DANISH EMISSION INVENTORIES FOR ROAD TRANSPORT AND OTHER MOBILE SOURCES

Inventories until the year 2016

Scientific Report from DCE – Danish Centre for Environment and Energy No. 277 2018

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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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, HCB, PCBs and PAHs. From 1990-2016 the fuel consumption and CO_2 emissions for road transport increased by 33 and 26 %, respectively, and CH_4 emissions have decreased by 83 %. A N_2O emission increase of 46 % is related to the relatively high emissions from older gasoline catalyst cars. The 1985-2016 emission decrease for NMVOC, CO, particulates (exhaust only: Size is below $PM_{2.5}$) NO_x and BC are 90, 88, 78, 63, 70 %, 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 1453 % (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 -16, -56 and -4 %, from 1990 to 2016. The emissions of SO_2, particulates (all size fractions), BC, NMVOC, NO_x and CO decreased by 95, 78, 78, 61, 34 and 36 % from 1985 to 2016. For NH_3 the emissions increased by 9 % 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, dioxins, PAHs, greenhouse gases, acidifying components.

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Preface

On behalf of the Ministry of Environment and Food and the Ministry of Energy, Utilities and Climate, DCE - Danish Centre for Environment and Energy – at Aarhus University prepares the Danish atmospheric emission inventories. DCE 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 as well as to the EU under the relevant European Union regulations and directives. The work is carried out by the Department of Environmental Science at Aarhus University.

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 1990-2016 as reported to the UNFCCC. For SO_2 (sulphur 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 1985-2016, and for heavy metals, dioxins, HCB (hexachlorobenzene), PCBs (polychlorinated biphenyls) and PAHs (poly-aromatic hydrocarbons) emission results are shown from 1990-2016, 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 sub-sectors for other mobile sources (Table 0.1) are military, railways, inland waterways, national sea traffic, national fishing, civil aviation and non-road machinery used in agriculture, forestry, industry, household/gardening and commercial/institutional.

The emissions of CO_2 (carbon dioxide), CH_4 (methane) and N_2O (nitrous oxide), SO_2 (sulphur 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, HCB (hexachlororbenzene), PCBs (polychlorinated biphenyls) and PAHs (polycyclic aromatic hydrocarbons) 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 0.4 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 5 (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 emission factors for hot engines, emission ratios between cold and hot engines and factors for gasoline evaporation.

The emissions from air traffic are also calculated with a DCE model. For 2001-2016, 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/EEA 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. By using appropriate assumptions, a consistent time-series of emissions is produced back to 1985 using also the detailed city-pair emission inventory results from 2001 as a basis.

National sea transport is split into regional ferries, small ferries (island and short cut ferries), freight transport between Denmark and Greenland/Faroe Islands, and other national sea transport. For 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 freight transport between Denmark and Greenland/Faroe Islands, and other national sea transport, the calculations are simply fuel based using fuel sale figures in combination with average fuel related emission factors.

Non-road working machines and equipment are grouped in the following sectors: Agriculture, Forestry, Industry, Household/Gardening and Commercial/Institutional. Recreational craft are grouped in the sector 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 fishery activities 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 for ferries is calculated directly by DCE. The difference between fuel sales statistics for national sea transport and bottom up fuel estimates for ferries is allocated to other national sea transport. 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_2, CO, BC, $PM_{2.5}$, PM_{10}, NMVOC and TSP. In 2016, the emission percentages were 30, 28, 28, 16, 8, 8, 7 and 4 %, respectively. The emissions of NH_3, N_2O, CH_4 and SO_2 have marginal shares of 1.3, 2.4, 0.1 and 0.7 %, respectively.

From 1990 to 2016, the calculated fuel consumption and emission changes for CO_2, CH_4 and N_2O are 33, 26, -83 and 46 %. The calculated 1985-2016 fuel consumption and emission changes for NO_x, NMVOC, CO, particulates (exhaust only: Size is below $PM_{2.5}$) and BC are 51, -63, -90, -88, -78 and -70 %.

The most significant emission changes from 1985 to 2016 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 1453 % (due to the introduction of cars with catalysts).

Table 0.2 Emissions (tonnes[a]) from road transport in 2016, changes from 1985 (1990[b]) to 2016, and 2016 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	43	16732	4152	246	55717	6841	184	938	353	353	353	249
Road transport:Light duty vehicles	9	6853	268	6	2031	1352	42	17	174	174	174	137
Road transport:Heavy duty vehicles	22	11366	282	52	4388	3538	214	39	181	181	181	124
Road transport: Mopeds & motorcycles	0	144	1300	84	7348	71	1	1	21	21	21	3
Road transport: Gasoline evaporation	0	0	1394	0	0	0	0	0	0	0	0	0
Road transport: Brake wear	0	0	0	0	0	0	0	0	523	513	204	14
Road transport: Tyre wear	0	0	0	0	0	0	0	0	971	582	408	149
Road transport: Road abrasion	0	0	0	0	0	0	0	0	1197	599	323	0
Road transport exhaust total	74	35095	7396	389	69483	11802	441	995	729	729	729	514
Road transport non exhaust total	0	0	0	0	0	0	0	0	2691	1694	935	162
Road transport total	74	35095	7396	389	69483	11802	441	995	3420	2423	1664	676
National total	10240	115153	103074	280917	244027	42437	18051	75371	90881	31179	20549	4196
Road- % of national total, 2016	0.7	30	7.2	0.1	28	28	2.4	1.3	3.8	7.8	8.1	16
Road- % change 1985-2016[b]	-99	-63	-90	-83	-88	26	46	1453	-78	-78	-78	-70

[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 2016, the most important CO_2 emission source for road transport is passenger cars (58 %), followed by heavy-duty vehicles (30 %), light-duty vehicles (11 %) and 2-wheelers (1 %). For CH_4 the 2016 emission shares were 63, 22, 13 and 2 % 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 42, 48 and 10 %, respectively.

For 2016, 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 (48, 32, 20 and 0 %), NMVOC (56, 4, 4 and 17 %), CO (80, 6, 3 and 11 %), particulates exhaust (48, 25, 24 and 3 %), BC (48, 24, 27 and 1 %), and NH_3 (94, 4, 2 and 0 %).

Set in relation to total road transport emissions in 2016, the emission shares of TSP, PM_{10}, $PM_{2.5}$ and BC were 79, 71, 57 and 19 %, respectively, related to tire, brake and road abrasion.

Emissions from other mobile sources

For other mobile sources, the emissions of NO_x, CO, BC, CO_2 and SO_2 have the largest shares of the national totals in 2016. The shares are 28, 26, 15, 8 and 7 %, respectively. The 2016 NMVOC, TSP, PM_{10} and $PM_{2.5}$ emission shares are 5, 1, 4 and 6 %, respectively, whereas the emissions of N_2O, NH_3 and CH_4 have marginal shares of around 1 % or less in 2016.

From 1990 to 2016 the calculated emission changes for CO_2 (and fuel use), CH_4 and N_2O are -16, -56 and -4 %, respectively. The emissions of SO_2, particulates (all size fractions), BC, NMVOC, NO_x and CO have changed by -95, -78, -78, -61, -34, and -36 % from 1985 to 2016. For NH_3 the emissions increased by 9 % in the same time period.

Table 0.3 Emissions from other mobile sources in 2016 (tonnes[a]), changes from 1985 (1990[b]) to 2016, and 2016 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	4	4009	832	28	4796	675	31	2	318	318	318	212
Civil aviation (Domestic)	43	684	76	2	532	133	7	0	5	5	5	2
Railways	2	2048	132	5	284	253	7	1	48	48	48	31
National navigation (Shipping)	406	12895	455	38	1563	647	16	0	296	293	291	57
Commercial/Institutional: Mobile	1	138	745	28	29809	83	2	0	17	17	17	4
Residential: Mobile	0	36	948	16	9437	24	0	0	11	11	11	1
Agriculture/Forestry: Off-road	7	5661	1235	84	13618	1068	50	3	404	404	404	249
National fishing	196	5273	245	8	732	309	8	0	94	93	93	28
Other, Mobile	63	1302	296	10	2897	206	8	1	85	85	85	33
Total Other mobile	720	32047	4963	219	63667	3399	129	7	1277	1273	1271	617
Total national	10240	115153	103074	280917	244027	42437	18051	75371	90881	31179	20549	4196
Other mobile- % of national total, 2016	7.0	28	4.8	0.1	26	8.0	0.7	0.01	1.4	4.1	6.2	15
Other mobile- % change 1985-2016[b]	-95	-34	-61	-56	-36	-16	-4	9	-78	-78	-78	-78

[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 emissions are national navigation, followed by agriculture/forestry, fisheries and industry. For CO_2, particulates (all size fractions) and BC the largest emission sources are agriculture/forestry, industry and national navigation, in this consecutive order. For NMVOC and CO most of the emissions come from gasoline fuelled working machinery in the commercial/institutional, agriculture/forestry 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 93, 50, 44, 11 and 7 % of national totals in 2016. For other mobile sources, the nickel (Ni), Arsenic (As) and Pb shares are 41, 12 and 10 %. For the remaining components, the emission shares are less than 7 %.

The most important exhaust related emissions (fuel and engine oil) for road transport (percent of national total in brackets) are Zn (13 %), Cd (6 %), Cr (6 %) and Hg (7 %). The most important wear related emissions are Cu (93 %) and Pb (48 %) almost solely coming from tyre wear, and Zn (31 %) 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, 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.

POPs

Dioxins, HCB, PCBs and PAHs are categorized as POPs (persistent organic pollutants). For the individual POP components, the emission shares for road transport and other mobile sources are 5 % or less of the national total in 2016.

Uncertainties

For mobile sources in 2016, the CO_2 emissions are determined with the highest accuracy, followed by the CH_4, TSP, SO_2, PM_{10}, NMVOC, $PM_{2.5}$, NO_x, BC, CO and N_2O emissions with increasing levels of uncertainties. The uncertainties are 5, 34, 46, 47, 48, 50, 52, 55, 55, 55 and 120 %, respectively.

The uncertainties for the 1990-2016 emission trends are 5, 7, 8, 1, 5, 4, 3, 9, 3, 9 and 50 % for the emissions in the same consecutive order. For NH_3, heavy metals and PAHs the 2016 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, fritidsfartøjer, national søfart, fiskeri, civil flyvning, og arbejdsredskaber- og maskiner i landbrug, skovbrug, industri, have/hushold og handel/service.

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, HCB, PCB'er og PAH'er er de beregnede emissioner vist i tidsserier iht. til UNFCCC og UNECE LRTAP konventionernes krav, og resultaterne grupperes i henhold til UNFCCC's Common Reporting Format (CRF) og UNECE's National Format for Reporting (NFR) rapporteringskoder.

Tabel 0.1 Mobile kilder og CRF/NFR koder.

SNAP koder	CRF/NFR koder
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 5 (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 antallet af køretøjer, køretøjernes årskørsler, emissionsfaktorerne for varme motorer, emissionsforholdet mellem kolde og varme motorer, og faktorerne for benzinfordampning.

For luftfart beregnes emissionerne også i en DCE model. For 2001-2016 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/EEA 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 de detaljerede city-pair emissionsresultater for 2001 som basis.

National søfart er opdelt i regionale færger, småfærger (ø- og genvejsfærger), godstransport mellem Danmark og Grønland/Færøerne og øvrig national søfart. For færger beregnes emissionerne som produktet af antallet af dobbeltture, sejltid pr. dobbelttur, motorstørrelsen, motorlastfaktoren og emissionsfaktoren. For godstransport mellem Danmark og Grønland/Færøerne og øvrig national søtransport beregnes emissionerne som produktet af brændstofsalget og gennemsnitlige brændstofrelaterede emissionsfaktorer.

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

For arbejdsredskaber og -maskiner inden for landbrug, skovbrug, industri, have/hushold, handel/service samt 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 for færger. Forskellen mellem det statistiske brændstofsalg for national søtransport og det beregnede forbrug for færger henføres til øvrig national søtransport. 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_2, CO, BC, $PM_{2.5}$, PM_{10}, NMVOC og TSP. Procentandelene for disse stoffer ligger på hhv. 30, 28, 28, 16, 8, 8, 7 og 4 %. Emissionsandelene for NH_3, N_2O, CH_4 og SO_2 er små og ligger på hhv. 1,3, 2,4, 0,1 og 0,7 %.

De beregnede ændringer i energiforbruget og CO_2-, CH_4- og N_2O-emissionerne er på hhv. 33, 26, -83 og 46 % fra 1990-2016. For NO_x, NMVOC, CO, partikler (kun udstødning: $< PM_{2.5}$) og BC er de beregnede ændringer på hhv. 51, -63, -90, -88, -78 and -70 % i perioden 1985-2016.

De mest markante emissionsændringer fra 1985 til 2016 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 1453 % (pga. indførelsen af biler med katalysator.

Tabel 0.2 Emissioner fra vejtrafik i 2016 (tons[a]), ændringer fra 1985 (1990[b]) til 2016, og 2016-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
Personbiler	43	16732	4152	246	55717	6841	184	938	353	353	353	249
Varebiler	9	6853	268	6	2031	1352	42	17	174	174	174	137
Tunge køretøjer	22	11366	282	52	4388	3538	214	39	181	181	181	124
Knallerter og motorcykler	0	144	1300	84	7348	71	1	1	21	21	21	3
Fordampning	0	0	1394	0	0	0	0	0	0	0	0	0
Bremseslid	0	0	0	0	0	0	0	0	523	513	204	14
Dækslid	0	0	0	0	0	0	0	0	971	582	408	149
Vejslid	0	0	0	0	0	0	0	0	1197	599	323	0
Total udstødning	74	35095	7396	389	69483	11802	441	995	729	729	729	514
Total slidrelateret	0	0	0	0	0	0	0	0	2691	1694	935	162
I alt	74	35095	7396	389	69483	11802	441	995	3420	2423	1664	676
National total	10240	115153	103074	280917	244027	42437	18051	75371	90881	31179	20549	4196
% af national total, 2016	0,7	30	7,2	0,1	28	28	2,4	1,3	3,8	7,8	8,1	16
% ændring 1985-2016[b]	-99	-63	-90	-83	-88	26	46	1453	-78	-78	-78	-70

[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 2016 beregnes for personbiler (58 %), fulgt af tunge køretøjer (30 %), varebiler (11 %) og 2-hjulede køretøjer (1 %). For CH_4 beregnes emissionsandele på hhv. 63, 22, 13 og 2 % for personbiler, 2-hjulede køretøjer, tunge køretøjer og varebiler, og N_2O-emissionsandelene for personbiler, tunge køretøjer og varebiler er på hhv. 42, 48 og 10 %.

I 2016 beregnes emissionsandele for personbiler, tunge køretøjer, varebiler og 2-hjulede køretøjer på hhv. 48, 32, 20 og 0 % (NO_x), 56, 4, 4 og 17 % (NMVOC), 80, 6, 3 og 11 % (CO), 48, 25, 24 og 3 % (TSP, PM_{10} og $PM_{2.5}$ fra udstødning, BC) samt 94, 4, 2 og 0 % (NH_3).

De samlede emissioner af TSP, PM_{10}, $PM_{2.5}$ og BC fra dæk-, bremse- og vejslid udgjorde i 2016 hhv. 79, 71, 57 og 19 % af vejtrafikkens samlede emissioner.

Emissioner fra andre mobile kilder

Andre mobile kilders NO_x-, CO-, BC-, CO_2- og SO_2-emissioner udgjorde i 2016 hhv. 28, 26, 15, 8 og 7 % af landets total. I 2016 er emissionsandelene for NMVOC, TSP, PM_{10} og $PM_{2.5}$ på hhv. 5, 1, 4 og 6 %, mens andelene for N_2O, NH_3 og CH_4 kun er på omtrent 1 % eller mindre.

Fra 1990-2016 beregnes emissionsændringer for CO_2 (og energiforbrug), CH_4 og N_2O på hhv. -16, -56 og -4 %. Fra 1985-2016 beregnes emissionsændringer for SO_2, partikler (alle størrelsesfraktioner), BC, NMVOC, NO_x og CO på hhv. -95, -78, -78, -61, -34 og -36 %. For NH_3 stiger emissionen med 9 % i samme periode.

Tabel 1.3 Emissioner (tons[a]) fra andre mobile kilder i 2016, ændringer fra 1985 (1990[b]) til 2016, og 2016-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	4	4009	832	28	4796	675	31	2	318	318	318	212
Civil luftfart	43	684	76	2	532	133	7	0	5	5	5	2
Jernbane	2	2048	132	5	284	253	7	1	48	48	48	31
National søfart	406	12895	455	38	1563	647	16	0	296	293	291	57
Handel og service, arbejdsredskaber	1	138	745	28	29809	83	2	0	17	17	17	4
Have-hushold, arbejdsredskaber	0	36	948	16	9437	24	0	0	11	11	11	1
Landbrug/skovbrug:Off-road	7	5661	1235	84	13618	1068	50	3	404	404	404	249
Fiskeri	196	5273	245	8	732	309	8	0	94	93	93	28
Øvrige mobile	63	1302	296	10	2897	206	8	1	85	85	85	33
Total Andre mobile kilder	720	32047	4963	219	63667	3399	129	7	1277	1273	1271	617
Total national	10240	115153	103074	280917	244027	42437	18051	75371	90881	31179	20549	4196
Andre mobile kilder -% af national total, 2016	7,0	28	4,8	0,1	26	8,0	0,7	0,01	1,4	4,1	6,2	15
Andre mobile kilder -% ændring 1985-2016[b]	-95	-34	-61	-56	-36	-16	-4	9	-78	-78	-78	-78

[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 er national søfart, efterfulgt af landbrug/skovbrug, fiskeri og industri. For CO_2, partikler (alle størrelsesfraktioner) og BC er den største emissionskilde landbrug/skovbrug, efterfulgt af industri og national søfart.

Den største del af NMVOC- og CO-emissionerne kommer fra benzindrevne arbejdsredskaber og maskiner inden for handel og service, landbrug/skovbrug 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 2016 er vejtrafikkens emissionsandele af de nationale totaler for kobber (Cu), bly (Pb), zink (Zn), krom (Cr) og kadmium (Cd) på hhv. 93, 50, 44, 11 og 7 %. For andre mobile kilder er nikkel (Ni), Arsen (As) og Pb andelene på 41, 12 og 10 %. For de øvrige komponenter er emissionsandelene på mindre end 7 %.

For vejtrafik beregnes de største udstødningsrelaterede emissionsandele (% af national total) for Zn (13 %), Cd (6 %), Cr (6 %) og Hg (7 %). De slidrelaterede emissionsandele for Cu (93 %) og Pb (48 %) kommer næsten udelukkende fra dækslid, og Zn (31 %) kommer fra bremse- og dækslid. Ni og As emissionerne fra andre mobile kilder skyldes forbruget af marin diesel og tung olie inden for 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.

POP

Dioxiner, HCB, PCB'er og PAH'er benævnes samlet set som POP'er (persistent organic pollutants). For de enkelte POP-komponenter udgør emissionsandelene for vejtransport og andre mobile kilder 5 % eller mindre af de nationale totaler i 2016.

Usikkerheder

I 2016 er CO_2-emissionerne de mest præcise, fulgt af CH_4, TSP, SO_2, PM_{10}, NMVOC, $PM_{2.5}$, NO_x, BC, CO og N_2O-estimaterne med stigende usikkerheder. Usikkerhederne er på hhv. 5, 34, 46, 47, 48, 50, 52, 55, 55, 55 og 120 %. I samme emissionsrækkefølge er usikkerheden på emissionsudviklingen fra 1990 til 2016 på hhv. 5, 7, 8, 1, 5, 4, 3, 9, 3, 9 og 50 %. For NH_3, tungmetaller og PAH'er er 2016-emissionerne bestemt med en usikkerhed på mellem 700 og 1000 %. Her er usikkerheden på 1990-2016 - 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 same applies for the air pollution inventory, which is also reported to the EU, as the EU is also a Party to CLRTAP. 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 2016, 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 explained 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 2016 are listed in the Tables 2.1-2.4. A thorough documentation of the Danish inventory can be seen in Nielsen et al (2018a) for greenhouse gases reported to the UNFCCC convention (the Danish NIR report), and in Nielsen et al. (2018b) 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 2016 reported to the UNFCCC convention.

	CO_2 (Gg)	CH_4 (Gg)	N_2O (Gg)	Total GHG[a] (Gg CO_2e)
1. Energy	35487	14.79	1.36	36262
2. Industrial processes and product use	1396	0.09	0.06	2124
3. Agriculture	217	222.45	15.96	10534
4. Land use, land-use change and forestry	5320	2.41	0.11	5413
5. Waste	17	41.18	0.56	1212
Total national	42437	280.92	18.05	55546
International transport (air)	2823	8.18	94.83	31289
International transport (sea)	1950	49.08	49.20	17840

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 2016 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	8354	96309	37195	237564	3108	21898	19697	18271	4168
2. Industrial processes and product use	1242	60	27935	2656	332	6599	3088	812	8
3. Agriculture	12	18697	37768	2280	70769	62131	8144	1215	19
5. Waste	631	88	175	1528	1162	252	251	251	0
Total national	10240	115153	103074	244027	75371	90881	31179	20549	4196
International transport (air)[1]	901	14449	207	2314	0	199	199	199	99
International transport (sea)	1230	45792	1587	5017	0	1201	1189	1183	137

Table 2.3 Heavy metal emissions 2016 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	231	697	1547	40399	305	2720	8265	616	53419
2. Industrial processes and product use	45	20	176	2142	18	173	754	38	2260
3. Agriculture	2	2	9	0.0	0.3	7	33	1	1
5. Waste	2	5	10	67	1	7	1938	0.4	7559
Total national	280	724	1742	42609	324	2906	10991	656	63239
International transport (air)[1]	0	0	0	0	0	0	9	0	0
International transport (sea)	129	10	60	129	24	6581	83	167	395

Table 2.4 PAH emissions 2016 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	2190	16485	2129	2376	922	1313	42981
2. Industrial processes and product use	5	159	17	16	10	11	66
3. Agriculture	119	23	108	106	42	39	0
5. Waste	9	5947	47	58	45	69	26
Total national	2324	22613	2301	2557	1018	1432	43073
International transport (air)[1]	0	0	0	0	0	0	0
International transport (sea)	0.1	0.3	22	6	3	0	0

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 2016/2284/EU)
- The UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol

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

- 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 original 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 as well as the revised NECD 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 %).

Additionally, the revised NECD included reduction commitments for 2030 relative to the emission level in 2005. The reduction commitments (in brackets) for 2030 are set for the following pollutants: SO_2 (59 %), NO_x (68 %), NMVOC (37 %), NH_3 (24 %), and $PM_{2.5}$ (55 %).

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 (for the second commitment period, NF_3 was added). 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 inventories, all activity rates and emissions are defined in SNAP (Selected Nomenclature for Air Pollution) sector categories. The emission inventories are compiled using the software tool CollectER (Pulles et al., 2009) supported by the European Environment Agency.

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 (Nomenclature 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 (3000 ft.). 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 the UNFCCC, the national emissions for aviation comprise the emissions from domestic LTO (080501)

[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.

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 (1A4cii) sector. Fishing activities (SNAP code 080403) is reported under 1A4ciii.

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.

4 Input data and calculation methods for road transport

For road transport, the detailed methodology (Tier 3) is used to make annual estimates of the Danish emissions, as described in the EMEP/EEA Air Pollutant Emission Inventory Guidebook (EMEP/EEA, 2016). The actual calculations are made with a model developed by ENVS, using the European COPERT 5 model methodology (EMEP/EEA, 2016)[3]. 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 5 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.

Fleet and annual mileage data are provided by DTU Transport for the vehicle categories present in COPERT 5 (Jensen, 2017). DTU Transport use data from the Danish vehicle register kept by Statistics Denmark. The vehicle register data consist of vehicle type (passenger cars, vans, trucks, buses, mopeds, motorcycles), fuel type, vehicle weight, gross vehicle weight, engine size (passenger cars registered from 2005+), Euro class (trucks and buses registered from 1997+), 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 used examined by Cowi (2008) for new Danish cars from 1998. For the years before 1998, data for 1998 is used, and for the years 1999-2004, a linear interpolation between 1998 and 2005 weight class-engine size relations is used. For trucks, truck driver registration notes gathered by Statistics Denmark are used to split the fleet figures of ordinary trucks into number of solo trucks and truck-trailer combinations. Further, the registration notes make it possible to assume the average total vehicle weight of the truck trailer combination. For articulated trucks also, the registration notes make it possible to assume the average total vehicle weight of the full articulated truck.

Danish mileage data comes from the Danish Road Directorate based on the Danish vehicle inspection program. Total mileage per year and vehicle category are derived for the years 1985-2016, 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

[3] The main difference between the previous COPERT 4 model version and COPERT 5 is NO_x emission factor updates for Euro 6 diesel cars and Euro 5 and 6 diesel vans.

determines the yearly mileage reduction percentages as a function of vehicle age. In a first step, the detailed mileage matrix is combined with corresponding fleet numbers 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, 2017) 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).

Table 4.1 Model vehicle classes and sub-classes, trip speeds and mileage split.

Vehicle classes	Fuel type	Engine size/weight	Trip speed [km per h] 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.	40	70	100
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/CNG	Rigid 3,5 - 7,5t	35	60	80
Trucks	Diesel/CNG	Rigid 7,5 - 12t	35	60	80
Trucks	Diesel/CNG	Rigid 12 - 14 t	35	60	80
Trucks	Diesel/CNG	Rigid 14 - 20t	35	60	80
Trucks	Diesel/CNG	Rigid 20 - 26t	35	60	80
Trucks	Diesel/CNG	Rigid 26 - 28t	35	60	80
Trucks	Diesel/CNG	Rigid 28 - 32t	35	60	80
Trucks	Diesel/CNG	Rigid >32t	35	60	80
Trucks	Diesel/CNG	TT/AT 14 - 20t	35	60	80
Trucks	Diesel/CNG	TT/AT 20 - 28t	35	60	80
Trucks	Diesel/CNG	TT/AT 28 - 34t	35	60	80
Trucks	Diesel/CNG	TT/AT 34 - 40t	35	60	80
Trucks	Diesel/CNG	TT/AT 40 - 50t	35	60	80
Trucks	Diesel/CNG	TT/AT 50 - 60t	35	60	80
Trucks	Diesel/CNG	TT/AT >60t	35	60	80
Urban buses	Gasoline		30	50	70
Urban buses	Diesel/CNG	< 15 tonnes	30	50	70
Urban buses	Diesel/CNG	15-18 tonnes	30	50	70
Urban buses	Diesel/CNG	> 18 tonnes	30	50	70
Coaches	Gasoline		35	60	80
Coaches	Diesel/CNG	< 15 tonnes	35	60	80
Coaches	Diesel/CNG	15-18 tonnes	35	60	80
Coaches	Diesel/CNG	> 18 tonnes	35	60	80
Mopeds	Gasoline	2 stroke	30	30	-
Mopeds	Gasoline	4 stroke	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

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 and a follow-up survey in 2014 has given additional information. This mileage contribution has been added to the total mileage for Danish trucks on Danish roads, for trucks > 16 tonnes of gross vehicle weight. The data has been further processed by DTU Transport; by using appropriate assumptions, the mileage have been backcasted to 1985 and forecasted to 2016.

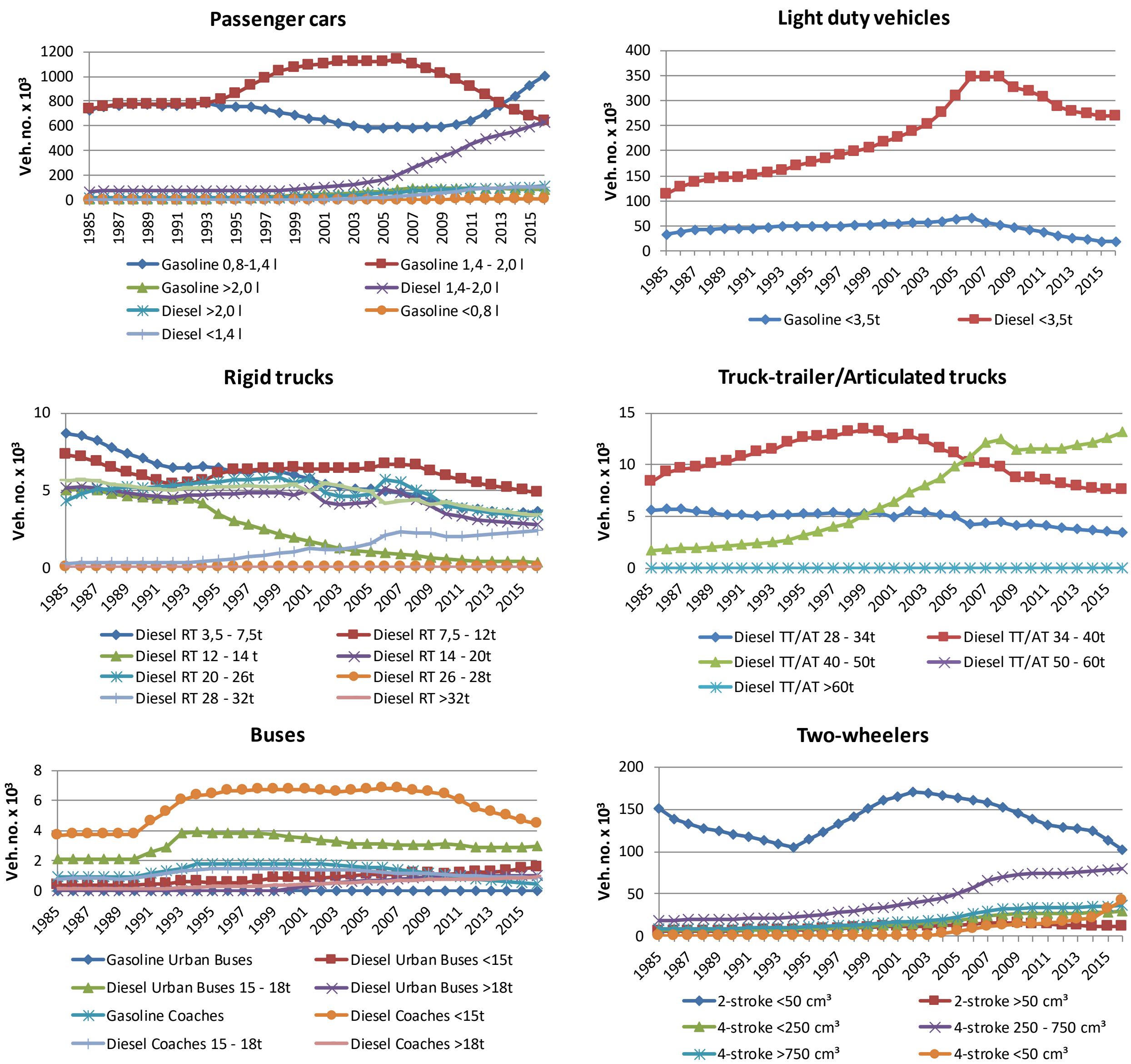


Figure 4.1 Number of vehicles in sub-classes in 1985-2016.

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

There has been a considerable growth in the number of diesel light-duty vehicles from 1985 to 2006; the number of vehicles has however decreased somewhat after 2006 due to the restructuring of car taxes that made it less advantageous buying vans for private use.

For the truck-trailer and articulated truck combinations, there is a tendency towards the use of increasingly fewer but larger trucks throughout the time period. The decline in fleet numbers for many of the truck categories is due to the combined effects of the global financial crisis, the fleet shift towards fewer and larger trucks, international market competition (foreign transport companies are effectively gaining Danish market shares), and the reflagging of Danish commercial trucks to companies based in the neighbouring countries.

The sudden change in the level of urban bus and coach numbers from 1991 to 1995 is due to uncertain fleet data from Statistics Denmark.

The reason for the significant growth in the number of mopeds from 1994 to 2002 is the introduction of the so-called Moped 45 vehicle type. From 2004 onwards, there is a 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 1985-2016 period. The increase is, however, most visible from the mid-1990s and onwards.

The vehicle numbers are summed up in layers for each year (Figure 4.2) by using the correspondence between layers and first year of registration:

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

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

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

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

Where M = annual mileage.

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 (2017). 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 1985-2016. 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 1-6, Euro I-VI etc.) have been introduced into the Danish motor fleet.

