
# DANISH EMISSION INVENTORIES FOR ROAD TRANSPORT AND OTHER MOBILE SOURCES

## Inventories until the year 2013

Scientific Report from DCE – Danish Centre for Environment and Energy No. 148 2015

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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# Data sheet

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Abstract: This report explains the parts of the Danish emission inventories related to road transport and other mobile sources. Emission results are shown for $CO_2$, $CH_4$, $N_2O$, $SO_2$, $NO_x$, NMVOC, CO, particulate matter (PM), BC, heavy metals, dioxins and PAH. From 1990-2013 the fuel consumption and $CO_2$ emissions for road transport increased by 25 and 19 %, respectively, and $CH_4$ emissions have decreased by 78 %. A $N_2O$ emission increase of 30 % is related to the relatively high emissions from older gasoline catalyst cars. The 1985-2013 emission decrease for NMVOC, CO, particulates (exhaust only: Size is below $PM_{2.5}$) $NO_x$ and BC are 88, 85, 74, 57 and 54 %, respectively, due to the introduction of vehicles complying with gradually stricter emission standards. For $SO_2$ the emission drop 99 % (due to reduced sulphur content in the diesel fuel), whereas the $NH_3$ emissions increased by 1916 % (due to the introduction of catalyst cars). For other mobile sources the calculated emission changes for $CO_2$ (and fuel use), $CH_4$ and $N_2O$ were -9, -34 and -9 %, from 1990 to 2013. The emissions of $SO_2$, particulates (all size fractions), BC, NMVOC, $NO_x$ and CO decreased by 90, 73, 68, 40, 29 and 5 % from 1985 to 2013. For $NH_3$ the emissions increased by 15 % in the same time period. Uncertainties for the emissions and trends were estimated.

Keywords: Road transport, military, railways, domestic navigation, domestic aviation, working equipment and machinery, $SO_2$, $NO_X$, NMVOC, $CH_4$, CO, $CO_2$, $N_2O$, PM, heavy metals, dioxin, PAH, greenhouse gases, acidifying components.

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# Preface

DCE - Danish Centre for Environment and Energy - prepares the Danish atmospheric emission inventories and reports the results on an annual basis to the UNFCCC (United Nations Framework Convention on Climate Change) and the UNECE LRTAP (United Nations Economic Commission for Europe Convention on Long Range Transboundary Pollutants) conventions. This report explains the parts of the Danish emission inventories related to road transport and other mobile sources. In the report emission results are shown for $CO_2$ (carbon dioxide), $CH_4$ (methane) and $N_2O$ (nitrous oxide) in a time-series from 1990-2013 as reported to the UNFCCC convention. For $SO_2$ (sulfur dioxide), $NO_x$ (nitrogen oxides), NMVOC (non-methane volatile organic compounds), CO (carbon monoxide), $NH_3$ (ammonia), PM (particulate matter) and BC (black carbon) emission results are shown from 1985-2013, and for heavy metals, dioxins and PAH (poly-aromatic hydrocarbons) emission results are shown from 1990-2013, as reported to the UNECE LRTAP convention. All results are grouped according to the UNFCCC Common Reporting Format (CRF) and UNECE National Format for Reporting (NFR) codes.

# Summary

This report explains the emission inventories for road transport and other mobile sources, which are part of the annual Danish emission inventories reported to the UNFCCC (United Nations Framework Convention on Climate Change) and the UNECE LRTAP (United Nations Economic Commission for Europe Long Range Transboundary Pollution) convention. The subsectors for other mobile sources are military, railways, navigation, fisheries, civil aviation and non-road machinery in agriculture, forestry, industry and household/gardening.

The emissions of $CO_2$ (carbon dioxide), $CH_4$ (methane) and $N_2O$ (nitrous oxide), $SO_2$ (sulfur dioxide), $NO_x$ (nitrogen oxides), NMVOC (non-methane volatile organic compounds), CO (carbon monoxide), $NH_3$ (ammonia), PM (particulate matter), BC (black carbon), heavy metals, dioxins and PAHs are shown in time-series as required by the UNFCCC and the UNECE LRTAP conventions, and grouped according to the UNFCCC Common Reporting Format (CRF) and UNECE National Format for Reporting (NFR) classification codes.

**Table 1.1.** Mobile sources and CRF/NFR codes.

| SNAP classification | CRF/NFR classification |
|---|---|
| 0701 Road traffic: Passenger cars | 1A3bi Road transport: Passenger cars |
| 0702 Road traffic: Light duty vehicles | 1A3bii Road transport:Light duty vehicles |
| 0703 Road traffic: Heavy duty vehicles | 1A3biii Road transport:Heavy duty vehicles |
| 0704 & 0705 Road traffic: Mopeds and motor cycles | 1A3biv Road transport: Mopeds & motorcycles |
| 0706 Road traffic: Evaporation | 1A3bv Road transport: Evaporation |
| 0707 Road traffic: Brake and tire wear | 1A3bvi Road transport: Brake and tire wear |
| 0708 Road traffic: Road abrasion | 1A3bvii Road transport: Road abrasion |
| 0801 Military | 1A5b Other, Mobile |
| 0802 Railways | 1A3c Railways |
| 0803 Inland waterways | 1A5b Other, Mobile |
| 080402 National sea traffic | 1A3dii National navigation (Shipping) |
| 080403 National fishing | 1A4ciii Agriculture/Forestry/Fishing: National fishing |
| 080404 International sea traffic | 1A3di (i) International navigation (Shipping) |
| 080501 Dom. airport traffic (LTO < 1000 m) | 1A3aii (i) Civil aviation (Domestic,LTO) |
| 080502 Int. airport traffic (LTO < 1000 m) | 1A3ai (i) Civil aviation (International, LTO) |
| 080503 Dom. cruise traffic (> 1000 m) | 1A3aii (ii) Civil aviation (Domestic,Cruise) |
| 080504 Int. cruise traffic (> 1000 m) | 1A3ai (ii) Civil aviation (International, Cruise) |
| 0806 Agriculture | 1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry |
| 0807 Forestry | 1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry |
| 0808 Industry | 1A2gvii Manufacturing industries/Construction (mobile) |
| 0809 Household and gardening | 1A4bii Residential: Household and gardening (mobile) |
| 0811 Commercial and institutional | 1A4aii Commercial/Institutional: Mobile |

## Methodologies

The emission calculations for road transport are made with an internal DCE model, with a structure similar to the European COPERT IV (COmputer Programme to calculate the Emissions from Road Transport) methodology. The emissions are calculated for operationally hot engines, during cold start and fuel evaporation. The model also includes the emission effect of catalyst wear. Input data for vehicle stock and mileage is obtained from DTU Transport, and is grouped according to average fuel consumption and emission behaviour. The emissions are estimated by combining vehicle and annual mileage numbers with hot emission factors, cold:hot ratios and evaporation factors.

The emissions from air traffic are also calculated with a DCE model. For 2001-2013 the emission estimates are made for each flight, using flight data from the Danish Transport Authority and landing/take off (LTO) and distance related emission factors from the EMEP/CORINAIR guidebook. For previous years the background data consist of LTO/aircraft type statistics from Copenhagen Airport and total LTO numbers from the Danish Transport Authority. With appropriate assumptions a consistent time-series of emissions is produced back to 1985 using also the findings from a Danish city-pair emission inventory in 1998 (Winther, 2001b).

National sea transport is split into regional ferries, small ferries, freight transport between Denmark and Greenland/Faroe Islands, and other national sea transport. For regional ferries, the fuel consumption and emissions are calculated as a product of number of round trips, sailing time per round trip, engine size, engine load factor and fuel consumption/emission factor. For small ferries, freight transport between Denmark and Greenland/Faroe Islands, and other national sea transport, the calculations are simply fuel based using the fuel consumption findings from Danish surveys in combination with average fuel related emission factors.

Non-road working machines and equipment, and recreational craft are grouped in the following sectors: Agriculture, Forestry, Industry, Household/Gardening, Commercial/Institutional and Inland Waterways. 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.

For military, railways and fisheries the emissions are calculated as the product of fuel use and emission factors.

Fuel sales data are obtained from the Danish energy statistics provided by the Danish Energy Agency (DEA). For road transport and aviation the emission results are adjusted in a fuel balance to ensure that all statistical fuel sold is accounted for in the calculations. For national sea transport, the fuel consumption of heavy oil and gas oil is calculated directly by DCE. Fuel adjustments are made in the fishery sector (gas oil) and stationary industry sources (heavy fuel oil) in order to maintain the overall national energy balance according to fuel sale statistics. In order to comply with the IPCC guidelines the fuel consumption by vessels between Denmark and Greenland/Faroe Islands are subtracted from the DEA fuel sales figures for international sea transport, and added to the national part of the emission inventories.

## Emissions from road transport

Set in relation to the Danish national emission totals, the largest emission shares for road transport are noted for $NO_x$, CO, $CO_2$, BC, $PM_{2.5}$, $PM_{10}$, NMVOC and TSP. In 2013 the emission percentages were 33, 26, 25, 19, 9, 8 and 8, respectively. The emissions of $NH_3$, $N_2O$, $CH_4$ and $SO_2$ have marginal shares of 1.7, 2.4, 0.1 and 0.5 %, respectively.

From 1990 to 2013 the calculated fuel consumption and emission changes for $CO_2$, $CH_4$ and $N_2O$ are 25, 19, -78 and 30 %. For $NO_x$, NMVOC, CO, particulates (exhaust only: Size is below $PM_{2.5}$) and BC, the 1985-2013 emission changes are -57, -88, -85, -74 and -54 %.

The most significant emission changes from 1985 to 2013 occur for $SO_2$ and $NH_3$. For $SO_2$ the emission drop is 99 % (due to reduced sulphur content in the diesel fuel), whereas the $NH_3$ emissions increase by 1916 % (due to the introduction of catalyst cars).

**Table 1.2.** Emissions (tonnes[a]) from road transport in 2013, changes from 1985 (1990[b]) to 2013, and 2013 shares of national emission totals.

| CRF/NFR ID | $SO_2$ | $NO_x$ | NMVOC | $CH_4$ | CO | $CO_2$ | $N_2O$ | $NH_3$ | TSP | $PM_{10}$ | $PM_{2.5}$ | BC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Road transport: | | | | | | | | | | | | |
| Passenger cars | 42 | 18094 | 5640 | 298 | 69286 | 6658 | 199 | 1218 | 503 | 503 | 503 | 364 |
| Light duty vehicles | 10 | 6230 | 546 | 14 | 3887 | 1552 | 49 | 28 | 344 | 344 | 344 | 274 |
| Heavy duty vehicles | 17 | 16185 | 389 | 82 | 5897 | 2751 | 130 | 25 | 258 | 258 | 258 | 178 |
| Mopeds & motorcycles | 0 | 144 | 1322 | 87 | 7550 | 60 | 1 | 1 | 26 | 26 | 26 | 4 |
| Gasoline evaporation | 0 | 0 | 1410 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Brake wear | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 497 | 487 | 194 | 13 |
| Tyre wear | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 877 | 526 | 369 | 134 |
| Road abrasion | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1080 | 540 | 292 | 0 |
| Exhaust total | 69 | 40654 | 9307 | 481 | 86619 | 11021 | 379 | 1272 | 1131 | 1131 | 1131 | 821 |
| Non exhaust total | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2454 | 1554 | 854 | 147 |
| Total | 69 | 40654 | 9307 | 481 | 86619 | 11021 | 379 | 1272 | 3585 | 2684 | 1985 | 968 |
| National total | 13643 | 123865 | 114431 | 329206 | 338801 | 43952 | 16017 | 74320 | 89246 | 32208 | 21237 | 4985 |
| % of national total, 2013 | 0.5 | 33 | 8.1 | 0.1 | 26 | 25 | 2.4 | 1.7 | 4.0 | 8.3 | 9.3 | 19 |
| % change 1985-2013 | -99 | -57 | -88 | -78 | -85 | 19 | 30 | 1916 | -74 | -74 | -74 | -54 |

[a] Unit for $CO_2$: ktonnes. [b] For the greenhouse gases $CO_2$, $CH_4$ and $N_2O$, the emission changes are relative to 1990

In 2013, the most important $CO_2$ emission source for road transport is passenger cars (60 %), followed by heavy-duty vehicles (25 %), light-duty vehicles (14 %) and 2-wheelers (1 %). For $CH_4$ the 2013 emission shares were 62, 18, 17 and 3 % for passenger cars, 2-wheelers, heavy-duty vehicles and light-duty vehicles, respectively, and for $N_2O$ the emission shares for passenger cars, heavy and light-duty vehicles were 53, 34 and 13 %, respectively.

For 2013 the following emission shares for passenger cars, heavy-duty vehicles, light-duty vehicles and 2-wheelers (percentage shares in brackets) are calculated for $NO_x$ (45, 40, 15 and 0 %), NMVOC (62, 4, 7 and 13 %), CO (80, 6, 6 and 8 %), particulates exhaust (45, 21, 32 and 2 %), BC (44, 22, 33 and 1 %) and $NH_3$ (97, 1, 2 and 0 %).

Set in relation to total road transport emissions in 2013, the emission shares of TSP, $PM_{10}$, $PM_{2.5}$ and BC were 74, 65, 50 and 15 %, respectively, related to tire, brake and road abrasion.

## Emissions from other mobile sources

For other mobile sources the emissions of CO, $NO_x$, BC, $SO_2$, $CO_2$, NMVOC and $PM_{2.5}$ have the largest shares of the national totals in 2013. The shares are 38, 30, 19, 12, 9, 8 and 8 %, respectively. The 2013 TSP and $PM_{10}$ emission shares are 2 and 6 %, respectively, whereas the emissions of $N_2O$, $NH_3$ and $CH_4$ have marginal shares of around 1 % or less in 2013.

From 1990 to 2013 the calculated emission changes for $CO_2$ (and fuel use), $CH_4$ and $N_2O$ are -9, -34 and -9 %. The emissions of $SO_2$, particulates (all size fractions), BC, NMVOC, $NO_x$ and CO have changed by -90, -73, -68, -40, -29, and -5 % from 1985 to 2013.

**Table 1.3.** Emissions from other mobile sources in 2013 (tonnes[a]), changes from 1985 (1990[b]) to 2013, and 2013 shares of national emission totals.

| CRF/NFR ID | $SO_2$ | $NO_x$ | NMVOC | $CH_4$ | CO | $CO_2$ | $N_2O$ | $NH_3$ | TSP | $PM_{10}$ | $PM_{2.5}$ | BC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry: Mobile | 6 | 7454 | 1079 | 34 | 6164 | 1025 | 44 | 3 | 613 | 613 | 613 | 433 |
| Civil aviation (Domestic) | 45 | 724 | 94 | 2 | 614 | 140 | 7 | 0 | 3 | 3 | 3 | 1 |
| Railways | 2 | 2361 | 164 | 6 | 372 | 248 | 7 | 1 | 70 | 70 | 70 | 46 |
| National navigation (Shipping) | 1243 | 8059 | 271 | 10 | 908 | 393 | 25 | 0 | 163 | 161 | 160 | 32 |
| Commercial/Institutional: Mobile | 1 | 219 | 3601 | 173 | 72587 | 171 | 3 | 0 | 67 | 67 | 67 | 3 |
| Residential: Mobile | 0 | 92 | 1924 | 42 | 26477 | 62 | 1 | 0 | 15 | 15 | 15 | 1 |
| Agriculture/Forestry: Off-road | 7 | 7257 | 1545 | 108 | 16294 | 1143 | 48 | 3 | 584 | 584 | 584 | 353 |
| National fishing | 323 | 9139 | 400 | 12 | 1318 | 511 | 32 | 0 | 149 | 147 | 147 | 46 |
| Other, Mobile | 72 | 1513 | 376 | 15 | 3881 | 239 | 9 | 1 | 99 | 99 | 99 | 39 |
| Total Other mobile | 1700 | 36819 | 9454 | 402 | 128615 | 3933 | 175 | 8 | 1763 | 1760 | 1758 | 954 |
| Total national | 13643 | 123865 | 114431 | 329206 | 338801 | 43952 | 16017 | 74320 | 89246 | 32208 | 21237 | 4985 |
| Other mobile- % of national total, 2013 | 12 | 30 | 8.3 | 0.1 | 38 | 8.9 | 1.1 | 0.01 | 2.0 | 5.5 | 8.3 | 19 |
| Other mobile- % change 1985-2013 | -90 | -29 | -40 | -34 | -5 | -9 | -9 | 15 | -73 | -73 | -73 | -68 |

[a] Unit for $CO_2$: ktonnes. [b] For the greenhouse gases $CO_2$, $CH_4$ and $N_2O$, the emission changes are relative to 1990

The largest source of $NO_x$, particulates and BC emissions are agriculture/forestry/fisheries, followed by industry and navigation. For NMVOC and CO most of the emissions come from gasoline fuelled working machinery in the commercial/institutional and residential sectors.

## Heavy metals

Heavy metal emissions are calculated for fuel and engine oil as well as for tyre, brake and road wear. The road transport shares for copper (Cu), lead (Pb), zinc (Zn), chromium (Cr) and cadmium (Cd) are 94, 47, 46, 12 and 8 % of national totals in 2013. For other mobile sources the nickel (Ni), Arsenic (As) and Pb shares are 40, 11 and 8 %. For the remaining components, the emission shares are less than 5 %.

The most important exhaust related emissions (fuel and engine oil) for road transport (% of national total in brackets) are Zn (14 %), Cd (7 %), Cr (7 %) and Hg (6 %). The most important wear related emissions are Cu (93 %) and Pb (46 %) almost solely coming from tyre wear, and Zn (33 %) from brake and tyre wear. For other mobile sources, the emissions of Ni and As arise from the use of marine diesel oil and residual oil in fisheries and navigation. The emissions of Pb almost solely come from the use of aviation gasoline.

In general terms the development in emissions follows the trends in fuel/engine oil consumption and vehicle mileage (wear related emissions). It must be noted, however, that there has been an almost 100 % decline in the exhaust related emissions of Pb, due to the phasing out of leaded gasoline fuels until 1994.

## PAHs

The PAH emission shares for road transport and other mobile sources are 10 % or less of the national total in 2013.

## Uncertainties

For mobile sources in 2013 the $CO_2$ emissions are determined with the highest accuracy, followed by the $CH_4$, TSP, $SO_2$, $PM_{10}$, $PM_{2.5}$, $NO_x$, NMVOC, BC, CO and $N_2O$ emissions with increasing levels of uncertainties. The uncertainties are 5, 33, 47, 49, 50, 54, 55, 56, 56, 63 and 144 %, respectively. The uncertainties for the 1990-2013 emission trends are 6, 7, 5, 3, 4, 3, 9, 8, 4 and 68 % for the emissions in the same consecutive order. For $NH_3$, heavy metals and PAHs the 2013 emissions have uncertainty levels of between 700 and 1000 %. In this case the emission trend uncertainties are significantly lower; still large fluctuations exist between the calculated values for the different emission components.

# Sammenfatning

Denne rapport dokumenterer de årlige danske emissionsopgørelser for vejtransport og andre mobile kilder. Opgørelserne laves som en del af de samlede danske opgørelser, og rapporteres til UNFCCC (United Nations Framework Convention on Climate Change) og UNECE LRTAP (United Nations Economic Commission for Europe Long Range Transboundary Pollution) konventionerne. Underkategorierne for andre mobile kilder er: Militær, jernbane, søfart, fiskeri, civil flyvning, og arbejdsredskaber- og maskiner i landbrug, skovbrug, industri samt have/hushold.

For $CO_2$, (kuldioxid) $CH_4$ (metan), $N_2O$ (lattergas), $SO_2$ (svovldioxid), $NO_x$ (kvælstofoxider), NMVOC (ikke-metan flygtige organiske forbindelser), CO (kulmonoxid), PM (partikler), BC (black carbon), tungmetaller, dioxiner og PAH'er er de beregnede emissioner vist i tidsserier iht. til UNFCCC og UNECE LRTAP konventionernes krav, og resultaterne grupperes i henhold til UNFCCCs Common Reporting Format (CRF) og UNECEs National Format for Reporting (NFR) rapporteringskoder.

**Table 1.4**. Mobile kilder og CRF/NFR koder.

| SNAP classification | CRF/NFR classification |
|---|---|
| 0701 Vejtrafik: Personbiler | 1A3bi Road transport: Passenger cars |
| 0702 Vejtrafik: Varebiler | 1A3bii Road transport:Light duty vehicles |
| 0703 Vejtrafik: Tunge køretøjer | 1A3biii Road transport:Heavy duty vehicles |
| 0704 & 0705 Vejtrafik: Knallerter og motorcykler | 1A3biv Road transport: Mopeds & motorcycles |
| 0706 Vejtrafik: Fordampning | 1A3bv Road transport: Evaporation |
| 0707 Vejtrafik: Bremse- og dækslid | 1A3bvi Road transport: Brake and tire wear |
| 0708 Vejtrafik: Vejslid | 1A3bvii Road transport: Road abrasion |
| 0801 Militær | 1A5b Other, Mobile |
| 0802 Jernbane | 1A3c Railways |
| 0803 Småbåde og fritidsfartøjer | 1A5b Other, Mobile |
| 080402 Indenrigs skibstrafik | 1A3dii National navigation (Shipping) |
| 080403 Indenrigs fiskeri | 1A4ciii Agriculture/Forestry/Fishing: National fishing |
| 080404 Udenrigs skibstrafik | 1A3di (i) International navigation (Shipping) |
| 080501 Indenrigs flytrafik (LTO < 1000 m) | 1A3aii (i) Civil aviation (Domestic,LTO) |
| 080502 Udenrigs flytrafik (LTO < 1000 m) | 1A3ai (i) Civil aviation (International, LTO) |
| 080503 Indenrigs flytrafik (Cruise> 1000 m) | 1A3aii (ii) Civil aviation (Domestic,Cruise) |
| 080504 Udenrigs flytrafik (Cruise > 1000 m) | 1A3ai (ii) Civil aviation (International, Cruise) |
| 0806 Landbrug | 1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry |
| 0807 Skovbrug | 1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry |
| 0808 Industri | 1A2gvii Manufacturing industries/Construction (mobile) |
| 0809 Have- og hushold | 1A4bii Residential: Household and gardening (mobile) |
| 08011 Handel og service | 1A4aii Commercial/Institutional: Mobile |

## Metoder

Emissionerne for vejtrafik beregnes med en intern DCE-model, der benytter samme modelprincip som den europæiske emissionsmodel COPERT IV (COmputer Programme to calculate the Emissions from Road Transport). I DCE-modellen beregnes emissionerne for køretøjer med driftsvarme motorer, under koldstart og som følge af brændstoffordampning. Modellen tager også højde for de forøgede emissioner som følge af katalysatorslid. Input data for køretøjsbestand og årskørsler oplyses af DTU Transport og køretøjerne grupperes iht. gennemsnitligt brændstofforbrug og emissioner. Emissionerne beregnes som produktet af antal køretøjer, årskørsler, varme emissionsfaktorer, kold/varm-forhold og fordampningsfaktorer.

For luftfart beregnes emissionerne også i en DCE model. For 2001-2013 opgøres emissionerne for hver enkelt flyvning. Til beregningerne bruges flydata fra Trafikstyrelsen samt landing/take off (LTO) og cruise emissionsfaktorer pr. fløjet distance fra EMEP/CORINAIR guidebogen. For årene før 2001 bruges som baggrundsdata en LTO/flytype statistik fra Københavns Lufthavn samt Trafikstyrelsens tal for antallet af starter og landinger. En konsistent emissionsopgørelse er beregnet tilbage til 1985 ved at gøre passende antagelser og ved at bruge resultaterne fra en dansk city-pair emissionsopgørelse for 1998.

National søfart er opdelt i regionale færger, småfærger, godstransport mellem Danmark og Grønland/Færøerne og øvrig søtransport. For regionale færger beregnes emissionerne som produktet af antallet af dobbeltture, sejltid pr. dobbelttur, motorstørrelsen, motorlastfaktoren og emissionsfaktoren. For små færger, godstransport mellem Danmark og Grønland/Færøerne og øvrig søtransport beregnes emissionerne som produktet af emissionsfaktorer og totalt brændstofforbrug, der bestemmes i danske undersøgelser.

For militær, jernbane og fiskeri beregnes emissionerne som produktet af brændstofsalg og emissionsfaktorer.

For arbejdsredskaber og -maskiner indenfor landbrug, skovbrug, industri, have/hushold, handel/service samt småbåde og fritidsfartøjer beregnes emissionerne som produktet af antallet af maskiner, lastfaktorer, motorstørrelser, årlige driftstider og emissionsfaktorer.

Data for energiforbrug stammer fra Energistyrelsens (ENS) energistatistik. For vejtransport og luftfart justeres de modelberegnede emissionsresultater ud fra en brændstofbalance, dvs. forholdet mellem det statistisk opgjorte forbrug og det beregnede forbrug i modellen. For national søtransport beregner DCE brændstofforbruget direkte for diesel og tung olie, og efterfølgende justeres brændstofforbruget for fiskeri (diesel) og stationære kilder indenfor industri. Brændstofbalancerne sikrer, at hele det oplyste brændstofsalg ligger til grund for emissionsopgørelserne. I henhold til IPCC's retningslinjer fratrækkes energiforbruget for skibstrafikken mellem Danmark og Grønland/Færøerne ENS totalen for international søtransport og overføres til den nationale del af opgørelserne.

## Emissioner fra vejtrafik

Set i forhold til landets samlede emissionstotal beregnes vejtrafikkens største emissionsandele for $NO_x$, CO, $CO_2$, BC, $PM_{2.5}$, $PM_{10}$, NMVOC og TSP. Procentandelene for disse stoffer ligger på hhv. 33, 26, 25, 19, 9, 8 og 8. Emissionsandelene for $NH_3$, $N_2O$, $CH_4$ og $SO_2$ er små og ligger på hhv. 1,7, 2,4, 0,1 og 0,5 %.

De beregnede ændringer i energiforbruget og $CO_2$, $CH_4$ og $N_2O$ emissionerne er på hhv. 25, 19, -78 og 30 % fra 1990-2013. For $NO_x$, NMVOC, CO, partikler (kun udstødning: < $PM_{2.5}$) og BC er de beregnede ændringer på hhv. -57, -88, -85, -74 and -54 % i perioden 1985-2013.

De mest markante emissionsændringer fra 1985 til 2013 sker for $SO_2$ og $NH_3$. $SO_2$-emissionerne falder med 99 % (pga. et lavere svovlindhold i diesel), hvorimod $NH_3$-emissionerne stiger med 1916 % (pga. indførelsen af katalysatorbiler).

**Table 1.5**. Emissioner fra vejtrafik i 2013 (tons[a]), ændringer fra 1985 (1990[b]) til 2013, og 2013 andele af den samlede danske emissionstotal.

| CRF/NFR ID | $SO_2$ | $NO_x$ | NMVOC | $CH_4$ | CO | $CO_2$ | $N_2O$ | $NH_3$ | TSP | $PM_{10}$ | $PM_{2.5}$ | BC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vejtrafik: | | | | | | | | | | | | |
| Personbiler | 42 | 18094 | 5640 | 298 | 69286 | 6658 | 199 | 1218 | 503 | 503 | 503 | 364 |
| Varebiler | 10 | 6230 | 546 | 14 | 3887 | 1552 | 49 | 28 | 344 | 344 | 344 | 274 |
| Tunge køretøjer | 17 | 16185 | 389 | 82 | 5897 | 2751 | 130 | 25 | 258 | 258 | 258 | 178 |
| Knallerter og motorcykler | 0 | 144 | 1322 | 87 | 7550 | 60 | 1 | 1 | 26 | 26 | 26 | 4 |
| Fordampning | 0 | 0 | 1410 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bremseslid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 497 | 487 | 194 | 13 |
| Dækslid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 877 | 526 | 369 | 134 |
| Vejslid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1080 | 540 | 292 | 0 |
| Total udstødning | 69 | 40654 | 9307 | 481 | 86619 | 11021 | 379 | 1272 | 1131 | 1131 | 1131 | 821 |
| Total slidrelateret | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2454 | 1554 | 854 | 147 |
| I alt | 69 | 40654 | 9307 | 481 | 86619 | 11021 | 379 | 1272 | 3585 | 2684 | 1985 | 968 |
| National total | 13643 | 123865 | 114431 | 329206 | 338801 | 43952 | 16017 | 74320 | 89246 | 32208 | 21237 | 4985 |
| % af national total, 2013 | 0,5 | 33 | 8,1 | 0,1 | 26 | 25 | 2,4 | 1,7 | 4,0 | 8,3 | 9,3 | 19 |
| % ændring 1985-2013 | -99 | -57 | -88 | -78 | -85 | 19 | 30 | 1916 | -74 | -74 | -74 | -54 |

[a] Enhed for $CO_2$: ktons. [b] For drivhusgasserne $CO_2$, $CH_4$ and $N_2O$, er emissionsændringerne beregnet I forhold til 1990

De største $CO_2$ emissioner for vejtrafik i 2013 beregnes for personbiler (60 %), fulgt af tunge køretøjer (25 %), varebiler (14 %) og 2-hjulede køretøjer (1 %). For $CH_4$ beregnes emissionsandele på hhv. 62, 18, 17 og 3 % for personbiler, 2-hjulede køretøjer, tunge køretøjer og varebiler, og $N_2O$ emissionsandelene for personbiler, tunge køretøjer og varebiler er på hhv. 53, 34 og 13 %.

I 2013 beregnes emissionsandele for personbiler, tunge køretøjer, varebiler og 2-hjulede køretøjer på hhv. 45, 40, 15 og 0 % ($NO_x$), 62, 4, 7 og 13 % (NMVOC), 80, 6, 6 og 8 % (CO), 45, 21, 32 og 2 % (TSP, $PM_{10}$ og $PM_{2.5}$ fra udstødning), 44, 22, 33 og 1 % (BC) samt 97, 1, 2 og 0 % ($NH_3$).

De samlede emissioner af TSP, $PM_{10}$, $PM_{2.5}$ og BC fra dæk-, bremse- og vejslid udgjorde i 2013 hhv. 74, 65, 50 og 15 % af vejtrafikkens samlede emissioner.

## Emissioner fra andre mobile kilder

Andre mobile kilders CO, $NO_x$, BC, $SO_2$, $CO_2$, NMVOC og $PM_{2.5}$ emissioner udgjorde i 2013 hhv. 38, 30, 19, 12, 9, 8 and 8 % af landets total. I 2013 er emissionsandelene for TSP og $PM_{10}$ på hhv. 2 og 6 %, mens andelene for $N_2O$, $NH_3$ og $CH_4$ kun er på omtrent 1 % eller mindre.

Fra 1990-2013 beregnes emissionsændringer for $CO_2$ (og energiforbrug), $CH_4$ og $N_2O$ på hhv. -9, -34 og -9 %. Fra 1985-2013 beregnes emissionsændringer for $SO_2$, partikler (alle størrelsesfraktioner), BC, $NO_x$, NMVOC og CO på hhv. -90, -73, -68, -29, -40 og -5 %.

**Table 1.6**. Emissioner (tons[a]) fra andre mobile kilder i 2013, ændringer fra 1985 (1990[b]) til 2013, og 2013 andele af den samlede danske emissionstotal

| CRF/NFR ID | $SO_2$ | $NO_x$ | NMVOC | $CH_4$ | CO | $CO_2$ | $N_2O$ | $NH_3$ | TSP | $PM_{10}$ | $PM_{2.5}$ | BC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industri, arbejdsredskaber | 6 | 7454 | 1079 | 34 | 6164 | 1025 | 44 | 3 | 613 | 613 | 613 | 433 |
| Civil luftfart | 45 | 724 | 94 | 2 | 614 | 140 | 7 | 0 | 3 | 3 | 3 | 1 |
| Jernbane | 2 | 2361 | 164 | 6 | 372 | 248 | 7 | 1 | 70 | 70 | 70 | 46 |
| National søfart | 1243 | 8059 | 271 | 10 | 908 | 393 | 25 | 0 | 163 | 161 | 160 | 32 |
| Handel og service, arbejdsredskaber | 1 | 219 | 3601 | 173 | 72587 | 171 | 3 | 0 | 67 | 67 | 67 | 3 |
| Have-hushold, arbejdsredskaber | 0 | 92 | 1924 | 42 | 26477 | 62 | 1 | 0 | 15 | 15 | 15 | 1 |
| Landbrug/skovbrug: | | | | | | | | | | | | |
| Off-road | 7 | 7257 | 1545 | 108 | 16294 | 1143 | 48 | 3 | 584 | 584 | 584 | 353 |
| Fiskeri | 323 | 9139 | 400 | 12 | 1318 | 511 | 32 | 0 | 149 | 147 | 147 | 46 |
| Øvrige mobile | 72 | 1513 | 376 | 15 | 3881 | 239 | 9 | 1 | 99 | 99 | 99 | 39 |
| Total Andre mobile kilder | 1700 | 36819 | 9454 | 402 | 128615 | 3933 | 175 | 8 | 1763 | 1760 | 1758 | 954 |
| Total national | 13643 | 123865 | 114431 | 329206 | 338801 | 43952 | 16017 | 74320 | 89246 | 32208 | 21237 | 4985 |
| Andre mobile kilder - % af national total, 2013 | 12 | 30 | 8,3 | 0,1 | 38 | 8,9 | 1,1 | 0,01 | 2,0 | 5,5 | 8,3 | 19 |
| Andre mobile kilder - % ændring 1985-2013 | -90 | -29 | -40 | -34 | -5 | -9 | -9 | 15 | -73 | -73 | -73 | -68 |

[a)] Enhed for $CO_2$: ktons. [b)] For drivhusgasserne $CO_2$, $CH_4$ and $N_2O$, er emissionsændringerne beregnet I forhold til 1990

De største emissionskilder for $NO_x$, partikler og BC er dieselmaskiner, der bruges indenfor landbrug/skovbrug/fiskeri, efterfulgt af industri og national søfart. Den største del af NMVOC- og CO-emissionerne kommer fra benzindrevne arbejdsredskaber og maskiner indenfor handel og service og have- og hushold.

## Tungmetaller

Tungmetalemissioner beregnes for brændstofforbrug og motorolie samt for dæk-, bremse- og vejslid. For tungmetaller følger emissionerne udviklingen i energiforbruget. I 2013 er vejtrafikkens emissionsandele af de nationale totaler for kobber (Cu), bly (Pb), zink (Zn), krom (Cr) og kadmium (Cd) på hhv. 94, 47, 46, 12 og 8 %. For andre mobile kilder er nikkel (Ni), Arsen (As) og Pb andelene på 40, 11 og 8 %. For de øvrige komponenter er emissionsandelene på mindre end 5 %.

For vejtrafik beregnes de største udstødningsrelaterede emissionsandele (% af national total) for Zn (14 %), Cd (7 %), Cr (7 %) og Hg (6 %). De slidrelaterede emissionsandele for Cu (93 %) og Pb (46 %) kommer næsten udelukkende fra dækslid, og Zn (33 %) kommer fra bremse- og dækslid. Ni og As emissionerne fra andre mobile kilder skyldes forbruget af marin diesel og tung olie indenfor fiskeri og national søfart og Pb emissionen stammer fra forbruget af flybenzin.

Overordnet set følger tungmetalemissionerne udviklingen i forbruget af brændstof og motorolie samt trafikarbejdet (for slidrelaterede emissioner). Dog har der været et fald på næsten 100 % for Pb, pga. udfasningen af bly i benzin til vejtransport frem til 1994.

### PAH

PAH emissionsandelene for vejtransport og andre mobile kilder udgør 10 % eller mindre af de nationale totaler i 2013.

### Usikkerheder

I 2013 er $CO_2$-emissionerne de mest præcise, fulgt af $CH_4$, TSP, $SO_2$, $PM_{10}$, $PM_{2.5}$, $NO_x$, NMVOC, BC, CO og $N_2O$-estimaterne med stigende usikkerheder. Usikkerhederne er på hhv. 5, 33, 47, 49, 50, 54, 55, 56, 56, 63 og 144 %. I samme emissionsrækkefølge er usikkerheden på emissionsudviklingen fra 1990 til 2013 på hhv. 6, 7, 5, 3, 4, 3, 9, 8, 4 og 68 %. For $NH_3$, tungmetaller og PAH'er er 2013-emissionerne bestemt med en usikkerhed på mellem 700 og 1000 %. Her er usikkerheden på 1990-2013 emissionsudviklingen signifikant lavere, men varierer dog meget fra stof til stof.

# 1 Introduction

The Danish atmospheric emission inventories are prepared on an annual basis and the results are reported to the *UN Framework Convention on Climate Change* (UNFCCC or Climate Convention) and to the UNECE LRTAP (United Nations Economic Commission for Europe Long Range Transboundary Pollution) convention. Furthermore, the greenhouse gas emission inventory is reported to the EU, because the EU – as well as the individual member states – is party to the Climate Convention. The Danish atmospheric emission inventories are prepared by the Department of Environmental Science (ENVS)/Danish Centre for Environment and Energy (DCE), Aarhus University (former: the Danish National Environmental Research Institute (NERI)).

This report documents the Danish emission inventories for road transport and other mobile sources in the sectors Military, Railways, Navigation, Fisheries, Civil aviation and non-road machinery in Agriculture, Forestry, Industry, Residential and Commercial/Institutional.

In Chapter 2 an overview of the Danish emissions in 2013, the UNFCCC and UNECE conventions and the Danish emission reduction targets is provided. A brief overview of the inventory structure is given in Chapter 3. In Chapter 4 and 5, the inventory input data and calculation methods are shown for road transport and other mobile sources, respectively, while fuel use data and emission results are provided in Chapters 4 and 5, respectively. Fuel consumption and emission results are described in Chapter 6, whereas uncertainties and time-series inconsistencies are explained in Chapters 7.

# 2 Total Danish emissions, international conventions and reduction targets

## 2.1 Total Danish emissions

The total Danish emissions in 2013 are listed in the Tables 2.1-2.4. A thorough documentation of the Danish inventory can be seen in Nielsen et al (2015a) for greenhouse gases reported to the UNFCCC convention (the Danish NIR report), and in Nielsen et al. (2015b) for the remaining emission components reported to the LRTAP Convention (the Danish IIR report). The emission reports are organised in six main source categories and a number of sub categories. The emission source *1 Energy* covers combustion in stationary and mobile sources as well as fugitive emissions from the energy sector.

Links to the latest emission inventories can be found on the ENVS/DCE home page http://www.dmu.dk/luft/emissioner/emissioninventory/. Information of the individual Danish inventory sectors, documentation reports of targeted emission surveys and updated emission factors are also available on the ENVS/DCE homepage.

Note that according to convention decisions the emissions from international transport as well as $CO_2$ emissions from renewable fuels are not included in the inventory emission totals. Although estimated, these emissions are reported as memo items only.

Further emission data for mobile sources are provided in Chapter 6.

**Table 2.1**. Greenhouse gas emissions 2013 reported to the UNFCCC convention.

| | $CO_2$ (Gg) | $CH_4$ (Mg) | $N_2O$ (Mg) | Total GHG[a] (Gg CO2e) |
|---|---|---|---|---|
| 1. Energy | 40169 | 17263 | 1346 | 41002 |
| 2. Industrial processes and product use | 1180 | 135 | 63 | 2126 |
| 3. Agriculture | 246 | 215493 | 14512 | 9958 |
| 4. Land use, land-use change and forestry | 2340 | 276 | 79 | 2370 |
| 5. Waste | 16 | 43367 | 663 | 1298 |
| Total national | 43952 | 276533 | 16662 | 56754 |
| International transport (air) | 2473 | 4 | 84 | 2500 |
| International transport (sea) | 1878 | 47 | 118 | 1916 |

a) Calculated in $CO_2$ equivalents. Referring to the fourth IPCC assessment report (IPCC, 2007), 1 g $CH_4$ and 1 g $N_2O$ has the greenhouse effect of 25 and 298 g $CO_2$, respectively.

**Table 2.2**. Emissions 2013 reported to the LRTAP Convention.

| | $SO_2$ (Mg) | $NO_x$ (Mg) | NMVOC (Mg) | CO (Mg) | $NH_3$ (Mg) | TSP (Mg) | $PM_{10}$ (Mg) | $PM_{2.5}$ (Mg) | BC (Mg) |
|---|---|---|---|---|---|---|---|---|---|
| 1. Energy | 11112 | 109302 | 43780 | 330888 | 2583 | 22608 | 20204 | 18628 | 4962 |
| 2. Industrial processes and product use | 1980 | 77 | 32239 | 4004 | 423 | 678 | 450 | 353 | 0 |
| 3. Agriculture | 14 | 14402 | 38250 | 2752 | 70531 | 65717 | 11312 | 2014 | 23 |
| 5. Waste | 537 | 84 | 162 | 1157 | 783 | 243 | 242 | 242 | - |
| Total national | 13643 | 123865 | 114431 | 338801 | 74320 | 89246 | 32208 | 21237 | 4985 |
| International transport (air)[1] | 790 | 12636 | 163 | 1898 | 0 | 40 | 40 | 40 | 19 |
| International transport (sea) | 7140 | 46358 | 1510 | 4982 | 0 | 835 | 827 | 822 | 146 |

**Table 2.3**. Heavy metal emissions 2013 reported to the LRTAP Convention.

| | As (kg) | Cd (kg) | Cr (kg) | Cu (kg) | Hg (kg) | Ni (kg) | Pb (kg) | Se (kg) | Zn (kg) |
|---|---|---|---|---|---|---|---|---|---|
| 1. Energy | 327 | 551 | 1305 | 40720 | 343 | 3936 | 8628 | 1071 | 46052 |
| 2. Industrial processes and product use | 37 | 23 | 161 | 2024 | 10 | 270 | 1083 | 415 | 2533 |
| 3. Agriculture | 3 | 2 | 10 | 0 | 0 | 8 | 40 | 2 | 1 |
| 5. Waste | 2 | 5 | 10 | 64 | 1 | 6 | 1848 | 0 | 7210 |
| Total national | 369 | 581 | 1486 | 42808 | 355 | 4220 | 11599 | 1488 | 55797 |
| International transport (air)[1] | 0 | 0 | 0 | 0 | 0 | 0 | 25 | 0 | 0 |
| International transport (sea) | 178 | 12 | 77 | 178 | 20 | 9948 | 92 | 184 | 428 |

**Table 2.4**. PAH emissions 2013 reported to the LRTAP Convention.

| | HCB (g) | PCDD/ PCDF (dioxins/furans) (g) | benzo(a) pyrene (kg) | benzo(b) fluoranthene (kg) | benzo(k) fluoranthene (kg) | Indeno (1,2,3-cd) pyrene (kg) | PCBs (g) |
|---|---|---|---|---|---|---|---|
| 1. Energy | 2436 | 16 | 2070 | 2252 | 845 | 1346 | 39917 |
| 2. Industrial processes and product use | 142 | 0 | 31 | 30 | 18 | 21 | 80 |
| 3. Agriculture | 133 | 0 | 130 | 128 | 50 | 48 | 0 |
| 5. Waste | 9 | 6 | 45 | 55 | 43 | 65 | 25 |
| Total national | 2720 | 22 | 2276 | 2466 | 956 | 1480 | 40021 |
| International transport (air)[1] | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| International transport (sea) | 0,1 | 0,3 | 3 | 10 | 5 | 16 | 0,3 |

[1] Emissions for international aviation reported to the LRTAP convention comprise the emissions from domestic and international LTO, cf. Chapter 3.

