DANISH EMISSION INVENTORIES FOR ROAD TRANSPORT AND OTHER MOBILE SOURCES

Inventories until 2022

Scientific Report from DCE – Danish Centre for Environment and Energy

no. 624 2024

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Data sheet

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Abstract: This report explains the parts of the Danish emission inventories related to road transport and other mobile sources. Emission results are shown for CO_2, CH_4, N_2O, SO_2, NO_x, NMVOC, CO, particulate matter (PM), BC, heavy metals, dioxins, HCB, PCBs and PAHs. From 1990-2022 the fuel consumption and CO_2 emissions for road transport increased by 26 and 19 %, respectively, and CH_4 emissions have decreased by 91 %. A N_2O emission increase of 44 % is related to the relatively high emissions from older gasoline catalyst cars. The 1985-2022 emission decrease for NO_x, NMVOC, CO, particulates (exhaust only: Size is below $PM_{2.5}$) and BC are 78, 93, 92, 94 and 93 %, respectively, due to the introduction of vehicles complying with gradually stricter emission standards. For SO_2 the emissions drop 99 % (due to reduced sulphur content in the diesel fuel), whereas the NH_3 emissions increased by 1001 % (due to the introduction of catalyst cars). For other mobile sources the calculated fuel consumption and emission changes for CO_2, CH_4 and N_2O were -14, -14, -69 and +3 %, from 1990 to 2022. The emissions of SO_2, NO_X, NMVOC, CO, PM (all size fractions) and BC decreased by 96, 47, 65, 35, 80 and 83 %, respectively, from 1985 to 2022. For NH_3 the emissions increased by 18 % in the same 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 Gender Equality in Denmark and the Danish Ministry of Climate, Energy and Utilities, 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 1990-2022 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 1985-2022, and for heavy metals, dioxins, HCB (hexachlorobenzene), PCBs (polychlorinated biphenyls) and PAHs (poly-aromatic hydrocarbons) emission results are shown from 1990-2022, 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 (hexachlorobenzene), 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 0.1 Mobile sources and CRF/NFR codes.

SNAP classification	CRF/NFR classification
0701 Road traffic: Passenger cars	1A3bi Road transport: Passenger cars
0702 Road traffic: Light duty vehicles	1A3bii Road transport: Light duty vehicles
0703 Road traffic: Heavy duty vehicles	1A3biii Road transport: Heavy duty vehicles
0704/0705 Road traffic: Mopeds and motorcycles	1A3biv Road transport: Mopeds & motorcycles
0706 Road traffic: Evaporation	1A3bv Road transport: Evaporation
0707 Road traffic: Brake and tire wear	1A3bvi Road transport: Brake and tire wear
0708 Road traffic: Road abrasion	1A3bvii Road transport: Road abrasion
0801 Military	1A5b Other, Mobile
0802 Railways	1A3c Railways
080204 Train contact wire wear	1A3c Railways
080205 Wheel and rail wear	1A3c Railways
080206 Brake wear	1A3c Railways
0803 Inland waterways	1A5b Other, Mobile
080402 National sea traffic	1A3dii National navigation (Shipping)
080403 National fishing	1A4ciii Agriculture/Forestry/Fishing: National fishing
080404 International sea traffic	1A3di (i) International navigation (Shipping)
080501 Dom. airport traffic (LTO < 1000 m)	1A3aii (i) Civil aviation (Domestic, LTO
080502 Int. airport traffic (LTO < 1000 m)	1A3ai (i) Civil aviation (International, LTO)
080503 Dom. cruise traffic (> 1000 m)	1A3aii (ii) Civil aviation (Domestic, Cruise)
080504 Int. cruise traffic (> 1000 m)	1A3ai (ii) Civil aviation (International, Cruise)
080505 Dom. airport traffic (tyre and brake wear)	1A3aii (i) Civil aviation (Domestic, LTO)
080506 Int. airport traffic (tyre and brake wear)	1A3ai (i) Civil aviation (International, LTO)
0806 Agriculture	1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry
0807 Forestry	1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry
0808 Industry	1A2gvii Manufacturing industries/Construction (mobile)
0809 Household and gardening	1A4bii Residential: Household and gardening (mobile)
0811 Commercial and institutional	1A4aii Commercial/Institutional: Mobile

Methodologies

The Danish emission inventories for mobile sources are calculated with the DEMOS (Danish Emission model system for Mobile Sources) model developed at DCE, Aarhus University. The DEMOS model system comprises database models for road transport (DEMOS-Road), aviation (DEMOS-Aviation), navigation (DEMOS-Navigation), railways (DEMOS-Rail) and non-road mobile machinery (DEMOS-NRMM).

DEMOS-Road is structured like the European COPERT 5 (COmputer Programme to calculate the Emissions from Road Transport) methodology. The road transport emissions are calculated for operationally hot engines, cold start and fuel evaporation. The calculations also include 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.

For aviation 2001 onwards, the emission estimates are made for each flight, using flight data from the Danish Civil Aviation and Railway Authority and landing/take off (LTO) and distance related emission factors from the EMEP/EEA guidebook. For previous years, air traffic data consist of LTO/aircraft type statistics from Copenhagen Airport and total LTO numbers from the Danish Civil Aviation and Railway 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 in DEMOS-Navigation 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.

For fishing vessels, log data is used as inventory input activity data in DEMOS-Navigation. The log data consist of vessel registration number, build year, type, overall vessel length, gross tonnage, total installed engine power and hours at sea, for each fishing trip made by Danish registered fishing vessels from 1985-2022. The emissions are calculated for each fishing trip as a product of hours at sea, vessel engine size, engine load factor and fuel consumption/emission factor.

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 Other. 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 and railways, 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, aviation and fisheries, 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 in DEMOS-Navigation. The difference between fuel sales statistics for national sea transport and model 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 2022, the emission percentages were 24, 37, 24, 17, 11, 10, 4 and 4 %, respectively. The emissions of NH_3, N_2O, CH_4 and SO_2 have marginal shares of 0.9, 2.2, 0.1 and 0.9 %, respectively.

From 1990 to 2022, the calculated fuel consumption and emission changes for CO_2, CH_4 and N_2O are 26, 19, -91 and 44 %. The calculated 1985-2022 fuel consumption and emission changes for NO_x, NMVOC, CO, particulates (exhaust only: Size is below $PM_{2.5}$) and BC are 43, -78, -93, -92, -94 and -93 %.

The most significant emission changes from 1985 to 2022 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 1001 % (due to the introduction of catalyst cars).

Table 0.2 Emissions (tonnes[a]) from road transport in 2022, changes from 1985 (1990[b]) to 2022, and 2022 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	37	10369	2016	180	34367	5873	126	593	74	74	74	46
Road transport:Light duty vehicles	10	6854	180	6	1626	1527	45	49	49	49	49	37
Road transport:Heavy duty vehicles	23	3499	155	43	1627	3668	248	45	51	51	51	28
Road transport: Mopeds & motorcycles	0	115	749	67	5712	68	1	1	12	12	12	2
Road transport: Gasoline evaporation	0	0	1339	0	0	0	0	0	0	0	0	0
Road transport: Brake wear	0	0	0	0	0	0	0	0	673	660	263	18
Road transport: Tyre wear	0	0	0	0	0	0	0	0	954	573	401	146
Road transport: Road abrasion	0	0	0	0	0	0	0	0	1213	607	328	0
Road transport exhaust total	70	20837	4438	296	43331	11135	420	688	186	186	186	112
Road transport non exhaust total	0	0	0	0	0	0	0	0	2841	1839	991	164
Road transport total	70	20837	4438	296	43331	11135	420	688	3027	2025	1177	276
National total	8128	86825	119109	318430	179892	29719	19191	73328	81825	21428	11221	1606
Road- % of national total, 2022	0,9	24	3,7	0,1	24	37	2,2	0,9	3,7	9,5	10,5	17
Road- % change 1985-2022	-99	-78	-93	-91	-92	19	44	1001	-94	-94	-94	-93

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 2022, the most important CO_2 emission source for road transport is passenger cars (53 %), followed by heavy-duty vehicles (33 %), light-duty vehicles (14 %) and 2-wheelers (0 %). For CH_4 the 2022 emission shares were 61, 23, 14 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 59, 30 and 11 %, respectively.