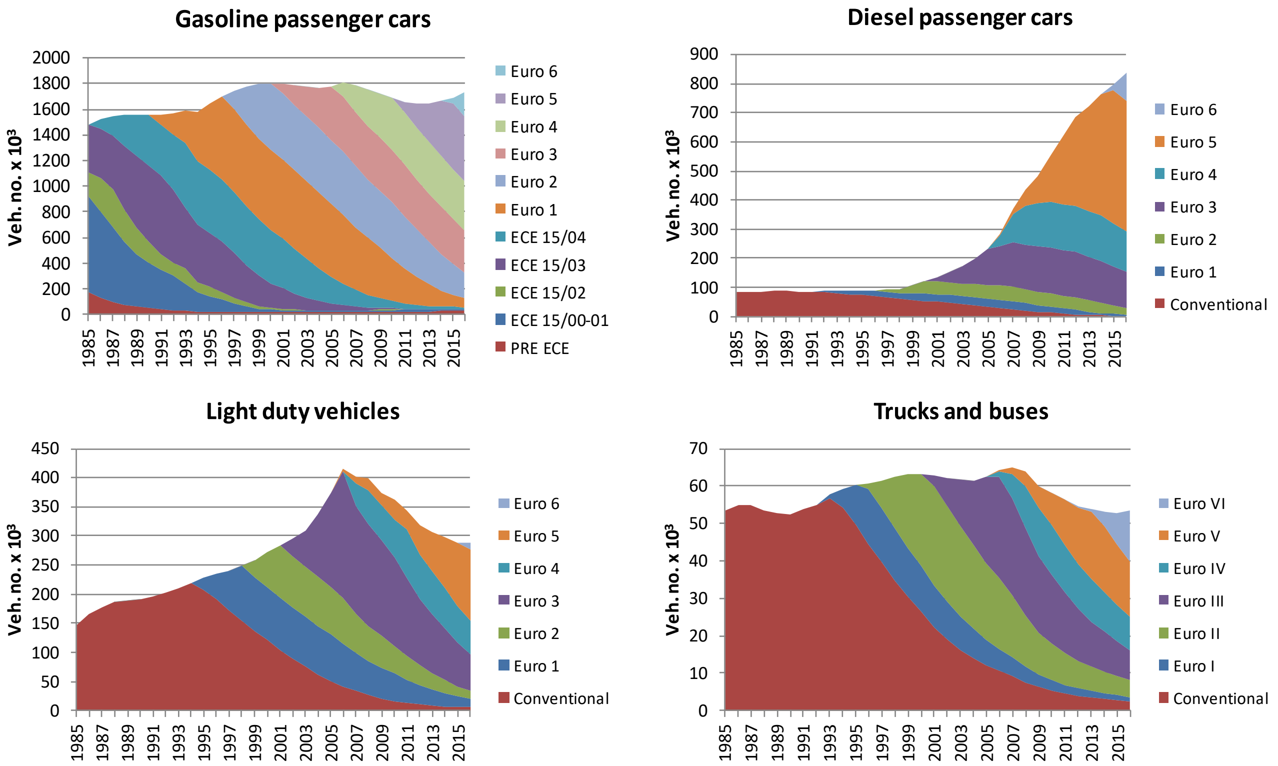


Figure 4.2 Layer distribution of vehicle numbers per vehicle type in 1985-2016.

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 had to comply on average with the limit value curve set by the legislation. This rises to 75 % in 2013, 80 % in 2014, 100 % in 2015-2019, 95 % in 2020, and 100 % from 2021 onwards.
- **Lower penalty payments for small excess emissions until 2018:** if the average CO_2 emissions of a manufacturer's fleet exceed its limit value in any year from 2012, the manufacturer has to pay an excess emissions premium for each car registered. This premium amounts to €5 for the first g per km of exceedance, €15 for the second g per km, €25 for the third g per km, and €95 for each subsequent g per km. From 2019, already the first g per km of exceedance will cost €95.
- **Long-term target:** a target of 95g CO_2 per km is specified for the year 2020.
- **Eco-innovations:** Manufacturers can be granted a maximum of 7g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.

The EU 510/2011 regulation 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 was phased in between 2014 and 2017. In 2014, an average of 70 % of each manufacturer's newly registered vans had to comply with the limit value curve set by the legislation. This proportion rises to 75 % in 2015, 80 % in 2016, and 100% from 2017 onwards.
- **Limit value curve:** emissions limits are set according to the mass of vehicle, using a limit value curve. The curve is set in such a way that a fleet average of 175 grams of CO_2 per kilometre is achieved. A so-called limit value curve of 100 % implies that heavier vans are allowed higher emissions than lighter vans while preserving the overall fleet average. Only the fleet average is regulated, so manufacturers will still be able to make vehicles with emissions above the limit value curve provided these are balanced by other vehicles, which are below the curve.
- **Vehicles affected:** the vehicles affected by the legislation are vans, which account for around 12 % of the market for light-duty vehicles. This includes vehicles used to carry goods weighing up to 3.5t (vans and car-derived vans, known as N1) and which weigh less than 2610 kg when empty.
- **Long-term target:** a target of 147g CO_2 per km is specified for the year 2020.
- **Excess emissions premium for small excess emissions until 2018:** if the average CO_2 emissions of a manufacturer's fleet exceed its limit value in any year from 2014, the manufacturer has to pay an excess emissions premium for each van registered. This premium amounts to €5 for the first g per km of exceedance, €15 for the second g per km, €25 for the third g per km, and €95 for each subsequent g per km. From 2019, the first g per km of exceedance will cost €95. This value is equivalent to the premium for passenger cars.
- **Super-credits:** vehicles with extremely low emissions (below 50g per km) was given additional incentives whereby each low-emitting van is counted as 3.5 vehicles in 2014 and 2015, 2.5 in 2016 and 1.5 vehicles in 2017.
- **Eco-innovations:** Manufacturers can be granted a maximum of 7g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.
- **Other flexibilities:** manufacturers may group together to form a pool and act jointly in meeting the specific emissions targets. Independent manufacturers who sell fewer than 22,000 vehicles per year can also apply to the Commission for an individual target instead.

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

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

average speed of 63 km per hour. More information regarding the fuel measurement procedure can be found in the EU-directive 80/1268/EEC.

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

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

In the road transport emission model, compromise dates for enter into service of the Euro 6d-TEMP technology are set to 1/9 2018 and 1/9 2019, for diesel cars and vans, respectively. For Euro 6d, the enter into service dates are set to 1/1 2021 and 1/1 2022 for cars and vans, respectively.

For NOx, VOC (NMVOC + CH4), CO and PM, the emissions from road transport vehicles have to comply with the different EU directives listed in Table 4.2. The emission directives distinguish between three vehicle classes according to vehicle reference mass[5]: Passenger cars and light duty trucks (<1305 kg), light duty trucks (1305-1760 kg) and light duty trucks (>1760 kg). The specific emission limits are shown in Annex 3.

For heavy-duty vehicles (trucks and buses), the emission limits are given in g per kWh and the measurements are carried out for engines in a test bench, using the ECE R-49, EU ESC (European Stationary Cycle) and ETC (European Transient Cycle) test cycles, depending on the Euro norm and exhaust gas after-treatment system installed. For Euro VI engines the WHSC (World Harmonized Stationary Cycle) and WHTC (World Harmonized Transient Cycle) test cycles are used. For a description of the test cycles see e.g. www.dieselnet.com.

In terms of the sulphur content in the fuels used by road transportation vehicles, the EU directive 2003/17/EF describes the fuel quality standards agreed by the EU. In Denmark, the sulphur content in gasoline and diesel was reduced to 10 ppm in 2005, by means of a fuel tax reduction for fuels with 10 ppm sulphur contents.

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

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 1	91/441	1.10.1990[e]
	Euro 2	94/12	1.1.1997
	Euro 3	98/69	1.1.2001
	Euro 4	98/69	1.1.2006
	Euro 5	715/2007(692/2008)	1.1.2011
	Euro 6	715/2007(692/2008)	1.9.2015
	Euro 6d-TEMP	2016/646	1.9.2018
	Euro 6d	2016/646	1.1.2021
Passenger cars (diesel and LPG)	Conventional	-	-
	ECE 15/04	83/351	1987[d]
	Euro 1	91/441	1.10.1990[e]
	Euro 2	94/12	1.1.1997
	Euro 3	98/69	1.1.2001
	Euro 4	98/69	1.1.2006
	Euro 5	715/2007(692/2008)	1.1.2011
	Euro 6	715/2007(692/2008)	1.9.2015
	Euro 6d-TEMP	2016/646	1.9.2018
	Euro 6d	2016/646	1.1.2021
Light duty trucks (gasoline and diesel)	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 1	93/59	1.10.1994
	Euro 2	96/69	1.10.1998
	Euro 3	98/69	1.1.2002
	Euro 4	98/69	1.1.2007
	Euro 5	715/2007	1.1.2012
	Euro 6	715/2007	1.9.2016
	Euro 6d-TEMP	2016/646	1.9.2019
	Euro 6d	2016/646	1.1.2022
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		0
	Euro I	97/24	2000

Continued	Euro II	2002/51	2004
	Euro III	2002/51	2007
	Euro IV	168/2013	2017
	Euro V	168/2013	2021

a,b,c,d,f: Expert judgement suggests that Danish vehicles enter into the traffic before EU directive first registration dates. The effective inventory starting years are a: 1970; b: 1979; c: 1981; d: 1986; f: 1/9 2018 (cars) and 1/9 2019 (vans).e: The directive came into force in Denmark in 1991 (EU starting year: 1993).

4.3 Fuel consumption and emission factors

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

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

The fuel consumption and emission factors used in the Danish inventory come from the COPERT 5 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 order to account for the trend towards more fuel efficient vehicles being sold in Denmark in the later years, fuel consumption factors for Euro 5 and Euro 6 passenger cars are estimated in the following way.

For passenger cars, COPERT 5 includes measurement based fuel consumption factors until Euro 4. Further, COPERT 5 uses a calculation routine for newer cars that compensate for the trend towards more fuel efficient vehicles being sold during the later years. The data basis for fuel efficiency adjustment in COPERT 5 is, however, new registered cars from 2009-2011. Hence, the COPERT calculation routine is not able to account for the decreasing gap before 2009 and the increasing gap after 2011, between new car's type approval fuel consumption and real world fuel consumption, as monitored by e.g. the International Council on Clean Transportation (ICCT), Tietge et al. (2017a).

It is therefore necessary to adjust the baseline COPERT 5 fuel consumption factors for Euro 4, Euro 5 and Euro 6 passenger cars. This adjustment is made in the following way.

In the Danish fleet and mileage database kept by DTU Transport, the type approval fuel efficiency value based on the NEDC driving cycle (TA_{NEDC}) is registered for each single car. Further, DTU Transport calculates a modified fuel efficiency value (TA_{inuse}) with a function provided by COPERT 5 that better reflects the fuel consumption associated with the NEDC driving cycle under real ("inuse") traffic conditions. The latter function uses TA_{NEDC}, vehicle weight and engine size as input parameters (EMEP/EEA, 2016). For each new registration year, i, fuel type, f, and engine size, k, number based average values of TA_{NEDC} and TA_{inuse} are summed up and referred to as $\overline{TA_{NEDC}}(i, f, k)$ and $\overline{TA_{inuse}}(i, f, k)$.

The TA_{inuse} function is established for Euro 4 cars and has been developed from a vehicle database consisting of new registered cars from 2009-2011 (Tietge et al., 2017a). The TA_{inuse} function is thus not able to account for the decreasing gap before 2009 and the increasing gap after 2011, between new car's type approval fuel consumption and real world fuel consumption as monitored and documented by ICCT in their annual monitoring reports (Tietge et al., 2017b). To account for the fuel gap changes, the $\overline{TA_{inuse}}(i, f, k)$ values are adjusted for the years 2006-2016 with an index function, C_{ICCT} (i, f), based on the reported ICCT fuel gap figures by fuel type and new registration year ($\overline{TA_{inuse,adjust}}(i, f, k)$).

In order to meet the target of 95 g CO_2/km in 2020, the following approach is used to forecast the average TA_{NEDC} values ($\overline{TA_{NEDC}}(i)$ until 2020. As a starting point, the average CO_2 emission factor (average from all new registrations) is calculated for the last historical year (2016) based on the registered average TA_{NEDC} values from DTU Transport. Next, the average CO_2 emission factor (and $\overline{TA_{NEDC}}(i)$) for each future year's new sold cars is reduced with a linear function, C_{2020} (i), until the emission factor reaches 95 g CO_2/km in 2020. For years beyond 2020 annual fuel efficiency, improvement rates are used for new cars depending on fuel type as suggested by DEA (2016b).

The reduction function C_{2020} (i) is then used to reduce the adjusted type approval fuel efficiency values, $\overline{TA_{inuse,adjust}}(i, f, k)$, for the years between last historical year and 2020, for each of the fuel type/engine size fleet segments.

Subsequently these $\overline{TA_{inuse,adjust}}(i, f, k)$ values are aggregated by mileage into layer specific values for each inventory year ($\overline{TA_{inuse,adjust}}(layer)$).

At the same time, corresponding layer specific fuel consumption factors exist for Euro 4+ vehicles in the COPERT model. These fuel consumption factors represent the COPERT test vehicles under the NEDC driving cycle in real world traffic ($TA_{COPERT, inuse}$).

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

For vans, trucks, urban buses and coaches, annual fuel efficiency improvement rates are used for new vehicles depending on fuel type as suggested by DEA (2016b).

4.3.2 Adjustment for EGR, SCR and filter retrofits

In COPERT 5, emission factors are available for Euro V heavy duty vehicles using exhaust gas recirculation (EGR) and selective catalyst reduction (SCR) exhaust emission aftertreatment systems, respectively. The estimated new sales of Euro V diesel trucks equipped with EGR and SCR during the 2006-

2010 time periods has been examined by Hjelgaard and Winther (2011). These inventory fleet data are used in the Danish inventory to calculate weighted emission factors for Euro V trucks in different size categories.

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 2000s. 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.

4.3.3 Adjustment for biofuel usage

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

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 (2016), 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":

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

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

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

In the case of trip speeds below 19 km per hour the deterioration factor, DF, equals UDF, whereas for trip speeds exceeding 63 km per hour, DF=EUDF (Danish rural and highway trip speed; c.f. Table 4.1). For trip speeds between 19 and 63 km per hour (Danish urban trip speed; c.f. Table 4.1) the deterioration factor, DF, is found as an interpolation between UDF and EUDF. Secondly, the deterioration factors, one for each of the three road types, are aggregated into layers by taking into account vehicle numbers and annual mileage levels per first registration year:

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

where DF is the deterioration factor.

For N_2O and NH_3, COPERT 5 takes into account deterioration as a linear function of mileage for gasoline fuelled EURO 1-6 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 (2016), for the corresponding layer. A cut-off mileage of 250.000 km is behind the calculation of the modified emission factors, and for the Danish situation, the low sulphur level interval is assumed to be most representative. The deterioration factors are shown in Annex 6 for 2016.

4.5 Calculation method

4.5.1 Emissions and fuel consumption for hot engines

Emissions and fuel-use results for operationally hot engines are calculated for each year and for layer and road type. The procedure is to combine fuel 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:

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

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

For catalyst vehicles the calculation becomes:

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

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 2016 are given in Cappelen et al. (2017). 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 (2016). For conventional gasoline and all diesel vehicles the extra emissions become:

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

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:

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

where β_{red} = the β reduction factor.

For CH_4, specific emission factors for cold driven vehicles are included in COPERT 5. The β and β_{red} factors for VOC are used to calculate the cold driven fraction for each relevant vehicle layer. The NMVOC emissions during cold start are found as the difference between the calculated results for VOC and CH_4.

For N_2O and NH_3, specific cold start emission factors are also proposed by COPERT 5. For catalyst vehicles, however, just like in the case of hot emission factors, the emission factors for cold start are functions of cumulated mileage (emission deterioration). The level of emission deterioration also relies on the content of sulphur in the fuel. The deterioration coefficients are given in EMEP/EEA (2016), 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 (see Ntziachristos et al., 2000). All emission types depend on RVP (Reid Vapour Pressure) as described in Danish legal announcements (Annex 14), and Danish ambient temperatures (e.g. Cappelen, 2017). The emission factors are shown in Ntziachristos et al. (2000).

Running loss emissions originate from vapour generated in the fuel tank while the vehicle is running. The distinction between hot and warm running loss emissions depends on engine temperature. In the model, hot and warm running losses occur for hot and cold engines, respectively. The emissions are calculated as annual mileage (broken down into cold and hot mileage totals using the β-factor) times the respective emission factors. For vehicles equipped with evaporation control (catalyst cars), the emission factors are only one tenth of the uncontrolled factors used for conventional gasoline vehicles.

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

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 vehicles without carbon canister $E^d(U)$:

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

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 5 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, 2017).

For gasoline, the DEA data for road transport are adjusted at first, in order to account for e.g. non-road machinery 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. Next, the fuel and emission results for all gasoline vehicles are scaled with the percentage difference between the adjusted bottom-up gasoline fuel consumption obtained after step one and total gasoline fuel sold.

The DEA data for diesel consist of fuel sold in Denmark and used on Danish roads and fuel sold in Denmark and used abroad. The latter diesel fuel contribution is estimated by the Danish Ministry of Taxation based on studies on fuel price differences across borders, fuel discount for haulage contractors and fuel tanking behaviour of truck and bus operators as well as private cars (see e.g. the Danish Ministry of Taxation, 2015).

The amount of diesel fuel sold in Denmark and used abroad is allocated to trucks and coaches in a first step and emissions are scaled accordingly (Figure 4.3). Next, the percentage difference between the adjusted bottom-up diesel fuel consumption obtained after step one and total diesel fuel sold is used to scale fuel and emission results for all diesel vehicles regardless of vehicle category (Figure 4.4). The data behind the Figures 4.3 and 4.4 are also listed in Annex 8.

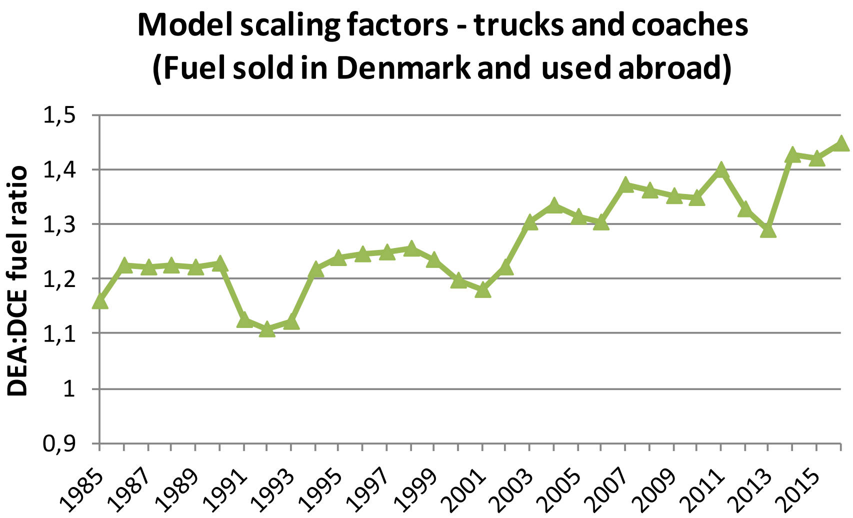


Figure 4.3 Fuel ratios (fuel and emission adjustment factors) for trucks and coaches: Bottom-up fuel consumption plus diesel used abroad vs bottom-up fuel consumption.

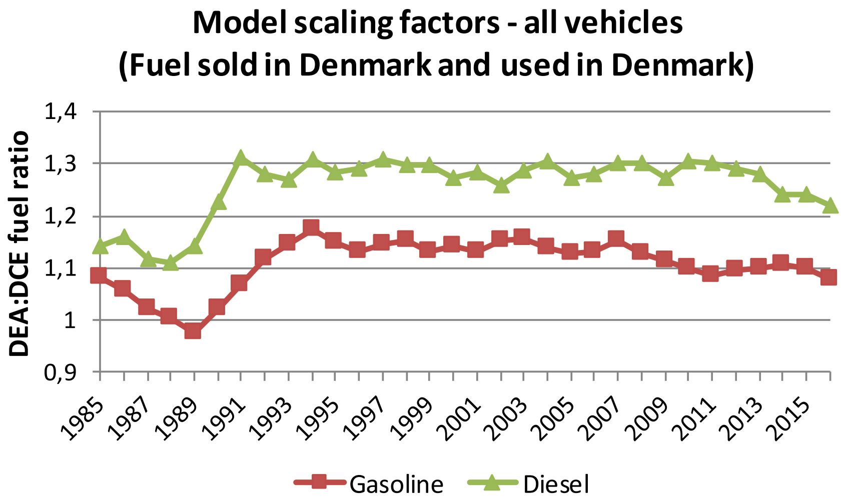


Figure 4.4 Gasoline and diesel fuel ratios (fuel and emission adjustment factors) regardless of vehicle category: Fuel sold and used in Denmark vs adjusted bottom-up fuel consumption.

The reasons for the differences between DEA sales figures and bottom-up fuel estimates shown in Figure 4.4 are mostly due to a combination of the uncertainties related to COPERT 5 fuel consumption factors, allocation of vehicle numbers in sub-categories, annual mileage, trip speeds and mileage splits for urban, rural and highway driving conditions.

The final fuel consumption and emission factors are shown in Annex 7 for 1985-2016. The total fuel consumption and emissions are shown in Annex 8, per vehicle category and as grand totals, for 1985-2016 (and NFR format in Annex 16. In Annex 15, fuel consumption and emission factors as well as total emissions are given in CollectER format for 2016.

In the following Figures 4.5 – 4.13, 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.

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, bio ethanol and biodiesel became available from a limited number of gas filling stations in Denmark, and today bio ethanol and biodiesel is added to all fuel commercially available. Following the IPCC guideline definitions, bio ethanol 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:

$$EF_{CO2,E}(BF\%) = EF_{CO2,E}(BF0) \cdot (100 - BF\%_E) \qquad (13)$$

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 kilometer 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:

$$EF_{CO2,km}(BF\%) = EF_{CO2,E}(BF\%) \cdot FC_E(BF0) \qquad (14)$$

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. For gasoline, diesel and compressed natural gas (CNG) the CO_2 emission factors are country-specific. For gasoline and diesel the emission factor source is Fenhann and Kilde (1994). For CNG, the CO_2 emission factor is estimated by the Danish gas transmission company, Energinet.dk, based on gas analysis data. For liquefied petroleum gas (LPG), the emission factor source is EMEP/EEA (2016).

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	2014	2015	2016
Neat gasoline	73	73	73	73	73	73	73	73	73	73	73	73
Neat diesel	74	74	74	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	63.1	63.1	63.1
CNG	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8
Bio ethanol	0	0	0	0	0	0	0	0	0	0	0	0
Biodiesel	0	0	0	0	0	0	0	0	0	0	0	0
Gasoline, average	73	72.9	72.8	72.8	72.8	71.8	70.7	70.4	70.5	70.6	70.6	70.6
Diesel, average	74	74.0	74.0	74.0	73.9	74.0	71.5	69.4	69.2	69.1	69.2	69.3
	Biofuel share (BF%) of Danish road transport fuels											
	1990-2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	0	0.09	0.14	0.12	0.21	0.68	3.28	5.31	5.43	5.47	5.39	5.38

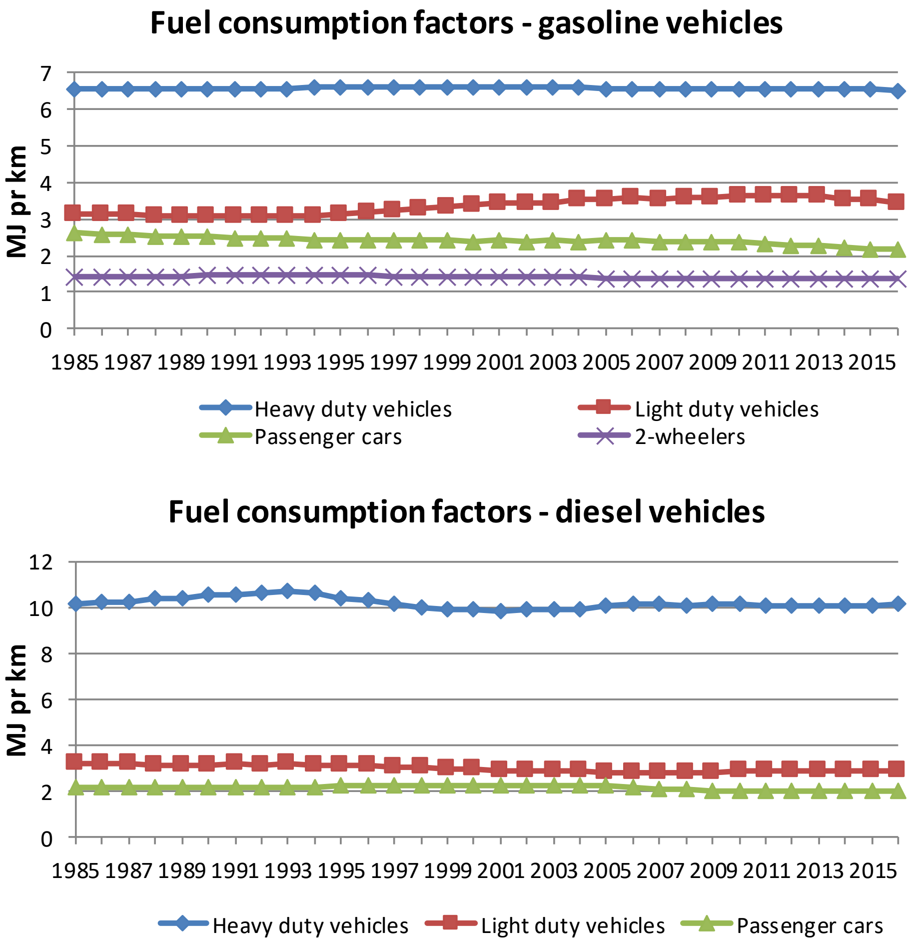


Figure 4.5 Km related fuel consumption factors per fuel type and vehicle type for Danish road transport (1985-2016).

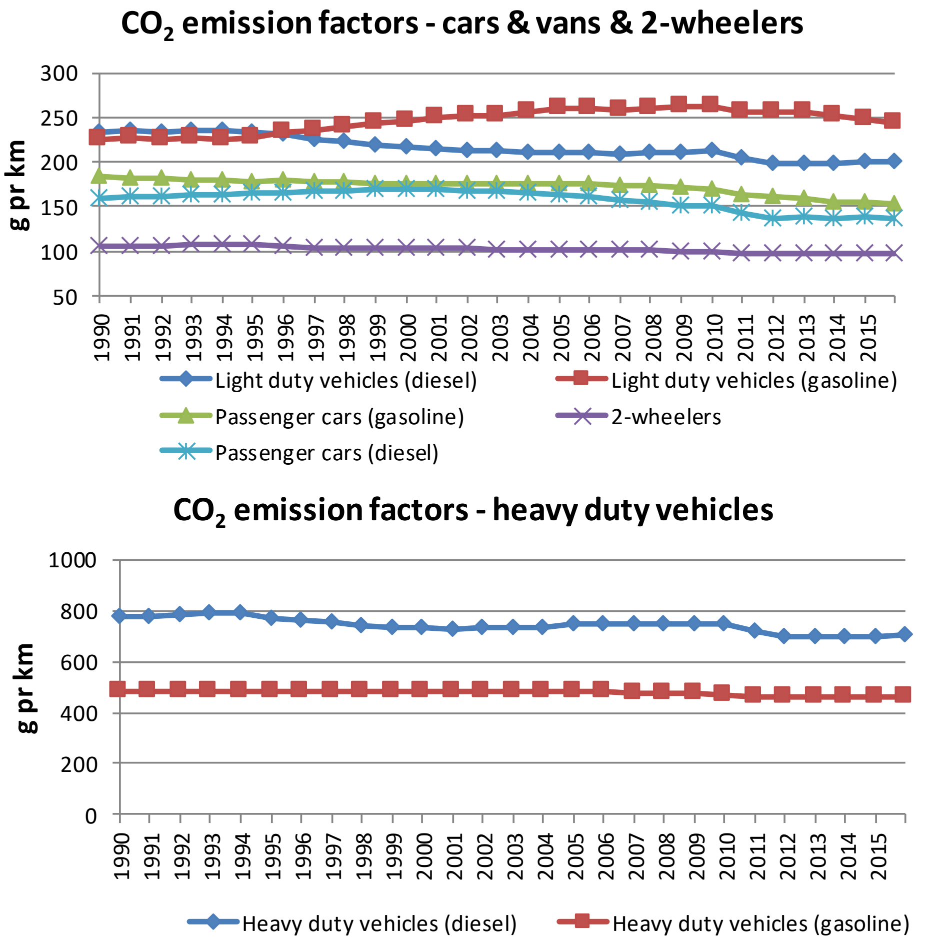


Figure 4.6 Km related CO_2 emission factors per vehicle type for Danish road transport (1990-2016).

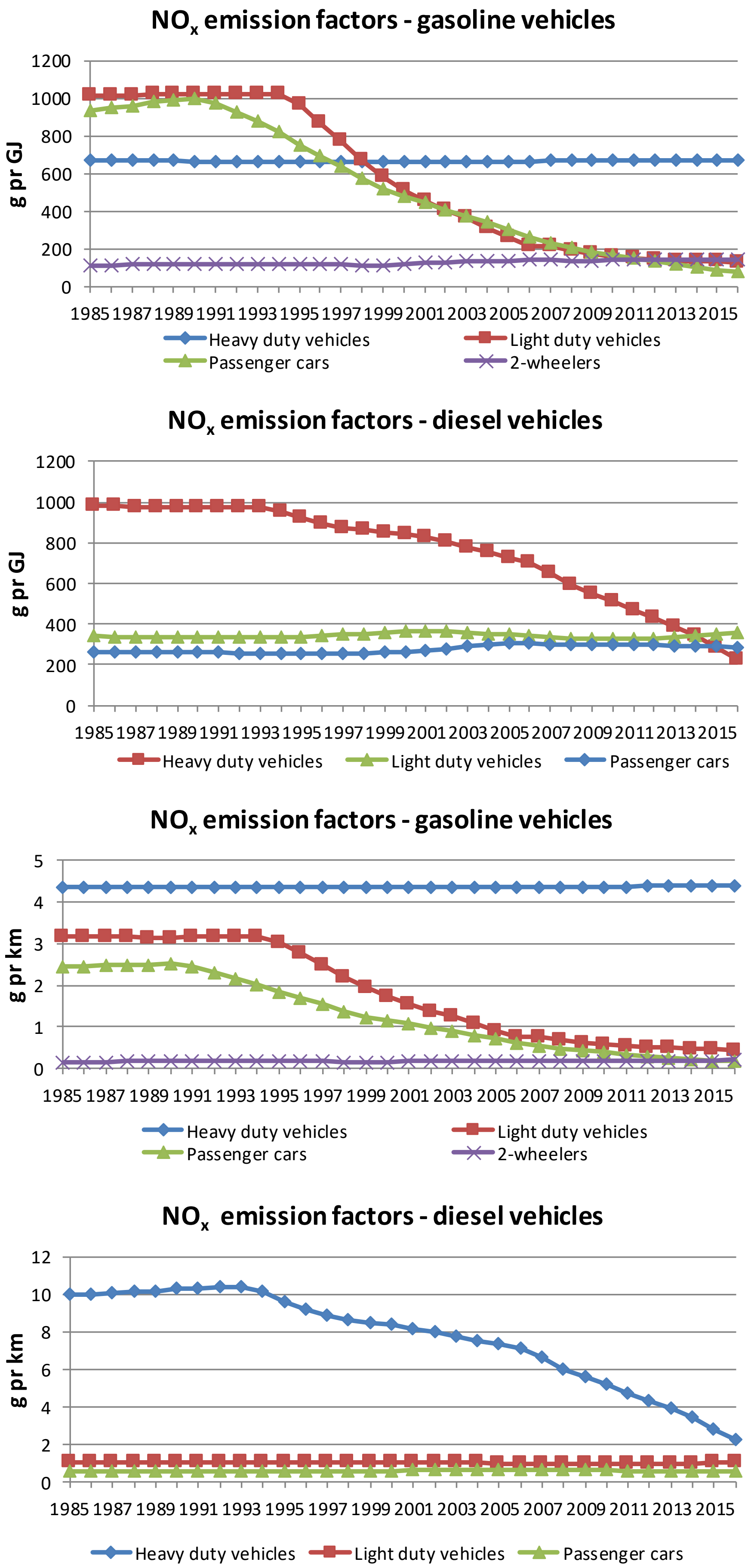


Figure 4.7 Fuel and km related NO_x emission factors per vehicle type for Danish road transport (1985-2016).

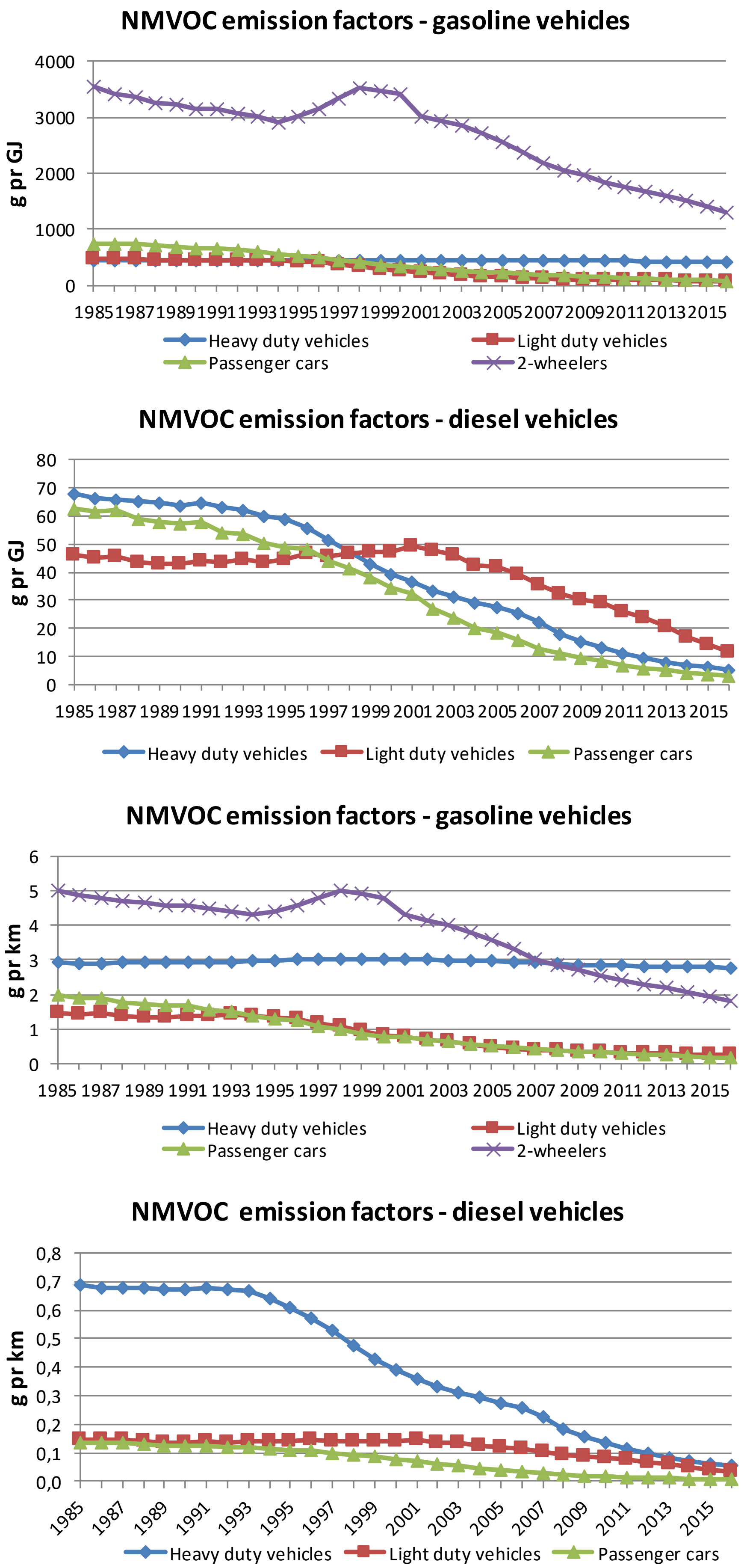


Figure 4.8 Fuel and km related NMVOC emission factors per vehicle type for Danish road transport (1985-2016).