## 2.2 International conventions and reduction targets

Denmark is a party to two international conventions and two EU directives with regard to emissions from road transport and other mobile sources:

The UNECE Convention on Long Range Transboundary Air Pollution (LRTAP Convention or the Geneva Convention)

The National Emission Ceilings Directive (NECD) (Directive 2001/81/EC)

The UN Framework Convention on Climate Change (UNFCCC)

The EU Monitoring Mechanism Regulation (Regulation (EU) No 525/2013)

The LRTAP Convention is a framework convention and has been expanded to cover eight protocols:

EMEP (The European Monitoring and Evaluation Programme) Protocol, 1984 (Geneva)

Protocol on Reduction of Sulphur Emissions, 1985 (Helsinki)

Protocol concerning the Control of Emissions of Nitrogen Oxides, 1988 (Sofia)

Protocol concerning the Control of Emissions of Volatile Organic Compounds, 1991 (Geneva)

Protocol on Further Reduction of Sulphur Emissions, 1994 (Oslo)

Protocol on Heavy Metals, 1988 (Aarhus), as amended in 2012

Protocol on Persistent Organic Pollutants (POPs), 1998 (Aarhus), as amended in 2009

Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, 1999 (Gothenburg), as amended in 2012

The emission ceilings included in the original Gothenburg Protocol (in brackets) are valid for 2010 and the following pollutants: $SO_2$ (55 Gg), $NO_x$ (127 Gg), NMVOC (85 Gg) and $NH_3$ (69 Gg).

Further, in the EU NECD ("The National Emission Ceilings Directive) the national emission ceilings given in the Gothenburg protocol, has been implemented.

The revised version of the Gothenburg Protocol includes reduction commitments relative to the emission level in 2005. The reduction commitments (in brackets) for 2020 are set for the following pollutants: $SO_2$ (35 %), $NO_x$ (56 %), NMVOC (35 %), $NH_3$ (24 %), and $PM_{2.5}$ (33 %).

The UN Framework Convention on Climate Change (UNFCCC) - also called the Climate Convention - is a framework convention from 1992. The Kyoto Protocol is a protocol to the Climate Convention.

The Kyoto Protocol sets legally binding emission targets and time-tables for six greenhouse gases: $CO_2$, $CH_4$, $N_2O$, HFC, PFC and $SF_6$. The greenhouse gas emission of each of the six pollutants is combined to $CO_2$ equivalents, which can be summed up to produce total greenhouse gas (GHG) emissions in $CO_2$ equivalents. Under the EU burden sharing agreement for the first commitment period (2008-2012), Denmark is obligated to reduce the average GHG emissions by 21 % compared to the base year (1995 for f-gases, 1990 for all other gases).

For the second commitment period (2013-2020) under the Kyoto Protocol, the EU has a joint target of 20 % reduction. For the entire EU this means that emissions covered by the European Union Emission Trading Scheme (EU ETS) are to be reduced by 24 %. The reduction commitment for the non-ETS sectors (e.g. transport and agriculture) has been established for each Member State in the Effort Sharing Decision. In this decision, Denmark is obligated to reduce emissions in the non-ETS sectors by 20 % in the period 2013-2020 compared to the level in 2005.

EU is party in the UNFCCC and the Kyoto Protocol and, thereby, EU Member States are obligated to submit emission data to the European Commission. For the first commitment period this was regulated by the Monitoring Mechanism Decision. This was updated for the second commitment period, so that now the EU Monitoring Mechanism Regulation is the legislation in place to ensure that the EU can meet its obligations under the UNFCCC and Kyoto Protocol.

# 3 Inventory structure

In the Danish emission database, all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution), according to the CollectER system. The emission inventories are prepared from a complete emission database based on the SNAP sectors.

For mobile sources, the aggregation of emission results into the formats used by the UNFCCC and UNECE Conventions is made by using the code correspondence information shown in Table 3.1. In the case of mobile sources, the CRF (Common Reporting Format) and NFR (National Format for Reporting) used by the UNFCCC and UNECE Conventions, respectively, are similar.

**Table 3.1**. SNAP – CRF/NFR correspondence table for mobile sources.

| SNAP classification | CRF/NFR classification |
|---|---|
| 0701 Road traffic: Passenger cars | 1A3bi Road transport: Passenger cars |
| 0702 Road traffic: Light duty vehicles | 1A3bii Road transport:Light duty vehicles |
| 0703 Road traffic: Heavy duty vehicles | 1A3biii Road transport:Heavy duty vehicles |
| 0704/0705 Road traffic: Mopeds and motor cycles | 1A3biv Road transport: Mopeds & motorcycles |
| 0706 Road traffic: Evaporation | 1A3bv Road transport: Evaporation |
| 0707 Road traffic: Brake and tire wear | 1A3bvi Road transport: Brake and tire wear |
| 0708 Road traffic: Road abrasion | 1A3bvii Road transport: Road abrasion |
| 0801 Military | 1A5b Other, Mobile |
| 0802 Railways | 1A3c Railways |
| 0803 Inland waterways | 1A5b Other, Mobile |
| 080402 National sea traffic | 1A3dii National navigation (Shipping) |
| 080403 National fishing | 1A4ciii Agriculture/Forestry/Fishing: National fishing |
| 080404 International sea traffic | 1A3di (i) International navigation (Shipping) |
| 080501 Dom. airport traffic (LTO < 1000 m) | 1A3aii (i) Civil aviation (Domestic,LTO |
| 080502 Int. airport traffic (LTO < 1000 m) | 1A3ai (i) Civil aviation (International, LTO) |
| 080503 Dom. cruise traffic (> 1000 m) | 1A3aii (ii) Civil aviation (Domestic,Cruise) |
| 080504 Int. cruise traffic (> 1000 m) | 1A3ai (ii) Civil aviation (International, Cruise) |
| 0806 Agriculture | 1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry |
| 0807 Forestry | 1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry |
| 0808 Industry | 1A2gvii Manufacturing industries/Construction (mobile) |
| 0809 Household and gardening | 1A4bii Residential: Household and gardening (mobile) |
| 0811 Commercial and institutional | 1A4aii Commercial/Institutional: Mobile |

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

Road traffic evaporation, brake and tire wear, and road abrasion (SNAP codes 0706-0708) is not a part of the CRF list since no greenhouse gases are emitted from these sources.

For aviation, LTO (Landing and Take Off)[2] refers to the part of flying which is below 1000 m. This part of the aviation emissions (SNAP codes 080501 and 080502) are included in the national emissions total as prescribed by the UNECE reporting guidelines. According to UNFCCC the national emissions for aviation comprise the emissions from domestic LTO (0805010) and domestic cruise (080503). The fuel consumption and emission development explained in Chapter 6 are based on these latter results.

Agricultural and forestry non-road machinery (SNAP codes 0806 and 0807) is accounted for in the Agriculture/forestry/fisheries (1A4c) sector together with fishing activities (SNAP code 080403).

For mobile sources, internal database models for road transport, air traffic, sea transport and non-road machinery have been set up at Department of Environmental Science (ENVS)/Danish Centre for Environment and Energy (DCE), Aarhus University (former NERI), in order to produce the emission inventories. The output results from the DCE models are calculated in a SNAP format, as activity rates (fuel consumption) and emission factors, which are then exported directly to the central Danish CollectER database.

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

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

# 4 Input data and calculation methods for road transport

For road transport, the detailed methodology is used to make annual estimates of the Danish emissions, as described in the EMEP/EEA Air Pollutant Emission Inventory Guidebook (EMEP/EEA, 2013). The actual calculations are made with a model developed by DCE, using the European COPERT IV model methodology explained by EMEP/EEA (2013). In COPERT, fuel consumption and emission simulations can be made for operationally hot engines, taking into account gradually stricter emission standards and emission degradation due to catalyst wear. Furthermore, the emission effects of cold-start and evaporation are simulated.

## 4.1 Vehicle fleet and mileage data

Corresponding to the COPERT IV 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 consumption and emission behaviour, according to EU emission legislation levels. Table 4.1 gives an overview of the different model classes and sub-classes, and the layer level with implementation years are shown in Annex 1.

**Table 4.1**. Model vehicle classes and sub-classes and trip speeds.

| | | | Trip speed [km per h] | | |
|---|---|---|---|---|---|
| Vehicle classes | Fuel type | Engine | Urban | Rural | Highway |
| PC | Gasoline | < 0.8 l. | 40 | 70 | 100 |
| PC | Gasoline | 0.8 - 1.4 l. | 40 | 70 | 100 |
| PC | Gasoline | 1.4 – 2 l. | 40 | 70 | 100 |
| PC | Gasoline | > 2 l. | 40 | 70 | 100 |
| PC | Diesel | < 1.4 l. | | | |
| PC | Diesel | 1.4 2 l. | 40 | 70 | 100 |
| PC | Diesel | > 2 l. | 40 | 70 | 100 |
| PC | LPG | | 40 | 70 | 100 |
| PC | 2-stroke | | 40 | 70 | 100 |
| LDV | Gasoline | | 40 | 65 | 80 |
| LDV | Diesel | | 40 | 65 | 80 |
| LDV | LPG | | 40 | 65 | 80 |
| Trucks | Gasoline | | 35 | 60 | 80 |
| Trucks | Diesel | Rigid 3,5 - 7,5t | 35 | 60 | 80 |
| Trucks | Diesel | Rigid 7,5 - 12t | 35 | 60 | 80 |
| Trucks | Diesel | Rigid 12 - 14 t | 35 | 60 | 80 |
| Trucks | Diesel | Rigid 14 - 20t | 35 | 60 | 80 |
| Trucks | Diesel | Rigid 20 - 26t | 35 | 60 | 80 |
| Trucks | Diesel | Rigid 26 - 28t | 35 | 60 | 80 |
| Trucks | Diesel | Rigid 28 - 32t | 35 | 60 | 80 |
| Trucks | Diesel | Rigid >32t | 35 | 60 | 80 |
| Trucks | Diesel | TT/AT 14 - 20t | 35 | 60 | 80 |
| Trucks | Diesel | TT/AT 20 - 28t | 35 | 60 | 80 |
| Trucks | Diesel | TT/AT 28 - 34t | 35 | 60 | 80 |
| Trucks | Diesel | TT/AT 34 - 40t | 35 | 60 | 80 |
| Trucks | Diesel | TT/AT 40 - 50t | 35 | 60 | 80 |
| Trucks | Diesel | TT/AT 50 - 60t | 35 | 60 | 80 |
| Trucks | Diesel | TT/AT >60t | 35 | 60 | 80 |
| Urban buses | Gasoline | | 30 | 50 | 70 |
| Urban buses | Diesel | < 15 tonnes | 30 | 50 | 70 |
| Urban buses | Diesel | 15-18 tonnes | 30 | 50 | 70 |
| Urban buses | Diesel | > 18 tonnes | 30 | 50 | 70 |

**Table 4.1**. *Continued*.

| | | | Trip speed [km per h] | | |
|---|---|---|---|---|---|
| Vehicle classes | Fuel type | Engine | Urban | Rural | Highway |
| Coaches | Gasoline | | 35 | 60 | 80 |
| Coaches | Diesel | < 15 tonnes | 35 | 60 | 80 |
| Coaches | Diesel | 15-18 tonnes | 35 | 60 | 80 |
| Coaches | Diesel | > 18 tonnes | 35 | 60 | 80 |
| Mopeds | Gasoline | | 30 | 30 | - |
| Motorcycles | Gasoline | 2 stroke | 40 | 70 | 100 |
| Motorcycles | Gasoline | < 250 cc. | 40 | 70 | 100 |
| Motorcycles | Gasoline | 250 – 750 cc. | 40 | 70 | 100 |
| Motorcycles | Gasoline | > 750 cc. | 40 | 70 | 100 |

Fleet and annual mileage data are provided by DTU Transport for the vehicle categories present in COPERT IV (Jensen, 2014). DTU Transport use data from the Danish vehicle register kept by Statistics Denmark. The vehicle register data consist of vehicle type (passenger cars, vans, trucks, buses, mopeds, motorcycles), fuel type, vehicle weight, gross vehicle weight, engine size (passenger cars registered from 2005 onwards, Euro class (trucks and buses registered from 1997 onwards), NEDC type approval fuel efficiency value (passenger cars registered from 1997+) and vehicle first registration year.

In order to establish engine size data for passenger cars registered before 2005, a weight class-engine size transformation key is examined by Cowi (2008) for new Danish cars from 1998. For the years before 1998, data for 1998 is used, and for the years 1999-2004 a linear interpolation between 1998 and 2005 weight class-engine size relations is used. For trucks, truck driver registration notes gathered by Statistics Denmark are used to split the fleet figures of ordinary trucks into number of solo trucks and truck-trailer combinations. Further the registration notes make it possible to assume the average total vehicle weight of the truck trailer combination. For articulated trucks also, the registration notes make it possible to assume the average total vehicle weight of the full articulated truck.

Danish mileage data comes from the Danish Road Directorate based on the Danish vehicle inspection program. Total mileage per year and vehicle category are derived for the years 1985-2013, together with a more detailed mileage matrix examined for the year 2008 (based on detailed vehicle inspection data analysis). The detailed mileage matrix contains annual mileage per vehicle subcategory for new vehicles and for every vintage back in time, which detemines the yearly mileage reduction percentages as a function of vehicle age. In a first step, the detailed mileage matrix is combined with corresponding fleet numbers in order to estimate intermediate total mileages for each year on a detailed fleet level. Next, each year’s detailed (intermediate) mileage figures are scaled according to the difference between true and intermediate total mileage per vehicle subcategory.

DTU Transport (Jensen, 2014) also provides information of the mileage split between urban, rural and highway driving based on traffic monitoring data. The respective average speeds come from The Danish Road Directorate (e.g. Winther & Ekman, 1998). Additional data for the moped fleet and motorcycle fleet disaggregation is given by The National Motorcycle Association (Markamp, 2013).

In addition data from a survey made by the Danish Road Directorate (Hansen, 2010) has given information of the total mileage driven by foreign trucks on Danish roads in 2009. This mileage contribution has been added to the total mileage for Danish trucks on Danish roads, for trucks > 16 tonnes of gross vehicle weight. The data has been further processed by DTU Transport; by using appropriate assumptions the mileage have been backcasted to 1985 and forecasted to 2013.

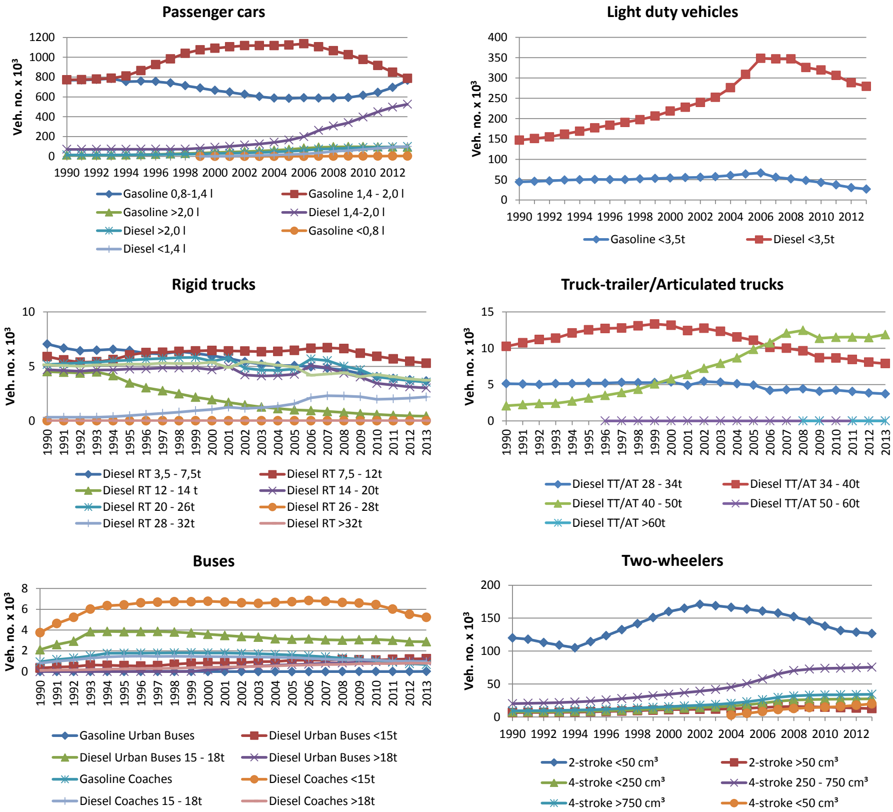



**Figure 4.1**. Number of vehicles in sub-classes in 1990-2013.

For passenger cars, the engine size differentiation is less certain for the years before 2005. The increase in the total number of passenger cars is mostly due to a growth in the number of diesel cars between 1.4 and 2 litres (from the 2000's up to now). Until 2005, there has been a decrease in the number of gasoline cars with an engine size between 0.8 and 1.4 litres. These cars, however, have also increased in numbers during the later years, while the number of 1.4-2 litres gasoline cars has decreased. Since the late 1990's small cars (< 0.8 l gasoline and <1.4 l. diesel) has slowly begun to penetrate the fleet.

There has been a considerable growth in the number of diesel light duty vehicles from 1985 to 2006; the number of vehicles has, however, decreased somewhat after 2006.

For the truck-trailer and articulated truck combinations there is a tendency towards the use of increasingly larger trucks throughout the time period. The decline in fleet numbers for many of the truck categories in 2007/2008 and until 2009 is caused by the impact of the global financial crisis and the reflagging of Danish commercial trucks to companies based in the neighbouring countries.

The number of urban buses has been almost constant between 1985 and 2011. 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. From 2004 onwards there is a gradual switch from 2-stroke to 4-stroke in new sales for this vehicle category. For motorcycles, the number of vehicles has grown in general throughout the entire 1985-2013 period. The increase is, however, most visible from the mid-1990s and onwards.

The vehicle numbers are summed up in EU emission layers for each year by using the correspondence between layers and first year of registration:

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

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

Weighted annual mileages 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.

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

Since 2006 economical incitements have been given to private vehicle owners to buy Euro 5 diesel passenger cars and vans in order to bring down the particulate emissions from diesel vehicles. The estimated sales between 2006 and 2010 have been examined by the Danish EPA and are included in the fleet data behind the Danish inventory (Winther, 2011).

For heavy duty trucks, there is a slight deviation from the strict correspondence between EU emission layers and first registration year.

In this case, specific Euro class information for most of the vehicles from 2001 onwards is incorporated into the fleet and mileage data model developed by Jensen (2014). For inventory years before 2001, and for vehicles with no Euro information the normal correspondence between layers and first year of registration is used.

Vehicle numbers and weighted annual mileages per layer are shown in Annex 1 and 2 for 1990-2013. The trends in vehicle numbers per layer are also shown in Figure 4.2. The latter figure shows how vehicles complying with the gradually stricter EU emission levels (EURO I-VI) have been introduced into the Danish motor fleet.

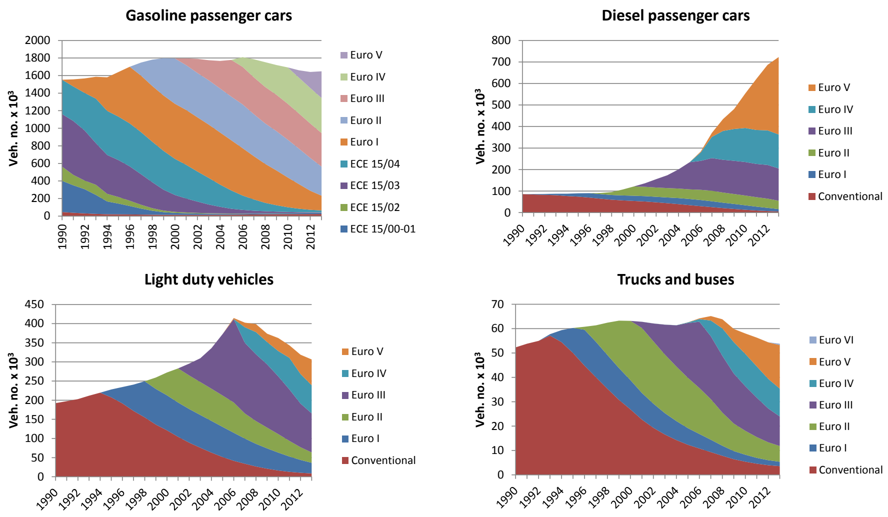



**Figure 4.2**. Layer distribution of vehicle numbers per vehicle type in 1990-2013.

## 4.2 Emission legislation

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

Limit value curve: the fleet average to be achieved by all cars registered in the EU is 130 gram $CO_2$ per kilometre (g per km). A so-called limit value curve implies that heavier cars are allowed higher emissions than lighter cars while preserving the overall fleet average.

Further reduction: a further reduction of 10 g $CO_2$ per km, or equivalent if technically necessary, will be delivered by other technological improvements and by an increased use of sustainable biofuels.

Phasing-in of requirements: in 2012, 65 % of each manufacturer's newly registered cars must comply on average with the limit value curve set by the legislation. This will rise to 75 % in 2013, 80 % in 2014, and 100 % from 2015 onwards.

Lower penalty payments for small excess emissions until 2018: if the average $CO_2$ emissions of a manufacturer's fleet exceed its limit value in any year from 2012, the manufacturer has to pay an excess emissions premium for each car registered. This premium amounts to €5 for the first g per km of exceedance, €15 for the second g per km, €25 for the third g per km, and €95 for each subsequent g per km. From 2019, already the first g per km of exceedance will cost €95.

Long-term target: a target of 95 g $CO_2$ per km is specified for the year 2020.

Eco-innovations: because the test procedure used for vehicle type approval is outdated, certain innovative technologies cannot demonstrate their $CO_2$ reducing effects under the type approval test. As an interim procedure until the test procedure is reviewed by 2014, manufacturers can be granted a maximum of 7 g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.

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

Target dates: the EU fleet average of 175 g $CO_2$ per km will be phased in between 2014 and 2017. In 2014 an average of 70 %of each manufacturer's newly registered vans must comply with the limit value curve set by the legislation. This proportion will rise to 75 % in 2015, 80 % in 2016, and 100% from 2017 onwards.

Limit value curve: emissions limits are set according to the mass of vehicle, using a limit value curve. The curve is set in such a way that a fleet average of 175 grams of $CO_2$ per kilometre is achieved. A so-called limit value curve of 100 % implies that heavier vans are allowed higher emissions than lighter vans while preserving the overall fleet average. Only the fleet average is regulated, so manufacturers will still be able to make vehicles with emissions above the limit value curve provided these are balanced by other vehicles which are below the curve.

Vehicles affected: the vehicles affected by the legislation are vans, which account for around 12 % of the market for light duty vehicles. This includes vehicles used to carry goods weighing up to 3.5 t (vans and car-derived vans, known as N1) and which weigh less than 2610 kg when empty.

Long-term target: a target of 147 g $CO_2$ per km is specified for the year 2020.

Excess emissions premium for small excess emissions until 2018: if the average $CO_2$ emissions of a manufacturer's fleet exceed its limit value in any year from 2014, the manufacturer has to pay an excess emissions premium for each van registered. This premium amounts to €5 for the first g per km of exceedance, €15 for the second g per km, €25 for the third g per km, and €95 for each subsequent g per km. From 2019, the first g per km of exceedance will cost €95. This value is equivalent to the premium for passenger cars.

Super-credits: vehicles with extremely low emissions (below 50 g per km) will be given additional incentives whereby each low-emitting van will be counted as 3.5 vehicles in 2014 and 2015, 2.5 in 2016 and 1.5 vehicles in 2017.

Eco-innovations: because the test procedure used for vehicle type approval is outdated, certain innovative technologies cannot demonstrate their $CO_2$ reducing effects under the type approval test. As an interim procedure until the test procedure is reviewed by 2014, manufacturers can be granted a maximum of 7 g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.

Other flexibilities: manufacturers may group together to form a pool and act jointly in meeting the specific emissions targets. Independent manufacturers who sell fewer than 22,000 vehicles per year can also apply to the Commission for an individual target instead.

For Euro 1-6 passenger cars and light duty trucks, the chassis dynamometer test cycle used in the EU for measuring fuel is the NEDC (New European Driving Cycle), see Nørgaard and Hansen (2004). The test cycle is also used for emissions testing. 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 cycle3 (average speed: 19 km per h). The second part of the test is the run-through of the EUDC (Extra Urban Driving Cycle) test driving segment, simulating the fuel consumption under rural and highway driving conditions. The driving length of EUDC is seven km at an average speed of 63 km per h. More information regarding the fuel measurement procedure can be found in the EU-directive 80/1268/-EØF.

The NEDC test cycle is not adequately describing real world driving behavior, and as an effect, for diesel cars and vans, there is an increasing mismatch between the step wise lowered EU emission limits the vehicles comply with during the NEDC test cycle, and the more or less constant emissions from the same vehicles experienced during real world driving. In order to bridge this emission inconsistency gap work have been made towards developing a new test procedure for Euro 6 vehicles, the "World-Harmonized Light-Duty Vehicles Test Procedure" (WLTP), which simulates much more closely real world driving behavior. In correspondence, the next generation of "WLTP certified" Euro 6 vehicles, the so-called "Euro 6c" vehicles, must still be able to comply with the Euro 6 emission limits as they are today. Due to political negotiations, changes in the EU emission legislation based on the new WLTP test procedure is still not finally agreed.

For $NO_x$, VOC (NMVOC + $CH_4$), CO and PM, the emissions from road transport vehicles have to comply with the different EU directives listed in Table 4.2. The emission directives distinguish between three vehicle classes according to vehicle reference mass[4]: 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 3.

**Table 4.2** Overview of the existing EU emission directives for road transport vehicles.

| Vehicle category | Emission layer | EU directive | First reg. date |
|---|---|---|---|
| Passenger cars (gasoline) | PRE ECE | - | - |
| | 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 | 1.10.1990[e] |
| | Euro II | 94/12 | 1.1.1997 |
| | Euro III | 98/69 | 1.1.2001 |
| | Euro IV | 98/69 | 1.1.2006 |
| | Euro V | 715/2007(692/2008) | 1.1.2011 |
| | Euro VI | 715/2007(692/2008) | 1.9.2015 |
| | Euro VIc | 459/2012 | 1.9.2018 |
| Passenger cars (diesel and LPG) | Conventional | - | - |
| | ECE 15/04 | 83/351 | 1987[d] |
| | Euro I | 91/441 | 1.10.1990[e] |
| | Euro II | 94/12 | 1.1.1997 |
| | Euro III | 98/69 | 1.1.2001 |
| | Euro IV | 98/69 | 1.1.2006 |
| | Euro V | 715/2007(692/2008) | 1.1.2011 |
| | Euro VI | 715/2007(692/2008) | 1.9.2015 |
| | Euro VIc | 459/2012 | 1.9.2018 |

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

**Table 4.2** Continued

| Vehicle category | Emission layer | EU directive | First reg. date |
|---|---|---|---|
| Heavy duty vehicles | Euro 0 | 88/77 | 1.10.1990 |
| | Euro I | 91/542 | 1.10.1993 |
| | Euro II | 91/542 | 1.10.1996 |
| | Euro III | 1999/96 | 1.10.2001 |
| | Euro IV | 1999/96 | 1.10.2006 |
| | Euro V | 1999/96 | 1.10.2009 |
| | Euro VI | 595/2009 | 1.10.2013 |
| Mopeds | Conventional | - | - |
| | Euro I | 97/24 | 2000 |
| | Euro II | 2002/51 | 2004 |
| | Euro III | 2002/51 | 2014[f] |
| | Euro IV | 168/2013 | 2017 |
| | Euro V | 168/2013 | 2021 |
| Motor cycles | Conventional | Conventional | 0 |
| | Euro I | 97/24 | 2000 |
| | Euro II | 2002/51 | 2004 |
| | Euro III | 2002/51 | 2007 |
| | Euro IV | 168/2013 | 2017 |
| | Euro V | 168/2013 | 2021 |
| Light duty trucks (gasoline and | Conventional | - | - |
| | 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 | 1.10.1994 |
| | Euro II | 96/69 | 1.10.1998 |
| | Euro III | 98/69 | 1.1.2002 |
| | Euro IV | 98/69 | 1.1.2007 |
| | Euro V | 715/2007 | 1.1.2012 |
| | Euro VI | 715/2007 | 1.9.2016 |
| | Euro VIc | 459/2012 | 1.9.2019 |

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 consumption 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 pr kWh and the measurements are carried out for engines in a test bench, using the ECE R-49, EU ESC (European Stationary Cycle) and ETC (European Transient Cycle) test cycles, depending on the Euro norm and exhaust gas after-treatment system installed. For Euro VI engines the WHSC (World Harmonized Stationary Cycle) and WHTC (World Harmonized Transient Cycle) test cycles are used. For a description of the test cycles see e.g. www.dieselnet.com. Measurement results in g per kWh from emission approval tests cannot be directly used for inventory work. Instead, emission factors used for national estimates must be transformed into g per km, and derived from a sufficient number of measurements that represent the different vehicle size classes, Euro engine levels and real world variations in driving behaviour.

## 4.3 Fuel consumption and emission factors

The fuel consumption and emission factors used in the Danish inventory come from the COPERT IV (version 11) model. The source for these data is various European measurement programmes. In general the COPERT data are transformed into trip-speed dependent fuel consumption and emission factors for all vehicle categories and layers by using trip speeds as shown in Table 4.1. The factors are listed in Annex 4.

### 4.3.1 Adjustment for fuel efficient vehicles

In the Danish fleet and mileage database, the type approval fuel efficiency value based on the NEDC driving cycle ($TA_{NEDC}$) is registered for each single car. Further, a modified fuel efficiency value ($TA_{inuse}$) is calculated using $TA_{NEDC}$, vehicle weight and engine size as input parameters. The $TA_{inuse}$ value better reflects the fuel consumption associated with the NEDC driving cycle under real ("in use") traffic conditions (Emisia, 2012).

From 2006 up to last historical year represented by fleet data, the average $CO_2$ emission factor (by fleet number) is calculated for each year's new sold cars, based on the registered $TA_{NEDC}$ values. Using the average $CO_2$ emission factor for the last historical year as starting point, the average emission factor for each year's new sold cars are linearly reduced, until the emission factor reaches 95 g $CO_2$ per km in 2020.

From 2006 up to last historical year, the average $CO_2$ emission factor (by fleet number) is also calculated for each year's new sold cars, and for each fuel type/engine size combination, based on $TA_{NEDC}$ and $TA_{inuse}$.

The linear reduction of the average emission factor for each year's new sold cars is then used to reduce the $CO_2$ emission factors for new sold cars based on $TA_{inuse}$, between last historical year and 2020, for each of the fuel type/engine size fleet segments.

Subsequently for each layer and inventory year, $CO_2$ emission factors are calculated based on $TA_{inuse}$ and weighted by total mileage. On the same time corresponding layer specific $CO_2$ factors from COPERT IV are set up valid for Euro 4+ vehicles in the COPERT model. The COPERT IV $CO_2$ factors are derived from fuel consumption factors assessed by the developers of COPERT IV (Emisia, 2012) to represent the COPERT test vehicles under the NEDC driving cycle in real world traffic ($TA_{COPERT\ IV,inuse}$).

In a final step the ratio between the layer specific $CO_2$ emission factors for the Danish fleet and the COPERT Euro IV vehicles under $TA_{inuse}$ are used to scale the trip speed dependent fuel consumption factors provided by COPERT IV for Euro 4 layers onwards.

### 4.3.2 Adjustment for EGR, SCR and filter retrofits

In COPERT IV updated emission factors have recently been made available for Euro V heavy duty vehicles using EGR (Exhaust Gas Recirculation) and SCR (Selective Catalyst Reaction) exhaust emission aftertreatment systems, respectively. The estimated new sales of Euro V diesel trucks equipped with EGR and SCR during the 2006-2010 time periods has been examined by Hjelgaard and Winther (2011). These inventory fleet data are used in the Danish inventory to calculate weighted emission factors for Euro V trucks in different size categories.

During the 2000's urban environmental zones have been established in Danish cities in order to bring down the particulate emissions from diesel fuelled heavy duty vehicles. Driving in these environmental zones prescribe the use of diesel particulate filters. The Danish EPA has provided the estimated number of Euro I-III urban buses and Euro II-III trucks and tourist buses which have been retrofitted with filters during the 2000's. These retrofit data are included in the Danish inventory by assuming that particulate emissions are lowered by 80 % compared with the emissions from the same Euro technology with no filter installed (Winther, 2011).

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.

## 4.4 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 year, the deterioration factors are calculated per first registration year by using deterioration coefficients and cut-off mileages, as given in EMEP/EEA (2013), for the corresponding layer. The deterioration coefficients are given for the two driving cycles: "Urban Driving Cycle" (UDF) and "Extra Urban Driving Cycle" (EUDF: urban and rural), with trip speeds of 19 and 63 km per hour, respectively.

Firstly, the deterioration factors are calculated for the corresponding trip speeds of 19 and 63 km per hour 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":

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

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

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 per hour the deterioration factor, DF, equals UDF, whereas for trip speeds exceeding 63 km per hour, DF=EUDF. For trip speeds between 19 and 63 km per hour 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:

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

where DF is the deterioration factor.

For $N_2O$ and $NH_3$, COPERT IV takes into account deterioration as a linear function of mileage for gasoline fuelled EURO 1-4 passenger cars and light duty vehicles. The level of emission deterioration also relies on the content of sulphur in the fuel. The deterioration coefficients are given in EMEP/EEA (2013), for the corresponding layer. A cut-off mileage of 250 000 km is behind the calculation of the modified emission factors, and for the Danish situation the low sulphur level interval is assumed to be most representative.

## 4.5 Calculation method

### 4.5.1 Emissions and fuel consumption for hot engines

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

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

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

For catalyst vehicles the calculation becomes:

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

### 4.5.2 Extra emissions and fuel consumption for cold engines

Extra emissions of $NO_x$, VOC, $CH_4$, CO, PM, $N_2O$, $NH_3$ and fuel consumption from cold start are simulated separately. For $SO_2$ and $CO_2$, the extra emissions are derived from the cold start fuel consumption results.

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 2013 are given in Cappelen et al. (2012). For previous years, temperature data are taken from similar reports available from The Danish Meteorological Institute (www.dmi.dk). The cold:hot ratios are equivalent for gasoline fuelled conventional passenger cars and vans and for diesel passenger cars and vans, respectively, see EMEP/EEA (2013). For conventional gasoline and all diesel vehicles the extra emissions become:

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

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:

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

where $\beta_{red}$ = the β reduction factor.

For $CH_4$, specific emission factors for cold driven vehicles are included in COPERT IV. The β and $\beta_{red}$ factors for VOC are used to calculate the cold driven fraction for each relevant vehicle layer. The NMVOC emissions during cold start are found as the difference between the calculated results for VOC and $CH_4$.

For $N_2O$ and $NH_3$, specific cold start emission factors are also proposed by COPERT IV. For catalyst vehicles, however, just like in the case of hot emission factors, the emission factors for cold start are functions of cumulated mileage (emission deterioration). The level of emission deterioration also relies on the content of sulphur in the fuel. The deterioration coefficients are given in EMEP/EEA (2013), for the corresponding layer. For cold start, the cut-off mileage and sulphur level interval for hot engines are used, as described in the deterioration factors paragraph.

### 4.5.3 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. 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 EMEP/EEA (2013).

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.

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

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:

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

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 $E^d(U)$:

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

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

### 4.5.4 Fuel consumption balance

The calculated fuel consumption in COPERT IV must equal the statistical fuel sale totals according to the UNFCCC and UNECE emissions reporting format. The statistical fuel sales for road transport are derived from the Danish Energy Agency data (see DEA, 2014). The DEA data are further processed for gasoline in order to account for e.g. non-road and recreational craft fuel consumption, which are not directly stated in the statistics, please refer to paragraph 5.5 for further information regarding the transformation of DEA fuel data.

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.

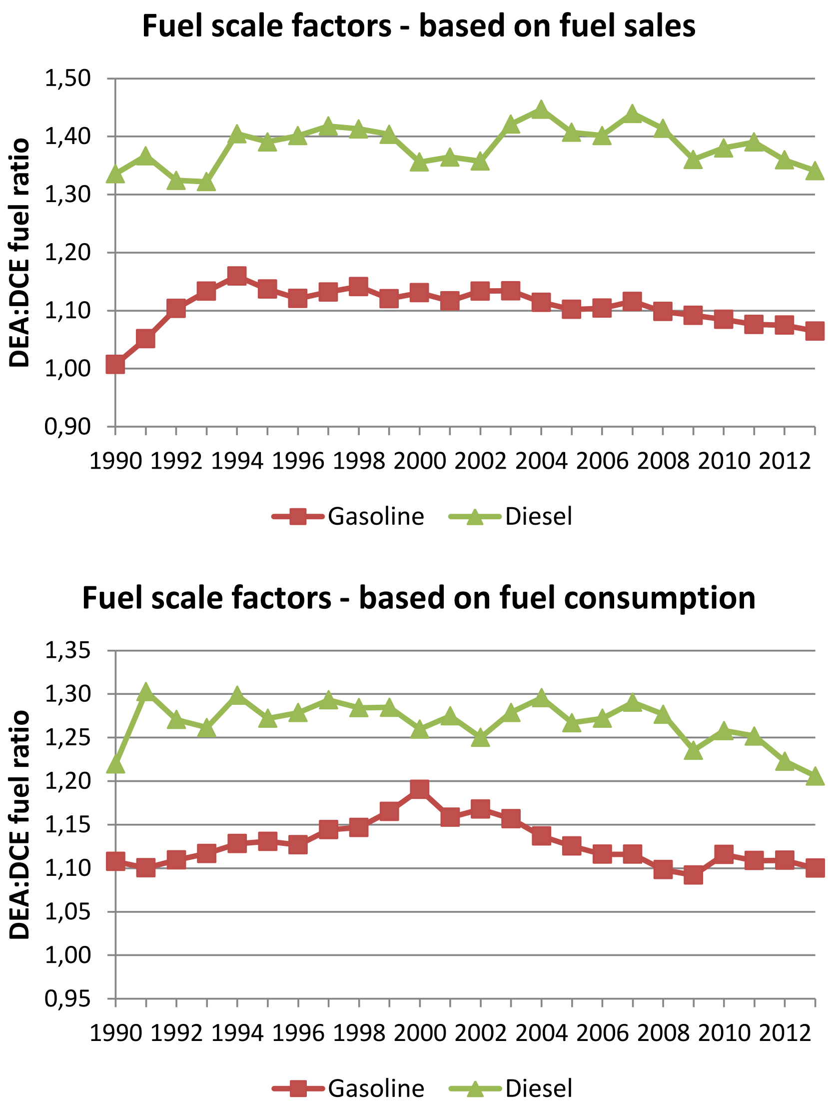



**Figure 4.3**. DEA:DCE Fuel ratios (mileage adjustment factors) based on DEA fuel sales and fuel consumption data and DCE fuel consumption estimates.

In Figure 4.3 the COPERT IV:DEA gasoline and diesel fuel consumption ratios are shown for fuel sales and fuel consumption from 1990-2013. The data behind the figures are also listed in Annex 8. The fuel consumption figures are related to the traffic on Danish roads.

Per fuel type, all mileage numbers are equally scaled in order to obtain fuel equilibrium, and hence the mileage factors used are the reciprocal values of the COPERT IV:DEA fuel consumption: fuel sales ratio.

The reasons for the differences between DEA sales figures and bottom-up fuel estimates are mostly due to a combination of the uncertainties related to COPERT IV fuel consumption factors, allocation of vehicle numbers in subcategories, annual mileage, trip speeds and mileage splits for urban, rural and highway driving conditions.

The final fuel consumption and emission factors per vehicle layer are shown in Annex 7 for 2013, split into urban, rural and highway driving conditions. The total fuel consumption and emissions for 1985-2013 are shown in Annex 8 (per vehicle category and as grand totals), and in Annex 16 (NFR format). Annex 15 shows fuel consumption and emission factors as well as total emissions in CollectER format for 1990 and 2013.