For 2022, the following emission shares for passenger cars, heavy-duty vehicles, light-duty vehicles and 2-wheelers (percentage shares in brackets) are calculated for for NO_x (50, 33, 17 and 0 %), NMVOC (exhaust: 45, 4, 4 and 17 %), CO (79, 4, 4 and 13 %), PM (40, 28, 26 and 6 %), BC (32, 49, 19 and 0 %), and NH_3 (86, 7, 7 and 0 %).

Set in relation to total road transport emissions in 2022, the non-exhaust emission shares of TSP, PM_{10}, $PM_{2.5}$ and BC were 94, 91, 84 and 59 %, respectively, related to tyre and brake wear and road abrasion.

Emissions from other mobile sources

For other mobile sources, the emissions of NO_x, CO, BC and CO_2 have the largest shares of the national totals in 2022. The shares are 25, 33, 18 and 10 %, respectively. The 2022 SO_2, NMVOC, TSP, PM_{10} and $PM_{2.5}$ emission shares are 7, 3, 1, 5 and 9 %, respectively, whereas the emissions of N_2O, NH_3 and CH_4 have marginal shares of around 1 % or less in 2022.

From 1990 to 2022, the total fuel consumption and the emissions of CO_2, CH_4, and N_2O have changed by -14, -14, -69 and +3 %, respectively. From 1985 to 2022, the calculated emission changes for SO_2, NO_x, NMVOC, CO, PM (exhaust only, all size fractions) and BC are -96, -47, -65, -35, -80 and -83 %, respectively. For NH_3 the emissions increased by 18 % in the same period.

Table 0.3 Emissions from other mobile sources in 2022 (tonnes[a]), changes from 1985 (1990[b]) to 2022, and 2022 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
Manufacturing industries/Construction (mobile)	4	1852	610	20	10320	648	30	2	122	122	122	82
Civil aviation (Domestic)	38	511	13	1	280	118	6	0	4	4	4	2
Civil Aviation (Domestic): Tyre and brake wear	0	0	0	0	0	0	0	0	1	0	0	0
Railways	1	846	48	2	149	154	5	0	8	8	8	5
Railways: Train brake wear	0	0	0	0	0	0	0	0	112	112	56	0
Railways: Train contact wire wear	0	0	0	0	0	0	0	0	3	3	1	0
Railways: Train wheel and rail wear	0	0	0	0	0	0	0	0	251	251	126	0
National navigation (Shipping)	185	8852	412	9	885	495	12	0	253	251	249	25
Commercial/Institutional: Mobile	1	448	741	31	27308	175	7	0	36	36	36	16
Residential: Mobile	0	32	819	19	11388	26	0	0	16	16	16	1
Agriculture/Forestry: Off-road	4	2115	632	41	5766	684	33	2	186	186	186	108
National fishing	238	5723	283	6	781	376	9	0	107	106	106	22
Other, Mobile	66	1013	244	8	2880	185	7	1	51	51	51	19
Other mobile exhaust total	536	21392	3802	137	59756	2861	109	5	783	780	778	281
Other mobile non exhaust total	0	0	0	0	0	0	0	0	367	366	183	0
Other mobile total	536	21392	3802	137	59756	2861	109	5	1150	1146	961	281
National total	8128	86825	119109	318430	179892	29719	19191	73328	81825	21428	11221	1606
Other mobile- % of national total, 2022	6,6	24,6	3,2	0,0	33,2	9,6	0,6	0,0	1,4	5,3	8,6	17,5
Other mobile- % change 1985-2022	-96	-47	-65	-69	-35	-14	3	18	-80	-80	-80	-83

[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 is national navigation, followed by Fisheries and Agriculture/Forestry. For CO_2, the largest emission sources are Agriculture/Forestry, Industry and National navigation, in this consecutive order.

For PM (all size fractions), the largest emission sources are Railways, National Navigation and Agriculture/Forestry. For BC, Agriculture/Forestry, Industry and National Navigation are the most important emission sources. For NMVOC and CO most of the emissions come from gasoline fuelled working machinery in the Commercial/Institutional, Residential, Agriculture/Forestry and Industry sectors.

Heavy metals

Heavy metal emissions are calculated for fuel and engine oil as well as for tyre, brake and road wear, and train contact wire, wheel and rail wear.

The road transport shares for copper (Cu), zinc (Zn), lead (Pb), chromium (Cr) and cadmium (Cd) are 89, 51, 56, 8 and 8 % of national totals in 2022. For other mobile sources, the nickel (Ni), chromium (Cr), selenium (Se) and arsenic (As) shares are 68, 44, 14 and 12 %. 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 (7.0 %), Cr (3.8 %) and Hg (8.8 %). The most important non-exhaust emissions are Cu (89 %) and Pb (55 %) almost solely coming from tyre wear, and Zn (37 %) from brake and tyre wear.

The most important exhaust related emissions (fuel and engine oil) for other mobile sources (percent of national total in brackets) are Ni (25 %), Se (14 %), and As (12 %). These emissions arise from the use of marine diesel oil and residual oil in fisheries and navigation. The most important non-exhaust emissions are Ni (44 %), Cr (43 %) and Cu (5 %). Train brake wear is the primary source of Ni and Cr, and Cu emissions almost solely stem from the wear of train contact wires.

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 7 % or less of the national total in 2022.

Uncertainties

For mobile sources in 2022, the CO_2 emissions are determined with the highest accuracy (5 % uncertainty), followed by the emissions of CH_4 (30 %), TSP (46 %), SO_2 (1 %), PM_{10} (48 %), $PM_{2.5}$ (53 %), NMVOC (54 %), BC (57 %), NO_x (7 %), CO (62 %) and N_2O (97 %).

The uncertainties for the 1990-2020 emission trends listed by emission component (percentage uncertainty in brackets) are: CO_2 (5 %), CH_4 (2 %), TSP (7 %), SO_2 (1 %), PM_{10} (4 %), $PM_{2.5}$ (2 %), NMVOC (4 %), BC (2 %), NO_x (8 %), CO (9 %) and N_2O (51 %).

For NH_3, heavy metals and POPs the 2022 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
080204 Slid på køreledninger	1A3c Railways
080205 Hjul- og skinneslid	1A3c Railways
080206 Bremseslid	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)
080505 Indenrigs flytrafik (dæk- og bremseslid)	1A3aii (i) Civil aviation (Domestic, LTO)
080506 Udenrigs flytrafik (dæk- og bremseslid)	1A3ai (i) Civil aviation (International, LTO)
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)
0811 Handel og service	1A4aii Commercial/Institutional: Mobile

Metoder

Emissionerne for vejtrafik beregnes med emissionsmodellen DEMOS (Danish Emission model system for Mobile Sources), der er udviklet på DCE ved Aarhus Universitet. DEMOS modelsystemet består af databasemodeller for vejtransport (DEMOS-Road), luftfart (DEMOS-Aviation), søtransport (DEMOS-Navigation), banetrafik (DEMOS-Rail) og non-road maskiner (DEMOS-NRMM).

DEMOS-Road benytter samme modelprincip som den europæiske emissionsmodel COPERT 5 (COmputer Programme to calculate the Emissions from Road Transport). Emissionerne beregnes for køretøjer med driftsvarme motorer, koldstart og fordampning af brændstof. Beregningerne 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 ved at kombinere antallet af køretøjer og køretøjernes årskørsler med emissionsfaktorerne for varme motorer, emissionsforholdet mellem kolde og varme motorer, og faktorerne for benzinfordampning.

For luftfart beregnes 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, små færger (ø- og genvejsfærger), godstransport mellem Danmark og Grønland/Færøerne og øvrig national søfart. For færger beregnes emissionerne i DEMOS-Navigation som produktet af antallet af dobbeltture, sejltid pr. dobbelttur, motorstørrelse, motorlastfaktor og emissionsfaktor. For godstransport mellem Danmark og Grønland/Færøerne og øvrig national søtransport beregnes emissionerne som produktet af brændstofsalget og gennemsnitlige brændstofrelaterede emissionsfaktorer.

For fiskeri bruges log data fra Fiskeristyrelsen som inputdata for aktivitet i DEMOS-Navigation. Logdata indeholder fartøjsregistreringsnummer, byggeår, fartøjstype, skibslængde, brutto ton, i alt installeret motoreffekt og antal timer til havs opsamlet for hver enkelt fangstrejse gjort af dansk indregistrerede fiskefartøjer i perioden 1985-2022. Emissionerne beregnes for hver enkelt fangstrejse som produktet af antal timer til havs, motorstørrelse, motorlastfaktor og emissionsfaktor.

