. SO_2: Country specific; NO_X and NMVOC: COPERT III (conventional passenger cars, light duty trucks, LPG passenger cars) and COPERT IV (remaining vehicle layers); PM: TNO/CEPMEIP database (conventional gasoline passenger cars and light duty trucks, LPG passenger cars) and COPERT III (conventional diesel passenger cars, light duty diesel trucks).

Non-exhaust particulate emissions from road transport

The TSP, PM_{10} and $PM_{2.5}$ emissions arising from tyre and brake wear (SNAP 0707) and road abrasion (SNAP 0708) are estimated for the years

2000-2005 as prescribed by the UNECE convention reporting format. The emissions are calculated 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 III model approach used to estimate the Danish national emissions coming from exhaust. A more thorough explanation of the calculations is given by Winther (2004), and emission factors are taken from EMEP/CORINAIR (2003). The emission factors and total emissions for 2005 are shown in Annex 2.B.13.

Methodologies and references for other mobile sources

Other mobile sources are divided into several subsectors: sea transport, fishery, air traffic, railways, military, and working machinery and materiel in the industry, forestry, agriculture and household and gardening sectors. The emission calculations are made using the detailed method as described in the EMEP/CORINAIR Emission Inventory Guidebook (EMEP/CORINAIR, 2003) for air traffic, off-road working machinery and equipment, and ferries, while for the remaining sectors the simple method is used.

3.3.3 Activity data

Air traffic

The activity data for air traffic consists of air traffic statistics provided by the Danish Civil Aviation Agency (CAA-DK) and Copenhagen Airport. For 2001 onwards, per flight records are provided by CAA-DK as data for aircraft type, and origin and destination airports. 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 CAA-DK. Fuel statistics for jet fuel use and aviation gasoline are obtained from the Danish energy statistics (DEA, 2005).

Prior to emission calculations, the aircraft types are grouped into a smaller number of representative aircraft groups, for which fuel use and emission data exist in the EMEP/CORINAIR databank. In this procedure, actual aircraft types are classified according to their overall aircraft type (jets, turbo props, helicopters and piston engines). Secondly, information on the aircraft MTOM (Maximum Take Off Mass) and number of engines are used to append a representative aircraft to the aircraft type in question. A more thorough explanation is given in Winther (2001a, b).

Non-road working machinery and equipment

Non-road working machinery and equipment are used in agriculture, forestry and industry, for household/gardening purposes and in inland waterways (recreational craft). Information on the number of different types of machines, their respective load factors, engine sizes and annual working hours has been provided by Winther et al. (2006). The stock development from 1985-2005 for the most important types of machinery are shown in Figures 3.51-3.58 below. The stock data are also listed in Annex 2.B.10, 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).

For agriculture, the total number of agricultural tractors and harvesters per year are shown in the Figures 3.51-3.52, respectively. The Figures clearly show a decrease in the number of small machines, these being replaced by machines in the large engine-size ranges.

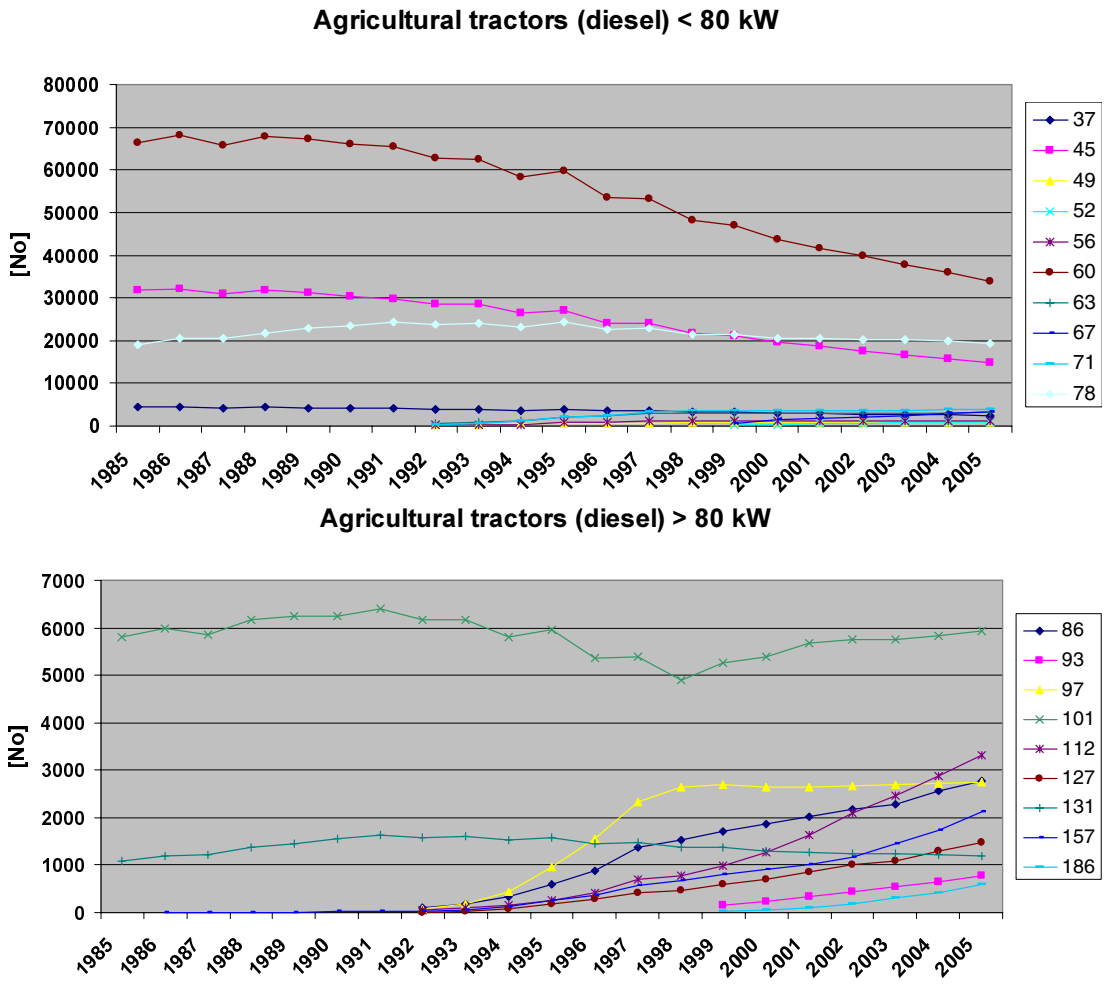


Figure 3.51 Total numbers in kW classes for tractors from 1985 to 2005

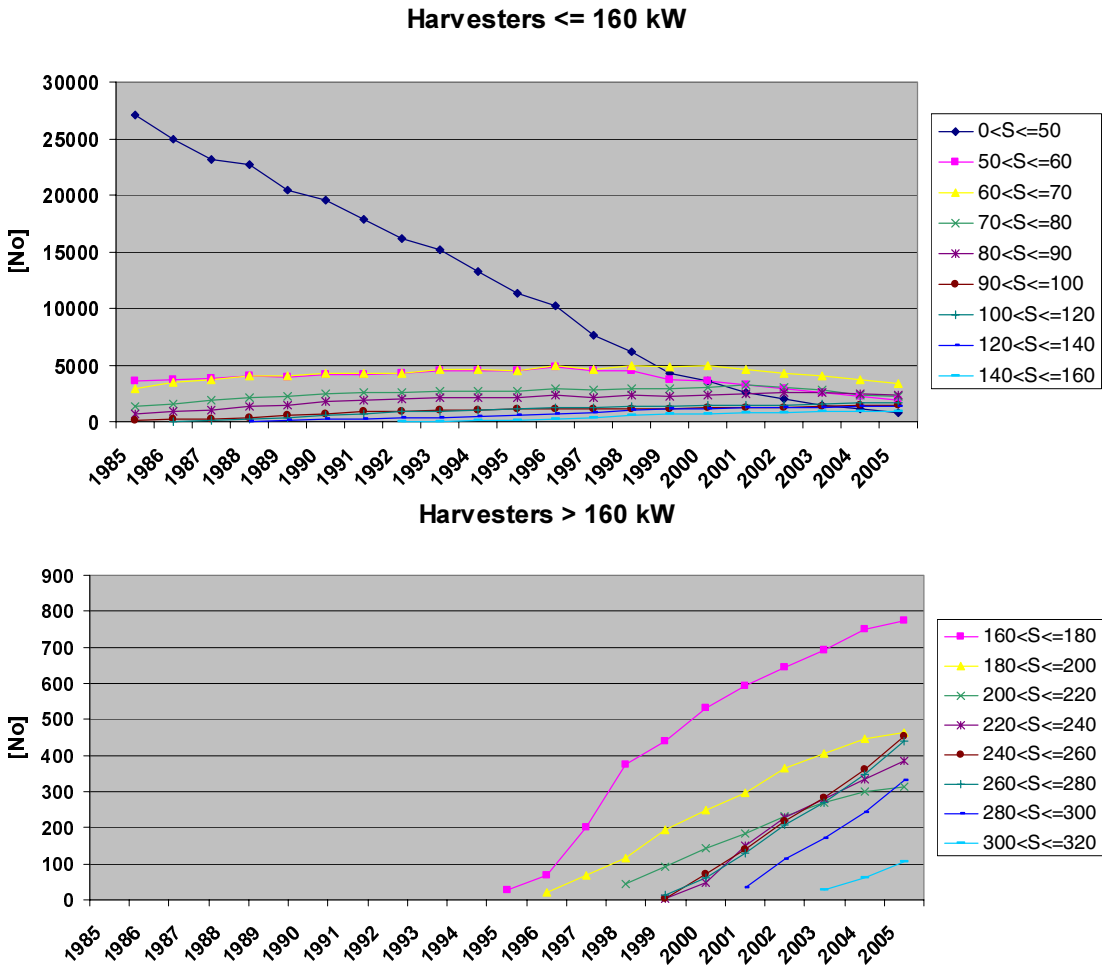


Figure 3.52 Total numbers in kW classes for harvesters from 1985 to 2005

The tractor and harvester developments towards fewer vehicles and larger engines, shown in Figure 3.53, are very clear. From 1985 to 2004, tractor and harvester numbers decrease by around 20% and 50%, respectively, whereas the average increase in engine size for tractors is 16%, and more than 100% for harvesters, in the same time period.

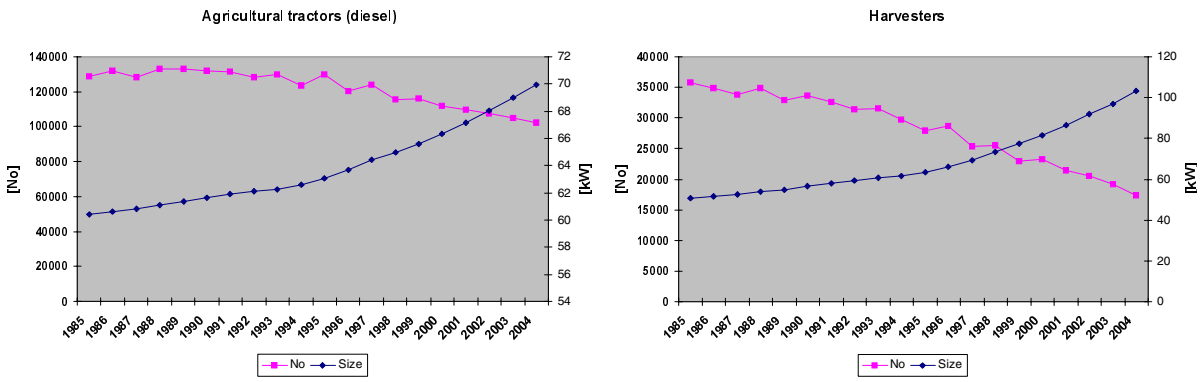


Figure 3.53 Total numbers and average engine size for tractors and harvesters (1985 to 2004)

The most important machinery types for industrial use are different types of construction machinery and fork lifts. The Figures 3.54 and 3.55

show the 1985-2005 stock development for specific types of construction machinery and diesel fork lifts. Due to lack of data, the construction machinery stock for 1990 is used also for 1985-1989. For most of the machinery types there is an increase in machinery numbers from 1990 onwards, due to increased construction activities. It is assumed that track type excavators/ wheel type loaders (0-5 tonnes), and telescopic loaders first enter into use in 1991 and 1995, respectively.

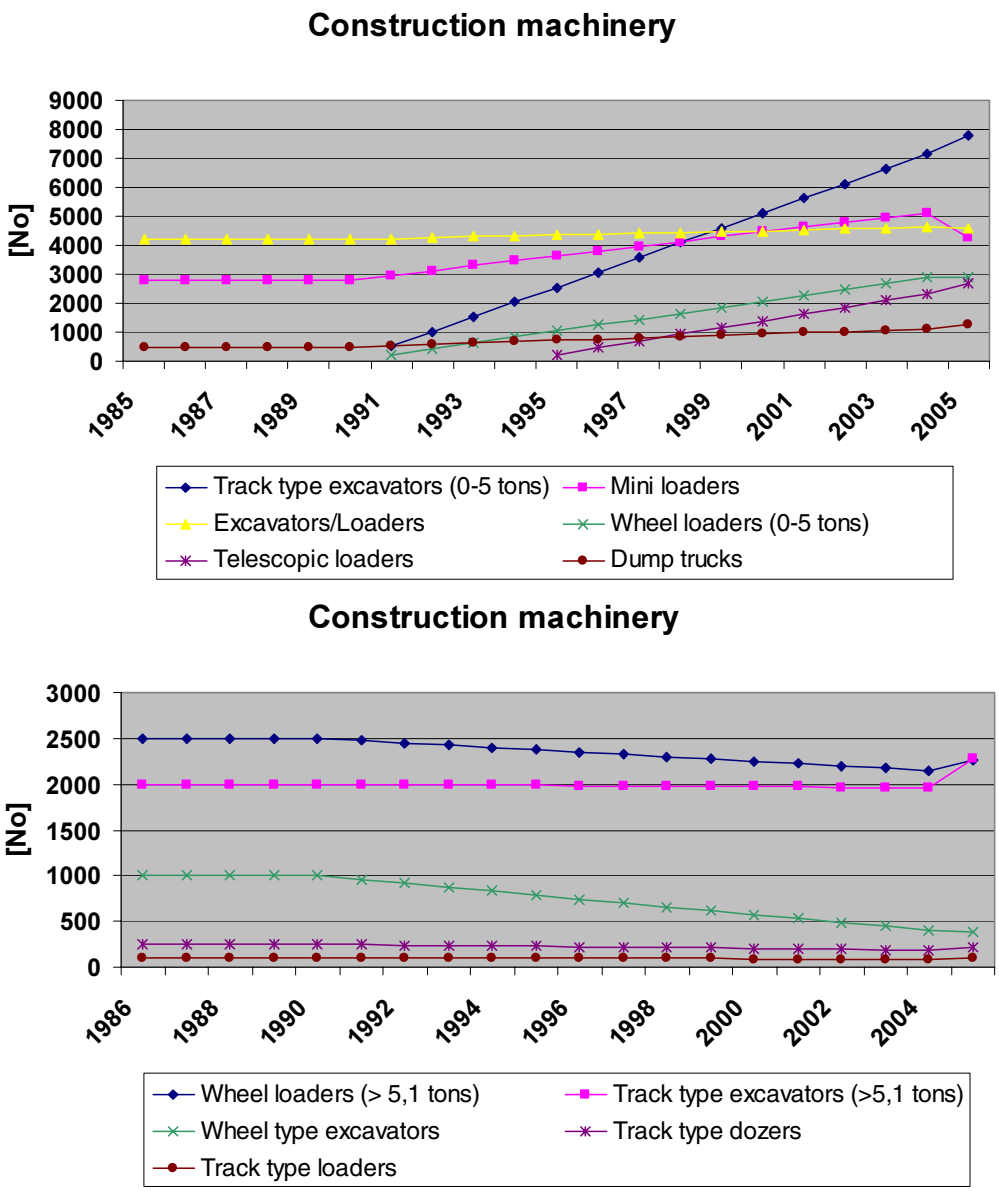


Figure 3.54 1985-2005 stock development for specific types of construction machinery

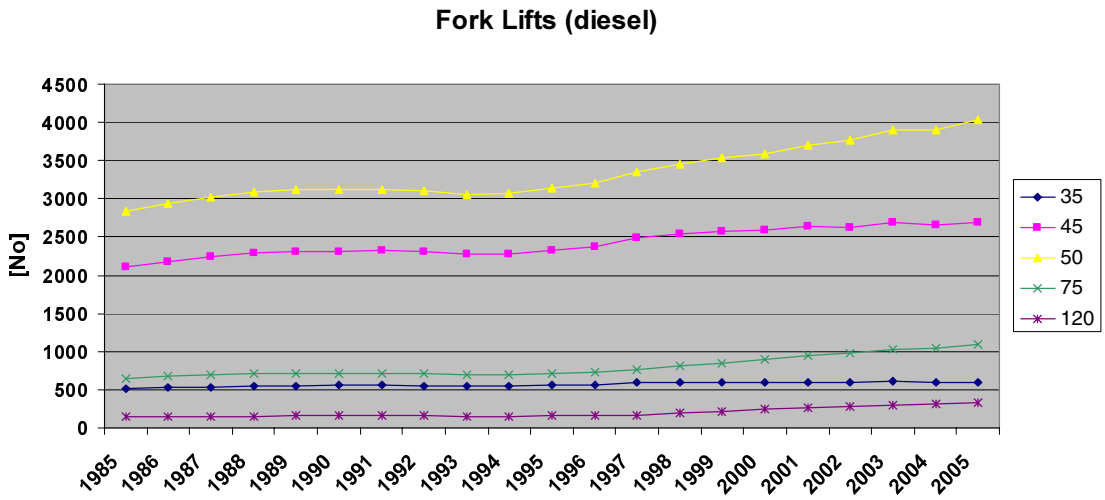


Figure 3.55 Total numbers of diesel fork lifts in kW classes from 1985 to 2005

The emission level shares for tractors, harvesters, construction machinery and diesel fork lifts are shown in Figure 3.56, and present an overview of the penetration of the different pre-Euro engine classes, and engine stages complying with the gradually stricter EU stage I and II emission limits. The average lifetimes of 30, 25, 20 and 10 years for tractors, harvesters, fork lifts and construction machinery, respectively, influence the individual engine technology turn-over speeds.

The EU emission directive Stage I and II implementation years relate to engine size, and for all four machinery groups the emission level shares for the specific size segments will differ slightly from the picture shown in Figure 3.56. Due to scarce data for construction machinery, the emission level penetration rates are assumed to be linear and the general technology turnover pattern is as shown in Figure 3.56.

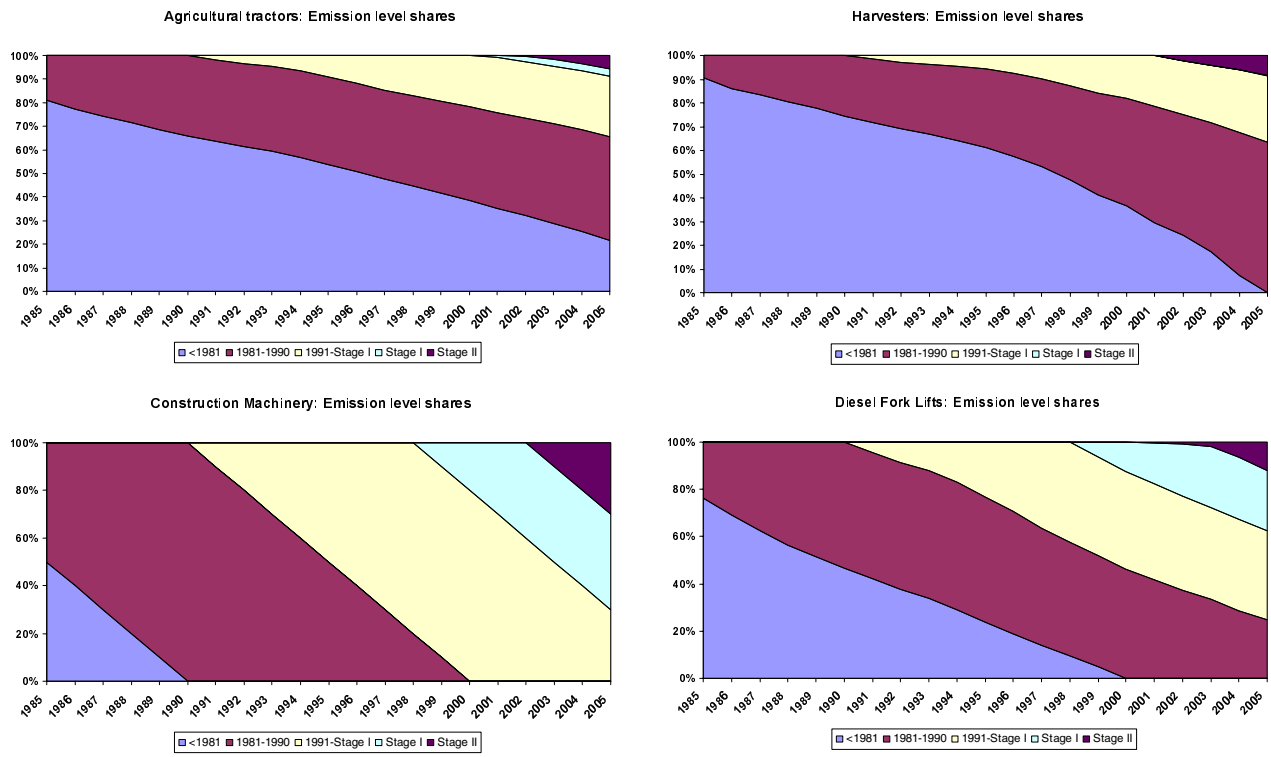


Figure 3.56 Emission level shares for tractors, harvesters, construction machinery and diesel fork lifts (1985 to 2005)

The 1985-2005 stock development for the most important household and gardening machinery types is shown in Figure 3.57. The 2004 stock data are repeated for 2005, since no new fleet information has been obtained for this sector of non road machinery.