In the following Figures 4.4 - 4.12, km related fuel consumption factors, and the fuel and km related emission factors for $CO_2$ (km related only), $NO_x$, NMVOC, CO, TSP, BC, $CH_4$ and $N_2O$ are shown per vehicle type for the Danish road transport (from 1990-2013).

For $CO_2$ the neat gasoline/diesel emission factors shown in Table 4.3 are country specific values, and come from the DEA. In 2006 and 2008, respectively, bioethanol and biodiesel became available from a limited number of gas filling stations in Denmark, and today bioethanol and biodiesel is added to all fuel commercially available. Following the IPCC guideline definitions, bioethanol is regarded as $CO_2$ neutral for the transport sector as such. The sulphur content for bio ethanol/biodiesel is assumed to be zero, and hence, the aggregated $CO_2$ (and $SO_2$) factors for gasoline/diesel have been adjusted, on the basis of the energy content of neat gasoline/diesel and bio ethanol/biodiesel, respectively, in the available fuels.

At present, the Danish road transport fuels only have low biofuel (BF) shares (Table 4.3), and hence, no thermal efficiency changes are expected for the fuels. Consequently, the energy based fuel consumption factors (MJ/km) derived from COPERT IV are used also in this case.

As a function of the current ethanol/biodiesel energy percentage, $BF\%_E$, (Table 4.3) the average fuel related $CO_2$ emission factors, $emf_{CO2,E}(BF\%)$ become:

$$EF_{CO_2,E}(BF\%) = EF_{CO_2,E}(BF0) \cdot (100 - BF\%_E) \quad (13)$$

Where:

$EF_{CO2,E}(BF\%)$ = average fuel related $CO_2$ emission factor (g $MJ^{-1}$) for current BF%

$EF_{CO2,E}(BF0)$ = fuel related $CO_2$ emission factor (g $MJ^{-1}$) for fossil fuels

The kilometre based average $CO_2$ emission factor is subsequently calculated as the product of the fuel related $CO_2$ emission factor from equation 3 and the energy based fuel consumption factor, $FC_{CO2,E}(BF0)$, derived from COPERT IV:

$$EF_{CO_2,km}(BF\%) = EF_{CO_2,E}(BF\%) \cdot FC_E(BF0) \quad (14)$$

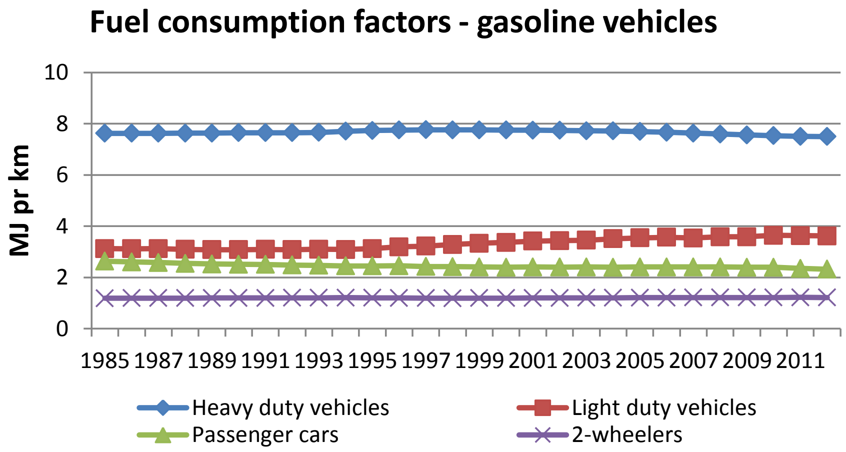
A literature review carried out in the Danish research project REBECa revealed no significant changes in emission factors between neat gasoline and E5 gasoline-ethanol blends for the combustion related emission components; $NO_x$, CO and VOC (Winther et al., 2012). Hence, due to the current low ethanol content in today's road transport gasoline, no modifications of the neat gasoline based COPERT emission factors are made in the inventories in order to account for ethanol usage.

REBECa results published by Winther (2009) have shown that the emission impact of using diesel-biodiesel blends is very small at low biodiesel blend ratios. Consequently no bio fuel emission factor adjustments are needed for diesel vehicles as well. However, adjustment of the emission factors for diesel vehicles will be made if the biodiesel content of road transport diesel fuel increases to a more significant level in the future.

The fuel related $CO_2$ emission factors for neat gasoline/diesel, bio ethanol/biodiesel, and aggregated $CO_2$ factors are shown in Table 4.3.

**Table 4.3**. Fuel-specific $CO_2$ emission factors and biofuel shares for road transport in Denmark.

| | Emission factors (g/MJ) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fuel type | 1990-2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
| Neat gasoline | 73 | 73 | 73 | 73 | 73 | 73 | 73 | 73 | 73 |
| Neat diesel | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 |
| LPG | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 | 63.1 |
| Bio ethanol | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Biodiesel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gasoline, average | 73 | 72.9 | 72.8 | 72.8 | 72.8 | 71.7 | 70.7 | 70.6 | 70.4 |
| Diesel, average | 74 | 74 | 74 | 74 | 73.9 | 74 | 71.5 | 69.4 | 69.2 |
| | Biofuel share (BF%) of Danish road transport fuels | | | | | | | | |
| | 1990-2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
| | 0 | 0.09 | 0.14 | 0.13 | 0.21 | 0.69 | 3.40 | 5.30 | 5.50 |



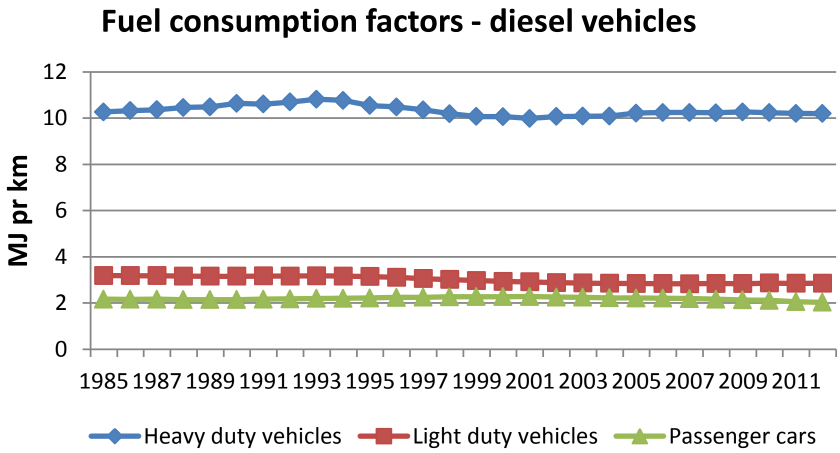
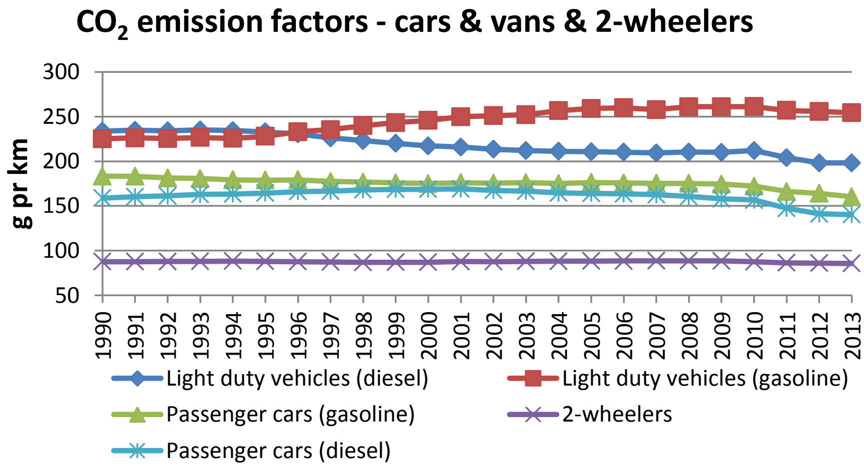




**Figure 4.4**. Km related fuel consumption factors per vehicle type for Danish road transport (1990-2013).



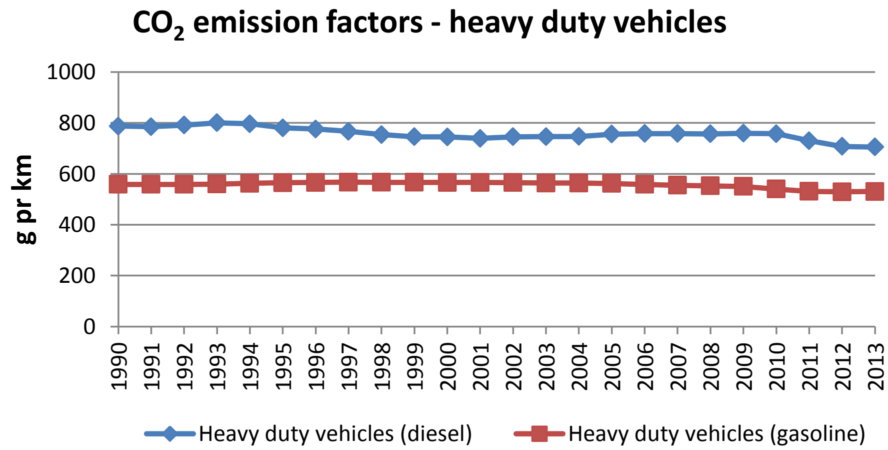




**Figure 4.5**. Km related $CO_2$ emission factors per vehicle type for Danish road transport (1990-2013).

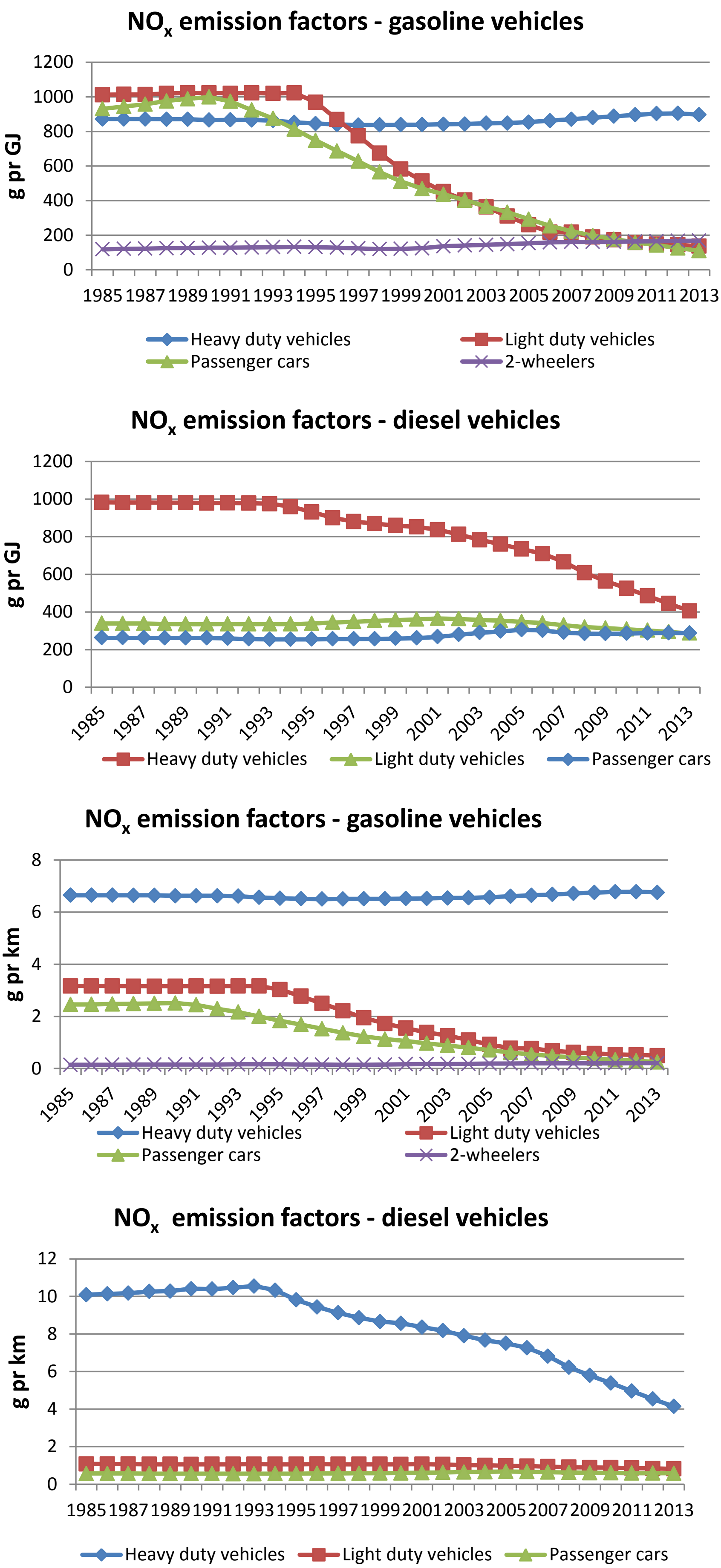



**Figure 4.6**. Fuel and km related $NO_x$ emission factors per vehicle type for Danish road transport (1990-2013).

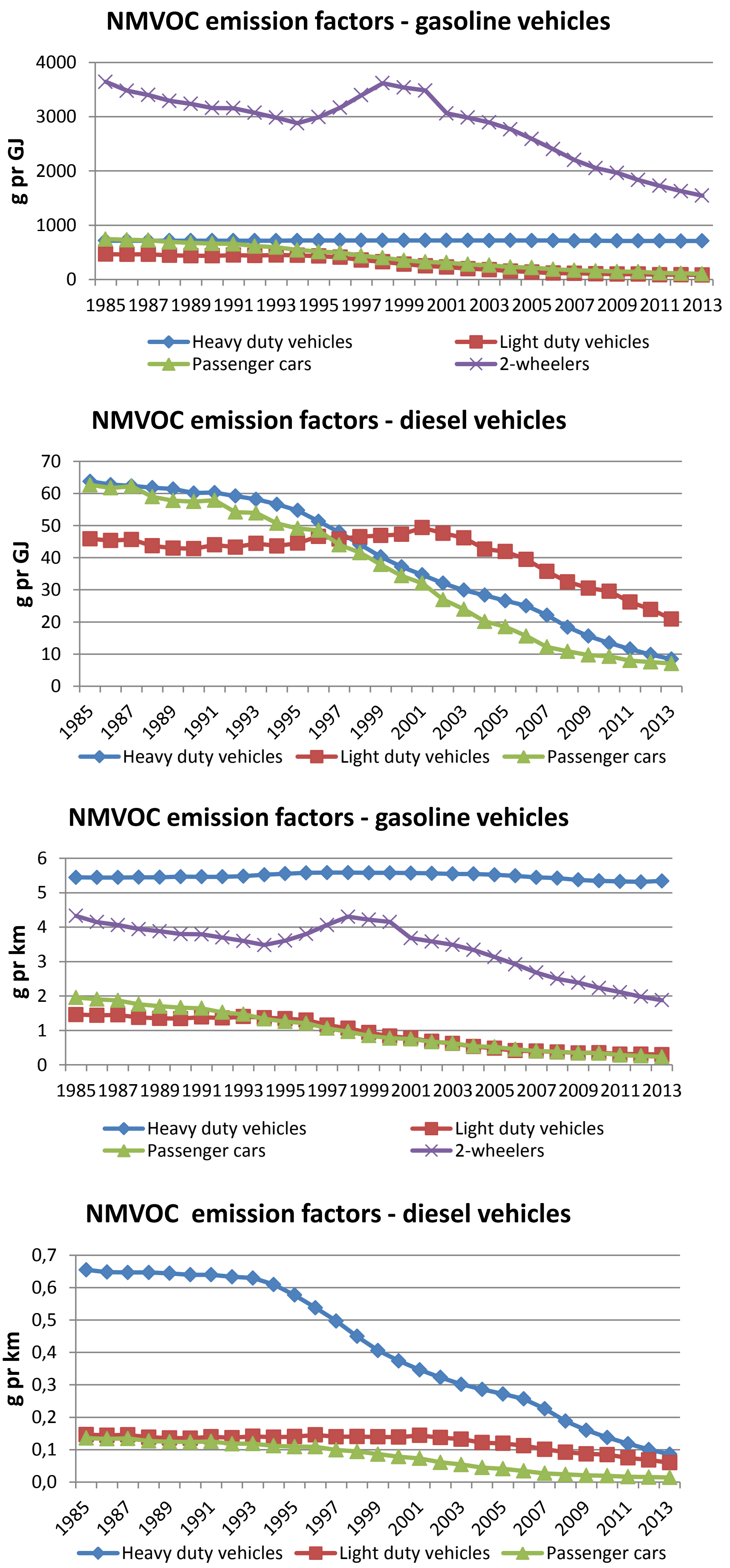



**Figure 4.7**. Fuel and km related NMVOC emission factors per vehicle type for Danish road transport (1990-2013).

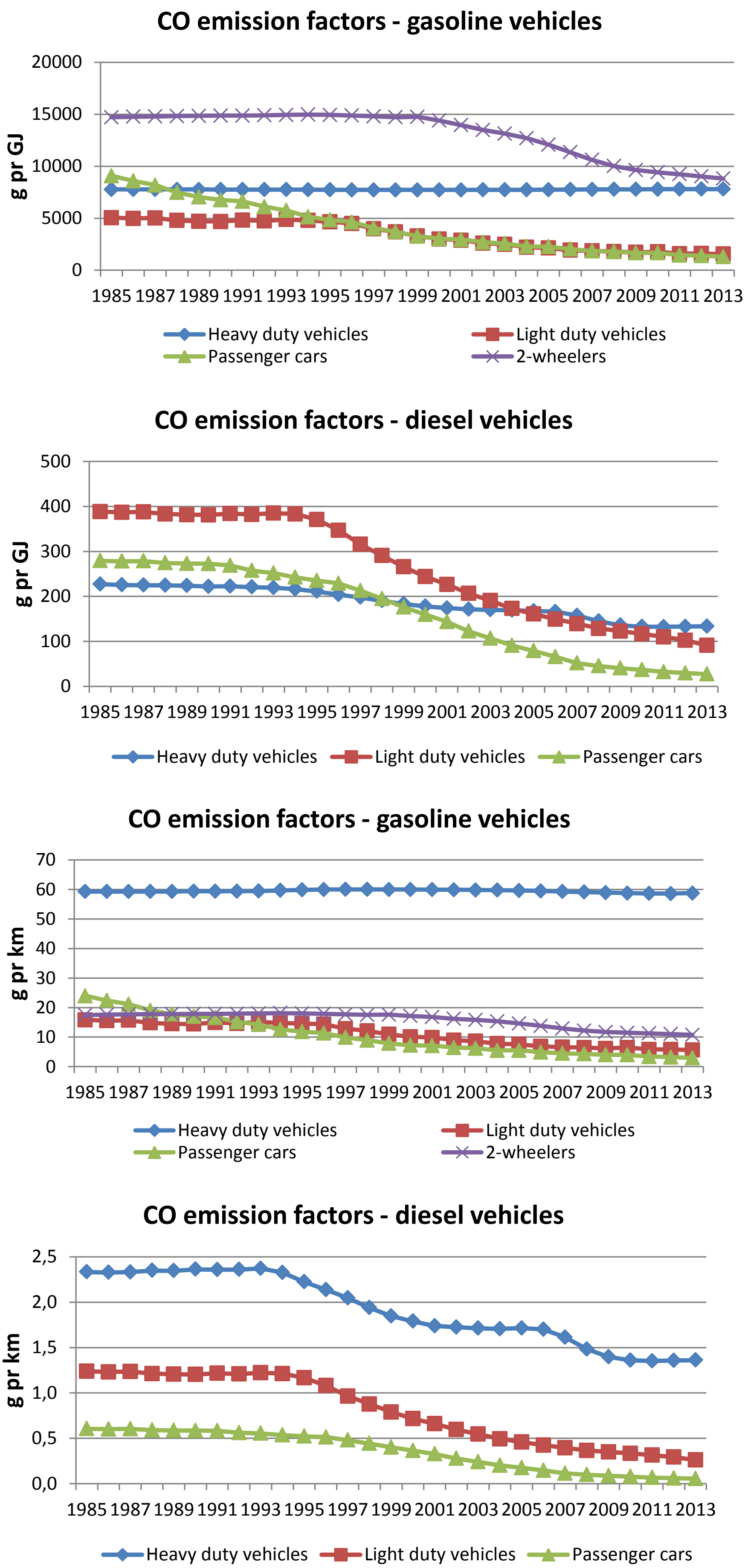



**Figure 4.8**. Fuel and km related CO emission factors per vehicle type for Danish road transport (1990-2013).

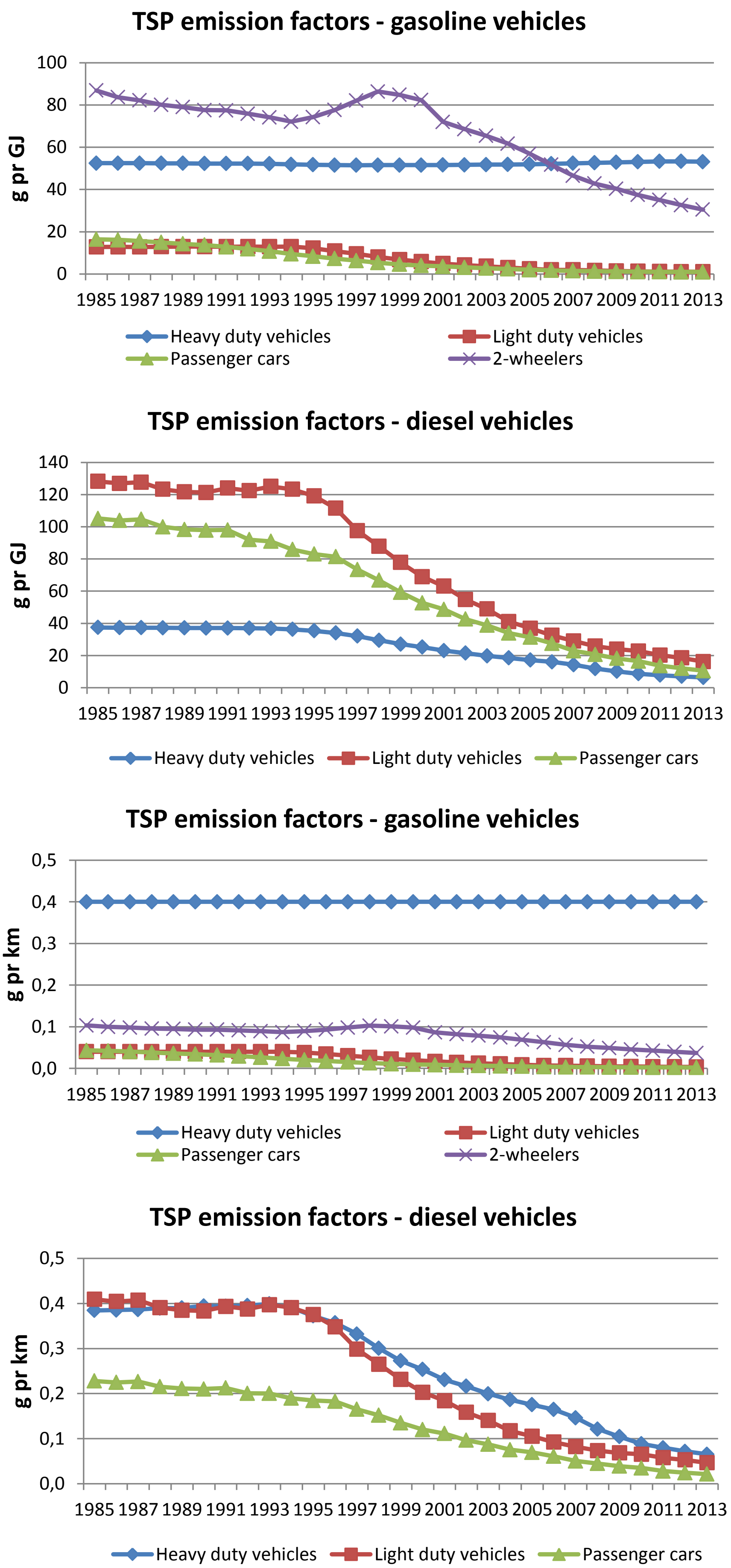



**Figure 4.9**. Fuel and km related TSP emission factors per vehicle type for Danish road transport (1990-2013).

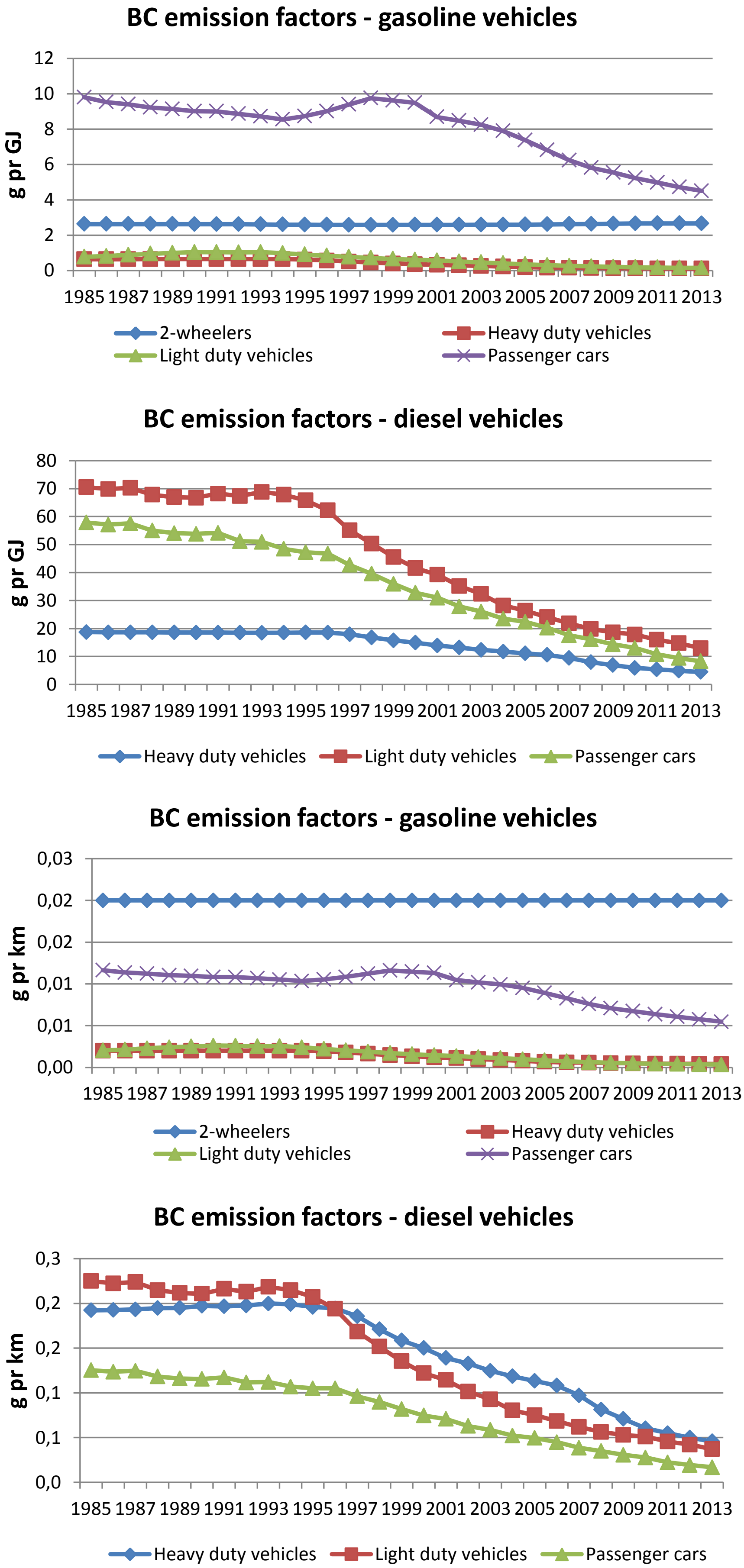



**Figure 4.10**. Fuel and km related BC emission factors per vehicle type for Danish road transport (1990-2013).

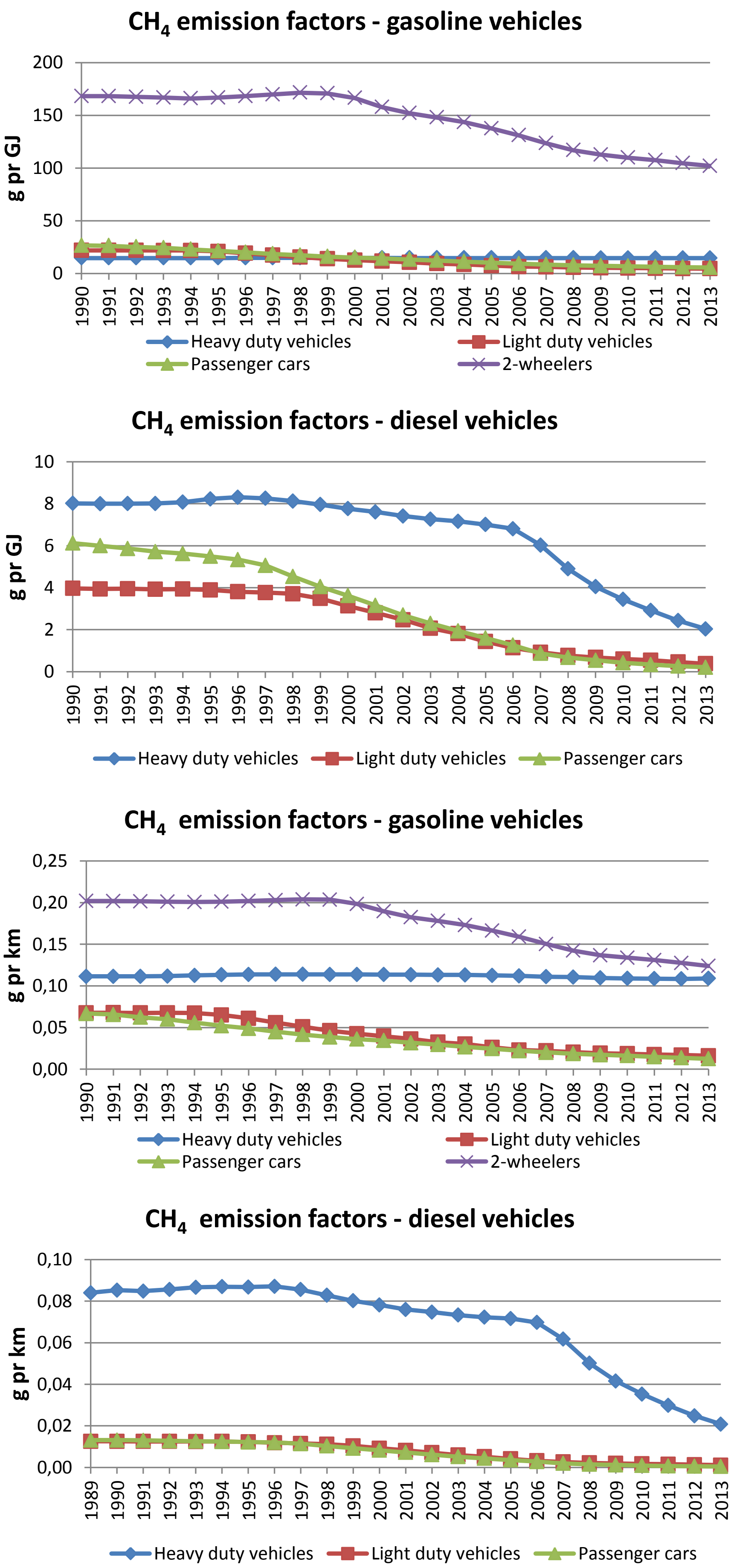



**Figure 4.11**. Fuel and km related $CH_4$ emission factors per vehicle type for Danish road transport (1990-2013).

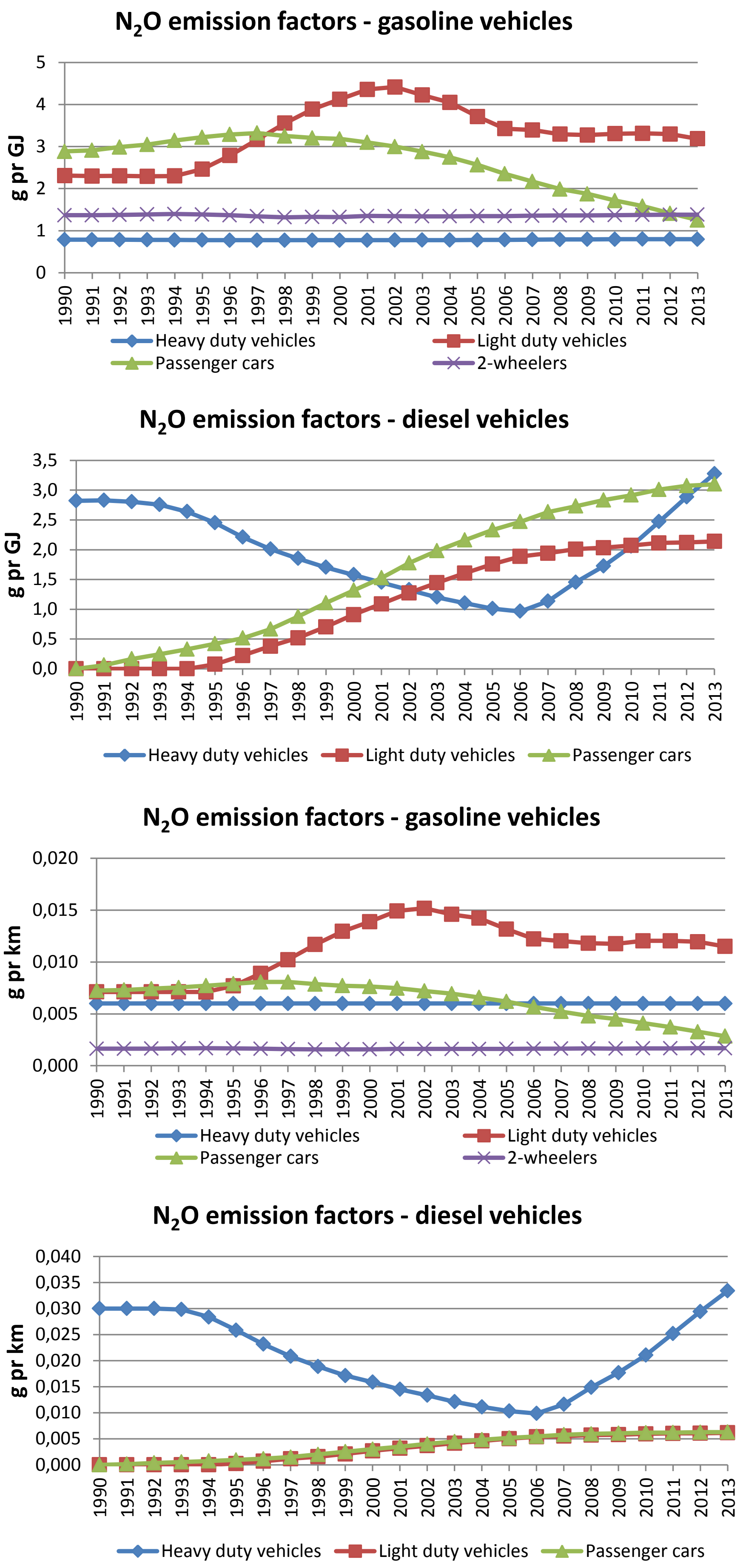



**Figure 4.12**. Fuel and km related $N_2O$ emission factors per vehicle type for Danish road transport (1990-2013).

# 5 Input data and calculation methods for other mobile sources

Other mobile sources are divided into several sub-sectors: sea transport, fishery, air traffic, railways, military, and working machinery and equipment in the sectors agriculture, forestry, industry and residential. The emission calculations are made in internal DCE models using the detailed method as described in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2013) for air traffic, off-road working machinery and equipment, and ferries, while for the remaining sectors the simple method is used.

## 5.1 Activity data

### 5.1.1 Air traffic

The activity data used in the DCE emission model for aviation consists of air traffic statistics provided by the Danish Transport Authority and Copenhagen Airport. Fuel statistics for jet fuel consumption and aviation gasoline is obtained from the Danish energy statistics (DEA, 2014).

For 2001 onwards, the Danish Transport Authority provides data records per flight (city-pairs). Each flight record consists of e.g. ICAO codes for aircraft type, origin and destination airport, maximum takeoff mass (MTOM), flight call sign and aircraft registration number.

In the DCE model each aircraft type is paired with a representative aircraft type, for which fuel consumption and emission data exist in the EMEP/EEA databank. As a basis the type relation table is taken from the Eurocontrol AEM model which is the primary source for the present EMEP/EEA fuel consumption and emission data. Supplementary aircraft types are assigned to representative aircraft types based on the type relation table already established in the previous version of the DCE model (e.g. Winther, 2012).

Additional aircraft types not present in the type relation table are identified by using different aircraft dictionaries and internet look-ups. In order to select the most appropriate aircraft representative type, the main selection criterias are the identified aircraft type, aircraft maximum takeoff mass, engine types, and number of engines. During this sequence, small aircraft with piston engines using aviation gasoline are excluded from the calculations.

Annex 10 shows the correspondence table between the actual aircraft type codes and representative aircraft types behind the Danish inventory. Annex 10 also show the number of LTO's per representative aircraft type for domestic and international flights starting from Copenhagen Airport and other airports, respectively[5], in a time series from 2001-2013. The airport split is necessary to make due to the differences in LTO emission factors (cf. section 5.3).

The same type of LTO activity data for the flights for Greenland and the Faroe Islands are shown in Annex 10 also, further detailed into an origin-

[5] Excluding flights for Greenland and the Faroe Islands. These flights are separately listed in Annex 10.

destination airport matrix and having flight distances attached. This level of detail satisfies the demand from UNFCCC to provide precise documentation for the part of the inventory for the Kingdom of Denmark being outside the Danish mainland.

The ideal flying distance (great circle distance) between the city-pairs is calculated by DCE in a separate database. The calculation algorithm uses a global latitude/altitude coordinate table for airports. In cases when airport coordinates are not present in the DCE database, these are looked up on the internet and entered into the database accordingly.

For inventory years prior to 2001, detailed LTO/aircraft type statistics are obtained from Copenhagen Airport (for this airport only), while information of total takeoff numbers for other Danish airports is provided by the Danish Transport Authority. The assignment of representative aircraft types for Copenhagen Airport is done as described above. For the remaining Danish airports representative aircraft types are not directly assigned. Instead appropriate average assumptions are made relating to the fuel consumption and emission data part.

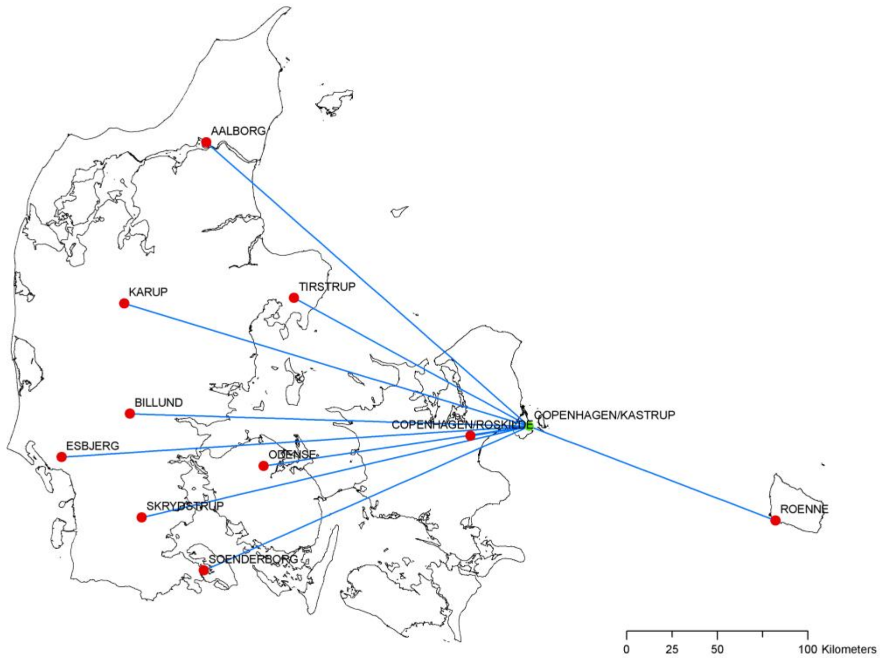



**Figure 5.1**. Most frequent domestic flying routes for large aircraft in Denmark.

Copenhagen Airport is the starting or end point for most of the domestic aviation made by large aircraft in Denmark (Figure 5.1; routes to Greenland/Faroe Islands are not shown). Even though many domestic flights not touching Copenhagen Airport are also reported in the flight statistics kept by the Danish Transport Authority, these flights, however, are predominantly made with small piston engine aircraft using aviation gasoline. Hence, the consumption of jet fuel by flights not using Copenhagen is merely marginal.