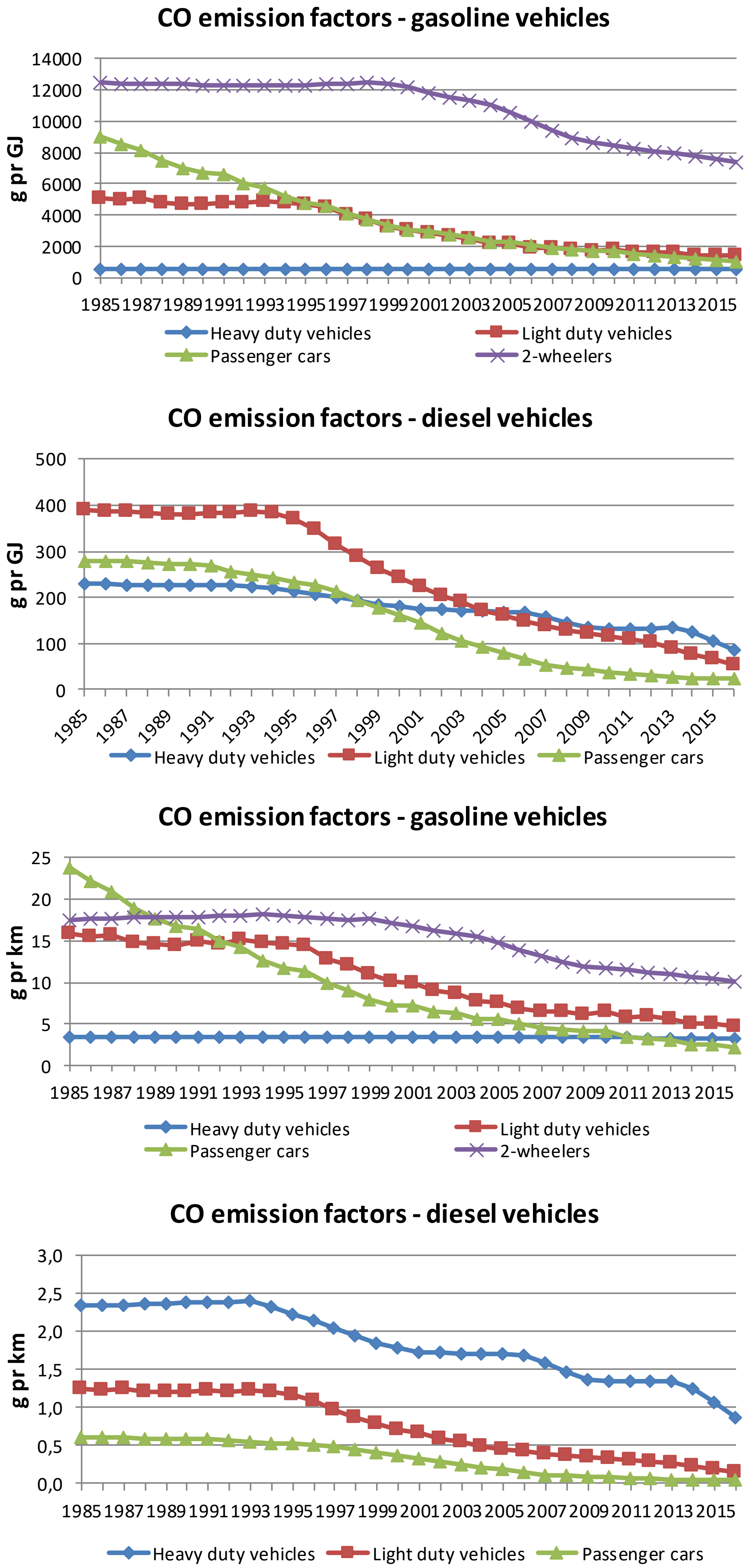


Figure 4.9 Fuel and km related CO emission factors per vehicle type for Danish road transport (1985-2016).

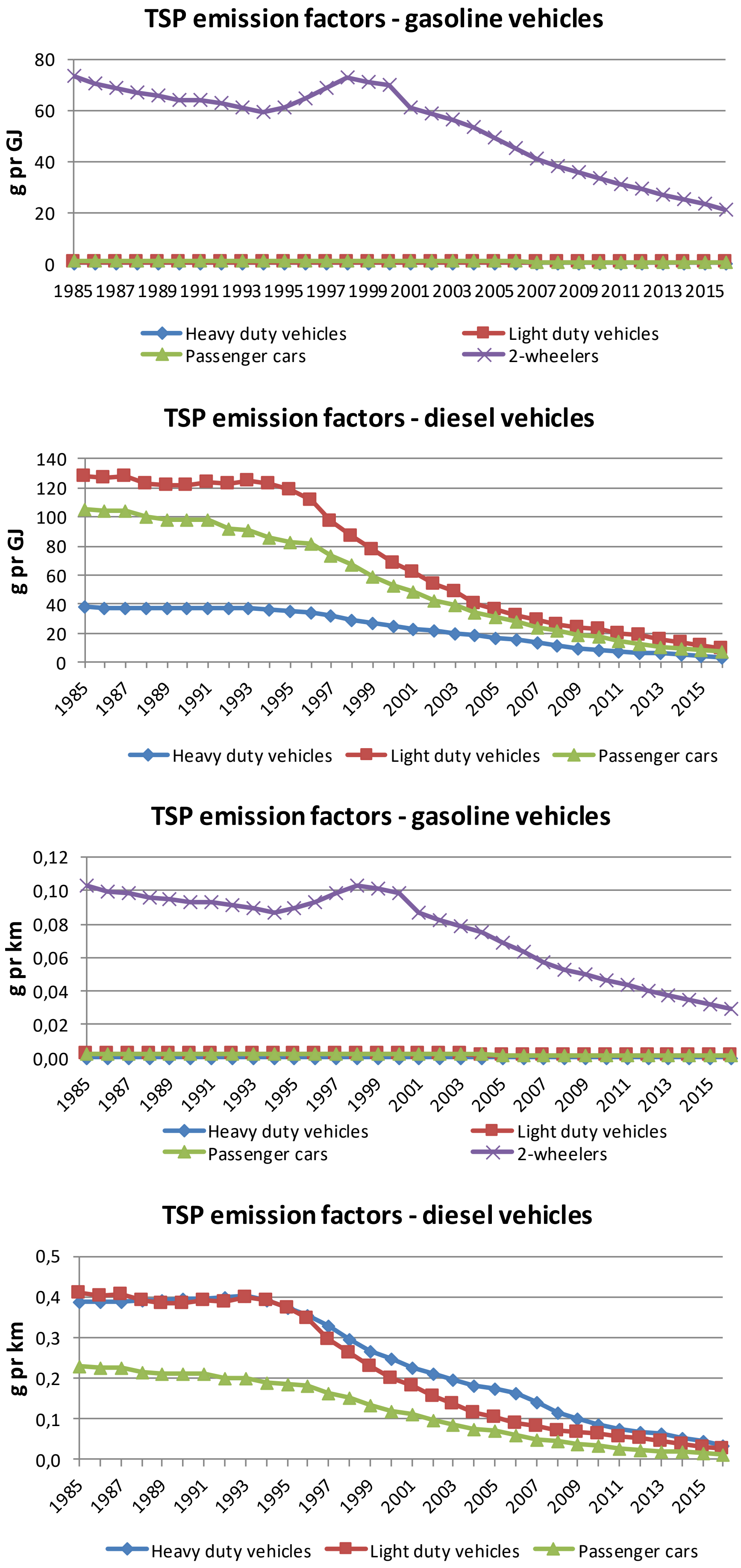
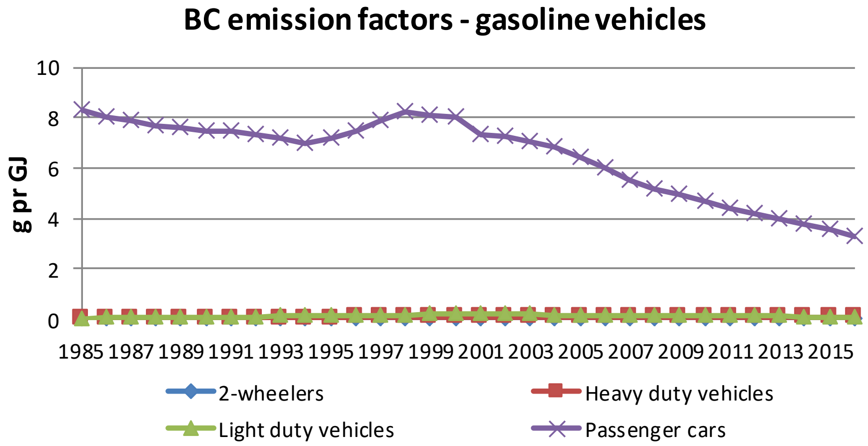
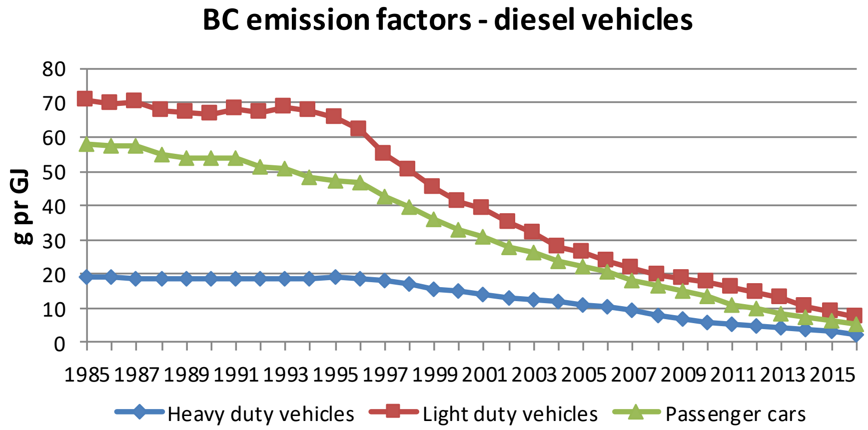
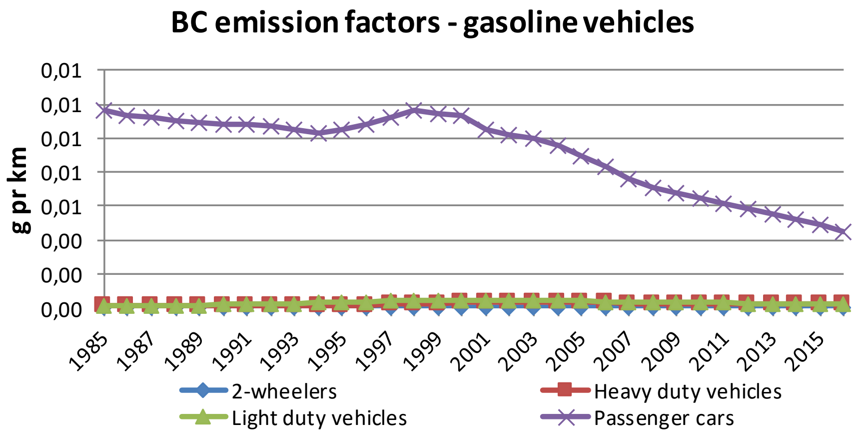


Figure 4.10 Fuel and km related TSP emission factors per vehicle type for Danish road transport (1985-2016).







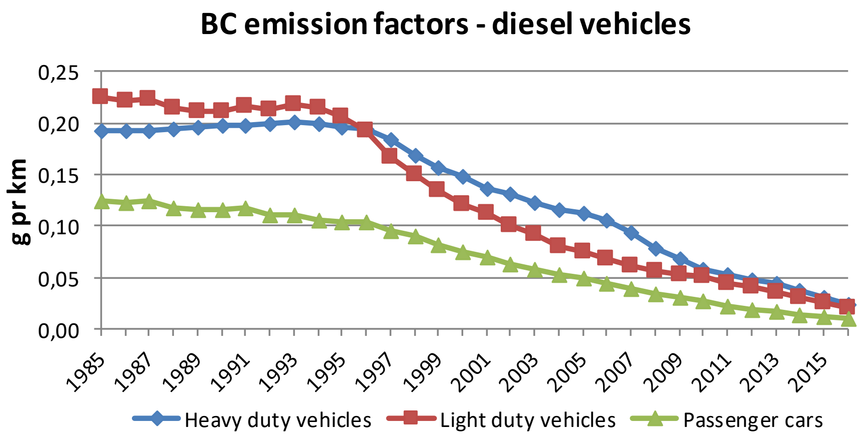


Figure 4.11 Fuel and km related BC emission factors per vehicle type for Danish road transport (1985-2016).

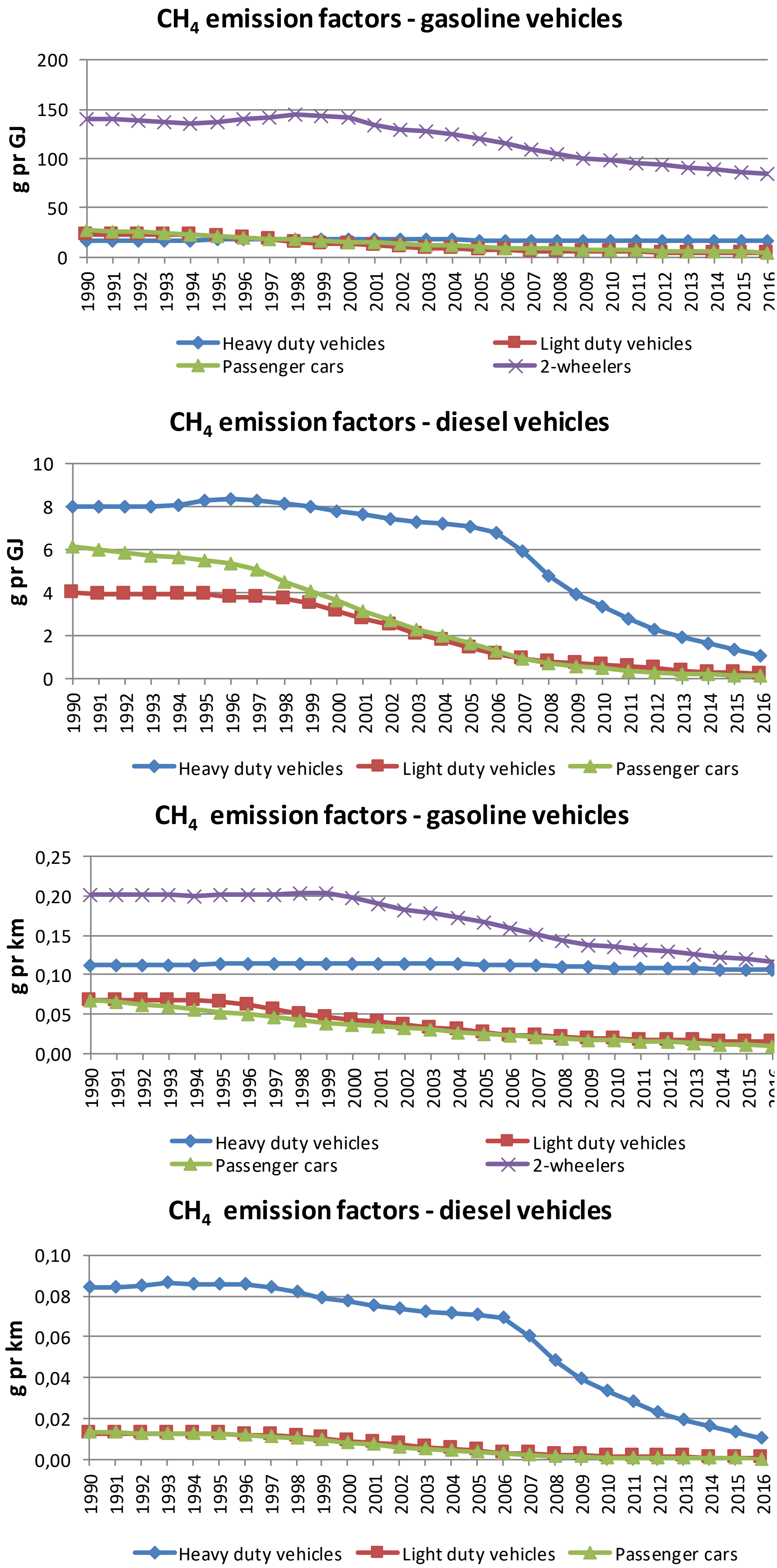


Figure 4.12 Fuel and km related CH4 emission factors per vehicle type for Danish road transport (1990-2016). Hvad sker der her??

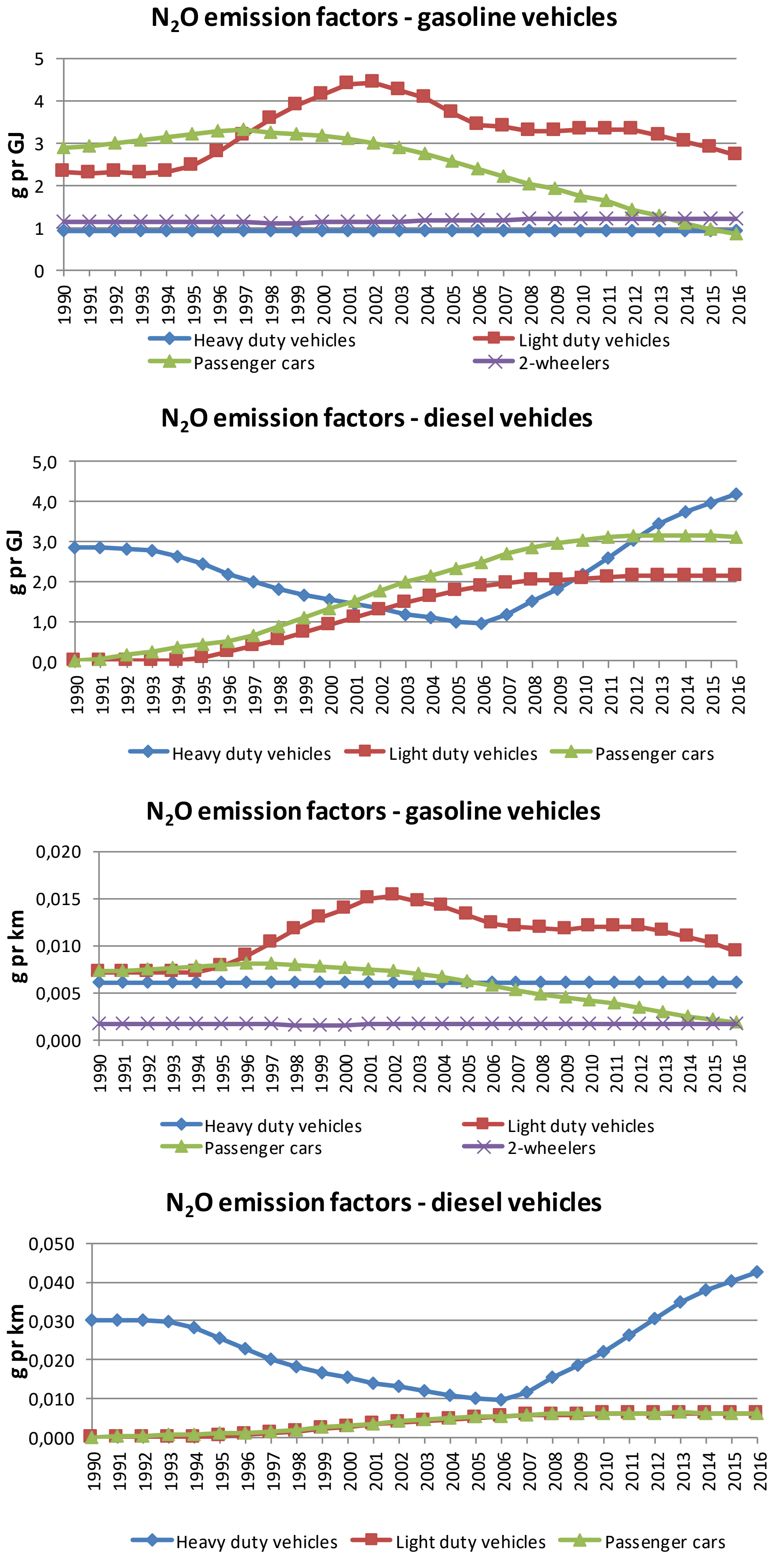


Figure 4.13 Fuel and km related N2O emission factors per vehicle type for Danish road transport (1990-2016).

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, 2016) 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 and Construction Agency and Copenhagen Airport. Fuel statistics for jet fuel consumption and aviation gasoline is obtained from the Danish energy statistics (DEA, 2017).

For 2001 onwards, the Danish Transport and Construction Agency 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 criteria are the identified aircraft type, aircraft maximum takeoff mass, engine types, and number of engines. During this sequence, small aircraft with piston engines using aviation gasoline are excluded from the calculations.

Annex 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[6], in a time series from 2001-2016. The airport split is necessary to make due to the differences in LTO emission factors (cf. section 5.4.1).

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-destination

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

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 and Construction Agency. 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.

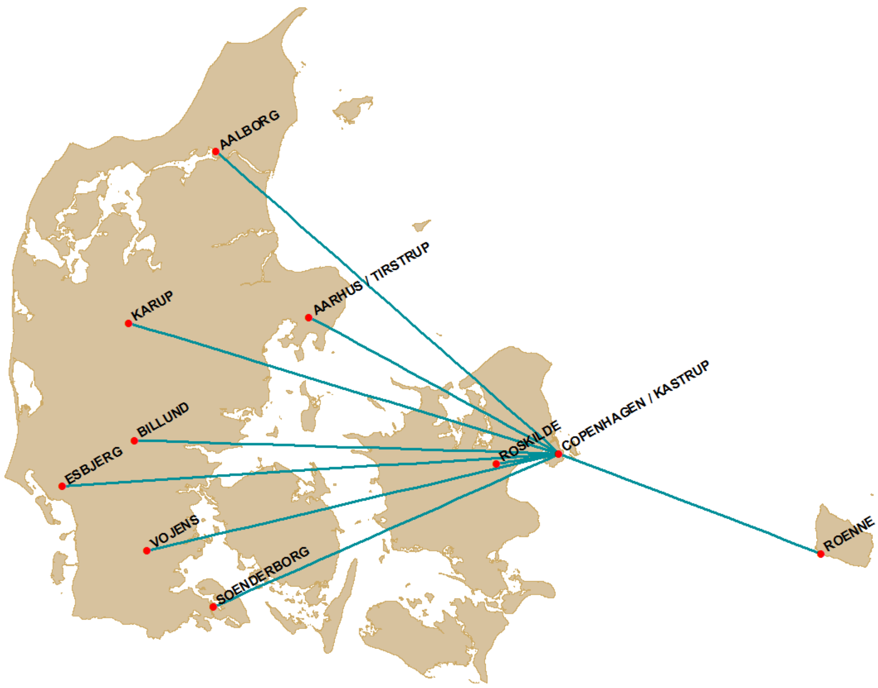


Figure 5.1 Most frequent domestic flying routes for large aircraft in Denmark.

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 and Construction Agency, 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.

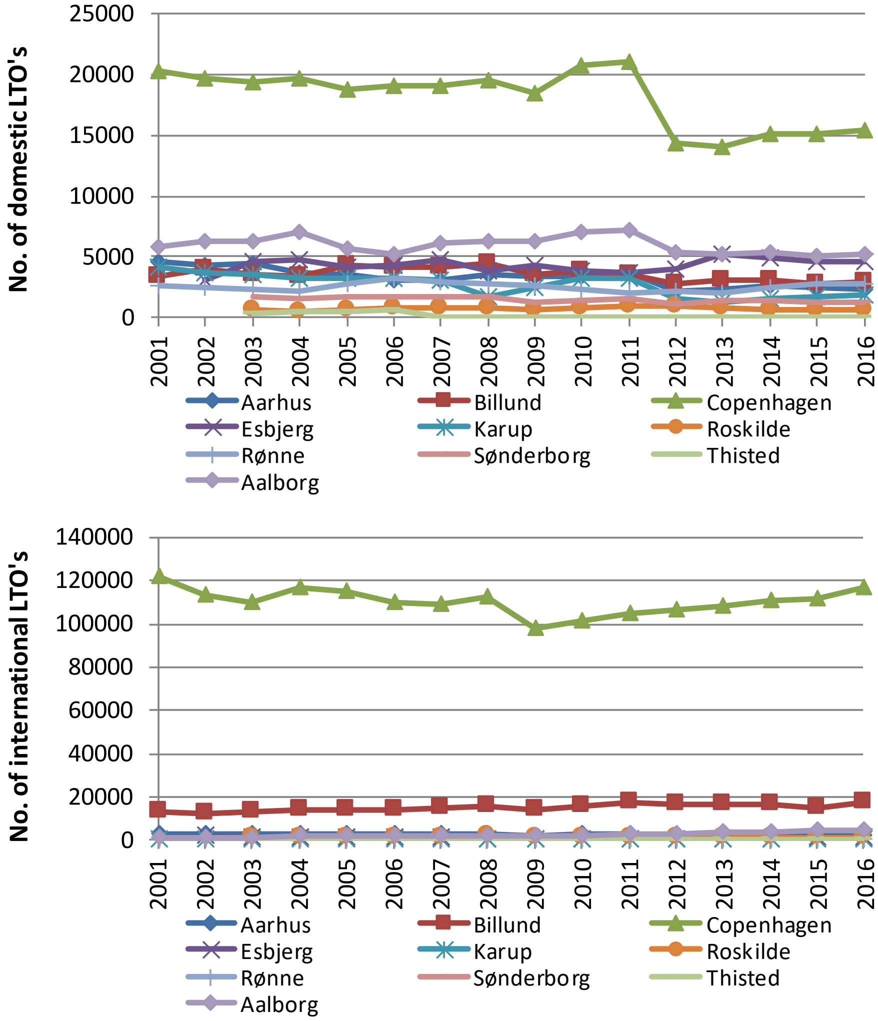


Figure 5.2 No. of LTO's for the most important airports in Denmark 2001-2016.

Figure 5.2 shows the number of domestic and international LTO's for Danish airports[7], in a time series from 2001-2016.

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 for sailing purposes (recreational craft).

For the most important types of building and construction machinery (industrial non road) annual new sales data for 1996 onwards has been provided by the Association of Danish Agricultural Machinery Dealers. From engine manufacturers engine load factors have been provided based on electronic engine power registrations (Sjøgren 2016; Mikkelsen 2016). Further, equipment size - engine size relations, equipment scrapping curves and annual working hours as a function of machinery age has been included in the model (Sjøgren 2016; Mikkelsen 2016).

For the most important household and gardening machinery types annual new sales data for 2006 onwards is provided by the Dealers Association of

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

Electric Tools and Gardening Machinery (LTEH: Leverandørforeningen for Transportabelt Elværktøj og Havebrugsmaskiner). Further, equipment size - engine size relations, equipment scrapping curves and annual working hours as a function of machinery age has been provided by LTEH (Nielsen and Schösser, 2016).

For other machinery types, 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 1985-2016 for the most important types of machinery are shown in Figures 5.3-5.10 below. 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).

It is important to note that key experts in the field of industrial non-road activities assume a significant decrease in the activities for 2009 due to the global financial crisis. This reduction is in the order of 25 % for 2009 for industrial non-road 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 5.3-5.4, respectively. The figures clearly show a decrease in the number of small machines, these being replaced by machines in the large engine-size ranges.

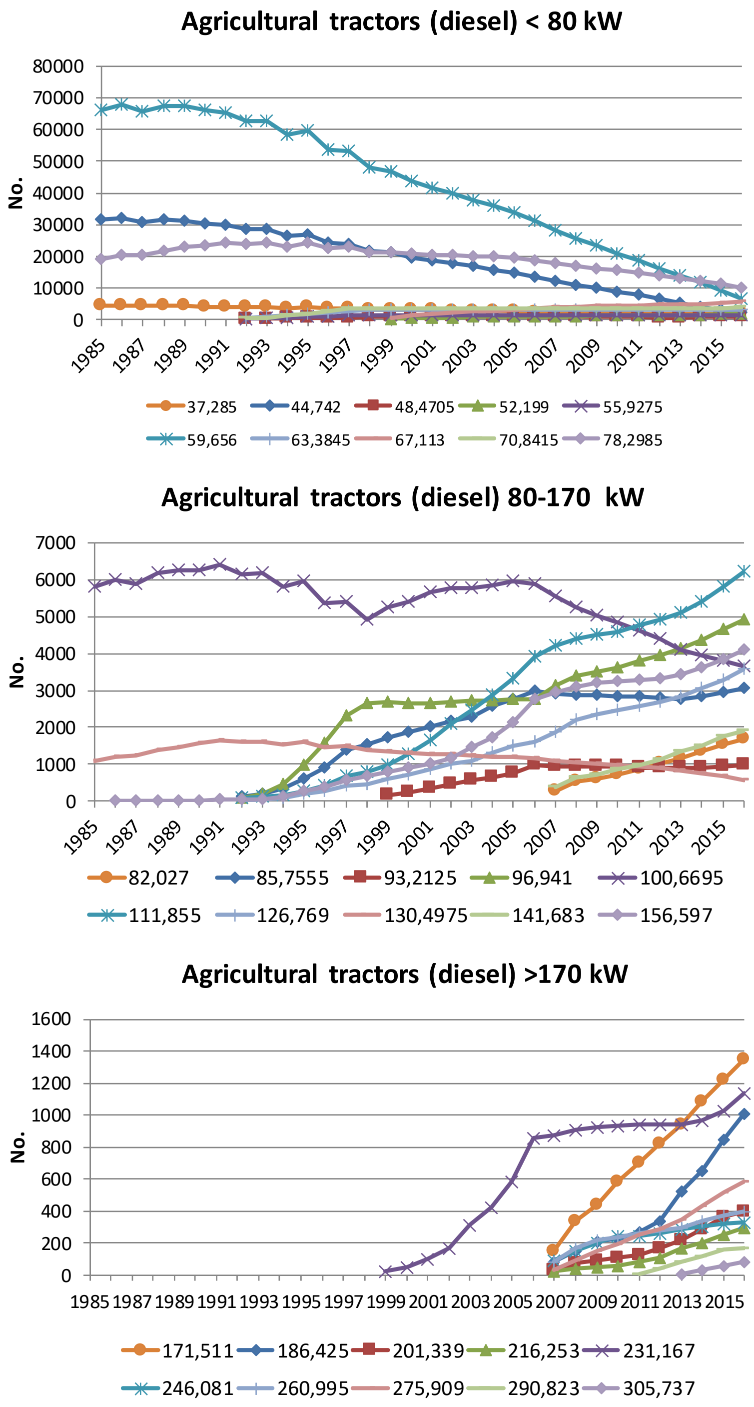


Figure 5.3 Total numbers in kW classes for tractors from 1985 to 2016.