For militær og jernbane 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, luftfart og fiskeri justeres de modelberegnede emissionsresultater ud fra en brændstofbalance, dvs. forholdet mellem det statistisk opgjorte forbrug og det beregnede forbrug i modellen.

For national søtransport beregnes brændstofforbruget direkte for diesel og tung olie for færger i DEMOS-Navigation. 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. 24, 37, 24, 17, 11, 10, 4 og 4 %. Emissionsandelene for NH_3, N_2O, CH_4 og SO_2 er små og ligger på hhv. 0.9, 2.2, 0.1 og 0.9 %.

De beregnede ændringer i energiforbruget og CO_2-, CH_4- og N_2O-emissionerne er på hhv. 26, 19, -91 og 44 % fra 1990-2022. For NO_x, NMVOC, CO, partikler (kun udstødning: < $PM_{2.5}$) og BC er de beregnede ændringer på hhv. 43, -78, -93, -92, -94 og -93 % i perioden 1985-2022.

De mest markante emissionsændringer fra 1985 til 2022 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 1001 % (pga. indførelsen af biler med katalysator.

Tabel 0.2 Emissioner fra vejtrafik i 2022 (tons[a]), ændringer fra 1985 (1990[b]) til 2022, og 2022-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	37	10369	2016	180	34367	5873	126	593	74	74	74	46
Varebiler	10	6854	180	6	1626	1527	45	49	49	49	49	37
Tunge køretøjer	23	3499	155	43	1627	3668	248	45	51	51	51	28
Knallerter og motorcykler	0	115	749	67	5712	68	1	1	12	12	12	2
Fordampning	0	0	1339	0	0	0	0	0	0	0	0	0
Bremseslid	0	0	0	0	0	0	0	0	673	660	263	18
Dækslid	0	0	0	0	0	0	0	0	954	573	401	146
Vejslid	0	0	0	0	0	0	0	0	1213	607	328	0
Total udstødning	70	20837	4438	296	43331	11135	420	688	186	186	186	112
Total slidrelateret	0	0	0	0	0	0	0	0	2841	1839	991	164
I alt	70	20837	4438	296	43331	11135	420	688	3027	2025	1177	276
National total	8128	86825	119109	318430	179892	29719	19191	73328	81825	21428	11221	1606
% af national total, 2022	0,9	24	3,7	0,1	24	37	2,2	0,9	3,7	9,5	10,5	17
% ændring 1985-2022[b]	-99	-78	-93	-91	-92	19	44	1001	-94	-94	-94	-93

[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 2022 (procentandele i parentes) beregnes for personbiler (53 %), fulgt af tunge køretøjer (33 %), varebiler (14 %) og 2-hjulede køretøjer (0 %). For CH_4 beregnes emissionsandele på hhv. 61, 23, 14 og 2 % for personbiler, 2-hjulede køretøjer, tunge køretøjer og varebiler, og N_2O-emissionsandelene for personbiler, tunge køretøjer og varebiler er på hhv. 59, 30 og 11 %.

I 2022 beregnes emissionsandele for personbiler, tunge køretøjer, varebiler og 2-hjulede køretøjer (procentandele i parentes) for NO_x (50, 33, 17 og 0 %), NMVOC (45, 4, 4 og 17 %), CO (79, 4, 4 og 13 %), PM (40, 28, 26 og 6 %), BC (32, 49, 19 og 0 %), og NH_3 (86, 7, 7 og 0 %).

De samlede emissioner af TSP, PM_{10}, $PM_{2,5}$ og BC fra dæk-, bremse- og vejslid udgjorde i 2022 hhv. 94, 91, 84 og 59 % af vejtrafikkens samlede emissioner.

Emissioner fra andre mobile kilder

NO_x, CO, BC og CO_2-emissionerne fra andre mobile kilder udgjorde i 2022 hhv. 25, 33, 18 og 10 % af landets total. I 2022 er emissionsandelene for SO_2, NMVOC, TSP, PM_{10} og $PM_{2.5}$ på hhv. 7, 3, 1, 5 og 9 %, mens andelene for N_2O, NH_3 og CH_4 kun er på omtrent 1 % eller mindre.

Fra 1990-2022 beregnes ændringer for energiforbrug, CO_2-, CH_4- og N_2O-emissioner på hhv. -14, -14, -69 og +3 %. Fra 1985-2022 beregnes emissionsændringer for SO_2, NO_X, NMVOC, CO og partikler (alle størrelsesfraktioner) på hhv. -96, -47, -65, -35, -80 og -83 %. For NH_3 stiger emissionen med 18 % i samme periode.

Table 0.3 Emissioner (tons[a]) fra andre mobile kilder i 2022, ændringer fra 1985 (1990[b]) til 2022, og 2022-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: Non-road	4	1852	610	20	10320	648	30	2	122	122	122	82
Indenrigs flytrafik	38	511	13	1	280	118	6	0	4	4	4	2
Indenrigs flytrafik: Dæk- og bremseslid	0	0	0	0	0	0	0	0	1	0	0	0
Jernbane	1	846	48	2	149	154	5	0	8	8	8	5
Jernbane: Slid på køreledninger	0	0	0	0	0	0	0	0	112	112	56	0
Jernbane: Hjul- og skinneslid	0	0	0	0	0	0	0	0	3	3	1	0
Jernbane: Bremseslid	0	0	0	0	0	0	0	0	251	251	126	0
Indenrigs skibstrafik	185	8852	412	9	885	495	12	0	253	251	249	25
Handel og service: Non-road	1	448	741	31	27308	175	7	0	36	36	36	16
Have-hushold: Non-road	0	32	819	19	11388	26	0	0	16	16	16	1
Landbrug/skovbrug: Non-road	4	2115	632	41	5766	684	33	2	186	186	186	108
Fiskeri	238	5723	283	6	781	376	9	0	107	106	106	22
Øvrige (militær og fritidsfartøjer)	66	1013	244	8	2880	185	7	1	51	51	51	19
Total, Andre mobile kilder: Udstødning	536	21392	3802	137	59756	2861	109	5	783	780	778	281
Total, Andre mobile kilder: Ikke udstødning	0	0	0	0	0	0	0	0	367	366	183	0
Total, Andre mobile kilder	536	21392	3802	137	59756	2861	109	5	1150	1146	961	281
National total	8128	86825	119109	318430	179892	29719	19191	73328	81825	21428	11221	1606
Andre mobile kilder, % af national total, 2022	6,6	24,6	3,2	0,0	33,2	9,6	0,6	0,0	1,4	5,3	8,6	17,5
Andre mobile kilder, % ændring 1985-2022[b]	-96	-47	-65	-69	-35	-14	3	18	-80	-80	-80	-83

[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 fiskeri, landbrug/skovbrug og industri. For CO_2, er landbrug/skovbrug den største emissionskilde, efterfulgt af industri og national søfart.

For partikler (alle størrelsesfraktioner) er den største emissionskilde jernbane, efterfulgt af national skibstrafik og landbrug/skovbrug. De største BC emissionskilder er landbrug/skovbrug, industri og national skibstrafik. Den største del af NMVOC- og CO-emissionerne kommer fra benzindrevne arbejdsredskaber og maskiner inden for handel og service, have- og hushold, landbrug/skovbrug og industri.

Tungmetaller

Tungmetalemissioner beregnes for brændstofforbrug og motorolie samt for dæk-, bremse- og vejslid, og togkøreledninger, hjul- og skinneslid.

I 2022 er vejtrafikkens emissionsandele af de nationale totaler for kobber (Cu), zink (Zn), bly (Pb), krom (Cr) og kadmium (Cd) på hhv. 89, 51, 56, 8 og 8 %. For andre mobile kilder er nikkel (Ni), krom (Cr), selen (Se) og arsen (As) emissionsandelene på 68, 44, 14 og 12 %. For de øvrige komponenter er emissionsandelene på mindre end 7 %.

For vejtrafik beregnes de største udstødningsrelaterede emissionsandele (% andel af national total i parentes) for Zn (13 %), Cd (7.0 %), Cr (3.8 %) og Hg (8.8 %). De slidrelaterede emissionsandele for Cu (89 %) og Pb (55 %) kommer næsten udelukkende fra dækslid, og Zn (37 %) kommer fra bremse- og dækslid.