For lawn movers and cultivators, the machinery stock remains the same for all years, whereas the stock figures for riders, chain saws, shrub clearers, trimmers and hedge cutters increase from 1990 onwards. The yearly stock increases, in most cases, become larger after 2000. The lifetimes for gasoline machinery are short and, therefore, there new emission levels (not shown) penetrate rapidly.

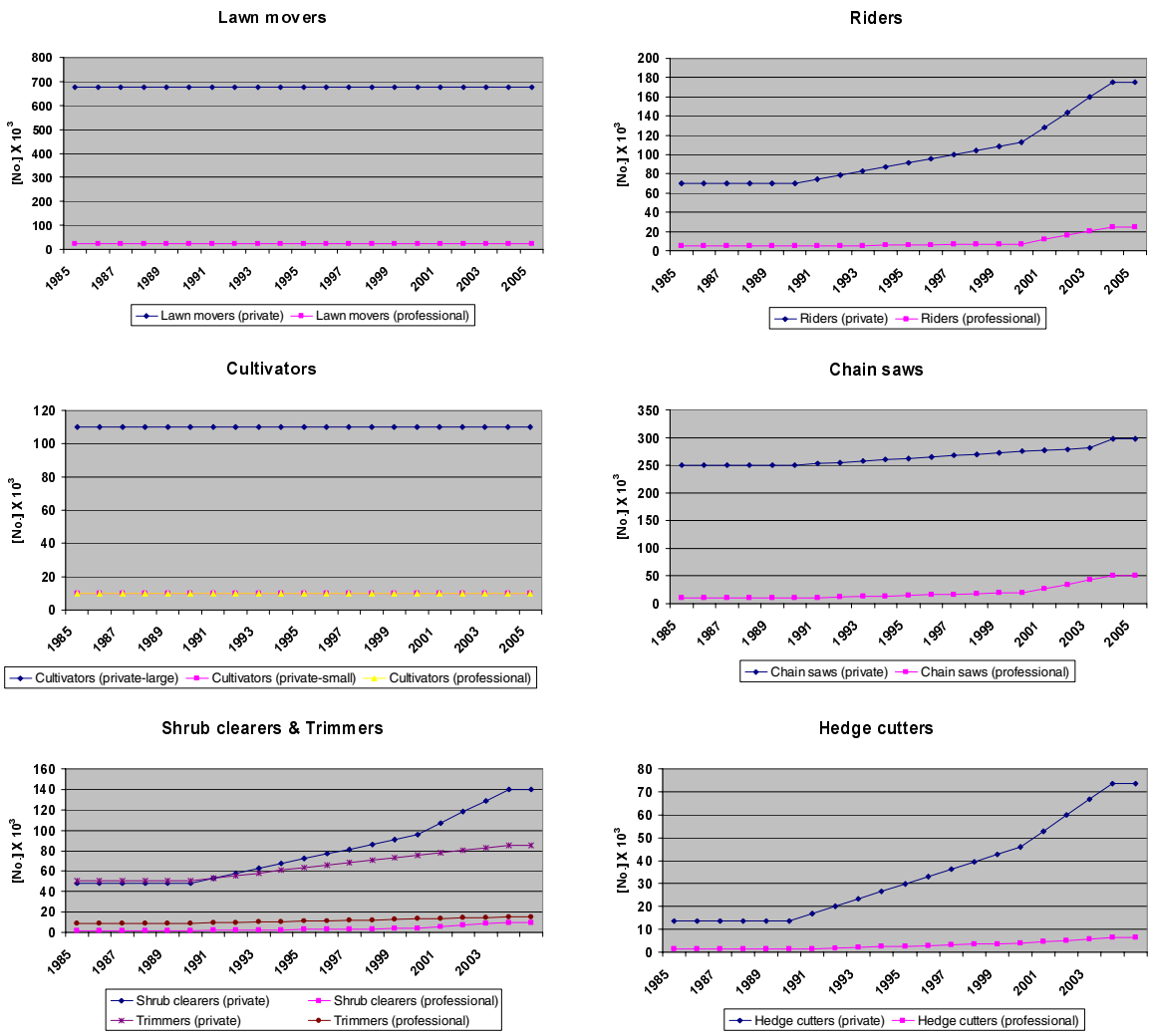


Figure 3.57 Stock development 1985-2005 for the most important household and gardening machinery types

Figure 3.58 shows the development in numbers of different recreational craft from 1985-2005. As for the residential sector the 2004 stock data for recreational craft are repeated for 2005, since no new fleet information has been obtained.

For diesel boats, increases in stock and engine size are expected during the whole period, except for the number of motor boats (< 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).

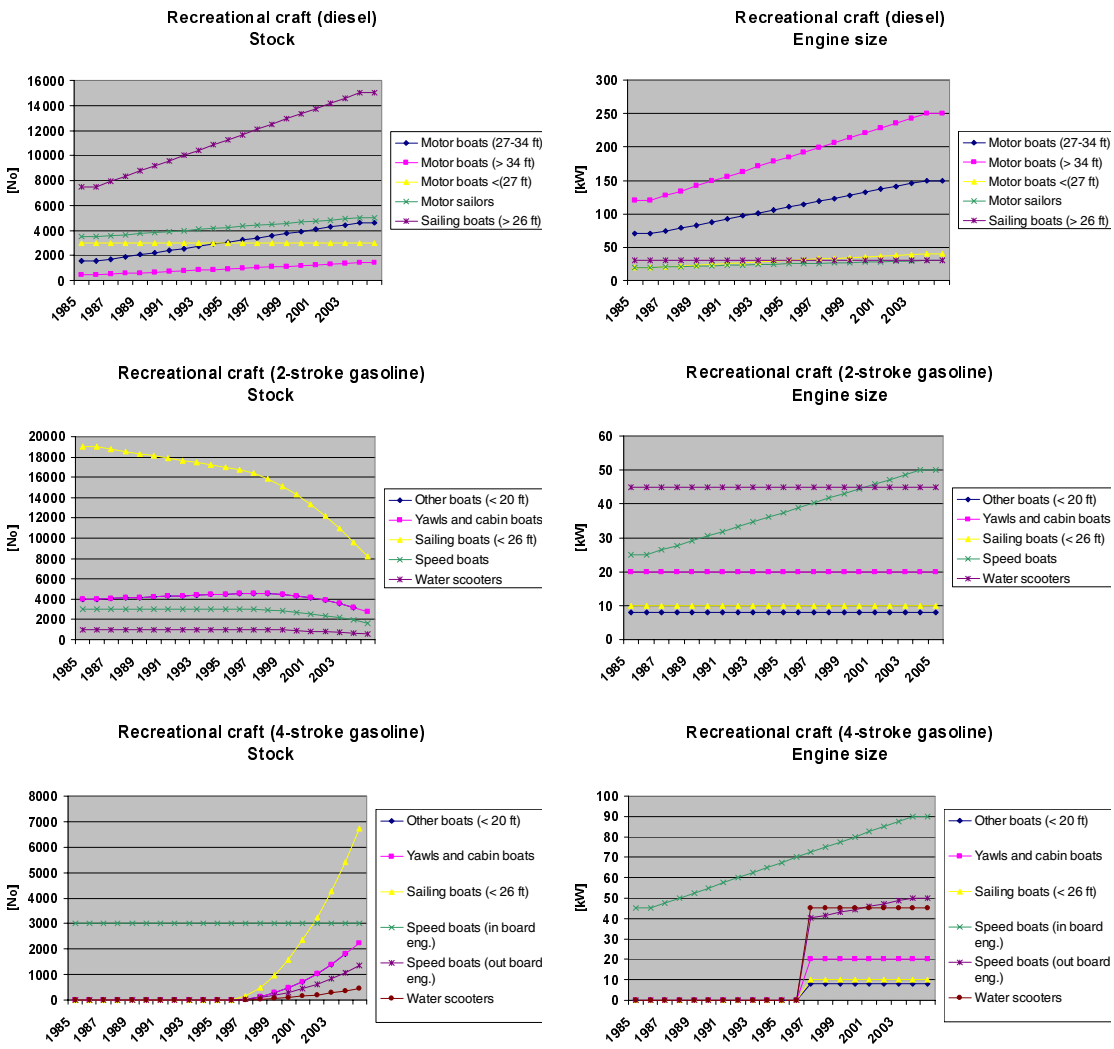


Figure 3.58 1985-2005 Stock and engine size development for recreational craft

Ferries

A new Danish research project has carried out detailed fuel use and emission calculations for Danish ferries (Winther, 2007b). Table 3.26 lists the most important domestic ferry routes in Denmark in the period 1990-2005. For these ferry routes the following detailed traffic and technical data have been gathered: Ferry name, year of service, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size and sailing time (single trip).

Table 3.26 Ferry routes comprised in the present project

Ferry service	Service period
Halsskov-Knudshoved	1990-1999
Hundested-Grenaa	1990-1996
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-
Tårs-Spodsbjerg	1990-

The number of round trips per ferry route is shown in Figure 3.59. The traffic data are also listed in Annex 2.B.11, together with different ferry specific technical and operational data. 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 use and emission calculations.

For each ferry, Annex 2.B.12 lists the relevant information as regards ferry route, name, year of service, engine size (MCR), engine type, fuel type, average load factor, auxillary engine size and sailing time (single trip).

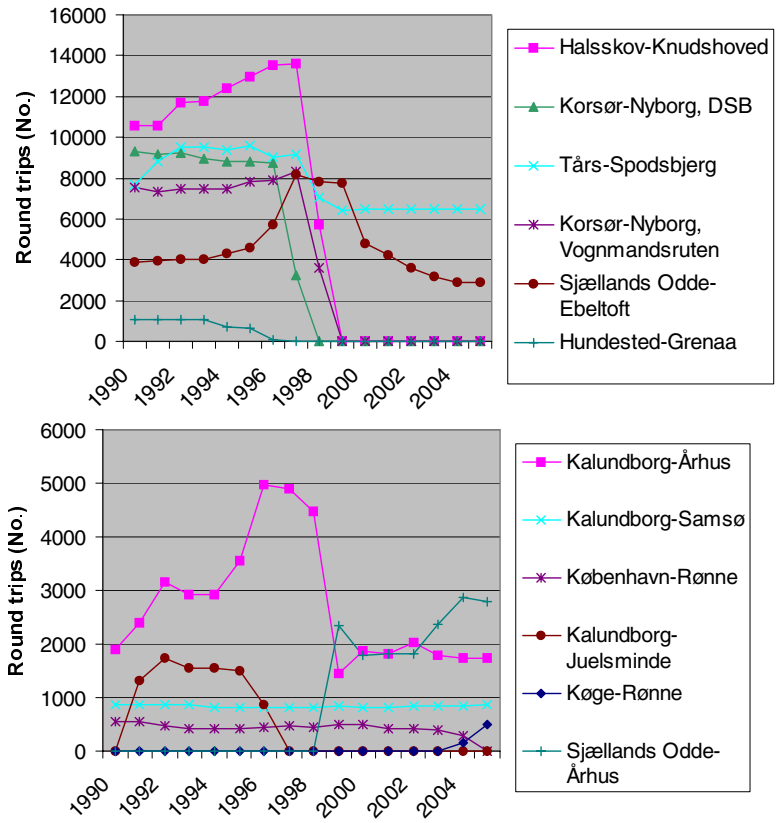


Figure 3.59 No. of round trips for the most important ferry routes in Denmark 1990-2005

It is seen from Table 3.26 (and Figure 3.59) that several ferry routes were closed in the time 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.

Other sectors

The activity data for military, railways, sea transport and fishery consists of fuel use information from DEA (2003). For sea transport, the basis is fuel sold in Danish ports and, depending on the destination of the vessels in question the traffic, is defined as either national or international, as prescribed by the IPCC guidelines. The part of fuel in national sea transport not being used by domestic ferries, is found as the DEA figures minus the bottom-up fuel use estimate for ferries (for gas oil and heavy fuel in each case), and is classified as fuel used by other national sea transport.

For all sectors, fuel-use figures are given in Annex 2.B.13 for the years 1990 and 2005 in CollectER format.

Emission legislation

For non-road working machinery and equipment, and recreational craft and railway locomotives/motor cars, the emission directives list specific emission limit values (g/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 relate to non-road machinery other than agricultural and forestry tractors, and the directives have different implementation dates for machinery operating under transient and constant loads. The latter directive also comprises emission limits for railway machinery. For tractors the relevant directives are 2000/25 and 2005/13. For gasoline, the directive 2002/88 distinguishes between hand-held (SH) and not hand-held (NS) types of machinery.

For engine type approval, the emissions (and fuel use) are measured using various test cycles (ISO 8178). Each test cycle consists of a number of measurement points for specific engine loads during constant operation. The specific test cycle used depends on the machinery type in question and the test cycles are described in more details in the directives.

Table 3.27 Overview of EU emission directives relevant for diesel fuelled non-road machinery

Stage/Engine size [kW]	CO	VOC	NO_x	$VOC+NO_x$	PM	Diesel machinery			Tractors	
							Implement. date		EU	Implement.
			[g/kWh]			EU Directive	Transient	Constant	directive	date
Stage I										
37<=P<75	6.5	1.3	9.2	-	0.85	97/68	1/4 1999	-	2000/25	1/7 2001
Stage II										
130<=P<560	3.5	1	6	-	0.2	97/68	1/1 2002	1/1 2007	2000/25	1/7 2002
75<=P<130	5	1	6	-	0.3		1/1 2003	1/1 2007		1/7 2003
37<=P<75	5	1.3	7	-	0.4		1/1 2004	1/1 2007		1/1 2004
18<=P<37	5.5	1.5	8	-	0.8		1/1 2001	1/1 2007		1/1 2002
Stage IIIA										
130<=P<560	3.5	-	-	4	0.2	2004/26	1/1 2006	1/1 2011	2005/13	1/1 2006
75<=P<130	5	-	-	4	0.3		1/1 2007	1/1 2011		1/1 2007
37<=P<75	5	-	-	4.7	0.4		1/1 2008	1/1 2012		1/1 2008
19<=P<37	5.5	-	-	7.5	0.6		1/1 2007	1/1 2011		1/1 2007
Stage IIIB										
130<=P<560	3.5	0.19	2	-	0.025	2004/26	1/1 2011	-	2005/13	1/1 2011
75<=P<130	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
56<=P<75	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
37<=P<56	5	-	-	4.7	0.025		1/1 2013	-		1/1 2013
Stage IV										
130<=P<560	3.5	0.19	0.4	-	0.025	2004/26	1/1 2014		2005/13	1/1 2014
56<=P<130	5	0.19	0.4	-	0.025		1/10 2014			1/10 2014

Table 3.28 Overview of the EU Emission Directive 2002/88 for gasoline fuelled non-road machinery

	Category	Engine size [ccm]	CO [g/kWh]	HC [g/kWh]	NO_x [g/kWh]	$HC+NO_x$ [g/kWh]	Implementation date
	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

For recreational craft, Directive 2003/44 comprises the 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 3.29. 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.

Table 3.29 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

Tabel 3.30 Overview of the EU Emission Directive 2004/26 for railway locomotives and motorcars

	Engine size [kW]		CO [g/kWh]	HC [g/kWh]	NOx [g/kWh]	HC+NO_X [g/kWh]	PM [g/kWh]	Implementation date
Locomotives	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
	Stage IIIB	RB	3.5	-	-	4	0.025	1/1 2012
Motor cars	Stage IIIA							
	130<P	RC A	3.5	-	-	4	0.2	1/1 2006
	Stage IIIB							
	130<P	RC B	3.5	0.19	2	-	0.025	1/1 2012

Aircraft engine emissions of NO_x, CO, VOC and smoke are regulated by ICAO (International Civil Aviation Organization). The legislation is relevant for aircraft engines with a rated engine thrust larger than 26.7 kN. A further description of the emission legislation and emission limits is given in ICAO Annex 16 (1993).

For seagoing vessels, NO_x emissions are regulated as explained in Marpol 73/78 Annex VI, formulated by IMO (International Maritime Organisation). The legislation is relevant 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 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/kWh, $n < 130$ RPM
- 45 x n-0.2 g/kWh, $130 \leq n < 2000$ RPM
- 9,8 g/kWh, $n \geq 2000$ RPM

Emission factors

In general, the SO_2 emission factors for other mobile sources are fuel-related and country-specific. For military ground equipment, aggregated emission factors for gasoline and diesel are derived from road traffic emission simulations. For aviation gasoline fuel use, aggregated emission factors for conventional cars are used. For railways, specific Danish measurements from the Danish State Railways (DSB) (Næraa, 2005) are used to calculate the emission factors of NO_x, VOC, CO and TSP, and a NMVOC/CH_4 split is made based on own judgment.

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

For national sea transport and fisheries, the NO_x emission factors predominantly come from the engine manufacturer MAN B&W, as a function of engine production year. The CO, VOC and TSP emission factors come from the Danish TEMA2000 emission model (Trafikministeriet, 2000), whereas the PM_{10} and $PM_{2.5}$ size fractions are obtained from MAN B&W. The N_2O emission factors and the NMVOC/CH_4 split are taken from EMEP/CORINAIR (2003). The baseline emission factors are shown in Annex 2.B.12.

The source for aviation (jet fuel) emission factors is the EMEP/CORINAIR guidebook (CORINAIR, 2003). The same emission factor source is used for all other mobile sources in relation to NH_3, heavy metal and PAH emissions.

For all sectors, emission factors are given in CollectER format in Annex 2.B.13 for the years 1990 and 2005. Table 3.31 shows the aggregated emission factors for SO_2, NO_X, NMVOC and TSP for road transport in Denmark in 2005 used to calculate the emissions from other mobile sources in Denmark.

Factors for deterioration, transient loads and gasoline evaporation for non road machinery

The emission effects of engine wear are taken into account 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), and are shown in Annex 2.B.9. For more details regarding the use of these factors, please refer to paragraph 3.1.4 or Winther et al. (2006).

Table 3.31 Fuel based emission factors for SO_2, NO_X, NMVOC and TSP for other mobile sources in Denmark (2005)

					Emission factors[1] [g/GJ]			
SNAP ID	NFR ID	Category	Fuel type	Mode	SO_2	NO_X	NMVOC	TSP
801	1A5	Military	Diesel		0.47	562.00	35.07	32.95
801	1A5	Military	Jet fuel	< 3000 ft	22.99	250.57	24.94	1.16
801	1A5	Military	Jet fuel	> 3000 ft	22.99	250.57	24.94	1.16
801	1A5	Military	Gasoline		0.46	239.21	276.15	2.71
801	1A5	Military	Av. gasoline		22.99	859.00	1242.60	10.00
802	1A3c	Railways	Diesel		0.47	1187.26	75.00	39.45
803	1A3d	Inland waterways	Diesel		93.68	877.17	170.01	104.92
803	1A3d	Inland waterways	Gasoline		0.46	420.56	2306.60	106.89
80402	1A3d	National sea traffic	Residual oil		978.00	2002.19	65.05	111.58
80402	1A3d	National sea traffic	Diesel		93.68	1281.79	50.12	27.04
80402	1A3d	National sea traffic	Kerosene		2.30	50.00	3.00	5.00
80402	1A3d	National sea traffic	LPG		0.00	1249.00	384.94	0.20
80403	1A4c	Fishing	Residual oil		1101.71	1393.60	56.90	139.40
80403	1A4c	Fishing	Diesel		93.68	1346.81	55.98	27.04
80403	1A4c	Fishing	Kerosene		2.30	50.00	3.00	5.00
80403	1A4c	Fishing	Gasoline		2.28	64.34	10809.60	23.25
80403	1A4c	Fishing	LPG		0.00	1249.00	384.94	0.20
80404	Memo item	International sea traffic	Residual oil		1711.49	2037.06	60.25	265.53
80404	Memo item	International sea traffic	Diesel		93.68	1500.33	54.93	27.04
80501	1A3a	Air traffic, other airports	Jet fuel	Dom. < 3000 ft	22.99	277.22	31.65	1.16
80501	1A3a	Air traffic, other airports	Av. gasoline		22.83	859.00	1242.60	10.00
80502	Memo item	Air traffic, other airports	Jet fuel	Int. < 3000 ft	22.99	296.77	16.90	1.16
80502	Memo item	Air traffic, other airports	Av. gasoline		22.83	859.00	1242.60	10.00
80503	1A3a	Air traffic, other airports	Jet fuel	Dom. > 3000 ft	22.99	286.83	24.68	1.16
80504	Memo item	Air traffic, other airports	Jet fuel	Int. > 3000 ft	22.99	242.86	6.72	1.16
806	1A4c	Agriculture	Diesel		2.34	834.38	92.05	68.11
806	1A4c	Agriculture	Gasoline		0.46	93.75	1031.99	23.83
807	1A4c	Forestry	Diesel		2.34	742.84	58.00	39.96
807	1A4c	Forestry	Gasoline		0.46	60.50	6513.81	75.31
808	1A2f	Industry	Diesel		2.34	786.04	104.04	84.64
808	1A2f	Industry	Gasoline		0.46	194.14	1474.91	13.33
808	1A2f	Industry	LPG		0.00	1328.11	146.09	4.89
809	1A4b	Household and gardening	Gasoline		0.46	80.39	2144.69	21.46
80501	1A3a	Air traffic, Copenhagen airport	Jet fuel	Dom. < 3000 ft	22.99	268.26	43.78	1.16
80501	1A3a	Air traffic, Copenhagen airport	Av. gasoline		22.83	859.00	1242.60	10.00
80502	Memo item	Air traffic, Copenhagen airport	Jet fuel	Int. < 3000 ft	22.99	335.97	39.34	1.16
80502	Memo item	Air traffic, Copenhagen airport	Av. gasoline		22.83	859.00	1242.60	10.00
80503	1A3a	Air traffic, Copenhagen airport	Jet fuel	Dom. > 3000 ft	22.99	284.42	21.69	1.16
80504	Memo item	Air traffic, Copenhagen airport	Jet fuel	Int. > 3000 ft	22.99	312.14	10.85	1.16

[1] References. SO_2: Country-specific; Military: Aggregated emission factors for road transport; Railways (NO_x, NMVOC and TSP): Danish State Railways; Agriculture, forestry, industry, household gardening and inland waterways (NO_x, VOC and TSP): IFEU (2004); National sea transport and fishing: MAN B&W (NO_x) and TEMA2000 (NMVOC, TSP); Aviation - jet fuel (NO_X, NMVOC and TSP): EMEP/CORINAIR; Aviation - av.gasoline: Aggregated emission factors for conventional gasoline cars

3.3.4 Calculation method

Air traffic

For aviation, the estimates are made separately for landing and take-off (LTOs < 3000 ft), and cruising (> 3000 ft). From 2001, the estimates are made on a city-pair level, by combining activity data and emission fac-

tors and subsequently grouping the emission results into domestic and international totals. The overall fuel precision in the model is around 0.8, derived as the fuel ratio between model estimates and statistical sales. The fuel difference is accounted for by adjusting cruising fuel use and emissions in the model according to domestic and international cruising fuel shares.