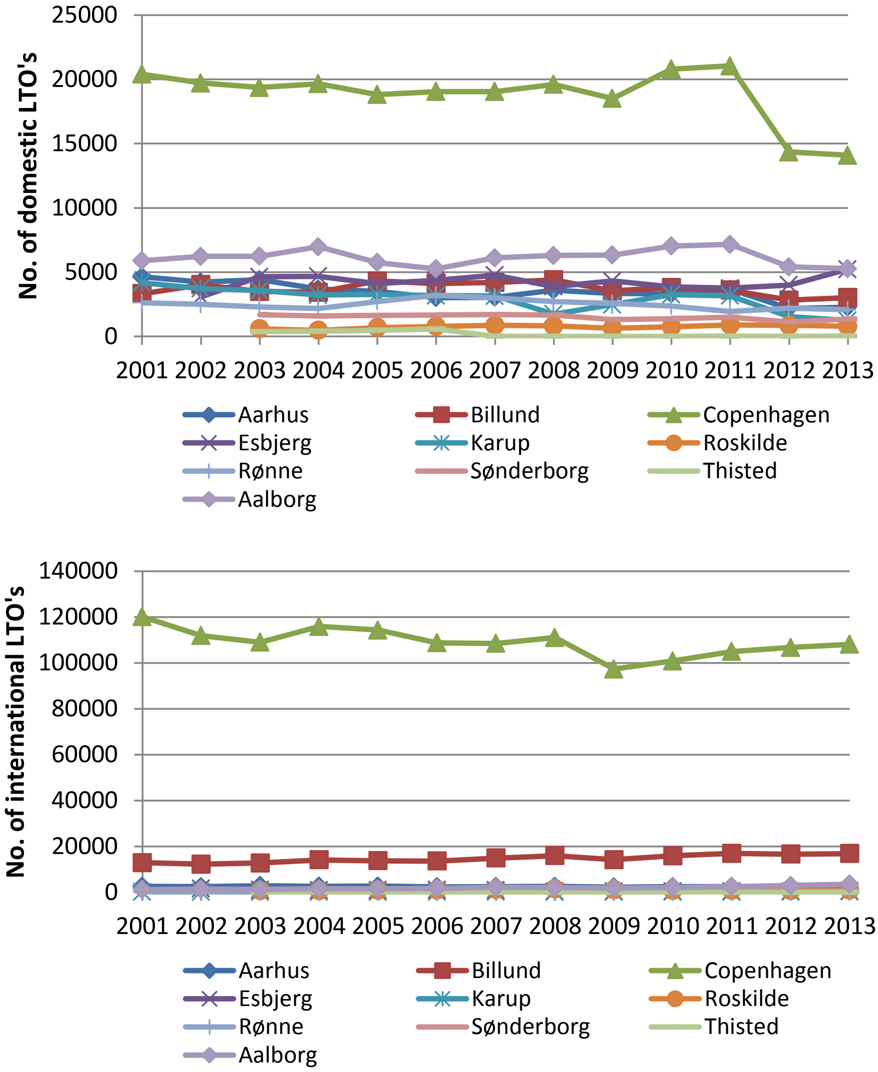



**Figure 5.2**. No. of LTO's for the most important airports in Denmark 2001-2013.

Figure 5.2 shows the number of domestic and international LTO's for Danish airports[6], in a time series from 2001-2013.

### 5.1.2 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) for the years until 2004. For later inventory years, supplementary stock data are annually provided by the Association of Danish Agricultural Machinery Dealers and the Association of Producers and Distributors of Fork Lifts in Denmark. The stock development from 1990-2013 for the most important types of machinery are shown in Figures 5.3 – 5.10. The stock data are also listed in Annex 11, together with figures for load factors, engine sizes and annual working hours. As regards stock data for the remaining machinery types, please refer to (Winther et al., 2006).

[6] Flights for Greenland and the Faroe Islands are included under domestic in the figure.

It is important to note that from key experts in the field of industrial non-road activities a significant decrease in the activities is assumed for 2009 due to the global financial crisis. This reduction is in the order of 25 % for 2009 for industrial non-road in general (pers. comm. Per Stjernqvist, Volvo Construction Equipment 2010). For fork lifts, 5 % and 20 % reductions are assumed for 2008 and 2009, respectively (pers. comm. Peter H. Møller, Rocla A/S).

For agriculture, the total number of agricultural tractors and harvesters per year are shown in the Figures 5.3 – 5.10, respectively. The figures clearly show a decrease in the number of small machines, these being replaced by machines in the large engine-size ranges.

The tractor and harvester developments towards fewer vehicles and larger engines, shown in Figure 5.5, are very clear. From 1990 to 2013, tractor and harvester numbers decrease by around 22 % and 42 %, respectively, whereas the average increase in engine size for tractors is 35 % and 169 % for harvesters, in the same time period.

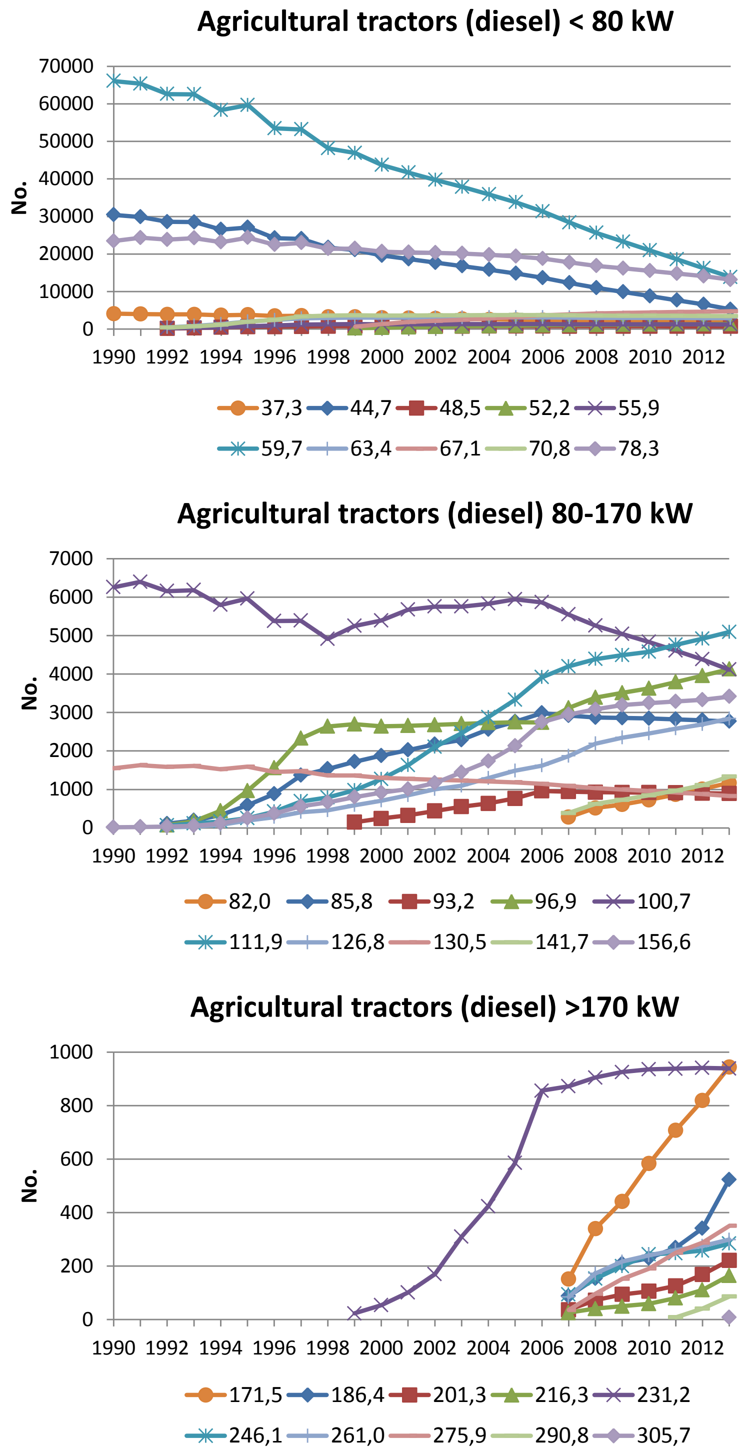



**Figure 5.3**. Total numbers in kW classes for tractors from 1990 to 2013.

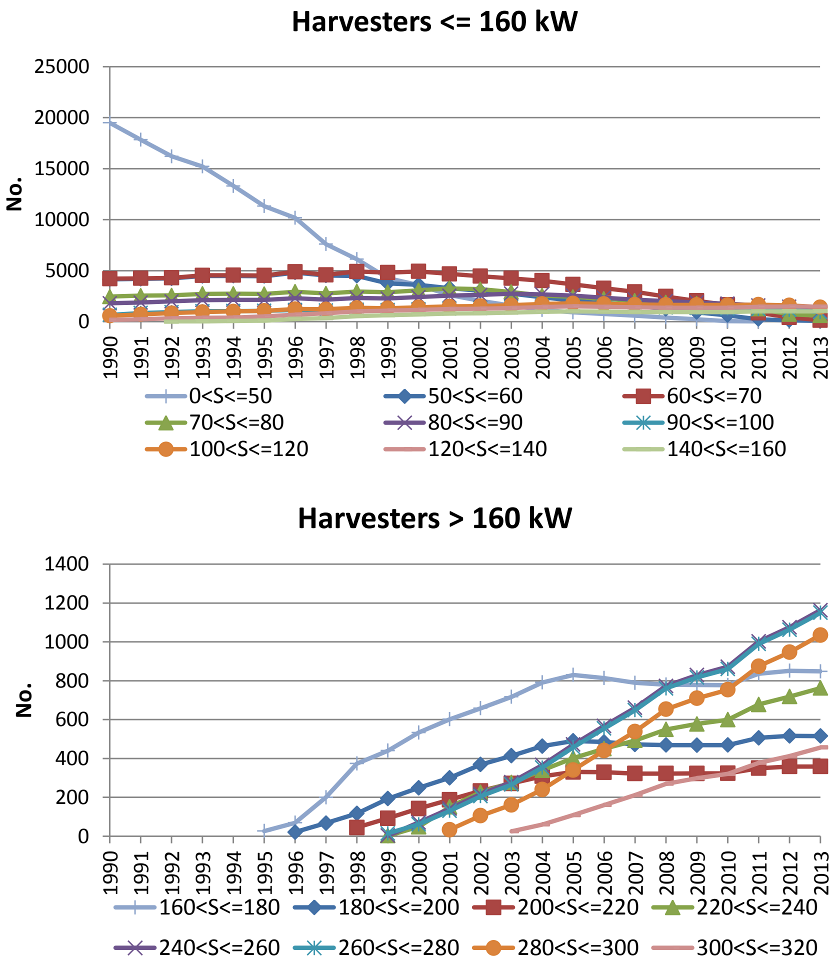



**Figure 5.4**. Total numbers in kW classes for harvesters from 1990 to 2013.

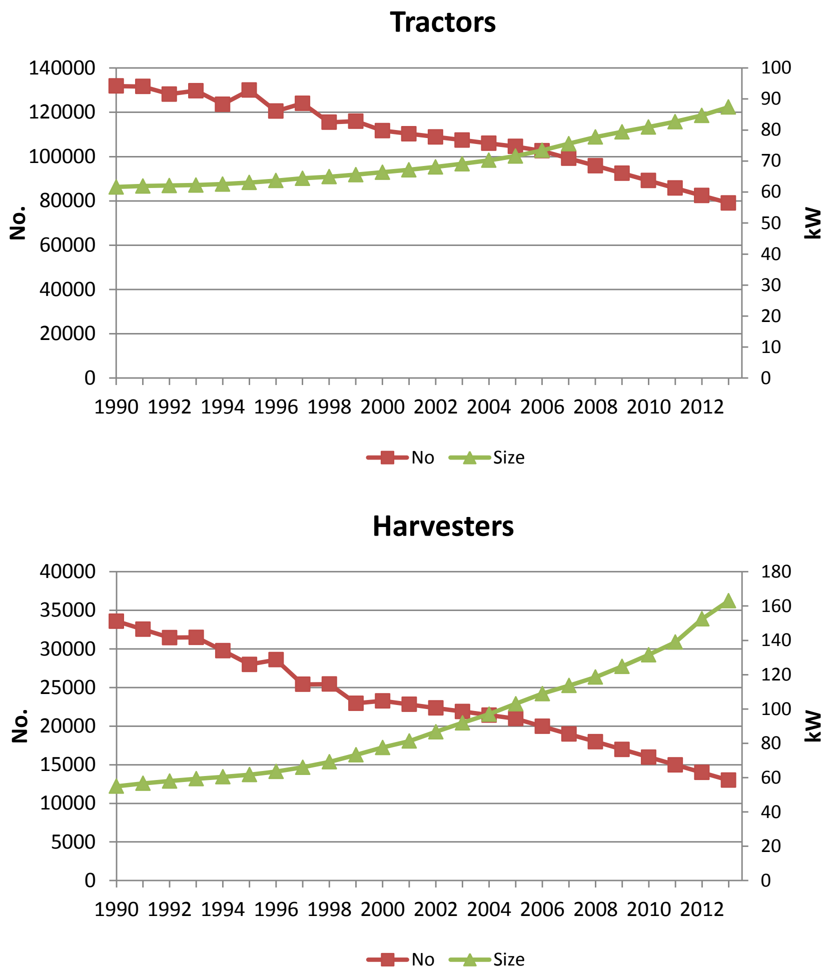



**Figure 5.5**. Total numbers and average engine size for tractors and harvesters (1990 to 2013).

The most important machinery types for industrial use are different types of construction machinery and fork lifts. The Figures 5.6 and 5.7 show the 1990-2013 stock development for specific types of construction machinery and diesel fork lifts. 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.

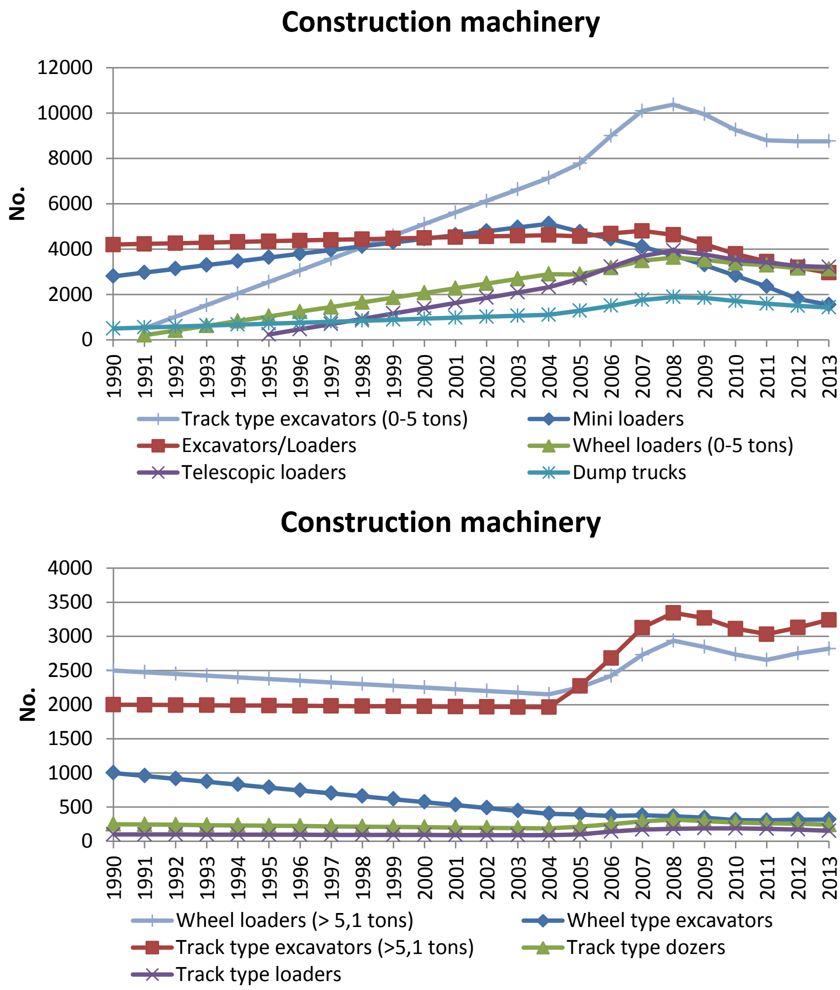



**Figure 5.6**. 1990-2013 stock development for specific types of construction machinery.

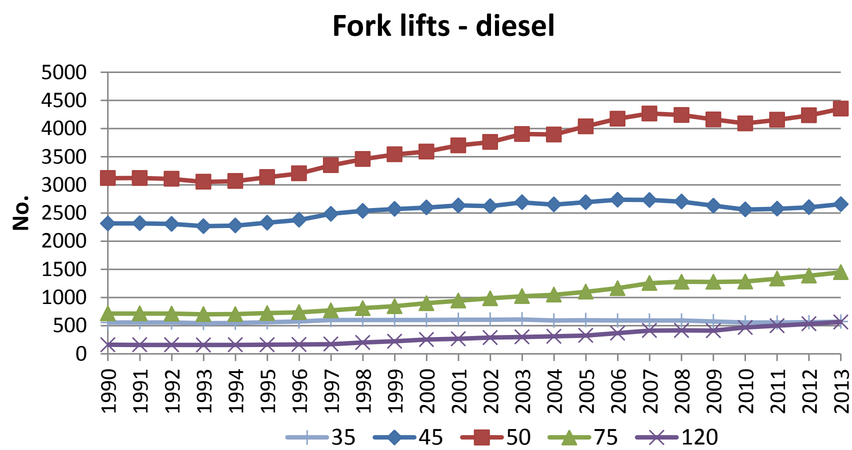



**Figure 5.7**. Total numbers of diesel fork lifts in kW classes from 1990 to 2013.

The emission level shares for tractors, harvesters, construction machinery and diesel fork lifts are shown in Figure 5.8, 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 5.8. 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 5.8.

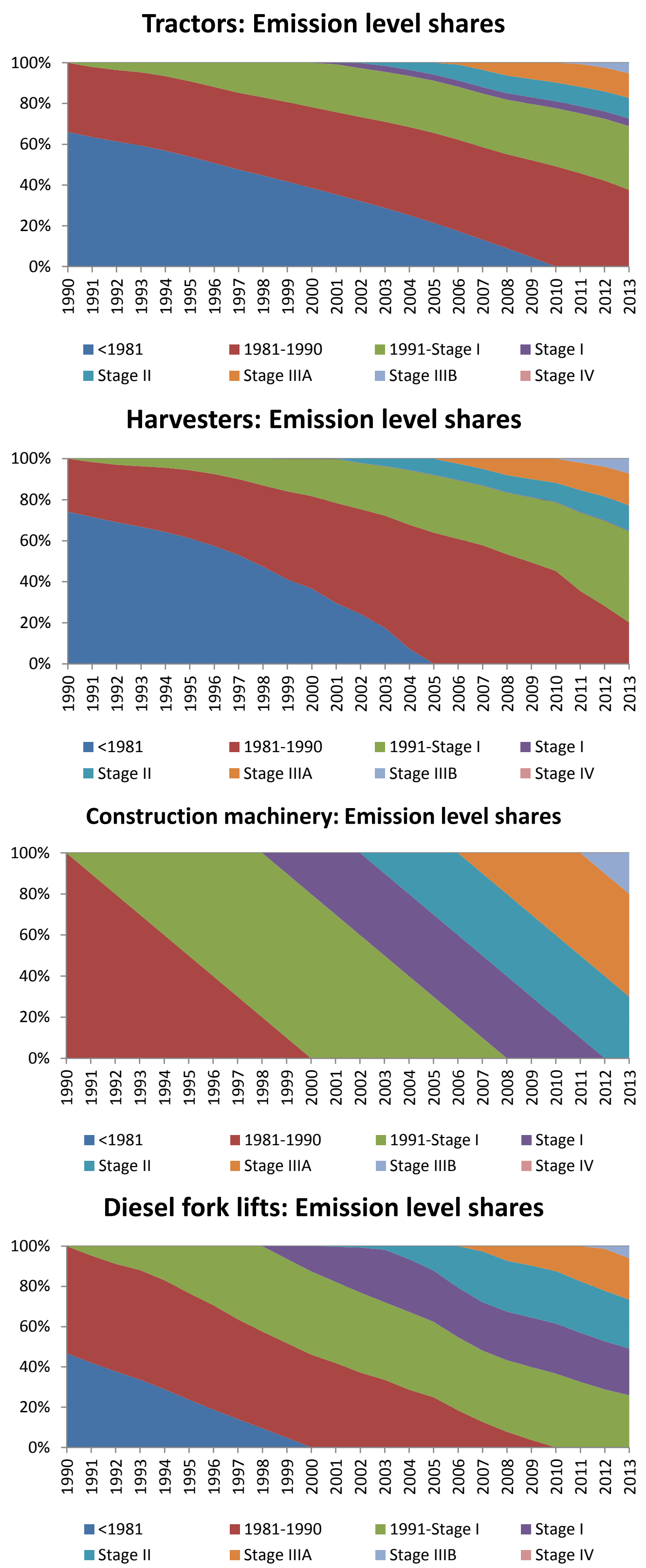



**Figure 5.8**. Emission level shares for tractors, harvesters, construction machinery and diesel fork lifts (1990 to 2013).

The 1990-2013 stock development for the most important household and gardening machinery types is shown in Figure 5.9.

For lawn movers and cultivators, the machinery stock remains approximately the same for all years. The stock figures for chain saws, shrub clearers, trimmers and hedge cutters increase from 1990 until 2004, and for riders this increase continues also after 2004. The yearly stock increases, in most cases, become larger after 2000. The lifetimes for gasoline machinery are short and, therefore, the new emission levels (not shown) penetrate rapidly.

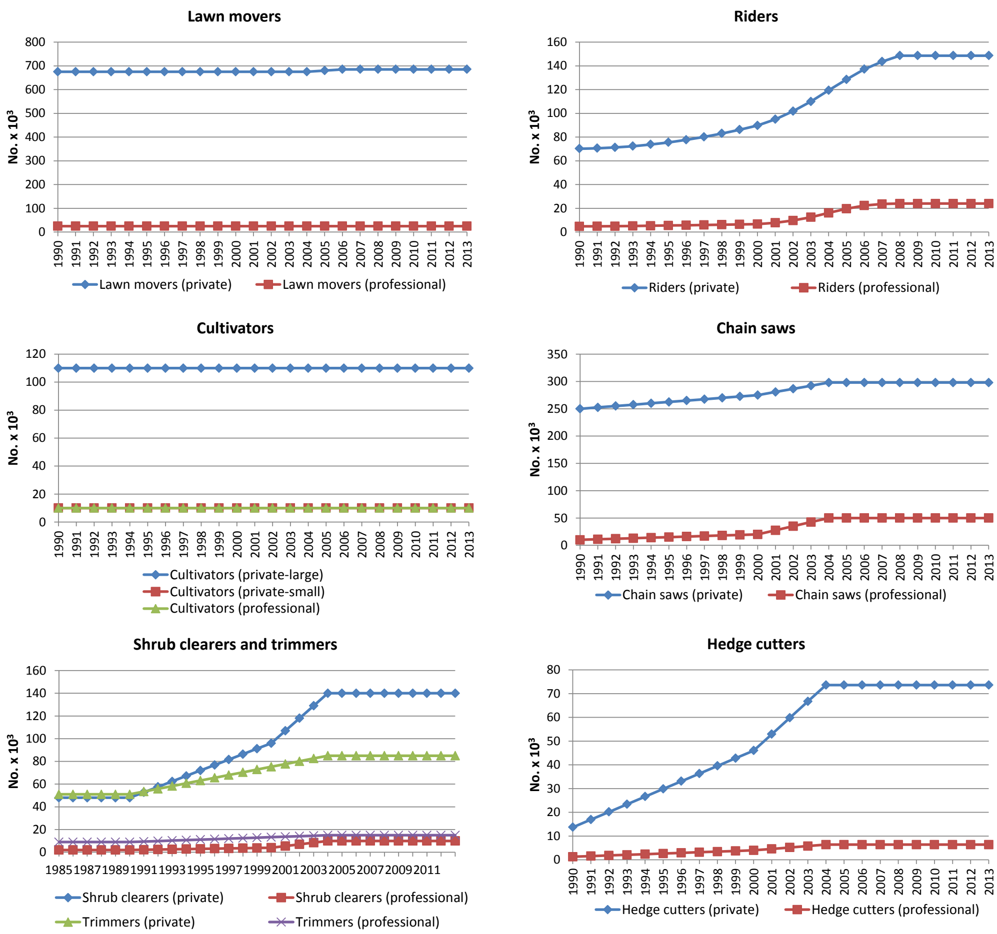



**Figure 5.9**. Stock development 1990-2013 for the most important household and gardening machinery types.

Figure 5.10 shows the development in numbers of different recreational craft from 1990-2013. 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).

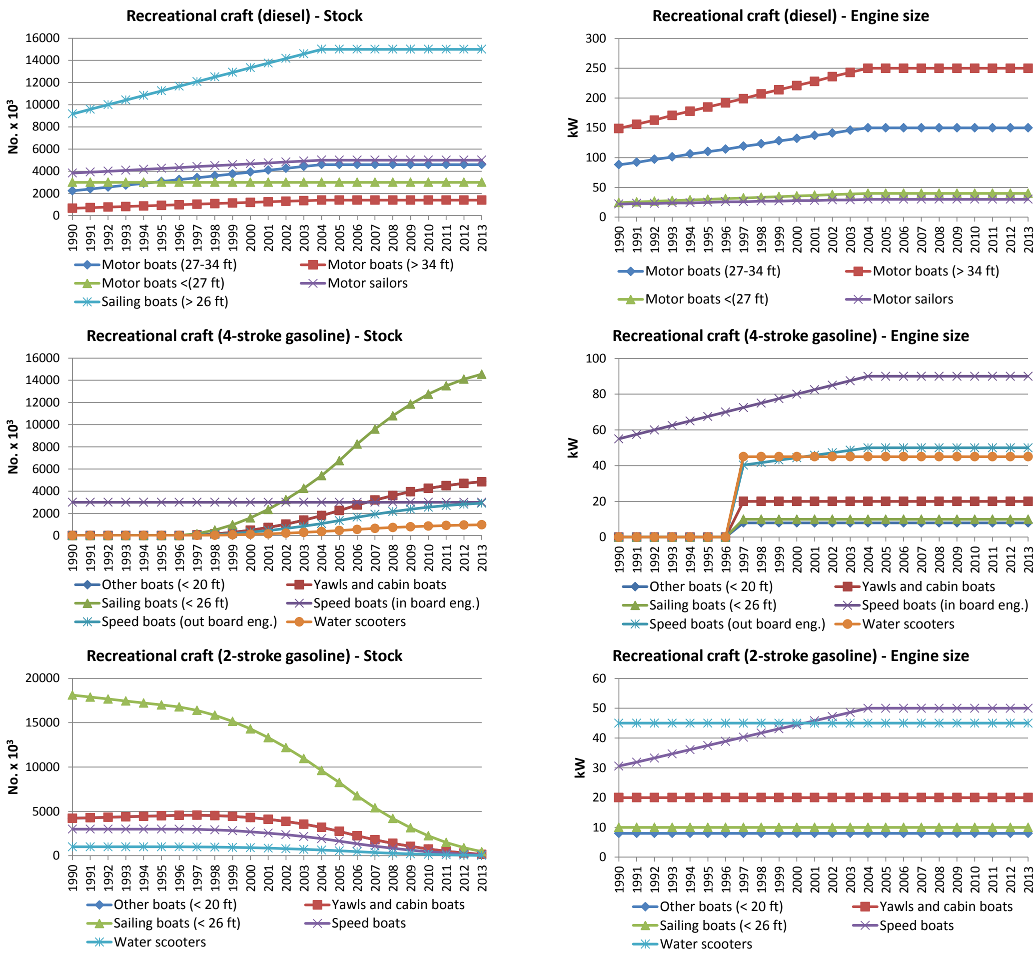



**Figure 5.10**. 1990-2013 Stock and engine size development for recreational craft.

### 5.1.3 National sea transport

A detailed methodology is used to estimate the fuel consumption figures for national sea transport, based on fleet activity estimates for regional ferries, local ferries and other national sea transport (Winther, 2008).

Table 5.1 lists the most important domestic ferry routes in Denmark in the period 1990-2013. For these ferry routes and the years 1990-2005, the following detailed traffic and technical data have been gathered by Winther (2008): Ferry name, year of service, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size and sailing time (single trip).

For 2006-2013, the above mentioned traffic and technical data for specific ferries have been provided by Kristensen (2014) in the case of Mols-Linien (Sjællands Odde-Ebeltoft, Sjællands Odde-Århus, Kalundborg-Århus), by Jørgensen (2014) for Færgen A/S (Køge-Rønne, Tårs-Spodsbjerg). For Esbjerg/Hanst-holm/Hirtshals-Torshavn traffic and technical data have been provided by Dávastovu (2010).

**Table 5.1**. Domestic ferry routes comprised in the Danish inventory.

| Ferry service | Service period |
|---|---|
| Esbjerg-Torshavn | 1990-1995, 2009+ |
| Halsskov-Knudshoved | 1990-1999 |
| Hanstholm-Torshavn | 1991-1992, 1999+ |
| Hirtshals-Torshavn | 2010 |
| 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+ |

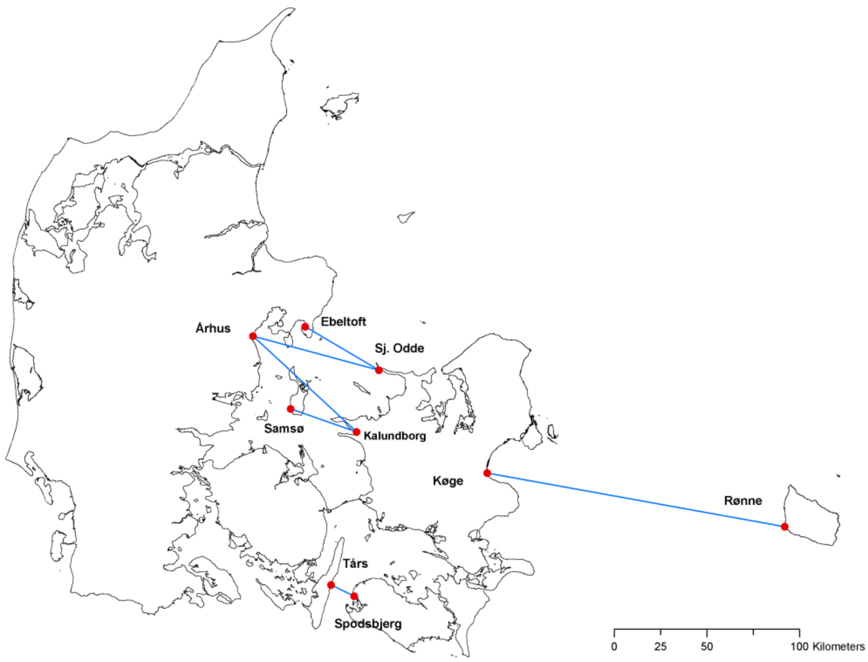



**Figure 5.11**. Domestic regional ferry routes in Denmark (2013).

The number of round trips per ferry route from 1990 to 2013 is provided by Statistics Denmark (2014), see Figure 5.12 (Esbjerg/Hanstholm/Hirtshals-Torshavn not shown). The traffic data are also listed in Annex 12, together with different ferry specific technical and operational data.

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

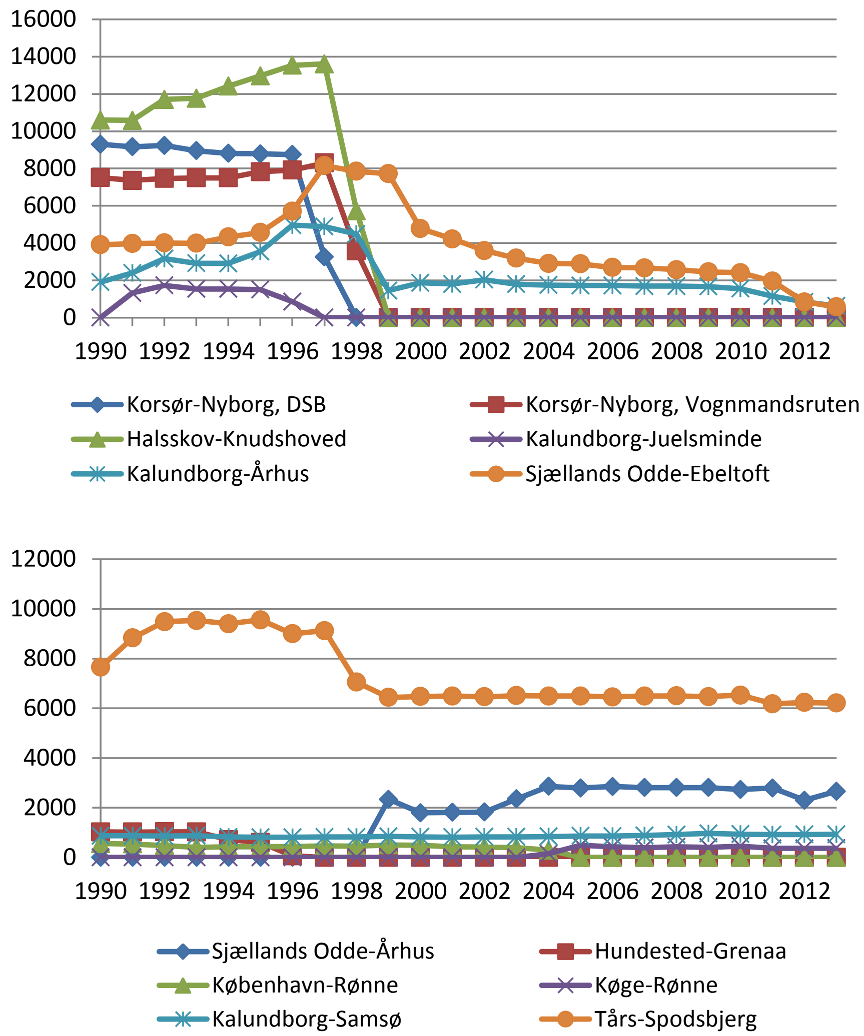



**Figure 5.12**. No. of round trips for the most important ferry routes in Denmark 1990-2013.

It is seen from Table 5.1 (and Figure 5.12) 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.

For the local ferries, a bottom-up estimate of fuel consumption for 1996 has been taken from the Danish work in Wismann (2001). The latter project calculated fuel consumption and emissions for all sea transport in Danish waters in 1995/1996 and 1999/2000. In order to cover the entire 1990-2013 inventory period, the fuel figure for 1996 has been adjusted according to the developments in local ferry route traffic shown in Annex 12.

Fuel sold for freight transport by Royal Arctic Line between Aalborg (Denmark) and Greenland and by Eim Skip - East route between Aarhus (Denmark) and Torshavn (Faroe Islands) are included under other national sea transport in the Danish inventories. In both cases all fuel is being bought in Denmark (Rasmussen, 2014 and Thorarensen, 2014).

For the remaining part of the traffic between two Danish ports, other national sea transport, bottom-up estimates for fuel consumption have been calculated for the years 1995 and 1999 by Wismann (2007). These fuel consumption estimates are used as activity data for the inventory years until 1995 and 1999 onwards. Interpolated figures are used for the inventory years 1996-1998.

The calculations use the database set up for Denmark in the Wismann (2001) study, with actual traffic data from the Lloyd's LMIS database (not including ferries). The database was split into three vessel types: bulk carriers, container ships, and general cargo ships; and five size classes: 0-1000, 1000-3000, 3000-10000, 10000-20000 and >20000 DTW. The calculations assume that bulk carriers and container ships use heavy fuel oil, and that general cargo ships use gas oil. For further information regarding activity data for local ferries and other national sea transport, please refer to Winther (2008).

The fleet activity data for regional ferries, and the fleet activity based fuel consumption estimates for local ferries and other national sea transport replace the fuel based activity data which originated directly from the DEA statistics.

### 5.1.4 Other sectors

The activity data for military, railways, international sea transport and fishery consists of fuel consumption information from DEA (2014). For international sea transport, the basis is fuel sold in Danish ports for vessels with a foreign destination, as prescribed by the IPCC guidelines.

However, it must be noted that fuel sold for sailing activities between Denmark and Greenland/Faroe Islands are reported as international in the DEA energy statistics. Hence, for inventory purposes in order to follow the IPCC guidelines the bottom-up fuel estimates for the ferry routes Esbjerg/Hanstholm-Torshavn, and fuel reports from Royal Arctic Line and Eim Skip is being subtracted from the fuel sales figures for international sea transport prior to inventory fuel input.

For fisheries, the calculation methodology described by Winther (2008) remains fuel based. However, the input fuel data differ from the fuel sales figures previously used. The changes are the result of further data processing of the DEA reported gas oil sales for national sea transport and fisheries, prior to inventory input. For years when the fleet activity estimates of fuel consumption for national sea transport (not including trips to Greenland/Faroe Islands) are smaller than DEA reported fuel sold for national sea transport, fuel is added to fisheries in the inventory. In the opposite case, fuel is being subtracted from the original DEA fisheries fuel sales figure in order to make up the final fuel consumption input for fisheries in the inventories.

The updated fuel consumption time series for national sea transport lead, in turn, to changes in the energy statistics for fisheries (gas oil) and industry (heavy fuel oil), so the national energy balance can remain unchanged.

For all sectors, fuel consumption figures are given in Annex 15 for the years 1990 and 2013 in CollectER format.

## 5.2 Emission legislation

For other modes of transport and non-road machinery, the engines have to comply with the emission legislation limits agreed by the EU and different UN organisations in terms of $NO_x$, CO, VOC and TSP emissions and fuel sulphur content. In terms of greenhouse gases, the emission legislation requirements for VOC influence the emissions of $CH_4$, the latter emission component forming a part of total VOC. Only for ships legislative limits for specific fuel consumption have been internationally agreed in order to reduce the emissions of $CO_2$.

For non-road working machinery and equipment, and recreational craft and railway locomotives/motor cars, the emission directives list specific emission limit values (g per kWh) for CO, VOC, $NO_x$ (or VOC + $NO_x$) and TSP, depending on engine size (kW for diesel, ccm for gasoline) and date of implementation (referring to engine market date).

For diesel, the directives 97/68 and 2004/26 (Table 5.2) 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 (Table 5.6). For tractors the relevant directives are 2000/25 and 2005/13 (Table 5.2). For gasoline, the directive 2002/88 distinguishes between hand-held (SH) and not hand-held (NS) types of machinery (Table 5.3).

For engine type approval, the emissions (and fuel consumption) 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 5.2**. 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 per 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 5.3**. Overview of the EU Emission Directive 2002/88 for gasoline fuelled non-road machinery.

| | Category | Engine size [ccm] | CO [g per kWh] | HC [g per kWh] | $NO_X$ [g per kWh] | HC+$NO_X$ [g per 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 Stage 1 emission legislation limits for diesel engines, and for 2-stroke and 4-stroke gasoline engines, respectively. The CO and VOC emission limits depend on engine size (kW) and the inserted parameters presented in the calculation formulas in Table 5.4. For $NO_x$, a constant limit value is given for each of the three engine types. For TSP, the constant emission limit regards diesel engines only.

In Table 5.5 the Stage II emission limits are shown for recreational craft. CO and HC+$NO_x$ limits are provided for gasoline engines depending on the rated engine power and the engine type (stern-drive vs. outboard) while CO, HC+$NO_x$, and particulate emission limits are defined for Compression Ignition (CI) engines depending on the rated engine power and the swept volume.

**Table 5.4**. Overview of the EU Emission Directive 2003/44 for recreational craft.

| Engine type | Impl. date | CO=A+B/$P^n$ | | | HC=A+B/$P^n$ | | | $NO_X$ | TSP |
|---|---|---|---|---|---|---|---|---|---|
| | | A | B | n | A | B | n | | |
| 2-stroke gasoline | 1/1 2007 | 150.0 | 600.0 | 1.0 | 30.0 | 100.0 | 0.75 | 10.0 | - |
| 4-stroke gasoline | 1/1 2006 | 150.0 | 600.0 | 1.0 | 6.0 | 50.0 | 0.75 | 15.0 | - |
| Diesel | 1/1 2006 | 5.0 | 0.0 | 0 | 1.5 | 2.0 | 0.5 | 9.8 | 1.0 |

**Table 5.5**. Overview of the EU Emission Directive 2013/53 for recreational craft.

| Diesel engines | | | | | |
|---|---|---|---|---|---|
| Swept Volume, SV<br>l/cyl. | Rated Engine Power, $P_N$<br>kW | Impl. Date | CO<br>g/kWh | HC + $NO_x$<br>g/kWh | PM<br>g/kWh |
| SV < 0.9 | $P_N$ < 37 | | | | |
| | 37 <= $P_N$ < 75 (*) | 18/1 2017 | 5 | 4.7 | 0.30 |
| | 75 <= $P_N$ < 3 700 | 18/1 2017 | 5 | 5.8 | 0.15 |
| 0.9 <= SV < 1.2 | $P_N$ < 3 700 | 18/1 2017 | 5 | 5.8 | 0.14 |
| 1.2 <= SV < 2.5 | | 18/1 2017 | 5 | 5.8 | 0.12 |
| 2.5 <= SV < 3.5 | | 18/1 2017 | 5 | 5.8 | 0.12 |
| 3.5 <= SV < 7.0 | | 18/1 2017 | 5 | 5.8 | 0.11 |
| **Gasoline engines** | | | | | |
| Engine type | Rated Engine Power, $P_N$<br>kW | | CO<br>g/kWh | HC + $NO_x$<br>g/kWh | PM<br>g/kWh |
| Stern-drive and inboard engines | $P_N$ <= 373 | 18/1 2017 | 75 | 5 | - |
| | 373 <= $P_N$ <= 485 | 18/1 2017 | 350 | 16 | - |
| | $P_N$ > 485 | 18/1 2017 | 350 | 22 | - |
| Outboard engines and PWC engines (**) | $P_N$ <= 4.3 | 18/1 2017 | 500 – (5.0 x $P_N$) | 15.7 + $(50/PN^{0.9})$ | - |
| | 4.3 <= $P_N$ <= 40 | 18/1 2017 | 500 – (5.0 x $P_N$) | 15.7 + $(50/PN^{0.9})$ | - |
| | $P_N$ > 40 | 18/1 2017 | 300 | | - |

(*) Alternatively, this engine segment shall not exceed a PM limit of 0.2 g/kWh and a combined HC + $NO_x$ limit of 5.8 g/kWh

(**) Small and medium size manufacturers making outboard engines <= 15 kW have until 18/1 2020 to comply

**Table 5.6**. Overview of the EU Emission Directive 2004/26 for railway locomotives and motorcars.

| | Engine size [kW] | | CO [g per kWh] | HC [g per kWh] | $NO_x$ [g per kWh] | HC+$NO_x$ [g per kWh] | PM [g per kWh] | Implement. 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 engine emission certification standards are contained in Annex 16 — Environmental Protection, Volume II — Aircraft Engine Emissions to the Convention on International Civil Aviation (ICAO Annex 16, 2008, plus amendments). The emission standards relate to the total emissions (in grams) from the so-called LTO (Landing and Take Off) cycle divided by the rated engine thrust (kN). The ICAO LTO cycle contains the idealised aircraft movements below 3000 ft (915 m) during approach, landing, airport taxiing, takeoff and climb out.