For andre mobile kilder beregnes de største udstødningsrelaterede emissionsandele (% andel af national total i parentes) for Ni (25 %), Se (14 %), og As (12 %). Disse emissioner skyldes forbruget af marin diesel og tung olie inden for fiskeri og national søfart. De vigtigste slidrelaterede emissioner er Ni (44 %), Cr (43 %) og Cu (5 %). Bremseslid fra tog er den vigtigste emissionskilde for Ni og Cr, og Cu emissionerne kommer næsten udelukkende fra slid på køreledninger.

Samlet set følger udviklingen i tungmetalemissionerne udviklingen i trafikaktiviteterne. Der er dog sket et fald på næsten 100 % for Pb, som følge af 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 7 % eller mindre af de nationale totaler i 2022.

Usikkerheder

I 2022 er CO_2-emissionerne bestemt med den største sikkerhed (5 % usikkerhed), fulgt af CH_4 (30 %), TSP (46 %), SO_2 (1 %), PM_{10} (48 %), $PM_{2.5}$ (53 %), NMVOC (54 %), BC (57 %), NO_x (7 %), CO (62 %) og N_2O (97 %).

Usikkerheden på emissionsudviklingen fra 1990 til 2022 pr. emissionskomponent (procentusikkerheder i parentes) er: CO_2 (5 %), CH_4 (2 %), TSP (7 %), SO_2 (1 %), PM_{10} (4 %), $PM_{2.5}$ (2 %), NMVOC (4 %), BC (2 %), NO_x (8 %), CO (9 %) and N_2O (51 %).

For NH_3, tungmetaller og POP er emissionerne for 2022 bestemt med en usikkerhed på mellem 700 og 1000 %. Her er usikkerheden på 1990-2022 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 2022, 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. 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 2022 are listed in the Tables 2.1-2.4. A thorough documentation of the Danish inventory can be seen in Nielsen et al. (2024a) for greenhouse gases reported to the UNFCCC convention (the Danish NIR report), and in Nielsen et al. (2024b) 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 2022 reported to the UNFCCC convention.

	CO_2 (Gg)	CH_4 (Gg)	N_2O (Gg)	Total GHG[a] (Gg CO_2e)
1. Energy	26500	13.6	1.12	27180
2. Industrial processes and product use	1525	0.08	0.07	1909
3. Agriculture	254	260	17.2	12088
4. Land use, land-use change and forestry	1425	10.78	0.14	1764
5. Waste	15	34.0	0.67	1144
Total national	29719	318.4	19.2	44085
International transport (air)	2169	6.38	73.1	24107
International transport (sea)	1547	27.3	39.0	13848

a) Calculated in CO_2 equivalents. Referring to the fifth IPCC assessment report (Myhre et al., 2017), 1 g CH_4 and 1 g N_2O has the greenhouse effect of 28 and 265 g CO_2, respectively.

Table 2.2 Emissions 2022 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	6895	67452	42726	173152	1599	11706	10261	8988	1587
2. Industrial processes and product use	866	64	29159	3005	440	6274	2618	810	9,1
3. Agriculture	10	19155	46666	1274	70640	63493	8208	1089	10
5. Waste	357	155	558	2461	648	353	341	334	0,0
Total national	8128	86825	119109	179892	73328	81825	21428	11221	1606
International transport (air)[1]	692	10206	155	1931	0	98	98	98	36
International transport (sea)	975	34395	1335	3743	0	1021	1010	1005	63

Table 2.3 Heavy metal emissions 2022 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	170	526	2354	59218	242	4868	9172	424	47747
2. Industrial processes and product use	105	22	223	3256	9	251	1878	37	2566
3. Agriculture	0,1	17	1,5	1,4	2,7	1,0	2,1	0,4	11
5. Waste	1,1	8,8	18	81	0,8	8,3	2412	0,3	9380
Total national	276	574	2596	62556	254	5129	13464	462	59704
International transport (air)[1]	0	0	0	0	0	0	0	0	0
International transport (sea)	99	8	46	99	13	5027	65	131	310

Table 2.4 PAH emissions 2022 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	1862	19459	1128	1230	713	690	317
2. Industrial processes and product use	5.8	179	21	20	11.8	14	66
3. Agriculture	357	38	8	22	9	13	0
5. Waste	10.0	4470	81	107	68	109	27
Total national	2234	24147	1238	1379	803	825	410
International transport (air)[1]	0	0	0	0	0	0	2190
International transport (sea)	0.1	0.3	18	4.7	2.5	0	1559

2.2 International conventions and reduction targets

Denmark is a party to two international conventions and two EU directives on 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
- The EU Monitoring Mechanism Regulation (Regulation (EU) No 525/2013)

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

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, 1998 (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 subsequent years 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 timetables for six greenhouse gases: CO_2, CH_4, N_2O, HFC (hydrofluorocarbon), PFC (perfluorocarbon) and SF_6 (sulphur hexafluoride); for the second commitment period, NF_3 (nitrogen triflouride) 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 motorcycles	1A3biv Road transport: Mopeds & motorcycles
0706 Road traffic: Evaporation	1A3bv Road transport: Evaporation
0707 Road traffic: Brake and tire wear	1A3bvi Road transport: Brake and tire wear
0708 Road traffic: Road abrasion	1A3bvii Road transport: Road abrasion
0801 Military	1A5b Other, Mobile
0802 Railways	1A3c Railways
080204 Train contact wire wear	1A3c Railways
080205 Wheel and rail wear	1A3c Railways
080206 Brake wear	1A3c Railways
0803 Inland waterways	1A5b Other, Mobile
080402 National sea traffic	1A3dii National navigation (Shipping)
080403 National fishing	1A4ciii Agriculture/Forestry/Fishing: National fishing
080404 International sea traffic	1A3di (i) International navigation (Shipping)
080501 Dom. airport traffic (LTO < 1000 m)	1A3aii (i) Civil aviation (Domestic, LTO
080502 Int. airport traffic (LTO < 1000 m)	1A3ai (i) Civil aviation (International, LTO)
080503 Dom. cruise traffic (> 1000 m)	1A3aii (ii) Civil aviation (Domestic, Cruise)
080504 Int. cruise traffic (> 1000 m)	1A3ai (ii) Civil aviation (International, Cruise)
080505 Dom. airport traffic (tyre and brake wear)	1A3aii (i) Civil aviation (Domestic, LTO)
080506 Int. airport traffic (tyre and brake wear)	1A3ai (i) Civil aviation (International, LTO)
0806 Agriculture	1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry
0807 Forestry	1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry
0808 Industry	1A2gvii Manufacturing industries/Construction (mobile)
0809 Household and gardening	1A4bii Residential: Household and gardening (mobile)
0811 Commercial and institutional	1A4aii Commercial/Institutional: Mobile

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.

Emissions from lubricants during use are reported under 2D3 as per the UNFCCC reporting guidelines. Two-stroke engines in road transport are only relevant for mopeds and motorcycles (and the odd veteran vehicle) and even in these categories, four-stroke engines have gained popularity in part due to environmental considerations. The Danish energy statistics only include lubricants for non-energy purposes and any consumption in two-stroke mopeds/motorcycles will be negligible and fall far below the threshold of significance.

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) is 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) 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) regardless of vessel flag is reported under 1A4ciii.

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

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

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

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

4 Input data and calculation methods for road transport

For road transport, the detailed methodology (Tier 3) is used to make annual estimates of the Danish emissions, as described in the EMEP/EEA Air Pollutant Emission Inventory Guidebook (EMEP/EEA, 2023). The calculations are made with DEMOS-Road (Danish Emission model system for Mobile Sources) model developed at DCE, Aarhus University, using the European COPERT 5 model methodology (EMEP/EEA, 2023). In COPERT, fuel consumption and emission simulations can be made for operationally hot engines, taking into account gradually stricter emission standards and emission degradation due to catalyst wear. Furthermore, the emission effects of cold-start and evaporation are simulated.

4.1 Vehicle fleet and mileage data

Corresponding to the COPERT 5 fleet classification, DEMOS-Road groups all present and future vehicles in the Danish fleet into vehicle classes, 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 all model layers are shown in Annex 1.