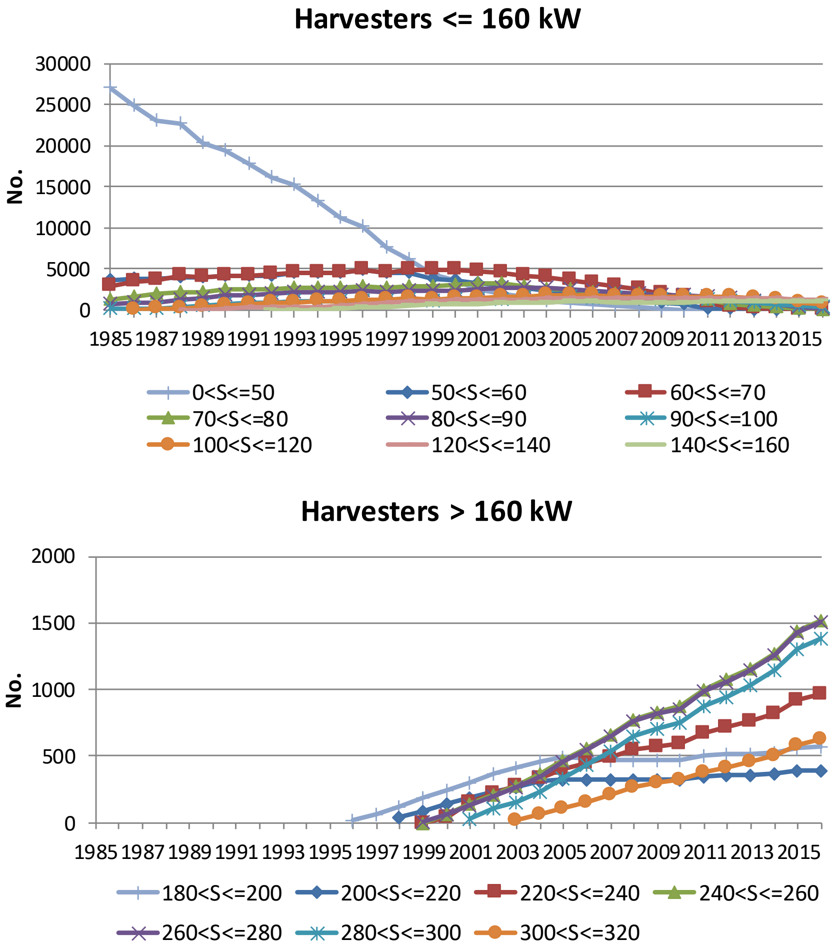


Figure 5.4 Total numbers in kW classes for harvesters from 1985 to 2016.

The tractor and harvester developments towards fewer vehicles and larger engines, shown in Figure 5.5, are very clear. From 1985 to 2016, tractor and harvester numbers decrease by around 43 % and 68 %, respectively, whereas the average increase in engine size for tractors is 60 % and 204 % for harvesters, in the same time period.

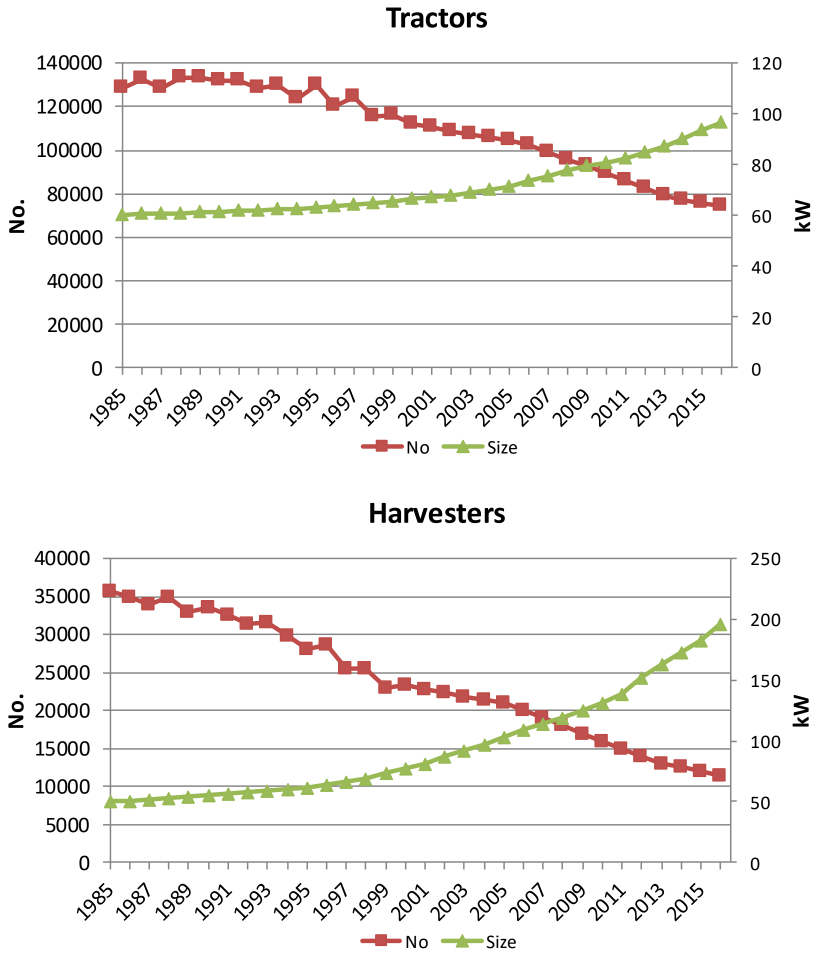


Figure 5.5 Total numbers and average engine size for tractors and harvesters from 1985 to 2016.

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 1985-2016 stock development for specific types of construction machinery and diesel fork lifts. Due to lack of data, 1996-1999 average sales data for construction machinery is used for 1995 and back. However, it is assumed that telescopic loaders first enter into use in 1986 (Jensen, Scantruck 2016). For most of the machinery types, there is an increase in machinery numbers from 1990 onwards, due to increased construction activities.

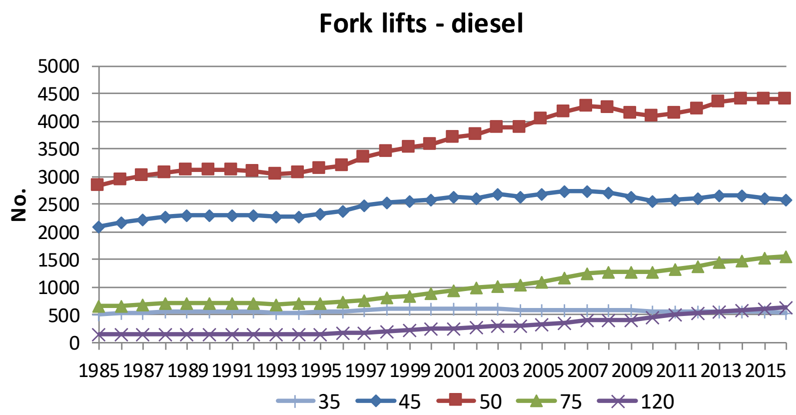


Figure 5.6 Total numbers of diesel fork lifts in kW classes from 1985 to 2016.

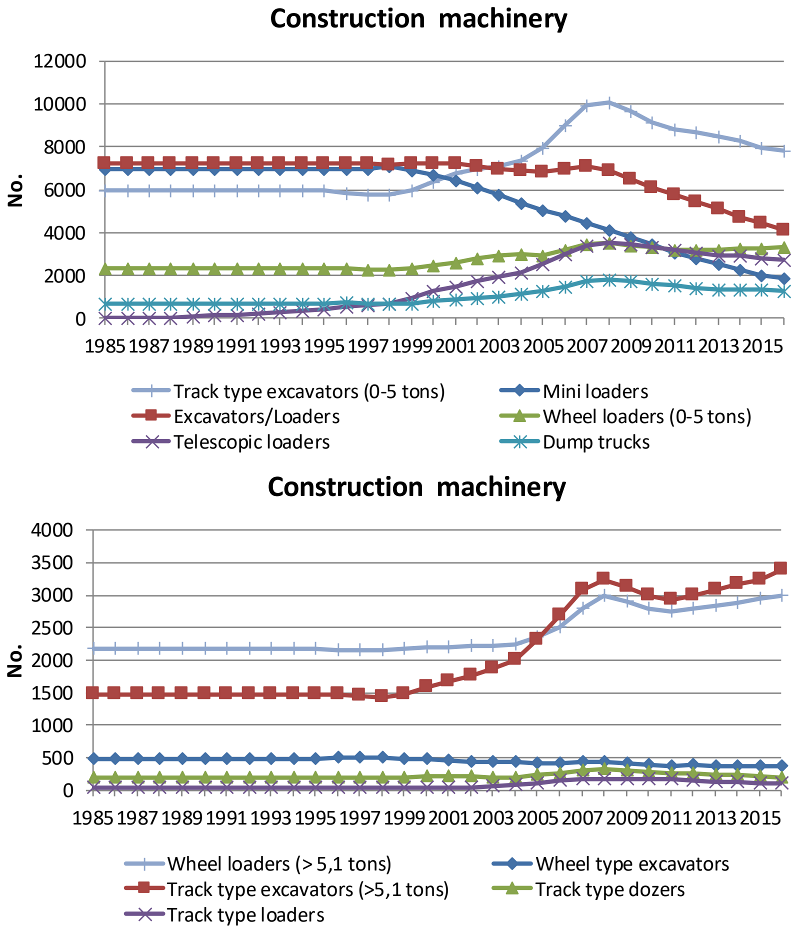


Figure 5.7 1985-2016 stock development for specific types of construction machinery.

The emission level shares for tractors, harvesters, construction machinery (wheel loaders > 5.1 tonnes, as an example) and diesel fork lifts are shown in Figure 5.8, and present an overview of the introduction of the different pre-Euro engine classes, and engine stages complying with the gradually stricter EU stage I-IV emission limits. The average lifetimes of 30, 25, 20 and 10 years for tractors, harvesters, fork lifts and most types of construction machinery, respectively, influence the individual engine technology turn-over speeds.

The EU emission directive stage implementation years relate to engine size, and for all four machinery groups the emission level shares into specific size segments will differ slightly from the picture shown in Figure 5.8.

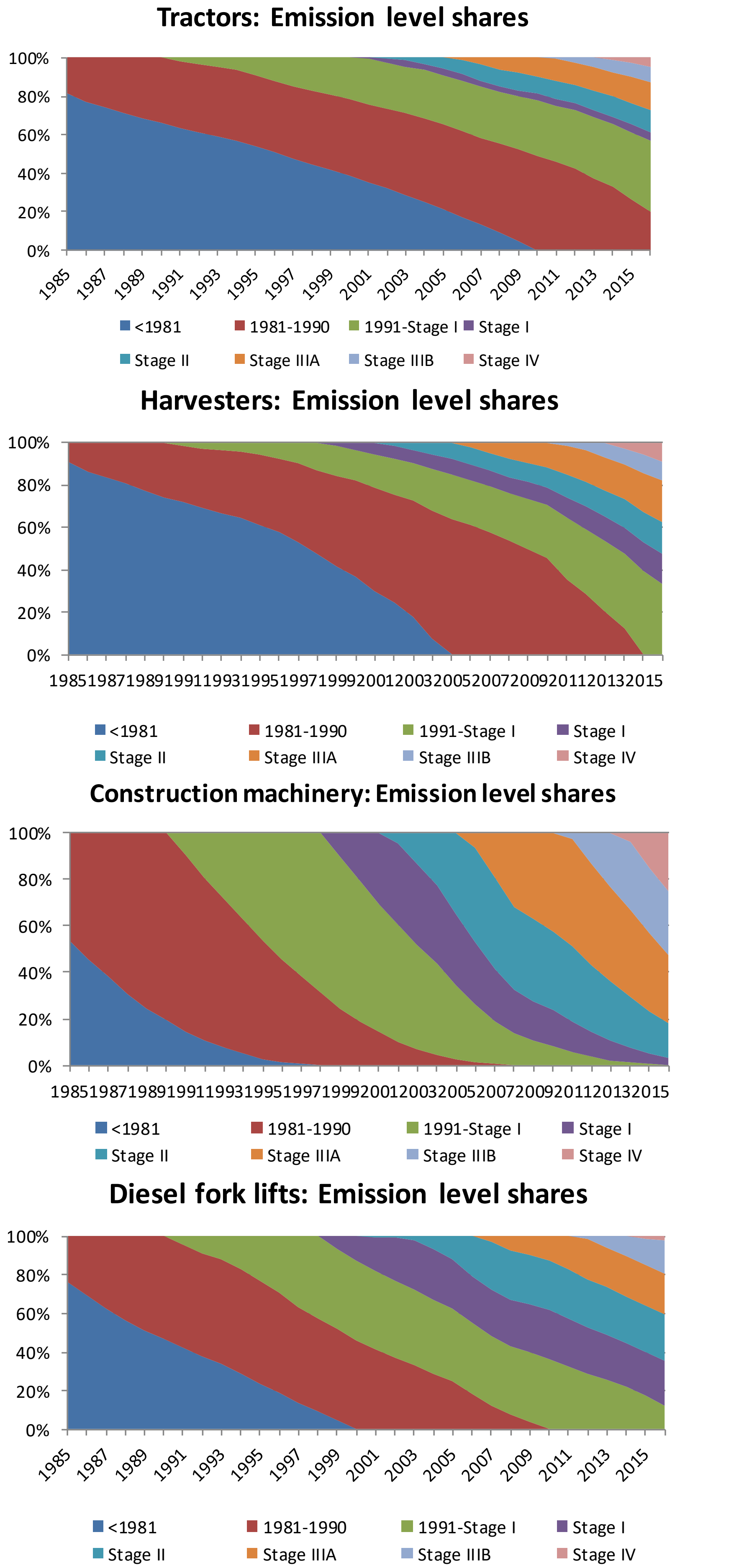


Figure 5.8 Emission level shares for tractors, harvesters, construction machinery and diesel fork lifts (1985 to 2016).

The 1985-2016 stock development for the most important household and gardening machinery types is shown in Figure 5.9.

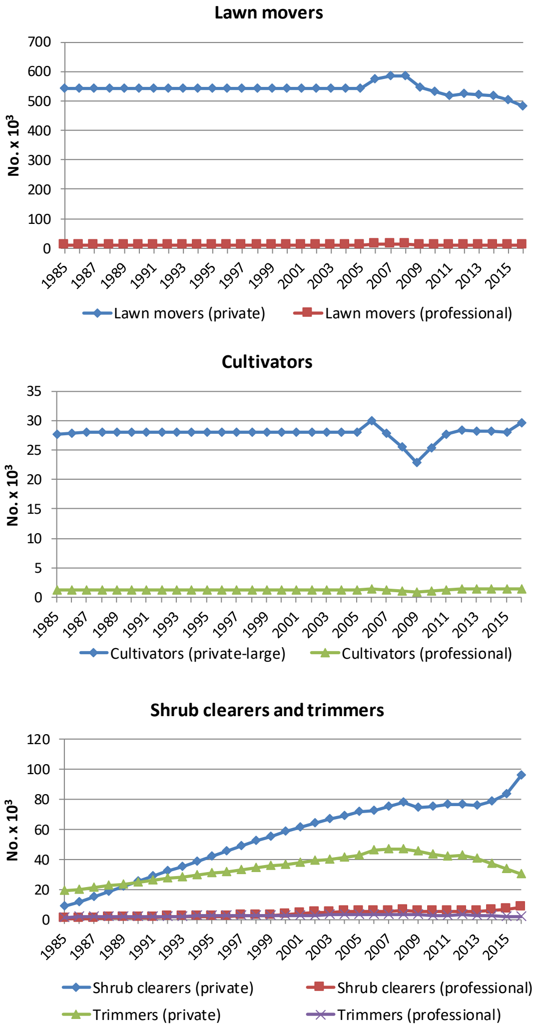


Figure 5.9 Stock developments 1985-2016 for the most important household and gardening machinery types.

Figure 5.10 shows the development in numbers of different recreational craft from 1985-2016. The 2004 stock data for recreational craft are repeated for 2005+, due to lack of data from the Danish Sailing Association.

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

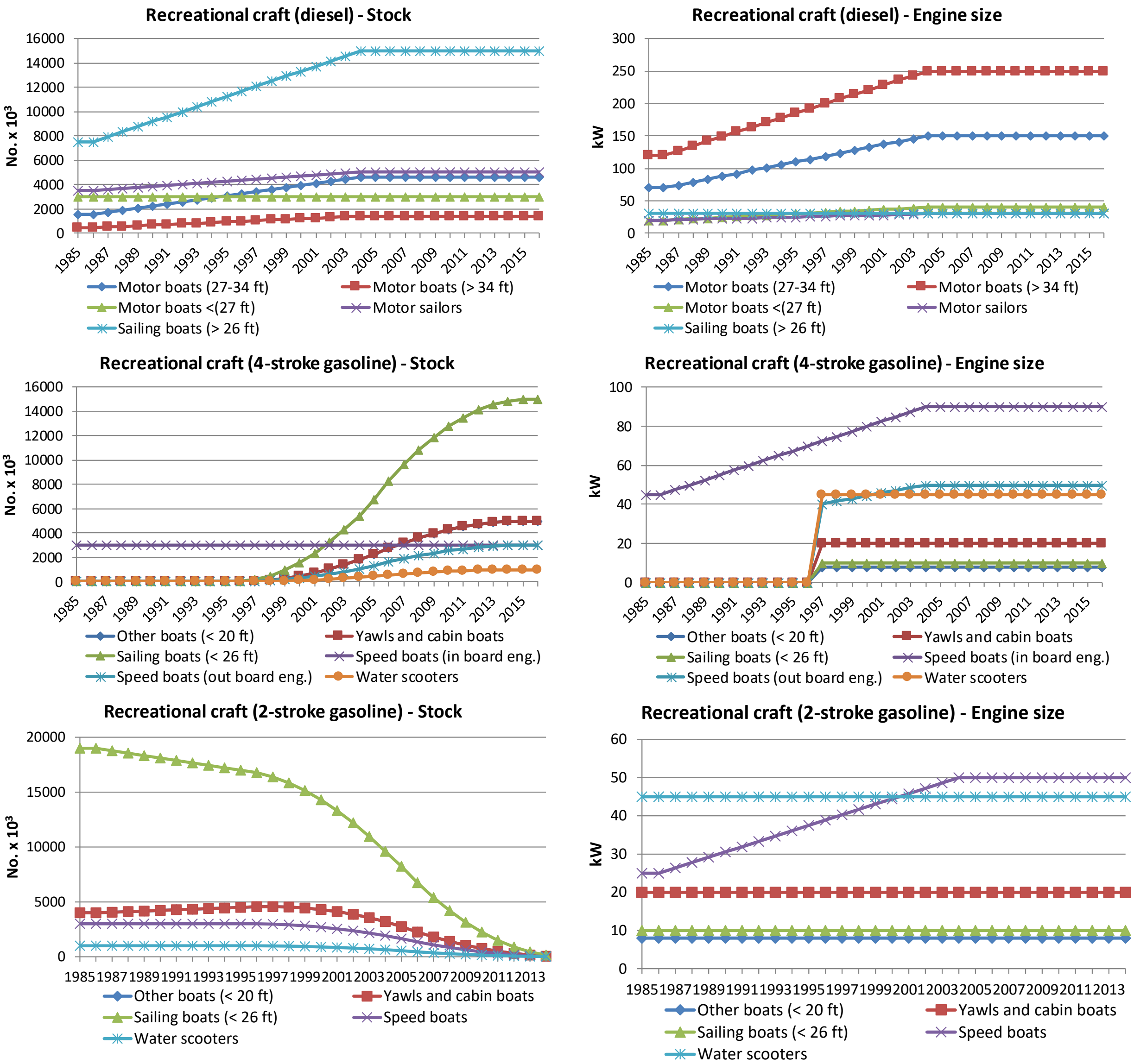


Figure 5.10 Stock and engine size development 1985-2016 for recreational craft.

5.1.3 National sea transport

Table 5.1 lists the most important domestic ferry routes (regional ferries) in Denmark in the period 1990-2016. 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 2006-2016, the above mentioned traffic and technical data for specific ferries have been provided by Nielsen (2017) in the case of Mols-Linien (Sjællands Odde-Ebeltoft, Sjællands Odde-Århus, Kalundborg-Århus), by Jørgensen (2017) for Færgen A/S (Køge-Rønne, Tårs-Spodsbjerg, Kalundborg-Samsø), by Kruse (2015) for Samsø Rederi (Hou-Sælvig), by Mortensen (2015) for Færgeselskabet Læsø (Frederikshavn-Læsø) and by Eriksen (2017) for Ærøfærgerne (Svendborg-Ærøskøbing). For Esbjerg/Hanstholm/Hirtshals-Torshavn traffic and technical data have been provided by Dávastovu (2010).

Table 5.1 Ferry routes included in the Danish inventory.

Ferry service	Service period
Esbjerg-Torshavn	1990-1995, 2009+
Halsskov-Knudshoved	1990-1999
Hanstholm-Torshavn	1991-1992, 1999+
Hirtshals-Torshavn	2010
Hou-Sælvig	1990+
Hundested-Grenaa	1990-1996
Frederikshavn-Læsø	1990+
Kalundborg-Juelsminde	1990-1996
Kalundborg-Samsø	1990+
Kalundborg-Århus	1990+
Korsør-Nyborg, DSB	1990-1997
Korsør-Nyborg, Vognmandsruten	1990-1999
København-Rønne	1990-2004
Køge-Rønne	2004+
Sjællands Odde-Ebeltoft	1990+
Sjællands Odde-Århus	1999+
Svendborg-Ærøskøbing	1990+
Tårs-Spodsbjerg	1990+

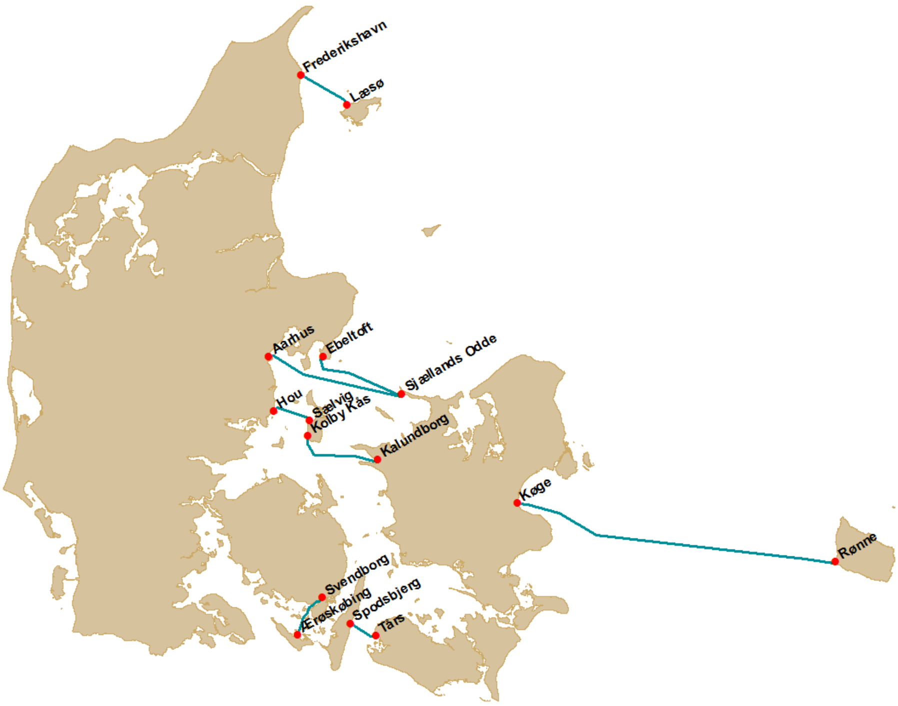


Figure 5.11 Domestic regional ferry routes in Denmark (2016).

Table 5.2 lists the small ferry routes (island and short cut ferries) included in the Danish inventory for the period 1990-2016. For these ferry routes and the years 1990-2015, the following detailed traffic and technical data have been gathered by Rasmussen (2017a): Ferry name, year of service, engine size (MCR), engine year, and sailing time (single trip). Supplementary data for engine type, fuel type and average load factor is provided by Kristensen (2017).

Table 5.2 Small ferry routes included in the Danish inventory.

Ferry service	Service period
Assens-Baagø	1990+
Ballebro-Hardeshøj	1990+
Bandholm-Askø	1990+
Branden-Fur	1990+
Bøjden-Fynshav	1990+
Esbjerg-Fanø	1990+
Feggesund overfart	1990+
Fejø-Kragenæs	1990+
Femø-Kragenæs	1990+
Frederikssund-Roskilde	1999-2000
Fåborg-Avernakø-Lyø	1990+
Fåborg-Søby	1990+
Grenaa-Anholt	1990+
Gudhjem-Christiansø	2015+
Hals-Egense	1994+
Havnsø-Sejerø	1990+
Holbæk-Orø	1990+
Horsens-Endelave	1990+
Hov-Tunø	1990+
Hundested-Rørvig	1990+
Hvalpsund-Sundsøre	1990+
Kastrup-Rønne	1990
Kleppen-Venø	1990+
Korsør-Lohals	1990+
København-Århus	1992-1993
Næssund overfart	1990+
Rudkøbing-Marstal	-2013
Rudkøbing-Strynø	1990+
Stigsnæs-Agersø	1990+
Stigsnæs-Omø	1990+
Stubbekøbing-Bogø	1990+
Svendborg-Skarø-Drejø	1990+
Søby-Fynshav	2009+
Søby-Mommark	-2009
Thyborøn-Agger	1990+
Aarø-Aarøsund	1990+

The number of round trips per ferry route from 1990 to 2016 is provided by Statistics Denmark (2017). Figure 5.12 show the regional ferry routes in 2016 (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). There is a lack of historical traffic data for 1985-1989, and hence, data for 1990 is used for these years, to support the fuel consumption and emission calculations.

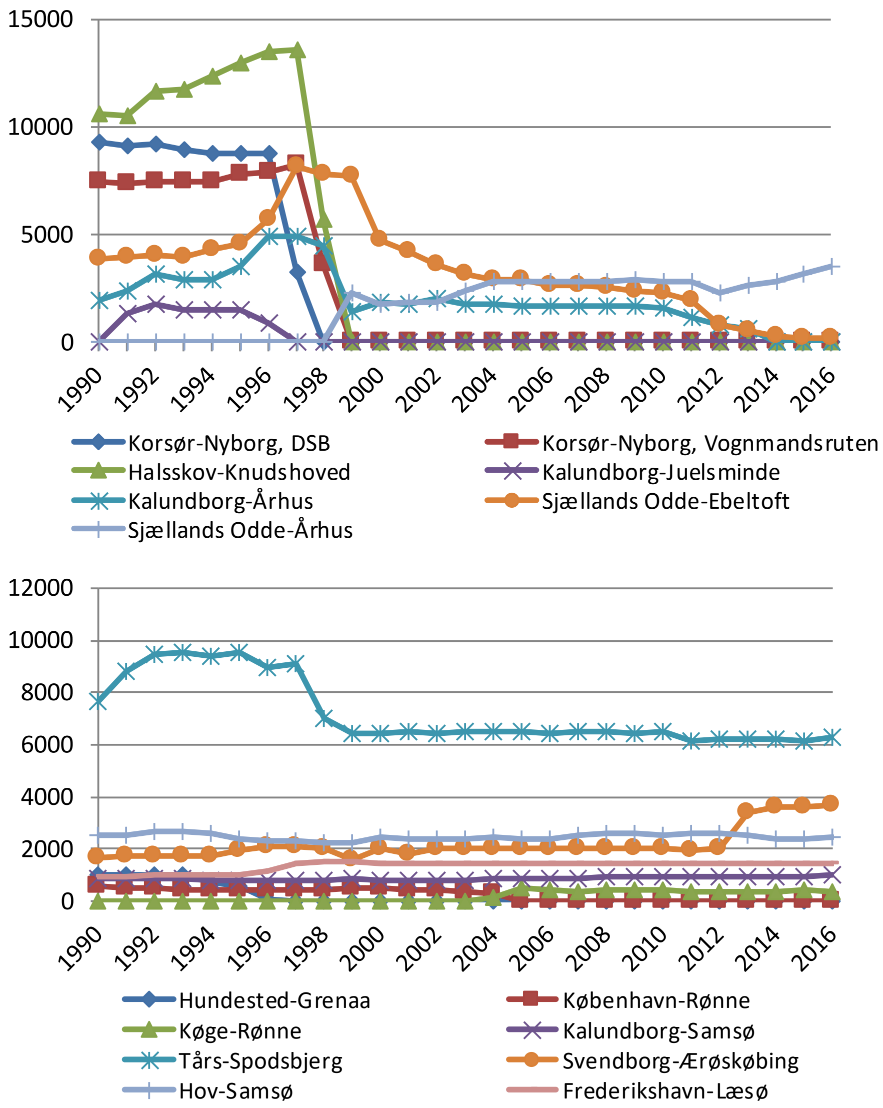


Figure 5.12 No. of round trips for the most important ferry routes in Denmark 1990-2016.

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.

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, 2017b and Thorarensen, 2017).

Fuel used for the remaining part of the traffic between two Danish ports, other national sea transport, is taken as the difference between DEA national fuel sales for national sea transport and the bottom-up calculated fuel consumption for Danish ferries. For years when the fuel estimates for ferries (not including the ferry to the Faroe Islands) are higher than DEA reported fuel sold for national sea transport, fuel is taken from fisheries in the case of marine diesel (1985-1999). For heavy fuel oil, the missing fuel amount is taken from stationary sources (1985-1986, 1988, 1994-1996) and international sea transport (2015 onwards).

In national sea transport, LNG fuel has been calculated for Danish ferries since 2015. However, in DEA fuel statistics, the consumption of LNG for national sea transport is included under diesel instead of being reported as LNG. In the Danish inventories, the bottom up estimated consumption of LNG is reported under national sea transport in the inventories, and the amount of diesel reported for national sea transport is subsequently being reduced by the same number.

5.1.4 Other sectors

The activity data for military, railways, international sea transport and fishery consists of fuel consumption information from DEA (2017).

For international sea transport, the basis is in principle fuel sold in Danish ports for vessels with a foreign destination (i.e. outside the Kingdom of Denmark), as prescribed by the IPCC guidelines. However, it must be noted that fuel sold for sailing activities between Denmark and Greenland/Faroe Islands are reported as international in the DEA energy statistics. Hence, for inventory purposes in order to follow the IPCC guidelines, the bottom-up fuel estimates for the ferry routes Esbjerg/Hanstholm/Hirtshals-Torshavn, and fuel buy reports from Royal Arctic Line and Eim Skip is transferred from international sea transport to national sea transport in fuel sales, prior to inventory fuel input.

For fisheries, the calculation methodology is fuel activity based and input fuel data is in principle the diesel fuel sold for fisheries reported by DEA. For years when bottom up diesel estimates for national sea transport are higher than DEA reported fuel sold for national sea transport, diesel is transferred from fisheries to national sea transport in the inventories. In addition, the bottom up diesel estimate for recreational craft is subtracted from fisheries and grouped in the "Other" inventory category together with military activities.

Summarized up per fuel type, the above described fuel transferals involving the sectors national and international sea transport, fisheries and stationary industrial sources becomes zero, thus leaving the national energy balance unchanged.

For all sectors, fuel consumption time series are given in Annex 14 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 5.3) relate to Stage I-IV non-road machinery other than agricultural and forestry tractors and the directives have different implementation dates for machinery operating under transient and constant loads. The latter directive also comprises emission limits for Stage IIIA and IIIB railways machinery (Table 5.7). For Stage I-IV tractors the relevant directives are 2000/25 and 2005/13 (Table 5.3).

For emission approval of the EU Stage I, II and IIIA engine technologies, emissions (and fuel consumption) measurements are made using the steady state test cycle ISO 8178 C1, referred to as the Non-Road Steady Cycle (NRSC), see e.g. www.dieselnet.com. In addition to the NRSC test, the newer Stage IIIB and IV (and optionally Stage IIIA) engine technologies are tested under more realistic operational conditions using the new Non-Road Transient Cycle (NRTC).

For gasoline, the directive 2002/88 distinguishes between Stage I and II hand-held (SH) and not hand-held (NS) types of machinery (Table 5.4). Emissions are tested using one of the specific constant load ISO 8178 test cycles (D2, G1, G2, G3) depending on the type of machinery.

For Stage V machinery, EU directive 2016/1628 relate to non-road machinery other than agricultural tractors and railways machinery (Table 5.3) and non-road gasoline machinery (Table 5.4). EU directive 167/2013 relate to Stage V agricultural and forestry tractors (Table 5.3). The Stage V emission limits are also shown in Annex 11.

Table 5.3 Overview of EU emission directives relevant for diesel fuelled non-road machinery.

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

A = For selected machinery types, Stage V includes emission limit values for particle number.

B = Article 63 in 2016/1628 revise Article 19 in 167/2013 to include Stage V limits as described in 2016/1628.

Table 5.4 Overview of the EU Emission Directives relevant for gasoline fuelled non-road machinery.

	Category	Engine size [ccm]	CO [g pr kWh]	HC [g pr kWh]	NO_X [g pr kWh]	$HC+NO_X$ [g pr kWh]	Implement. date
EU Directive 2002/88	Stage I						
Hand held	SH1	S<20	805	295	5.36	-	1/2 2005
	SH2	20≤S<50	805	241	5.36	-	1/2 2005
	SH3	50≤S	603	161	5.36	-	1/2 2005
Not hand held	SN3	100≤S<225	519	-	-	16.1	1/2 2005
	SN4	225≤S	519	-	-	13.4	1/2 2005
	Stage II						
Hand held	SH1	S<20	805	-	-	50	1/2 2008
	SH2	20≤S<50	805	-	-	50	1/2 2008
	SH3	50≤S	603	-	-	72	1/2 2009
Not hand held	SN1	S<66	610	-	-	50	1/2 2005
	SN2	66≤S<100	610	-	-	40	1/2 2005
	SN3	100≤S<225	610	-	-	16.1	1/2 2008
	SN4	225≤S	610	-	-	12.1	1/2 2007
EU Directive 2016/1628	Stage V						
Hand held (<19 kW)	NRSh-v-1a	S<50	805	-	-	50	2019
	NRSh-v-1b	50≤S	805	-	-	72	2019
Not hand held (P<19 kW)	NRS-vr/vi-1a	80≤S<225	610	-	-	10	2019
	NRS-vr/vi-1b	S≥225	610	-	-	8	2019
Not hand held (19=<P<30 kW)	NRS-v-2a	S≤1000	610	-	-	8	2019
	NRS-v-2b	S>1000	4.40*	-	-	2.70*	2019
Not hand held (30=<P<56 kW)	NRS-v-3	any	4.40*	-	-	2.70*	2019

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

For recreational craft, Directive 2003/44 comprises the Stage 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 5.5. 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 5.6, 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 5.5 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 5.6 Overview of the EU Emission Directive 2013/53 for recreational craft.