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

For $NO_x$, the emission regulations fall in five categories:

For engines of a type or model for which the date of manufacture of the first individual production model was before 1 January 1996, and for which the production date of the individual engine was before 1 January 2000.

For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 1996, or for individual engines with a production date on or after 1 January 2000.

For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2004.

For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2008, or for individual engines with a production date on or after 1 January 2013.

For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2014.

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

The limit values for $NO_x$ are given by the formulae in Table 5.7.

**Table 5.7**. Current certification limits for $NO_x$ for turbo jet and turbo fan engines.

| | Engines first produced before 1.1.1996 & for engines manufactured before 1.1.2000 | Engines first produced on or after 1.1.1996 & for engines manufactured on or after 1.1.2000 | Engines for which the date of manufacture of the first individual production model was on or after 1 January 2004 | Engines first produced on or after 1.1.2047 & for engines manufactured on or after 1.1.2013 | Engines for which the date of manufacture of the first individual production model was on or after 1.1.2014 |
|---|---|---|---|---|---|
| Applies to engines >26.7 kN | $Dp/F_{oo} = 40 + 2\pi_{oo}$ | $Dp/F_{oo} = 32 + 1.6\pi_{oo}$ | | | |
| Engines of pressure ratio less than 30 | | | | | |
| Thrust more than 89 kN | | | $Dp/F_{oo} = 19 + 1.6\pi_{oo}$ | $Dp/F_{oo} = 16.72 + 1.4080\pi_{oo}$ | $7.88 + 1.4080\pi_{oo}$ |
| Thrust between 26.7 kN and not more than 89 kN | | | $Dp/F_{oo} = 37.572 + 1.6\pi_{oo} - 0.208F_{oo}$ | $Dp/F_{oo} = 38.54862 + (1.6823\pi_{oo}) – (0.2453F_{oo}) – (0.00308\pi_{oo}F_{oo})$ | $Dp/F_{oo} = 40.052 + 1.5681\pi_{oo} - 0.3615F_{oo} - 0.0018\ \pi_{oo} \times F_{oo}$ |
| Engines of pressure ratio more than 30 and less than 62.5 (104.7) | | | | | |
| Thrust more than 89 kN | | | $Dp/F_{oo} = 7+2.0\pi_{oo}$ | $Dp/F_{oo} = -1.04+ (2.0*\pi_{oo})$ | |
| Thrust between 26.7 kN and not more than 89 kN | | | $Dp/F_{oo} = 42.71 +1.4286\pi_{oo} -0.4013F_{oo} +0.00642\pi_{oo}F_{oo}$ | $Dp/F_{oo} = 46.1600 + (1.4286\pi_{oo}) – (0.5303F_{oo}) – (0.00642\pi_{oo}F_{oo})$ | |
| Engines with pressure ratio 62.5 or more | | | | | |
| Engines with pressure ratio 82.6 or more | | | $Dp/F_{oo} = 32+1.6\pi_{oo}$ | $Dp/F_{oo} = 32+1.6\pi_{oo}$ | |
| Engines of pressure ratio more than 30 and less than (104.7) | | | | | |
| Thrust more than 89 kN | | | | | $Dp/F_{oo} = -9.88 + 2.0\pi_{oo}$ |
| Thrust between 26.7 kN and not more than 89 kN | | | | | $Dp/F_{oo} = 41.9435 + 1.505\pi_{oo} - 0.5823F_{oo} + 0.005562\pi_{oo} \times F_{oo}$ |
| Engines with pressure ratio 104.7 or more | | | | | $Dp/F_{oo} = 32 + 1.6\pi_{oo}$ |

Source: International Standards and Recommended Practices, Environmental Protection, ICAO Annex 16 Volume II 3rd edition July 2008, plus amendments: Amendment 7 (17 November 2011), Amendment 8 (July 2014),
where:
$D_p$ = the sum of emissions in the LTO cycle in g.
$F_{oo}$ = thrust at sea level takeoff (100 %).
$\pi_{oo}$ = pressure ratio at sea level takeoff thrust point (100 %).

The equivalent limits for HC and CO are $D_p/F_{oo}$ = 19.6 for HC and $D_p/F_{oo}$ = 118 for CO (ICAO Annex 16 Vol. II paragraph 2.2.2). Smoke is limited to a regulatory smoke number = 83 $(F_{oo})^{-0.274}$ or a value of 50, whichever is the lower.

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

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

The baseline $NO_x$ emission regulation of Annex VI apply for diesel engines with a power output higher than 130 kW, which are installed on a ship constructed on or after 1 January 2000 and diesel engines with a power output higher than 130 kW which undergo major conversion on or after 1 January 2000.

The baseline $NO_x$ emission limits for ship engines in relation to their rated engine speed (n) given in RPM (Revolutions Per Minute) are the following:

- 17 g per kWh, n < 130 RPM
- 45 x n-0.2 g per kWh, 130 ≤ n < 2000 RPM
- 9.8 g per kWh, n ≥ 2000 RPM

The further amendment of Annex VI Regulation 13 contains a three tiered approach in order to strengthen the emission standards for $NO_x$. The three tier approach comprises the following:

Tier I: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2000 and prior to 1 January 2011 (initial regulation).

Tier II: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2011.

Tier III[7]: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2016.

The three tier $NO_x$ emission limit functions are shown in Table 5.8.

**Table 5.8**. Tier I-III $NO_x$ emission limits for ship engines in MARPOL Annex VI.

| | $NO_x$ limit | RPM (n) |
|---|---|---|
| Tier I | 17 g per kWh | n < 130 |
| | 45 · n-0.2 g per kWh | 130 ≤ n < 2000 |
| | 9,8 g per kWh | n ≥ 2000 |
| Tier II | 14.4 g per kWh | n < 130 |
| | 44 · n-0.23 g per kWh | 130 ≤ n < 2000 |
| | 7.7 g per kWh | n ≥ 2000 |
| Tier III | 3.4 g per kWh | n < 130 |
| | 9 · n-0.2 g per kWh | 130 ≤ n < 2000 |
| | 2 g per kWh | n ≥ 2000 |

[7] For ships operating in a designated Emission Control Area. Outside a designated Emission Control Area, Tier II limits apply.

Further, the $NO_x$ Tier I limits are to be applied for existing engines with a power output higher than 5000 kW and a displacement per cylinder at or above 90 litres, installed on a ship constructed on or after 1 January 1990 but prior to 1 January 2000.

In relation to the sulphur content in heavy fuel and marine gas oil used by ship engines, Table 5.9 shows the EU and IMO (Regulation 14 plus amendments) legislation in force for SECA (Sulfur Emission Control Area) areas and outside SECA's.

**Table 5.9**. Current legislation in relation to marine fuel quality.

| Legislation | | Heavy fuel oil | | Gas oil | |
|---|---|---|---|---|---|
| | | S- % | Implement. date (day/month/year) | S- % | Implement. date (day/month/year) |
| EU-directive 93/12 | | None | | 0.2[1] | 01.10.1994 |
| EU-directive 1999/32 | | None | | 0.2 | 01.01.2000 |
| EU-directive 2005/33[2] | SECA - Baltic sea | 1.5 | 11.08.2006 | 0.1 | 01.01.2008 |
| | SECA - North sea | 1.5 | 11.08.2007 | 0.1 | 01.01.2008 |
| | Outside SECA's | None | | 0.1 | 01.01.2008 |
| MARPOL Annex VI | SECA – Baltic sea | 1.5 | 19.05.2006 | | |
| | SECA – North sea | 1.5 | 21.11.2007 | | |
| | Outside SECA | 4.5 | 19.05.2006 | | |
| MARPOL Annex VI amendments | SECA's | 1 | 01.03.2010 | | |
| | SECA's | 0.1 | 01.01.2015 | | |
| | Outside SECA's | 3.5 | 01.01.2012 | | |
| | Outside SECA's | 0.5 | 01.01.2020[3] | | |

[1] Sulphur content limit for fuel sold inside EU.

[2] From 1.1.2010 fuel with a sulphur content higher than 0.1 % must not be used in EU ports for ships at berth exceeding two hours.

[3] Subject to a feasibility review to be completed no later than 2018. If the conclusion of such a review becomes negative the effective date would default 1 January 2025.

In Marpol 83/78 Annex VI (Chapter 4) the EEDI fuel efficiency regulations are mandatory from 1st January 2013 for new built ships larger than 400 GT.

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

The EEDI percentage reductions that need to be achieved for new built ships relative to existing ships, are shown in Table 5.10 stratified according to ship type and dead weight tonnes (DWT) in the temporal phases (new built year in brackets); 0 (2013-14), 1 (2015-19), 2 (2020-24) and 3 (2025+).

**Table 5.10**. EEDI percentage reductions for new built ships relative to existing ships.

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

It is envisaged that also ro-ro cargo, ro-ro passenger and cruise passenger ships will be included in the EEDI scheme in the near future.

For non-road machinery, the EU directive 2003/17/EC gives a limit value of 10 ppm sulphur in diesel (from 2011).

## 5.3 Emission factors

The $SO_2$ emission factors are fuel related, and rely on the sulphur contents given in the relevant EU fuel directives or in the Danish legal announcements. However, for jet fuel the default factor from IPCC (1996) is used. Road transport diesel is assumed to be used by engines in military and railways, and road transport gasoline is assumed to be used by non-road working machinery and recreational craft. Hence, these types of machinery have the same $SO_2$ emission factors, as for road transport.

The $CO_2$ emission factors are country-specific and come from the DEA. The $N_2O$ emission factors and BC shares of PM emission factors are taken from the EMEP/EEA guidebook (EMEP/EEA, 2013).

For all mobile sources, the emission factor source for BC, $NH_3$, heavy metals and PAHs is the EMEP/EEA guidebook (EMEP/EEA, 2013). The heavy metal emission factors for road transport and other mobile sources except national sea transport and fisheries originate from Winther and Slentø (2010). For civil aviation jet fuel, no heavy metal emission factors are proposed due to lack of data.

In the case of military ground equipment, aggregated emission factors for gasoline and diesel are derived from road traffic emission simulations. For piston engine aircraft using aviation gasoline, aggregated emission factors for conventional cars are used.

For railways, specific Danish measurements from the Danish State Railways (DSB) (Delvig, 2014) are used to calculate the emission factors of $NO_x$, VOC, CO and TSP, and a NMVOC/$CH_4$ split is made based on expert judgment.

For agriculture, forestry, industry, household gardening and recreational craft, the $NO_x$, VOC, CO and TSP emission factors are derived from various European measurement programmes; see IFEU (2004, 2009) and Winther et al. (2006). The NMVOC/$CH_4$ split is taken from IFEU (2009).

For national sea transport and fisheries, the $NO_x$ emission factors predominantly come from the engine manufacturer MAN Diesel, as a function of engine production year. The CO, VOC and TSP emission factors come from the Danish TEMA2010 emission model (Trafikministeriet, 2010), whereas the $PM_{10}$ and $PM_{2.5}$ size fractions are obtained from MAN Diesel.

Specifically for the ferries used by Mols Linjen new $NO_x$, VOC and CO emission factors are provided by Kristensen (2008), originating from measurement results by Hansen et al. (2004), Wismann (1999) and PHP (1996). Kristensen (2013) has provided complimentary emission factor data for new ferries.

For ship engines VOC/$CH_4$ splits are taken from EMEP/EEA (2013), and all emission factors are shown in Annex 2.B.13.

The source for aviation (jet fuel) emission factors is the EMEP/EEA guidebook (EMEP/EEA, 2013). For a number of different representative aircraft types, the EMEP/EEA guidebook comprises fuel flow and $NO_x$, CO and VOC emission indices for the four LTO modes and distance based emission factors for cruise. VOC/$CH_4$ splits for aviation are taken from EMEP/EEA (2013).

For all sectors, emission factors are given in CollectER format in Annex 15 for 2013. Table 5.11 shows the aggregated emission factors for $CH_4$, $CO_2$, $N_2O$, $SO_2$, $NO_x$, NMVOC, CO, $NH_3$, TSP and BC $CO_2$, $CH_4$ and $N_2O$ in 2013 used to calculate the emissions from other mobile sources in Denmark.

**Table 5.11**. Fuel based emission factors for $CH_4$, $CO_2$, $N_2O$, $SO_2$, $NO_x$, NMVOC, CO, $NH_3$, TSP and BC for other mobile sources in Denmark (2013).

| | | | Emission factors[1] (g/GJ)[2] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SNAP ID | Category | Fuel type | $CH_4$ | $CO_2$ | $N_2O$ | $SO_2$ | $NO_X$ | NMVOC | CO | $NH_3$ | TSP | BC |
| 080100 | Military | AvGas | 21.90 | 73.00 | 2.00 | 22.99 | 859.00 | 1242.60 | 6972.00 | 1.60 | 10.00 | 1.50 |
| 080100 | Military | Diesel | 0.94 | 74.00 | 2.97 | 0.44 | 332.41 | 10.40 | 80.77 | 0.62 | 10.12 | 7.79 |
| 080100 | Military | Gasoline | 7.03 | 73.00 | 1.30 | 0.44 | 112.69 | 150.85 | 1434.44 | 22.16 | 1.48 | 0.21 |
| 080100 | Military | Jet fuel | 2.65 | 72.00 | 2.30 | 22.99 | 250.57 | 24.94 | 229.89 | 0.00 | 1.16 | 0.56 |
| 080200 | Railways | Diesel | 1.89 | 74.00 | 2.04 | 0.47 | 705.00 | 49.11 | 111.00 | 0.20 | 21.00 | 13.65 |
| 080300 | Recreational craft | Diesel | 3.40 | 74.00 | 2.97 | 46.84 | 764.00 | 138.41 | 392.19 | 0.17 | 85.15 | 31.51 |
| 080300 | Recreational craft | Gasoline | 22.96 | 73.00 | 1.58 | 0.46 | 577.88 | 597.66 | 9513.05 | 0.11 | 10.93 | 0.55 |
| 080402 | National sea traffic | Diesel | 1.81 | 74.00 | 4.68 | 46.84 | 1276.29 | 43.54 | 148.56 | 0.00 | 21.55 | 6.68 |
| 080402 | National sea traffic | Residual oil | 1.96 | 78.00 | 4.89 | 489.00 | 1910.03 | 63.36 | 209.02 | 0.00 | 43.98 | 5.28 |
| 080403 | Fishing | Diesel | 1.79 | 74.00 | 4.68 | 46.84 | 1323.46 | 57.86 | 190.89 | 0.00 | 21.55 | 6.68 |
| 080404 | International sea traffic | Diesel | 1.80 | 74.00 | 4.68 | 46.84 | 1588.52 | 58.07 | 191.57 | 0.00 | 21.55 | 6.68 |
| 080404 | International sea traffic | Residual oil | 1.98 | 78.00 | 4.89 | 489.00 | 2120.24 | 63.89 | 210.76 | 0.00 | 43.98 | 5.28 |
| 080501 | Air traffic, Dom. < 3000 ft. | AvGas | 21.90 | 73.00 | 2.00 | 22.83 | 859.00 | 1242.60 | 6972.00 | 1.60 | 10.00 | 1.50 |
| 080501 | Air traffic, Dom. < 3000 ft. | Jet fuel | 1.06 | 72.00 | 9.32 | 22.99 | 330.14 | 9.51 | 107.31 | 0.00 | 1.16 | 0.56 |
| 080502 | Air traffic, Int. < 3000 ft. | AvGas | 21.90 | 73.00 | 2.00 | 22.83 | 859.00 | 1242.60 | 6972.00 | 1.60 | 10.00 | 1.50 |
| 080502 | Air traffic, Int. < 3000 ft. | Jet fuel | 1.09 | 72.00 | 5.63 | 22.99 | 352.63 | 9.77 | 105.59 | 0.00 | 1.16 | 0.56 |
| 080503 | Air traffic, Dom. > 3000 ft. | Jet fuel | 0.00 | 72.00 | 2.30 | 22.99 | 356.58 | 7.07 | 102.73 | 0.00 | 1.16 | 0.56 |
| 080504 | Air traffic, Int. > 3000 ft. | Jet fuel | 0.00 | 72.00 | 2.30 | 22.99 | 312.14 | 6.47 | 76.02 | 0.00 | 1.16 | 0.56 |
| 080600 | Agriculture | Diesel | 1.18 | 74.00 | 3.20 | 0.47 | 484.78 | 48.03 | 297.49 | 0.18 | 37.96 | 23.72 |
| 080600 | Agriculture | Gasoline | 150.56 | 73.00 | 1.70 | 0.46 | 109.75 | 1172.11 | 21868.55 | 1.49 | 30.50 | 1.52 |
| 080700 | Forestry | Diesel | 0.67 | 74.00 | 3.22 | 0.47 | 327.36 | 27.43 | 213.51 | 0.18 | 23.10 | 17.25 |
| 080700 | Forestry | Gasoline | 240.84 | 73.00 | 0.46 | 0.46 | 54.79 | 3754.36 | 17915.98 | 0.09 | 82.19 | 4.11 |
| 080800 | Industry | Diesel | 1.32 | 74.00 | 3.11 | 0.47 | 476.00 | 53.75 | 298.69 | 0.18 | 47.06 | 33.66 |
| 080800 | Industry | Gasoline | 60.50 | 73.00 | 1.49 | 0.46 | 213.59 | 1571.80 | 14228.73 | 0.10 | 22.10 | 1.10 |
| 080800 | Industry | LPG | 7.69 | 63.10 | 3.50 | 0.00 | 1328.11 | 146.09 | 104.85 | 0.21 | 4.89 | 0.24 |
| 080900 | Household and gardening | Gasoline | 49.71 | 73.00 | 1.26 | 0.46 | 108.21 | 2256.56 | 31048.01 | 0.09 | 17.36 | 0.87 |
| 081100 | Commercial and institutional | Gasoline | 73.80 | 73.00 | 1.13 | 0.46 | 93.28 | 1533.43 | 30913.57 | 0.09 | 28.53 | 1.43 |
| 080501 | Air traffic, Dom. < 3000 ft. | AvGas | 21.90 | 73.00 | 2.00 | 22.83 | 859.00 | 1242.60 | 6972.00 | 1.60 | 10.00 | 0.00 |
| 080501 | Air traffic, Dom. < 3000 ft. | Jet fuel | 1.39 | 72.00 | 5.69 | 22.99 | 327.09 | 12.49 | 141.70 | 0.00 | 1.16 | 0.56 |
| 080502 | Air traffic, Int. < 3000 ft. | AvGas | 21.90 | 73.00 | 2.00 | 22.83 | 859.00 | 1242.60 | 6972.00 | 1.60 | 10.00 | 0.00 |
| 080502 | Air traffic, Int. < 3000 ft. | Jet fuel | 1.17 | 72.00 | 3.64 | 22.99 | 359.17 | 10.56 | 130.33 | 0.00 | 1.16 | 0.56 |
| 080503 | Air traffic, Dom. > 3000 ft. | Jet fuel | 0.00 | 72.00 | 2.30 | 22.99 | 370.16 | 4.98 | 51.13 | 0.00 | 1.16 | 0.56 |
| 080504 | Air traffic, Int. > 3000 ft. | Jet fuel | 0.00 | 72.00 | 2.30 | 22.99 | 376.37 | 3.71 | 43.02 | 0.00 | 1.16 | 0.56 |

1) References. $SO_2$ and $CO_2$: Country-specific. $N_2O$ and BC: EMEP/EEA. $CH_4$: Railways: Danish State Railways/DCE; Agriculture/Forestry/Industry/Household-Gardening: IFEU; National sea traffic/Fishing/International sea traffic: Trafikministeriet/EMEP/EEA; domestic and international aviation: EMEP/EEA. Military: Aggregated emission factors for road transport; Railways ($NO_x$, CO, NMVOC and TSP): Danish State Railways; Agriculture, forestry, industry, household gardening and inland waterways ($NO_x$, CO, VOC and TSP): IFEU (2004, 2009, 2014); National sea transport and fishing: MAN B&W ($NO_x$) and TEMA2000 (CO, NMVOC, TSP); Aviation - jet fuel ($NO_x$, CO, NMVOC): EMEP/EEA; Aviation - av.gasoline: Aggregated emission factors for conventional gasoline cars.

2) kg/GJ for $CO_2$

### 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, 2009, 2014), and are shown in Annex 10. For more details regarding the use of these factors, please refer to paragraph 3.3.4 or Winther et al. (2006).

## 5.4 Calculation method

### 5.4.1 Air traffic

For aviation, the domestic and international estimates are made separately for landing and takeoff (LTOs < 3000 ft), and cruising (> 3000 ft).

By using the LTO mode specific fuel flow and emission indices from EMEP/EEA (2013), the fuel consumption and emission factors for the full LTO cycle can be estimated for each of the representative aircraft types used in the Danish inventory.

The fuel consumption for one LTO cycle is calculated according to the following sum formula:

$$FC^{a}_{LTO} = \sum_{m=1}^{4} t_m \cdot ff_{a,m} \tag{15}$$

Where FC = fuel consumption (kg), m = LTO mode (approach/landing, taxiing, takeoff, climb out), t = times in mode (s), ff = fuel flow (kg per s), a = representative aircraft type.

The emissions for one LTO cycle are estimated as follows:

$$E^{a}_{LTO} = \sum_{m=1}^{4} FC_{a,m} \cdot EI_{a,m} \tag{16}$$

Due to lack of specific airport data, for approach/descent, takeoff and climb out, standardised times-in-modes of 4, 0.7 and 2.2 minutes are used as defined by ICAO (ICAO, 1995), whereas for taxiing the appropriate time interval is 13 minutes in Copenhagen Airport and 5 minutes in other airports present in the Danish inventory.

For each representative aircraft type, the calculated fuel consumption and emission factors per LTO are shown in Annex 10 for Copenhagen Airport and other airports.

The calculations for cruise use the distance specific fuel consumption and emissions given by EMEP/EEA (2013) per representative aircraft type. Data interpolations or extrapolations are made – in each case determined by the great circle distance between the origin and the destination airports.

If the great circle distance, y, is smaller than the maximum distance for which fuel consumption and emission data are given in the EMEP/EEA data bank the fuel consumption or emission E (y) becomes:

$$E(y) = E_{x_i} + \frac{(y - x_i)}{x_{i+1} - x_i} \cdot (E_{x_{i+1}} - E_{x_i}) \qquad y<x_{max},\ i = 0,1,2\ldots max-1 \tag{17}$$

In (17) $x_i$ and $x_{max}$ denominate the separate distances and the maximum distance, respectively, with known fuel consumption and emissions. If the flight distance y exceeds $x_{max}$ the maximum figures for fuel consumption and emissions must be extrapolated and the equation then becomes:

$$E(y) = E_{x_{\max}} + \frac{(y - x_{\max})}{x_{\max} - x_{\max-1}} \cdot (E_{x_{\max}} - E_{x_{\max-1}}) \quad y > x_{max} \qquad (18)$$

Total results are summed up and categorised according to each flight's destination airport code in order to distinguish between domestic and international flights.

Annex 10 shows the average fuel consumption and emission factors per representative aircraft type for cruise flying, as well as total distance flown, for 2013[8]. The factors are split between Copenhagen Airport and other airports and distinguish between domestic and international flights.

Specifically for flights between Denmark and Greenland or the Faroe Islands, for each representative aircraft type, the flight distances are directly shown in Annex 10, which go into the cruise calculation expressions 17 and 18.

The overall fuel precision (fuel balance) in the model is 0.92 in 2013, derived as the fuel ratio between model estimates and statistical sales. The fuel difference is accounted for by adjusting cruising fuel consumption and emissions in the model according to domestic and international cruising fuel shares.

For inventory years before 2001, the calculation procedure is to estimate each year's fuel consumption and emissions for LTO based on LTO/aircraft type statistics from Copenhagen Airport, and total takeoff numbers for other airports provided by the Danish Transport Authority. Due to lack of aircraft type specific LTO data, fuel consumption and emission factors derived for domestic LTO's in Copenhagen Airport is used for all LTO's in other airports. In a next step, the total fuel consumption for cruise (true cruise fuel consumption) is found year by year as the statistical fuel consumption total minus the calculated fuel consumption for LTO.

For each inventory year, intermediate cruise fuel consumption figures are calculated internally in the DCE model. The intermediate fuel totals are split into four parts (Copenhagen/Other airports; domestic/international), found as proportional values between part specific LTO fuel consumption values estimated as described previously, and part specific cruise: LTO fuel consumption ratios for 1998. In the latter ratio, the cruise fuel contribution is taken from a Danish city-pair emission inventory in 1998 (Winther, 2001a), whereas the LTO fuel consumption is the 1998 figures estimated as explained above.

Each inventory year's true cruise fuel consumption is finally split into four parts by using the intermediate cruise fuel consumption values as a distribution key. As emission factor input data for cruise, aggregated fuel related emission factors are derived from the present model and the first historical year 2001.

[8] Excluding flights for Greenland and the Faroe Islands.

### 5.4.2 Non-road working machinery and recreational craft

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

$$E_{Basis}(X)_{i,j,k} = N_{i,j,k} \cdot HRS_{i,j,k} \cdot P \cdot LF_i \cdot EF_{y,z} \tag{19}$$

where $E_{Basis}$ = fuel consumption/emissions in the basic situation, N = number of engines, HRS = annual working hours, P = average rated engine size in kW, LF = load factor, EF = fuel consumption/emission factor in g per kWh, i = machinery type, j = engine size, k = engine age, y = engine-size class and z = emission level. The basic fuel consumption and emission factors are shown in Annex 11.

The deterioration factor for a given machinery type, engine size and engine age in year X depends on the engine-size class (only for gasoline), y, and the emission level, z. The deterioration factors for diesel and gasoline 2-stroke engines are found from:

$$DF_{i,j,k}(X) = \frac{K_{i,j,k}}{LT_i} \cdot DF_{y,z} \tag{20}$$

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:

$$DF_{i,j,k}(X) = \sqrt{\frac{K_{i,j,k}}{LT_i}} \cdot DF_{y,z} \tag{21}$$

The deterioration factors inserted in (20) and (21) are shown in Annex 11. No deterioration is assumed for fuel consumption (all fuel types) or for LPG engine emissions and, hence, DF = 1 in these situations.

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

$$TF_{i,j,k}(X) = TF_z \tag{22}$$

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

The transient factors inserted in (20) are shown in Annex 11. No transient corrections are made for gasoline and LPG engines and, hence, $TF_z$ = 1 for these fuel types.

The final calculation of fuel consumption and emissions in year X for a given machinery type, engine size and engine age, is the product of the expressions 17-20:

$$E(X)_{i,j,k} = E_{Basis}(X)_{i,j,k} \cdot TF(X)_{i,j,k} \cdot (1 + DF(X)_{i,j,k}) \quad (23)$$

The evaporative hydrocarbon emissions from fuelling are calculated as:

$$E_{Evap,\,fueling,i} = FC_i \cdot EF_{Evap,\,fueling} \quad (24)$$

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

For tank evaporation, the hydrocarbon emissions are found from:

$$E_{Evap,\tan k,i} = N_i \cdot EF_{Evap,\tan k,i} \quad (25)$$

Where $E_{Evap,tank,i}$ = hydrocarbon emissions from tank evaporation, N = number of engines, i = machinery type and $EF_{Evap,fueling}$ = emission factor in g NMVOC per year.

### 5.4.3 Ferries, other national sea transport and fisheries

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

$$E(X) = \sum_i N_i \cdot T_i \cdot S_{i,j} \cdot P_i \cdot LF_j \cdot EF_{k,l,y} \quad (26)$$

Where E = fuel consumption/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 consumption/emission factor in g per 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:

$$E(X) = \sum_i EC_{i,k} EF_{k,l,y} \quad (27)$$

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

The emission factor inserted in (27) 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:

$$EF_{k,l,y} = \frac{\sum_{year=X}^{year=X-LT} EF_{k,l}}{LT_{k,l}} \quad (28)$$

### 5.4.4 Other sectors

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

$$E = FC \cdot EF \tag{29}$$

where E = emission, FC = fuel consumption and EF = emission factor. The calculated emissions for other mobile sources are shown in CollectER format in Annex 16 for the years 1990 and 2013 and as time series 1990-2013 in Annex 15 (CRF format).

## 5.5 Fuel balance between DEA statistics and inventory estimates

Following convention rules, the DEA statistical fuel sales figures are the basis for the full Danish inventory. However, in some cases for mobile sources the DEA statistical sectors do not fully match the inventory sectors. This is the case for non-road machinery, where relevant DEA statistical sectors also include fuel consumed by stationary sources.

In other situations, fuel consumption figures estimated by DCE from specific bottom-up calculations are regarded as more reliable than DEA reported sales. This is the case for national sea transport.

In the following the transferral of fuel consumption data from DEA statistics into inventory relevant categories is explained for national sea transport and fisheries, non-road machinery and recreational craft, and road transport. A full list of all fuel consumption data, DEA figures as well as intermediate fuel consumption data, and final inventory input figures is shown in Annex 14.

### 5.5.1 National sea transport and fisheries

For national sea transport in Denmark, the fuel consumption estimates obtained by DCE (see 5.1.3 Activity data – national sea transport) are regarded as much more accurate than the DEA fuel sales data, since the large fluctuations in reported fuel sales cannot be explained by the actual development in the traffic between different national ports. As a consequence, the new bottom-up estimates replace the previous fuel based figures for national sea transport.

There are different potential reasons for the differences between estimated fuel consumption and reported sales for national sea transport in Denmark. According to the DEA, the latter fuel differences are most likely explained by inaccurate costumer specifications made by the oil suppliers. This inaccuracy can be caused by a sector misallocation in the sales statistics between national sea transport and fisheries for gas oil, and between national sea transport and industry for heavy fuel oil (Peter Dal, DEA, personal communication, 2007). Further, fuel sold for vessels sailing between Denmark and Greenland/Faroe Islands are reported as international in the DEA statistics, and this fuel categorisation is different from the IPCC guideline definitions (see following paragraph "Bunkers").

Following this, for fisheries and industry the updated fuel consumption time series for national sea transport lead, in turn, to changes in the fuel activity data for fisheries (gas oil), industry (heavy fuel oil) and international sea transport, so the national energy balance can remain unchanged.

For fisheries, fuel investigations made prior to the initiation of the work made by Winther (2008) have actually pointed out a certain area of inaccuracy in the DEA statistics. No engines installed in fishing vessels use heavy fuel oil, even though a certain amount of heavy fuel oil is listed in the DEA numbers for some statistical years (H. Amdissen, Danish Fishermen's Association, personal communication, 2006). Hence, for fisheries small amounts of fuel oil are transferred to national sea transport, and in addition small amounts of gasoline and diesel are transferred to recreational craft.

### 5.5.2 Non road machinery and recreational craft

For diesel and LPG, the non-road fuel consumption estimated by DCE is partly covered by the fuel consumption amounts in the following DEA sectors: agriculture and forestry, market gardening, and building and construction. The remaining quantity of non-road diesel and LPG is taken from the DEA industry sector.

For gasoline, the DEA residential sector, together with the DEA sectors mentioned for diesel and LPG, contribute to the non-road fuel consumption total. In addition, a certain amount of fuel from road transport is needed to reach the fuel consumption 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 consumption totals for diesel and gasoline are subsequently subtracted from the DEA fishery sector. For gasoline, the DEA reported fuel consumption for fisheries is far too small to fill the fuel gap, and hence the missing fuel amount is taken from the DEA road transport sector.

## 5.6 Bunker fuel definition by IPCC

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.

### 5.6.1 Aviation

As prescribed by the IPCC guidelines, for aviation, the fuel consumption and emissions associated with flights inside the Kingdom of Denmark are counted as domestic.

This report includes flights from airports in Denmark and associated jet fuel sales. Hence, the flights between airports in Denmark and flights from Denmark to Greenland and the Faroe Islands are classified as domestic and flights from Danish airports with destinations outside the Kingdom of Denmark are classified as international flights.

In Greenland and in the Faroe Islands, the jet fuel sold is treated as domestic. This decision becomes reasonable when considering that almost no fuel is bunkered in Greenland/the Faroe Islands by flights other than those going to Denmark.

### 5.6.2 Navigation

In DEA statistics, the domestic fuel total consists of fuel sold to Danish ferries and other ships sailing between two Danish ports. The DEA international fuel total consists of the fuel sold in Denmark to international ferries, international warships, other ships with foreign destinations, transport to Greenland and the Faroe Islands, tank vessels and foreign fishing boats.

In order to follow the IPCC guidelines the bottom-up fuel estimates for the ferry routes between Denmark and the Faroe Islands, and freight transport between Denmark and Greenland/Faroe Islands are being subtracted from the fuel sales figures for international sea transport prior to inventory fuel input.

In Greenland, all marine fuel sales are treated as domestic. In the Faroe Islands, fuel sold in Faroese ports for Faroese fishing vessels and other Faroese ships is treated as domestic. The fuel sold to Faroese ships bunkering outside Faroese waters and the fuel sold to foreign ships in Faroese ports or outside Faroese waters is classified as international (Lastein and Winther, 2003).

Conclusively, the domestic/international fuel split (and associated emissions) for navigation is not determined with the same precision as for aviation. It is considered, however, that the potential of incorrectly allocated fuel quantities is only a small part of the total fuel sold for navigational purposes in the Kingdom of Denmark.

# 6 Fuel consumption and emissions

## 6.1 Fuel consumption

Table 6.1 shows the fuel consumption for domestic transport based on DEA statistics for 2013 and grouped according to the CRF/NFR classification codes shown in Table 3.1. For civil aviation the fuel consumption totals in Table 6.1 are summarized in two groups according to the CRF format; domestic aviation (domestic LTO + domestic cruise) and international aviation (international LTO + international cruise), as noted in Chapter 3.

The fuel consumption figures in time series 1985-2013 are given in Annex 16 in both CRF and NFR formats. For civil aviation the NFR format consist of four groups; domestic and international LTO and domestic and international cruise. Fuel results are also shown for 2013 in Annex 15 (CollectER format).

Road transport has a major share of the fuel consumption for domestic transport. In 2013 this sector's fuel consumption share is 75 %, while the fuel consumption shares for Off-road agriculture/forestry and Manufacturing industries (mobile) are 7 %, in both cases. For the remaining sectors the total fuel consumption share is 11 %.

**Table 6.1**. Fuel consumption (PJ) for domestic transport in 2013 in CRF sectors.

| CRF/NFR category | Fuel consumption (PJ) |
|---|---|
| Manufacturing industries/Construction (mobile) | 14.0 |
| Civil aviation (Domestic)* | 1.9 |
| Road transport: Passenger cars | 95.3 |
| Road transport:Light duty vehicles | 22.4 |
| Road transport:Heavy duty vehicles | 39.8 |
| Road transport: Mopeds & motorcycles | 0.9 |
| Railways | 3.3 |
| National navigation (Shipping) | 5.2 |
| Commercial/Institutional: Mobile | 2.3 |
| Residential: Household and gardening (mobile) | 0.9 |
| Agriculture/Forestry/Fishing: Off-road agriculture/forestry | 15.5 |
| Agriculture/Forestry/Fishing: National fishing | 6.9 |
| Other, Mobile | 3.3 |
| Road transport total | 158.3 |
| Other mobile total | 53.3 |
| Domestic total | 211.7 |
| Civil aviation (International) * | 34.4 |
| Navigation (international) | 24.7 |

* Grouped according to UNFCCC reporting definitions

From 1990 to 2013, diesel (sum of diesel and biodiesel) and gasoline (sum of gasoline and E5) fuel consumption has changed by 40 % and - 15 %, respectively (Figure 6.1), and in 2013 the fuel consumption shares for diesel and gasoline were 69 % and 28 %, respectively (not shown). Other fuels only have a 3 % share of the domestic transport total (Figure 6.2). Almost all gasoline is used in road transportation vehicles. Gardening machinery and recreational craft are merely small consumers. Regarding diesel, there is considerable fuel consumption in most of the domestic 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[9].

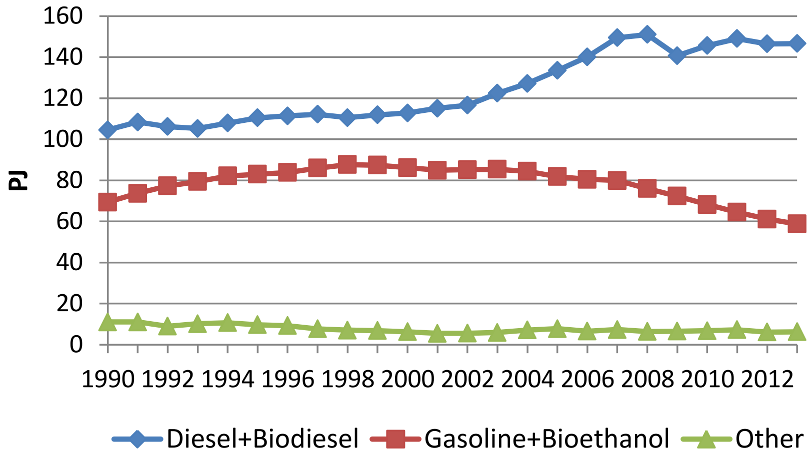



**Figure 6.1**. Fuel consumption per fuel type for domestic transport 1990-2013.

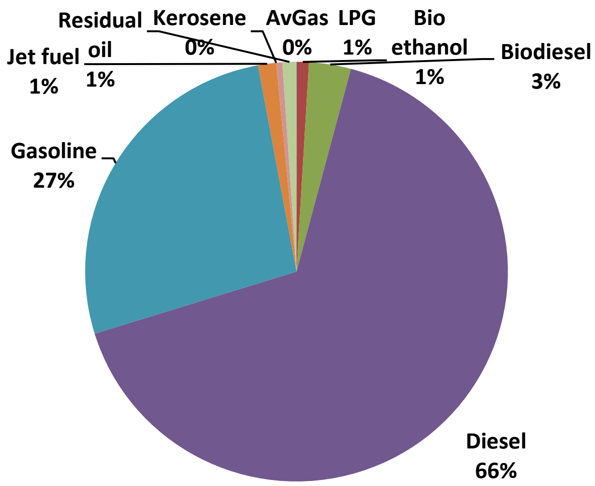



**Figure 6.2**. Fuel consumption share per fuel type for domestic transport in 2013.

### 6.1.1 Road transport

As shown in Figure 6.3, the fuel consumption for road transport[10] has generally increased until 2007, except from a small fuel consumption decline noted in 2000. The impact of the global financial crisis on fuel consumption for road transport becomes visible for 2008 and 2009. The fuel consumption development is due to a decreasing trend in the use of gasoline fuels from 1999 onwards combined with a steady growth in the use of diesel until 2007. Within sub-sectors, passenger cars represent the most fuel-consuming vehicle category, followed by heavy -duty vehicles, light duty vehicles and 2-wheelers, in decreasing order (Figure 6.4).

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[9] Biofuels are sold at gas filling stations and are assumed to be used by road transport vehicles.

[10] The sum share of bioethanol and biodiesel in the gasoline and diesel fuel blends for road transport is 5.5 %, in 2013.