Fleet and annual mileage data are provided by DTU Transport for the vehicle categories present in COPERT 5 (Jensen, 2023). DTU Transport use data from the Danish vehicle register kept by Statistics Denmark. The vehicle register data consists of vehicle type (passenger cars, vans, trucks, buses, mopeds, motorcycles), fuel type, vehicle weight, gross vehicle weight, engine size (passenger cars registered from 2005+), Euro norm, NEDC type approval fuel efficiency value (passenger cars registered from 1997+) and vehicle first registration year. The Euro norm information is very complete in the Danish vehicle register for vehicle first registrations 2001 onwards for trucks and buses and 2011 onwards in the case of passenger cars and vans. For vehicles with no EU norm information, the EU norm is assigned, associated with the date for first registration (entry into service) listed in Table 4.2.

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 1985-2022, together with a more detailed mileage matrix examined for the year 2008 (based on detailed vehicle inspection data analysis). The detailed mileage matrix contains annual mileage per vehicle subcategory for new vehicles and for every vintage back in time, which determines the yearly mileage reduction percentages as a function of vehicle age. In a first step, the detailed mileage matrix is combined with corresponding fleet numbers to estimate intermediate total mileages for each year on a detailed fleet level. Next, each year's detailed (intermediate) mileage figures are scaled according to the difference between true and intermediate total mileage per vehicle subcategory.

DTU Transport (Jensen, 2023) also provides information of the mileage split between urban, rural and highway driving based on traffic monitoring data. The respective average speeds come from The Danish Road Directorate (e.g. Winther & Ekman, 1998). Additional data for the moped fleet and motorcycle fleet disaggregation is given by The National Motorcycle Association (Markamp, 2013) and supplementary moped stock information is obtained from The Danish Bicycle Traders Association (Johnsen, 2018) and Prince (2021).

In addition, data from a survey made by the Danish Road Directorate (Hansen, 2010) has given information of the total mileage driven by foreign cars, vans, coaches and trucks on Danish roads in 2009 and a follow-up survey in 2014 has given additional information. For trucks, the mileage contribution from foreign vehicles has been added to the total mileage on Danish roads for Danish truck-trailers and articulated trucks in two gross vehicle weight categories, < 40 tonnes and > 40 tonnes. The data has been further processed by DTU Transport; by using appropriate assumptions, the mileage have been backcasted to 1985 and forecasted to 2022.

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

Vehicle classes	Fuel type	Engine size/weight	Trip speed [km per h] Urban	Rural	Highway
Passenger cars	Gasoline	< 0.8 l.	40	70	100
Passenger cars	Gasoline	0.8 - 1.4 l.	40	70	100
Passenger cars	Gasoline	1.4 – 2 l.	40	70	100
Passenger cars	Gasoline	> 2 l.	40	70	100
Passenger cars	Diesel	< 0.8 l.	40	70	100
Passenger cars	Diesel	0.8 - 1.4 l.	40	70	100
Passenger cars	Diesel	< 1.4 - 2 l.	40	70	100
Passenger cars	Diesel	> 2 l.	40	70	100
Passenger cars	2-stroke		40	70	100
Passenger cars	LPG		40	70	100
Passenger cars	CNG		40	70	100
Passenger cars	Plug-in hybrid		40	70	100
Light commercial vehicles (LCV)	Gasoline	<1305 kg	40	65	80
Light commercial vehicles (LCV)	Gasoline	1305-1760 kg	40	65	80
Light commercial vehicles (LCV)	Gasoline	>1760 kg	40	65	80
Light commercial vehicles (LCV)	Diesel	<1305 kg	40	65	80
Light commercial vehicles (LCV)	Diesel	1305-1760 kg	40	65	80
Light commercial vehicles (LCV)	Diesel	>1760 kg	40	65	80
Light commercial vehicles (LCV)	LPG	<1305 kg	40	65	80
Light commercial vehicles (LCV)	LPG	1305-1760 kg	40	65	80
Light commercial vehicles (LCV)	LPG	>1760 kg	40	65	80
Light commercial vehicles (LCV)	CNG	<1305 kg	40	65	80
Light commercial vehicles (LCV)	CNG	1305-1760 kg	40	65	80
Light commercial vehicles (LCV)	CNG	>1760 kg	40	65	80
Light commercial vehicles (LCV)	Plug-in hybrid	<1305 kg	40	65	80
Light commercial vehicles (LCV)	Plug-in hybrid	1305-1760 kg	40	65	80
Light commercial vehicles (LCV)	Plug-in hybrid	>1760 kg	40	65	80
Trucks	Gasoline		35	60	80
Trucks	Diesel/CNG	Rigid 3,5 - 7,5t	35	60	80
Trucks	Diesel/CNG	Rigid 7,5 - 12t	35	60	80
Trucks	Diesel/CNG	Rigid 12 - 14 t	35	60	80
Trucks	Diesel/CNG	Rigid 14 - 20t	35	60	80
Trucks	Diesel/CNG	Rigid 20 - 26t	35	60	80
Trucks	Diesel/CNG	Rigid 26 - 28t	35	60	80
Trucks	Diesel/CNG	Rigid 28 - 32t	35	60	80
Trucks	Diesel/CNG	Rigid >32t	35	60	80
Trucks	Diesel/CNG	TT/AT 14 - 20t	35	60	80
Trucks	Diesel/CNG	TT/AT 20 - 28t	35	60	80
Trucks	Diesel/CNG	TT/AT 28 - 34t	35	60	80
Trucks	Diesel/CNG	TT/AT 34 - 40t	35	60	80
Trucks	Diesel/CNG	TT/AT 40 - 50t	35	60	80
Trucks	Diesel/CNG	TT/AT 50 - 60t	35	60	80
Trucks	Diesel/CNG	TT/AT >60t	35	60	80
Urban buses	Gasoline		30	50	70
Urban buses	Diesel/CNG	< 15 tonnes	30	50	70
Urban buses	Diesel/CNG	15-18 tonnes	30	50	70
Urban buses	Diesel/CNG	> 18 tonnes	30	50	70
Coaches	Gasoline		35	60	80
Coaches	Diesel/CNG	< 15 tonnes	35	60	80
Coaches	Diesel/CNG	15-18 tonnes	35	60	80
Coaches	Diesel/CNG	> 18 tonnes	35	60	80
Mopeds	Gasoline		30	30	-
Motorcycles	Gasoline	2 stroke	40	70	100
Motorcycles	Gasoline	< 250 cc.	40	70	100
Motorcycles	Gasoline	250 – 750 cc.	40	70	100
Motorcycles	Gasoline	> 750 cc.	40	70	100