Prior to 2001, the calculation procedure was first to estimate each year's fuel use and emissions for LTO. Secondly, total cruising fuel use was found year by year as the statistical fuel use total minus the calculated fuel use for LTO. Lastly, the cruising fuel use was split into a domestic and international part by using the results from a Danish city-pair emission inventory in 1998 (Winther, 2001a). For more details of this latter fuel allocation procedure, see Winther (2001b).

Non-road working machinery and recreational craft

Prior to adjustments for deterioration effects and transient engine operations, the fuel use and emissions in year X, for a given machinery type, engine size and engine age, are calculated as:

$$E_{Basis}(X)_{i,j,k} = N_{i,j,k} \cdot HRS_{i,j,k} \cdot P \cdot LF_i \cdot EF_{y,z} \quad (13)$$

where E_{Basis} = fuel use/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 use/emission factor in g/kWh, i = machinery type, j = engine size, k = engine age, y = engine-size class and z = emission level. The basic fuel use and emission factors are shown in Annex 2.B.9.

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:

$$DF_{i,j,k}(X) = \frac{K_{i,j,k}}{LT_i} \cdot DF_{y,z} \quad (14)$$

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:

$$DF_{i,j,k}(X) = \sqrt{\frac{K_{i,j,k}}{LT_i}} \cdot DF_{y,z} \quad (15)$$

The deterioration factors inserted in (14) and (15) are shown in Annex 2.B.9. No deterioration is assumed for fuel use (all fuel types) or for LPG engine emissions and, hence, DF = 1 in these situations.

The transient factor for a given machinery type, engine size and engine age in year X, relies only on emission level and load factor, and is denominated as:

$$TF_{i,j,k}(X) = TF_z \quad (16)$$

Where i = machinery type, j = engine size, k = engine age and z = emission level.

The transient factors inserted in (16) are shown in Annex 2.B.9. No transient corrections are made for gasoline and LPG engines and, hence, TF_z = 1 for these fuel types.

The final calculation of fuel use and emissions in year X for a given machinery type, engine size and engine age, is the product of the expressions 13-16:

$$E(X)_{i,j,k} = E_{Basis}(X)_{i,j,k} \cdot TF(X)_{i,j,k} \cdot (1 + DF(X)_{i,j,k}) \quad (17)$$

The evaporative hydrocarbon emissions from fuelling are calculated as:

$$E_{Evap,fueling,i} = FC_i \cdot EF_{Evap,fueling} \quad (18)$$

Where $E_{Evap,fueling}$, = hydrocarbon emissions from fuelling, i = machinery type, FC = fuel consumption in kg, $EF_{Evap,fueling}$ = emission factor in g NMVOC/kg fuel.

For tank evaporation, the hydrocarbon emissions are found from:

$$E_{Evap,\tan k,i} = N_i \cdot EF_{Evap,\tan k,i} \quad (19)$$

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/year.

Ferries, other national sea transport and fisheries

The fuel use and emissions in year X, for ferries are calculated as:

$$E(X) = \sum_i N_i \cdot T_i \cdot S_{i,j} \cdot P_i \cdot LF_j \cdot EF_{k,l,y} \quad (20)$$

Where E = fuel use/emissions, N = number of round trips, T = sailing time per round trip in hours, S = ferry share of ferry service round trips, P = engine size in kW, LF = engine load factor, EF = fuel use/emission factor in g/kWh, i = ferry service, j = ferry, k = fuel type, l = engine type, y = engine year.

For the remaining navigation categories, the emissions are calculated using a simplified approach:

$$E(X) = \sum_i EC_{i,k} EF_{k,l,y} \quad (21)$$

Where E = fuel use/emissions, EC = energy consumption, EF = fuel use/emission factor in g/kg fuel, i = category (ferry boats, other national sea, fishery, international sea), k = fuel type, l = engine type, y = average engine year.

The emission factor inserted in (21) 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:

$$EF_{k,l,y} = \frac{\sum_{year=X}^{year=X-LT} EF_{k,l}}{LT_{k,l}} \quad (22)$$

Other sectors

For military and railways, the emissions are estimated with the simple method using fuel-related emission factors and fuel use from the DEA:

$$E = FC \cdot EF \quad (23)$$

where E = emission, FC = fuel consumption and EF = emission factor. The calculated emissions for other mobile sources are shown in CollectER format in Annex 2.B.13 for the years 1990 and 2005 and as time-series 1985-2005 in Annex 2.B.14 (NFR format).

Fuel use balance for national sea transport

For national sea transport, bottom-up fuel use estimates are calculated for ferries, and rough fuel use estimates are also produced for ferry boats. For inventory years, when the fuel sum (heavy fuel oil and gas oil treated separately) is above the reported fuel totals from the DEA statistics, adjustments must then be made to the fuel use and emission results, in order to fulfil the convention rules. The adjustments are made per fuel type by simply scaling the results with the DEA:Calculated fuel use ratio.

Figure 3.60 shows the ratios between the calculated fuel use and the statistical fuel sales from 1990-2005, split into fuel type and as totals for national sea transport.

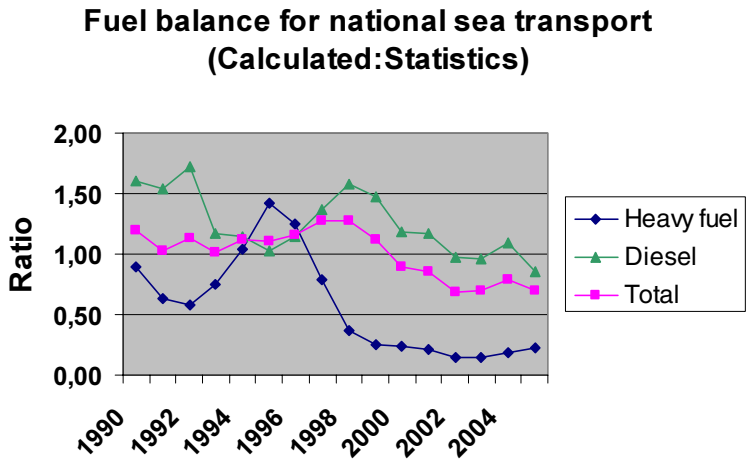


Figure 3.60 The ratio between calculated fuel use and DEA fuel sales for 1990-2005

For gas oil, the surplus of calculated fuel use is very big for the years until 1992, and from 1997-1999; only for the years 2002, 2003 and 2005 the calculated gas oil fuel total becomes lower than statistical sales. For heavy fuel, only the years 1994-1996 show a surplus of calculated fuel, and from 1998 onwards the calculated fuel use is significantly lower than statistical sales. In terms of total fuel use, the calculated fuel use surplus tends to increase until 1998, followed by a decreasing trend up to today's situation.

There are many potential reasons for the fuel use differences. From the fuel supplier's side, errors such as sector misallocation or incorrect fuel type descriptions may cause disturbances in the fuel balance, and general calculation uncertainties may bring a certain displacement in the estimated fuel use trend. At the moment it is, however, not possible to determine what are the exact reasons for the very fluctuating fuel use ratios. A more thorough discussion is given in Winther (2007b).

Non road machinery: DEA statistics and NERI estimates

For diesel and LPG, the non-road fuel use estimated by NERI is partly covered by the fuel-use 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 use total. In addition, a certain amount of fuel from road transport is needed to reach the fuel-use goal.

The amount of diesel and LPG in DEA industry not being used by non-road machinery is included in the sectors, "Combustion in manufacturing industry" (0301) and "Non-industrial combustion plants" (0203) in the Danish emission inventory.

For recreational craft, the calculated fuel-use totals are subsequently subtracted from the DEA fishery (diesel) and road transport (gasoline) sectors.

Bunkers

The distinction between domestic and international emissions from aviation and navigation should be in accordance with the Revised 1996 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

For aviation, the emissions associated with flights inside the Kingdom of Denmark are counted as domestic. The flights from Denmark to Greenland and the Faroe Islands are classified as domestic flights in the inventory background data. In Greenland and the Faroe Islands, the jet fuel sold is treated as domestic. This decision can be considered sensible since in the real world almost no fuel is bunkered in Greenland/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 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).

To comply with the IPCC classification rules, the fuel used by vessels sailing to Greenland and the Faroe Islands should form part of the domestic total. To improve the fuel data quality for Greenland and the Faroe Islands, the fuel sales should be grouped according to vessel destination and IPCC classifications subsequently be made.

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

Emission uncertainty estimates are made for road transport and other mobile sources using the guidelines formulated in the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000). However, for TSP the latter source indicates no uncertainty factor and, instead, this factor is based on own judgement.

The activity data uncertainty factor is assumed to be 2 and 10% for road transport and other mobile sources, respectively, based on own 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 2.B.15 for all emission components.

Table 3.32 Uncertainties for activity data, emission factors and total emissions in 2004 and as a trend

	Emission factor uncertainties [%]		Emission uncertainties [%]	
Pollutant	Road	Other	Overall 2004	Trend
SO_2	50	50	50	5
NO_x	50	100	51	8
NMVOC	50	100	49	10
CO	50	100	52	15
NH_3	1000	1000	997	3475
TSP	50	100	47	9
PM_{10}	50	100	49	7
$PM_{2.5}$	50	100	51	6
Arsenic	1000	1000	1000	7
Cadmium	1000	1000	788	143
Chromium	1000	1000	788	149
Copper	1000	1000	823	79
Mercury	1000	1000	1000	11
Nickel	1000	1000	837	78
Lead	1000	1000	964	18
Selenium	1000	1000	742	147
Zinc	1000	1000	807	101
Dioxins	1000	1000	707	139
Flouranthene	1000	1000	783	21
Benzo(b) flouranthene	1000	1000	780	36
Benzo(k) flouranthene	1000	1000	822	67
Benzo(a) pyrene	1000	1000	853	40
Benzo(g,h,i) perylene	1000	1000	788	29
indeno(1,2,3-c,d) pyrene	1000	1000	771	123

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 assump-

tions, a sound 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 use information for working equipment and machinery.

3.3.6 Quality assurance/quality control (QA/QC)

It is the intention to publish annually a sector report for road transport and other mobile sources. The last sector report concerned the 2004 inventory.

The QA/QC descriptions of the Danish emission inventories for transport are given in Illerup et al. (2007).

3.3.7 Recalculations

The following recalculations and improvements of the emission inventories have been made since the emission reporting in 2006.

Road transport

A revision of the 1985-2004 time-series of emissions has been made, based on revised mileage data from the Danish Road Directorate (derived from the Danish vehicle inspection and maintenance programme) and updated emission factors from the latest version of the European road transport emission model - COPERT IV.

Military

A revision of the 1985-2004 time-series of emission factors has been made based on new aggregated emission factors from road transport.

Railways

No changes have been made.

Inland waterways

A fuel use error has been corrected for the years 1985-2003, giving fuel use and emission decreases for this time period. This affects also the fishery category, since more fuel now appears in fisheries.

National sea transport and fisheries

A new research project carried out by Winther (2007b) has given new knowledge, and the following changes have therefore been made to the national inventory: 1) Updated emission factors has given some changes in the total emissions from 1985-2004, 2) The residual fuel use amount from the fishery sector in the national energy statistics, has been moved to the national sea transport category, resulting in fuel use and emission changes 1985-2004.

Less diesel fuel is subtracted from fisheries, due to an error correction for inland waterways. This results in fuel use and emission changes 1985-2003.

Aviation

No changes have been made.

Agriculture

Updated stock information for tractors and harvesters 2001-2004, has given a fuel use and emissions increase for these years.

3.3.8 Improvements

Heavy metals and POPs

It is the intention this year to update the heavy metal and POP emission inventories for mobile sources.

QA/QC

Based on the improved inventory QA/QC description for mobile sources, a list of work is planned to be carried out this year. For more information, please refer to Illerup et al., (2007).

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3.4 Fugitive emissions (CRF sector 1B)

3.4.1 Source category description

Fugitive emission from solid fuels, CRF sector 1B1c

Coal mining is not occurring in Denmark and no emissions are estimated for solid fuel.

Fugitive emissions from oil (1B2a)

The category "Fugitive emissions from oil (1B2a)" includes emissions from offshore activities and refineries.

Fugitive emissions from natural gas, transmission and distribution (CRF sector 1B2b)

In the year 2005, the length of transmission pipelines excluding offshore pipeline was 860 km. The length of distribution pipelines was 18682 km in 2005 (cast iron 0 km, steel 1868 km, plastics 16814 km). Two natural gas storage facilities are in operation in Denmark. In 2005 the gas input was 530 Mm^3 and the withdrawal was 555 Mm^3. Emission from gas storage is included in transmission.

Flaring, gas (CRF sector 1B2c, Flaring ii)

Offshore flaring of natural gas is the main source of emissions in the Fugitive emission sector. Flaring in gas treatment and gas storage plants are, however, also included in the sector.

3.4.2 Methodological issues

Fugitive emissions from oil (1B2a)

Offshore activities

Emissions from offshore activities include emissions from extraction of oil and gas, onshore oil tanks, onshore and offshore loading of ships.

The total emission can then be expressed as:

$$E_{total} = E_{extraction} + E_{ship} + E_{oil\,tanks} \qquad (3.5.1)$$

Fugitive emissions from extraction

According to the EMEP/CORINAIR Guidebook (EMEP/CORINAIR, 2004) the total fugitive emissions of VOC from extraction can be estimated by means of Equation 3.5.2.

(3.5.2)

$$E_{VOC,fugitive} = 40.2 \cdot N_P + 1.1 \cdot 10^{-2} P_{gas} + 8.5 \cdot 10^{-6} \cdot P_{oil}$$

where N_P is the number of platforms, P_{gas} (10^6 Nm^3) is the production of gas and P_{oil} (10^6 tons) is the production of oil.

It is assumed that the VOC contains 75% methane and 25% NMVOC, meaning that the total emission of CH_4 and NMVOC for extraction of oil and gas can be calculated as:

$$E_{extraction,NMVOC} = E_{fugitive,NMVOC} + E_{flaring,NMVOC}$$
$$= 0.25(40.2 \cdot N_P + 1.1 \cdot 10^{-2} P_{gas} + 8.5 \cdot 10^{-6} \cdot P_{oil}) + F_P \cdot EMF_{flaring,NMVOC}$$

(3.5.3)

$$E_{extraction,CH4} = E_{fugitive;CH4} + E_{flaring,CH4}$$
$$= 0.75(40.2 \cdot N_P + 1.1 \cdot 10^{-2} P_{gas} + 8.5 \cdot 10^{-6} \cdot P_{oil}) + F_P \cdot EMF_{flaring,CH4}$$

(3.5.4)

In Denmark, the venting of gas is assumed to be negligible because controlled venting enters the gas flare system.

Ships

This source includes the transfer of oil from storage tanks or directly from the well into a ship. This activity also includes losses during transport. When oil is loaded hydrocarbon vapour will be displaced by oil and new vapour will be formed, both leading to emissions. The emissions from ships are calculated by equation 3.5.5.

(3.5.5) $$MF_{ships} \cdot L_{oil}$$

where EMF_{ships} is the emission factor for loading of ships off-shore and on-shore and L_{oil} is the amount of oil loaded.

Oil tanks

The emissions from storage of raw oil are calculated by equation 3.5.6.

(3.5.6) $$EMF_{tanks} \cdot T_{oil}$$

where EMF_{tanks} is the emission factor for storage of raw oil in tanks.

Activity data

Activity data used in the calculations of the emissions is shown in Table 3.33 and is based on information from the Danish Energy Authority (Danish Energy Authority, 2006a and 2006b) or from the green accounts from the Danish gas transmission company DONG (DONG, 2006).

Table 3.33 Activity data for 2005

Activity	Symbols	Year 2005	Ref.
Number of platforms	N_p	50	Danish Energy Agency (2006a)
Produced gas (10^6Nm3)	P_{gas}	11523	Danish Energy Agency (2006a)
Produced oil(10^3m3)	$P_{oil,vol}$	21886	Danish Energy Agency (2006a)
Produced oil (10^3ton)	P_{oil}	18822	Danish Energy Agency (2006a)
Oil loaded (10^3m3)	$L_{oil\ off\text{-}shore}$	3880	Danish Energy Agency (2006a)
Oil loaded (10^3ton)	$L_{oil\ off\text{-}shore}$	3337	Danish Energy Agency (2006a)
Oil loaded (10^3m3)	$L_{oil\ on\text{-}shore}$	14500	DONG (2006)
Oil loaded (10^3ton)	$L_{oil\ on\text{-}shore}$	12470	DONG (2006)

Mass weight raw oil = 0.86 ton/m^3

In the EMEP/CORINAIR Guidebook (EMEP/CORINAIR, 2004) emission factors for different countries are given. In the Danish emission inventory the Norwegian emission factors are used (EMEP/CORINAIR, 2004, Table 3.30). The emissions for storage of oil are given in the green accounts from DONG for 2005 (DONG, 2006) and the emission factor is calculated on the basis of the amount of oil transported in pipeline.

Table 3.34 Emission factors.

	CH_4	NMVOC	Unit	Reference.
Ships off-shore	0.00005	0.001	Fraction of loaded	EMEP/CORINAIR, 2004
Ships on-shore	0.000002	0.0002	Fraction of loaded	EMEP/CORINAIR, 2004
Oil tanks	113	249	kg/10^3m^3	DONG, 2006

From the activity data in Table 3.33 and the emission factors in Table 3.34 the emissions for NMVOC and CH_4 are calculated in Table 3.35.

Table 3.35 CH_4 and NMVOC emissions for 2005 (tonnes)

	CH_4	NMVOC
Extraction (fugitive)	1594	531
Oil tanks	2045	4507
Offshore loading of ships	167	3337
Onshore loading of ships	25	2494
Total	3831	10869

Oil Refineries

Petroleum products processing: in the production process at refineries, a part of the volatile hydrocarbons (VOC) is emitted to the atmosphere. It is assumed that CH_4 accounts for 1% and NMVOC for 99% of the emissions. The VOC emissions from the petroleum refinery processes cover non-combustion emissions from feedstock handling/storage, petroleum products processing, product storage/handling and flaring. SO_2 is also emitted from the non-combustion processes and includes emissions from products processing and sulphur recovery plants. The emission calculations are based on information from the Danish refineries and the energy statistics.

Table 3.36 Oil Refineries. Processed crude oil, emissions and emission factors

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Crude oil (1000 Mg)	7263	7798	8232	8356	8910	9802	10522	7910	7906	8106	8406	8284	8045	8350	8264	8264
CH4 emission (Mg)	37	39	42	43	57	48	62	45	45	45	50	44	43	37	613	613
CH4 emission factor (g/Mg)	5	5	5	5	6	5	6	6	6	6	6	5	5	4	74	74
NMVOC emission (Mg)	3667	3937	4203	4219	5855	4546	5875	4547	4558	4558	4983	4338	4302	3708	3732	3732
NMVOC emission factor (g/Mg)	505	505	511	505	657	464	558	575	577	562	593	524	535	444	451	452

Fugitive emissions from natural gas, transmission and distribution (CRF sector 1B2b)

Inventories of NMVOC emission from gas transmission and distribution are based on annual environmental reports from DONG and on a Danish emission inventory for the years 1999-2005 reported by the Danish gas sector (transmission and distribution companies) (Karll 2003, Karll 2005 & Oertenblad 2006). The inventories estimated by the Danish gas sector are based on the work carried out by Marcogas and the International Gas Union (IGU).

In the 1990-1999 inventories, fugitive NMVOC emissions from storage facilities and the gas treatment plant are included in the emission factor for transmission. In the 2000-2005, emission inventories transmission, gas storage and gas treatment are registered separately and added.

Gas transmission data are shown in Table 3.37. Emissions from gas storage facilities and venting in the gas treatment plant are shown in Table 3.38. Gas distribution data are shown in Table 3.39.