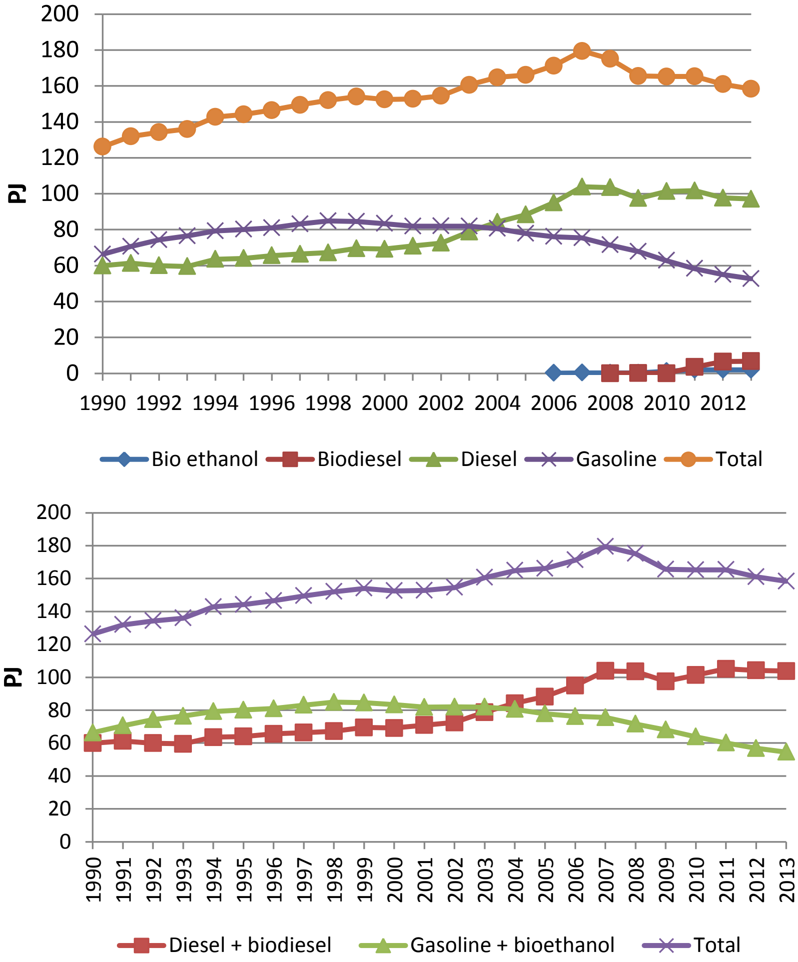


**Figure 6.3**. Fuel consumption per fuel type and as totals for road transport 1990-2013.

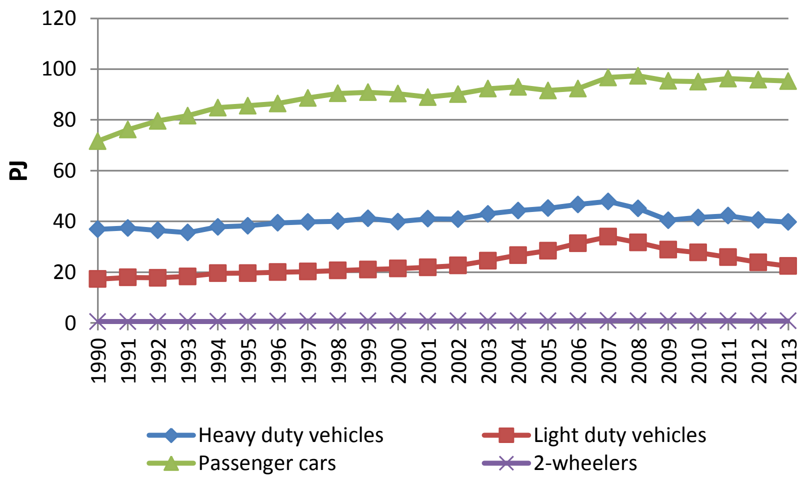


**Figure 6.4**. Total fuel consumption per vehicle type for road transport 1990-2013.

As shown in Figure 6.5, fuel consumption for gasoline passenger cars dominates the overall gasoline consumption trend. The development in diesel fuel consumption in recent years (Figure 6.6) is characterised by increasing fuel consumption for diesel passenger cars, while declines in the fuel consumption for trucks and buses (heavy-duty vehicles) and light duty vehicles are noted for 2008- 2009, 2012, and 2008-2012, respectively.

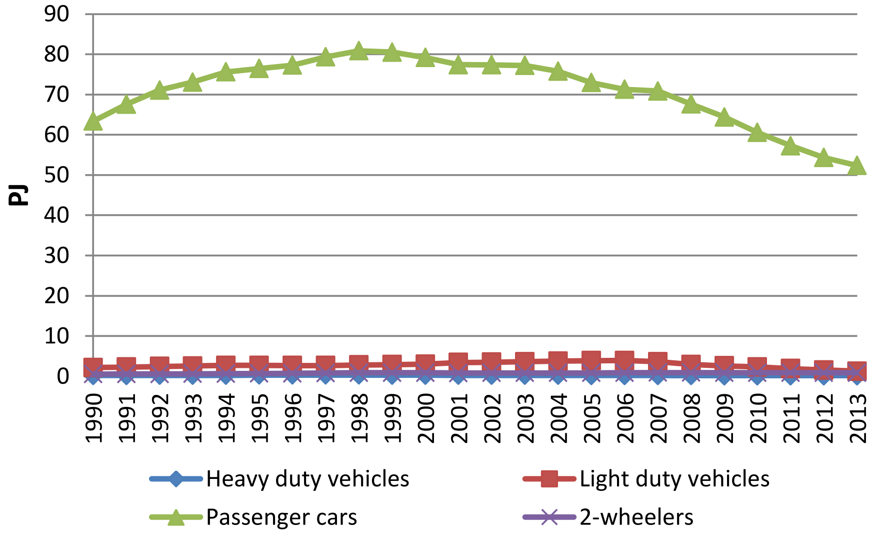


**Figure 6.5**. Gasoline fuel consumption per vehicle type for road transport 1990-2013.

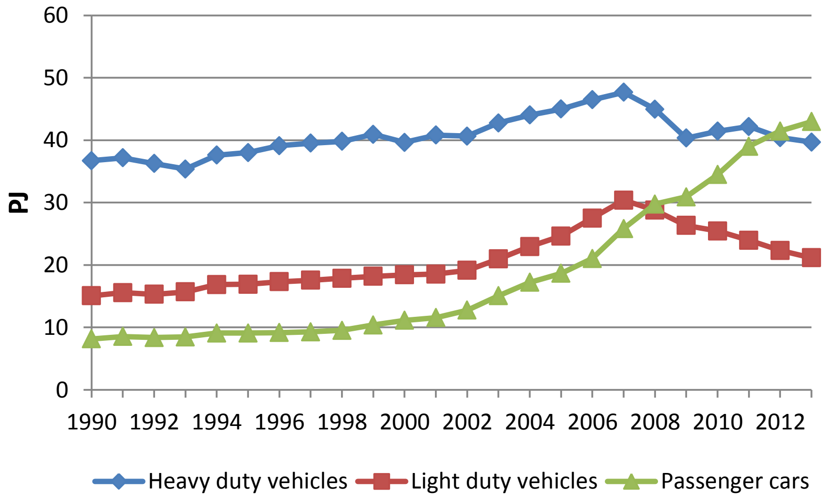


**Figure 6.6**. Diesel fuel consumption per vehicle type for road transport 1990-2013.

In 2013, fuel consumption shares for gasoline passenger cars, diesel passenger cars, heavy duty vehicles and gasoline light duty vehicles were 33, 27, 25, 13 and 1 %, respectively (Figure 6.7).

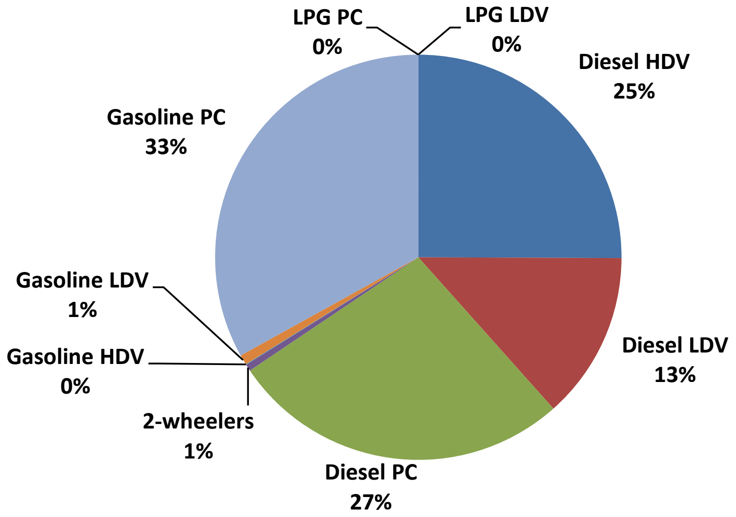


**Figure 6.7**. Fuel consumption share (PJ) per vehicle type for road transport in 2013.

### 6.1.2 Other mobile sources

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

As seen in Figure 6.8, classified according to CRF the most important sectors are Agriculture/forestry (1A4cii), Industry-other (mobile machinery part of 1A2g) and Navigation (1A3d). Minor fuel consuming sectors are Civil Aviation (1A3a), Railways (1A3c), Other (military mobile and recreational craft: 1A5b), Commercial/institutional (1A4a) and Residential (1A4b).

The 1985-2013 time series are shown per fuel type in Figures 6.9 - 6.12 for diesel, gasoline and jet fuel, respectively.

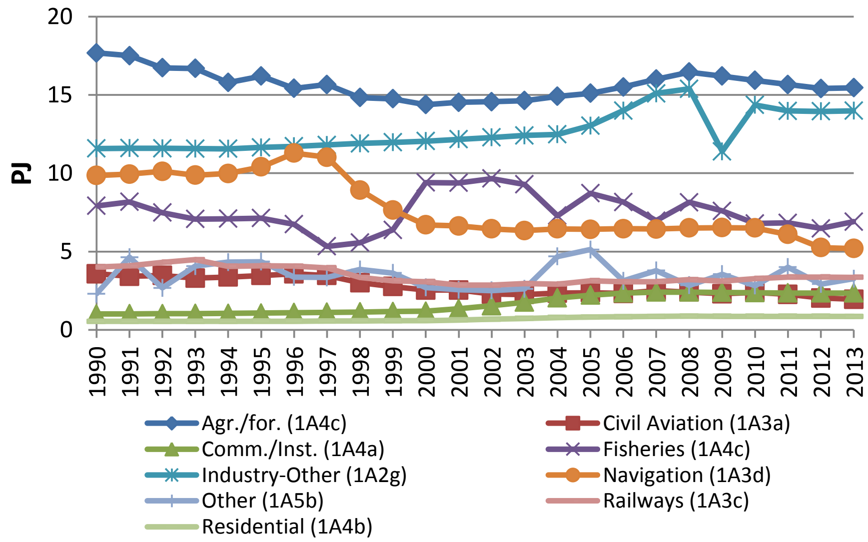


**Figure 6.8**. Total fuel consumption in CRF sectors for other mobile sources 1990-2013.

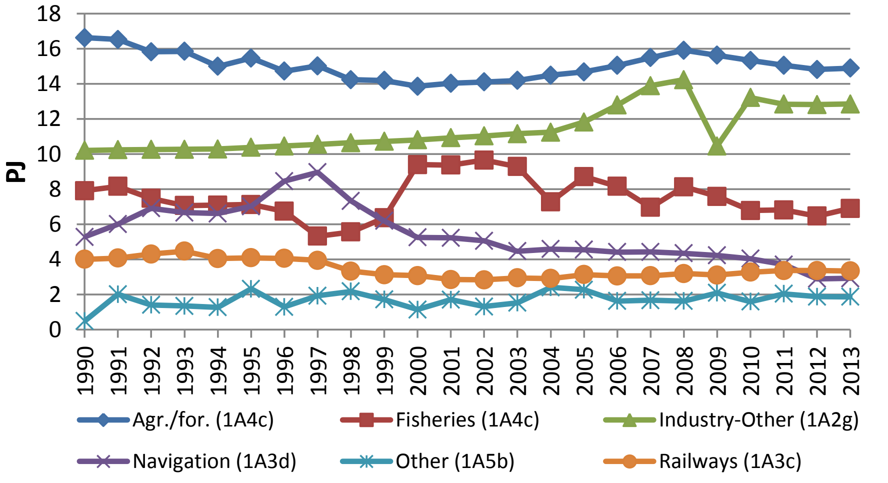


**Figure 6.9**. Diesel fuel consumption in CRF sectors for other mobile sources 1990-2013.

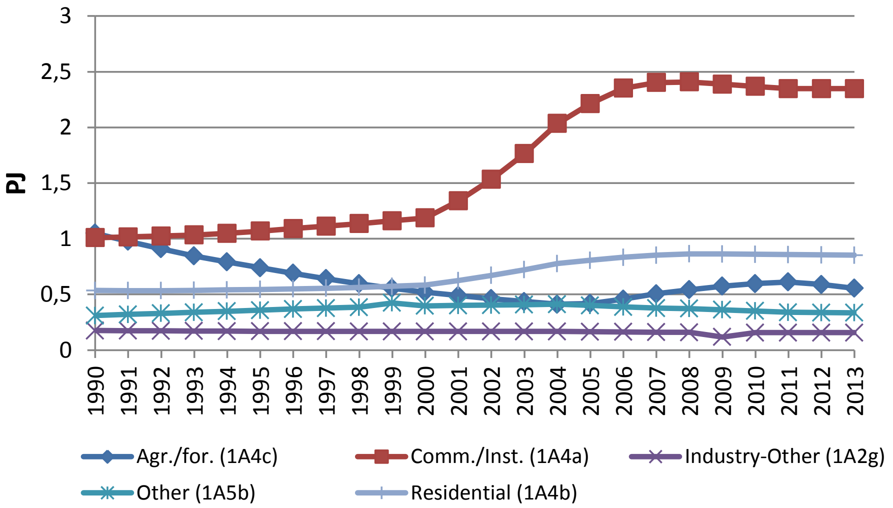


**Figure 6.10**. Gasoline fuel consumption in CRF sectors for other mobile source 1990-2013.

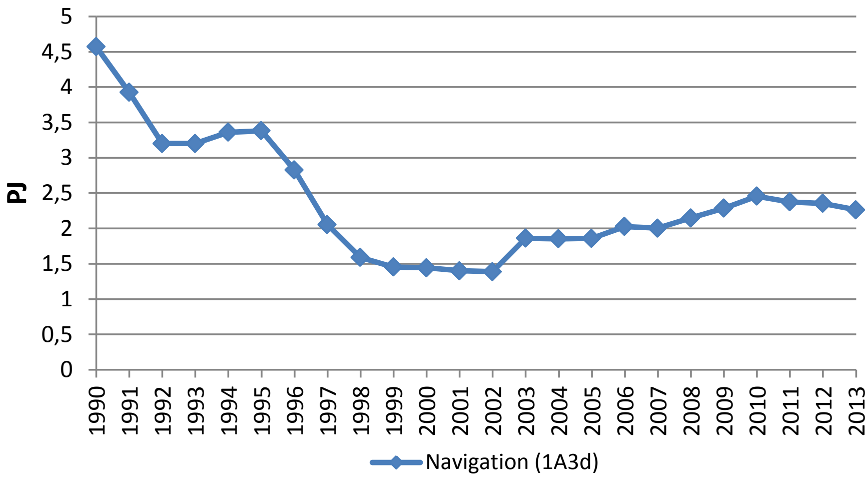


**Figure 6.11**. Residual oil fuel consumption in CRF sectors for other mobile sources 1990-2013.

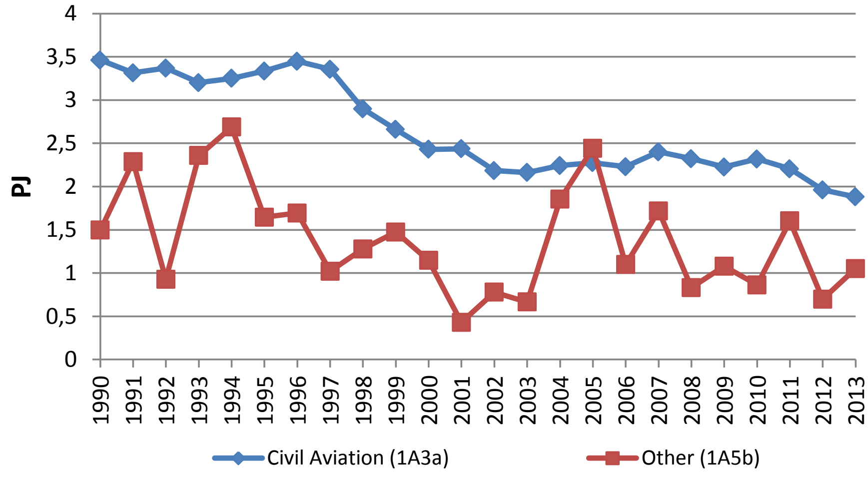


**Figure 6.12**. Jet fuel consumption in CRF sectors for other mobile sources 1990-2013.

In terms of diesel, the fuel consumption 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 consumption for industry has increased from the beginning of the 1990's, due to an increase in the activities for construction machinery. The fuel consumption increase has been very pronounced in 2005-2008, for 2009, however, the global financial crisis has a significant impact on the building and construction activities. For fisheries, the development in fuel consumption reflects the activities in this sector.

The Navigation sector comprises national sea transport (fuel consumption between two Danish ports including sea travel directly between Denmark and Greenland/Faroe Islands). For national sea transport, the diesel fuel consumption curve reflects the combination of traffic and ferries in use for regional ferries. From 1998 to 2000, a significant decline in fuel consumption is apparent. The most important explanation here is the closing of ferry service routes in connection with the opening of the Great Belt Bridge in 1997. The fuel consumption decreases in 2011 and 2012 are due to reductions in the number of round trips made by regional ferries. For railways, the gradual shift towards electrification explains the lowering trend in diesel fuel consumption and the emissions for this transport sector. The fuel consumed (and associated emissions) to produce electricity is accounted for in the stationary combustion part of the Danish inventories.

The largest gasoline fuel consumption is found for household and gardening machinery in the Commercial/Institutional (1A4a) and Residential (1A4b) sectors. Especially from 2001-2006, a significant fuel consumption increase is apparent due to considerable growth in the machinery stock. The decline in gasoline fuel consumption for Agriculture/forestry/fisheries (1A4c) is due to the gradual phasing out of gasoline-fuelled agricultural tractors.

In terms of residual oil there has been a substantial decrease in the fuel consumption for regional ferries. The fuel consumption decline is most significant from 1990-1992 and from 1997-1999.

The considerable variations from one year to another in military jet fuel consumption are due to planning and budgetary reasons, and the passing demand for flying activities. Consequently, for some years, a certain amount of jet fuel stock-building might disturb the real picture of aircraft fuel consumption. Civil aviation has decreased until 2004, since the opening of the Great Belt Bridge in 1997, both in terms of number of flights and total jet fuel consumption. After 2004 an increase in the consumption of jet fuel is noted until 2007/2008.

### 6.1.3 Bunkers

The residual oil and diesel oil fuel consumption fluctuations reflect the quantity of fuel sold in Denmark to international ferries, international warships, other ships with foreign destinations, tank vessels and foreign fishing boats. For jet petrol, the sudden fuel consumption 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. In 2009, the impact of the global financial crisis on flying activities becomes very visible.

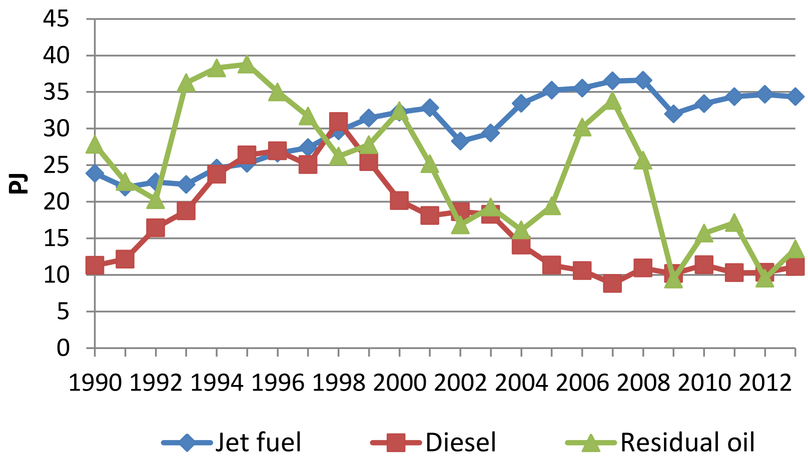


**Figure 6.13**. Bunker fuel consumption 1990-2013.

## 6.2 Emissions of $CO_2$, $CH_4$ and $N_2O$

In Table 6.2 the emissions of $CO_2$, $CH_4$ and $N_2O$ and the total greenhouse gas emissions[11] for road transport and other mobile sources are shown for 2013 in CRF sectors. The emission figures in time series 1990-2013 are given in Annex 16 (CRF format) and are shown for 1990 and 2013 in Annex 15 (CollectER format).

From 1990 to 2013 the road transport emissions of $CO_2$ and $N_2O$ have increased by 19 and 30 %, respectively, whereas the emissions of $CH_4$ have decreased by 78 % (from Figures 6.14 - 6.16). From 1990 to 2013 the other mobile $CO_2$ emissions have decreased by 9 %, (from Figure 6.18).

[11]Calculated in $CO_2$ equivalents. Referring to the second IPCC assessment report, 1 g $CH_4$ and 1 g $N_2O$ has the greenhouse effect of 25 and 298 g $CO_2$, respectively.

**Table 6.2**. Emissions of $CO_2$, $CH_4$ and $N_2O$ and total greenhouse gases in 2013 for road transport and other mobile sources.

| | $CO_2$ ktonnes | $CH_4$ tonnes | $N_2O$ tonnes | Total GHG Ktonnes $CO_2$e |
|---|---|---|---|---|
| Manufacturing industries/Construction (mobile) | 1025 | 34 | 44 | 1038 |
| Civil aviation (Domestic) | 140 | 2 | 7 | 142 |
| Road transport: Passenger cars | 6658 | 298 | 199 | 6725 |
| Road transport:Light duty vehicles | 1552 | 14 | 49 | 1567 |
| Road transport:Heavy duty vehicles | 2751 | 82 | 130 | 2791 |
| Road transport: Mopeds & motorcycles | 60 | 87 | 1 | 63 |
| Railways | 248 | 6 | 7 | 0 |
| National navigation (Shipping) | 393 | 10 | 25 | 0 |
| Commercial/Institutional: Mobile | 171 | 173 | 3 | 0 |
| Residential: Household and gardening (mobile) | 62 | 42 | 1 | 0 |
| Agriculture/Forestry/Fishing: Off-road agriculture/forestry | 1143 | 108 | 48 | 250 |
| Agriculture/Forestry/Fishing: National fishing | 511 | 12 | 32 | 401 |
| Other, Mobile | 239 | 15 | 9 | 177 |
| Road transport exhaust total | 11021 | 481 | 379 | 64 |
| Road transport non exhaust total | 0 | 0 | 0 | 1161 |
| Other mobile sources total | 3933 | 402 | 175 | 521 |
| Domestic total | 14954 | 884 | 555 | 242 |
| Civil aviation (International) | 2473 | 4 | 84 | 11146 |
| Navigation (International) | 1878 | 47 | 118 | 0 |

### 6.2.1 Road transport

$CO_2$ emissions are directly fuel consumption dependent and, in this way, the development in the emission reflects the trend in fuel consumption. As shown in Figure 6.14, the most important emission source for road transport is passenger cars, followed by heavy duty vehicles, light duty vehicles and 2-wheelers in decreasing order. In 2013, the respective emission shares were 60, 25, 14 and 1 %, respectively (Figure 6.17).

The majority of $CH_4$ emissions from road transport come from gasoline passenger cars (Figure 6.15). The emission drop from 1992 onwards is explained by the penetration of catalyst cars into the Danish fleet. The 2013 emission shares for $CH_4$ were 62, 18, 17 and 3 % for passenger cars, 2-wheelers, heavy duty vehicles and light duty vehicles, respectively (Figure 6.17).

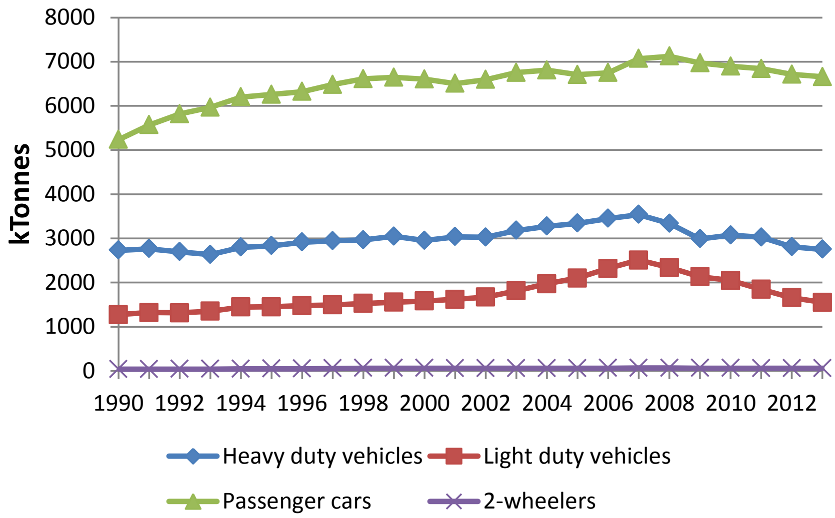


**Figure 6.14**. $CO_2$ emissions (k-tonnes) per vehicle type for road transport 1990-2013.

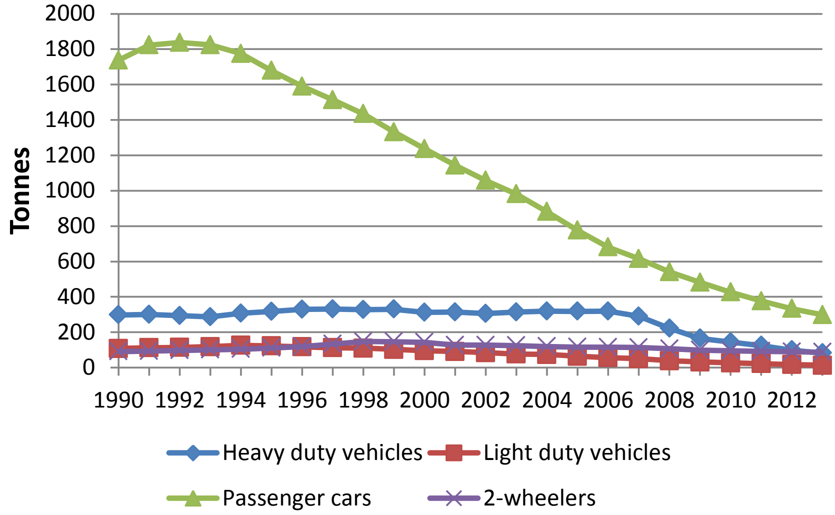


**Figure 6.15**. $CH_4$ emissions (tonnes) per vehicle type for road transport 1990-2013.

An undesirable environmental side effect of the introduction of catalyst cars is the increase in the emissions of $N_2O$ from the first generation of catalyst cars (Euro 1) compared to conventional cars. The emission factors for later catalytic converter technologies are considerably lower than the ones for Euro 1, thus causing the emissions to decrease from 1998 onwards (Figure 6.16). In 2013, emission shares for passenger cars, heavy and light duty vehicles were 53, 34 and 13 %, of the total road transport $N_2O$, respectively (Figure 6.17).

In spite of the relatively large $CH_4$ and $N_2O$ global warming potentials, 1 g $CH_4$ and 1 g $N_2O$ has the greenhouse effect of 21 and 310 g $CO_2$, respectively, the largest contribution to the total $CO_2$ emission equivalents for road transport comes from $CO_2$, and the $CO_2$ emission equivalent shares per vehicle category are almost the same as the $CO_2$ shares.

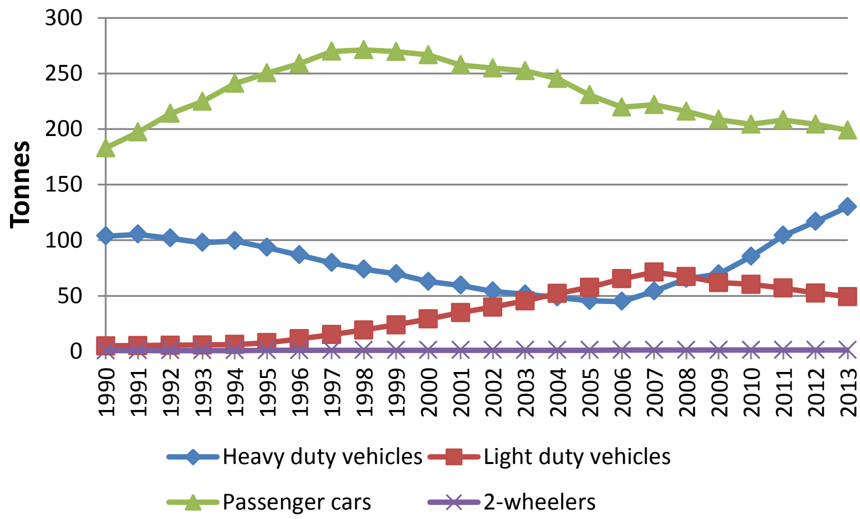


**Figure 6.16.** $N_2O$ emissions (tonnes) per vehicle type for road transport 1990-2013.

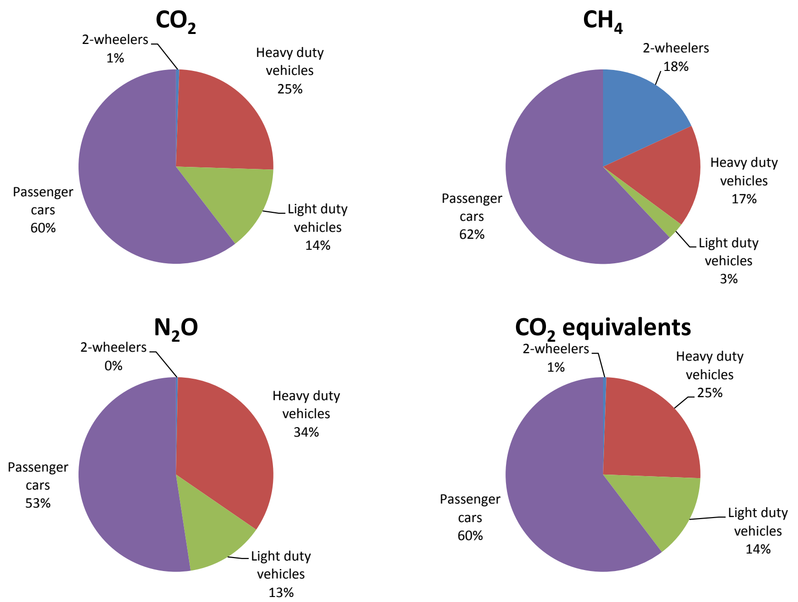


**Figure 6.17.** $CO_2$, $CH_4$ and $N_2O$ emission shares and GHG equivalent emission distribution for road transport in 2013.

### 6.2.2 Other mobile sources

For other mobile sources, the highest $CO_2$ emissions in 2013 come from Agriculture/forestry/fisheries (1A4c), Industry-other (1A2g) and Navigation (1A3d), with shares of 42, 26 and 10 %, respectively (Figure 6.21). The 1990-2013 emission trend is directly related to the fuel consumption development in the same time-period. Minor $CO_2$ emission contributors are sectors such as Commercial/Institutional (1A4a), Residential (1A4b), Railways (1A3c), Civil Aviation (1A3a) and Military (1A5).

For $CH_4$, far the most important sources are the gasoline fuelled gardening machinery in the Commercial/Institutional (1A4a) and Residential (1A4b) sectors, see Figure 6.21. The emission shares are 43 % and 11 %, respectively in 2013. The 2013 emission shares for Agriculture/forestry/fisheries (1A4c) and Industry (1A2g) are 40 and 8 %, respectively, whereas the remaining sectors have emission shares of 4 % or less.

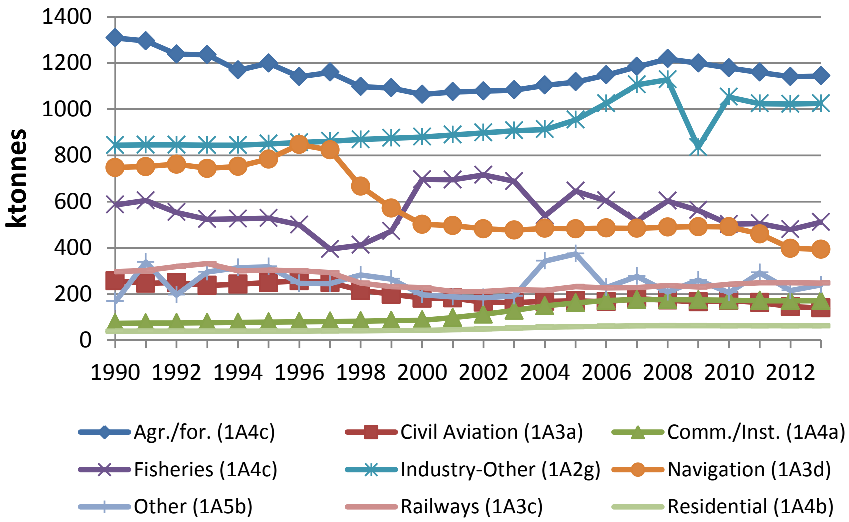


**Figure 6.18**. $CO_2$ emissions (ktonnes) in CRF sectors for other mobile sources 1990-2013.

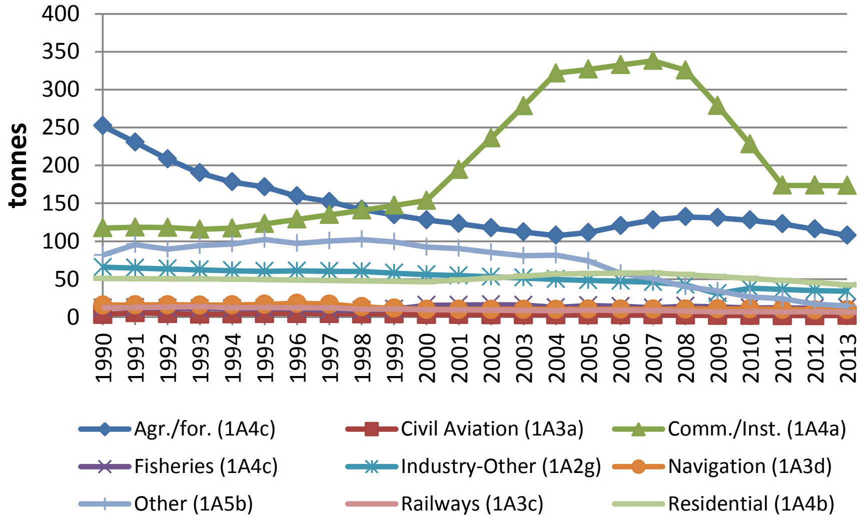


**Figure 6.19**. $CH_4$ emissions (tonnes) in CRF sectors for other mobile sources 1990-2013.

For $N_2O$, the emission trend in sub-sectors is the same as for fuel consumption and $CO_2$ emissions (Figure 6.20).

As for road transport, $CO_2$ alone contributes with by far the most $CO_2$ emission equivalents in the case of other mobile sources, and per sector the $CO_2$ emission equivalent shares are almost the same as those for $CO_2$, itself (Figure 6.21).

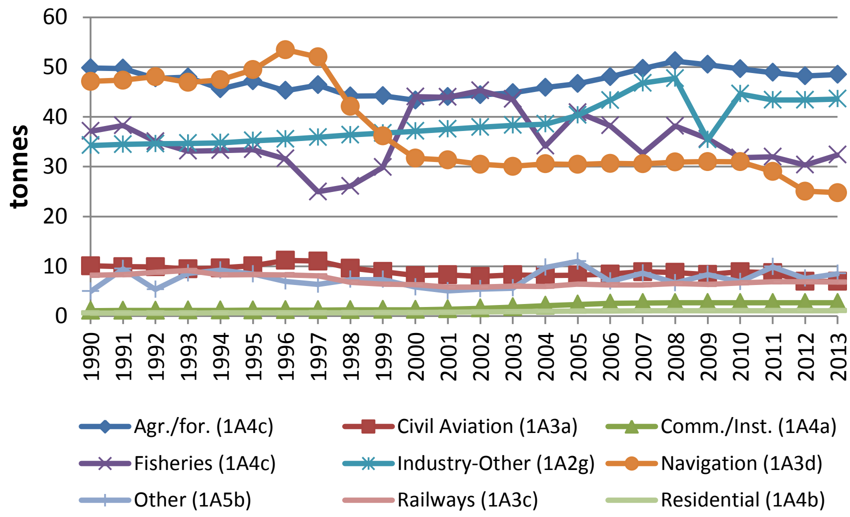


**Figure 6.20**. $N_2O$ emissions (tonnes) in CRF sectors for other mobile sources 1990-2013.

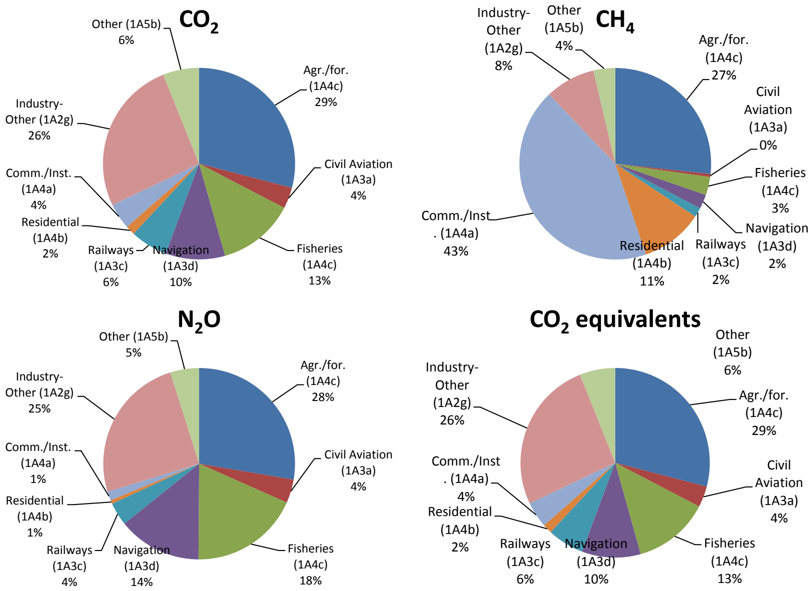


**Figure 6.21**. $CO_2$, $CH_4$ and $N_2O$ emission shares and GHG equivalent emission distribution for other mobile sources in 2013.

## 6.3 Emissions of $SO_2$, $NO_X$, NMVOC, CO, $NH_3$, TSP, $PM_{10}$, $PM_{2.5}$ and BC

In Table 6.3 the $SO_2$, $NO_X$, NMVOC, CO $NH_3$, TSP, $PM_{10}$, $PM_{2.5}$ and BC emissions for road transport and other mobile sources are shown for 2013 in NFR sectors. For Civil aviation, however, the emissions totals in Table 6.3 are summarized according to the CRF definition of Domestic aviation (domestic LTO + domestic cruise) and International aviation (international LTO + international cruise), as noted in Chapter 3 and in the beginning of paragraph 6.1.

The emission figures in the time series 1985-2013 are given in Annex 16 (NFR format) and are shown for 2013 in Annex 15 (CollectER format).

From 1985 to 2013, the road transport emissions of $SO_2$, $NO_X$, NMVOC, CO, PM (exhaust emissions; all size fractions) and BC have decreased by 99, 57, 88, 85, 74 and 54 %, respectively (Figures 6.22 – 6.27), whereas the $NH_3$ emissions have increased by 1916 % during the same time period (Figure 6.28).

For other mobile sources, the emission changes for $SO_2$, $NO_X$, NMVOC, CO and PM (all size fractions) are -90, -29, -40, -5, -73 and -68 %, respectively (Figures 6.31 – 6.36). The $NH_3$ emissions have increased by 15 % during the same time period (Figure 6.37).

**Table 6.3**. Emissions of $SO_2$, $NO_X$, NMVOC, CO $NH_3$, TSP, $PM_{10}$, $PM_{2.5}$ and BC in 2013 for road transport and other mobile sources.

| | $SO_2$ tonnes | $NO_x$ tonnes | NMVOC tonnes | CO tonnes | $NH_3$ tonnes | TSP tonnes | $PM_{10}$ tonnes | $PM_{2.5}$ tonnes | BC tonnes |
|---|---|---|---|---|---|---|---|---|---|
| Manufacturing industries/Construction (mobile) | 6 | 7 454 | 1 079 | 6 164 | 3 | 613 | 613 | 613 | 433 |
| Civil aviation (Domestic) | 45 | 724 | 94 | 614 | 0 | 3 | 3 | 3 | 1 |
| Road transport: Passenger cars | 42 | 18 094 | 5 640 | 69 286 | 1 218 | 503 | 503 | 503 | 364 |
| Road transport:Light duty vehicles | 10 | 6 230 | 546 | 3 887 | 28 | 344 | 344 | 344 | 274 |
| Road transport:Heavy duty vehicles | 17 | 16 185 | 389 | 5 897 | 25 | 258 | 258 | 258 | 178 |
| Road transport: Mopeds & motorcycles | 0 | 144 | 1 322 | 7 550 | 1 | 26 | 26 | 26 | 4 |
| Road transport: Gasoline evaporation | 0 | 0 | 1 410 | 0 | 0 | 0 | 0 | 0 | 0 |
| Road transport: Brake wear | 0 | 0 | 0 | 0 | 0 | 497 | 487 | 194 | 13 |
| Road transport: Tyre wear | 0 | 0 | 0 | 0 | 0 | 877 | 526 | 369 | 134 |
| Road transport: Road abrasion | 0 | 0 | 0 | 0 | 0 | 1 080 | 540 | 292 | 0 |
| Railways | 2 | 2 361 | 164 | 372 | 1 | 70 | 70 | 70 | 46 |
| National navigation (Shipping) | 1 243 | 8 059 | 271 | 908 | 0 | 163 | 161 | 160 | 32 |
| Commercial/Institutional: Mobile | 1 | 219 | 3 601 | 72 587 | 0 | 67 | 67 | 67 | 3 |
| Residential: Household and gardening (mobile) | 0 | 92 | 1 924 | 26 477 | 0 | 15 | 15 | 15 | 1 |
| Agriculture/Forestry/Fishing: Off-road agriculture/forestry | 7 | 7 257 | 1 545 | 16 294 | 3 | 584 | 584 | 584 | 353 |
| Agriculture/Forestry/Fishing: National fishing | 323 | 9 139 | 400 | 1 318 | 0 | 149 | 147 | 147 | 46 |
| Other, Mobile | 72 | 1 513 | 376 | 3 881 | 1 | 99 | 99 | 99 | 39 |
| Road transport exhaust total | 69 | 40 654 | 9 307 | 86 619 | 1 272 | 1 131 | 1 131 | 1 131 | 821 |
| Road transport non exhaust total | 0 | 0 | 0 | 0 | 0 | 2 454 | 1 554 | 854 | 147 |
| Other mobile sources total | 1 700 | 36 819 | 9 454 | 128 615 | 8 | 1 763 | 1 760 | 1 758 | 954 |
| Domestic total | 1 769 | 77 473 | 18 761 | 215 234 | 1 280 | 5 348 | 4 444 | 3 743 | 1 922 |
| Civil aviation (International) | 790 | 12 636 | 163 | 1 898 | 0 | 40 | 40 | 40 | 19 |
| Navigation (International) | 7 140 | 46 358 | 1 510 | 4 982 | 0 | 835 | 827 | 822 | 146 |

### 6.3.1 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 6.22). 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 2013 shares for $SO_2$ emissions and fuel consumption for passenger cars, heavy duty vehicles, light duty vehicles and 2-wheelers are the same in each case: 60, 25, 14 and 1 %, respectively (Figure 6.22).