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

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

Table 5.7 Overview of the EU Emission Directives relevant for railway locomotives and motorcars.

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

Aircraft engine emissions of NO_x, CO, VOC and smoke are regulated by ICAO (International Civil Aviation Organization). The engine emission certification standards are contained in Annex 16 — Environmental Protection, Volume II — 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, take off and climb out.

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

For NO_x, the 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 5.8.

Table 5.8 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 1.1.2007 & for engines manufactured on or after 1.1.2013	Engines for which the date of manufacture of the first individual production model was on or after 1.1.2014
Applies to engines >26.7 kN	$Dp/F_{oo} = 40 + 2\pi_{oo}$	$Dp/F_{oo} = 32 + 1.6\pi_{oo}$			
Engines of pressure ratio less than 30					
Thrust more than 89 kN			$Dp/F_{oo} = 19 + 1.6\pi_{oo}$	$Dp/F_{oo} = 16.72 + 1.4080\pi_{oo}$	$7.88 + 1.4080\pi_{oo}$
Thrust between 26.7 kN and not more than 89 kN			$Dp/F_{oo} = 37.572 + 1.6\pi_{oo} - 0.208F_{oo}$	$Dp/F_{oo} = 38.54862 + (1.6823\pi_{oo}) - (0.2453F_{oo}) - (0.00308\pi_{oo}F_{oo})$	$Dp/F_{oo} = 40.052 + 1.5681\pi_{oo} - 0.3615F_{oo} - 0.0018\ \pi_{oo} \times F_{oo}$
Engines of pressure ratio more than 30 and less than 62.5 (104.7)					
Thrust more than 89 kN			$Dp/F_{oo} = 7+2.0\pi_{oo}$	$Dp/F_{oo} = -1.04+ (2.0{*}\pi_{oo})$	
Thrust between 26.7 kN and not more than 89 kN			$Dp/F_{oo} = 42.71 +1.4286\pi_{oo} - 0.4013F_{oo} +0.00642\pi_{oo}F_{oo}$	$Dp/F_{oo} = 46.1600 + (1.4286\pi_{oo}) - (0.5303F_{oo}) - (0.00642\pi_{oo}F_{oo})$	
Engines with pressure ratio 62.5 or more					
Engines with pressure ratio 82.6 or more			$Dp/F_{oo} = 32+1.6\pi_{oo}$	$Dp/F_{oo} = 32+1.6\pi_{oo}$	
Engines of pressure ratio more than 30 and less than (104.7)					
Thrust more than 89 kN					$Dp/F_{oo} = -9.88 + 2.0\pi_{oo}$
Thrust between 26.7 kN and not more than 89 kN					$Dp/F_{oo} = 41.9435 + 1.505\pi_{oo} - 0.5823F_{oo} + 0.005562\pi_{oo} \times F_{oo}$
Engines with pressure ratio 104.7 or more					$Dp/F_{oo} = 32 + 1.6\pi_{oo}$

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

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

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

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

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

Embedded applicability dates are:

- **Subsonic jet aeroplanes**, including their derived versions, of greater than 5 700 kg maximum take-off mass for which the application for a type certificate was submitted on or after 1 January 2020, except for those aeroplanes of less than or equal to 60 000 kg maximum take-off mass with a maximum passenger seating capacity of 19 seats or less;
- **Subsonic jet aeroplanes**, including their derived versions, of greater than 5 700 kg and less than or equal to 60 000 kg maximum take-off mass with a maximum passenger seating capacity of 19 seats or less, for which the application for a type certificate was submitted on or after 1 January 2023;
- **All propeller-driven aeroplanes**, including their derived versions, of greater than 8 618 kg maximum take-off mass, for which the application for a type certificate was submitted on or after 1 January 2020;
- **Derived versions of non-CO_2-certified subsonic jet aeroplanes** of greater than 5 700 kg maximum certificated take-off mass for which the application for certification of the change in type design was submitted on or after 1 January 2023;
- **Derived versions of non-CO_2 certified propeller-driven aeroplanes** of greater than 8 618 kg maximum certificated take-off mass for which the application for certification of the change in type design was submitted on or after 1 January 2023;
- **Individual non-CO_2-certified subsonic jet aeroplanes** of greater than 5 700 kg maximum certificated take-off mass for which a certificate of airworthiness was first issued on or after 1 January 2028; and
- **Individual non-CO_2-certified propeller-driven aeroplanes** of greater than 8 618 kg maximum certificated take-off mass for which a certificate of airworthiness was first issued on or after 1 January 2028.

Marpol 73/78 Annex VI agreed by IMO (International Maritime Organisation) concerns the control of NO_x emissions (Regulation 13 plus amendments) and SO_x and particulate emissions (Regulation 14 plus amendments) from ships (DNV, 2009). 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 pr kWh, $n < 130$ RPM
- $45 \times n^{-0.2}$ g pr kWh, $130 \leq n < 2000$ RPM
- 9.8 g pr kWh, $n \geq 2000$ 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[8]: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2016 operating in the North American ECA (Emission Control Area) or the United States Carribean Sea ECA and diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2021 operating in the Baltic Sea and North Sea ECA.

The three tier NO_x emission limit functions are shown in Table 5.9.

Table 5.9 Tier I-III NO_x emission limits for ship engines in MARPOL Annex VI.

	NO_x limit	RPM (n)
Tier I	17 g pr kWh	$n < 130$
	$45 \cdot n^{-0.2}$ g pr kWh	$130 \leq n < 2000$
	9,8 g pr kWh	$n \geq 2000$
Tier II	14.4 g pr kWh	$n < 130$
	$44 \cdot n^{-0.23}$ g pr kWh	$130 \leq n < 2000$
	7.7 g pr kWh	$n \geq 2000$
Tier III	3.4 g pr kWh	$n < 130$
	$9 \cdot n^{-0.2}$ g pr kWh	$130 \leq n < 2000$
	2 g pr kWh	$n \geq 2000$

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 5.10 shows the EU and IMO (Regulation 14 plus amendments) legislation in force for SECA (Sulphur Emission Control Area) areas and outside SECAs.

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

Table 5.10 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		

[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.

In Marpol 83/78 Annex VI (Chapter 4) the EEDI fuel efficiency regulations are mandatory from 1 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/tonnes.nm). At present, the IMO EEDI scheme comprises the following ship types; bulk carriers, gas carriers, tankers, container ships, general cargo ships, refrigerated and combination cargo carriers.

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

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

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

It is envisaged that also ro-ro 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 (2006) 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. Time series of fuel sulphur contents for the relevant fuel types and their references are listed in Annex 14.

Annex 14 also list the lower heating values (LHV) for the inventory fuel types together with their references. The LHV's are used to transform emission factors from g/kg fuel into g/MJ or fuel results from kg into MJ if needed in the inventories.

The CO_2 emission factors are country-specific and come from Fenhann and Kilde (1994). For LNG, however, the CO_2 emission factor is estimated by the Danish gas transmission company, Energinet.dk, based on gas analysis data. For LPG, the emission factor source is EMEP/EEA (2016).

The N_2O emission factors are taken from the EMEP/EEA guidebook; EMEP/EEA (2016) for road transport and non road machinery, and IPCC (1997) for national sea transport and fisheries as well as aviation.

For all mobile sources, the emission factor source for BC, NH_3 and PAH is the EMEP/EEA guidebook (EMEP/EEA, 2016). The heavy metal emission factors for road transport and other mobile sources originate from Winther and Slentø (2010). For national sea transport and fisheries, the heavy metal emission factor source is the EMEP/EEA guidebook (EMEP/EEA, 2016). For HCB and PCB's the emission factors come from Nielsen et al. (2014). For civil aviation jet fuel, no heavy metal emission factors are proposed due to lack of data.

In the case of military ground equipment, due to lack of fleet/activity and emission data, aggregated emission factors for gasoline and diesel are derived from total road traffic emission results. For piston engine aircraft using aviation gasoline, aggregated emission factors for conventional cars are used.

For railways, specific Danish measurements from the Danish State Railways (DSB) (Mølgård, 2017) are used to calculate the emission factors of NO_x, VOC, CO and TSP, and a NMVOC/CH_4 split is made based on DCE 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, 1999) and Winther et al. (2006). The NMVOC/CH_4 split is taken from IFEU (1999).

For national sea transport and fisheries, the NO_x emission factors predominantly come from the engine manufacturer MAN Diesel & Turbo, as a function of engine production year. The CO and VOC emission factors come from the Danish TEMA2010 emission model (Trafikministeriet, 2010). TSP emission factors are provided by IMO (2015), whereas the PM_{10} and $PM_{2.5}$ size fractions are obtained from MAN Diesel & Turbo.

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 used by Mols Linjen. For the LNG fuelled ferry in service on the Hou-Sælvig route NO_x, NMVOC, CO and TSP emission factors are taken from Bengtsson et al. (2011).

For ship diesel and residual oil fuelled engines VOC/CH_4 splits are taken from EMEP/EEA (2016), and all emission factors are shown in Annex 13.

The source for aviation (jet fuel) emission factors is the EMEP/EEA guidebook (EMEP/EEA, 2016). 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. For auxiliary power units (APU), ICAO (2011) is the data source for APU load specific NO_x, CO and VOC emission factors for different APU aircraft groups to be linked with the different representative aircraft types. VOC/CH_4 splits for aviation are taken from EMEP/EEA (2016).

For all sectors, emission factors are given in CollectER format in Annex 15 for 2016. Table 5.12 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 2016 are used to calculate the emissions from other mobile sources in Denmark.

Table 5.12 Fuel based emission factors for CO_2, CH_4, N_2O, SO_2, NO_X, NMVOC, CO, NH_3, TSP and BC for other mobile sources in Denmark (2016).

					Emission factors[1] [g per GJ][2]									
SNAP ID	Category	Fuel type	Tier level	CH_4 split of VOC	CH_4	CO_2	N_2O	SO_2	NO_X	NMVOC	CO	NH_3	TSP	BC
080100	Military	AvGas	Tier 1	1.7	21.90	73.00	2.00	22.99	859.00	1242.60	6972.00	1.60	10.00	1.50
080100	Military	Diesel	Tier 1	8.8	0.52	74.00	3.44	0.44	269.15	5.43	56.04	0.71	5.92	4.43
080100	Military	Gasoline	Tier 1	4.6	5.96	73.00	0.89	0.44	80.23	122.59	1141.51	16.53	0.98	0.16
080100	Military	Jet fuel	Tier 1	9.6	2.65	72.00	2.30	22.99	250.57	24.94	229.89	0.00	1.16	0.56
080200	Railways	Diesel	Tier 1	3.7	1.48	74.00	2.04	0.47	598.00	38.52	83.00	0.20	14.00	9.10
080300	Recreational craft	Diesel	Tier 3	2.4	3.12	74.00	2.97	46.84	721.56	127.07	369.51	0.17	77.74	28.76
080300	Recreational craft	Gasoline	Tier 3	2.8	12.96	73.00	1.61	0.46	588.77	444.73	7060.69	0.11	4.29	0.21
080402	National sea traffic	Diesel	Tier 3	3.6	1.82	74.00	1.86	46.84	1429.55	49.52	173.49	0.00	22.63	6.73
080402	National sea traffic	LNG	Tier 3	74.0	263.14	56.80	0.00	0.00	161.63	92.45	269.39	0.00	8.51	1.28
080402	National sea traffic	Residual oil	Tier 3	3.0	1.96	78.00	1.95	48.90	1808.22	63.48	205.12	0.00	86.40	6.44
080403	Fishing	Diesel	Tier 1	3.0	1.81	74.00	1.87	46.84	1262.35	58.53	175.13	0.00	22.60	6.68
080404	International sea traffic	Diesel	Tier 1	3.0	1.83	74.00	1.87	46.84	1590.13	59.26	187.36	0.00	22.95	6.68
080404	International sea traffic	Residual oil	Tier 1	3.0	2.02	78.00	1.96	48.90	2111.40	65.27	206.35	0.00	90.92	2.70
080501	Other airports, Air traffic, Dom. < 3000 ft.	AvGas	Tier 1	1.7	21.90	73.00	2.00	22.83	859.00	1242.60	6972.00	1.60	10.00	1.50
080501	Other airports, Air traffic, Dom. < 3000 ft.	Jet fuel	Tier 3	10.0	2.34	72.00	11.74	22.99	303.44	21.02	297.33	0.00	1.94	0.97
080502	Other airports, Air traffic, Int. < 3000 ft.	AvGas	Tier 1	1.7	21.90	73.00	2.00	22.83	859.00	1242.60	6972.00	1.60	10.00	1.50
080502	Other airports, Air traffic, Int. < 3000 ft.	Jet fuel	Tier 3	10.0	2.41	72.00	5.08	22.99	305.21	21.67	211.42	0.00	2.51	1.12
080503	Other airports, Air traffic, Dom. > 3000 ft.	Jet fuel	Tier 3	0.0	0.00	72.00	2.30	22.99	374.92	6.89	97.15	0.00	1.93	0.93
080504	Other airports, Air traffic, Int. > 3000 ft.	Jet fuel	Tier 3	0.0	0.00	72.00	2.30	22.99	314.98	6.53	95.75	0.00	4.35	1.86
080600	Agriculture	Diesel	Tier 3	2.4	0.96	74.00	3.51	0.47	403.40	39.09	270.76	0.20	27.82	17.82
080600	Agriculture	Gasoline	Tier 3	11.2	140.63	73.00	1.65	0.46	106.18	1112.95	22340.63	1.38	28.62	1.43
080700	Forestry	Diesel	Tier 3	2.4	0.49	74.00	3.63	0.47	228.65	19.98	194.06	0.21	14.28	11.30
080700	Forestry	Gasoline	Tier 3	6.0	240.84	73.00	0.46	0.46	54.79	3754.36	17915.98	0.09	82.19	4.11
080800	Industry	Diesel	Tier 3	2.4	1.36	74.00	3.32	0.47	406.01	55.21	301.14	0.19	37.89	25.91
080800	Industry	Gasoline	Tier 3	3.7	59.72	73.00	1.49	0.46	215.25	1556.83	14359.20	0.10	23.93	1.20
080800	Industry	LPG	Tier 3	5.0	7.69	63.10	3.50	0.00	699.01	146.09	104.85	0.21	4.89	0.24
080900	Household and gardening	Gasoline	Tier 3	1.7	48.71	73.00	1.19	0.46	108.50	2845.04	28334.79	0.09	34.27	1.71
081100	Commercial and institutional	Diesel	Tier 3	2.4	0.55	74.00	3.66	0.47	251.43	22.49	212.75	0.21	17.70	13.73
081100	Commercial and institutional	Gasoline	Tier 3	3.7	32.03	73.00	1.32	0.46	82.43	844.94	34014.72	0.09	13.90	0.69
080501	Copenhagen airport, Air traffic, Dom. < 3000 ft.	AvGas	Tier 1	1.7	21.90	73.00	2.00	22.83	859.00	1242.60	6972.00	1.60	10.00	0.00
080501	Copenhagen airport, Air traffic, Dom. < 3000 ft.	Jet fuel	Tier 3	10.0	2.27	72.00	6.04	22.99	305.51	20.42	180.33	0.00	1.92	0.87
080502	Copenhagen airport, Air traffic, Int. < 3000 ft.	AvGas	Tier 1	1.7	21.90	73.00	2.00	22.83	859.00	1242.60	6972.00	1.60	10.00	0.00
080502	Copenhagen airport, Air traffic, Int. < 3000 ft.	Jet fuel	Tier 3	10.0	1.73	72.00	3.09	22.99	337.20	15.57	160.19	0.00	2.84	1.49
080503	Copenhagen airport, Air traffic, Dom. > 3000 ft.	Jet fuel	Tier 3	0.0	0.00	72.00	2.30	22.99	377.84	4.74	48.11	0.00	2.91	1.14
080504	Copenhagen airport, Air traffic, Int. > 3000 ft.	Jet fuel	Tier 3	0.0	0.00	72.00	2.30	22.99	379.46	3.51	39.29	0.00	5.47	2.75

References. CO_2: Country-specific, Energinet.dk (LNG), EMEP/EEA (LPG). N_2O: EMEP/EEA. CH_4: Railways: Danish State Railways, DCE; Agriculture/Forestry/Industry/Household-Gardening: IFEU (2004, 1999, 2014); National sea traffic/Fishing/International sea traffic: Trafikministeriet (2010), specific data from Mols Linjen, Bengtsson et al. (2011), EMEP/EEA; domestic and international aviation: EMEP/EEA. SO_2: Country-specific; Military: Aggregated emission factors for road transport; Railways (NO_x, CO, NMVOC and TSP): Danish State Railways; Agriculture, forestry, industry, household gardening and inland waterways (NO_x, CO, VOC and TSP): IFEU (2004, 1999, 2014); National sea transport/Fishing/International sea traffic: MAN B&W (NO_x), Trafikministeriet (2010) (CO, NMVOC), IMO (TSP), specific data from Mols Linjen (NO_x, CO, NMVOC, TSP) and LNG emission factors (NO_x, CO, NMVOC, TSP) from Bengtsson et al. (2011); 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, 1999, 2014), and are shown in Annex 10. For more details regarding the use of these factors, please refer to paragraph 5.4.2 or Winther et al. (2006).

Engine load adjustment factors for ship engines

For ship engines, specific fuel consumption (sfc) and emission factors are found to vary with engine load, and hence engine load adjustment factors, LAF, are used in the fleet activity calculations for ferries to account for these engine load changes. For sfc and NO_x, N_2O, CO, VOC and PM, engine load adjustment functions are provided by IMO (2015) based on Starcrest (2013). For practical purposes only sfc is adjusted in the calculations, due to the actual engine load levels for ferries in the Danish inventories. The load adjustment factors are shown in Annex 12.

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 (2016), the fuel consumption and emission factors for the full LTO cycle are estimated for each of the representative aircraft types used in the Danish inventory.

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

$$FC_{LTO}^{a} = \sum_{m=1}^{5} t_m \cdot ff_{a,m} \qquad (15)$$

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

The emissions for one LTO cycle are estimated as follows:

$$E_{LTO}^{a} = \sum_{m=1}^{5} FC_{a,m} \cdot EI_{a,m} \qquad (16)$$

Where EI = emission index (g per kg fuel). Due to lack of specific airport data for approach/descent, take off and climb out, standardised times-in-modes of 4.0, 0.7 and 2.2 minutes are used as defined by ICAO (ICAO, 1995). For taxi in and taxi out, specific times-in-modes data are provided by Eurocontrol for the airports present in the Danish inventory. The taxi times-in-modes data are shown in Annex 10 for the years 2001-2016.

The fuel consumption and emissions for aircraft auxiliary power units (APU's) are calculated with the same method used to estimate LTO fuel consumption and emissions for aircraft main engines (formulas 15 and 16). ICAO (2011) is the data source for APU load specific fuel flows (kg per s) and emission rates (g per kg fuel) for different APU aircraft groups (characterised by seating capacity and age). APU times-in-modes for arrival, start-up, boarding and main engine start are also provided by ICAO (2011), whereas push back time intervals are taken from an emission study made in Copenhagen Airport (Ellermann et al., 2011; Winther et al., 2015).

For each representative aircraft type, the calculated fuel consumption and emission factors per LTO are shown in Annex 10 for Copenhagen Airport and other airports (aggregated) for 2016. APU data for fuel flows, emission rates and times-in-modes are also shown in Annex 10, together with the correspondence table for APU group-representative aircraft type.

The calculations for cruise use the distance specific fuel consumption and emissions given by EMEP/EEA (2016) 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:

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

In (15) 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 2016[9]. The factors are split between Copenhagen Airport and other airports and distinguish between domestic and international flights.

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

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 0.94 in 2016, 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 take off numbers for other airports provided by the Danish Transport and Construction Agency. Due to lack of aircraft type specific LTO data, fuel consumption and emission factors derived for domestic LTO's in Copenhagen Airport is used for all LTO's in other airports. In a next step, the total fuel consumption for cruise (true cruise fuel consumption) is found year by year as the statistical fuel consumption total minus the calculated fuel consumption for LTO.

For each inventory year, intermediate cruise fuel consumption figures split into four parts (Copenhagen/Other airports; domestic/international) are found as proportional values between part specific LTO fuel consumption values estimated as described previously, and part specific cruise: LTO fuel consumption ratios for 2001 derived from the detailed city-pair emission inventory.

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

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:

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

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 pr kWh, i = machinery type, j = engine size, k = engine age, y = engine-size class and z = emission level. The basic fuel consumption and emission factors are shown in Annex 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:

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

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:

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

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:

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

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

The transient factors inserted in (22) 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 19-22:

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

The evaporative hydrocarbon emissions from fuelling are calculated as:

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

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

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

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

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

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, LAF = engine load adjustment 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 (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:

$$E = FC \cdot EF \quad (29)$$

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 2016 and as time series 1990-2016 in Annex 15 (CRF format).

5.5 Energy 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.

In the following, the transferal 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 years when the fuel estimates for ferries (not including the ferry to the Faroe Islands) are higher than DEA reported fuel sold for national sea transport, fuel is taken from fisheries in the case of marine diesel (1985-1999). For heavy fuel oil, the missing fuel amount is taken from stationary sources (1985-1986, 1988, 1994-1996) and international sea transport (2015 onwards).

In national sea transport, LNG fuel has been calculated for Danish ferries since 2015. However, in DEA fuel statistics, the consumption of LNG for national sea transport is included under diesel instead of being reported as LNG. In the Danish inventories, the bottom up estimated consumption of LNG is reported under national sea transport in the inventories, and the amount of diesel reported for national sea transport is subsequently being reduced by the same number.

For fisheries, the calculation methodology is fuel activity based and input fuel data is in principle the diesel fuel sold for fisheries reported by DEA. For years when bottom up diesel estimates for national sea transport are higher than DEA reported fuel sold for national sea transport, diesel is transferred from fisheries to national sea transport in the inventories. In addition, the bottom up diesel estimate for recreational craft is subtracted from fisheries and grouped in the “Other” inventory category together with military activities. Incorrectly, reported gasoline and heavy fuel oil for fisheries is transferred to recreational craft (reported under “Other”) and national sea transport, respectively.

According to the DEA, in some cases inaccurate customer specifications are made by the oil suppliers, which result in sector misallocation in the sales statistics between national sea transport and fisheries for diesel 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 5.5.4).

Inaccurate fuel sale specifications is also the reason for heavy fuel oil being reported for fisheries in the DEA statistics. No engines installed in fishing vessels use heavy fuel oil, even though a certain amount of heavy fuel oil is listed in the DEA numbers for some statistical years (H. Amdissen, Danish Fishermen's Association, personal communication, 2006).

5.5.2 Non road machinery and recreational craft

From 2014 onwards, the bottom up estimate for diesel in the DCE non road emission model exceed the diesel fuel sales reported by the DEA under the categories: agriculture and forestry, market gardening, building and construction, industry, and the residual part of diesel not being used for heating in private houses (as estimated by DCE). For these years, the fuel consumption and emission estimates for diesel machinery in the Danish non road model (agriculture, forestry, industry, commercial/institutional) are scaled down accordingly, to keep the national fuel balance.

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 (before 2014) 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.

5.5.3 Road transport

For natural gas and LPG, the difference between fuel reported in DEA statistics and bottom-up estimates for road transport is outbalanced with fuel totals from "non-industrial combustion plants" (020200) in order to obtain a fuel balance.

5.5.4 Distinction between domestic and international aviation and navigation for Denmark

The distinction between domestic and international fuel consumption and emissions from aviation and navigation for Denmark should be in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. For the national emission inventory, this, in principle, means that fuel sold (and associated emissions) for flights/sea transportation starting from a seaport/airport in the Kingdom of Denmark, with destinations inside or outside the Kingdom of Denmark, are regarded as domestic or international, respectively.

Aviation

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

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

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

Navigation

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

In order to follow the IPCC guidelines the bottom-up fuel estimates for the ferry routes between Denmark and the Faroe Islands, and 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. However, it is considered 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 2016 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 1985-2016 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 2016 in Annex 15 (CollectER format).

Road transport has a major share of the fuel consumption for domestic transport. In 2016, this sector's fuel consumption share is 79 %, while the fuel consumption shares for Off road agriculture/forestry, Manufacturing industries (mobile) and National navigation are 7 %, 4 % and 4 %, respectively. For the remaining sectors, the total fuel consumption share is 6 %.

Table 6.1 Fuel consumption (PJ) for domestic transport in 2016 in CRF sectors.

CRF/NFR category	Fuel consumption (PJ)
Manufacturing industries/Construction (mobile)	9.3
Civil aviation (Domestic)*	1.9
Road transport: Passenger cars	97.7
Road transport: Light duty vehicles	19.5
Road transport: Heavy duty vehicles	51.1
Road transport: Mopeds & motorcycles	1.0
Railways	3.4
National navigation (Shipping)	8.7
Commercial/Institutional: Mobile	1.1
Residential: Household and gardening (mobile)	0.3
Agriculture/Forestry/Fishing: Off-road agriculture/forestry	14.4
Agriculture/Forestry/Fishing: National fishing	4.2
Other, Mobile	2.8
Road transport total	169.4
Other mobile total	46.1
Domestic total	215.5
Civil aviation (International) *	39.2
Navigation (international)	25.9

*Grouped according to UNFCCC reporting definitions

From 1985 to 2016, diesel (sum of diesel and biodiesel) and gasoline (sum of gasoline and E5) fuel consumption has changed by 66 % and - 13 %, respectively (Figure 6.1), and in 2016 the fuel consumption shares for diesel and gasoline were 71 % and 27 %, respectively (not shown). Other fuels only have a 2 % 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[10].

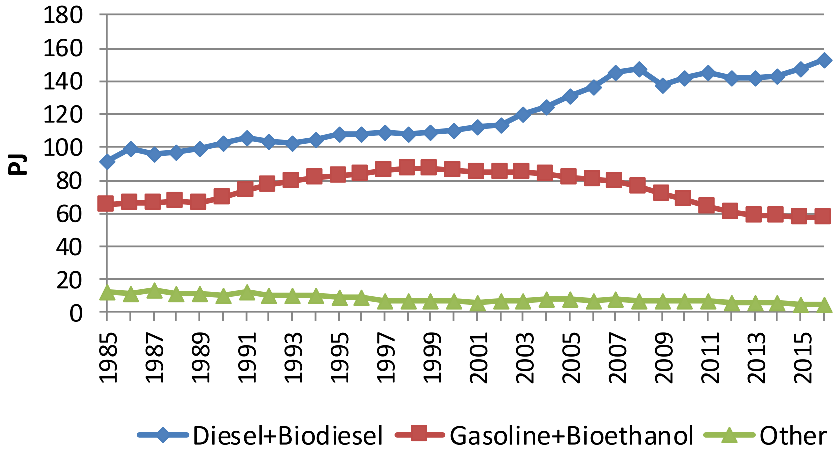


Figure 6.1 Fuel consumption per fuel type for domestic transport 1985-2016.

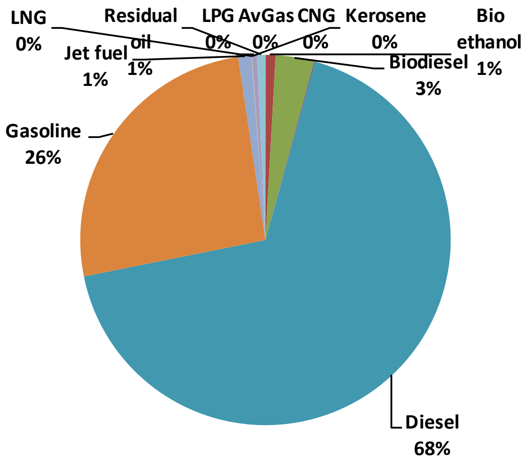


Figure 6.2 Fuel consumption share per fuel type for domestic transport in 2016.

6.1.1 Road transport

As shown in Figure 6.3, the fuel consumption for road transport[11] 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 to 2013 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).

[10] Biofuels are sold at gas filling stations and are assumed used by road transport vehicles.
[11] The sum share of bioethanol and biodiesel in the gasoline and diesel fuel blends for road transport is 4.3 %, in 2016.

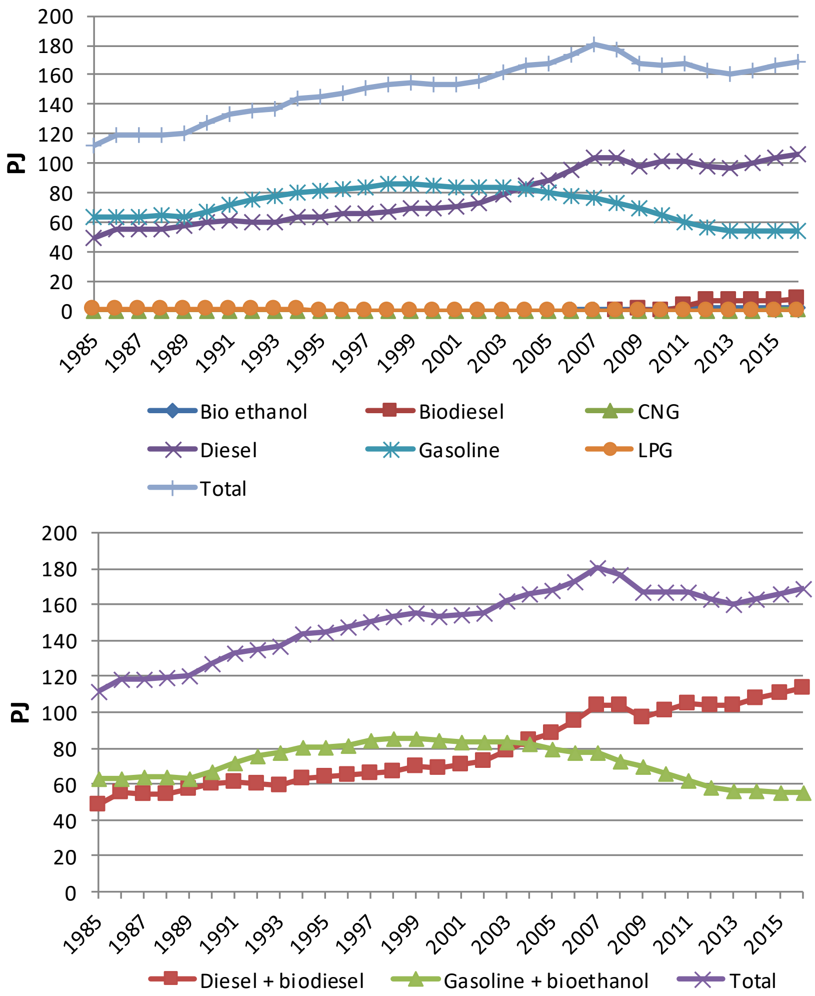


Figure 6.3 Fuel consumption per fuel type and as totals for road transport 1985-2016.

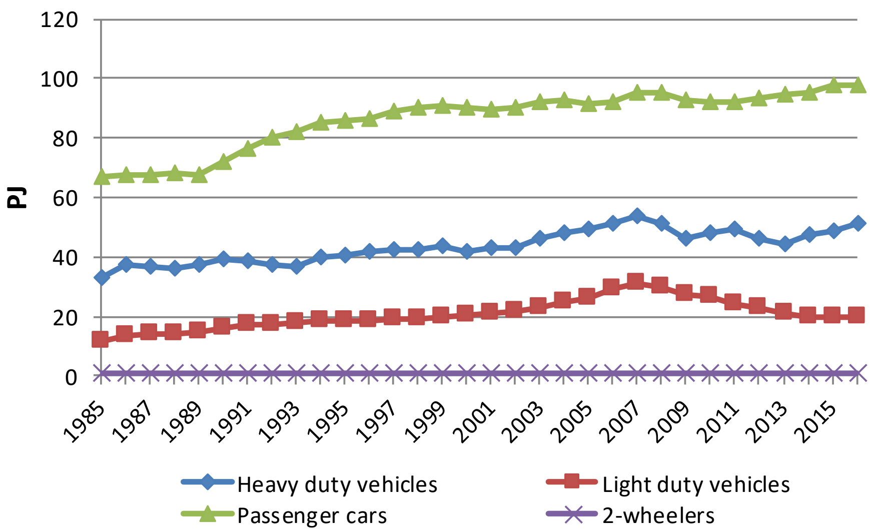


Figure 6.4 Total fuel consumption per vehicle type for road transport 1985-2016.

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, 2012-2013, and 2008-2014, respectively.

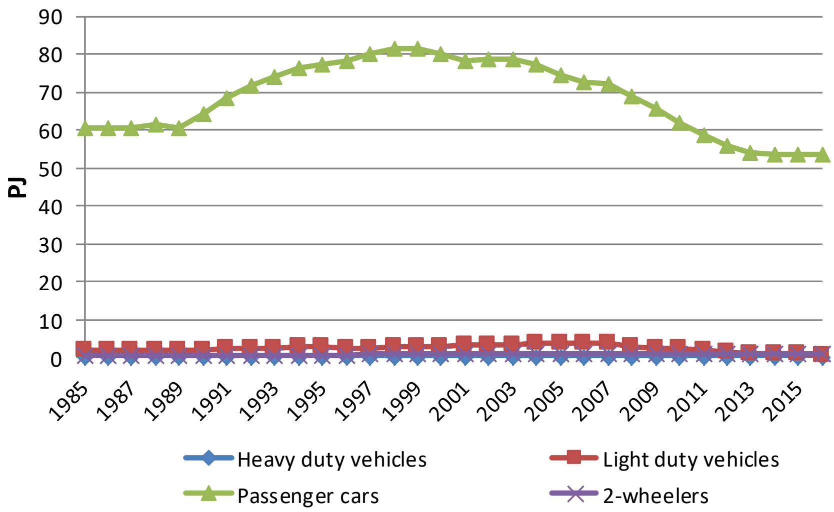


Figure 6.5 Gasoline fuel consumption per vehicle type for road transport 1985-2016.