Table 3.37 NMVOC emission from natural gas transmission

TRANSMISSION		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Transmission rate Mm^3	1)	2739	3496	3616	3992	4321	4689	5705	6956	6641	6795	7079	7289	7287	7275	7384	7600
NMVOC emission Mg	2)		94	28	57	46	163	56	72	45	56	26	48	24	27	27	45
NMVOC IEF kg/Mm^3	3)	27.018	27.018	7.821	14.220	10.665	34.839	10.976	10.300	6.776	8.241	3.704	6.567	3.263	3.688	3.656	5.893

1) In 1990-1997 transmission rates refer to Danish energy statistics, in 1998 the transmission rate refers to the annual environmental report of DONG, in 1999-2005 emissions refer to DONG/Danish Gas Technology Centre (Karll 2003, Karll 2005, Oertenblad 2006)

2) In 1991-95 NMVOC emissions are based on the annual environmental report from DONG for the year 1995. In 1996-99 the NMVOC emission refers to the annual environmental reports from DONG for the years 1996-99. In 2000-2005 the NMVOC emission refers to DONG/Danish Gas Technology Centre (Karll 2003, Karll 2005, Oertenblad 2006)

3) IEF=Emission/transmission rate. In 1990 the IEF is assumed to be the same as in 1991.

Table 3.38 Additional fugitive NMVOC emissions from natural gas storage facilities and venting in gas treatment plant (Mg)

	2000	2001	2002	2003	2004	2005
Gas treatment plant	2.27	0	0	0	0	0
Gas storage facilities	23.05	21.96	20.00	19	24	18

Table 3.39 NMVOC emission from natural gas distribution

DISTRIBUTION	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003[4)5)]	2004[4)]	2005[4)]
Distribution rate Mm^3 1)	1574	1814	1921	2185	2362	2758	3254	3276	3403	3297	3181	3675	3420	3420	3248	2983
NMVOC emission Mg 2)										13.11	14.94	17.07	11.86	11.86	45.07	18.77
NMVOC IEF kg/Mm^3 3)	4.44	4.44	4.44	4.44	4.44	4.44	4.44	4.44	4.44	3.98	4.70	4.65	3.47	3.47	13.88	6.292

1) In 1999-2005 distribution rates refer to DONG / Danish Gas Technology Centre / Danish gas distribution companies (Karll 2005, Oertenblad 2006), In 1990-98 distribution rates 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.

2) Danish Gas Technology Centre / DONG/ Danish gas distribution companies (Karll 2003)

3) In the years 1999-2005 IEF=NMVOC emission / distribution rate. In 1990-1998 an average of the IEF in 1999-2001 is assumed.

4) Data from Naturgas Fyn not included (data not complete)

5) Assumed same emission as in 2002

Flaring, gas (CRF sector 1B2c, Flaring ii)

Emissions from offshore flaring are estimated based on data for fuel consumption from the Danish energy statistics (DEA, 2006b) and emission factors for flaring. The emissions from flaring in gas treatment and gas storage plants are estimated based on the annual environmental reports of the plants.

The fuel consumption rates are shown in Table 3.40. Flaring rates in gas treatment and gas storage plants are not available until 1995.

The emission factors for offshore flaring are shown in Table 3.41. The CO_2 emission factor follows the same time-series as natural gas combusted in stationary combustion plants. All other emission factors are constant in 1990-2005.

The time-series for the CO_2 emission from gas flaring fluctuates due to the fluctuation of offshore flaring rates as shown in Figure 3.61.

Table 3.40 Natural gas flaring rate (DEA 2006b)

Year	Flaring, offshore [TJ]	Gas treatment and gas storage [TJ]
1990	4218	-
1991	8692	-
1992	8977	-
1993	7819	-
1994	7709	-
1995	5964	43
1996	6595	30
1997	9629	35
1998	7053	29
1999	15509	32
2000	10023	29
2001	10806	36
2002	8901	44
2003	9333	33
2004	10299	25
2005	7269	42

Table 3.41 Emission factors for offshore flaring of natural gas

Pollutant	Emission factor	
CO_2	56,96	kg/GJ
CH_4	5	g/GJ
N_2O	1	g/GJ
SO_2	0,3	g/GJ
NO_x	300	g/GJ
NMVOC	3	g/GJ
CO	25	g/GJ

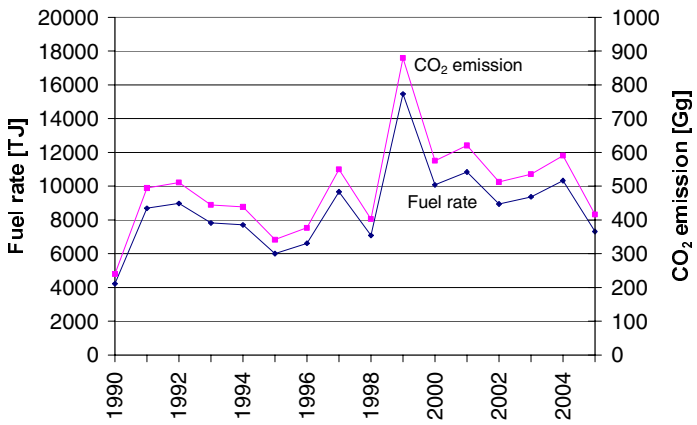

Figure 3.61 Time-series for off shore gas flaring and the CO_2 emission in sector 1B2c ii Flaring, gas

The fuel consumption for offshore flaring was higher in 1999 due to the opening of new gas fields.

Besides 1999, consumption has been fairly stable for a number of years. The decrease from 15455 TJ in 1999 to 7311 TJ in 2005 represents a decrease of around 50%.

3.4.3 Uncertainties and time-series consistency

Uncertainty estimates are included in the uncertainty estimate for stationary combustion plants.

3.4.4 Source-specific QA/QC and verification

No source-specific QA/QC and verification have been performed.

3.4.5 Source-specific recalculations

No recalculations have been carried out.

3.4.6 Source-specific planned improvements

No source-specific improvements are planned.

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4 Industrial processes (NFR sector 2)

4.1 Overview of the sector

The present sector *"Industrial processes"* (NFR sector 2) comprises combustion processes combined with *"process emissions"* (combustion in manufacturing industry - processes with contact) as well as process emissions without any contact with energy-related emissions. This means that the energy source may be power from central power plants or process heat from e.g. natural gas-fired boilers, turbines or stationary engines. The presentation is outlined as follows:

- Mineral products (NFR 2A) including "Other" (NFR 1A2f)
- Chemical industry (NFR 2B)
- Metal production (NFR 2C) including "Iron and steel" (NFR 1A2a) and "Non-ferrous metals" (NFR 1A2b)
- Other production (NFR 2D)

The industrial processes included in the Danish inventory are those in large companies, e.g. cement factories or steelworks, as well as a number of smaller companies e.g. iron foundries. Furthermore, asphalt concrete plants are to be included in future.

Table 4.1 presents a survey of sources and groups of pollutants included in the present survey as well as pollutants and sources that will be included in the survey. Explanations to the abbreviations are given below the table.

Table 4.1 indicates that some groups of substances are planned to be included in the inventory. In addition to the indicated groups of substances some groups do not include all relevant substances or the time-series are not complete. Detailed information on this subject can be found in the following table with an indication of which substances that will be completed/improved in the inventory.

Table 4.1 Survey of industrial sector with SNAP-code and NFR-code included in the Danish inventory.

Industrial sector	SNAP	NFR	Energy	SO_X/ NO_X/ NH_3	NMVOC/ CO	TSP/ $PM_{10/2.5}$	HM	POP
Grey iron foundries	030303	1A2a	ie	+	+	x	x	-
Secondary lead production	030307	1A2b	ie	-	-	x	x	-
Secondary zinc production	030308	1A2b	ie	-	-	x	+	-
Secondary aluminium production	030310	1A2b	ie	-	-	x	+	-
Cement	030311	1A2f	y	x	x	x	x	-
Lime (incl. iron, steel and paper pulp industry)	030312	1A2f	ie	+	-	x	+	-
Asphalt concrete plants	030313	1A2f	+	+	+	+	-	+/?
Container glass	030315	1A2f	y	x	x	x	x	-
Glass wool	030316	1A2f	ie	x/+	-	x	+	-
Mineral wool	030318	1A2f	y	x/+	x	x	+	-
Paper mill industry	030321	1A2d	y	-	+	x	-	-
Electric arc furnace	040207	2C1	-	-	-	x	x	+/?
Allied metal manufacturing	040306	2C5	-	-	-	+	x	-
Sulphuric acid	040401	2B5	-	x	-	-	-	-
Nitric acid	040402	2B2	y	x	-	x	-	-
NPK-fertiliser	040407	2B5	-	x	ie	x	ie	-
Other (catalysts)	040416	2B5	y	x	-	x	-/?	-
Pesticide production	040525	2B5	-	+	x	+	-	+/?
Bread	040605	2D2	-	-	+	-	-	
Beer	040607	2D2	-	-	x	-	-	
Roof covering with asphalt materials	040610	2A5	-	-	x	-	-	+/?
Road paving with asphalt	040611	2A6	-	+	x	-	-	+/?
Cement (decarbonising)	040612	2A1	-	ie	-	-	+	-
Glass (decarbonising)	040613	2A7	-	ie	-	-	+	-
Lime (decarbonising)	040614	2A2	-	ie	-	-	+	-
Other (sugar, chemical ingredients, slaughterhouse waste)	040617	2A7	y	x/+	x	x	-	+/?
Limestone and dolomite use	040618	2A3	-	ie	+	ie	ie	-

x Included in the present inventory.
+ Will be included.
- Not included/not relevant.
ie Included elsewhere.
y Included in the present inventory.

4.2 Mineral products (NFR 1A2f/2A)

4.2.1 Source category description

The sub-sector *Mineral products* (NFR 1A2f/2A) cover the following processes:

- Production of cement (SNAP 030311/040612)
- Production of lime (quicklime) (SNAP 030312/040614)
- Production of container glass/glass wool (SNAP 030315/030316-/040613)
- Production of mineral wool (SNAP 030318)
- Limestone and dolomite use (SNAP 040618)
- Roof covering with asphalt (SNAP 040610)
- Road paving with asphalt (SNAP 040611)

- Other (SNAP 040617; Danisco sugar/Danisco ingredients/ Slaughterhouse waste)

The time-series for emission of acidifying substances, heavy metals, NMVOC and particulate matter from *Mineral products* (NFR 1A2f/2A) are presented in Table 4.2 and Table 4.3.

The emission of SO_2, NO_X and CO from the production of cement depends on raw materials, fuels and combustion conditions. Emissions of NO_X are, among other things, a consequence of high temperature processes and the emission shows only minor fluctuations. The emission follows the activity, with a minor decrease in recent years. The emission of SO_2 depends on the S-content in fuels and raw materials. However, the process acts as a sink for acidifying gases due to the alkaline conditions in the rotary kiln. The emission of CO displays significant fluctuations that cannot be explained by known factors.

The emission of NO_X from production of container glass is increasing slightly, whereas the emission of CO is decreasing in the period 1997-2005. In the same period of time, the activity is nearly constant. Emissions of both substances are related to combustion/process conditions and will be investigated further. Emissions of the heavy metals lead, selenium and zinc are related to the raw materials used. Recycled glass constitutes a considerable part of raw materials and, therefore, the quality/purity of the glass is a determining factor. Emission of lead shows a decreasing trend that is in accordance with the attempts to avoid lead in glass as well as in wine bottle seals.

Production of glass wool is expected to result in emission of approximately the same pollutants as in production of container glass. NH_3 shows a decreasing trend from 1996-2004 as can be verified by the decreasing emission per amount produced. Potential emissions of NO_X, CO and heavy metals are planned to be investigated and included in the inventory.

Table 4.2 Time-series for pollutants from *Mineral products 1A2f* (combustion/process emissions; metals: kg and other pollutants: tonnes).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SO_2	2 128	2 467	2 655	2 680	2 682	2 706	2 804	3 631	3 372	2 186
NO_x	6 740	8 255	9 116	9 237	9 230	9 569	10 138	10 306	10 478	9 583
NMVOC	98	116	124	125	131	136	132	136	129	113
NH_3	489	489	489	489	489	489	475	561	552	560
CO	12 260	12 601	12 795	12 822	12 820	12 848	12 462	13 506	16 993	15 353
TSP										
PM_{10}										
$PM_{2.5}$										
As	52.1	78.1	79.1	78.6	80.9	82.1	68.0	57.4	58.3	54.5
Cd	35.9	61.7	59.0	57.9	60.8	58.0	38.0	19.1	19.4	18.0
Cr	410	783	718	697	743	697	362	29.3	29.9	28.0
Cu	115	211	196	191	203	194	111	30.1	30.7	28.8
Hg	105	136	147	149	150	152	154	165	167	155
Ni	344	644	595	579	616	582	318	58.5	59.5	55.7
Pb	1 180	1 101	950	879	879	1 540	730	205	452	594
Se	339	316	276	255	271	464	227	290	91.8	236
Zn	245	243	227	211	217	292	200	171	187	184

	2000	2001	2002	2003	2004	2005
SO_2	1 692	2 156	1 431	1 470	1 929	1 827
NO_x	10 451	10 300	9 417	8 624	8 685	8 660
NMVOC	118	108	107	89	102	103
NH_3	497	444	358	334	363	335
CO	15 302	13 545	10 340	9 574	10 754	9 927
TSP	532	567	446	429	422	368
PM_{10}	467	497	386	373	369	321
$PM_{2.5}$	270	287	235	234	232	203
As	55.3	56.0	56.5	53.1	59.8	56.5
Cd	18.4	18.7	19.0	17.9	20.1	19.0
Cr	28.3	28.6	28.8	27.1	30.5	28.8
Cu	29.1	29.4	29.4	27.6	31.1	29.4
Hg	158	161	163	154	173	164
Ni	56.4	57.1	57.4	54.0	60.8	57.4
Pb	362	204	204	302	470	179
Se	359	290	290	252	245	126
Zn	198	167	168	160	177	168

Table 4.3 Time-series for pollutants from *Mineral products 2A* (process emissions; tonnes).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CH_4	16.0	16.0	16.8	17.5	15.8	16.3	16.3	16.3	14.3	15.5
CO	241	241	252	263	237	245	245	245	215	234
NMVOC	654	655	656	658	654	655	656	648	654	617
NH_3	24.2	32.4	32.2	35.1	32.1	31.5	31.2	30.0	31.4	36.3
TSP										
PM_{10}										
$PM_{2.5}$										

	2000	2001	2002	2003	2004	2005
CH_4	14.8	13.0	13.0	13.3	18.5	18.2
CO	223	196	196	199	278	275
NMVOC	594	565	563	561	578	576
NH_3	34.0	31.9	47.9	157	167	132
TSP	191	189	172	-[1]	-[1]	-[1]
PM_{10}	47.8	47.3	43.0	-[1]	-[1]	-[1]
$PM_{2.5}$	7.64	7.56	6.88	-[1]	-[1]	-[1]

1. Emission of TSP, PM_{10}, $PM_{2.5}$ are related to energy consumption from 2003.

The emission of NMVOC from production of chemical ingredients shows a decreasing trend and can probably be explained by the decreasing emission per amount produced.

4.2.2 Methodological issues

The emissions of SO_2, NO_X, CO and TSP from the production of cement are measured yearly from 1997 to 2005 (TSP from 2000 to 2005). PM_{10} and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ from CEPMEIP (2003). For the years 1990-1996, the emission has been estimated from the production of cement, expressed as TCE (total cement equivalents[4]), and emission factors from the company Aalborg Portland (Aalborg Portland, 2006). The emissions of heavy metals are measured in 1997 (Illerup et al., 1999) and estimated for the other years from emission factors (based on the measurements) and TCE. The activity has varied from 1.6 million tonne TCE in 1990 to 2.7 million tonne TCE in 2005.

The emission of NO_X, CO, TSP, lead, selenium, and zinc from production of container glass is measured yearly from 1997 to 2005 (TSP from 2000 to 2005) (Rexam Glass Holmegaard, 2006). PM_{10} and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ from CEPMEIP (2003). For 1990 to 1996, emissions of arsenic, cadmium, chromium, copper, mercury and nickel are estimated from standard emission factors and activity data. For 1997 to 2004, the energy related emissions are estimated from emission factors and the actual energy consumption. This change in methodology results in inconsistency in the emission trend that cannot be explained by natural factors. Emission factors for lead, selenium, and zinc from 1990 to 1996 are estimated by interpolation from the 1990 and 1997 figures (Illerup et al., 1999).

[4] TCE (total cement equivalent) express the total amount of cement produced for sale and the theoretical amount of cement from the produced amount of clinker for sale.

The emission of NH_3 and TSP from the production of glass wool has been measured yearly from 1996 to 2005 (TSP from 2000 to 2005) (Saint-Gobain Isover, 2006). PM_{10} and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ from CEPMEIP (2003). The activity has varied between 33,600 and 37,295 tonnes glass wool from 1996 to 2005 and, during the same period, the emission decreased from approximately 300 to 116 tonne NH_3.

The emission of NMVOC from production of chemical ingredients has been measured from 1996 to 2005 (Danisco Grindsted, 2006). The emission has decreased from 100 to 15 tonnes NMVOC in this period. However, no explanation can be given on these conditions, as information on activity is not available.

The emissions from asphalt roofing and road paving have been estimated from production statistics compiled by Statistics Denmark and default emission factors presented by IPCC/Corinair. The default emission factors are presented in Table 4.4.

Table 4.4 Default emission factors for application of asphalt products.

		Road paving with asphalt	Use of cutback asphalt	Asphalt Roofing
CH_4	g/tonnes	5	0	0
CO	g/tonnes	75	0	10
NMVOC	g/tonnes	15	64 935	80
Carbon content fraction of NMVOC	%	0.667	0.667	0.8

4.2.3 Uncertainties and time-series consistency

The time-series are presented in Table 4.2 and Table 4.3. The methodologies applied for the different sources within *Mineral products* are considered to be consistent either as measurements or emission factors based on the measurements. However, not all the sources are considered to be complete regarding pollutants and these are expected to be completed in the next inventory, either by use of company-specific information or by application of general emission factors.

The time-series for emissions from production of cement are based on measurements combined with emissions factors based on the measurements.

4.2.4 Source-specific QA/QC and verification

The emission factors have been verified and the order of magnitude confirmed by comparison with standard emission factors (EMEP/CORINAIR, 2004; CEPMEIP, 2003). Detailed discussion of QA/QC can be found in Illerup et al. (2006).

4.2.5 Source-specific recalculations

The inventory has been completed with emissions from roof covering with asphalt and road paving with asphalt.

4.2.6 Source-specific planned improvements

The inventory will be improved regarding coverage of pollutants included. Especially glass wool, mineral wool, chemical ingredients and production of sugar will be extended. The incomplete time-series will also be completed. The inconsistent methodology applied for emission of As, Cd, Cr, Cu, Hg, and Ni from glass production will be improved.

4.3 Chemical industry (NFR 2B)

4.3.1 Source category description

The sub-sector *Chemical industry* (NFR 2B) covers the following processes:

- Production of nitric acid/fertiliser (SNAP 040402/040407)
- Production of catalysts/fertilisers (SNAP 040416/040407)
- Production of pesticides (SNAP 040525)

The time-series for emission of acidifying substances, NMVOC and particulate matter from *Chemical industry* (NFR 2B) are presented in Table 4.5.

Table 4.5 Time-series for pollutants from *Chemical industry 2B* (tonnes).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SO_2	636	496	600	461	514	406	247	397	408	487
NO_x	842	778	691	619	636	648	543	611	472	509
NH_3	25.0	35.0	48.0	62.0	104	75.0	75.0	50.0	25.0	33.0
NMVOC	390	150	62.0	40.0	54.0	57.0	113	44.0	40.0	41.0
TSP										
PM_{10}										
$PM_{2.5}$										

	2000	2001	2002	2003	2004	2005
SO_2	421	449	436	321	340	402
NO_x	447	422	419	475	302	30
NH_3	27.0	101	93.0	113	101	79.0
NMVOC	29.0	29.0	26.7	25.4	31.4	25.7
TSP	362	346	310	323	192	-[1]
PM_{10}	290	277	248	258	153	-[1]
$PM_{2.5}$	217	208	186	194	115	-[1]

1. Nitric acid production ceased in 2004.

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; however, the emission of NO_X per amount produced is decreasing from 1994 to 2004. The emission of NH_3 does not follow the activity as it appears from the fluctuation in the emission per amount produced. The production of nitric acid and fertiliser stopped in the middle of 2004.

The emission of NO_X from production of catalysts/fertilisers decreases from 1996 to 2005, whereas the emission of NH_3 increases. Fluctuations and the increase in the "emission factor" can explain the increase in NH_3 emission.

The emission of NMVOC from production of pesticides reduced significantly from 1990 to 2005. The decrease can probably be explained by introduction of flue gas cleaning equipment rather than any decrease in activity. The emission of SO_2 is from the sulfur regeneration plant (Claus plant).

The time-series will be explained further in the following section.

4.3.2 Methodological issues

The emission of SO_2, NO_X, NH_3 and TSP from production of sulfuric acid, nitric acid and fertiliser is measured yearly or estimated, from 1990 to 2004 (TSP from 2000 to 2004) (Kemira GrowHow, 2005). PM_{10} and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ from CEPMEIP (2003). The emission for SO_2 and NO_X for 1991 to 1993 was estimated by using interpolated emission factors and activity data. Production of sulphuric acid was stopped in 1997. The emission factor for SO_2 fluctuated and the emission factor for NO_X decreased from 1990 to 2004. Production of sulphuric acid decreased from approximately 150,000 to 60,000 tonnes from 1990 to 1996, and production of nitric acid decreased from approximately 450,000 to 229,000 tonnes from 1990 to 2004. Overall, production of fertiliser decreased from approximately 800,000 to approximately 395,000 tonnes from 1990 to 2004.