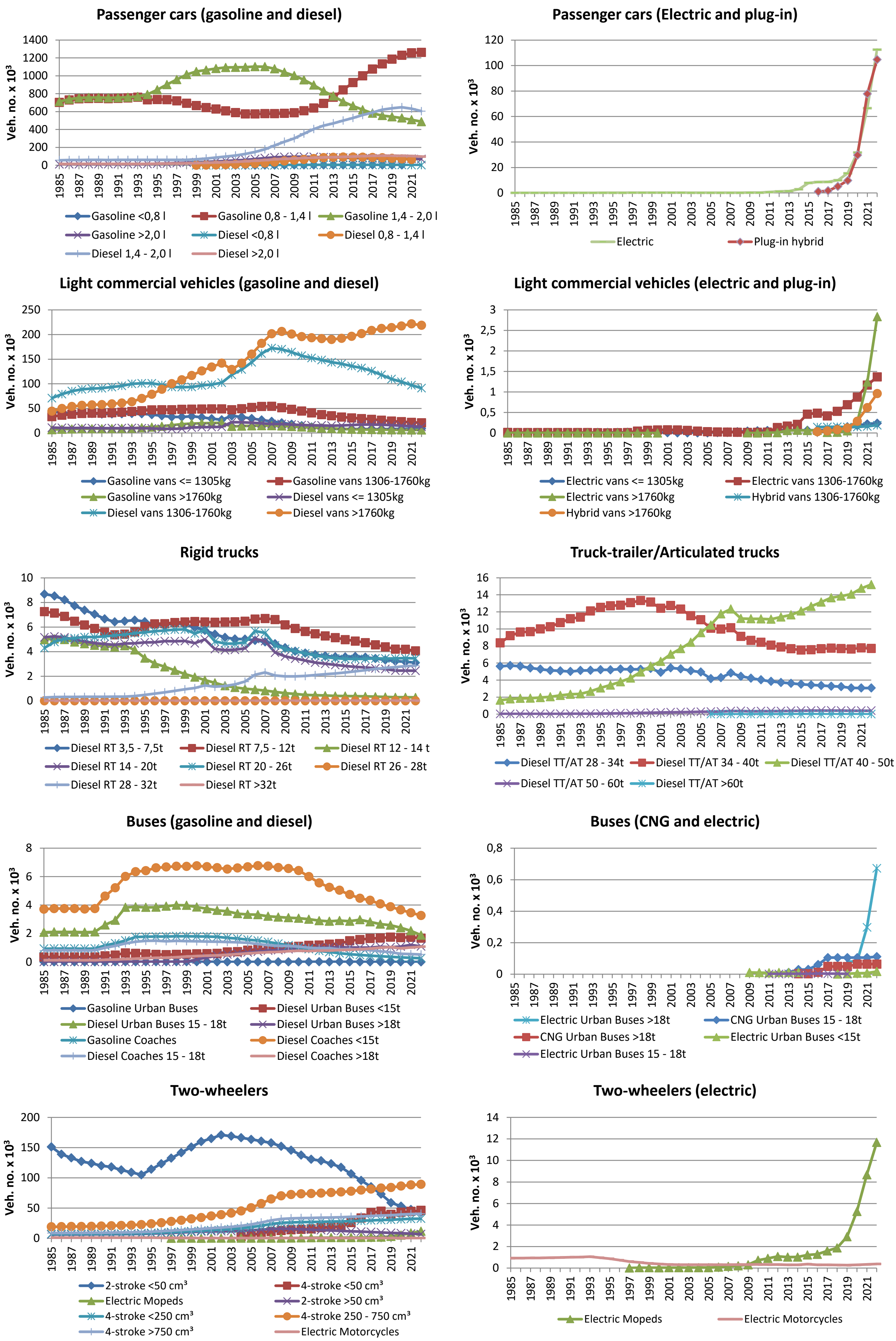


Figure 4.1 Number of vehicles in sub-classes in 1985-2022.

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

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

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

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

The reason for the significant growth in the number of mopeds from 1994 to 2002 is the introduction of the so-called Moped 45 vehicle type. From 2004 onwards there is a switch from 2-stroke to 4-stroke in new sales for this vehicle category, and this gradually influences the composition of the total moped fleet. From 2017 onwards, there is a big increase in the number of electric mopeds, whereas the number of electric motorcycles has been quite stable for many years. The total number of motorcycles has grown throughout the 1990-2010 period and from 2012-2022.

The vehicle numbers are summed up in layers for each year:

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

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:

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

Vehicle numbers and weighted annual mileages per layer are shown in Annex 1 and 2 for 1985-2022. 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.

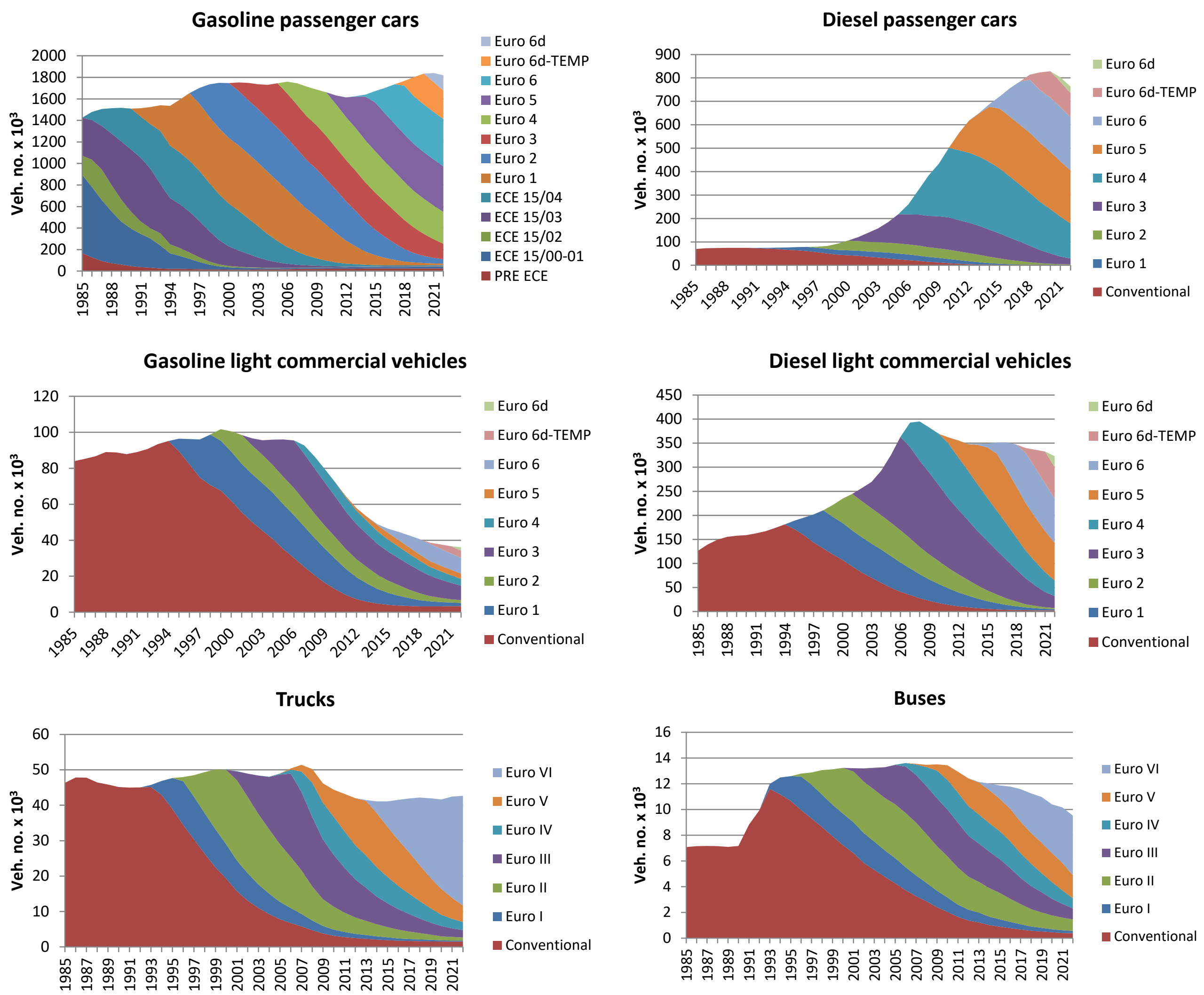


Figure 4.2 Layer distribution of vehicle numbers per vehicle type in 1985-2022.

4.2 Emission legislation

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

- **Limit value curve:** the fleet average to be achieved by all cars registered in the EU is 130 gram CO_2 per kilometre (g per km). A so-called limit value curve implies that heavier cars are allowed higher emissions than lighter cars while preserving the overall fleet average.
- **Further reduction:** a further reduction of 10 g CO_2 per km, or equivalent if technically necessary, will be delivered by other technological improvements and by an increased use of sustainable biofuels.
- **Phasing-in of requirements:** in 2012, 65 % of each manufacturer's newly registered cars must comply on average with the limit value curve set by the legislation. This will rise to 75 % in 2013, 80 % in 2014, and 100 % from 2015 onwards.
- **Lower penalty payments for small excess emissions until 2018:** if the average CO_2 emissions of a manufacturer's fleet exceed its limit value in any year from 2012, the manufacturer has to pay an excess emissions premium for each car registered. This premium amounts to €5 for the first g per km of exceedance, €15 for the second g per km, €25 for the third g per km, and

€95 for each subsequent g per km. From 2019, already the first g per km of exceedance will cost €95.
- **Long-term target:** a target of 95g CO_2 per km is specified for the year 2021.
- **Eco-innovations:** Manufacturers can be granted a maximum of 7g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.

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

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

On 17 April 2019, the European Parliament and the Council adopted Regulation (EU) 2019/631 setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles (vans) in the EU.

This Regulation started applying on 1 January 2020, replacing and repealing the former Regulations setting CO_2 emission standards for cars ((EC) 443/2009) and vans ((EU) 510/2011).

On 19 April 2023, the European Parliament and the Council amended the Regulation 2019/631 to strengthen the CO_2 emission performance standards for new passenger cars and vans, and bring them in line with the EU's ambition to reach climate neutrality by 2050. This amendment strengthened the emission targets applying from 2030 and set a 100% emission reduction target for both cars and vans from 2035 onwards.