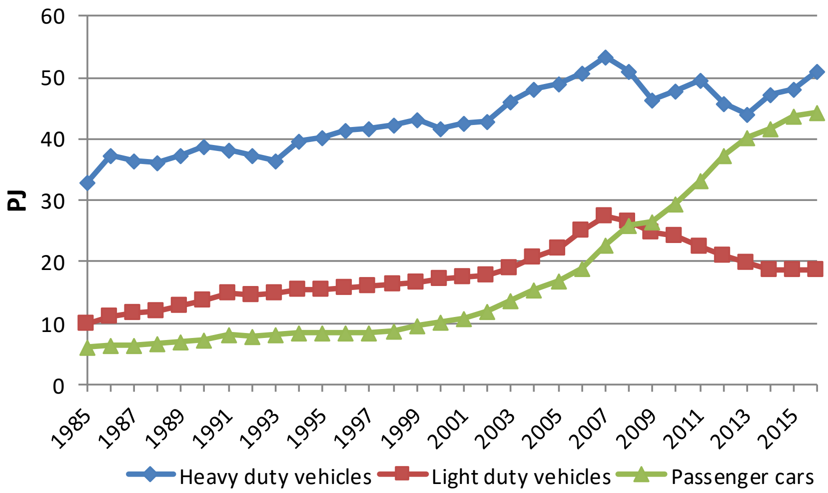


Figure 6.6 Diesel fuel consumption per vehicle type for road transport 1985-2016.

In 2016, fuel consumption shares for gasoline passenger cars, diesel heavy-duty vehicles, diesel passenger cars, diesel light duty vehicles and gasoline light duty vehicles were 32, 30, 26 and 11 %, respectively (Figure 6.7).

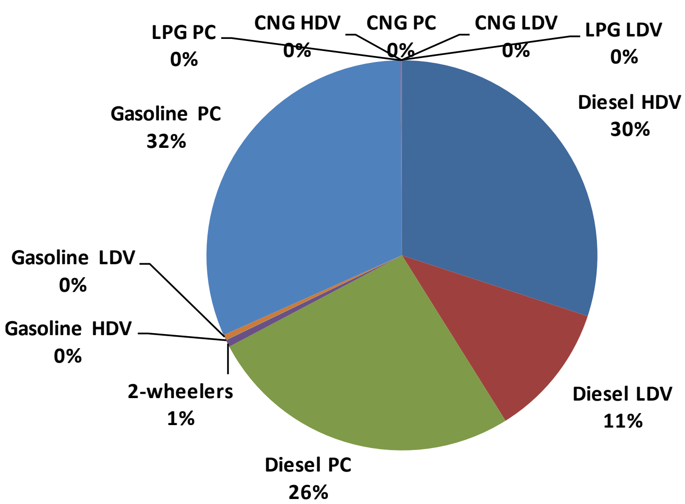


Figure 6.7 Fuel consumption share (PJ) per vehicle type for road transport in 2016.

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/fisheries (1A4c), Industry-other (mobile machinery part of 1A2g) and Navigation (1A3d). Minor fuel consuming sectors are Civil Aviation (1A3a), Railways (1A3c), Other (military mobile and recreational craft: 1A5b), Commercial/institutional (1A4a) and Residential (1A4b).

The 1985-2016 time series are shown per fuel type in Figures 6.9-6.12 for diesel, gasoline, residual oil and jet fuel, respectively.

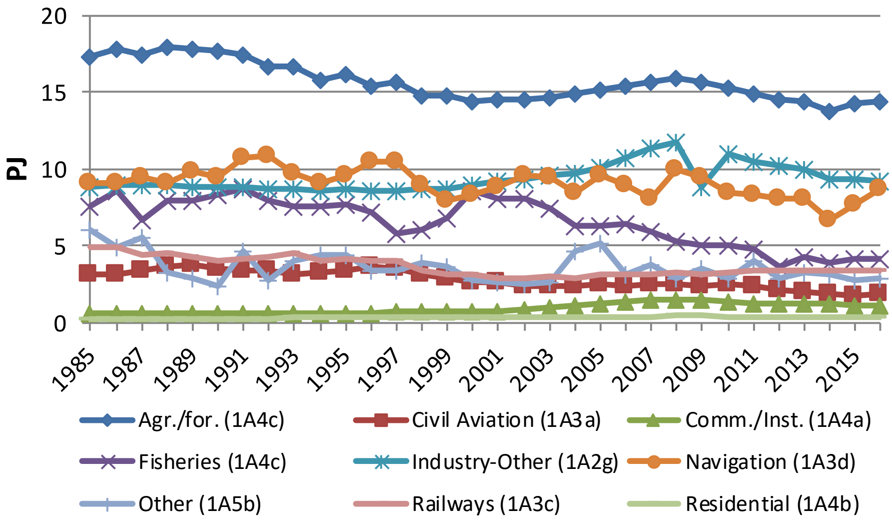


Figure 6.8 Total fuel consumption in CRF sectors for other mobile sources 1985-2016.

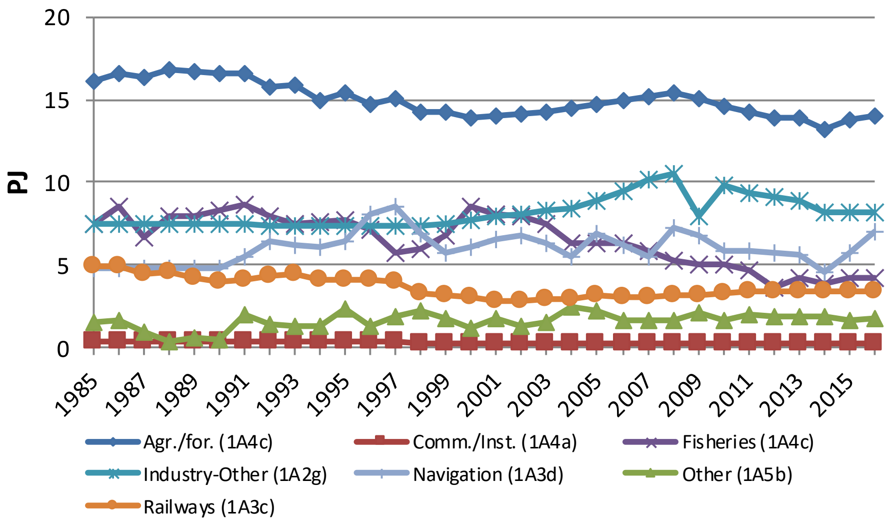


Figure 6.9 Diesel fuel consumption in CRF sectors for other mobile sources 1985-2016.

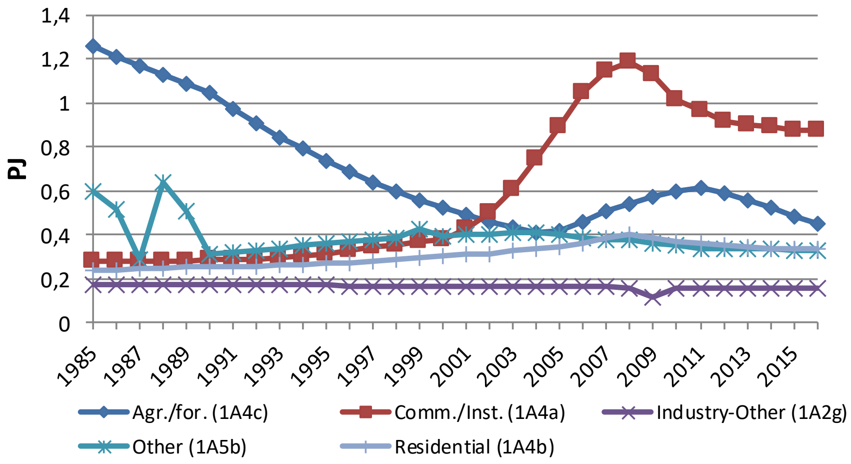


Figure 6.10 Gasoline fuel consumption in CRF sectors for other mobile source 1985-2016.

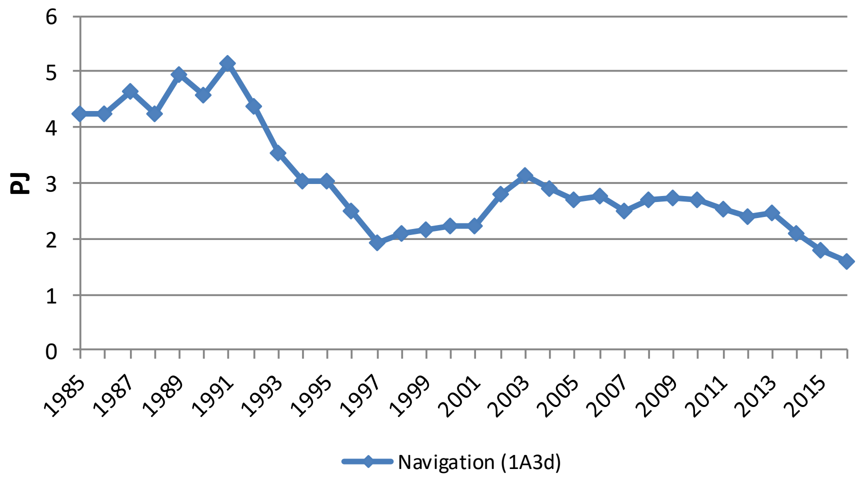


Figure 6.11 Residual oil fuel consumption in CRF sectors for other mobile sources 1985-2016.

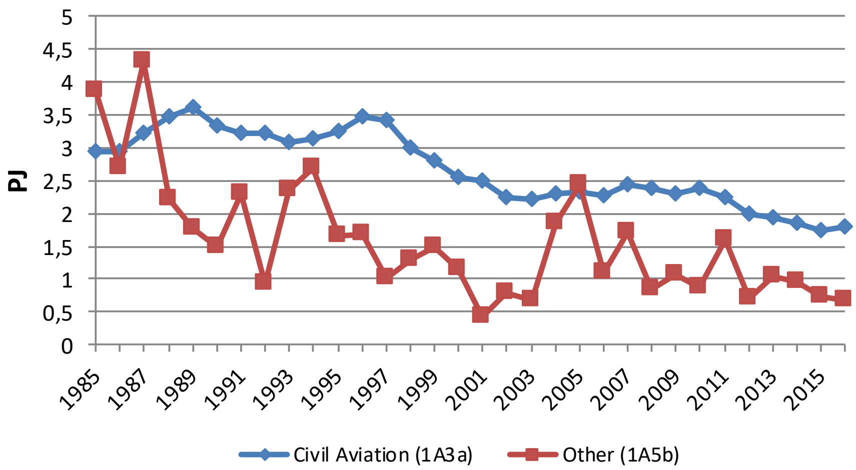


Figure 6.12 Jet fuel consumption in CRF sectors for other mobile sources 1985-2016.

In terms of diesel, the fuel consumption decreases for agricultural machines until 2000, due to a decline in the number of tractors and harvesters. After 2000, the increase in the engine sizes of new sold machines makes the total fuel consumption grow until 2008, whereas from 2008 to 2013 the turnover of old less fuel efficient machinery is the key factor for the total fuel consumption decrease. The fuel consumption for industry has increased from the beginning of the 1990s, 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. From 2009 onwards the fuel efficiency improvements for new sold vehicles is the main reason for total fuel consumption decline. For fisheries, the development in fuel consumption reflects the activities in this sector.

The Navigation sector comprises national sea transport (fuel consumption between two Danish ports including sea travel directly between Denmark and Greenland/Faroe Islands). For national sea transport, the diesel fuel consumption curve reflects the combination of traffic and ferries in use for regional ferries. In 1998 and 1999, a significant decline in fuel consumption is apparent. The most important explanation here is the closing of ferry service routes in connection with the opening of the Great Belt Bridge in 1997. For railways, the gradual shift towards electrification explains the lowering trend in diesel fuel consumption 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 calculated for the Commercial/Institutional (1A4a) sector related to the use of household and gardening machinery. For these types of machinery, a somewhat smaller gasoline fuel consumption is calculated for the Residential (1A4b) sector. For household and gardening equipment, especially from 2001-2006, a significant fuel consumption increase is apparent due to considerable growth in the machinery stock. The gasoline fuel consumption development for Agriculture/forestry/fisheries (1A4c) is due to the gradual phasing out of gasoline-fuelled agricultural tractors until 2005 and the gradual increase in the use of ATV's from the mid-2000s.

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

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

6.1.3 Fuel consumption for international transport

The residual oil and diesel oil fuel consumption fluctuations reflect the quantity of fuel sold in Denmark to international ferries, international warships, other ships with foreign destinations, transport to Greenland and the Faroe Islands, tank vessels and foreign fishing boats. For jet petrol, the sudden fuel consumption drop in 2002 is explained by the recession in the 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.

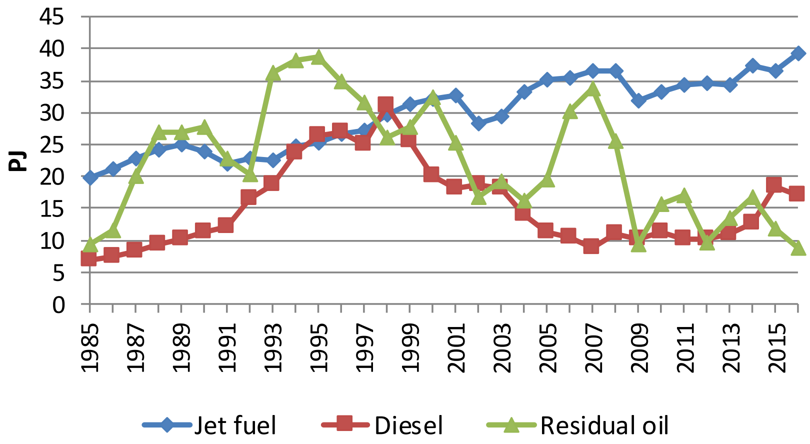


Figure 6.13 Fuel consumption for international transport 1985-2016.

6.2 Emissions of CO_2, CH_4 and N_2O

In Table 6.2, the CO_2, CH_4 and N_2O emissions for road transport and other mobile sources are shown for 2016 in CRF sectors. The emission figures in time series 1990-2016 are given in Annex 16 (CRF format) and are shown for 1990 and 2016 in Annex 15 (CollectER format).

From 1990 to 2016, the road transport emissions of CO_2 and N_2O have increased by 26 and 46 %, respectively, whereas the emissions of CH_4 have decreased by 83 % (from Figures 6.14 - 6.16). From 1990 to 2016 the other mobile CO_2, CH_4 and N_2O emissions have decreased by 16, 56 and 4 % (from Figures 6.18 - 6.20)[12].

Table 6.2 Emissions of CO_2, CH_4 and N_2O in 2016 for road transport and other mobile sources.

	CO_2 ktonnes	CH_4 tonnes	N_2O tonnes
Manufacturing industries/Construction (mobile)	675	28	31
Civil aviation (Domestic)	133	2	7
Road transport: Passenger cars	6841	246	184
Road transport:Light duty vehicles	1352	6	42
Road transport:Heavy duty vehicles	3538	52	214
Road transport: Mopeds & motorcycles	71	84	1
Railways	253	5	7
National navigation (Shipping)	647	38	16
Commercial/Institutional: Mobile	83	28	2
Residential: Household and gardening (mobile)	24	16	0
Agriculture/Forestry/Fishing: Off-road agriculture/forestry	1068	84	50
Agriculture/Forestry/Fishing: National fishing	309	8	8
Other, Mobile	206	10	8
Road transport exhaust total	11802	389	441
Road transport non exhaust total	0	0	0
Other mobile sources total	3399	219	129
Domestic total	15201	608	570
Civil aviation (International)	2823	8	95
Navigation (International)	1950	49	49

[12] From 1985 to 2016, the road transport emissions of CO_2 and N_2O have increased by 43 and 64 %, respectively, whereas the emissions of CH_4 have decreased by 83 %. From 1990 to 2016 the other mobile CO_2, CH_4 and N_2O emissions have decreased by 20, 57 and 7 %.

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 2016, the respective emission shares were 58, 30, 11 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 2016 emission shares for CH_4 were 63, 22, 13 and 2 % for passenger cars, 2-wheelers, heavy-duty vehicles and light-duty vehicles, respectively (Figure 6.17).

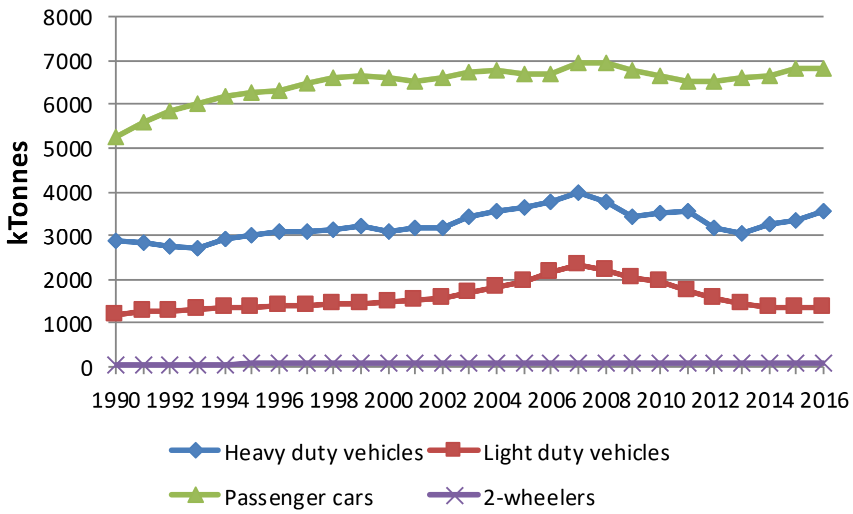


Figure 6.14 CO_2 emissions (k-tonnes) per vehicle type for road transport 1990-2016.

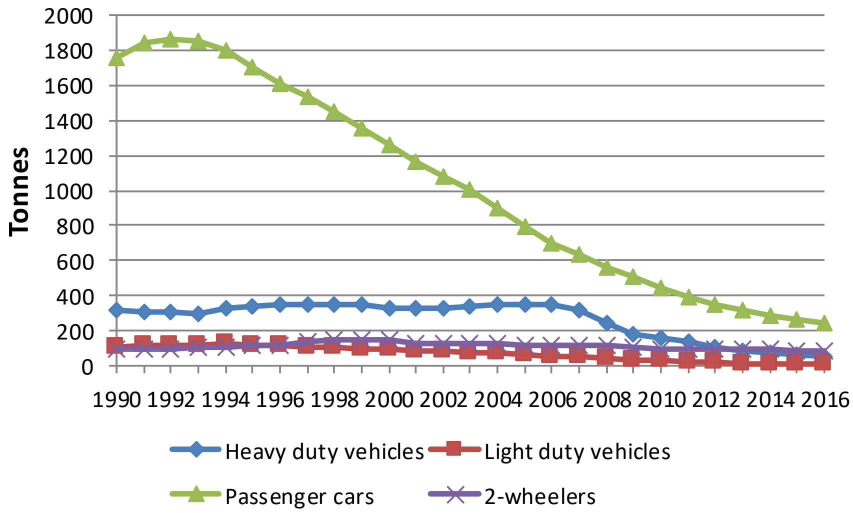


Figure 6.15 CH_4 emissions (tonnes) per vehicle type for road transport 1990-2016.

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 2016, emission shares for passenger cars, heavy and light-duty vehicles were 42, 48 and 10 %, of the total road transport N_2O, respectively (Figure 6.17).

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. In spite of the relatively large CH_4 and N_2O global warming potentials, 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.

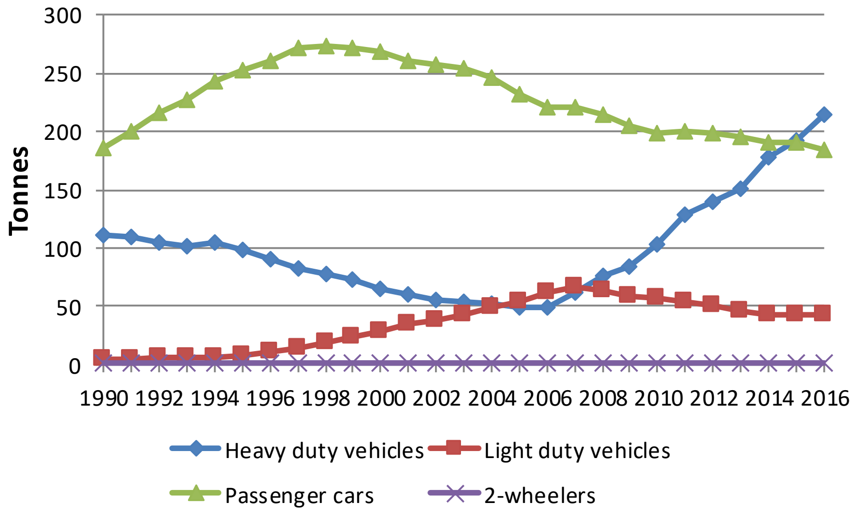


Figure 6.16 N_2O emissions (tonnes) per vehicle type for road transport 1990-2016.

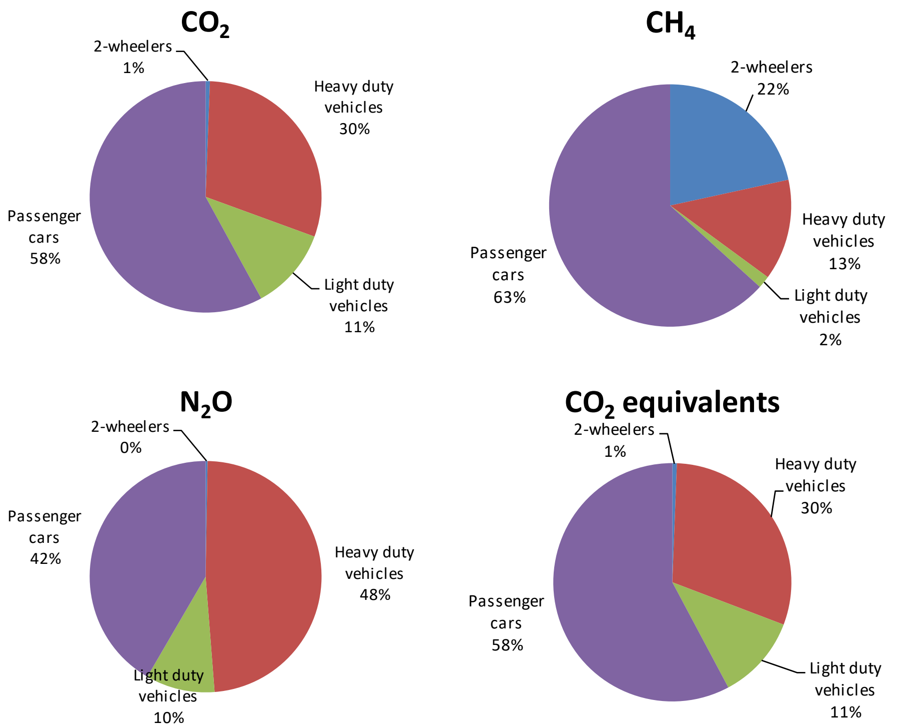


Figure 6.17 CO_2, CH_4 and N_2O emission shares and GHG equivalent emission distribution for road transport in 2016.

6.2.2 Other mobile sources

For other mobile sources, the highest CO_2 emissions in 2016 come from Agriculture/forestry/fisheries (1A4c), Industry-other (1A2g) and Navigation (1A3d), with shares of 40, 20 and 19 %, respectively (Figure 6.21). The 1990-2016 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 Other (1A5).

For CH_4, the most important sources are Agriculture/forestry/fisheries (1A4c), Navigation (1A3d), Industry-other (1A2g), Commercial/Institutional (1A4a) and Residential (1A4b), see Figure 6.21. The emission shares are 43 %, 17 %, 13 %, 13 % and 7 %, respectively in 2016. For the remaining sectors the emission shares 4 % or less. The CH_4 emission contributions from Commercial/Institutional (1A4a) and Residential (1A4b) are quite high compared to their relative fuel consumption (and CO_2 emissions) contributions, due the high CH_4 emission factors for gasoline fuelled working machinery in general.

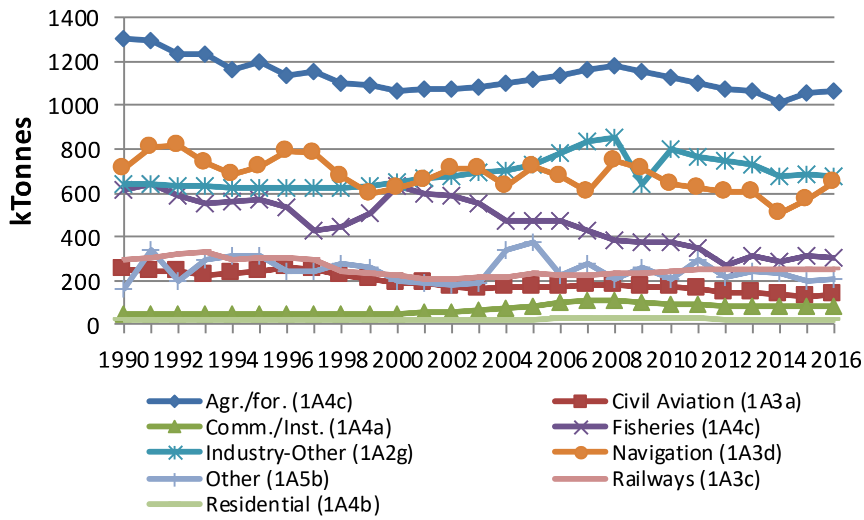


Figure 6.18 CO_2 emissions (ktonnes) in CRF sectors for other mobile sources 1990-2016.

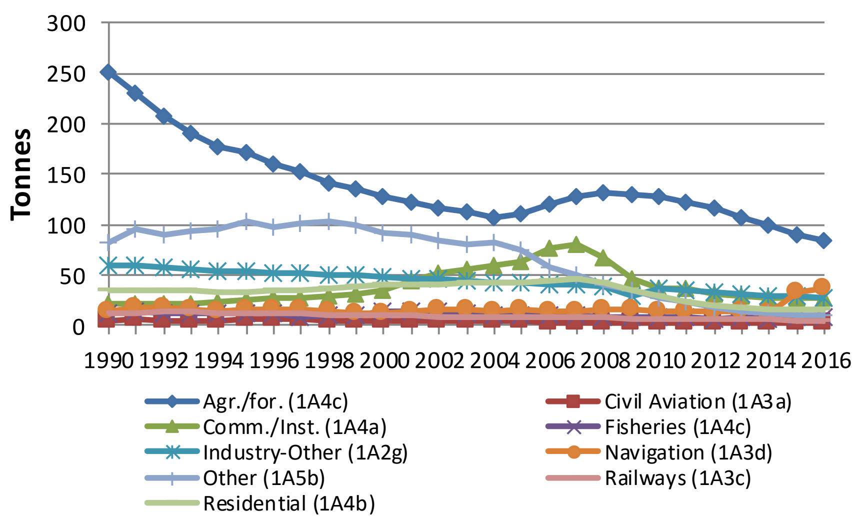


Figure 6.19 CH_4 emissions (tonnes) in CRF sectors for other mobile sources 1990-2016.

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).

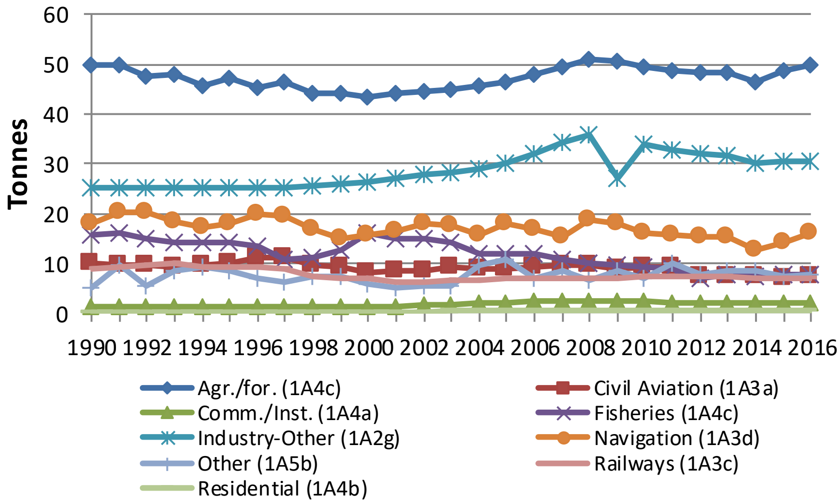


Figure 6.20 N_2O emissions (tonnes) in CRF sectors for other mobile sources 1990-2016.

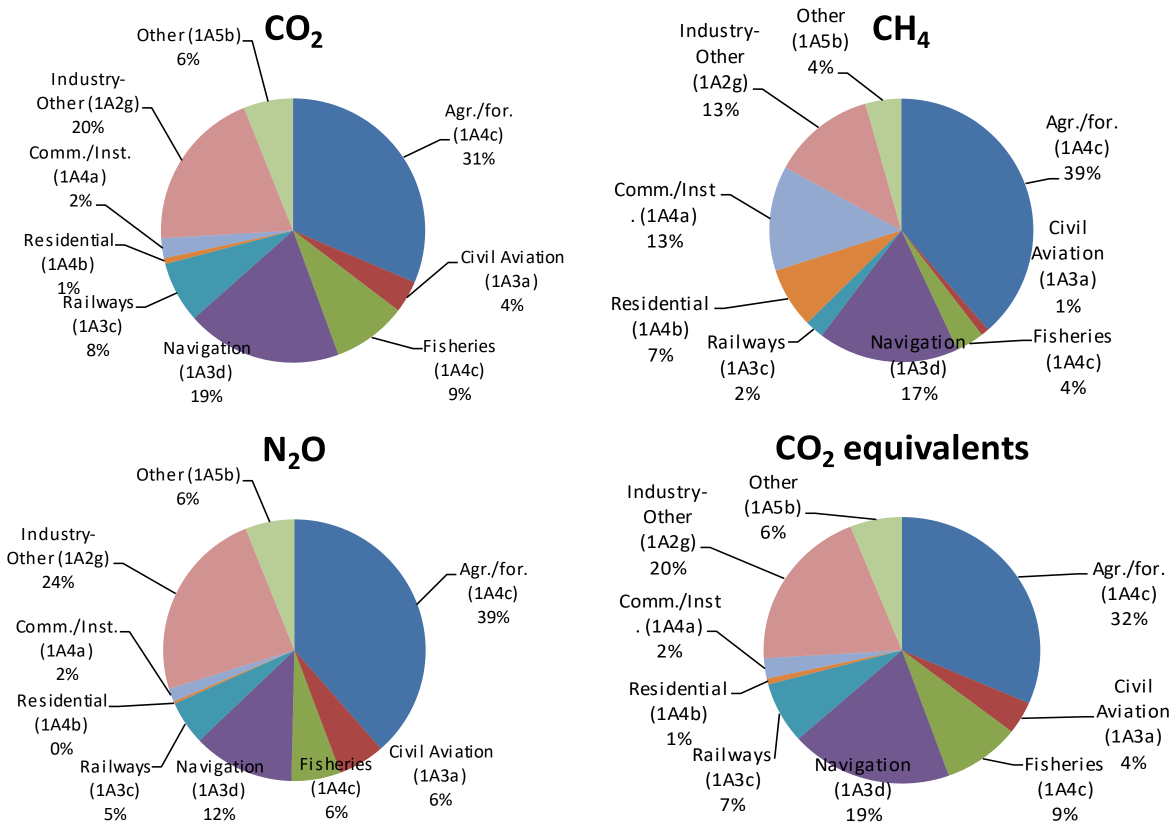


Figure 6.21 CO_2, CH_4 and N_2O emission shares and GHG equivalent emission distribution for other mobile sources in 2016.

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 2016 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 1985-2016 are given in Annex 16 (NFR format) and are shown for 2016 in Annex 15 (CollectER format).

From 1985 to 2016, the road transport emissions of SO_2, NO_X, NMVOC, CO, PM (exhaust emissions; all size fractions) and BC have decreased by 99, 63, 90, 88, 78 and 70 %, respectively (Figures 6.22-6.27), whereas the NH_3 emissions have increased by 1453 % during the same time period (Figure 6.28).

For other mobile sources, the emission changes for SO_2, NO_X, NMVOC, CO, PM (all size fractions) and BC are -95, -34, -61, -36, -78 and -78 %, respectively (Figures 6.31-6.36). The NH_3 emissions have increased by 9 % 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 2016 for road transport and other mobile sources.