The emission of NH_3, NO_X and TSP from production of catalysts and fertilisers is measured yearly from 1996 to 2005 (TSP from 2000 to 2005) (Haldor Topsøe, 2005). PM_{10} and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ from CEPMEIP (2003). The process-related NO_X emission has been estimated as 80% of the total NO_X emission; Haldor Topsøe reports this assumption in their environmental report. The emission of NH_3 shows an increasing trend and varies between 13 and 68 tonne from 1990 to 2005. In the same period, the production of catalysts and fertilisers increased from approximately 33,000 to 49,000 tonnes.

The emission of NMVOC from production of pesticides is measured yearly from 1990 to 2000 (Cheminova, 2006) and estimated for 2001 to 2005. An emission factor based on 2000 figures is used for estimation of 2001 to 2005 emissions. The emission of NMVOC shows a decreasing trend from 1990 to 2005.

4.3.3 Uncertainties and time-series consistency

The time-series are either based on specific measurements or by using company-specific emission factors and activity data. Therefore, the time-series are considered to be consistent.

4.3.4 Source-specific QA/QC and verification

The emission factors for production of nitric acid and sulphuric acid have been verified by comparison with standard emission factors (EMEP/CORINAIR, 2004). Detailed discussion of QA/QC can be found in Illerup et al. (2006).

4.3.5 Source-specific recalculations

SO_2 emission from sulphur regeneration plant has been included in the inventory.

4.3.6 Source-specific planned improvements

No source-specific improvements are planned.

4.4 Metal production (NFR 1A2/2C)

4.4.1 Source category description

The sub-sector *Metal production* (NFR 1A2/2C) covers the following processes:

- Steelworks (SNAP 040207)
- Iron foundries (SNAP 030303)
- Secondary lead production (SNAP 030307)
- Secondary zinc production (SNAP 030308)
- Secondary aluminium production (SNAP 030310)
- Allied metal manufacturing (SNAP 040306)

The time-series for emission of heavy metals and particulate matter from *Metal production* (NFR 1A2/2C) are presented in Table 4.6 and Table 4.7.

The emission inventory for metal production is based on specific emissions from steelworks and secondary aluminium manufacturing as well as average emission factors for iron foundries, secondary lead and zinc manufacturing, and allied metal manufacturing. 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 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.

Table 4.6 Time-series for pollutants from *Metal production 1A2ab* (combustion/process emissions; metals: kg and other pollutants: tonnes).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
TSP										
PM_{10}										
$PM_{2.5}$										
As	30.9	-[1]	-[1]	-[1]	-[1]	-[1]	-[1]	25.5	25.7	25.8
Cd	14.5	-[1]	-[1]	-[1]	-[1]	-[1]	-[1]	12.0	12.1	12.1
Cr	113	-[1]	-[1]	-[1]	-[1]	-[1]	-[1]	93.6	94.4	94.6
Cu	1.10	-[1]	-[1]	-[1]	-[1]	-[1]	-[1]	1.10	1.10	1.10
Hg	0							0	0	0
Ni	134	-[1]	-[1]	-[1]	-[1]	-[1]	-[1]	111	112	112
Pb	750	-[1]	-[1]	-[1]	-[1]	-[1]	-[1]	621	627	628
Se	515	-[1]	-[1]	-[1]	-[1]	-[1]	-[1]	426	429	430
Zn	515	-[1]	-[1]	-[1]	-[1]	-[1]	-[1]	426	429	430

	2000	2001	2002	2003	2004	2005
TSP	227	206	207	200	204	205
PM_{10}	88.7	82.6	81.8	75.6	74.9	79.7
$PM_{2.5}$	22.8	22.0	21.3	18.6	17.8	20.6
As	28.9	25.7	26.2	26.2	27.2	26.2
Cd	13.6	12.1	12.3	12.3	12.8	12.3
Cr	106	94.3	96.0	96.0	100	96.0
Cu	1.10	1.10	1.10	1.10	1.10	1.10
Hg	0	0	0	0	0	0
Ni	125	111	113	113	118	113
Pb	703	626	637	637	661	637
Se	482	429	437	437	453	436
Zn	482	429	437	437	453	436

1. Will be included.

Table 4.7 Time-series for pollutants from *Metal production 2C* (process emissions; metals: kg and other pollutants: tonnes).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
TSP										
PM10										
PM2.5										
Cd	43.0	-[1]	-[1]	-[1]	-[1]	-[1]	46.0	35.0	43.0	7.00
Cr	-[1]	-[1]	-[1]	-[1]	-[1]	-[1]	7.00	0.00	1.00	0.00
Cu	39.0	39.9	40.8	41.7	42.6	43.5	44.0	45.3	45.3	45.3
Hg	246	-[1]	-[1]	-[1]	-[1]	-[1]	147	84.0	60.6	49.5
Ni	758	-[1]	-[1]	-[1]	-[1]	-[1]	294	228	112	86.1
Pb	3 026	59.9	61.2	62.6	63.9	65.3	794	704	441	735
Zn	12 041	559	571	584	596	609	6 398	5 656	3 050	2 755

	2000	2001	2002	2003	2004	2005
TSP	41.0	93.0	-[2]	-[2]	-[2]	32.5
PM10	39.0	88.0	-[2]	-[2]	-[2]	30.8
PM2.5	25.0	56.0	-[2]	-[2]	-[2]	19.6
Cd	25.0	41.0	5.00	5.00	5.00	5.00
Cr	0.00	0.00	0.00	0.00	0.00	0.00
Cu	45.3	45.3	45.3	45.3	45.3	45.3
Hg	90.0	184	-[2]	-[2]	-[2]	64
Ni	60.0	123	-[2]	-[2]	-[2]	43
Pb	508	939	68.0	68.0	68.0	370
Zn	2 024	3 420	634	634	634	1 599

1. Will be included.
2. Steelwork was closed 2002-2004.

The steelworks closed in the beginning of 2002 and re-opened at the end of 2004.

4.4.2 Methodological issues

The emission of heavy metals and TSP from the production of steel bars and sheets from steel scrap are based on measurements from the company Stålvalseværket (Stålvalseværket, 2002). PM_{10} and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ from CEPMEIP (2003). The distribution of metals for 1995/96 (Illerup et al., 1999) is used in estimation of the different metals for the following years. The activity has varied between approximately 600,000 and 800,000 tonnes from 1990 to 2001. The production ceased in the beginning of 2002 and restarted at the end of 2004 with regard to melting of steel scrap in the electric arc furnace. The production of steel bars at the steelwork is assumed to be 1/3 of the production in 2001; the steelwork has been closed from end of 2005/beginning of 2006.

The emission of heavy metals from iron foundries is based on standard emission factors and yearly production statistics from The Association of Danish Foundries. The emission of TSP and distribution between TSP, PM_{10} and $PM_{2.5}$ is obtained from CEPMEIP (2003).

The emission of heavy metals from production of secondary lead and allied metal manufacturing is based on average emission factors for Danish producers (Illerup et al., 1999) and activity data from Statistics Den-

mark. The emission of TSP and distribution between TSP, PM_{10} and $PM_{2.5}$ is obtained from CEPMEIP (2003).

4.4.3 Uncertainties and time-series consistency

The time-series are either based on specific measurements, company-specific emission factors combined with activity data or on standard emission factors combined with public statistics. The same methodology has been applied for the entire time-series and, therefore, the time-series are considered to be consistent.

4.4.4 Source specific recalculations

No source-specific recalculation has been performed for the sector *Metal production*.

4.4.5 Source-specific QA/QC and verification

Detailed discussion of QA/QC can be found in Illerup et al. (2006)

4.4.6 Source-specific planned improvements

The time-series will be completed and new emission factors for the latest years will be established, if possible. Especially for secondary aluminium and zinc production, potential emissions of heavy metals will be investigated.

4.5 Other production (NFR 2D)

4.5.1 Source category description

The sub-sector *Other production* (NFR 2D) covers the following process:

- Beer (SNAP 040607)

The time-series for emission of NMVOC from *Other production* (NFR 2D) is presented in Table 4.8.

Table 4.8 Time-series for emission of NMVOC from *Other production 2D2* (tonnes)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
NMVOC	582	604	611	590	588	629	599	574	503	502

	2000	2001	2002	2003	2004	2005
NMVOC	466	452	533	522	534	531

The emission of NMVOC from production of beer follows the activity as the same emission factor has been used for the entire period.

4.5.2 Methodological issues

The emission of NMVOC from breweries is estimated from production statistics (Statistics Denmark) and standard emission factors from the IPCC guidelines (IPCC (1997) Vol. 3, Table 2-24).

4.5.3 Uncertainties and time-series consistency

The time-series is based on the same methodology throughout, using public statistics and standard emission factors. Therefore, the time-series is considered to be consistent.

4.5.4 Source-specific recalculations

Detailed discussion of QA/QC can be found in Illerup et al. (2006)

4.5.5 Source-specific QA/QC and verification

No source-specific QA/QC and verification has been performed for the sector *Other production*.

4.5.6 Source-specific planned improvements

The time-series for emission of NMVOC from production of beer is planned to be completed. Furthermore, production of bread and other food products are planned to be included in the next inventory.

4.6 Uncertainty estimates

Uncertainty estimates for industrial processes (SNAP 04) are presented in Table 4.9. The uncertainty estimates are based on standard uncertainty factors (EMEP/CORINAIR, 2004).

Table 4.9 Uncertainty estimates for industrial processes (%).

	Activity data uncertainty	Emission factor uncertainty	Overall 2005	Trend
SO_2	2	20	20.10	0.47
NO_x	2	50	50.04	0.10
NMVOC	2	50	50.04	2.50
CO	50	100	50.04	3.23
NH_3	2	1 000	1 000	12.1
Cadmium	2	1 000	1 000	0.30
Copper	2	1 000	1 000	3.29
Lead	2	1 000	1 000	0.35
Zinc	2	1 000	1 000	0.38

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5 Solvents and other product use (CRF Sector 3)

5.1 Overview of the sector

Use of solvents and other organic compounds in industrial processes and households are important sources of evaporation of non-methane volatile hydrocarbons (NMVOC), and are related to the source categories *Paint application* (CRF sector 3A), *Degreasing and dry cleaning* (CRF sector 3B), *Chemical products, manufacture and processing* (CRF sector 3C) and *Other* (CRF sector 3D). In this section, the methodology for the Danish NMVOC emission inventory is presented and the results for the period 1995-2005 are summarised. The method is based on a chemical approach, and this implies that the SNAP category system is not directly applicable. Instead, emissions will be related to specific chemicals, products, industrial sectors and households and to the CRF sectors mentioned above.

5.2 Paint application (CRF Sector 3A), Degreasing and dry cleaning (CRF Sector 3B), Chemical products, Manufacture and processing (CRF Sector 3C) and Other (CRF Sector 3D)

5.2.1 Source category description

Table 5.1 and Figure 5.1 show the emissions of chemicals from 1985 to 2005, where the used amounts of single chemicals have been assigned to specific products and CRF sectors. The methodological approach for finding emissions in the period 1995 - 2005 is described in the following section. A linear extrapolation is made for the period 1985 – 1995. A general decrease is seen throughout the sectors, however, with an increase in total emissions during the latest three reported years. Table 5.2 shows the used amounts of chemicals for the same period. Table 5.1 is derived from Table 5.2 by applying emission factors relevant to individual chemicals and production or use activities. Table 5.3 showing the used amount of products is derived from Table 5.2, by assessing the amount of chemicals that is comprised within products belonging to each of the four source categories. The conversion factors are very rough estimates, and more thorough investigations are needed in order to quantify the used amount of products more accurately.

In Table 5.4 the emission for 2005 is split into individual chemicals. Propane and butane are main contributors, which can be attributed to propellants in spraying cans. Turpentine is defined as a mixture of stoddard solvent and solvent naphtha. For each chemical the emission factors are based on rough estimates from SFT (1994). High emission factors are assumed for use of chemicals (products) and lower factors for industrial production processes.

Table 5.1 Emission of chemicals in Gg pr year

Total emissions Gg pr year	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986	1985
Paint application (3A)	16	17	18	18	18	19	19	20	20	20	21
Degreasing and dry cleaning (3B)	5,9	6,4	6,6	6,7	6,8	7,0	7,1	7,3	7,4	7,5	7,7
Chemical products, manufacturing and processing (3C)	1,6	1,3	1,2	1,1	1,0	1,0	0,9	0,8	0,7	0,6	0,5
Other (3D)	21	18	18	18	19	19	19	19	20	20	20
Total NMVOC	44	43	44	44	45	46	46	47	48	49	49
Total CO_2'[a]	136	134	136	138	141	143	145	147	149	151	153

Total emissions Gg pr year	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996
Continued										
Paint application (3A)	14	14	13	14	15	16	15	16	18	17
Degreasing and dry cleaning (3B)	4,9	5,1	5,2	5,5	5,1	6,0	6,1	5,6	6,2	6,7
Chemical products, manufacturing and processing (3C)	2,6	2,3	1,7	2,1	2,1	1,9	1,7	1,6	1,6	1,6
Other (3D)	16	16	15	16	16	16	15	16	15	17
Total NMVOC	37	37	35	37	38	40	38	39	41	42
Total CO_2'[a]	116	114	111	115	118	124	118	120	128	132

[a] 0.85*3.67*total NMVOC

Table 5.2 Used amounts of chemicals in Gg pr year

Used amounts of chemical Gg pr year	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986	1985
Paint application (3A)	59	61	60	59	58	58	57	56	55	54	53
Degreasing and dry cleaning (3B)	29	28	28	28	28	28	28	29	29	29	29
Chemical products, manufacturing and processing (3C)	105	99	96	94	92	90	88	85	83	81	79
Other (3D)	53	45	45	44	44	43	43	42	41	41	40
Total NMVOC	245	233	230	226	222	219	215	212	208	204	201

Used amounts of chemical Gg pr year	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996
Continued										
Paint application (3A)	92	79	60	54	54	59	55	62	98	63
Degreasing and dry cleaning (3B)	29	29	27	28	26	28	29	25	29	29
Chemical products, manufacturing and processing (3C)	136	122	101	117	116	114	107	103	108	104
Other (3D)	58	56	45	45	46	46	43	43	48	47
Total NMVOC	315	285	233	244	242	247	234	233	283	243

Table 5.3 Used amounts of products in Gg pr year

Used amounts of products Gg pr year	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986	1985
Paint application (3A)	391	409	403	396	390	384	378	372	366	359	353
Degreasing and dry cleaning (3B)	57	57	57	57	57	57	57	57	57	57	57
Chemical products, manufacturing and processing (3C)	520	500	492	484	476	467	459	451	443	435	427
Other (3D)	263	228	227	226	225	224	223	222	220	219	218
Total products	1231	1193	1178	1163	1148	1132	1117	1102	1087	1071	1056

Used amounts of products Gg pr year	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996
Continued										
Paint application (3A)	614	530	400	361	360	393	369	414	652	420
Degreasing and dry cleaning (3B)	59	58	53	55	52	57	58	51	57	59
Chemical products, manufacturing and processing (3C)	643	585	498	568	557	553	536	513	540	518
Other (3D)	272	266	224	214	218	220	214	217	242	234
Total products	1587	1439	1174	1198	1188	1223	1177	1194	1492	1231

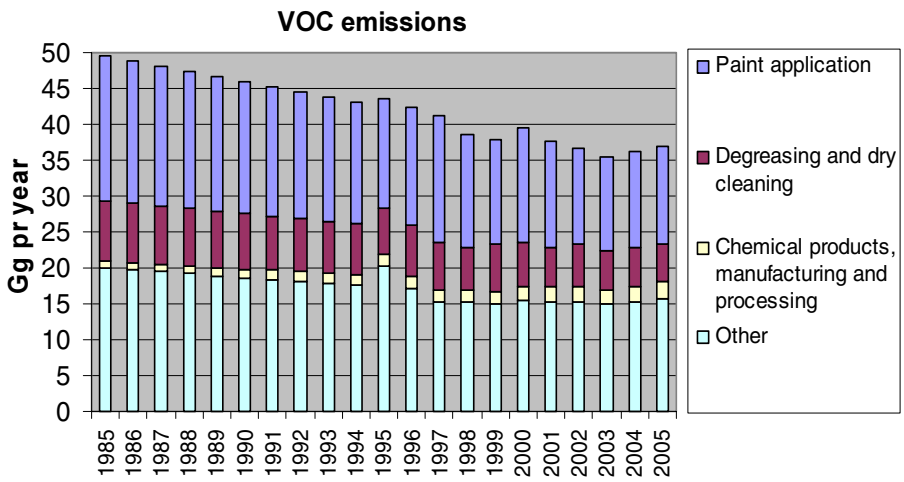

Figure 5.1 Emissions of chemicals in Gg per year. The methodological approach for finding emissions in the period 1995 – 2005 is described in the text, and a linear extrapolation is made for 1985 – 1995. The underlying figures can be seen in Table 5.1.

Table 5.4 Chemicals with highest emissions 2005

Chemical	Emissions 2005 (kg/year)
Turpentine (solvent naphtha and Stoddard solvent)	5339412
propane	5000000
butane	5000000
methanol	4350997
aminooxygengroups	3005451
ethanol	2024512
naphthalene	2022969
pentane	1995706
glycerol	1934542
acetone	1204261
propylenglycol	784147
ethylenglycol	652206
glycolethers	579784
formaldehyde	484883
Propylalcohol	466252
Butanone	441071
Xylene	280520
1-butanol	248607
Methylbromide	234033
toluene	214520
Toluendiisocyanate	195034
phenol	124694
acyclic monoamines	90468
methyl methacrylate	85784
butanoles	50571
Dioctylphthalate	50307
styrene	43502
tetrachloroethylene	32674
triethylamine	6481
diethylenglycol	5725
diamines	83

5.2.2 Methodological issues

The emissions of Non-Methane Volatile Organic Compounds (NMVOC) from industrial use and production processes and household use in Denmark have been assessed. Until 2002 the NMVOC inventory in Denmark was based on questionnaires and interviews with different industries, regarding emissions from specific activities, such as lacquering, painting impregnation etc. However, this approach implies large uncertainties due to the diverse nature of many solvent-using processes. For example, it is inaccurate to use emission factors derived from one printwork in an analogue printwork, since the type and combination of inks may vary considerably. Furthermore the employment of abatement techniques will result in loss of validity of estimated emission factors.

A new approach has been introduced, focusing on single chemicals instead of activities. This will lead to a clearer picture of the influence from each specific chemical, which will enable 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. Mass balances are simple and functional methods for calculating the use and emissions of chemicals

$$use = production + import - export - destruction/disposal - hold\ up \quad \text{(Eq.1)}$$

$$emission = use * emission\ factor \quad \text{(Eq.2)}$$

where "hold up" is the difference in the amount in stock in the beginning and at the end of the year of inventory.

A mass balance can be made for single substances or groups of substances, and the total amount of emitted chemical is obtained by summing up the individual contributions. It is important to perform an in-depth investigation in order to include all relevant emissions from the large amount of chemicals. The method for a single chemical approach is shown in Figure 5.2.

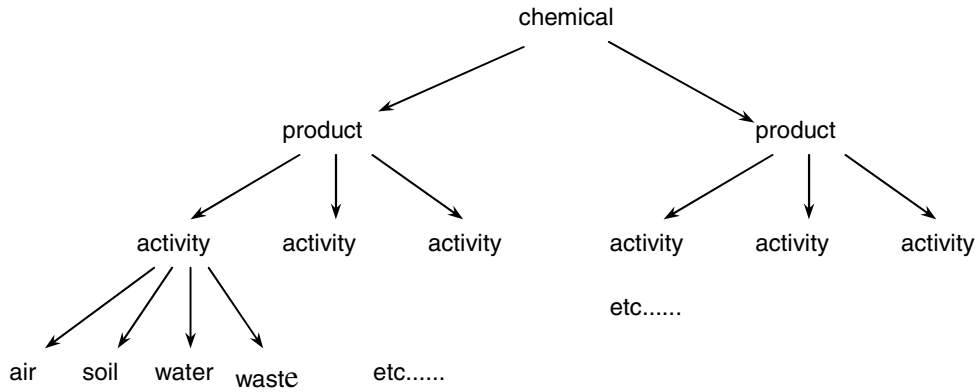

Figure 5.2 Methodological flow in a chemical based emission inventory.

The tasks in a chemical focused approach are

- 1) Definition of chemicals to be included
- 2) Quantification of use amounts from Eq.1
- 3) Quantification of emission factors for each chemical

In principle all chemicals that can be classified as NMVOC must be included in the analysis, which implies that it is essential to have an explicit definition of NMVOC. The definition of NMVOC is, however, not consistent; In the EMEP-guidelines for calculation and reporting of emissions, NMVOC is defined as "all hydrocarbons and hydrocarbons where hydrogen atoms are partly or fully replaced by other atoms, e.g. S, N, O, halogens, which are volatile under ambient air conditions, excluding CO, CO_2, CH_4, CFCs and halons". The amount of chemicals that fulfil these criteria is large and a list of 650 single chemicals and a few chemical groups described in "National Atmospheric Emission Inventory", cf. Annex 3.F, is used. It is probable that the major part will be insignificant in a mass balance, but it is not correct to exclude any chemicals before a more detailed investigation has been made. It is important to be aware

that some chemicals are comprised in products and will not be found as separate chemicals in databases, e.g. di-ethylhexyl –phthalate (DEHP), which is the predominant softener in PVC. In order to include these chemicals the product use must be found and the amount of chemicals in the product must be estimated. It is important to distinguish the amount of chemicals that enters the mass balance as pure chemical and the amount that is associated to a product, in order not to overestimate the use.