The following description of the amendment of the regulation (EU) 2019/631 is given on the EU Commission Climate Action web page (https://climate.ec.europa.eu/eu-action/transport/road-transport-reducing-co2-emissions-vehicles/co2-emission-performance-standards-cars-and-vans_en). The main elements of the amended regulation are:

Target levels

Below are the EU fleet-wide CO_2 emission targets set in the Regulation:

2020 to 2024

Cars: 95 g CO_2/km

Vans: 147 g CO_2/km

These target levels refer to the NEDC emission test procedure.

2025 to 2034

The targets that will apply from 2025 onwards are based on the WLTP (World-wide harmonized Light vehicles Test Procedure) and were set out in Commission Implementing Decision (EU) 2023/1623:

Cars: 93,6 g CO_2/km (2025-2029) and 49,5 g CO_2/km (2030-2034)

Vans: 153,9 g CO_2/km (2025-2029) and 90,6 g CO_2/km (2030-2034)

From **2035 onwards**, the EU fleet-wide CO_2 emission target for both cars and vans is 0 g CO_2/km, corresponding to a 100% reduction.

The **annual specific emission targets** of each manufacturer are based on these EU fleet-wide targets, taking into account the average mass of its registered new vehicles. Since 2021, those specific emission targets are based on the WLTP.

The manufacturer targets for the **years 2021-2024** are calculated in accordance with point 4 of Annex I (parts A and B) to Regulation (EU) 2019/631, using the values set out in Annex II to Commission Implementing Decision (EU) 2022/2087.

The manufacturer targets **from 2025 onwards** are calculated in accordance with point 6 of Annex I (parts A and B) to Regulation (EU) 2019/631, using the values set out in Annex II to Commission Implementing Decision (EU) 2023/1623.

Incentive mechanism for zero- and low-emission vehicles (ZLEV):

From 2025 to 2029, a ZLEV **crediting system** will apply both for car and van manufacturers. The system will alleviate a manufacturer's specific emission target if its share of new ZLEV (vehicles with emissions between 0 and 50 g CO_2/km) registered in a given year exceeds the following benchmarks:

Cars: 25% ZLEV

Vans: 17% ZLEV

A one percentage point exceedance of the ZLEV benchmark will increase the manufacturer's CO_2 target (in g CO_2/km) by one percent. The alleviation of the emission target will be capped at maximum 5% to safeguard the environmental integrity of the Regulation.

To calculate the ZLEV share in a manufacturer's fleet, an accounting rule give a greater weight to ZLEVs with lower CO_2 emissions. An additional multiplier may apply for cars registered in Member States with a low share and number of ZLEVs registered in 2017.

Penalties for excess emissions:

If the average CO_2 emissions of a manufacturer's fleet exceed its specific emission target in a given year, the manufacturer must pay – for each of its new vehicles registered in that year – an **excess emissions premium** of €95 per g/km of target exceedance.

Pooling:

Different manufacturers can act jointly to meet their emissions target. When forming a pool, manufacturers must respect the rules of competition law. Pooling between car and van manufacturers is not possible.

Exemptions and derogations:

Manufacturers responsible for fewer than 1 000 new cars or fewer than 1 000 new vans registered in the EU per year are **exempt** from meeting a specific emission target in the following year, unless they voluntarily apply for a derogation.

Manufacturers may apply for a **derogation** from their specific emission target with the following conditions:

A "small-volume" manufacturer (responsible for less than 10 000 new cars or less than 22 000 new vans registered per year) can propose its own derogation target, based on the criteria set in Article 10 of the Regulation.

A "niche" car manufacturer (responsible for between 10 000 and 300 000 new cars registered per year) can apply for a derogation for the years until 2028, included. The derogation targets are calculated as set out in Article 10(4) of the Regulation and in point 5 of Part A of its Annex I. Feel free to access the values used to calculate the "niche" derogation target from 2025 onwards.

Eco-innovations:

To promote the development of new and advanced technologies reducing CO_2 emissions from vehicles, manufacturers may obtain emission credits for cars and vans which are equipped with innovative technologies (eco-innovations) whose full CO_2 savings are impossible to demonstrate during their type-approval.

The manufacturer must demonstrate these savings based on independently verified data. The maximum emission credits for these eco-innovations per manufacturer are 7 g CO_2/km per year until 2024, 6 g CO_2/km from 2025 to 2029, and 4 g CO_2/km from 2030 to 2034. As of 2025, the efficiency improvements for air conditioning systems will become eligible as eco-innovations.

In-service verification:
Manufacturers must ensure that the CO_2 emissions recorded in the certificates of conformity of their vehicles and the in-service CO_2 emissions of such vehicles correspond. Type-approval authorities must verify this correspondence in selected vehicles, as well as the presence of any strategies to artificially improve the vehicle's performance during type-approval tests.

In case deviations or artificial strategies are detected, type-approval authorities must report those to the Commission, who will take them into account when calculating the average specific emissions of a manufacturer. Authorities must also ensure the correction of the certificates of conformity, and may take additional measures as set out in the Type Approval Regulation.

Real-world emissions:
To assess the real-world representativeness of the CO_2 emissions and the fuel or energy consumption values determined during type-approval, as well as to prevent the growing of the gap between emissions tested in the laboratory and real-world emissions, the Commission is collecting real-world data from cars and vans using on-board fuel consumption monitoring (OBFCM) devices, starting with vehicles first registered in 2021.

On 14 February 2023, the European Commission tabled a legislative proposal to revise Regulation (EU) 2019/1242 setting CO_2 emission standards for new HDVs in the EU, see https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2023)747880. The revision was approved by the European Parliament on 10 April 2024 and ratified by the Council of the European Union on 13 May 2024.

The revision expands the scope of the regulation to include urban buses, coaches, trailers and additional types of lorries. The average CO_2 emissions of trucks and coaches, compared with 2019 levels, would have to fall by 45 % from 2030, by 65 % from 2035, and by 90 % from 2040 onwards.

The revision introduced a 2035 100% zero emissions target for urban buses, with an intermediate 90% 2030 goal.

For Euro 1-6 passenger cars and vans, the chassis dynamometer test cycle used in the EU for emission approval is the NEDC (New European Driving Cycle), see e.g. www.dieselnet.com. The test cycle is also used for fuel consumption measurements. The NEDC cycle consists of two parts, the first part being a 4-time repetition (driving length: 4 km) of the ECE test cycle. The latter test cycle is the so-called urban driving cycle[3] (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

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

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

The NEDC test cycle is not adequately describing real world driving behaviour, and consequently, for diesel cars and vans, there is an increasing mismatch between the step wise lowered EU emission limits the vehicles comply with during the NEDC test cycle, and the more or less constant 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 newer Euro 6 vehicles and Euro 7 vehicles emission measurements must also be made with portable emission measurement systems (PEMS) during real traffic driving conditions with random acceleration and deceleration patterns. During the new Real Driving Emission (RDE) test procedure in a temporary phase, the emissions of NO_x are not allowed to exceed the NEDC based Euro 6 emission limits by more than 110 % by 1 September 2017 for all new car models and by 1 September 2019 for all new cars (Euro 6d-TEMP). From 1 January 2020 in the final phase, the NO_x emission not-to-exceed levels are adjusted downwards to 50 % for all new car models and by 1 January 2021 for all new cars (Euro 6d). Implementation dates for vans are one year later.

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

For NOx, VOC (NMVOC + CH_4), CO and PM, the emissions from road transport vehicles must comply with the emission limit values agreed by the EU. An overview of the different emission layers in the road transport emission model and the corresponding EU emission directive numbers are given in Table 3.3.6. The specific emission limits are shown in Annex 2.B.3.

Table 4.2 shows the EU directive dates for new type approvals and the date for first registration (entry into service) of existing, previously type approved vehicle models. The latter date is used in the model for vehicles with no EU norm information given in the car register. In most cases the entry into service date used in the model is the same as the entry into service date specified by the EU directive.

For passenger cars and light commercial vehicles, the emission directives distinguish between three vehicle classes according to vehicle reference mass[4]: Passenger cars and light duty trucks (<1305 kg) have the same emission limits but different legislation dates. Light duty trucks (1305-1760 kg) and light duty trucks (>1760 kg) have the same legislation dates but different emission limits.