	SO_2	NO_x	NMVOC	CO	NH_3	TSP	PM_{10}	$PM_{2.5}$	BC
	tonnes	tonnes	tonnes	tonnes	tonnes	tonnes	tonnes	tonnes	tonnes
Manufacturing industries/Construction (mobile)	4	4009	832	4796	2	318	318	318	212
Civil aviation (Domestic)	43	684	76	532	0	5	5	5	2
Road transport: Passenger cars	43	16732	4152	55717	938	353	353	353	249
Road transport:Light duty vehicles	9	6853	268	2031	17	174	174	174	137
Road transport:Heavy duty vehicles	22	11366	282	4388	39	181	181	181	124
Road transport: Mopeds & motorcycles	0	144	1300	7348	1	21	21	21	3
Road transport: Gasoline evaporation	0	0	1394	0	0	0	0	0	0
Road transport: Brake wear	0	0	0	0	0	523	513	204	14
Road transport: Tyre wear	0	0	0	0	0	971	582	408	149
Road transport: Road abrasion	0	0	0	0	0	1197	599	323	0
Railways	2	2048	132	284	1	48	48	48	31
National navigation (Shipping)	406	12895	455	1563	0	296	293	291	57
Commercial/Institutional: Mobile	1	138	745	29809	0	17	17	17	4
Residential: Household and gardening (mobile)	0	36	948	9437	0	11	11	11	1
Agriculture/Forestry/Fishing: Off-road agriculture/forestry	7	5661	1235	13618	3	404	404	404	249
Agriculture/Forestry/Fishing: National fishing	196	5273	245	732	0	94	93	93	28
Other, Mobile	63	1302	296	2897	1	85	85	85	33
Road transport exhaust total	74	35095	7396	69483	995	729	729	729	514
Road transport non exhaust total	0	0	0	0	0	2691	1694	935	162
Other mobile sources total	720	32047	4963	63667	7	1277	1273	1271	617
Domestic total	794	67142	12359	133150	1002	4697	3696	2935	1293
Civil aviation (International)	901	14449	207	2314	0	199	199	199	99
Navigation (International)	1230	45792	1587	5017	0	1201	1189	1183	137

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 2016 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: 58, 30, 11 and 1 %, respectively (Figure 6.29).

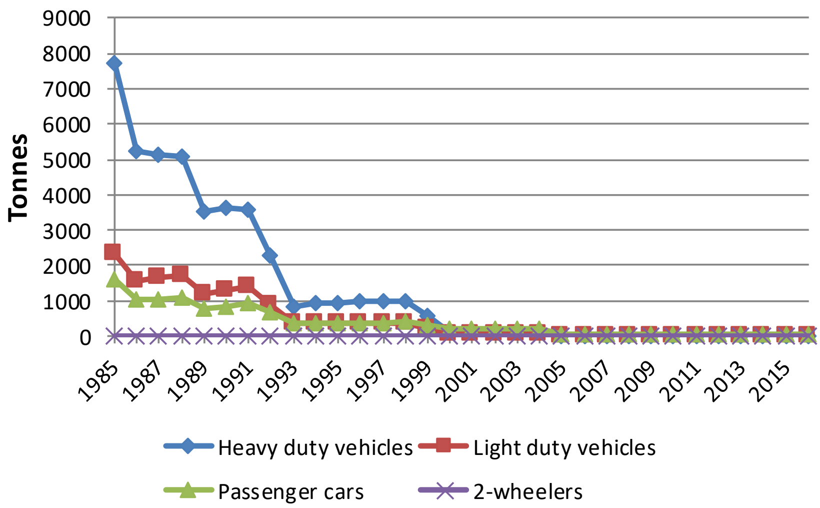


Figure 6.22 SO_2 emissions (tonnes) per vehicle type for road transport 1985-2016.

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 vehicle fleet, 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 vehicles, and a traffic induced emission increase for diesel vehicles; 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 emissions are not reduced in the order as intended by the EU emission legislation. Most markedly for Euro II engines the emission factors are even higher than for Euro I due to the so-called engine cycle-beating effect. Outside the legislative test cycle stationary measurement points, the electronic engine control for heavy duty Euro II and III engines 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 and improved emission factors 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 due to gradually stricter EURO emission standards. In recent years until 2008 the environmental benefit of introducing gradually cleaner diesel private cars has been somewhat outbalanced by an increase in sales of new vehicles. After 2008, the PM emissions gradually become lower due to the increasing number of Euro V cars equipped with particulate filter sold in Denmark from 2006 onwards (Figure 6.26).

BC - commonly understood as the solid part of the particulate emissions - is calculated as shares of TSP for each Euro engine technology class (Figure 6.27). In broad terms, the development in BC emissions follows the TSP emission trend, but deviates in some cases, most markedly for diesel cars and vans. For these vehicle types the BC share of TSP increases in moderate steps from conventional engine technologies to Euro IV. As a result, the BC emission development becomes environmentally less positive than for TSP, until the introduction of Euro V vehicles, for which the installed particulate filters have very high removal rates of BC.

An undesirable environmental side effect of the introduction of catalyst cars is the increase in the emissions of NH_3 from the first two generations of catalyst cars (Euro 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 2016 emission shares for passenger cars, heavy-duty vehicles, light-duty vehicles and 2-wheelers for NO_x (48, 32, 20 and 0 %), NMVOC (56, 4, 4 and 17 %), CO (80, 6, 3 and 11 %), PM (48, 25, 24 and 3 %), BC (48, 24, 27 and 1 %), and NH_3 (94, 4, 2 and 0 %), are also shown in Figure 6.29.

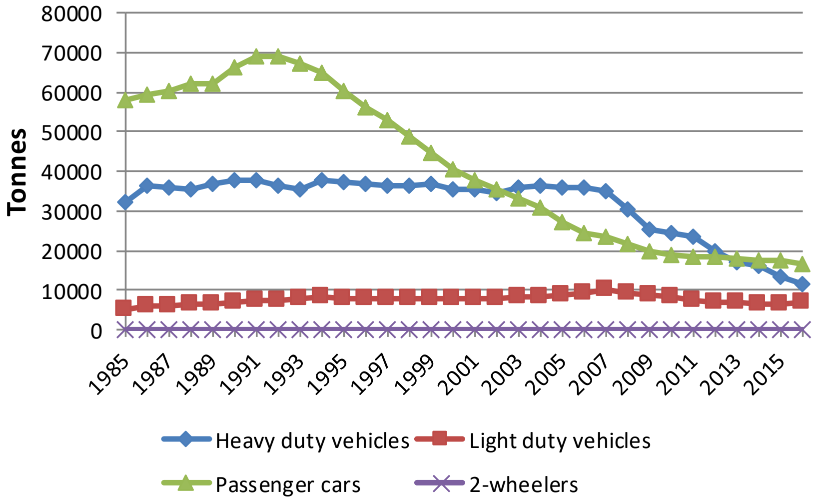


Figure 6.23 NO_X emissions (tonnes) per vehicle type for road transport 1985-2016.

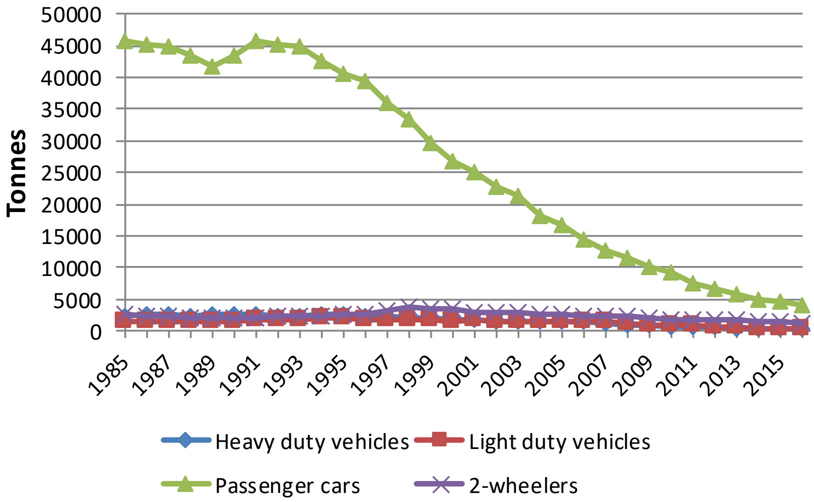


Figure 6.24 NMVOC emissions (tonnes) per vehicle type for road transport 1985-2016.

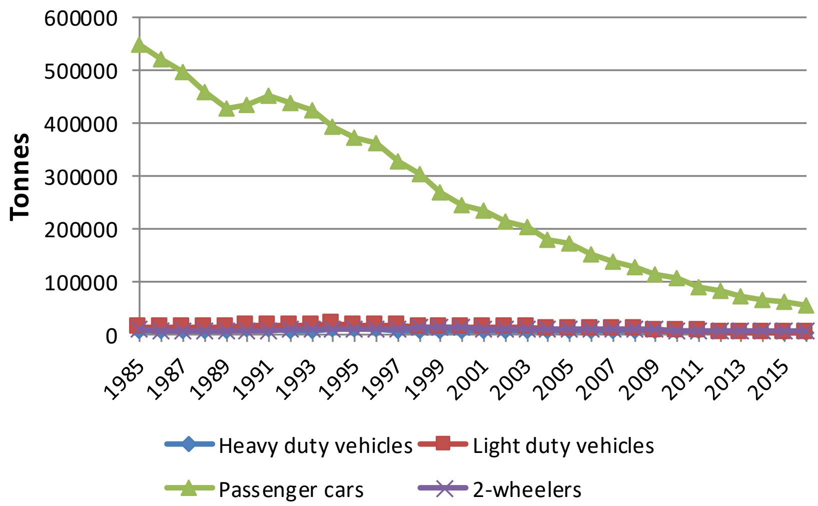


Figure 6.25 CO emissions (tonnes) per vehicle type for road transport 1985-2016.

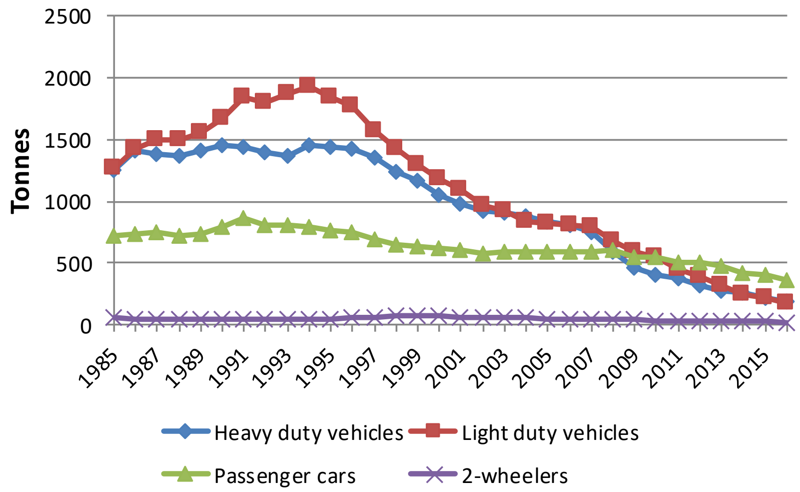


Figure 6.26 PM emissions (tonnes) per vehicle type for road transport 1985-2016.

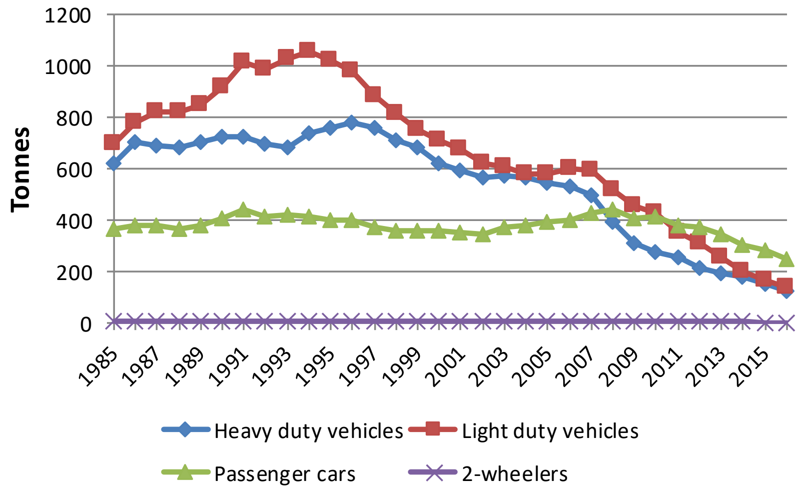


Figure 6.27 BC emissions (tonnes) per vehicle type for road transport 1985-2016.

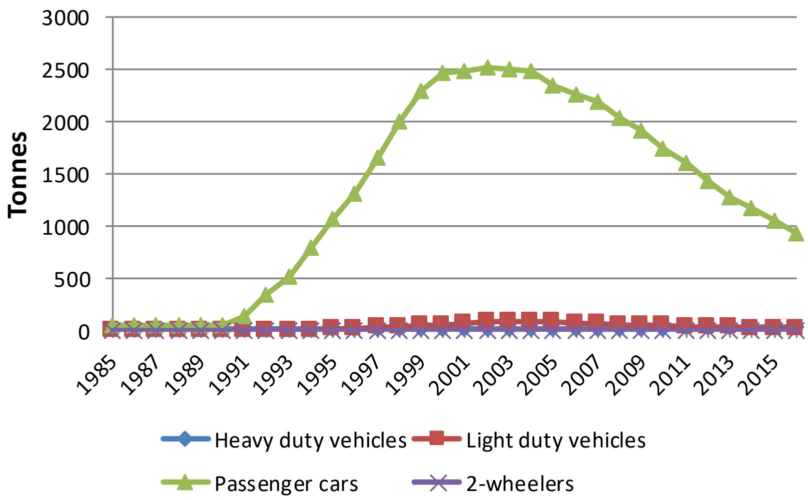


Figure 6.28 NH_3 emissions (tonnes) per vehicle type for road transport 1985-2016.

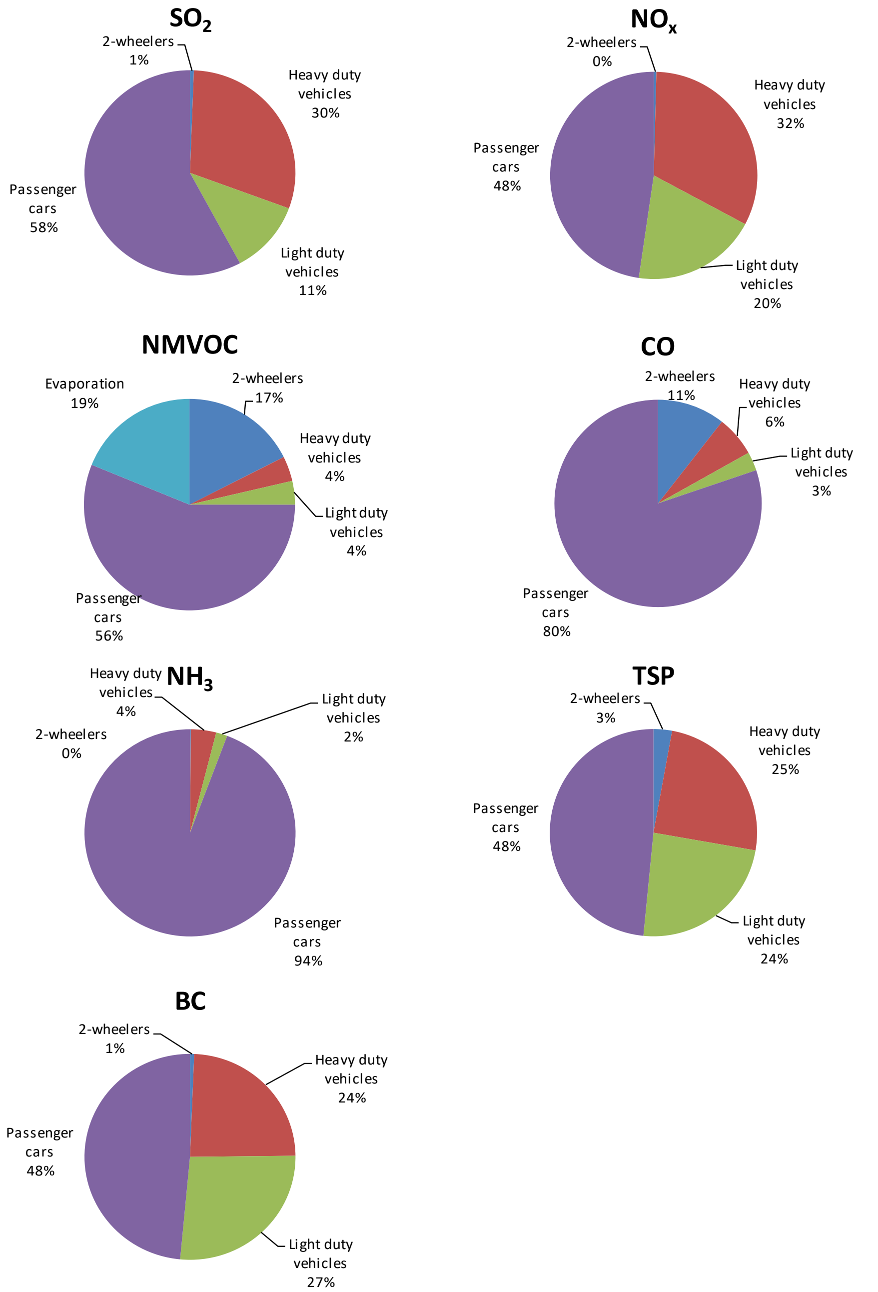


Figure 6.29 SO_2, NO_X, NMVOC, CO, NH_3, PM and BC emission shares per vehicle type for road transport in 2016.

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 2016 in NFR sectors. 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 types: 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 2016, followed by trucks, light-duty vehicles, buses and 2-wheelers.

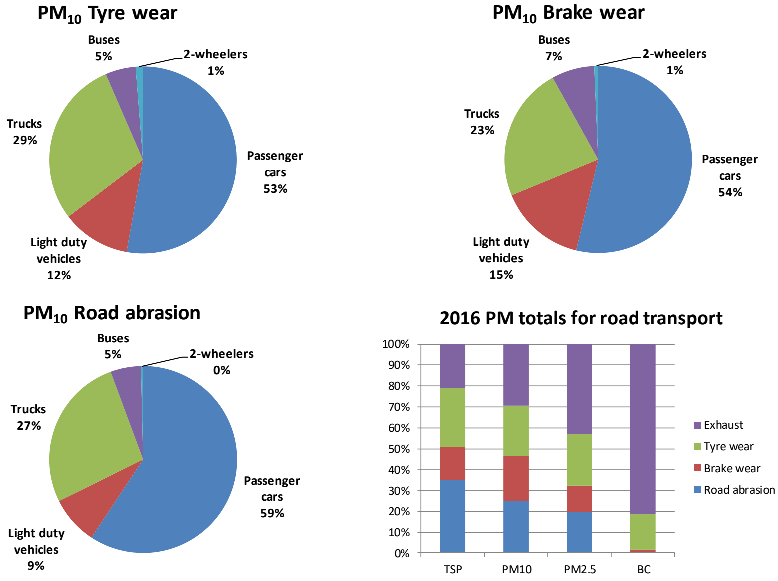


Figure 6.30 Brake and tyre wear and road abrasion PM_{10} emission shares and PM and BC exhaust/non-exhaust distributions for road traffic in 2016.

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 21, 29, 43 and 81 %, respectively, in 2016. For brake and tyre wear and road abrasion, the TSP shares are 15, 29 and 35 %, respectively. The same three sources have PM_{10} shares of 21, 24 and 25 %, respectively, $PM_{2.5}$ shares of 12, 25 and 20 %, and BC shares of 2, 17 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). 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.

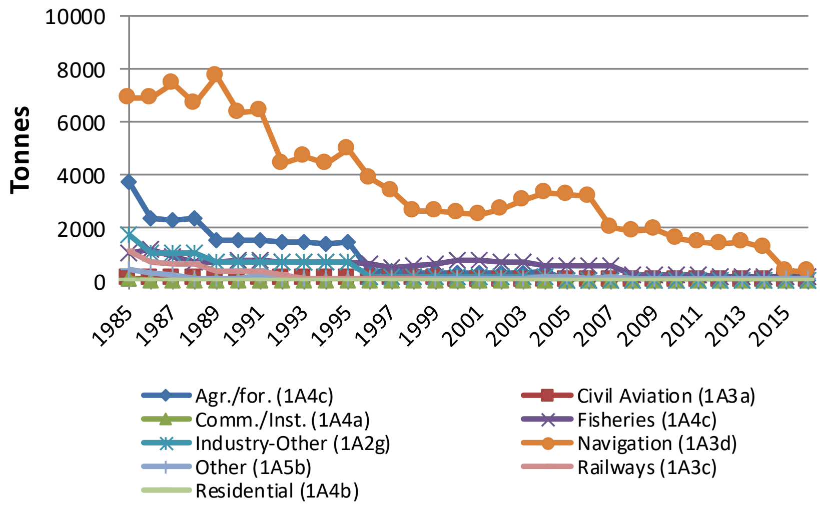


Figure 6.31 SO_2 emissions (ktonnes) in NFR sectors for other mobile sources 1985-2016.

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 Navigation (1A3d), Agriculture/forestry/fisheries (1A4c), Industry (1A2f) and Railways (1A3c), as shown in Figure 6.32. The 2016 emission shares are 40, 35, 13 and 6 %, respectively (Figure 6.38). Minor emissions come from the sectors Other (1A5), Civil Aviation (1A3a), Commercial/Institutional (1A4a) 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. From 2012, the high-speed ferry “Catexpress” entered into service on the two important Danish domestic ferry routes “Sjællands Odde-Ebeltoft” and “Sjællands Odde-Aarhus”. The ferry “Catexpress” has relatively high NOx emission factors and relatively low specific fuel consumption factors, this causes the implied NO_x emission factor to change. 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.

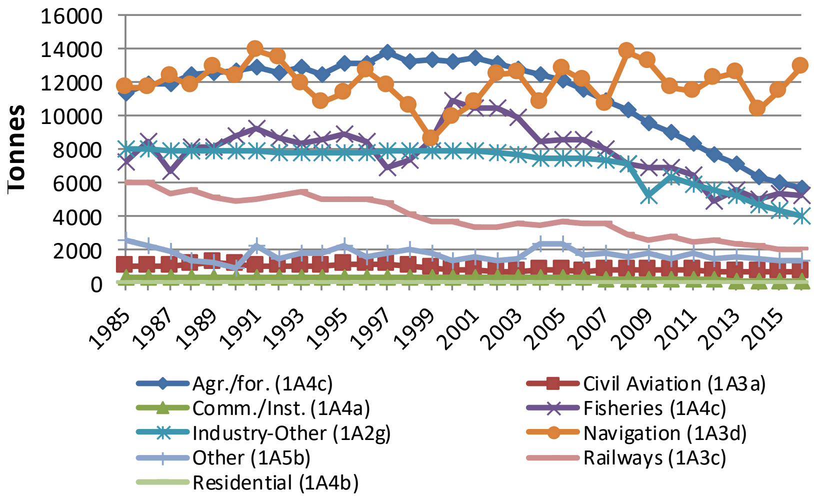


Figure 6.32 NO_X emissions (tonnes) in NFR sectors for other mobile sources 1985-2016.

The 1985-2016 time series of NMVOC and CO emissions are shown in Figures 6.33 and 6.34 for other mobile sources. The 2016 sector emission shares are shown in Figure 6.38. For NMVOC, the most important sectors are Agriculture/forestry/-fisheries (1A4c), Residential (1A4b), Industry (1A2g) and Commercial/Institutional (1A4a), with 2016 emission shares of 34, 19, 17 and 15 %, respectively. The same four sectors also contribute with most of the CO emissions. For Commercial/Institutional (1A4a), Agriculture/forestry/fisheries (1A4c) and Residential (1A4b) the emission shares are 47, 22 and 15 %, respectively. Minor NMVOC and CO emissions come from Navigation (1A3d), Railways (1A3c), Civil Aviation (1A3a) and Other (1A5).

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

As shown in Figure 6.38, for other mobile sources the largest TSP contributors in 2016 are Agriculture/forestry/fisheries (1A4c), Industry (1A2f) and Navigation (1A3d), with emission shares of 39 %, 25 % and 23 %, respectively. The remaining sectors: Railways (1A3c), Civil aviation (1A3a), Other (1A5), Commercial/Institutional (1A4a) and Residential (1A4b) represent only minor emission sources.

The 1985-2016 TSP emissions for navigation and fisheries are determined by the fuel consumption fluctuations in these years, and the development of the emission factors, which to a major extent is a function of the fuel type and fuel sulphur content. With fuel consumption being at a rather constant level for 1985-2016 (Figure 6.35), the emission development for Agriculture/forestry is mainly determined by the 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 decreasing fuel consumption from 2009 onwards (Figure 6.35), 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).

BC is calculated as shares of TSP for each engine emission technology class. In broad terms the development in BC emissions follows the TSP emission trend (Figure 6.36).

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 49 %, 26 %, 12 % and 10 %, respectively (Figure 6.37).

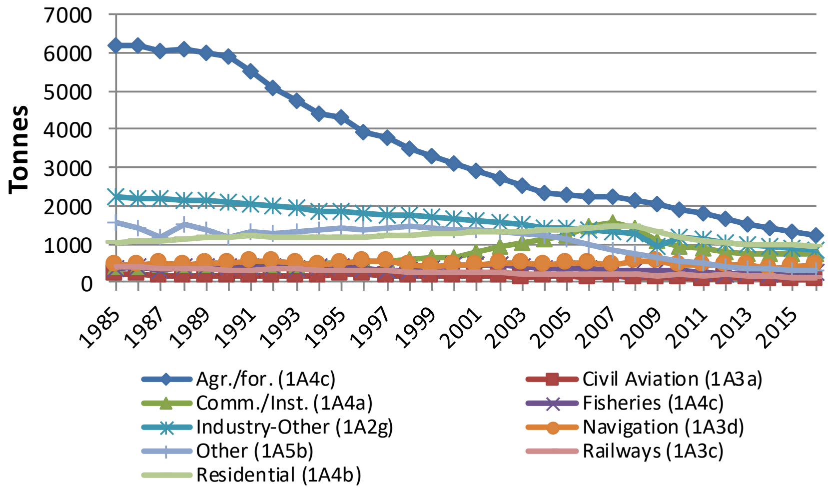


Figure 6.33 NMVOC emissions (tonnes) in NFR sectors for other mobile sources 1985-2016.

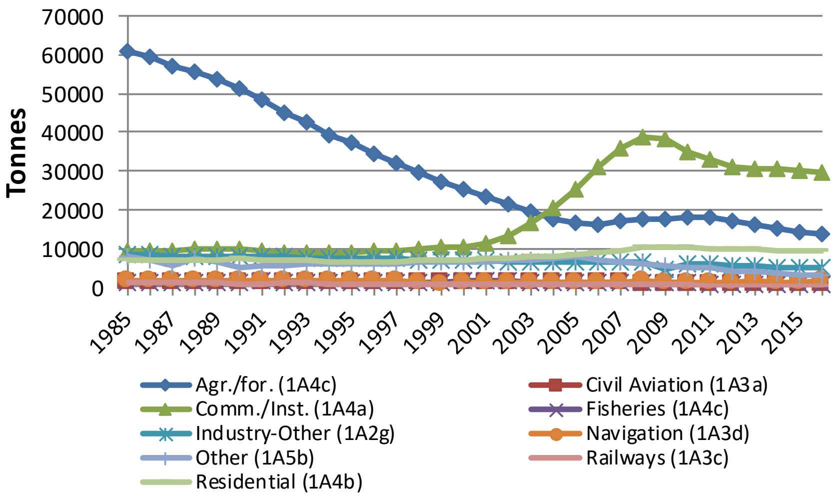


Figure 6.34 CO emissions (tonnes) in NFR sectors for other mobile sources 1985-2016.

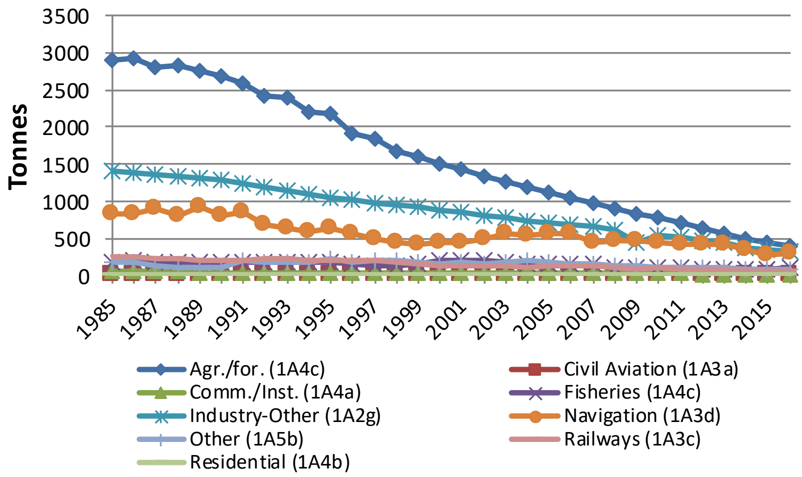


Figure 6.35 TSP emissions (tonnes) in NFR sectors for other mobile sources 1985-2016.

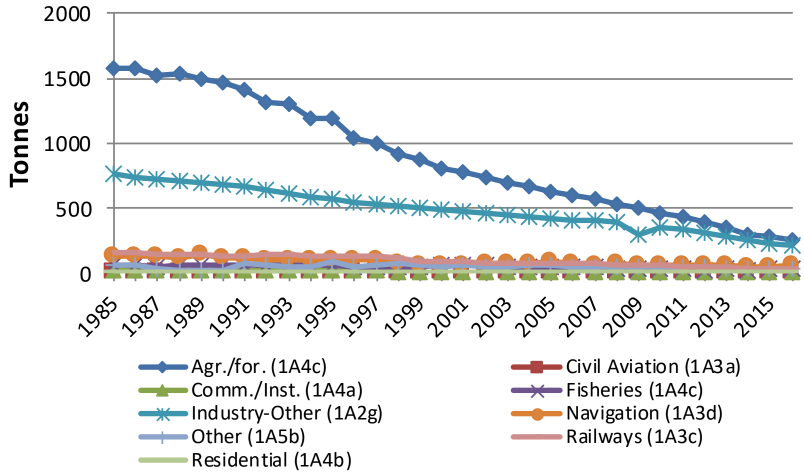


Figure 6.36 BC emissions (tonnes) in NFR sectors for other mobile sources 1985-2016.

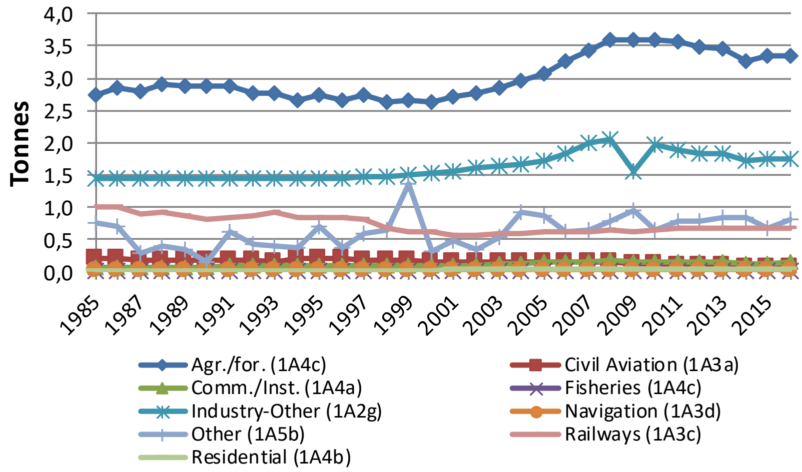


Figure 6.37 NH_3 emissions (tonnes) in NFR sectors for other mobile sources 1985-2016.

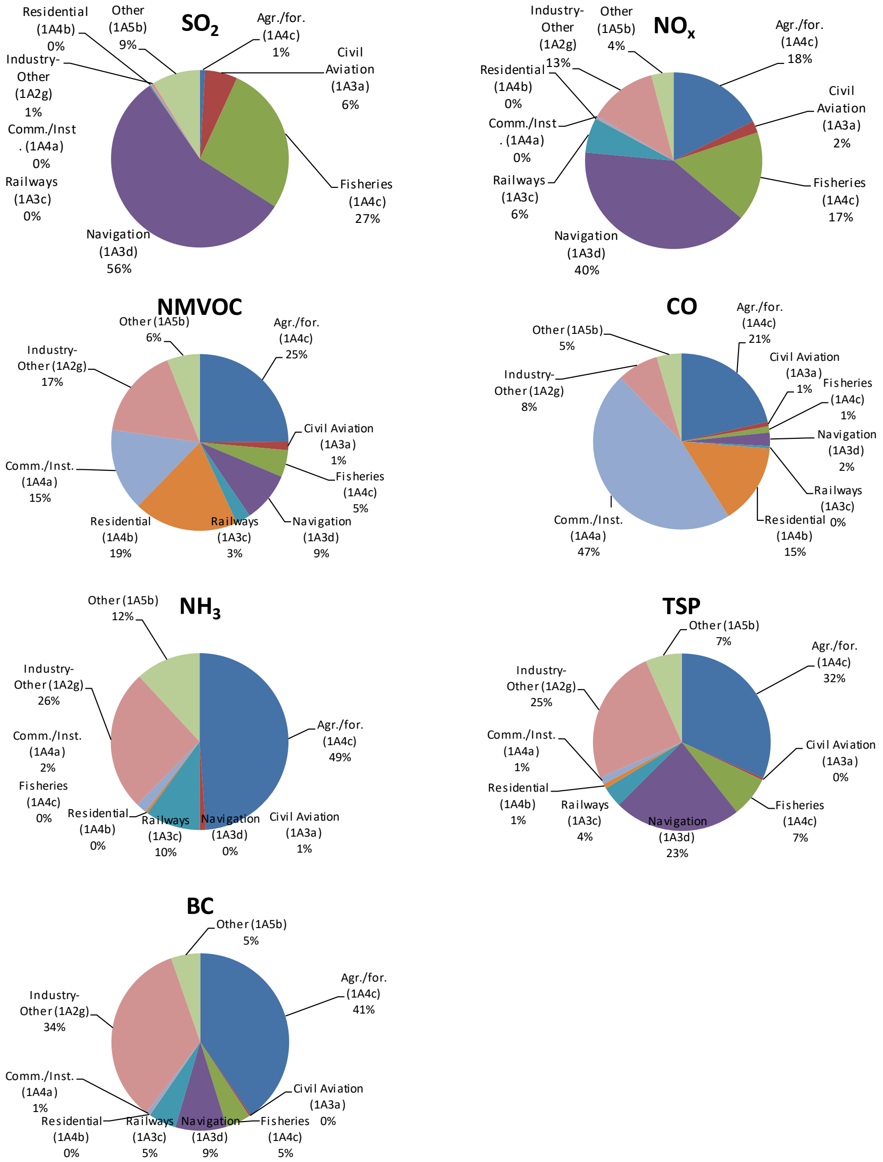


Figure 6.38 SO_2, NO_X, NMVOC, CO, NH_3, PM and BC emission shares per source category for other mobile sources in 2016.