Production, import and export figures are extracted from Statistics Denmark, from which a list of 427 single chemicals, a few groups and products is generated. For each of these a *use* amount in tonnes pr. year (from 1995 to 2005) is calculated. It is found that 44 different NMVOCs comprise over 95 % of the total use, and it is these 44 chemicals that are investigated further.

In the Nordic SPIN database (Substances in Preparations in Nordic Countries) information for industrial use categories and products specified for individual chemicals, according to the NACE coding system is available. This information is used to distribute the *use* amounts of individual chemicals to specific products and activities. The product amounts are then distributed to the CRF sectors 3A – 3D.

Emission factors, cf. Eq. 2, are obtained from regulators or the industry and can be provided on a site by site basis or as a single total for whole sectors. Emission factors can be related to production processes and to use. In production processes the emissions of solvents typically are low and in use it is often the case that the entire fraction of chemical in the product will be emitted to the atmosphere. Each chemical will therefore be associated with two emission factors, one for production processes and one for use.

Outputs from the inventory are

- a list where the 44 most predominant NMVOCs are ranked according to emissions to air,
- specification of emissions from industrial sectors and from households,
- contribution from each NMVOC to emissions from industrial sectors and households,
- yearly trend in NMVOC emissions, expressed as total NMVOC and single chemical, and specified in industrial sectors and households.

5.2.3 Uncertainties and time-series consistency

Estimation of uncertainty is based on the Tier 1 methodology in IPCC Good Practice Guidance. Input to the uncertainty estimates are shown in Table 5.5.

Overall uncertainty in 2005: 32.5%

Trend uncertainty: 26.1%

Table 5.5 Emission uncertainties for solvents (NMVOCs). Only combined uncertainties are applied as uncertainties are not differentiated into activity data and emission factors in the Emission Inventory Guidebook. Furthermore uncertainties are only stated for the total emissions. This uncertainty is distributed equally on activity data and emission factors.

Source Activity	SNAP code	Activity	Base year emission	2005 emissions	Activity data uncertainty	Emission factor uncertainty	Combined uncertainty
			Input data (Mg)	Input data (Mg)	Input data (%)	Input data (%)	(%)
Paint application	60101	Manufacture of Automobiles			Not estimated	Not estimated	Not estimated
	60102	Car Repairing					
	60103	Construction and Buildings					
	60104	Domestic Use					
	60105	Coil Coating					
	60106	Boat Building					
	60107	Wood					
	60108	Other Industrial Paint Application					
	60109	Other Non-Industrial Paint Application	18454	13579			
Degreasing and dry cleaning	60201	Metal Degreasing			Not estimated	Not estimated	Not estimated
	60202	Dry Cleaning					
	60203	Electronic Components Manufacturing					
	60204	Other Industrial Dry Cleaning	7658	5240			
Chemical products, manufacturing and processing	60301	Polyester Processing			Not estimated	Not estimated	Not estimated
	60302	Polyvinylchloride Processing					
	60303	Polyurethane Foam Processing					
	60304	Polystyrene Foam Processing					
	60305	Rubber Processing					
	60306	Pharmaceutical Products Manufacturing					
	60307	Paints Manufacturing					
	60308	Inks Manufacturing					
	60309	Glues Manufacturing					
	60310	Asphalt Blowing					
	60311	Adhesive, Magnetic Tapes, Film and Photographs Manufacturing					
	60312	Textile Finishing					
	60313	Leather Tanning					
	60314	Other	1221	2460			
Other	60401	Glass Wool Enduction			Not estimated	Not estimated	Not estimated
	60402	Mineral Wool Enduction					
	60403	Printing Industry					
	60404	Fat, Edible and Non-Edible Oil Extraction					
	60405	Application of Glues and Adhesives					
	60406	Preservation of Wood					
	60407	Underseal Treatment and Conservation of Vehicles					
	60408	Domestic Solvent Use (Other Than Paint Application)	18638	15671			

	60409	Vehicles Dewaxing					
	60411	Domestic Use of Pharmaceutical Products					
	60412	Other(Preservation of Seeds, ...)					
Total	60000	Solvent and Other Product Use	45971	36949	46	46	65

NE: Not estimated

Important uncertainty issues related to the mass-balance approach are

(i) Identification of chemicals that qualify as NMVOCs. The definition is vague, and no approved list of agreed NMVOCs is available. Although a tentative list of 650 chemicals from the "National Atmospheric Emission Inventory" has been used, it is possible that relevant chemicals are not included.

(ii) Collection of data for quantifying production, import and export of single chemicals and products where the chemicals are comprised. For some chemicals no data are available in Statistics Denmark. This can be due to confidentiality or that the amount of chemicals must be derived from products wherein they are comprised. For other chemicals the amount is the sum of the single chemicals *and* product(s) where they are included. The data available in Statistics Denmark is obtained from Danish Customs & Tax Authorities and they have not been verified in this assessment.

(iii) Distribution of chemicals on products, activities, sectors and households. The present approach is based on amounts of single chemicals. To differentiate the amounts into industrial sectors it is necessary to identify and quantify the associated products and activities and assign these to the industrial sectors and households. No direct link is available between the amounts of chemicals and products or activities. From the Nordic SPIN database it is possible to make a relative quantification of products and activities used in industry, and combined with estimates and expert judgement these products and activities are differentiated into sectors. The contribution from households is also based on estimates. If the household contribution is set too low, the emission from industrial sectors will be too high and vice versa. This is due to the fact that the total amount of chemical is constant. A change in distribution of chemicals between industrial sectors and households will, however, affect the total emissions, as different emission factors are applied in industry and households, respectively.

A number of activities are assigned as "other", i.e. activities that can not be related to the comprised source categories. This assignment is based on expert judgement but it is possible that the assigned amount of chemicals may more correctly be included in other sectors. More detailed information from the industrial sectors is continuously being implemented.

(iv) Rough estimates and assumed emission factors are used for many compounds. For some compounds more reliable information has been obtained from the literature and from communication with industrial sectors. In some cases it is more appropriate to define emission factors for sector specific activities rather than for the individual chemicals.

A quantitative measure of the uncertainty has not been assessed. Single values have been used for emission factors and activity distribution ratios etc. In order to perform a stochastic evaluation more information is needed.

5.2.4 QA/QC and verification

Please refer to the Danish National Inventory Report reported to the UNFCCC (Illerup et al., 2006)

5.2.5 Recalculations

The previous method was based on results from an agreement between the Danish Industry and the Danish Environmental Protection Agency (EPA). The emissions from various industries were reported to the Danish EPA. The reporting was not annual and linear interpolation was used between the reporting years. It is important to notice that not all use of solvents was included in this agreement and no activity data were available. It is not possible to perform direct comparison of methodologies or to make corrections to the previous method, due to the fundamental differences in structure. But an increase in total emissions was expected due to the more comprehensive list of chemicals.

Improvements and additions are continuously being implemented in the new approach, due to the comprehensiveness and complexity of the use and application of solvents in industries and households. The improvements in the 2005 reporting include revisions of the following

- More detailed information concerning chemical patterns and amounts have been made for four industrial branches, comprising approximately 20% of the total emissions. The branches are plastic industry, graphic industry, auto repairers and colour and lacquer industry.
- Use amounts and emission factors have been refined for pentane and styrene used especially in the plastic industry.
- The group of glycolethers has been rearranged and comprises more single chemical compounds. The distribution of glycolethers in industrial branches has been revised, and the emission factors have been changed. E.g. for use in dry cleaning an emission factor of 0.0001 is used.
- Tetrachloroethylene has been removed from use in auto repairers and others, and has been assigned to dry cleaners and metal industry. Emission factor of 0.0001 is assigned for use in dry cleaning as a recovery of 99.99% of solvent used is stated in the literature.
- Some product categories (as defined in SPIN database) have been transferred from degreasing to paints category. This implies that the used amounts of products in Table 5.3 has increased compared to the latest inventory, because the amount of chemical in a product from the paints category is lower than the amount of chemical in a product from the degreasing category.

5.2.6 Planned improvements

In line with the latest refinements of four industrial branches, more branches will be addressed for further adjustments in the following inventory. More detailed information will be obtained for selected industries with respects to used products and chemicals and emission factors related to the activities.

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Emission Inventory Guidebook 3rd edition, prepared by the UN-ECE/EMEP Task Force on Emissions Inventories and Projections, 2002 update. Available on the Internet at http://reports.eea.eu.int/EMEP-CORINAIR3/en (07-11-2003)

Solvent Balance for Norway, 1994. Statens Forurensningstilsyn, rapport 95:02

SPIN on the Internet. Substances in Preparations in Nordic Countries, http://www.spin2000.net/spin.html

Statistics Denmark, http://www.dst.dk/HomeUK.aspx

6 Emission of ammonia and particulate matter from the agricultural sector

6.1 Overview

6.1.1 Ammonia

The majority of the Danish ammonia emission, corresponding to 97%, originates from the agricultural sector. The remaining 3% originates from traffic and industrial process. Figure 6.1 shows the distribution of sources of NH_3 emission from the agricultural sector 2005. The main part of the emission is related to manure management, corresponding to 79%. Emissions from use of synthetic fertiliser and crops contribute with 6% and 15%, respectively. Emissions from "Other" as ammonia-treated straw and sewage sludge used as fertiliser amount to less than 1%.

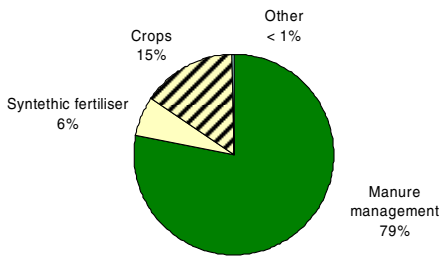

Figure 6.1 Ammonia emissions from the agricultural sector (2005)

From 1985 to 2005, the emission of ammonia from the agricultural sector decreased from 139.24 Gg NH_3 to 89.57 Gg NH_3, which corresponds to a 36% reduction (Figure 6.2). This is due to the active national environmental policy of the last twenty years. A series of measures have been introduced to prevent loss of nitrogen from agriculture to the aquatic environment. The measures include improved utilisation of nitrogen in livestock manure, requirements with regard to storage and application of livestock manure, increased area with winter green fields to catch nitrogen, a maximum number of animals per hectare and maximum nitrogen application rates to agricultural crops.

The main part of the emission from the agricultural sector is related to livestock production and, hence, the management of manure. The result of the active environmental policy has brought about a decrease in the N-excretion, a decrease of emission per produced animal and a fall in use of mineral fertilizer, which all has reduced the overall ammonia emission significant.

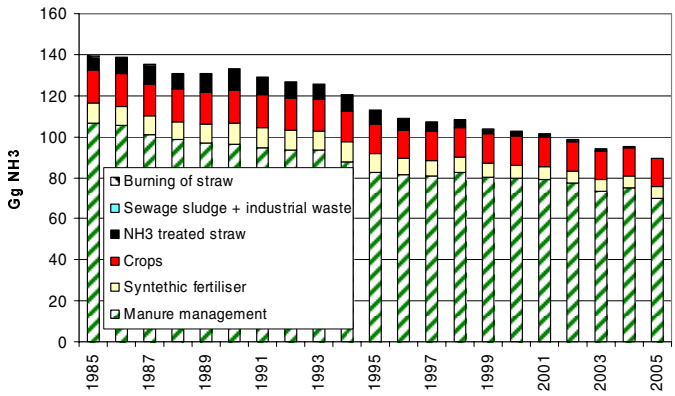

Figure 6.2 Ammonia emissions from the agricultural sector 1985 to 2005

Particulate matter

In NRF, the emission of particulate matter (PM) is registered for the years 2000 to 2005. The emission from the agricultural sector includes the emission of dust from ventilated animal housing systems, which include emission from cattle, pigs, poultry and horses.

Change in emission factor has been preformed due to updated information in the EMEP-CLRTAP Emission Inventory Guidebook. Chapter B1100 covers PM emission from animal husbandry and recommended emission factor for Swine, poultry, cattle and horses. These categories are subdivided into subcategories and into solid- or slurry based stable systems.

Due to lack of data the PM emission not includes emission from plant production, which means activities related to field operations as harvesting and cultivation of the soil. At present, first draft to guidelines is preformed (Hinz 2004, Hinz 2006). When the final paper is confirmed, the PM emission will be implemented in the inventory and registered under NFR Tables 4.D Agricultural soils.

Given in TSP, emission from animal housing systems contributes with 31 % of the national PM emission in 2005.

From 2000 to 2005 the PM emission from agricultural activities, given in TSP, has decreased by 7% due to a fall in the production of broilers (Figure 6.3). The same emission factor is used for all years. The changes in the total emission for each livestock category is mainly reflected the changes in number of animal, but also effected by the distribution of the subcategories and changes in the stable type.

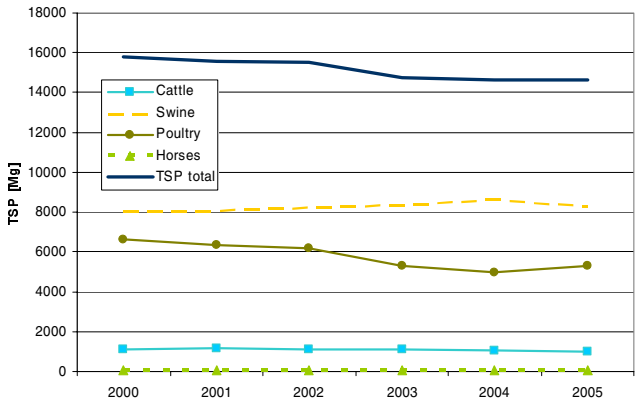

Figure 6.3 Emission of particulate matter (TSP) from the agricultural sector 2000 to 2005

6.1.2 References – sources of information

Data on activity and emissions are collected, evaluated and discussed in cooperation with Statistics Denmark, the Danish Institute of Agricultural Sciences, the Danish Agricultural Advisory Centre, Danish Environmental Protection Agency and the Danish Plant Directorate. It means that both the data and the methods used are evaluated continuously according to latest knowledge and information. Table 6.1 shows the source of data input from the different institutes.

Table 6.1 List of institutes involved in the emission inventory

References	Abbreviation	Data / information
National Environmental Research Institute, University of Aarhus (http://www.dmu.dk)	NERI	-reporting -data collecting
Statistics Denmark - Agricultural Statistics (http://www.dst.dk)	DS	-livestock production -milk yield -slaughtering data -land use
Faculty of Agricultural Sciences, University of Aarhus (http://www.agrsci.dk)	FAS	-N-excretion -feeding situation -NH_3 emissions factor -PM emissions factor
The Danish Agricultural Advisory Centre (http://www.lr.dk)	DAAC	-stable type -grazing situation -manure application time and methods
Danish Environmental Protection Agency (http://www.mst.dk)	EPA	-sewage sludge used as fertiliser
The Danish Plant Directorate (http://www.plantedirektoratet.dk)	PD	-organic farming -synthetic fertiliser -stable type (from 2005)

6.1.3 Methods

The calculation of the emission is based on the EMEP-CLRTAP Emission Inventory Guidebook.

The emissions from agricultural activities include NRF Table 4B Manure Management and Table 4D Agricultural Soils. Table 4F with regard to field burning of agricultural wastes is only registered until 1989. Burning of straw has been prohibited since 1989 and may only take place in connection with cultivation of seed grass. It is assumed that the emission is insignificant and, hence, is not included in the emission inventory from 1990.

The emission is calculated as the sum of activities (a_i) multiplied by the implied emission factor (IEF) for each activity, *i*.

$$E_{total} = \sum a_i \bullet IEF_i$$

The emissions from the agricultural sector are calculated in a comprehensive agricultural model complex called DIEMA (Danish Integrated Emission Model for Agriculture). This model, as shown in Figure 6.4, is implemented in great detail and it is used to cover emissions of ammonia, particulate matter and greenhouse gases (N_2O and CH_4). Thus, there is direct coherence between the ammonia emission and the emission of N_2O. A more detailed description is published in Mikkelsen et al. (2006).

The National Environmental Research Institute (NERI), which is responsible for the emission inventory, has established data agreements with the institutes and organisations to assure that the necessary data is available for timely completion of the emission inventory. The main part of the emission is related to livestock production and much of the data is based on Danish standards. The Faculty of Agricultural Sciences, University of Aarhus (FAS) delivers Danish standards relating to feeding consumption, manure type in different stable types, nitrogen content in manure, etc. Previously, the standards were updated and published every third or fourth year – the last one is Poulsen et al. from 2001. From year 2001, NERI receives updated data annually directly from FAS in the form of spreadsheets. These standards have been described and published in English in Poulsen & Kristensen (1998).

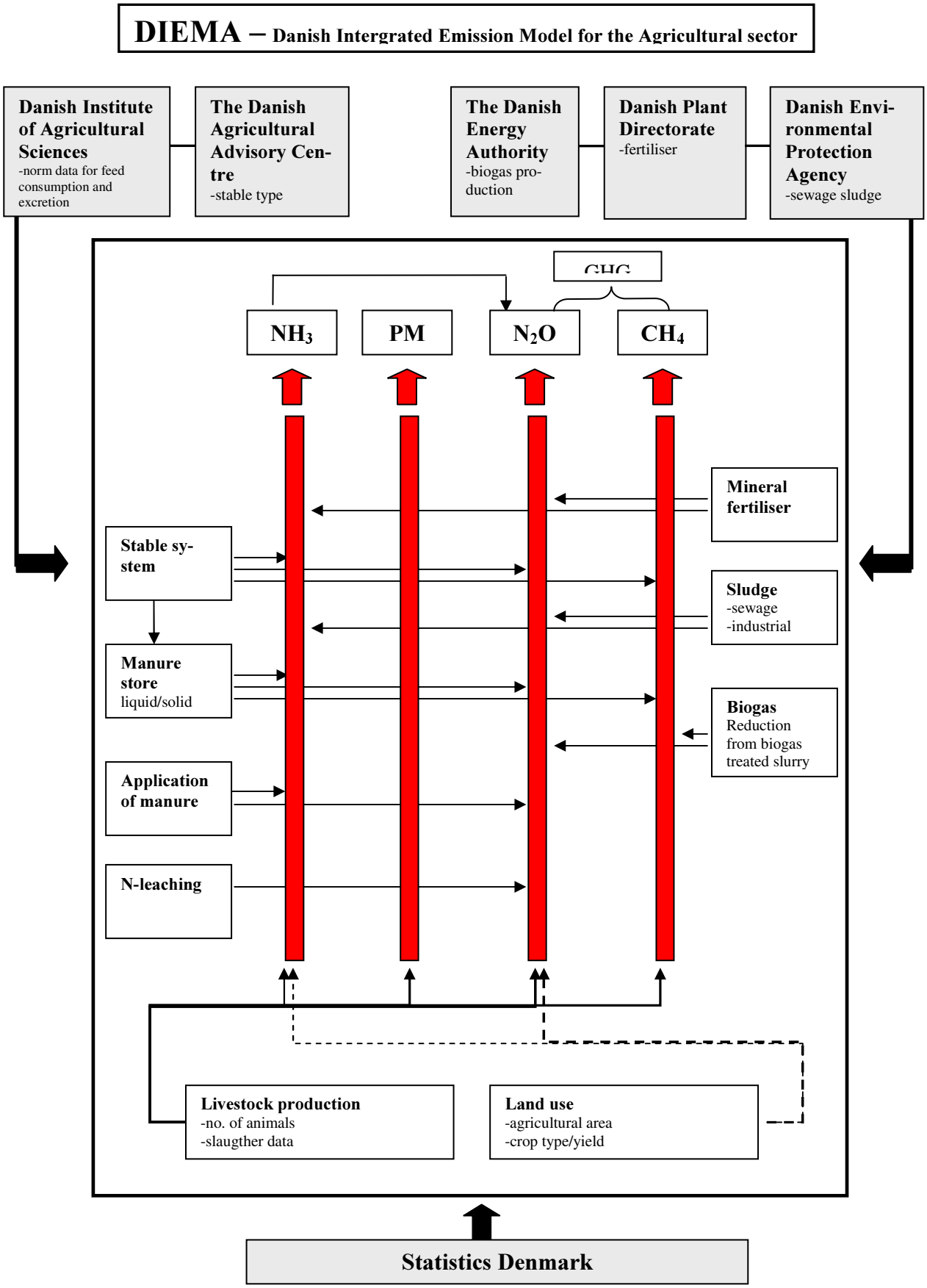

Figure 6.4 DIEMA – Danish Integrated Emission Model for Agriculture

DIEMA includes approximately 30 different livestock categories, dependent on livestock category, weight class and age. Each of these subcategories is subdivided according to stable type and manure type, which results in the region of 100 different combinations of subcategories and stable type (Table 6.2). The emission is 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 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, changes in feed consumption, changes in stable type and changed practices with regard to the handling of livestock manure in relation to storage and application.

Table 6.2 Livestock categories and subcategories.