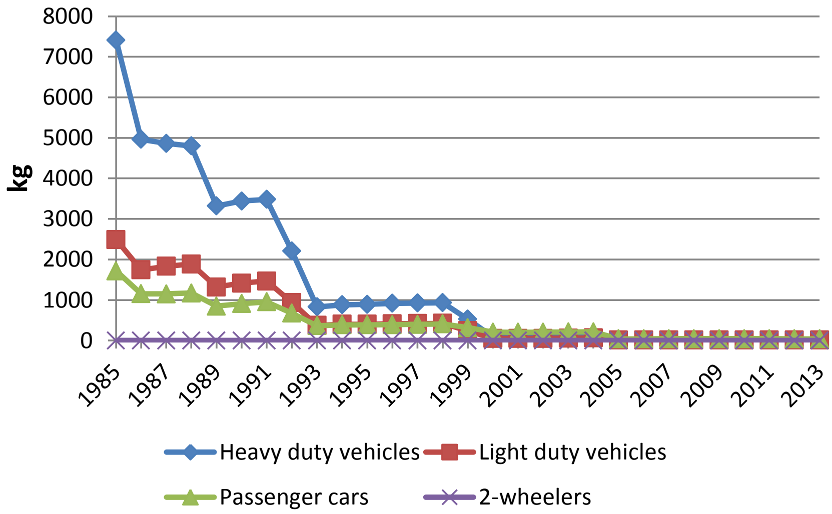


**Figure 6.22**. $SO_2$ emissions (tonnes) per vehicle type for road transport 1985-2013.

Historically, the emission totals of NMVOC and CO have been very dominated by the contributions coming from private cars, as shown in Figures 6.24 - 6.25. 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, III, IV and V private cars (introduced in 1997, 2001, 2006 and 2011, respectively).

For $NO_x$ the emission decrease for passenger cars is composed of a significant drop in emissions from gasoline cars driven by technology improvements, and an increase in emissions from diesel cars due to the dieselization of the Danish fleet of passenger cars (Figure 4.2), and almost unchanged emission factors for diesel passenger cars throughout the period regardless of EU emission legislation demands. For light duty vehicles the $NO_x$ emission trend is also the result of a technology driven emission reduction for gasoline vans, and a traffic induced emission increase for diesel vans; the emission factors for the latter vehicle category have been relatively constant over the years just as for diesel cars.

For heavy duty vehicles the real traffic $NO_x$ emissions are not reduced in the order as intended by the EU emission legislation. Most markedly for Euro II engines the emission factors are even higher than for Euro I due to the so-called engine cycle-beating effect. Outside the legislative test cycle stationary measurement points, the electronic engine control for heavy duty Euro II engines switches to a fuel efficient engine running mode, thus leading to increasing $NO_x$ emissions (Figure 6.23). However, the reduction in transport activities due to the global financial crisis causes the $NO_x$ emissions for heavy duty vehicles to decrease significantly in 2008 and 2009.

Exhaust particulate emissions from road transportation vehicles are well below $PM_{2.5}$. The emissions from light- and heavy-duty vehicles have significantly decreased since the mid-1990s (Figure 6.26) due to gradually stricter EURO emission standards. In recent years until 2008 the environmental benefit of introducing gradually cleaner diesel private cars and vans has been somewhat outbalanced by an increase in sales of new vehicles (e.g. Figure 4.1). After 2008 new sales of diesel private cars still increase due to the continuous dieselization of the private car fleet, whereas diesel van new sales decrease mainly due to the financial crisis. In both cases PM emissions gradually reduce due to the increasing number of Euro V cars equipped with particulate filter sold in Denmark from 2006 onwards (Figure 6.26).

BC is commonly understood as the solid part of the particulate emissions. BC is calculated as shares of TSP for each Euro engine technology class and in broad terms the development in BC emissions follows the TSP emission trend, but deviates to some extent, most markedly for diesel cars and vans. For these vehicle types the BC share of TSP increases in moderate steps from conventional engine technologies to Euro IV. Therefore the BC emission development becomes environmentally less positive than for TSP, until Euro V vehicles enter into the fleet, in which case the installed particulate filters have very high removal rates of BC.

An undesirable environmental side effect of the introduction of catalyst cars is the increase in the emissions of $NH_3$ from the first two generations of catalyst cars (Euro I and II) compared to conventional cars. The emission factors for later catalytic converter technologies are considerably lower than the ones for Euro I and II, thus causing the emissions to decrease from 2001 onwards (Figure 6.28).

The 2013 emission shares for heavy duty vehicles, passenger cars, light duty vehicles and 2-wheelers for $NO_x$ (40, 45, 15 and 0 %), NMVOC (4, 62, 7 and 13 %), CO (6, 80, 6 and 8 %), PM (21, 45, 32 and 2 %), BC (22, 44, 33 and 1 %) and $NH_3$ (1, 97, 2 and 0 %), are also shown in Figure 6.29.

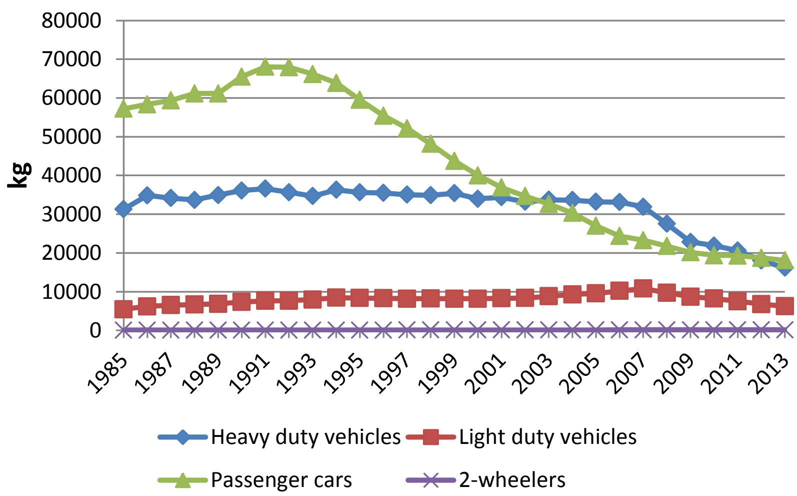


**Figure 6.23**. $NO_x$ emissions (tonnes) per vehicle type for road transport 1985-2013.

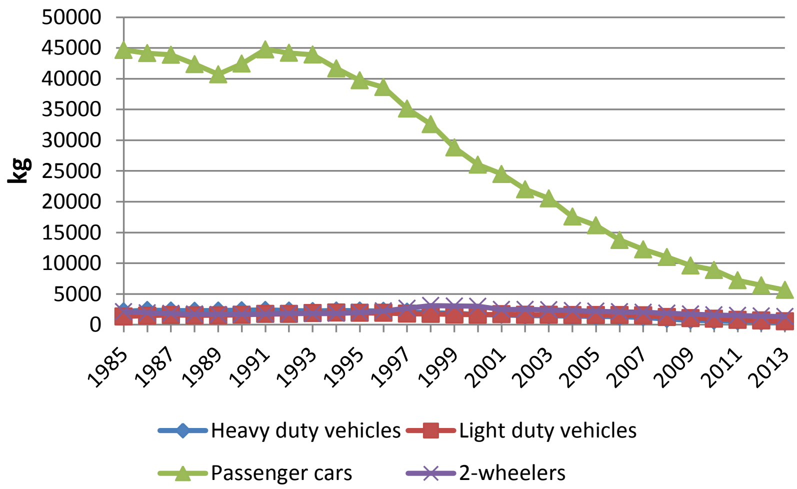


**Figure 6.24**. NMVOC emissions (tonnes) per vehicle type for road transport 1985-2013.

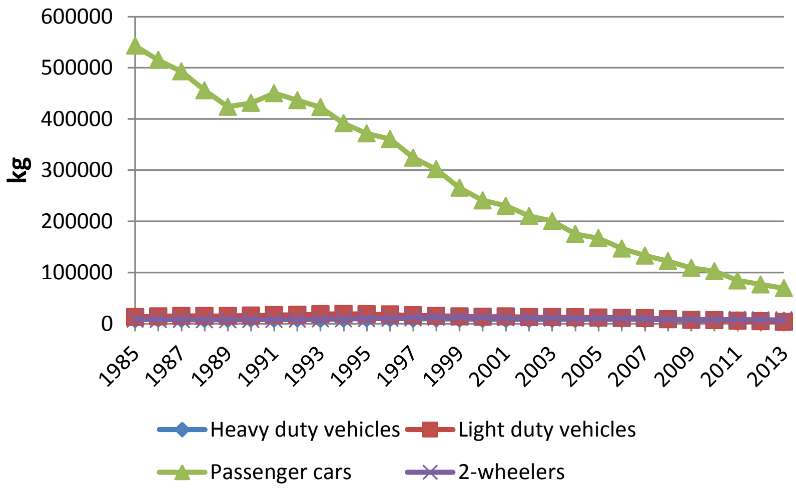


**Figure 6.25**. CO emissions (tonnes) per vehicle type for road transport 1985-2013.

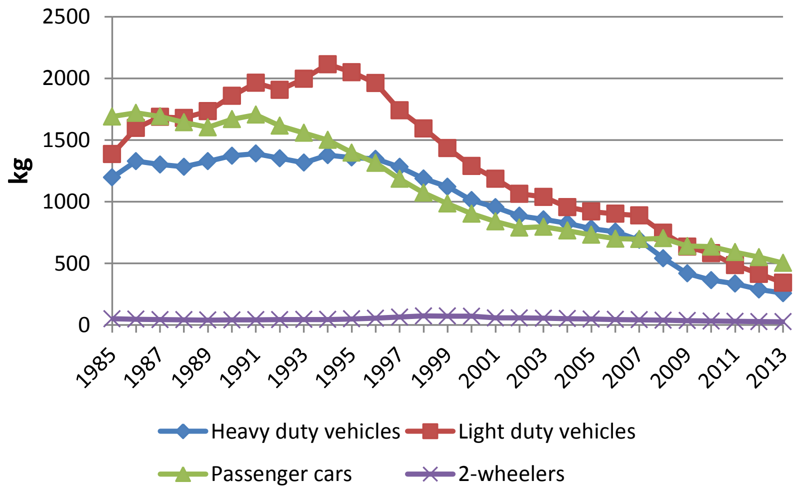


**Figure 6.26**. PM emissions (tonnes) per vehicle type for road transport 1985-2013.

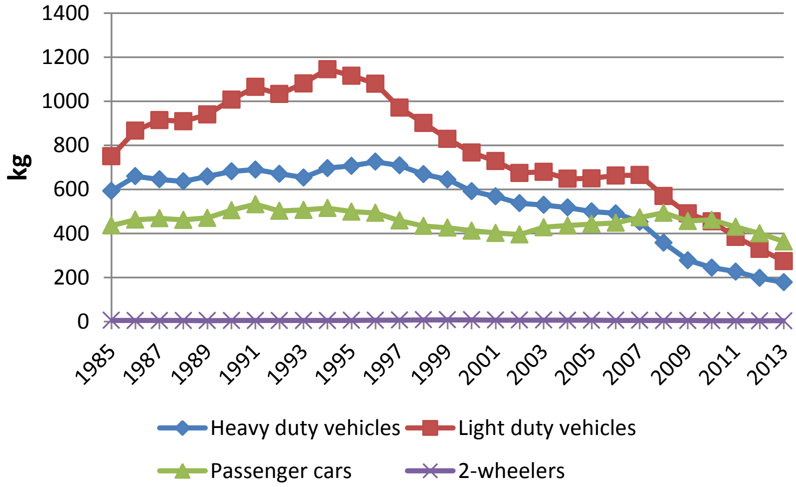


**Figure 6.27**. BC emissions (tonnes) per vehicle type for road transport 1985-2013.

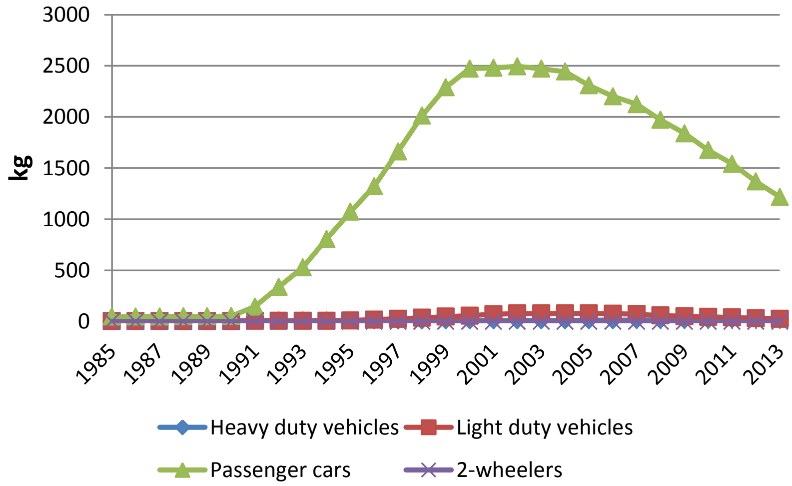


**Figure 6.28**. $NH_3$ emissions (tonnes) per vehicle type for road transport 1985-2013.

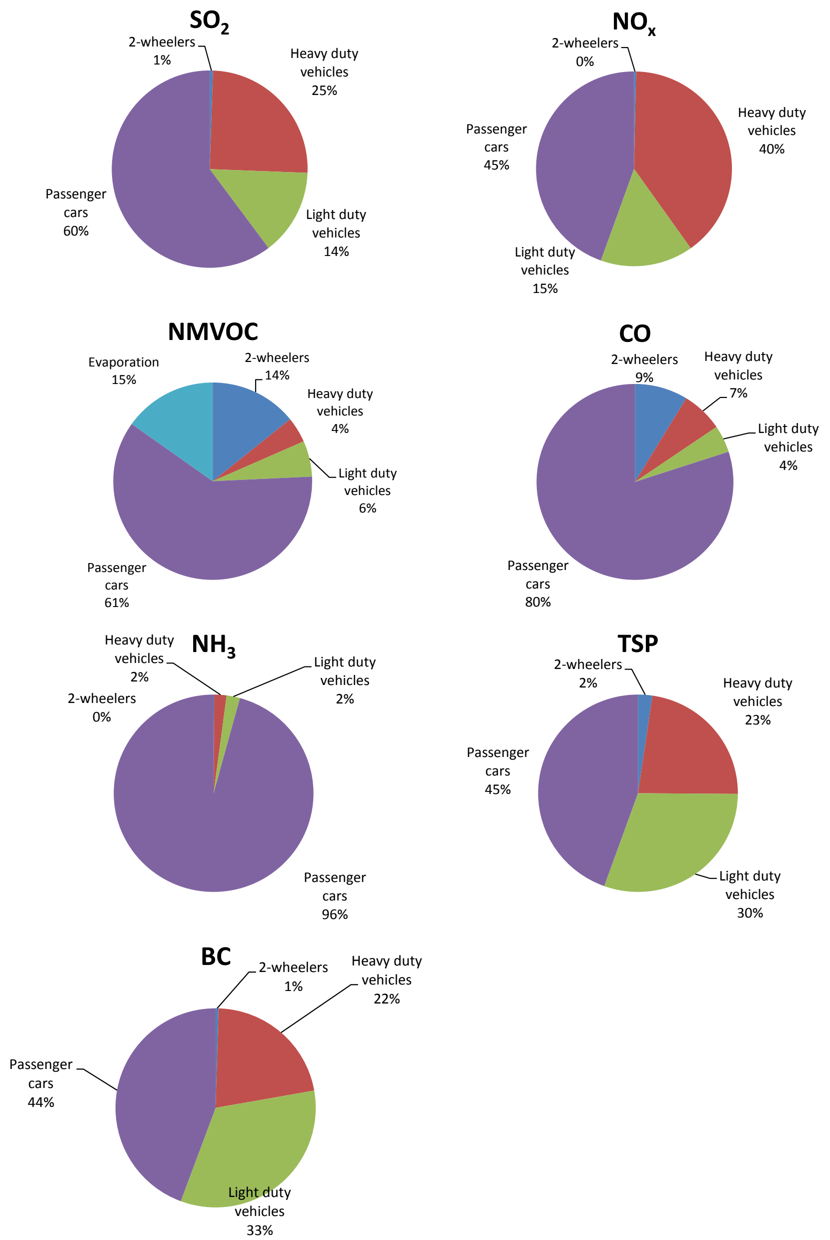


**Figure 6.29**. $SO_2$, $NO_x$, NMVOC, CO, $NH_3$, PM and BC emission shares per vehicle type for road transport in 2013.

### Non-exhaust emissions of TSP, $PM_{10}$ , $PM_{2.5}$ and BC

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

In Table 6.3, the non-exhaust TSP, $PM_{10}$, $PM_{2.5}$ and BC emissions for road transport are shown for 2013 in NFR sectors. Separate figures are given for brake and tire wear, though, in order to provide a better overview and to improve the emission explanations. The activity data and emission factors are also shown in Annex 15.

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 6.30. Passenger cars caused the highest emissions in 2013, followed by trucks, light duty vehicles, buses and 2-wheelers.

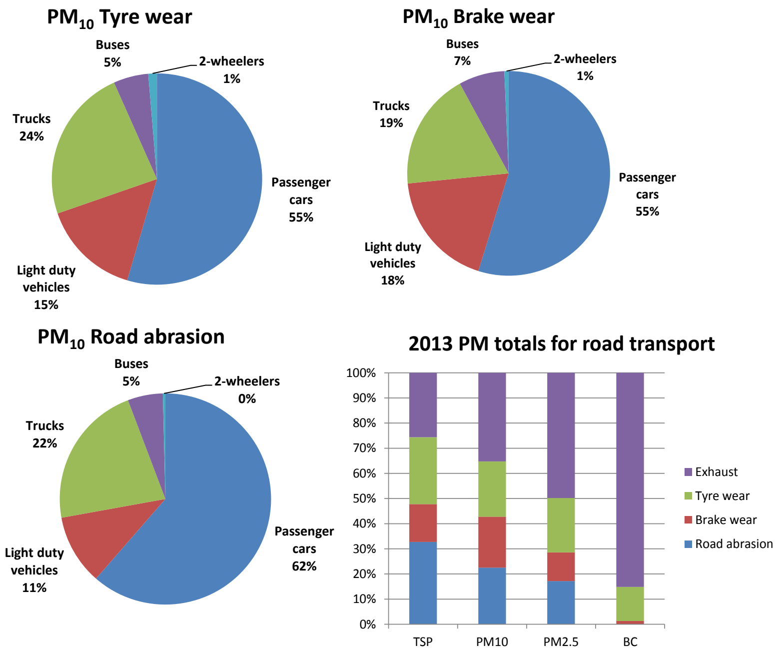


**Figure 6.30**. Brake and tyre wear and road abrasion $PM_{10}$ emission shares and PM and BC exhaust/non-exhaust distributions for road traffic in 2013.

Figure 6.30 also shows the exhaust/non-exhaust distribution of the total particulate emissions from road transport, for each of the size classes TSP, $PM_{10}$ and $PM_{2.5}$ and for BC. The exhaust emission shares of total road transport TSP, $PM_{10}$, $PM_{2.5}$ and BC are 26, 35, 50 and 85 %, respectively, in 2013. For brake and tyre wear and road abrasion the TSP shares are 15, 27 and 33 %, respectively. The same three sources have $PM_{10}$ shares of 20, 22 and 22 %, respectively, $PM_{2.5}$ shares of 11, 22 and 17 %, and BC shares of 1, 14 and 0 %, respectively. In general, the non-exhaust shares of total particulate emissions are expected to increase in the future as total exhaust emissions decline. The latter emission trend is due to the stepwise strengthening of exhaust emission standards for all vehicle types.

### 6.3.2 Other mobile sources

For $SO_2$ the trends in the Navigation (1A3d) emissions shown in Figure 6.31 mainly follow the development of the heavy fuel oil consumption (Figure 6.11). Though, from 1993 to 1995 relatively higher contents of sulphur in the fuel (estimated from sales) cause a significant increase in the emissions of $SO_2$. The $SO_2$ emissions for Fisheries (1A4c) correspond with the development in the consumption of marine gas oil. The main explanation for the development of the $SO_2$ emission curves for Railways (1A3c) and non-road machinery in Agriculture/forestry (1A4c) and Industry (1A2f), are the stepwise sulphur content reductions for diesel used by machinery in these sectors.

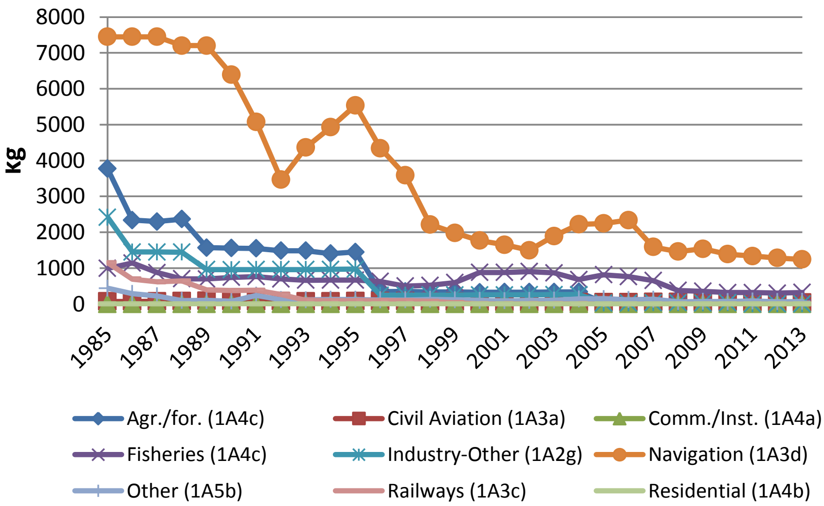


**Figure 6.31**. $SO_2$ emissions (ktonnes) in NFR sectors for other mobile sources 1985-2013.

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. For industry, the emission impact from the global financial crisis becomes very visible for 2009.

$NO_x$ emissions mainly come from diesel machinery, and the most important sources are Agriculture/forestry/fisheries (1A4c), Navigation (1A3d), Industry (1A2f) and Railways (1A3c), as shown in Figure 6.32. The 2013 emission shares are 45, 22, 20 and 6 %, respectively (Figure 6.38). Minor emissions come from the sectors, Civil Aviation (1A3a), Other (1A5) and Residential (1A4b).

The $NO_x$ emission trend for Navigation, Fisheries and Agriculture is determined by fuel consumption fluctuations for these sectors, and the development of emission factors. For ship engines the emission factors tend to increase for new engines until mid-1990s. After that, the emission factors gradually reduce until 2000, bringing them to a level comparable with the emission limits for new engines in this year. 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 from 1985 to 2008 for industry $NO_x$ is the product of a fuel consumption increase, most pronounced from 2005-2008, 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 consumption and $NO_x$ emissions for this transport sector until 2001.

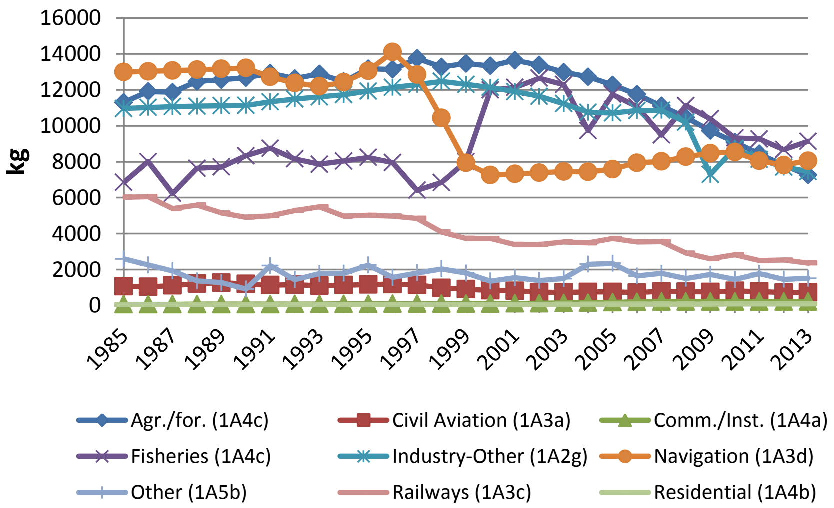


**Figure 6.32**. $NO_x$ emissions (tonnes) in NFR sectors for other mobile sources 1985-2013.

The 1985-2013 time series of NMVOC and CO emissions are shown in Figures 6.33 and 6.34 for other mobile sources. The 2013 sector emission shares are shown in Figure 6.38. For NMVOC, the most important sectors are Commercial/Institutional (1A4a), Agriculture/forestry/-fisheries (1A4c), Residential (1A4b) and Industry (1A2g) with 2013 emission shares of 38, 20, 20 and 12 %, respectively. The same five sectors also contribute with most of the CO emissions. For Commercial/Institutional (1A4a), Residential (1A4b), Agriculture/forestry/fisheries (1A4c) and Industry (1A2g) the emission shares are 56, 21, 14 and 5 %, respectively. Minor NMVOC and CO emissions come from Navigation (1A3d), Railways (1A3c), Civil Aviation (1A3a) and Other (1A5).

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

As shown in Figure 6.38, for other mobile sources the largest TSP contributors in 2013 are Agriculture/forestry/fisheries (1A4c), Industry (1A2f) and Navigation (1A3d), with emission shares of 41, 35 and 9 %, respectively. The remaining sectors: Railways (1A3c), Civil aviation (1A3a), Other (1A5) and Residential (1A4b) represent only minor emission sources.

The 1985-2013 TSP emissions for navigation and fisheries are determined by the fuel consumption fluctuations in these years, and the development of the emission factors, which to a major extent is a function of the fuel sulphur content. The emission development for Agriculture/forestry is determined by the generally decreasing total diesel fuel consumption and gradually reducing emission factors over the time period.

The TSP emission development for industrial non-road machinery is the product of a fuel consumption increase from 1985 to 2008 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 6.32).

For other mobile sources the largest BC contributors in 2013 are Industry (1A2g) and Agriculture/forestry/fisheries (1A4c), and, with emission shares of 46 and 42 %, respectively. The remaining sectors: Railways (1A3c), Navigation (1A3d), Other (1A5), Civil aviation (1A3a), and Residential (1A4b) represent only minor emission sources (Figure 6.38).

As explained in paragraph 6.3.1 BC is calculated as shares of TSP depending on engine technology levels. Except for navigation the source specific TSP and BC emission trends are very similar. For ship engines the BC share of TSP emissions is smaller for heavy fuel oil than for marine diesel oil. This explains the low BC emissions for navigation until 1997, during which period significant navigation emissions of TSP are noted predominantly caused by the use heavy fuel oil.

The amounts of $NH_3$ emissions calculated for other mobile sources are very small. The largest emission sources are Agriculture/forestry/fisheries (1A4c), Industry (1A2f), Other (1A5b) and Railways (1A3c), with emission shares of 44, 32, 10 and 9 %, respectively.

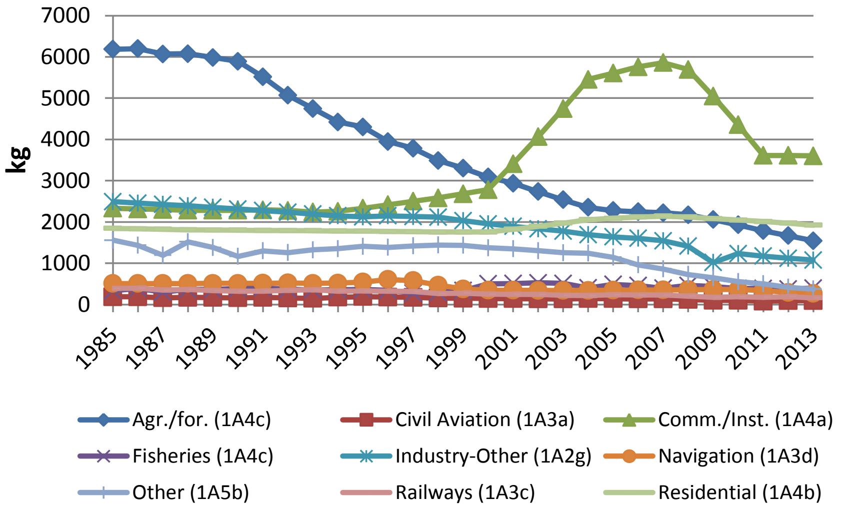


**Figure 6.33**. NMVOC emissions (tonnes) in NFR sectors for other mobile sources 1985-2013.

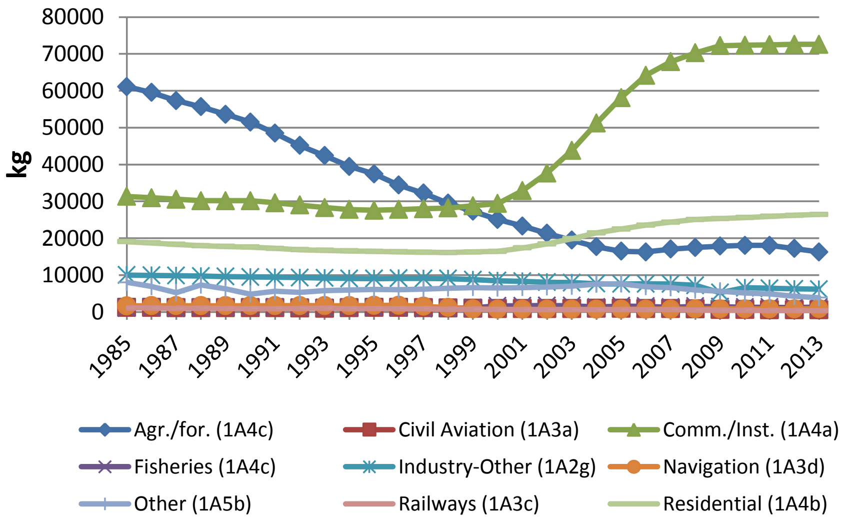


**Figure 6.34**. CO emissions (tonnes) in NFR sectors for other mobile sources 1985-2013.

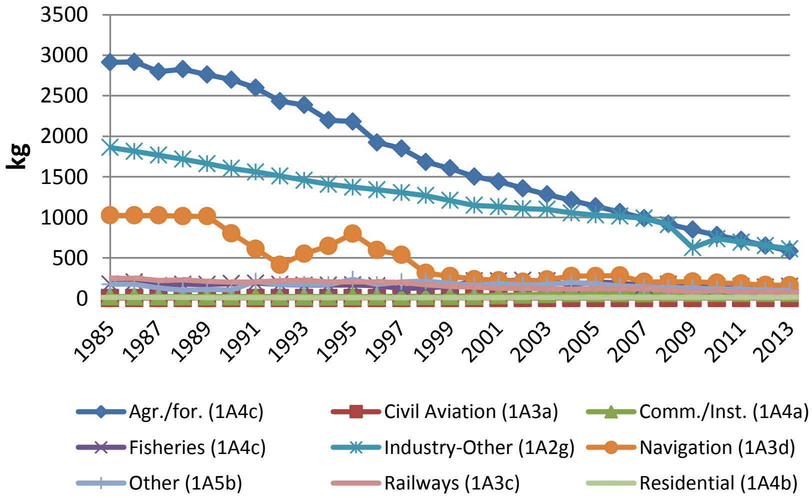


**Figure 6.35**. TSP emissions (tonnes) in NFR sectors for other mobile sources 1985-2013.

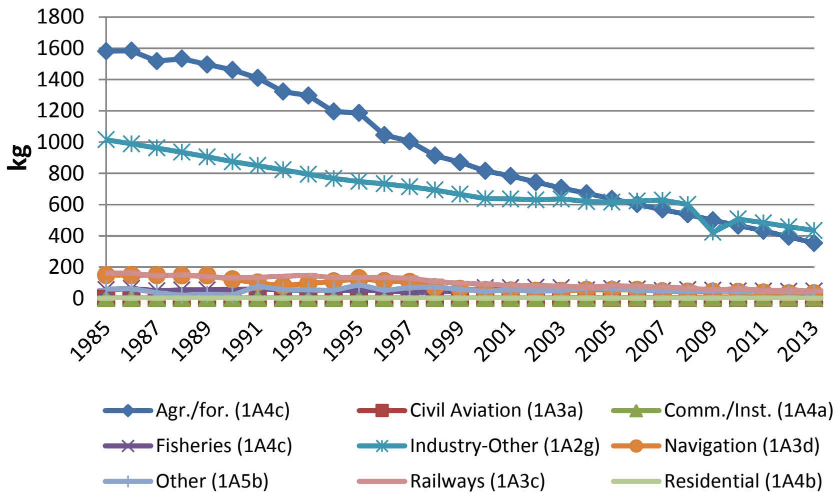


**Figure 6.36**. BC emissions (tonnes) in NFR sectors for other mobile sources 1985-2013.

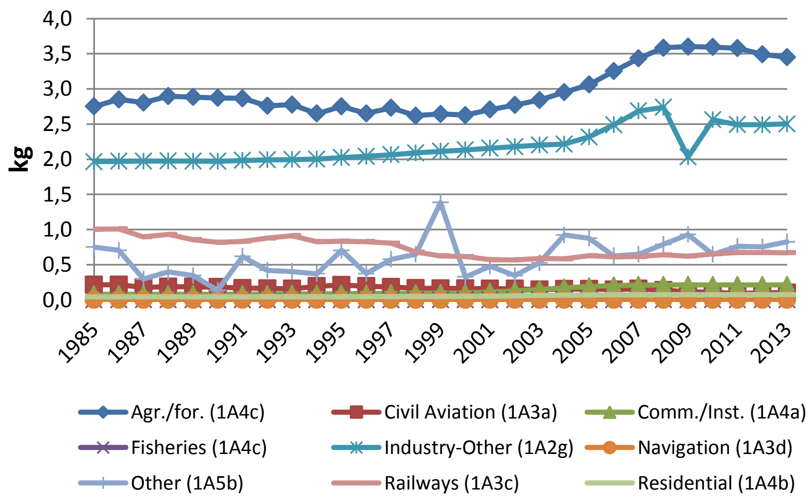


**Figure 6.37**. $NH_3$ emissions (tonnes) in NFR sectors for other mobile sources 1985-2013.

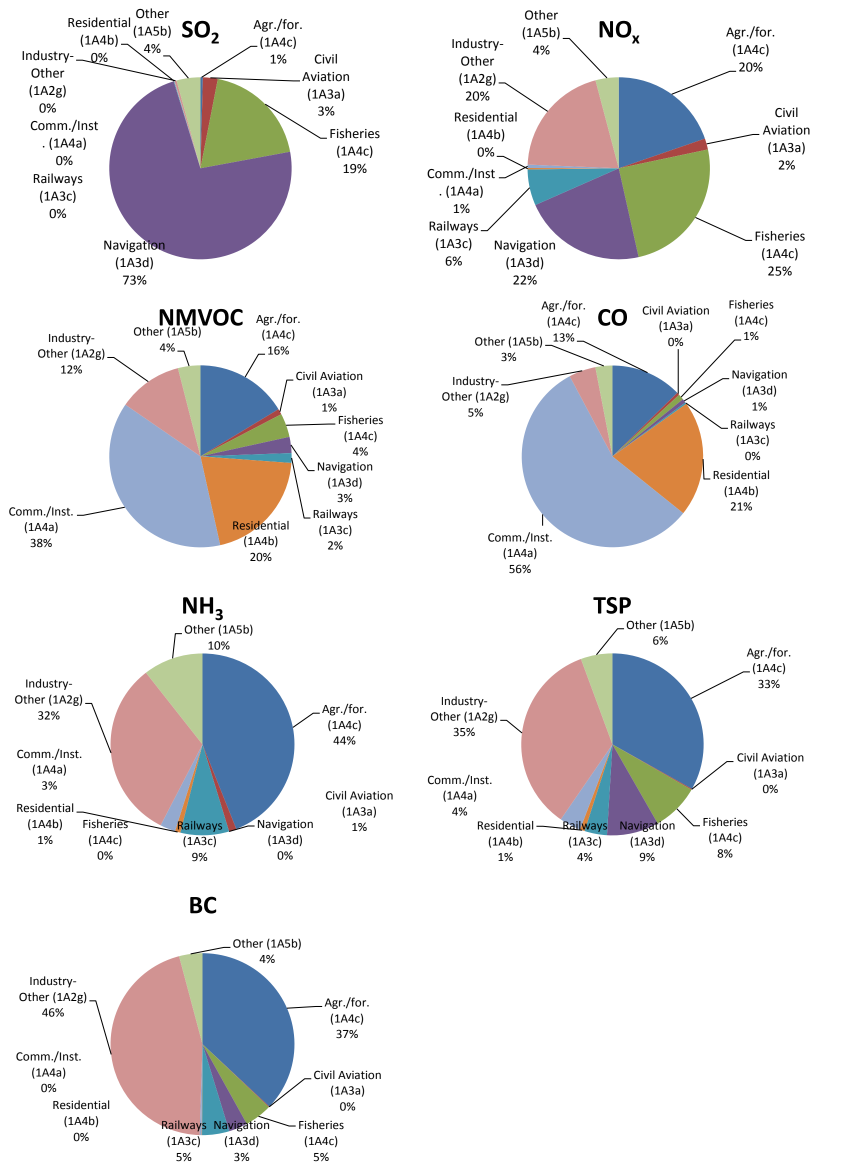


**Figure 6.38**. $SO_2$, $NO_x$, NMVOC, CO, $NH_3$, PM and BC emission shares per vehicle type for other mobile sources in 2013.

## 6.4 Heavy metals

In Table 6.4, the heavy metal emissions for road transport and other mobile sources are shown for 2013 in NFR sectors (CFR totals for civil aviation, c.f Chapter 3). The emission figures in the time series 1990-2013 are given in Annex 16 (NFR format) and are shown for 1990 and 2013 in Annex 15 (CollectER format).

**Table 6.4**. Heavy metal emissions in 2013 for road transport and other mobile sources.

| | Arsenic (As) | Cadmium (Cd) | Chromium (Cr) | Copper (Cu) | Mercury (Hg) | Nickel (Ni) | Lead (Pb) | Selenium (Se) | Zinc (Zn) |
|---|---|---|---|---|---|---|---|---|---|
| | kg | kg | kg | kg | kg | kg | kg | kg | kg |
| Manufacturing industries/Construction (mobile) | 0 | 3 | 9 | 7 | 2 | 3 | 15 | 0 | 513 |
| Civil aviation (Domestic) | 0 | 0 | 0 | 0 | 0 | 0 | 876 | 0 | 3 |
| Road transport: Passenger cars | 0 | 28 | 60 | 86 | 15 | 30 | 122 | 0 | 5 578 |
| Road transport:Light duty vehicles | 0 | 5 | 16 | 12 | 3 | 5 | 28 | 0 | 960 |
| Road transport:Heavy duty vehicles | 0 | 6 | 21 | 15 | 5 | 6 | 34 | 0 | 1 138 |
| Road transport: Mopeds & motorcycles | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 |
| Road transport: Gasoline evaporation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Road transport: Brake wear | 5 | 4 | 56 | 39 913 | 0 | 55 | 5 169 | 10 | 8 464 |
| Road transport: Tyre wear | 1 | 2 | 3 | 14 | 0 | 22 | 71 | 18 | 9 595 |
| Road transport: Road abrasion | 0 | 0 | 21 | 11 | 0 | 17 | 51 | 0 | 82 |
| Railways | 0 | 1 | 2 | 2 | 0 | 1 | 4 | 0 | 125 |
| National navigation (Shipping) | 31 | 2 | 14 | 31 | 5 | 1 664 | 18 | 36 | 84 |
| Commercial/Institutional: Mobile | 0 | 1 | 1 | 2 | 0 | 1 | 2 | 0 | 118 |
| Residential: Household and gardening (mobile) | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 43 |
| Agriculture/Forestry/Fishing: Off-road agriculture/forestry | 0 | 3 | 10 | 7 | 2 | 3 | 17 | 0 | 584 |
| Agriculture/Forestry/Fishing: National fishing | 8 | 2 | 6 | 8 | 8 | 11 | 16 | 32 | 81 |
| Other, Mobile | 0 | 0 | 1 | 1 | 0 | 0 | 34 | 0 | 92 |
| Road transport exhaust total | 1 | 38 | 97 | 113 | 22 | 41 | 184 | 0 | 7 695 |
| Road transport non exhaust total | 6 | 6 | 81 | 39 937 | 0 | 95 | 5 291 | 27 | 18 141 |
| Other mobile sources total | 39 | 11 | 44 | 59 | 18 | 1 683 | 983 | 68 | 1 644 |
| Domestic total | 46 | 56 | 222 | 40 110 | 40 | 1 819 | 6 457 | 96 | 27 480 |
| Civil aviation (International) | 0 | 0 | 0 | 0 | 0 | 0 | 25 | 0 | 0 |
| Navigation (International) | 178 | 12 | 77 | 178 | 20 | 9 948 | 92 | 184 | 428 |

The heavy metal emission estimates for road transport are based on a national research study made by Winther and Slentø (2010). The latter study calculate the exhaust related emissions from fuel and engine oil as well as the wear related emissions from tyre, brake and road wear. Apart from Pb, the emission factors only deviate to a less extent due to changes in fleet and mileage composition over the years, which bring relative changes in fuel consumption per fuel type, engine oil use and aggregated emission factors for brake, tyre and road wear.