6.4 Heavy metals

In Table 6.4, the heavy metal emissions for road transport and other mobile sources are shown for 2016 in NFR sectors. The emission figures in the time series 1990-2016 are given in Annex 16 (NFR format) and are shown for 1990 and 2016 in Annex 15 (CollectER format).

Table 6.4 Heavy metal emissions in 2016 for road transport and other mobile sources.

	Arsenic	Cadmium	Chromium	Copper	Mercury	Nickel	Lead	Selenium	Zinc
	kg	kg	kg	kg	kg	kg	kg	kg	kg
Manufacturing industries/Construction (mobile)	0	2	6	4	1	2	10	0	337
Civil aviation (Domestic)	0	0	0	0	0	0	635	0	2
Road transport: Passenger cars	0	30	64	91	15	32	131	0	5 963
Road transport:Light duty vehicles	0	4	13	10	2	4	24	0	817
Road transport:Heavy duty vehicles	0	7	27	19	6	7	43	0	1 447
Road transport: Mopeds & motorcycles	0	0	0	0	0	0	0	0	21
Road transport: Gasoline evaporation	0	0	0	0	0	0	0	0	0
Road transport: Brake wear	5	0	61	39 629	0	58	5 112	10	8 601
Road transport: Tyre wear	1	0	3	15	0	25	78	19	10 616
Road transport: Road abrasion	0	0	24	12	0	19	56	0	90
Railways	0	1	2	2	0	1	4	0	128
National navigation (Shipping)	27	3	14	27	9	1 166	24	48	117
Commercial/Institutional: Mobile	0	0	0	1	0	0	1	0	54
Residential: Household and gardening (mobile)	0	0	0	0	0	0	0	0	17
Agriculture/Forestry/Fishing: Off-road agriculture/forestry	0	3	9	7	2	3	16	0	544
Agriculture/Forestry/Fishing: National fishing	5	1	4	5	5	7	10	20	49
Other, Mobile	0	0	1	1	0	0	18	0	89
Road transport exhaust total	1	41	105	121	24	44	198	0	8 248
Road transport non exhaust total	6	0	88	39 656	0	102	5 247	30	19 308
Other mobile sources total	32	10	37	48	18	1 179	717	68	1 337
Domestic total	39	51	230	39 825	42	1 325	6 163	98	28 893
Civil aviation (International)	0	0	0	0	0	0	9	0	0
Navigation (International)	129	10	60	129	24	6 581	83	167	395

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.

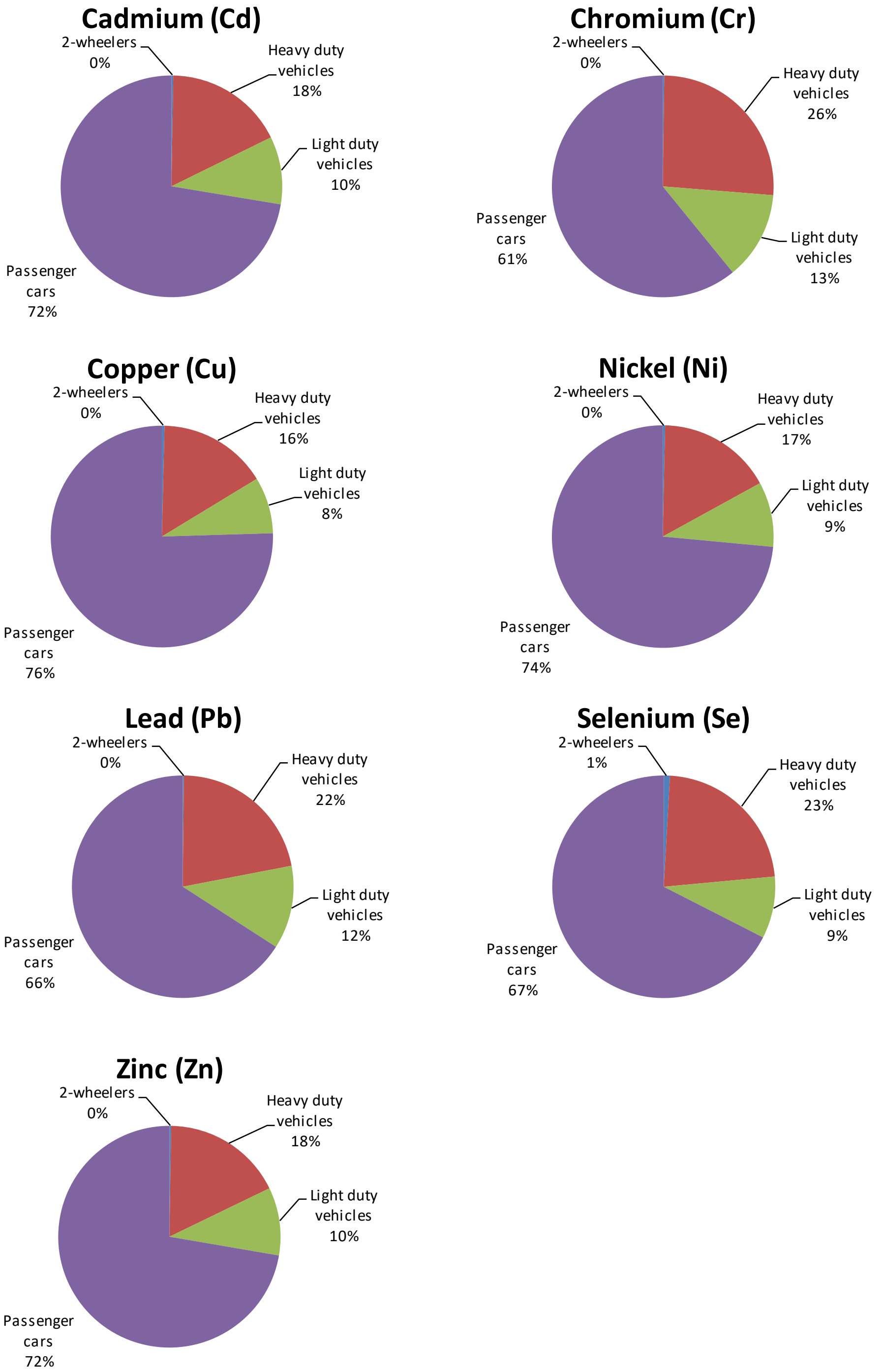


Figure 6.39 Heavy metal emission shares for road transport in 2016.

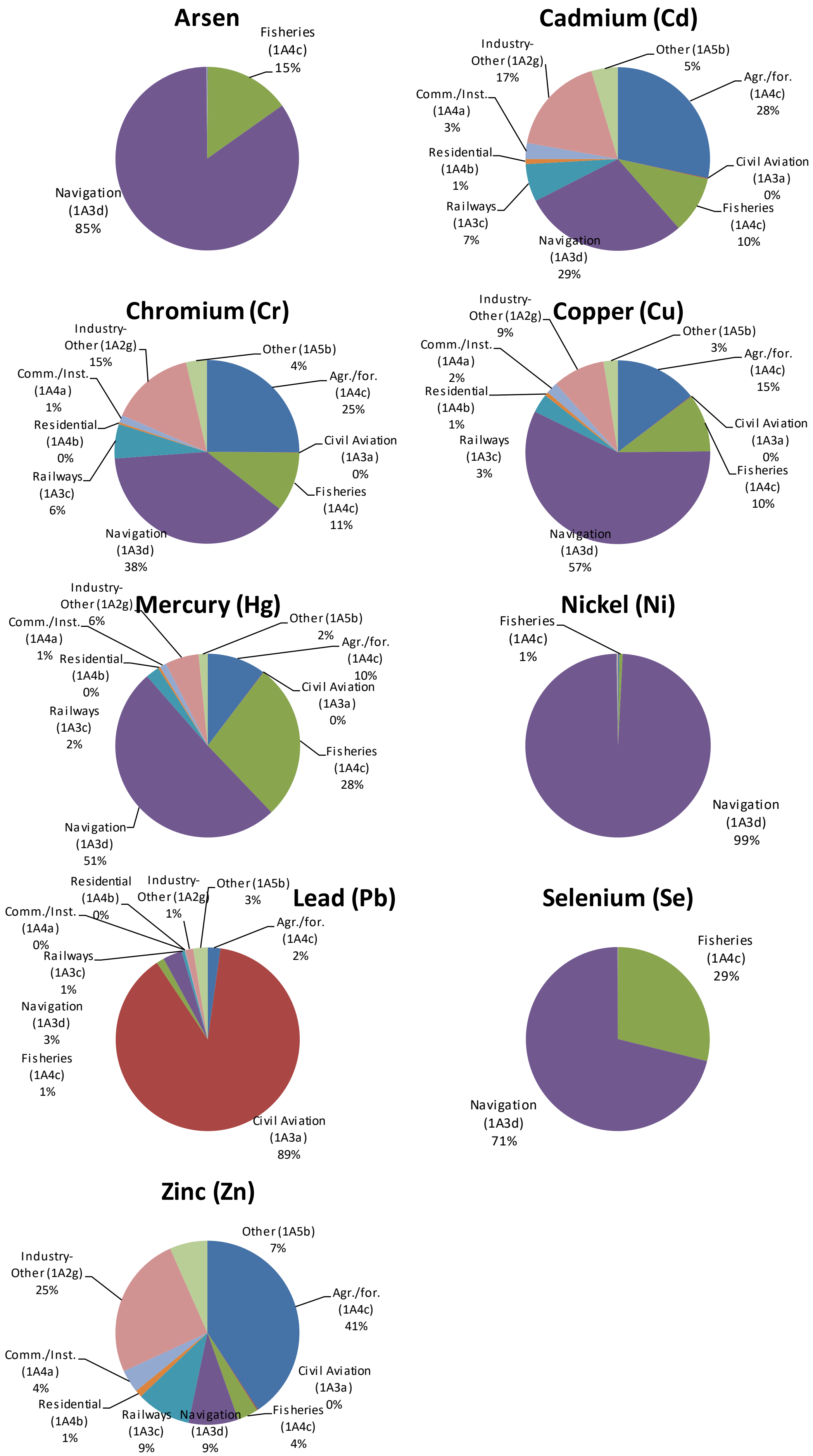


Figure 6.40 Heavy metal emission shares for other mobile sources in 2016.

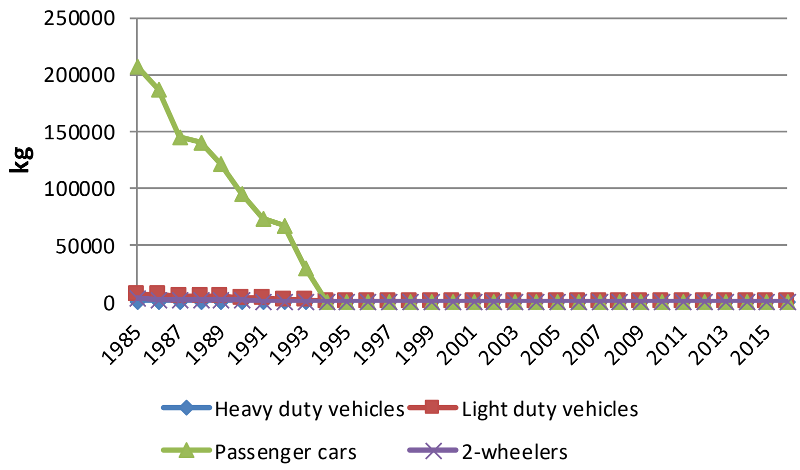


Figure 6.41 Pb emissions (kg) per vehicle type for road transport 1985-2016.

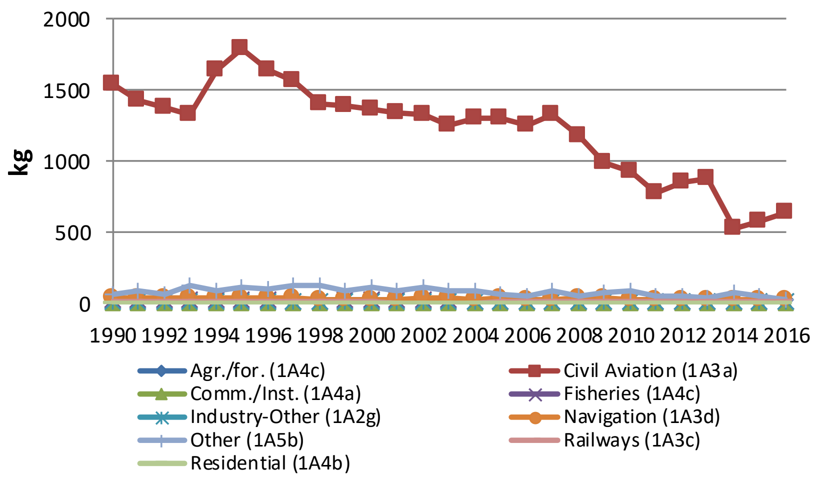


Figure 6.42 Pb emissions (kg) in NFR sectors for other mobile sources 1990-2016.

6.5 Persistent organic pollutants

In Table 6.5, the emissions of persistent organic pollutants (POPs), i.e. dioxins, PAHs, HCB and PCBs for road transport and other mobile sources are shown for 2016 in NFR sectors. The emission figures in the time series 1990-2016 are given in Annex 16 (NFR format) and are shown for 1990 and 2016 in Annex 15 (CollectER format).

Table 6.5 Dioxin, PAH, HCB and PCB emissions in 2016 for road transport and other mobile sources.

	HCB	Dioxins/Furans	Benzo(b) flouranthene	Benzo(k) flouranthene	Benzo(a) pyrene	Indeno (1,2,3-c,d) pyrene	PCBs
	g	g	kg	kg	kg	kg	g
Manufacturing industries/Construction (mobile)	0.050	0.007	4	4	2	2	4
Civil aviation (Domestic)	0.000	0.000	0	0	0	0	0
Road transport: Passenger cars	0.273	0.047	53	41	47	46	1
Road transport:Light duty vehicles	0.115	0.010	13	10	11	11	0
Road transport:Heavy duty vehicles	0.313	0.055	27	31	5	7	27
Road transport: Mopeds & motorcycles	0.000	0.015	0	0	0	0	0
Road transport: Gasoline evaporation	0.000	0.000	0	0	0	0	0
Road transport: Brake wear	0.000	0.000	0	0	0	0	0
Road transport: Tyre wear	0.000	0.000	0	0	0	0	0
Road transport: Road abrasion	0.000	0.000	0	0	0	0	0
Railways	0.021	0.002	1	1	0	0	2
National navigation (Shipping)	0.019	0.105	5	2	1	8	0
Commercial/Institutional: Mobile	0.002	0.005	0	0	0	0	0
Residential: Household and gardening (mobile)	0.000	0.002	0	0	0	0	0
Agriculture/Forestry/Fishing: Off-road agriculture/forestry	0.086	0.012	7	7	4	4	7
Agriculture/Forestry/Fishing: National fishing	0.008	0.050	3	1	1	5	0
Other, Mobile	0.011	0.003	1	1	0	1	1
Road transport exhaust total	0.701	0.127	93	81	63	64	28
Road transport non exhaust total	0.000	0.000	0	0	0	0	0
Other mobile sources total	0.197	0.186	22	17	8	21	14
Domestic total	0.898	0.313	115	98	71	85	43
Civil aviation (International)	0.000	0.000	0	0	0	0	0
Navigation (International)	0.064	0.323	13	6	3	22	0

For mobile sources, road transport displays the largest emission of dioxins and PAHs. The dioxin emission share for road transport is 40 % of all mobile emissions in 2016, whereas Navigation and Agriculture/forestry-/fisheries have smaller shares of 34 and 20 %. 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.

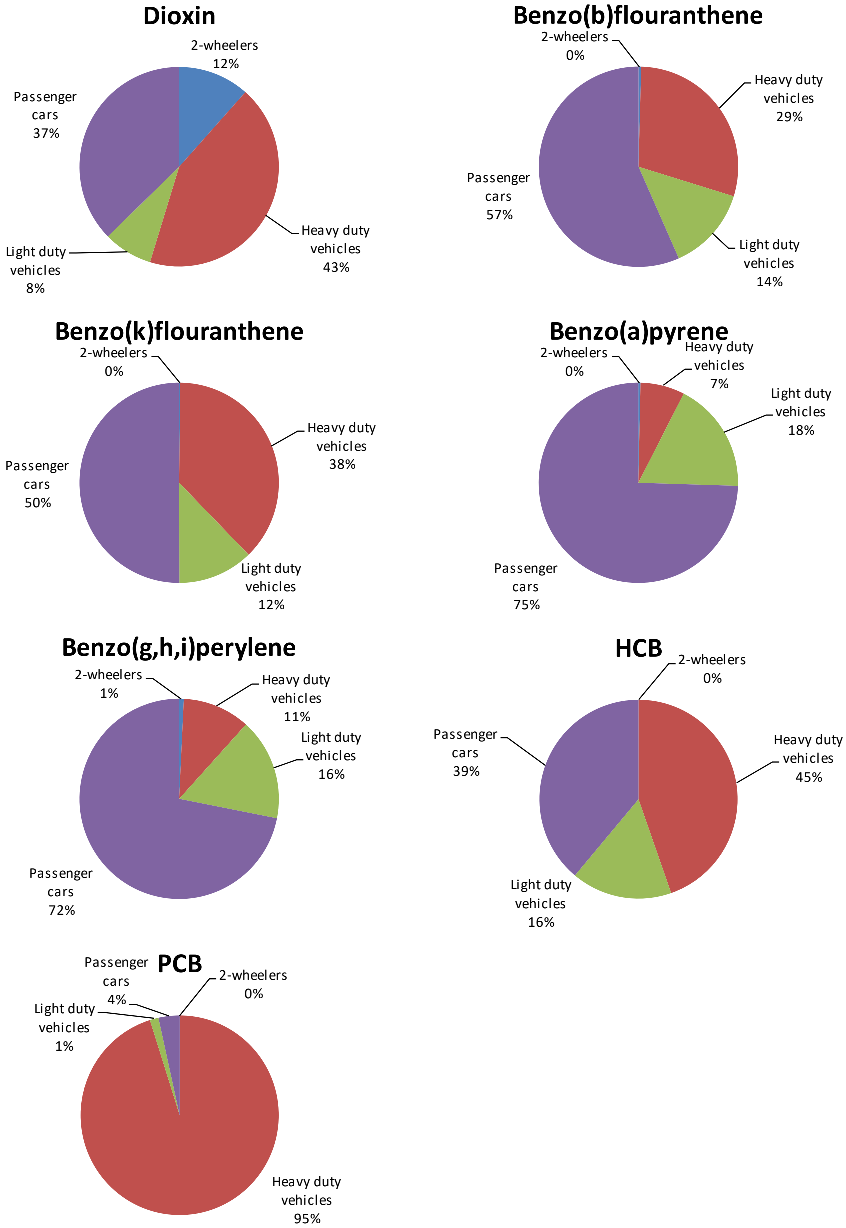


Figure 6.43 Dioxin, PAH, HCB and PCB emission shares for road transport in 2016.

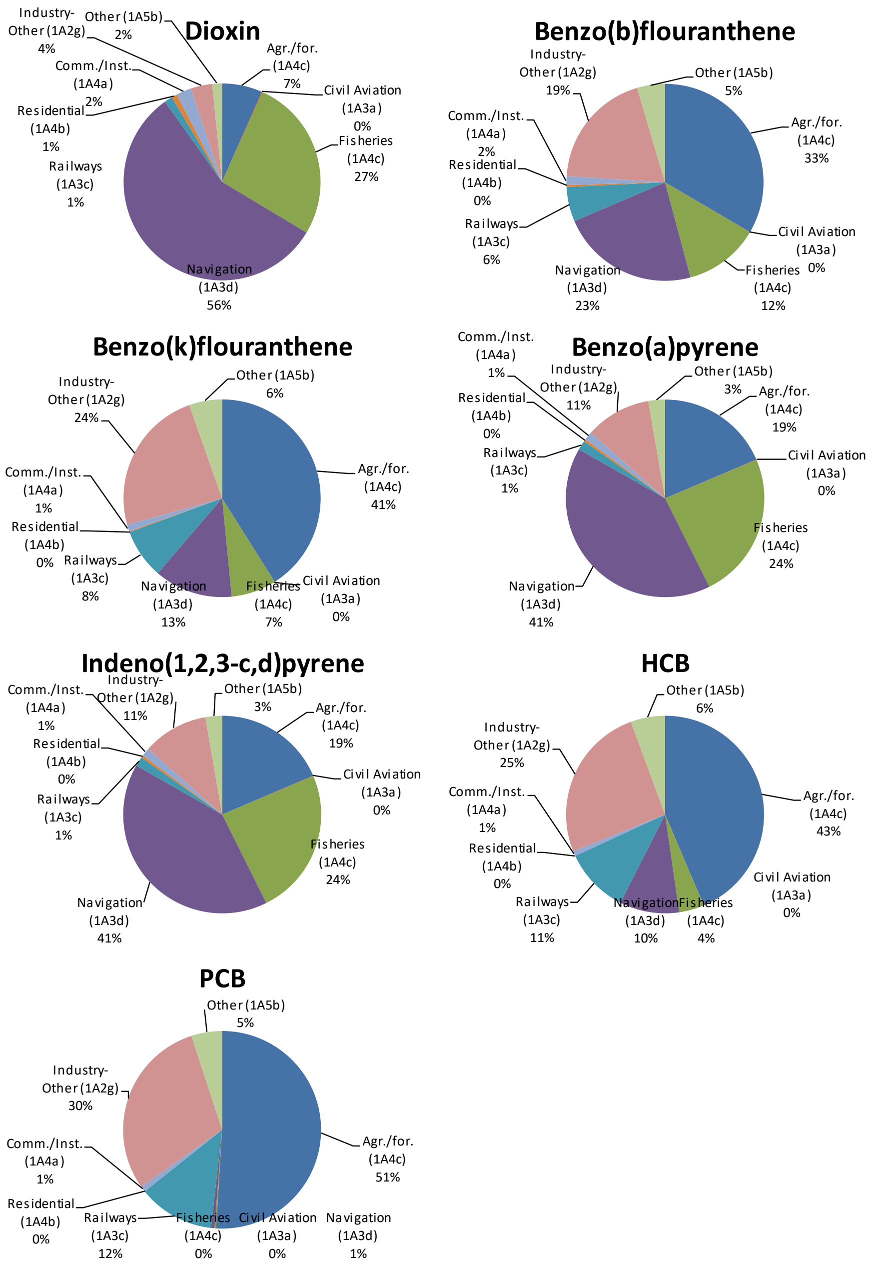


Figure 6.44 Dioxin, PAH, HCB and PCB emission shares for other mobile sources in 2016.

6.6 International transport

6.6.1 Emissions of CO_2, CH_4 and N_2O

In terms of greenhouse gas emissions, the level of emissions from Danish international transport are 31 %, 9 % and 25 %, respectively, for CO_2, CH_4 and N_2O, compared with the emission total for mobile sources.

The international transport emission totals of CO_2, CH_4 and N_2O are shown in Table 6.3 for 2016, split into sea transport and civil aviation. All emission figures in the 1990-2016 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 2016.

The differences in CH_4 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.

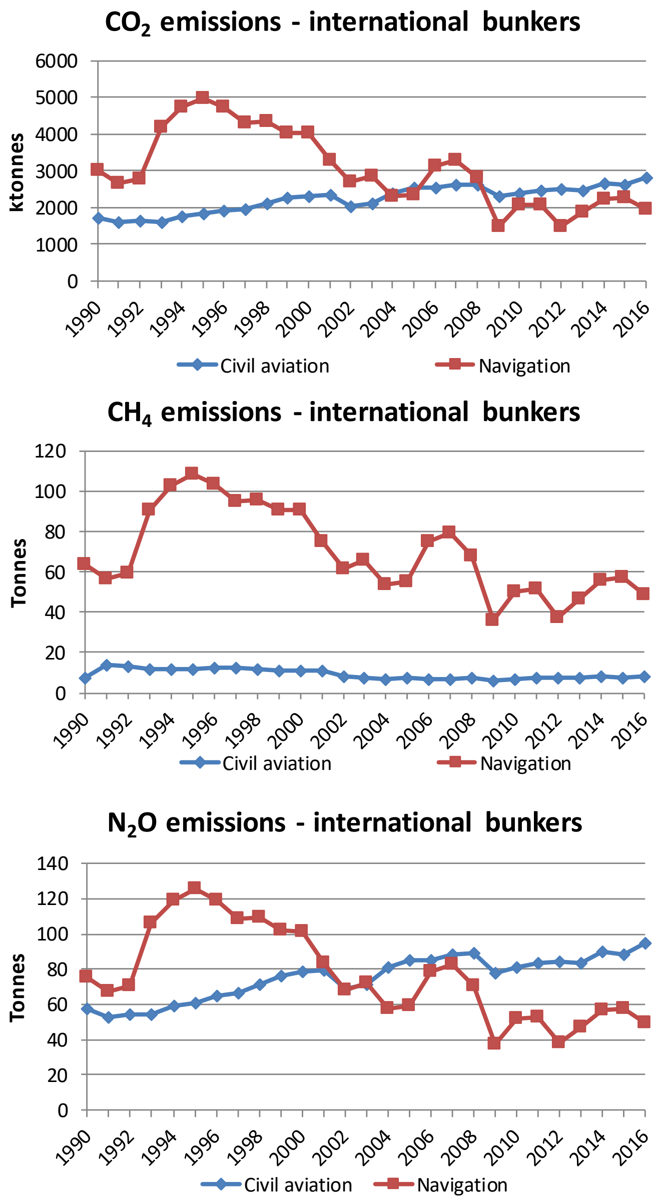


Figure 6.45 CO_2, CH_4 and N_2O emissions for international transport 1990-2016.

6.6.2 Emissions of SO_2, NO_x, TSP and BC

The most important emissions 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 international transport emission totals are shown in Table 6.3 for 2016, split into sea transport and civil aviation. All emission figures in the 1985-2016 time series are given in Annex 16 (NFR format). In Annex 15, the emissions are also given in CollectER format for 2016.

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).

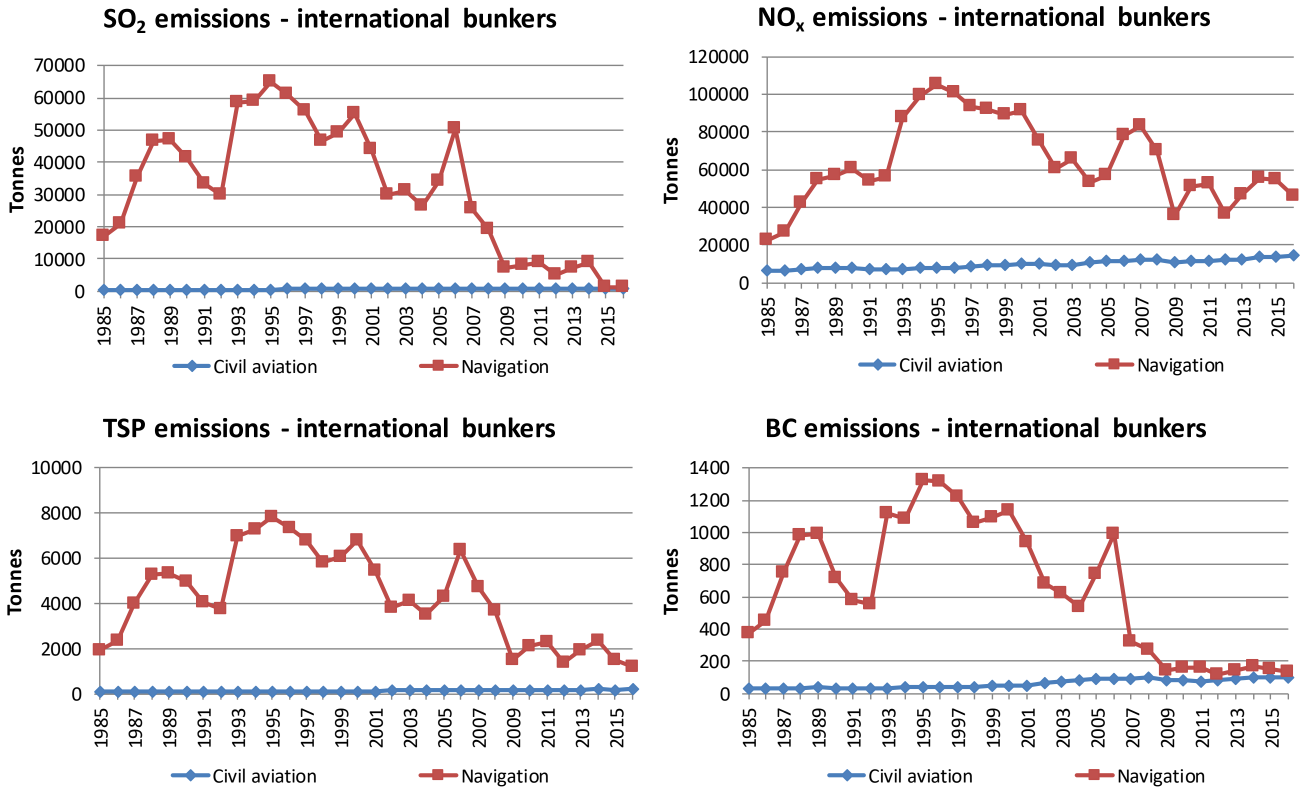


Figure 6.46 SO_2, NO_x, TSP and BC emissions for international transport 1985-2016.

7 Uncertainties

Tier 1 uncertainty estimates for greenhouse gases, are made for road transport and other mobile sources using the guidelines formulated in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). 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 for all emission components.

Table7.1 Tier 1 uncertainties for activity data, emission factors and total emissions in 2016 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 2016		4.9	33.5	119.5
Trend uncertainty 1990-2016		4.9	7.0	50.4

As regards time series consistency, background flight data cannot be made available on a city-pair level prior to 2000. However, aided by LTO/aircraft statistics for these years and the use of proper assumptions, a good level of consistency is in any case obtained for this part of the transport inventory.

The time series of emissions for mobile machinery in the agriculture, forestry, industry, household and gardening (residential) and inland waterways (part of navigation) sectors are less certain than time series for other sectors, since DEA statistical figures do not explicitly provide fuel consumption information for working equipment and machinery.

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, 2016). 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 7.2 Uncertainties for activity data, emission factors and total emissions in 2016 and as a trend for emission components reported to UNECE LRTAP.

Pollutant	Emission factor uncertainties [%] Road	Emission factor uncertainties [%] Other	Emission uncertainties [%] Overall 2016	Emission uncertainties [%] Trend 1990-2016
SO_2	50	50	47	1
NO_x	50	100	55	9
NMVOC	50	100	50	4
CO	50	100	55	9
NH_3	1000	1000	993	1168
TSP	50	100	46	8
PM_{10}	50	100	48	5
$PM_{2.5}$	50	100	52	3
BC	50	100	55	3
Arsenic	1000	1000	847	75
Cadmium	1000	1000	850	207
Chromium	1000	1000	853	254
Copper	1000	1000	999	5
Mercury	1000	1000	715	117
Nickel	1000	1000	897	43
Lead	1000	1000	890	8
Selenium	1000	1000	757	158
Zinc	1000	1000	955	55
Dioxins	1000	1000	720	145
Flouranthene	1000	1000	833	224
Benzo(b) flouranthene	1000	1000	845	330
Benzo(k) flouranthene	1000	1000	891	333
Benzo(a) pyrene	1000	1000	796	179
Benzo(g,h,i) perylene	1000	1000	811	311
indeno(1,2,3-c,d) pyrene	1000	1000	743	98
HCB	1000	1000	47	1
PCB	1000	1000	55	9

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DANISH EMISSION INVENTORIES FOR ROAD TRANSPORT AND OTHER MOBILE SOURCES

Inventories until the year 2016

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, NOx, NMVOC, CO, particulate matter (PM), BC, heavy metals, dioxins, HCB, PCBs and PAHs. From 1990-2016 the fuel consumption and CO_2 emissions for road transport increased by 33 and 26 %, respectively, and CH_4 emissions have decreased by 83 %. A N_2O emission increase of 46 % is related to the relatively high emissions from older gasoline catalyst cars. The 1985-2016 emission decrease for NMVOC, CO, particulates (exhaust only: Size is below $PM_{2.5}$) NOx and BC are 90, 88, 78, 63, 70 %, 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 1453 % (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 -16, -56 and -4 %, from 1990 to 2016. The emissions of SO_2, particulates (all size fractions), BC, NMVOC, NOx and CO decreased by 95, 78, 78, 61, 34 and 36 % from 1985 to 2016. For NH_3 the emissions increased by 9 % in the same time period. Uncertainties for the emissions and trends were estimated.

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