NFR 4B	Animal categories	Includes	No. of subcategories in DIEMA (animal type/stable system)
4B 1a	Dairy Cattle[1]	Dairy Cattle (heavy breeding and Jersey)	9
4B 1b	Non-dairy Cattle[1]	Calves, heifers, bulls, suckling cattle (heavy breeding and Jersey)	26
4B 3	Sheep	including lambs	1
4B 4	Goats	Including kids	1
4B 6	Horses	400 kg, 600 kg, 800 kg	3
4B 8	Swine	Sows, piglets, slaughtering pigs	17
4B 9	Poultry	Hens, pullet, broilers, turkey, geese, ducks	16
4B 13	Other	Fur farming + Sewage sludge	4

[1]For all subcategories distinguish between large breed and the smaller Jersey cattle

6.2 NH_3 emission from Manure Management – NRF 4.B

6.2.1 Description

The NH_3 emission from manure management (NRF category 4.B) includes emissions from sewage sludge used as fertiliser. The emission from sewage sludge contributes with less than 1% of the total emission from manure management.

Figure 6.5 shows the emission from manure management distributed according to the different livestock categories in 2005. The main part of the emission is related to cattle and pig production, corresponding to 81%

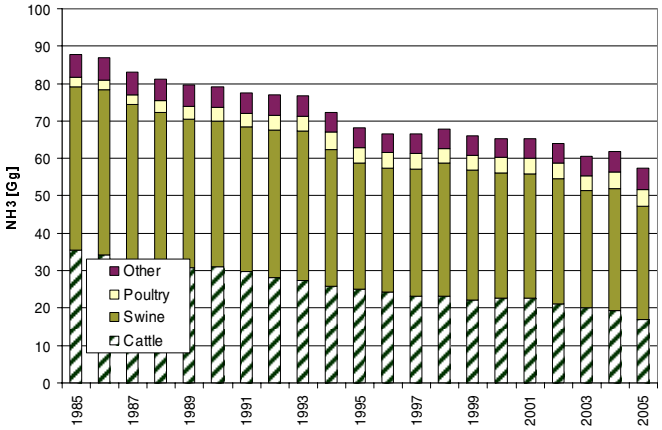

Figure 6.5 Ammonia emission from manure management 1985 - 2005

6.2.2 Methodological issues

Activity data

Table 6.3 shows the development in livestock production 1990-2004 based on the Agricultural Statistics (Statistics Denmark). The emission from pigs and poultry is based on slaughter data from the Agricultural Statistics. Only farms larger than 5 hectares are included in the annual census. An approximation of number of the horses, goats and sheep on small farms is added to the numbers in the Agricultural Statistics, in agreement with DAAC. The largest difference is found for horses. In the agricultural census, the number of horses is estimated at47 300 in 2005. The total number of horses in 2005, however, including horses placed at small farms and riding schools, is approximately 156 000.

Since 1990, production of pigs and poultry has increased. This is contrary to the production of cattle, which has decreased as a result of rising milk yields. Buffalo, camels and llamas, mules and donkeys do not occur in Denmark.

Table 6.3 Livestock production 1990 – 2005 [1000 head] - NRF category 4B

NRF	Animal category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
4B 1a	Dairy Cattle	753	742	712	714	700	702	701	670	669	640
4B 1b	Non-dairy cattle	1486	1480	1478	1481	1405	1388	1393	1334	1308	1247
4B 3	Sheep*	92	107	102	88	80	81	94	78	83	83
4B 4	Goats*	8	9	9	9	9	9	9	10	10	10
4B 6	Horses*	135	137	138	140	141	143	144	146	147	149
4B 8	Swine	9497	9783	10455	11568	10923	11084	10842	11383	12095	11626
4B 9	Poultry	16249	15933	19041	19898	19852	19619	19888	18994	18674	21010
4B 13	Other (fur farming)	2264	2112	2283	1537	1828	1850	1918	2212	2345	2089

NRF	Animal category	2000	2001	2002	2003	2004	2005
4B 1a	Dairy Cattle	636	623	610	596	563	558
4B 1b	Non-dairy cattle	1232	1284	1187	1128	1082	986
4B 3	Sheep*	81	92	74	83	79	88
4B 4	Goats*	10	11	11	12	12	14
4B 6	Horses*	150	152	153	155	155	156
4B 8	Swine	11922	12608	12732	12949	13233	13466
4B 9	Poultry	21830	21236	20580	17796	16598	17514
4B 13	Other (fur farming)	2199	2304	2422	2361	2471	2552

* Includes animals on small farms (less than 5 ha), which are not included in Statistics Denmark figures.

Implied emission factor

Table 6.4 shows the implied emission factor for each NFR livestock category from 1990 to 2005. The implied emission factor expresses the average emission of ammonia per animal (from the census) per year. The implied emission factor is changing from year to year depending on a combination of several factors, such as:

- change in the livestock production level or change in the share of different subcategories
- change in fodder condition and N-excretion
- change in stable type
- change in handling of manure in relation to storage and application

In Annex 2C1, more detailed information about N-excretion and stable type for each livestock category, 1990–2005, used in the Danish emission inventory are given. Furthermore, tables show the Danish standards for emission factors used to calculate the ammonia emission in stables and in relation to storage and application of manure.

For most of the animal categories, the implied emission factor has decreased from 1990 to 2005, which is the result of measures in relation to implementation of the action plans for the aquatic environment and the Ammonia Action Plan. Increasingly strict requirements to improve the utilisation of nitrogen in manure have resulted in reduction of N-excretion, especially for slaughter pigs. Changes in manure management

in relation to spreading are another important factor which has reduced the emission. Measures include a requirement for a minimum 9-month manure storage capacity, requirement that manure applied to soil be ploughed down within 6 hours, a ban on the spreading of manure in winter and, from 1 August 2003, broad spreading is no longer allowed.

Table 6.4 Implied emission factor from – manure management 1990 to 2005 [kg NH_3/hd/yr] (NRF category 4B)

NFR	Animal category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
4b 1a	Dairy cattle	31.97	30.98	30.00	29.03	28.07	27.12	26.32	26.42	26.53	26.34
4b 1b	Non-dairy cattle	7.48	7.21	7.01	6.82	6.54	6.30	6.21	6.14	6.10	6.28
4B 3	Sheep	1.86	1.87	1.87	1.88	1.88	1.89	1.74	1.58	1.43	1.29
4B 4	Goats	1.86	1.87	1.87	1.88	1.88	1.89	1.74	1.58	1.43	1.29
4B 6	Horses	7.90	7.71	7.51	7.32	7.13	6.94	6.92	6.89	6.85	7.01
4B 8	Swine	4.99	4.81	4.60	4.19	4.09	3.70	3.71	3.63	3.57	3.61
4B 9	Poultry	0.27	0.27	0.24	0.25	0.27	0.26	0.25	0.26	0.26	0.24
4B 13	Other animals (fur farming)	2.30	2.40	2.21	3.21	2.66	2.59	2.49	2.16	2.03	2.25

NFR	Animal category	2000	2001	2002	2003	2004	2005
4b 1a	Dairy cattle	27.07	26.96	26.34	26.00	26.41	25.27
4b 1b	Non-dairy cattle	6.58	6.61	6.27	5.96	6.02	4.63
4B 3	Sheep	1.45	1.43	1.41	1.37	1.37	1.37
4B 4	Goats	1.45	1.43	1.36	1.33	1.32	1.32
4B 6	Horses	6.87	6.77	6.69	6.50	6.49	6.49
4B 8	Swine	3.40	3.19	3.18	2.94	3.00	2.73
4B 9	Poultry	0.23	0.24	0.24	0.27	0.31	0.30
4B 13	Other animals (fur farming)	2.09	2.05	2.00	1.98	2.12	2.23

6.2.3 Time-series

The emission of NH_3 from manure management is estimated to 67.50 Gg NH_3 in 2005 (Table 6.5). From 1990 to 2005, the emission reduced by 28%. As mentioned, this development is mainly due to an active environmental policy to reduce nitrogen losses in agricultural production.

The number of cattle has decreased as a result of a growth in milk yield. In 2005, cattle production contributes with 28% of the total emission from manure management. The pig production contributes with a still increases share of the emission – in 2005, 54% of the total emission from manure management. The production of slathering pigs has decreased by more than 35% compared with 1990. However, despite this development the emission from pigs is decreasing. This is due to measures focused on the biological development and improvement in fodder efficiency.

Table 6.5 Emission of NH_3 from manure management 1990 – 2005 [Gg NH_3]

NFR	Animal category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
4b 1a	Dairy cattle	24.08	22.97	21.36	20.73	19.64	19.05	18.44	17.71	17.75	16.86
4b 1b	Non-dairy cattle	11.11	10.67	10.37	10.10	9.19	8.75	8.65	8.18	7.98	7.84
4B 3	Sheep	0.17	0.20	0.19	0.17	0.15	0.15	0.16	0.12	0.12	0.11
4B 4	Goats	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01
4B 6	Horses	1.07	1.05	1.04	1.02	1.01	0.99	1.00	1.00	1.01	1.04
4B 8	Pig	47.40	47.05	48.11	48.48	44.69	40.98	40.19	41.27	43.14	42.02
4B 9	Poultry	4.31	4.32	4.56	4.90	5.41	5.05	4.93	4.89	4.81	4.95
4B 13	Other										
	a. Fur farming	5.21	5.08	5.05	4.93	4.87	4.79	4.78	4.77	4.75	4.70
	b. Sewage sludge	0.07	0.07	0.09	0.11	0.10	0.11	0.10	0.09	0.09	0.08
	Total emission	93.44	91.43	90.78	90.45	85.07	79.89	78.26	78.06	79.66	77.62

NFR	Animal category	2000	2001	2002	2003	2004	2005
4b 1a	Dairy cattle	17.20	16.81	16.06	15.49	14.88	14.10
4b 1b	Non-dairy cattle	8.11	8.48	7.45	6.73	6.52	4.57
4B 3	Sheep	0.12	0.13	0.10	0.11	0.11	0.12
4B 4	Goats	0.01	0.01	0.02	0.02	0.02	0.02
4B 6	Horses	1.03	1.03	1.02	1.00	1.01	1.01
4B 8	Pig	40.59	40.23	40.47	38.01	39.69	36.70
4B 9	Poultry	5.01	5.03	4.98	4.88	5.12	5.22
4B 13	Other						
	a. Fur farming	4.60	4.72	4.85	4.68	5.25	5.69
	b. Sewage sludge	0.08	0.08	0.08	0.08	0.07	0.07
	Total emission	76.77	76.52	75.03	71.01	72.65	67.50

Figure 6.6 shows the percentage distribution of the NH_3 emission in stables, storage, spreading of manure in fields and in deposits to grass. The main part of the reduction in ammonia emission has taken place in connection with the spreading of manure in fields, due to changes in manure application practice. There has been a reduction in emissions in relation to storage as a result of improved covering of slurry tanks. From 1990 to 2005, the emission relating to manure management in stables increased from 37% to 50%. In future, the possibilities for ammonia reduction will be likely to be focused on measurements in stables.

It should be mentioned here that the emission from manure deposited by grazing animals is included in the emission from agricultural soils (NRF – 4.D).

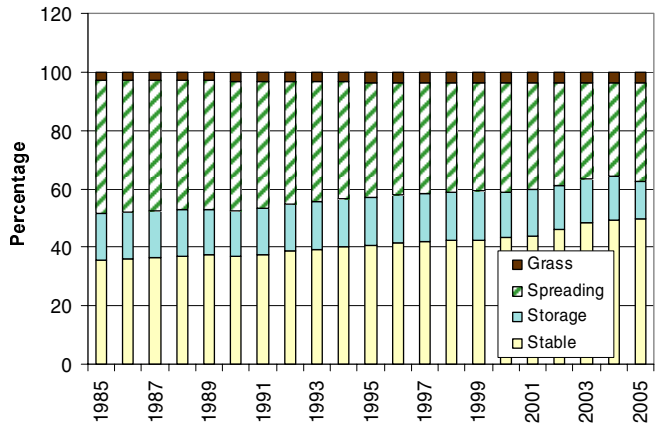

Figure 6.6 The percentage distribution of the NH_3 emission in the agricultural production 1990 – 2005

6.3 NH_3 emission from Agricultural Soils – NRF 4.D

6.3.1 Description

Figure 6.7 shows the different emission sources from agricultural soils (NFR Table 4.D). The majority of the ammonia emission from agricultural soils originates from crops, which in 2005 corresponds to 62%. Another 25% is related to use of synthetic fertiliser and the remaining part comes from nitrogen deposited by grazing animals and from ammonia-treated straw used as feed.

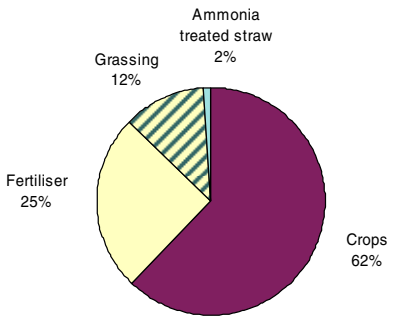

Figure 6.7 Ammonia emissions from agricultural soils 2005

6.3.2 Methodological issues

More detailed description covering the calculation of the different emission sources and information about activity data and emission factors used is given in Annex 2C2.

Activity data

At present, farmed area covers about 60% of the total land area in Denmark. In recent decades, farmed area has decreased, being replaced by forest, semi-natural, road and built-up areas, and this development is

expected to continue. Table 6.6 shows the activity data used in calculation of the ammonia emission from agricultural soils. Information on farmed area and cultivation of different crop types is collected by Statistics Denmark. The amount of nitrogen used in synthetic fertiliser is based on information from the Danish Plant Directorate. The use of fertiliser has decreased considerably – consumption in 2005 is nearly half that in 1990.

Table 6.6 Activity data used to estimate the NH_3 emission from agricultural soils 1990 - 2005

NFR 4.D	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Activity data											
Cultivated area	1000 ha	2 788	2 770	2 756	2 739	2 691	2 726	2 716	2 688	2 672	2 644
N in fertiliser	M kg N	400	395	370	333	326	316	291	288	283	263
N deposit on grass	M kg N	34	35	35	36	35	36	36	35	35	34
NH_3, straw	M kg N	13	11	10	10	10	8	6	6	5	3

NFR 4.D	Unit	2000	2001	2002	2003	2004	2005
Activity data							
Cultivated area	1000 ha	2 647	2 676	2 666	2 658	2 645	2 589
N in fertiliser	M kg N	251	234	211	201	207	206
N deposit on grass	M kg N	33	34	32	32	31	30
NH_3, straw	M kg N	3	2	1	1	0	0

Implied emission factor

The implied emission factors, 1990-2005, in relation to agricultural soils are given in Table 6.7.

The implied emission factors relating to crops are expressed as total emission divided by total area under cultivation, and are decreasing due to the growth in set-a-side area. The implied emission factors relating to use of synthetic fertiliser depend on consumption and type of fertiliser and remain almost the same for all years. The implied emission factors for grazing animals and ammonia used for straw treatment remain unaltered.

Table 6.7 Implied emission factors used to estimate the NH_3 emission from agricultural soils

NFR 4.D Source	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Crops	Kg NH_3 per hectare	5.7	5.7	5.7	5.7	55	5.2	5.3	5.4	5.4	5.3
Fertiliser	% of total N	2.2	2.1	2.1	2.3	2.4	2.4	2.3	2.1	2.2	2.2
N grass	% of total N	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
NH_3, straw	% of total NH_3-N	65	65	65	65	65	65	65	65	65	65

NFR 4.D Source	Unit	2000	2001	2002	2003	2004	2005
Crops	Kg NH_3 per hectare	5.3	5.2	5.3	5.3	5.3	5.3
Fertiliser	% of total N	2.2	2.2	2.2	2.2	2.2	2.2
N grass	% of total N	7.0	7.0	7.0	7.0	7.0	7.0
NH_3, straw	% of total NH_3-N	65	65	65	65	65	65

6.3.3 Time-series

From 1990 to 2005 the ammonia emission from agricultural soils decreased from 39.51 Gg NH_3 to 22.85 Gg NH_3, which corresponds to a 42% reduction (Table 6.8). A considerable increase in the use of fertiliser and ammonia used for straw treatment has, in particular, been important for this development.

As mentioned, there has been an active effort in recent decades to reduce nitrogen leaching by means of action plans. This focus on environmental impact in agricultural production has led to an improvement in the utilisation of nitrogen in manure. A consequence of this development is that the use of fertiliser and, in turn, the NH_3 emission has been reduced.

Table 6.8 Emission of NH_3 from Agricultural Soils from 1990 – 2005 [Gg NH_3]

NFR 4.D Agricultural Soils	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Crops	15.83	15.72	15.64	15.48	14.80	14.18	14.27	14.47	14.41	14.00
Use of fertiliser	10.54	10.25	9.57	9.21	9.56	9.25	8.08	7.51	7.58	7.04
N deposit on grass	2.94	2.99	2.98	3.01	2.94	2.98	3.00	2.90	2.89	2.81
NH_3 treated straw	10.21	8.66	7.69	7.59	8.12	6.65	5.07	4.49	3.71	2.08
Emission, total	39.51	37.63	35.87	35.29	35.41	33.06	30.41	29.37	28.59	25.94

NFR 4.D Agricultural Soils	2000	2001	2002	2003	2004	2005
Crops	13.93	14.04	14.01	13.96	13.99	13.71
Use of fertiliser	6.79	6.26	5.64	5.40	5.62	5.56
N deposit on grass	2.82	2.87	2.75	2.70	2.64	2.54
NH_3 treated straw	2.47	1.62	0.94	0.80	0.53	0.26
Emission, total	26.01	24.79	23.34	22.86	22.78	22.08

6.4 PM emission from stables – NRF 4.B

6.4.1 Description

Investigations have shown that farmers, as well as livestock, are subject to an increased risk of developing lung and respiratory related diseases due to the particulate emissions (Hartung og Seedorf. 1999). This is since the particles are able to carry bacteria, viruses and other organic compounds.

In 2005 the PM emission from stables, given in TSP, is estimated to 14621. Of this, 57% relates to pig production. The emission from poultry and cattle contributes with 36% and 7%, respectively.

Presently, only the emission from 2000 to 2005 is given in NRF. The emissions for the previous year are estimated and will be implemented in the next EMEP report preparation.

6.4.2 Methodological issues

The estimation of PM emission is based on the EMEP-CLRTAP Emission Inventory Guidebook chapter B1010, where the scientific data mainly is based on an investigation of PM emission in North European stables (Takai et al. 1998).

The particle emission includes primary particles in the form of dust from ventilated stables. Three main types of stables, cattle, pig and poultry stables, are included in this inventory (Table 6.9). These are divided into subcategories and for each category it is distinguished between solid and slurry based stable systems.

The PM emission is related to the number of stable places and to the time the animal is housed. The PM emission from grassing animals is considered as negligible.

Table 6.9 Livestock categories used in the PM emission inventory

Livestock categories as given in NFR	Subcategories as given in the EMEP-CLRTAP Emission Inventory Guidebook	Danish inventory	Grassing days
Cattle			
Dairy Cattle	Dairy cattle	Dairy cattle	55
Non-Dairy Cattle	Calves	Calves < ½ yr	0
	Beef cattle	Bulls	0
		Heifer	196
		Suckling cattle	224
Swine	Sows	Sows (incl piglets until 7 kg)	0
	Weaners	Weaners (7-30 kg)	0
	Fattening pigs	Fattening pigs (30-104 kg)	0
Poultry	Laying hens	Laying hens	0
	Broilers	Broilers	0
Horses	Horses	Horses	184

Due to considerable uncertainties and lack of data, this inventory only includes emission from stables. The PM emission from the handling of fertiliser and crops in the field are not taken into account. This will be included when preformed draft is final committed (Hinz 2004, Hinz 2006).

Activity data

Livestock production data is based on Statistics Denmark, Agricultural Statistics (www.dst.dk) – Table 6.10.

Table 6.10 Livestock production 1990 – 2005 [1000 head]

NRF	Animal category	2000	2001	2002	2003	2004	2005
4B 1a	Dairy Cattle	636	623	610	596	563	558
4B 1b	Non-dairy cattle	1868	1907	1796	1724	1646	1544
4B 6	Horses	150	152	153	155	155	156
4B 8	Swine[1]	10489	10489	10706	10826	11257	10882
4B9	Poultry[2]	20982	20347	19734	17152	16136	16901

[1] Includes sows, weaners (7-30 kg) and fattening pigs (30-104 kg)

[2] Includes laying hens and broilers

Emission factor

Emission factor for PM_{10} and $PM_{2.5}$ recommended in the EMEP-CLRTAP emission inventory guidebook Table 4.1 are used. The same emissions factors are used for all years.

In Takai et al. (1998), dust emission from stables is estimated as "inhalable dust". This is defined as particles that can be transported into the body via the respiratory system. Approximately, "inhalable dust" equates to TSP (Hinz, T. 2002 and ISO/CEN. 1993). Estimation of TSP is based on the transformation factors for the conversion of inhalable dust into PM_{10} given in inventory guidebook Table B3 in appendix B.