The most important exhaust related emissions for road transport are Cd, Cr, Hg and Zn. the most important wear related emissions are Cu and Pb almost solely coming from tyre wear, and Zn from brake and tyre wear. For other mobile sources, the most important emission contributions are calculated for Ni, Se and As, coming from the use of marine diesel oil in fisheries and navigation and residual oil in navigation.

The Figures 6.39 and 6.40 show the heavy metal emission distributions for all road transport sources split into vehicle categories, and for other mobile sectors, respectively.

For non-road mobile machinery in Agriculture, Forestry, Industry, Commercial/Institutional and Recreational, as well as Military and Railways, fuel related emission factors from road transport are used derived for the year 2009.

For Civil aviation jet fuel no emissions are estimated due to lack of emission data, whereas for aviation gasoline fuel related emission factors for road transport gasoline is used derived for the year 2009, except for Pb where national data exist.

For Navigation and Fisheries, the heavy metal emission factors are fuel related, and are taken from the EMEP/EEA guidebook.

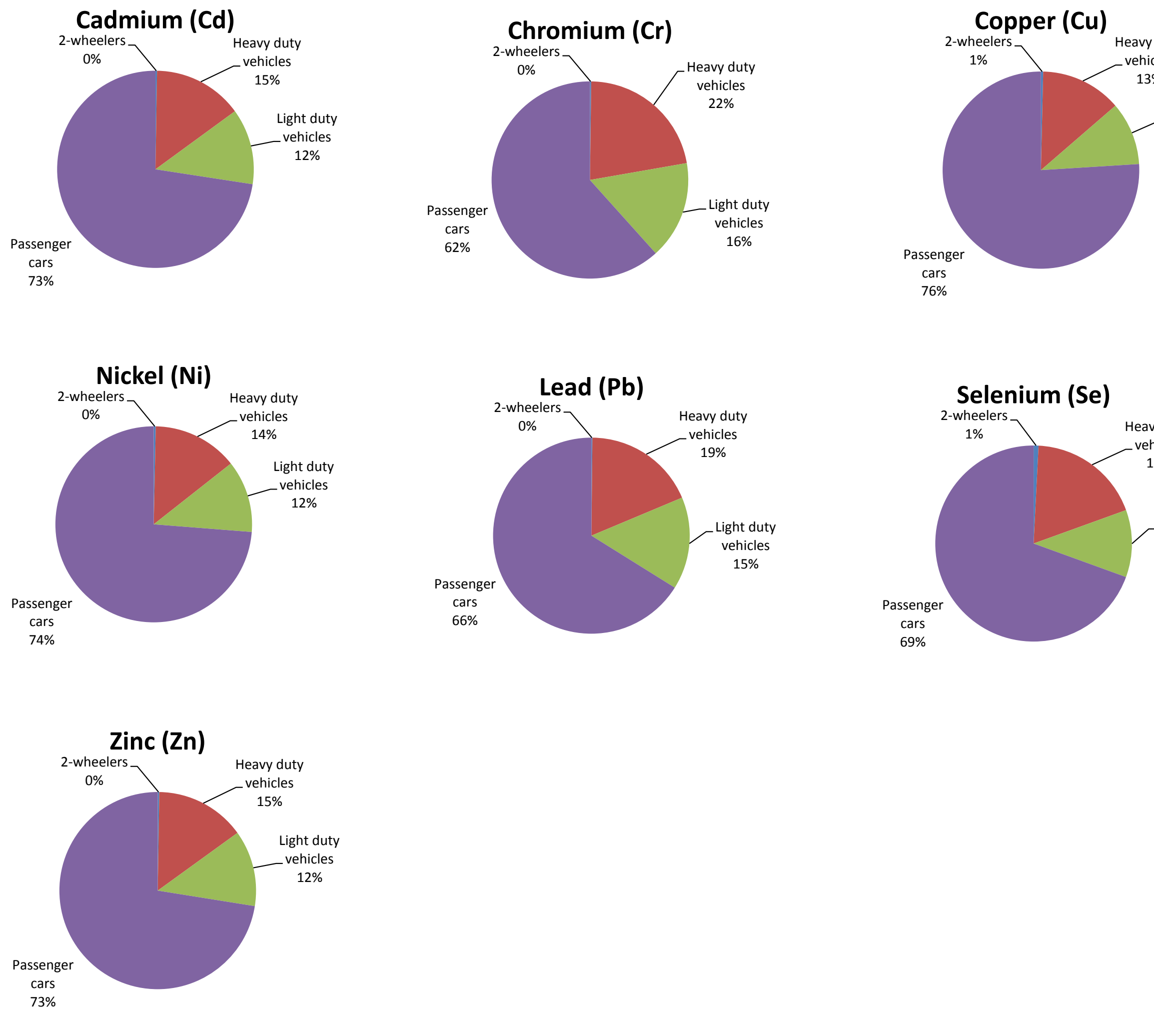


**Figure 6.39**. Heavy metal emission shares for road transport in 2013.

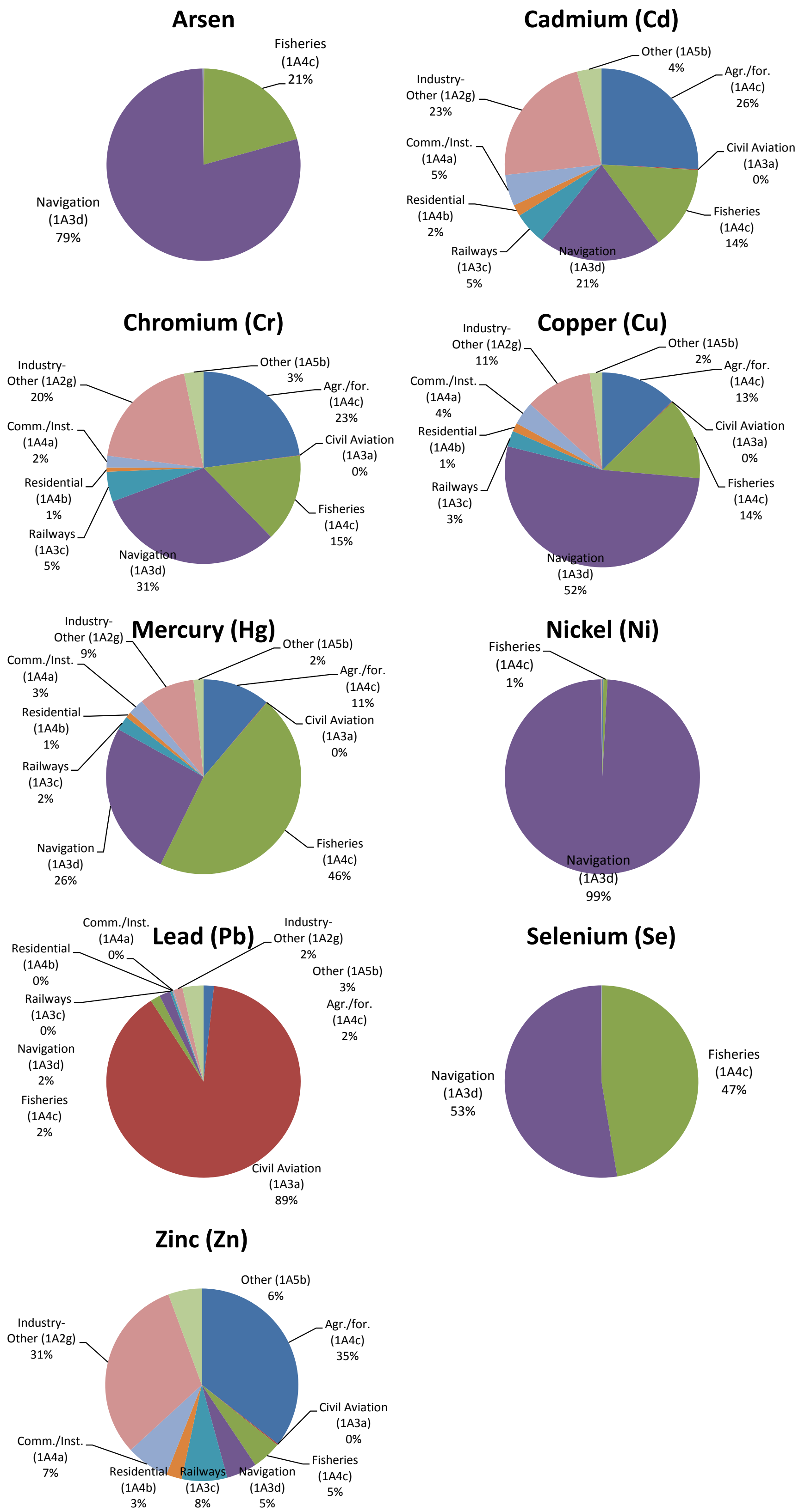


**Figure 6.40**. Heavy metal emission shares for other mobile sources in 2013.

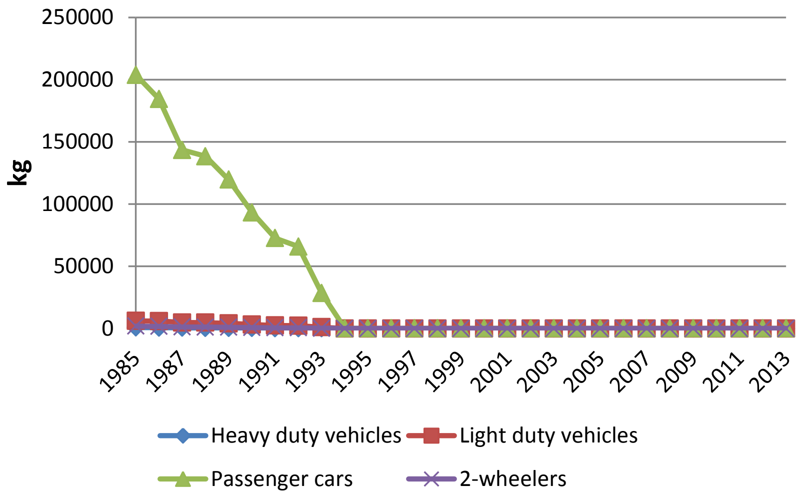


**Figure 6.41**. Pb emissions (kg) per vehicle type for road transport 1985-2013.

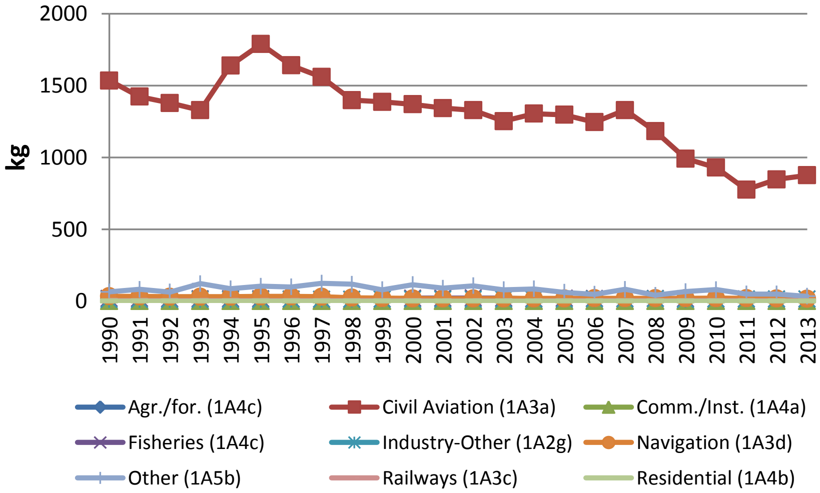


**Figure 6.42**. Pb emissions (kg) in NFR sectors for other mobile sources 1990-2013.

## 6.5 Dioxin and PAH

In Table 6.5, the dioxin, PAH, HCB and PCB emissions for road transport and other mobile sources are shown for 2013 in NFR sectors. The emission figures in the time series 1990-2013 are given in Annex 16 (NFR format) and are shown for 1990 and 2013 in Annex 15 (CollectER format).

**Table 6.5**. Dioxins, PAHs, HCB and PCB emissions in 2013 for road transport and other mobile sources.

| | HCB | Dioxins/Furans | Flouranthene | Benzo(b) flouranthene | Benzo(k) flouranthene | Benzo(a) pyrene | Benzo-(g,h,i) perylene | Indeno (1,2,3-c,d) pyrene | PCB |
|---|---|---|---|---|---|---|---|---|---|
| | g | g | kg | kg | kg | kg | kg | kg | g |
| Manufacturing industries/Construction (mobile) | 0.079 | 0.010 | 57 | 7 | 6 | 3 | 6 | 3 | 7 |
| Civil aviation (Domestic) | 0.000 | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Road transport: Passenger cars | 0.265 | 0.048 | 669 | 50 | 38 | 44 | 88 | 44 | 1 |
| Road transport:Light duty vehicles | 0.130 | 0.012 | 209 | 15 | 11 | 13 | 26 | 12 | 0 |
| Road transport:Heavy duty vehicles | 0.244 | 0.042 | 83 | 21 | 24 | 4 | 3 | 5 | 21 |
| Road transport: Mopeds & motorcycles | 0.000 | 0.014 | 8 | 0 | 0 | 0 | 1 | 0 | 0 |
| Road transport: Gasoline evaporation | 0.000 | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Road transport: Brake wear | 0.000 | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Road transport: Tyre wear | 0.000 | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Road transport: Road abrasion | 0.000 | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Railways | 0.021 | 0.002 | 5 | 1 | 1 | 0 | 0 | 0 | 2 |
| National navigation (Shipping) | 0.014 | 0.066 | 33 | 2 | 1 | 0 | 4 | 4 | 0 |
| Commercial/Institutional: Mobile | 0.000 | 0.012 | 10 | 0 | 0 | 0 | 2 | 1 | 0 |
| Residential: Household and gardening (mobile) | 0.000 | 0.004 | 4 | 0 | 0 | 0 | 1 | 0 | 0 |
| Agriculture/Forestry/Fishing: Off-road agriculture/forestry | 0.092 | 0.013 | 67 | 8 | 7 | 4 | 7 | 4 | 8 |
| Agriculture/Forestry/Fishing: National fishing | 0.013 | 0.083 | 51 | 4 | 2 | 1 | 10 | 8 | 0 |
| Other, Mobile | 0.012 | 0.003 | 10 | 1 | 1 | 1 | 1 | 1 | 1 |
| Road transport exhaust total | 0.639 | 0.116 | 969 | 86 | 74 | 61 | 118 | 62 | 22 |
| Road transport non exhaust total | 0.000 | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other mobile sources total | 0.230 | 0.194 | 237 | 24 | 19 | 10 | 31 | 21 | 17 |
| Domestic total | 0.869 | 0.310 | 1206 | 110 | 93 | 71 | 149 | 82 | 39 |
| Civil aviation (International) | 0.000 | 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Navigation (International) | 0.069 | 0.315 | 138 | 10 | 5 | 3 | 19 | 16 | 0 |

For mobile sources, road transport displays the largest emission of dioxins and PAHs. The dioxin emission share for road transport is 37 % of all mobile emissions in 2013, whereas Agriculture/forestry-/fisheries and Navigation have smaller shares of 31 and 21 %. For the different PAH components, road transport shares are around 80 % of total emissions for mobile sources. The remaining emissions almost solely come from Agriculture/forestry-/fisheries, Navigation and Industry with Agriculture/forestry/fisheries as the largest source.

Figures 6.43 and 6.44 show the dioxin and PAH emission distributions into vehicle categories and other mobile sectors, respectively.

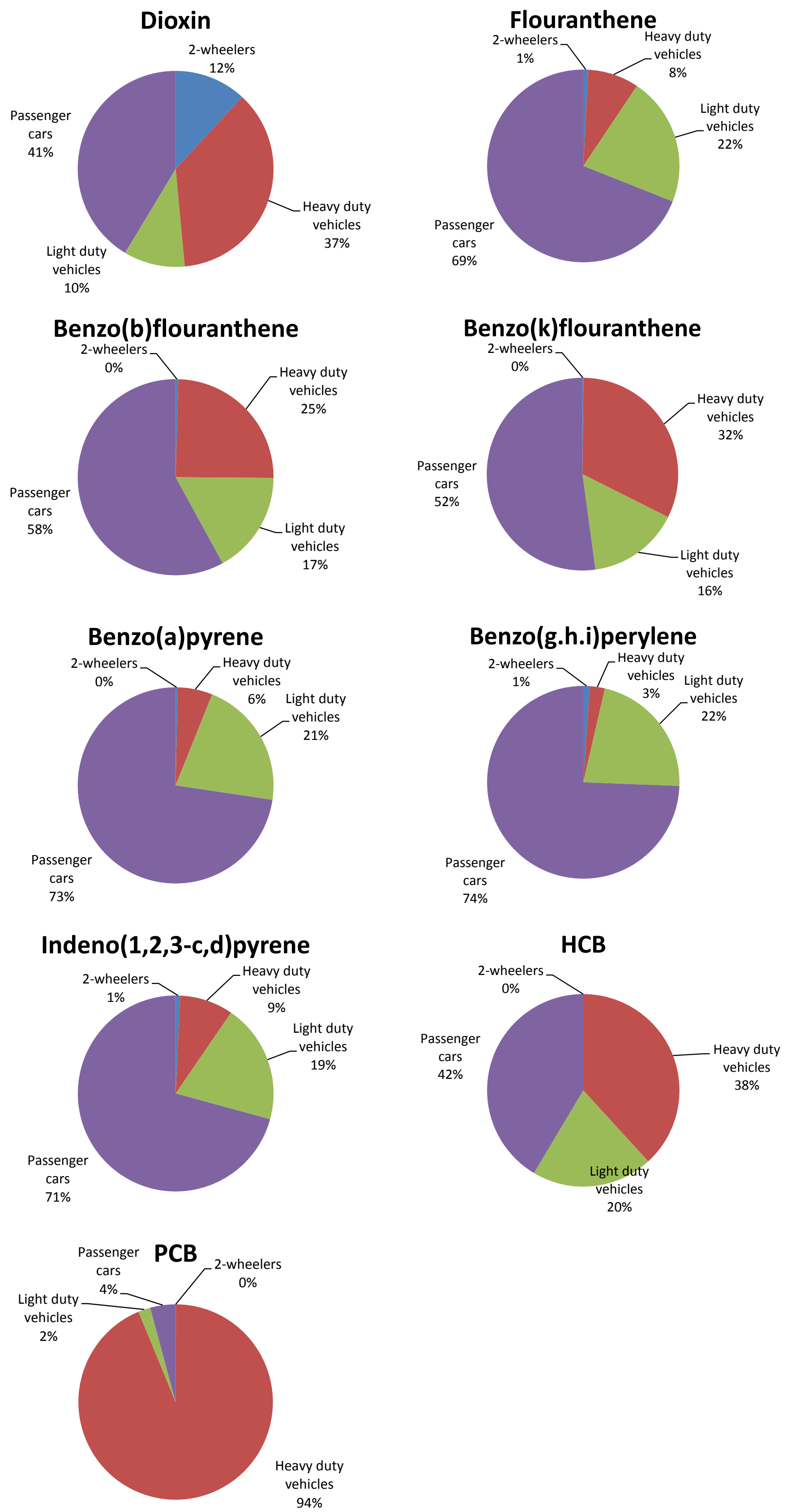


**Figure 6.43**. Dioxins, PAHs, HCB and PCB emission shares for road transport in 2013.

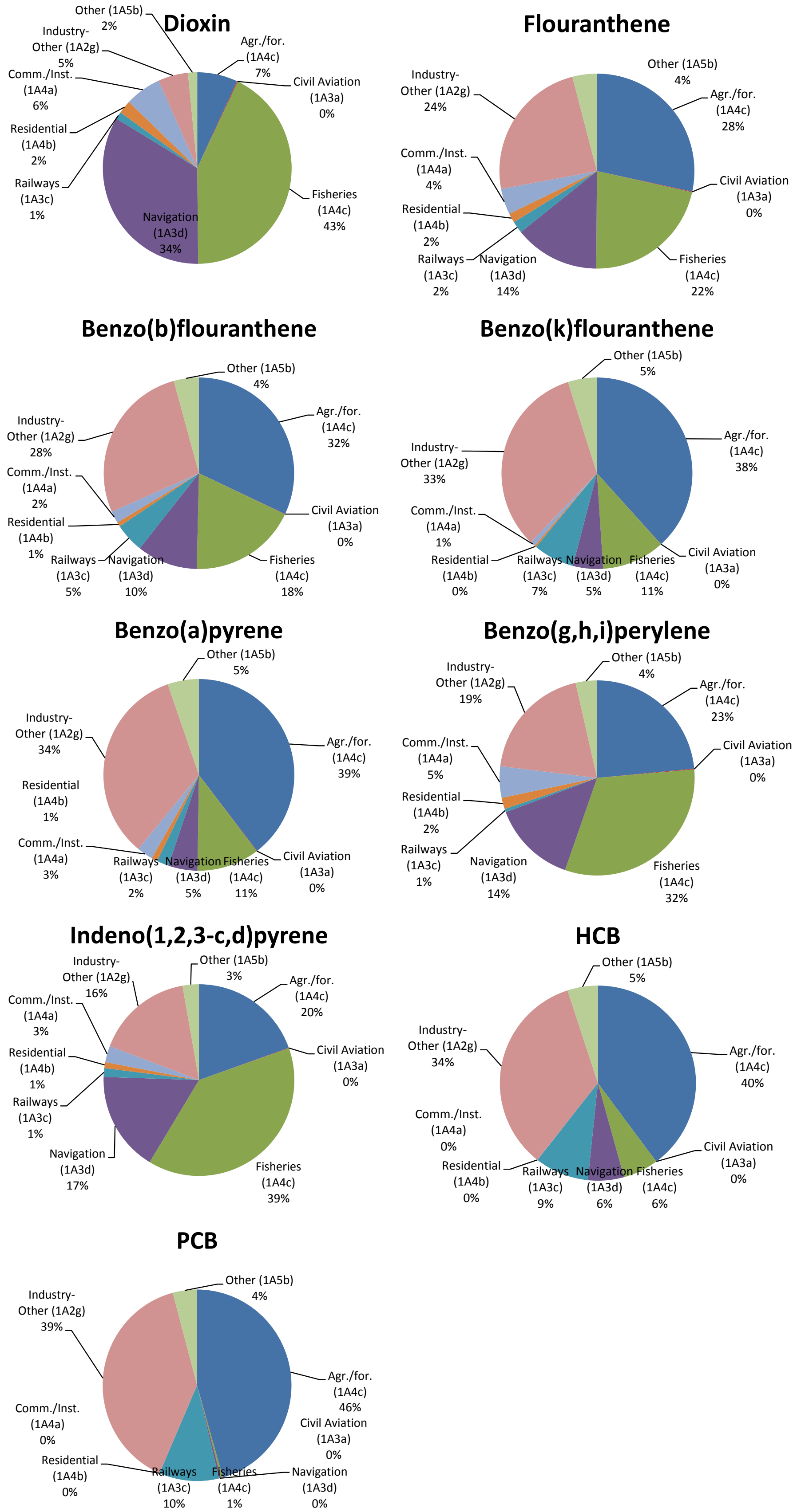


**Figure 6.44**. Dioxins, PAHs, HCB and PCB emission shares for other mobile sources in 2013.

## 6.6 Bunkers

### 6.6.1 Emissions of $CO_2$, $CH_4$ and $N_2O$

The most important emissions from bunker fuel consumption (fuel consumption for international transport) are $SO_2$ and $NO_x$. In terms of greenhouse gas emissions, the level of emissions from Danish bunker fuel consumption are 29 %, 6 % and 37 %, respectively, for $CO_2$, $CH_4$ and $N_2O$, compared with the emission total for mobile sources.

The bunker emission totals of $CO_2$, $CH_4$ and $N_2O$ are shown in Table 6.3 for 2013, split into sea transport and civil aviation. All emission figures in the 1990-2013 time series are given in Annex 16 (CRF format). In Annex 15, the emissions are also given in CollectER format for the years 1990 and 2013.

The differences in $CH_4$ and $N_2O$ emissions between Navigation and Civil aviation are much larger than the differences in fuel consumption (and derived $CO_2$ emissions), and display a poor emission performance for international sea transport. In broad terms, the emission trends shown in Figure 6.45 are similar to the fuel consumption development.

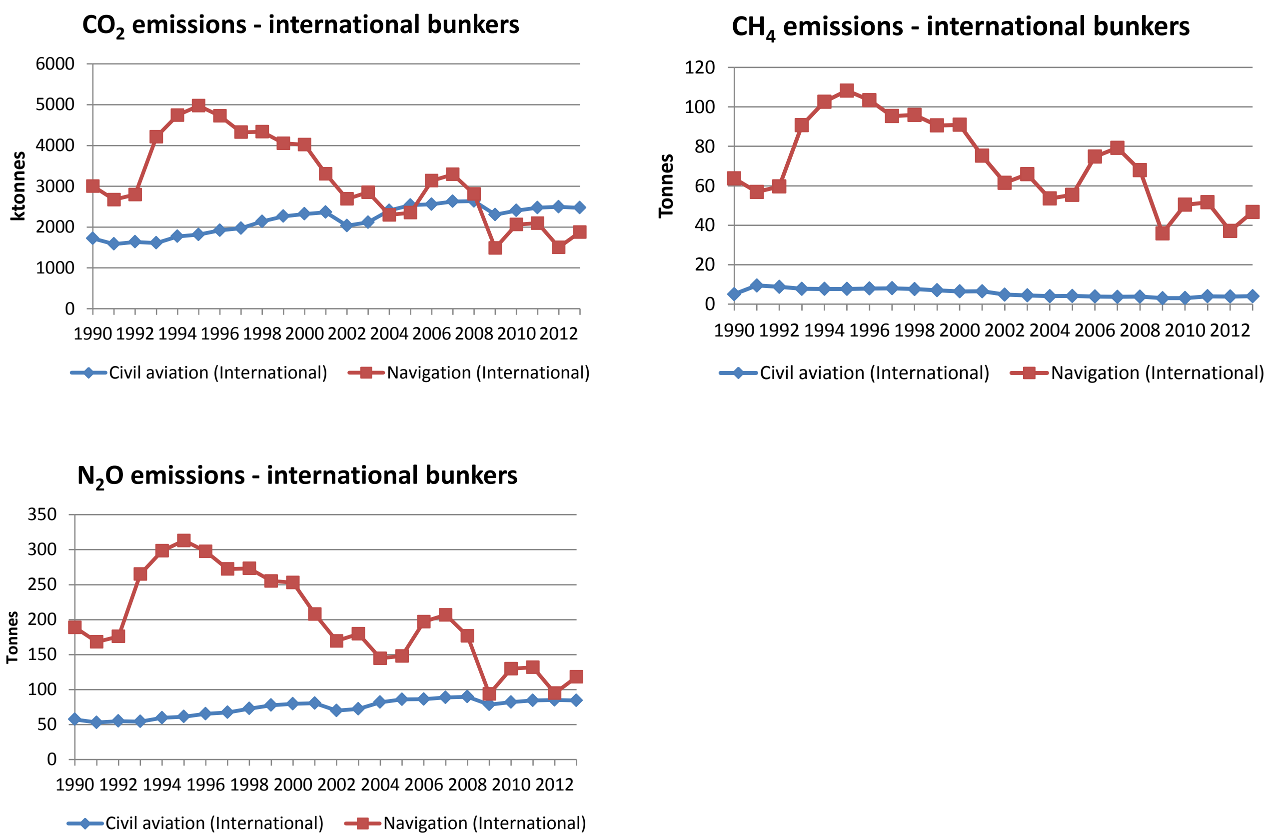


**Figure 6.45**. $CO_2$, $CH_4$ and $N_2O$ emissions for international transport 1990-2013.

### 6.6.2 Emissions of $SO_2$, $NO_x$, TSP and BC

The most important emissions from bunker fuel consumption (fuel consumption for international transport) are $SO_2$ and $NO_x$. However, particles emitted from navigation near coastal areas can be a reason of concern due to the various effects from particles on human health. Also the part of BC being emitted in or near snow and ice covered regions (e.g. the Arctic area) is important from a global warming point of view, due to BC's ability to absorb light and due the darkening effect of BC when deposited to snow and ice surfaces.

The bunker emission totals are shown in Table 6.3 for 2013, split into sea transport and civil aviation. All emission figures in the 1985-2013 time series are given in Annex 16 (NFR format). In Annex 15, the emissions are also given in CollectER format for 2013.

The differences in emissions between Navigation and Civil aviation are much larger than the differences in fuel consumption and display a poor emission performance for international sea transport. In broad terms, the emission trends shown in Figure 6.46 are similar to the fuel consumption development.

However, for Navigation minor differences occur for the emissions of $SO_2$ and $NO_x$ due to varying amounts of marine gas oil and residual oil, and for $SO_2$ and $NO_x$ the development in the emission factors also have an impact on the emission trends. For Civil aviation, apart from the annual consumption of jet fuel, the development of the $NO_x$ emissions is also due to yearly variations in LTO/aircraft type (earlier than 2001) and city-pair statistics (2001 onwards).

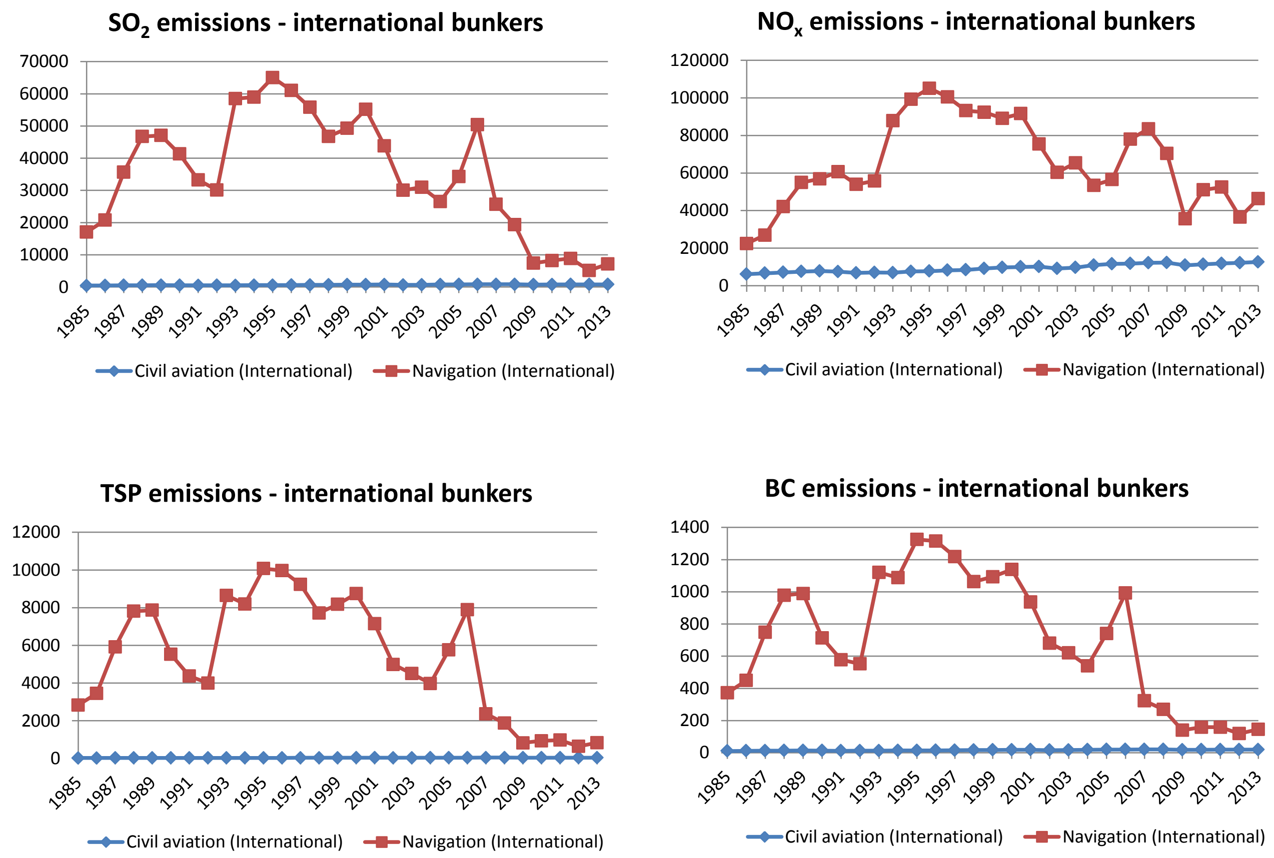


**Figure 6.46**. $SO_2$, $NO_x$, TSP and BC emissions for international transport 1985-2013.

# 7 Uncertainties

Uncertainty estimates for greenhouse gases on Tier 1 and Tier 2 levels, 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). For road transport, railways and fisheries, these guidelines provide uncertainty factors for activity data that are used in the Danish situation. For other sectors, the factors reflect specific national knowledge (Winther et al., 2006 and Winther, 2008). These sectors are (SNAP categories): Inland Waterways (a part of 1A3d: Navigation), Agriculture and Forestry (parts of 1A4c: Agriculture-/forestry/fisheries), Industry (mobile part of (1A2f: Industry-other), Residential (1A4b) and National sea transport (a part of 1A3d: Navigation).

The activity data uncertainty factor for Civil aviation is based on expert judgement.

The calculations for Tier 1 are shown in Annex 17-1 for all emission components. Please refer to Nielsen et al. (2015a) for further information regarding the calculation procedure for Tier 2 uncertainty calculations.

**Table 7.1**. Tier 1 uncertainties for activity data, emission factors and total emissions in 2013 and as a trend.

| Category | Activity data | $CO_2$ | $CH_4$ | $N_2O$ |
|---|---|---|---|---|
| | % | % | % | % |
| Road transport | 2 | 5 | 40 | 50 |
| Military | 2 | 5 | 100 | 1000 |
| Railways | 2 | 5 | 100 | 1000 |
| Navigation (small boats) | 41 | 5 | 100 | 1000 |
| Navigation (large vessels) | 11 | 5 | 100 | 1000 |
| Fisheries | 2 | 5 | 100 | 1000 |
| Agriculture | 24 | 5 | 100 | 1000 |
| Forestry | 30 | 5 | 100 | 1000 |
| Industry (mobile) | 41 | 5 | 100 | 1000 |
| Residential | 35 | 5 | 100 | 1000 |
| Commercial/Institutional | 35 | 5 | 100 | 1000 |
| Civil aviation | 10 | 5 | 100 | 1000 |
| Overall uncertainty in 2013 | | 5.3 | 32.7 | 143.9 |
| Trend uncertainty | | 5.8 | 7.1 | 67.7 |

**Table 7.2**. Tier 2 uncertainty factors for activity data and emission factors in 2013.

| Category | Activity data % | $CO_2$ % | $CH_4$ % | $N_2O$ % |
|---|---|---|---|---|
| Road transport | 2 | 5 | 40 | 500 |
| Military | 2 | 5 | 100 | 1000 |
| Railways | 2 | 5 | 100 | 1000 |
| Pleasure craft | 41 | 5 | 100 | 1000 |
| Regional ferries | 20 | 5 | 100 | 1000 |
| Local ferries | 20 | 5 | 100 | 1000 |
| Fisheries | 2 | 5 | 100 | 1000 |
| Greenland & Faroe Islands | 20 | 5 | 100 | 1000 |
| Other national sea transport | 20 | 5 | 100 | 1000 |
| Civil aviation | 10 | 5 | 100 | 1000 |
| Agriculture | 24 | 5 | 100 | 1000 |
| Forestry | 30 | 5 | 100 | 1000 |
| Industry | 41 | 5 | 100 | 1000 |
| Household and gardening | 35 | 5 | 100 | 1000 |
| Commercial and institutional | 35 | 5 | 100 | 1000 |

**Table 7.3**. Tier 2 uncertainty estimates for $CO_2$, $CH_4$, $N_2O$ and $CO_2$-eq. in 2013.

| | | 1990 | | | 2013 | | | 1990-2013 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Median | Uncertainty (%) | | Median | Uncertainty (%) | | Median | Uncertainty (%) | |
| | | Emission | Lower (-) | Upper (+) | Emission | Lower (-) | Upper (+) | Emission | Lower (-) | Upper (+) |
| $CO_2$ | ktonnes | 13643 | 5 | 5 | 14993 | 5 | 5 | 10 | 11 | 11 |
| $CH_4$ | Tonnes | 2930 | 27 | 37 | 930 | 26 | 39 | -68 | 30 | 42 |
| $N_2O$ | Tonnes | 694 | 46 | 202 | 750 | 42 | 170 | 9 | 259 | 559 |
| $CO_2$ eq. | ktonnes | 13948 | 5 | 6 | 15268 | 5 | 6 | 9 | 12 | 14 |

For the emission components reported to the UNECE LRTAP convention, emission uncertainty estimates are made for road transport and other mobile sources using the guidelines for estimating uncertainties in the EMP/EEA guidebook (EMEP/EEA, 2013). However, for TSP, $PM_{10}$, $PM_{2.5}$ and BC the latter source indicates no uncertainty factor and, instead, this factor is based on expert judgement.

The activity data uncertainty factor is assumed to be 2 and 10 % for road transport and other mobile sources, respectively, based on expert judgement.

The uncertainty estimates should be regarded as preliminary only and may be subject to changes in future inventory documentation. The calculations are shown in Annex 17-2 for all emission components reported to the LRTAP Convention.

**Table 7.4**. Uncertainties for activity data, emission factors and total emissions in 2013 and as a trend for emission components reported to UNECE LRTAP.

| | Emission factor uncertainties [ %] | | Emission uncertainties [ %] | |
|---|---|---|---|---|
| Pollutant | Road | Other | Overall 2013 | Trend |
| $SO_2$ | 50 | 50 | 49 | 3 |
| $NO_x$ | 50 | 100 | 55 | 9 |
| NMVOC | 50 | 100 | 56 | 8 |
| CO | 50 | 100 | 63 | 17 |
| $NH_3$ | 1000 | 1000 | 994 | 1679 |
| TSP | 50 | 100 | 47 | 5 |
| $PM_{10}$ | 50 | 100 | 50 | 4 |
| $PM_{2.5}$ | 50 | 100 | 54 | 3 |
| BC | 50 | 100 | 56 | 4 |
| Arsenic | 1000 | 1000 | 873 | 62 |
| Cadmium | 1000 | 1000 | 824 | 160 |
| Chromium | 1000 | 1000 | 826 | 200 |
| Copper | 1000 | 1000 | 999 | 5 |
| Mercury | 1000 | 1000 | 713 | 106 |
| Nickel | 1000 | 1000 | 928 | 34 |
| Lead | 1000 | 1000 | 859 | 12 |
| Selenium | 1000 | 1000 | 767 | 137 |
| Zinc | 1000 | 1000 | 942 | 39 |
| Dioxins | 1000 | 1000 | 729 | 153 |
| Flouranthene | 1000 | 1000 | 827 | 84 |
| Benzo(b) flouranthene | 1000 | 1000 | 811 | 180 |
| Benzo(k) flouranthene | 1000 | 1000 | 818 | 269 |
| Benzo(a) pyrene | 1000 | 1000 | 873 | 288 |
| Benzo(g,h,i) perylene | 1000 | 1000 | 818 | 64 |
| indeno(1,2,3-c,d) pyrene | 1000 | 1000 | 789 | 164 |
| HCB | 1000 | 1000 | 782 | 235 |
| PCB | 1000 | 1000 | 713 | 130 |

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# Annex

Se enclosed annex 1-17 in separate excel file
http://dce2.au.dk/pub/SR148_Annex.

# DANISH EMISSION INVENTORIES FOR ROAD TRANSPORT AND OTHER MOBILE SOURCES

Inventories until the year 2013

This report explains the parts of the Danish emission inventories related to road transport and other mobile sources. Emission results are shown for $CO_2$, $CH_4$, $N_2O$, $SO_2$, $NO_X$, NMVOC, CO, particulate matter (PM), BC, heavy metals, dioxins and PAH. From 1990-2013 the fuel consumption and $CO_2$ emissions for road transport increased by 25 and 19 %, respectively, and $CH_4$ emissions have decreased by 78 %. A $N_2O$ emission increase of 30 % is related to the relatively high emissions from older gasoline catalyst cars. The 1985-2013 emission decrease for NMVOC, CO, particulates (exhaust only: Size is below $PM_{2.5}$) $NO_X$ and BC are 88, 85, 74, 57 and 54 %, respectively, due to the introduction of vehicles complying with gradually stricter emission standards. For $SO_2$ the emission drop 99 % (due to reduced sulphur content in the diesel fuel), whereas the $NH_3$ emissions increased by 1916 % (due to the introduction of catalyst cars). For other mobile sources the calculated emission changes for $CO_2$ (and fuel use), $CH_4$ and $N_2O$ were -9, -34 and -9 %, from 1990 to 2013. The emissions of $SO_2$, particulates (all size fractions), BC, NMVOC, $NO_X$ and CO decreased by 90, 73, 68, 40, 29 and 5 from 1985 to 2013. For $NH_3$ the emissions increased by 15 % in the same time period. Uncertainties for the emissions and trends were estimated.

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