Table 6.12 Emission factor for particle emission from animal housing system

Livestock category	Stable system	Emission factor PM_{10} [kg/hd/yr]	$PM_{2.5}$ [kg/hd/yr]	TSP [kg/hd/yr]	Transformation factor PM_{10} to TSP [kg/hd/yr]
Cattle:					
Dairy cattle	Solid	0.36	0.23	0.78	0.46
	Slurry	0.70	0.45	1.52	0.46
Calves < ½ yr	Solid	0.16	0.10	0.35	0.46
	Slurry	0.15	0.10	0.33	0.46
Beef cattle	Solid	0.24	0.16	0.52	0.46
	Slurry	0.32	0.21	0.70	0.46
Heifer[1]	Solid	0.26	0.17	0.57	0.46
	Slurry	0.43	0.28	0.93	0.46
Suckling cattle[2]	Solid	0.24	0.16	0.52	0.46
	Slurry	0.32	0.21	0.70	0.46
Swine:					
Sows	Solid	0.58	0.094	1.29	0.45
	Slurry	0.45	0.073	1.00	0.45
Weaners	Solid[3]	0.18	0.029	0.40	0.45
	Slurry	0.18	0.029	0.40	0.45
Fattening pigs	Solid	0.50	0.081	1.11	0.45
	Slurry	0.42	0.069	0.93	0.45
Poultry:					
Laying hens	Solid	0.017	0.0021	0.017	1.0
	Slurry	0.27	0.052	0.27	1.0
Broilers	Solid	0.35	0.045	0.35	1.0
Horses	Solid	0.18	0.12	0.39	0.46

[1] Average of "calves" and "dairy cattle"

[2] Assumed the same value as "Beef cattle"

[3] Same as slurry based systems

6.4.3 Time-series

Table 6.12 shows the emission of particulate matter (PM) for each animal category in the period 2000 to 2005. It is seen that the main part of the emission originates from pig stables. In the period 2000 to 2005, the emission has decreased by 7% due to a fall in production of broilers.

Table 6.12 PM emission 2000 – 2005 [Mg TSP]

NRF	Animal category	2000	2001	2002	2003	2004	2005
4B 1a	Dairy	704	704	700	700	669	643
4B 1b	Non-dairy	431	431	402	384	370	341
4B 6	Horses	30	30	30	30	30	31
4B 8	Swine	8051	8051	8228	8316	8622	8293
4B9	Poultry	6359	6359	6171	5300	4948	5313
	PM total - TSP	15574	15574	15531	14731	14639	14621

UncertainTable 6.13 shows the estimated uncertainties for ammonia sources. The figures are primarily based on the expert judgement of the Faculty of Agricultural Sciences, University of Aarhus. The uncertainties for the number of animals and hectares under cultivation with different crops are very small. The Danish Normative System for animal excretions is based on data from the Danish Agricultural Advisory Centre (DAAC), which is the central office for all Danish agricultural advisory services.

DAAC engages in a great deal of research as well as the collection of efficacy reports from Danish farmers for dairy production, meat production, pig production, etc to optimise productivity in Danish agriculture. In total, feeding plans from 15-18% of Danish dairy production, 25-30% of pig production, 80-90% of poultry production and approximately 100% of fur production are collected annually. These basic feeding plans are used to develop the standard values of the "Danish Normative System".

The system of standard values has been updated annually from 2000. For dairy cows, approximately 800 feeding plans are used to develop the normative figures. The normative figures (Poulsen et al. 2001) are comprised of arithmetic means. Based on feeding plans, the standard deviation in N-excretion rates between farms can be estimated to ±20% for all animal types (Hanne D. Poulsen, DIAS, pers. comm). However, due to the large number of farms included in the norm figures the arithmetic mean, it can be assumed as a very good estimate with a low uncertainty. All cattle, sheep and goats have their own ID-number (ear tags) and, hence, uncertainty with regard to their numbers is almost absent. Statistics Denmark has estimated the uncertainty in the number of pigs to be less than 1%.

The combined effect of low uncertainty in actual animal numbers, feed consumption and excretion rates gives a very low uncertainty in the activity data as a whole. The major uncertainty, therefore, relates to the emission factors.

Table 6.13 Estimated uncertainty associated with activities and emission factors for NH_3 and PM

Source	Emission Gg NH_3	Activity data %	Emission factor %	Combined uncertainty %	Total uncertainty %	Uncertainty 95% Gg NH3
4 Agriculture – NH_3 total	89.57				10.8	9.6
4B NH_3 Manure Management	67.50	3.2	12.8	13.2	13.2	8.9
Stable	34.92	5	20	20.6		
Storage	8.73	5	20	20.6		
Spreading	23.77	5	20	20.6		
Sewage sludge	0.07	2	20	20.1		
4.D Agricultural Soils	22.08	0.9	16.9	16.9	16.9	3.7
Grazing animal	2.54	5	20	20.6		
Synthetic fertiliser	5.56	1	25	25.0		
Crops	13.71	1	25	25.0		
Ammonia treated straw	0.26	10	25	26.9		
Source	Emission Mg TSP	Activity data %	Emission factor %	Combined uncertainty %	Total uncertainty %	Uncertainty 95% Mg TSP
4 Agriculture – PM total	14621	2	500	500	500	73106

6.5 Quality assurance and quality control (QA/QC)

A general QA/QC and verification plan for the agricultural sector is still under development, but some measures have been formulated as general lines for the further work. 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 in the inventory, certain time-series have been prepared for both the activity data and the emission factors, 1985 - 2004. Considerable variation between years can reveal miscalculations or changes in methods. These variations are checked and errors have been rectified.

Activity data and emission factors are collected and discussed in cooperation with specialists and researchers at different institutes and research sections. As a consequence, 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 the Denmark´s National Inventory Report 2006 - submitted under the United Nations Framework Convention on Climate Change (http://www2-.dmu.dk/1_Viden/2_miljoetilstand/3_luft/4_adaei/default_en.asp).

6.6 Recalculations

Compared with the previous NH_3 emissions inventory (submission 2006), some updates have been made. These changes only reflect small changes for the total NH_3 emission - less than 2% (Table 6.14).

In relation to the new chapter in EMEP-CLRTAP emission inventory guidebook chapter B1100, the PM emission from animal husbandry been recalculated. The recalculated total PM emission given in TSP is lower due to a lower emission factor for cattle and swine. In 2004 the emission is 11%lower than estimated in previous emission inventory (Table 6.14).

Table 6.14 Changes in NH_3 emission in the agricultural sector compared to NRF reported last year

NH_3 emission	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
							Gg NH_3								
Previous	133055	128817	126769	124178	119555	112052	107928	107311	108411	103189	102623	101680	98816	94667	94757
Updated	132950	129057	126660	125741	120482	112946	108675	107433	108243	103553	102778	101310	98369	93867	95437
Difference (pct)	-0.1	0.2	-0.1	1.3	0.8	0.8	0.7	0.1	-0.2	0.4	0.2	-0.4	-0.5	-0.8	0.7

PM emission	2000	2001	2002	2003	2004
			Gg TSP		
Previous	16067	16727	16653	16412	16406
Updated	15772	15574	15531	14731	14639
Difference (pct)	-2	-7	-7	-10	-11

6.7 Planned improvements

At present, the NH_3 emission from sewage sludge used as fertiliser is registered under NFR category 4.B 13 Manure Management "Other". It is planned to replace this emission source into NFR category 4.D Agricultural Soils. The sewage sludge is applied to fields and, therefore, relates more to the latter category.

Until now the number of bulls is based on the annually census. Instead, it is planned to use information on slaughtering data received from Statistics Denmark, which better reflects the year production. At the same time the exported animals will be included.

In recent years, there has been focus on reduction of the ammonia emission and especially the possibilities for emission reduction in stables. A number of investigations to estimate the effects from technical measures on the emission have been initiated. However, very few stables have implemented ammonia reduction technologies, although these probably will be an important issue in future. When data is available, it is planned to implement the reduction effect in the emission inventory.

The PM emission from stables in 1985 to 1999 will be implemented in NRF for the next reporting period.

For PM emission, it is planned to include the dust emission from arable farming – i.e. harvesting and field preparation by machines. First draft to guidelines is preformed but not yet final confirmed. The inventory from Finland shows that dust emission from arable farming contributes with approximately 25% of the total emission from the agricultural sector (Karvosenoja et al., 2001 and Louhekainen et al., 1987), which indicates the potential of a relevant PM emission source.

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7 Reporting spatially distributed emissions on grid

7.1 Background for reporting

Geographically distributed emissions, has been reported to the UNECE LRTAP Convention for the years 1990, 1995, 2000 and 2005. Emission data are disaggregated to the standard EMEP grid with a resolution of 50km x 50km. Mandatory reporting are following 14 air pollutants: SO_x, NO_x, NH_3, NMVOC, CO, TSP, PM_{10}, $PM_{2.5}$, Pb, Cd, Hg, DIOX, PAH and HCB. The reporting includes gridded data for sector totals as well as totals for all sectors together. Guidelines for reporting air emissions on grid are given in UN (2003). Gridded emission data are used in integrated European air pollution models - e.g. RAINS/GAINS and EMEP's chemical transport models. Table 7.1 lists the categories (sectors) used for reporting emission data on grid based on the Danish inventories.

Table 7.1 Categories used for reporting gridded emission data according to the guidelines from United Nations

Categories for Gridding		UN categories used for DK reporting
01	Combustion in Power Plants and Industry	√
02a	Transport above 1000m	√
02b	Transport below 1000m	√
03	Commercial Residential and Other Stationary Combustion	√
04	Fugitive Emissions from Fuels	√
05	Industrial Processes	√
06	Solvents and other product use	√
07	Agriculture	√
08	Waste	√
09	Other	-
	Natural	-

The gridded emission data for the 2007 reporting are available at the EU eionet homepage that can be linked from either the NERI homepage (www[5]) or the homepage of the European Environment Agency (www[6]).

7.2 Methods and data for disaggregation of emission data

In the present work geographic data was used as proxies positioning the activity, which causes the emission. As an example we used a geographic data set for land cover of forest for distributing emissions from forest machinery.

[5] http://www.dmu.dk/

[6] http://www.eea.europa.eu/

Based on the theme of forest land cover, fractions of forest in each grid cell were calculated, and the total emission from forest machinery was distributed in harmony with the fractions of forest in each grid cell. A similar methodology was used for distributing emissions from other categories.

An explanation of the applied methodology in greater detail is available in Jensen *et al.*, (2007). A wide range of different geographic data sets has been applied in the mapping procedure. The most essential data are listed in Table 7.2.

Table 7.1 List of different geographic data used in the mapping exercise.

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.
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)	Geo-referenced information on stock of livestock at farm level
The Directorate for Food, Fisheries and Agri Business	The General Agricultural Register (GLR)	Geo-referenced information on agricultural fields
National Environmental Research Institute	Large Point Sources (LPS)	Geo-referenced information on power plants and large industrial plants
Danish Forest and Nature Agency	Military training terrain	Geo-referenced information on military training terrains

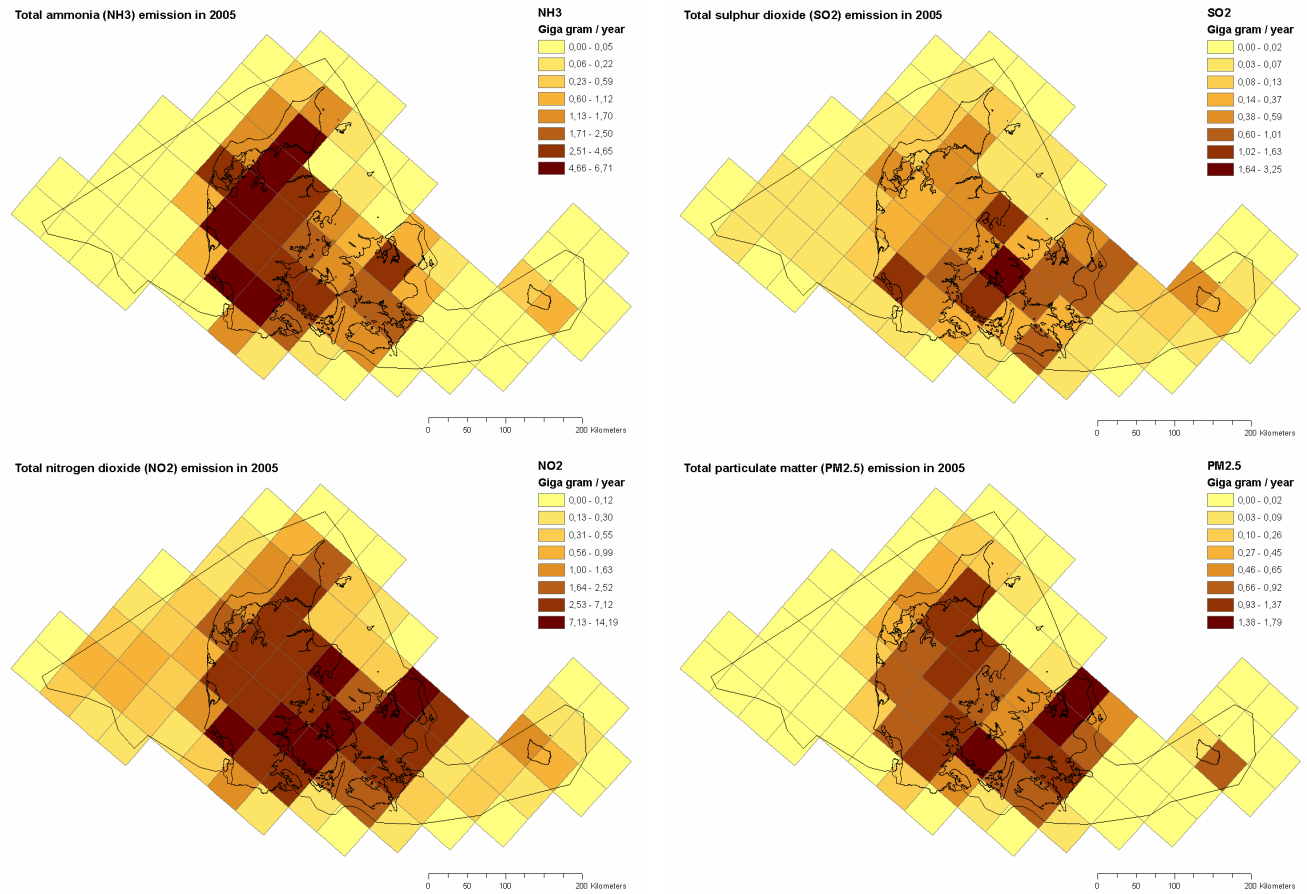
The disaggregation was as far as possible done at the SNAP level within the different reporting categories listed in Table 7.1. The disaggregation at the highly detailed SNAP level was later aggregated to the reporting categories (sector totals), and these were again further aggregated to national totals for all sectors. It is worth to mention that the composition of the predefined reporting categories for gridded emission data are not fully compatible with the categories used in the NFR-schemes for annual reporting of emission data[7] to UNECE.

7.3 Maps with geographical distributed emission data

It is not possible in this section to present all maps for all reporting years and sectors. Therefore, we choose to show national totals for selected air pollutants from the latest reporting year (2005). The selected air pollutants are: Ammonia (NH_3), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and small particulate matter ($PM_{2.5}$). Figure 7.1 shows the geographical distributed emissions for these air pollutants. Even from the national distributed totals, spatial patterns from the major sectors are recognisable.

[7] The annual reporting of emission data to UNECE includes all air pollutants except greenhouse gases.

Figure 7.1 Geographical distribution of national emissions of NH_3, SO_2, NO_2 and $PM_{2.5}$ in 2005.



The agricultural sector is the major contributor to the national total NH_3 emission. Emission of NH_3 is mainly related to livestock farming and especially to the handling of manure from the animals. Emissions of NH_3 are therefore related to storage and spreading of manure as well as emissions from stables (Mikkelsen *et al.*, 2006). The geographical pattern of the NH_3 emission is in good agreement with the localisation and concentration of the Danish livestock farming in the northern and western part of Jutland.

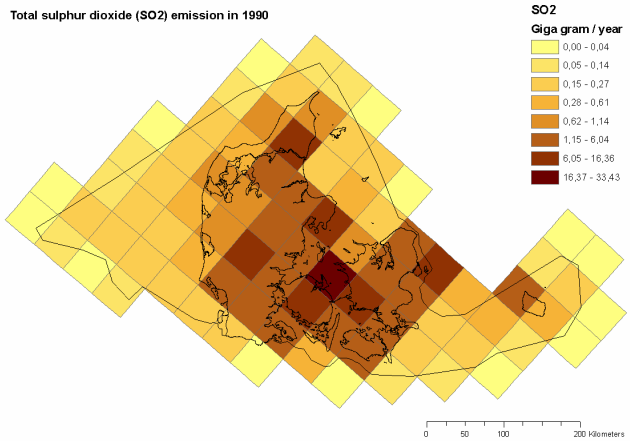
The geographical distribution of SO_2 reflects mainly the localisation of large power plants in Denmark, because these are the overall sources of SO_2 emissions. During the 4 reporting years, this pattern has become weaker, due to the implementation of techniques for reduction of sulphur in the outlet smoke from the power plants. Even though the SO_2 emission has decreased dramatically it still produces a distinct pattern reflecting the localisation of large power plants in Denmark.

For NO_2 the pattern is not that distinct as for SO_2, because it reflects a combination of emission contributions from both power plants and industry, commercial and residential plants and as well transport – mainly road transport. This means that the geographic pattern to a certain point reflects the localisation of infrastructure, dwellings and power plants and industry in Denmark.

The distribution of $PM_{2.5}$ is mainly related to road transport and emissions from residential wood use. Therefore the emissions of $PM_{2.5}$ follow the localisation of the Danish road network and the large residential areas with single family houses.

As already mentioned the total SO_2 emission for Denmark has decreased significantly since 1990. The total emission of SO_2 in 2005 corresponds to approx. 12 percent of the total SO_2 emission in 1990. The spatially distributed pattern of SO_2 in 1990 is illustrated in Figure 7.2. For making comparisons between the two reporting years – see also Figure 7.1.

Figure 7.2 Spatial pattern of the total annual SO_2 emission in Denmark in 1990.



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8 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/CORINAIR guidebook, and the work of the Task Force on Emission Inventories and its expert groups are followed closely in order to be able to incorporate the best scientific information as the basis for the inventories. The further important references in this regard are the IPCC guidelines and IPCC good practice guidance.

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 reasoning for the recalculations performed is to be found in the sectoral chapters of this report. The text below focuses on improvements and recalculations, in general, and further serves as an overview and summary of the relevant text in the sectoral chapters.

8.1 Energy

Improvements and updates of the Danish energy statistics are made regularly by the producer of the statistics, the Danish Energy Agency. In close cooperation with the DEA, these improvements and updates are reflected in the emission inventory for the energy sector. The Danish energy statistics have, for the most part, been aggregated to the SNAP categorisation. This, however, does not include energy statistics for fuel consumption data for specific industries. In the current year the data for disaggregation of fuel consumption and emissions has been updated.

The inventories are still being improved through work to increase the number of large point sources, e.g. power plants, included in the databases as individual point sources. Such an inclusion makes it possible to use plant-specific data for emissions, etc, available e.g. in annual environmental reports from the plants in question.

8.1.1 Energy

Stationary Combustion

The national energy statistics has been updated for the years 2000-2004. This has resulted in increased emissions for the residential sector due to an increase in the estimated wood consumption in residential plants. The emission factors for NMVOC, PM, PAH and dioxin have been updated for the residential sector.

8.1.2 Mobile sources

NO_x

The largest changes are for road transport, military, national sea transport and agriculture.

Road transport: The 1985-2004 emission inventories have been updated with new emission factors (COPERT IV) and mileage information (Danish Vehicle Inspection and Maintenance Programme). The COPERT IV emission factors are derived from the European research project ARTEMIS, which has conducted new emission measurements and simulations of emission factors for road transport vehicles. It is important to note that ARTEMIS includes measurements for Euro I-IV engines and moreover incorporates the so-called engine cycle beating effect.

Military: Emission factors derived from the new road transport simulations have caused some changes in the emissions from 1985-2004.

National sea transport: A new research project has given new knowledge, and the following changes have therefore been made to the national inventory which affects the emission results:

1) Updated emission factors from 1985-2004, and 2) The residual fuel use amount from the fishery sector in the national energy statistics has been moved to the national sea transport category, in the 1985-2004 period

Agriculture: Updated stock information for tractors and harvesters 2001-2004, has given a fuel use and emissions increase for these years.

NMVOC

The largest changes are for road transport and agriculture.

Road transport: The emission factor and mileage updates have given a slight emission change for NMVOC from 1985-2004.

Military: Emission factors derived from the new road transport simulations have caused minor changes in the emissions from 1985-2004.

Agriculture: Updated stock information for tractors and harvesters 2001-2004, has given a fuel use and emissions increase for these years.

SO_2 and NH_3

No changes of significance have occurred.

8.1.3 Industrial processes

SO_2 emissions from a sulphur recovery plant in sector 'Chemical Industry' have been included as process emissions.

The estimated SO_2 and NO_x emissions from cement production have been updated for the years 2002 to 2004.

Solvent

A survey based on new methodologies results in new NMVOC emission estimates. Revisions have been made regarding use of pentane and styrene in the plastic industry, use and emission factors of glycolethers, use and emission factor of tetrachloroethylene and reassignment of some product groups from degreasing to paints.

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611 Projection of Greenhouse Gas Emissions – 2005-2030. By Illerup, J.B. et al. 187 pp.

610 Modellering af fordampning af pesticider fra jord og planter efter sprøjtning. Af Sørensen, P.B. et al. 41 s.

609 OML : Review of a model formulation. By Rørdam, H., Berkowicz, R. & Løfstrøm, P. 128 pp.

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 due by 15 February 2007. The report contains information on Denmark's emission inventories regarding emissions of (1) SOX for the years 1980-2005, (2) NO_X, CO, NMVOC and NH_3 for the years 1985-2005; (3) Particulate matter: TSP, PM_{10}, $PM_{2.5}$ for the years 2000-2005, (4) Heavy Metals: Pb, Cd, Hg, As, Cr, Cu, Ni, Se and Zn for the years 1990-2005, and (5) Polyaromatic hydrocarbons (PAH): Benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene and indeno(1,2,3-cd)pyrene for the years 1990-2005. Further, the report contains information on background data for emissions inventory.

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