For heavy-duty vehicles (trucks and buses), the emission limits are given in g per kWh and the measurements are carried out for engines in a test bench, using the ECE R-49, EU ESC (European Stationary Cycle) and ETC (European

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

Transient Cycle) test cycles, depending on the Euro norm and exhaust gas after-treatment system installed. For Euro VI and Euro VII engines the WHSC (World Harmonized Stationary Cycle) and WHTC (World Harmonized Transient Cycle) test cycles are used. For a description of the test cycles, see e.g. www.dieselnet.com.

For Euro VII engines emissions measured during a Real Driving Emission (RDE) test procedure with random acceleration and deceleration patterns, must comply with specific emission limits given in EU directive 2024/1257.

Specific emission limits (Euro 7) for non-exhaust particulate emissions from brake wear and tyre wear are also comprised in EU directive 2024/1257. The emission limits are valid for new brake systems for different powertrain types and vehicle categories, and for tyres of different size classes. For further descriptions, see e.g. ICCT (2024).

For brake systems, as a first step, Euro 7 defines particulate matter limits for passenger cars and light commercial vehicles until the end of 2029. From 2030 onwards, the scope is extended to buses and trucks of categories M_2, M_3 and N_2, N_3. The emission limits will be defined for two time periods, from 2030-2034 and from 2035 onwards. To define the actual emission limits, the European Commission will submit an analysis by the end of 2027.

Brake particle emissions of brake systems for M_1 and N_1 vehicles are tested according to the UN Global Technical Regulation No. 24.8[5]. The type-approval is granted for the brake system, which can then be fitted to many vehicle models. The test procedure for heavy-duty vehicles is yet to be developed.

Tyres will be subject to type-approval testing to receive type approval for Euro 7. The test procedure and emission limits for tyre wear are under development at the United Nations Economic Commission for Europe (UNECE) and will amend the Euro 7 regulation. If a UNECE regulation is not adopted in time, the Commission is empowered to develop a tyre testing procedure and set limits instead.

Euro 7 requirements will apply to tyres of different classes at different times—first to C1 tyres (cars and LCV) from July 2028, then to C2 tyres (medium load heavy duty vehicles) from April 2030, and to C3 tyres (high load heavy duty vehicles) from April 2032. The introduction sequence is the same for all categories. In the first stage, Euro 7 applies to new tyre models that are type-approved for the first time. One year later, new vehicles put on the market must be equipped with Euro 7 type-approved tyres, and another year later, all tyres put on the market must comply with Euro 7 requirements.

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

[5] United Nations Economic Commission for Europe, "Addendum 24: UN Global Technical Regulation No. 24 - Laboratory Measurement of Brake Emissions for Light-Duty Vehicles," Pub. L. No. ECE/TRANS/180/Add.24 (2023), https://unece.org/sites/default/files/2023-07/ECE-TRANS-180-Add.24.pdf.

Table 4.2 Overview of emission layers in the road transport emission model and the related EU emission directives.

Vehicle category	Emission layer	EU directive	Type approval	First registration date
Passenger cars (gasoline)	PRE ECE	-	-	<1970-
	ECE 15/00-01	70/220 - 74/290	1972[a]	1970[a]
	ECE 15/02	77/102	1981[b]	1979[b]
	ECE 15/03	78/665	1982[c]	1981[c]
	ECE 15/04	83/351	1987[d]	1986[d]
Passenger cars (diesel)	Conventional	-	-	<1991-
Passenger cars	Euro 1	91/441	1.7.1992[e]	1.1.1991[e]
	Euro 2	94/12	1.1.1996	1.1.1997
	Euro 3	98/69	1.1.2000	1.1.2001
	Euro 4	98/69	1.1.2005	1.1.2006
	Euro 5	715/2007(692/2008)	1.9.2009	1.1.2011
	Euro 6	715/2007(692/2008)	1.9.2014	1.9.2015
	Euro 6d-TEMP	2016/646	1.9.2017	1.9.2018
	Euro 6d	2016/646	1.1.2020	1.1.2021
	Euro 7	2024/1257	29.11.2026	29.11.2027
LCV < 1305 kg	Conventional	-	-	<1995
	Euro 1	91/441	1.10.1994	1.1.1995
	Euro 2	94/12	1.1.1998	1.1.1999
	Euro 3	98/69	1.1.2001	1.1.2002
	Euro 4	98/69	1.1.2006	1.1.2007
	Euro 5	715/2007(692/2008)	1.9.2010	1.1.2012
	Euro 6	715/2007(692/2008)	1.9.2015	1.9.2016
	Euro 6d-TEMP	2016/646	1.9.2018	1.9.2019
	Euro 6d	2016/646	1.1.2021	1.1.2022
	Euro 7	2024/1257	29.11.2026	29.11.2027
LCV 1305-1760 kg & > 1760 kg	Conventional	-	-	<1995
	Euro 1	93/59	1.10.1994	1.1.1995
	Euro 2	96/69	1.1.1998	1.1.1999
	Euro 3	98/69	1.1.2001	1.1.2002
	Euro 4	98/69	1.1.2006	1.1.2007
	Euro 5	715/2007	1.9.2010	1.1.2012
	Euro 6	715/2007	1.9.2015	1.9.2016
	Euro 6d-TEMP	2016/646	1.9.2018	1.9.2019
	Euro 6d	2016/646	1.1.2021	1.1.2022
	Euro 7	2024/1257	29.11.2026	29.11.2027
Heavy duty vehicles	Euro 0	88/77	1.10.1990	1.10.1990
	Euro I	91/542	1.10.1993	1.10.1993
	Euro II	91/542	1.10.1996	1.10.1996
	Euro III	1999/96	1.10.2000	1.10.2001
	Euro IV	1999/96	1.10.2005	1.10.2006
	Euro V	1999/96	1.10.2008	1.10.2009
	Euro VI	595/2009	1.1.2013	1.1.2014
	Euro VII	2024/1257	29.5.2028	29.5.2029
Mopeds	Conventional	-	-	-
	Euro I	97/24	2000	2000
	Euro II	2002/51	2004	2004
	Euro III	2002/51	2014[f]	2014[f]
	Euro IV	168/2013	2017	2017
	Euro V	168/2013	2021	2021
Motor cycles	Conventional		0	0
	Euro I	97/24	2000	2000
	Euro II	2002/51	2004	2004
	Euro III	2002/51	2007	2007

Continued

	Euro IV	168/2013	2017	2017
	Euro V	168/2013	2021	2021

a,b,c,d: Expert judgement suggests that Danish vehicles enter into the traffic before EU directive first registration dates. The effective inventory starting years are a: 1970; b: 1979; c: 1981; d: 1986; e: The directive came into force in Denmark 1. October 1990.

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

The fuel consumption and emission factors used in DEMOS-Road come from the COPERT 5 model[6]. The source for these data is various European measurement programs. In general, the COPERT data are transformed into trip-speed dependent fuel consumption and emission factors for all vehicle categories and layers by using trip speeds as shown in Table 3.3.6. The factors are listed in Annex 4.

It should be noted that for PHEV (plug-in hybrid electric vehicles) cars and vans, the utility factor is set to 0.3, i.e. 30 % of total mileage is assumed to be battery driven, according to assumptions made by DEA (2023)[7]. The fuel consumption and emission factors for plug-in vehicles used in the Danish national emission inventories for road transport, and shown in the present NIR, only contain the part of fuel consumption and emissions related to the combustion of fossil fuel (gasoline) in the vehicles. The emissions related to the generation of the electricity used by battery electric vehicles and plug-in vehicles are included under stationary sources in the Danish emission inventories as prescribed by the UNFCCC reporting guidelines.

4.3.1 Adjustment for vehicle fuel efficiency

For passenger cars, COPERT 5 include measurement-based fuel consumption factors until Euro 4. A calculation function is provided for newer cars that one hand compensates for the trend towards more fuel-efficient vehicles being

[6] For vans, the COPERT model do not fully stratify fuel consumption factors into vehicle weight classes. Instead fuel consumption factor data for vans are obtained from the HBEFA (Handbook of Emission Factors) model version 4.1 (e.g. Matzer et al., 2019).

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

sold during the later years and on the other hand compensate for the increasing fuel gap between fuel consumption measured during vehicle type approval and real world fuel consumption.

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

The baseline COPERT 5 fuel consumption factors for Euro 4, Euro 5 and Euro 6 passenger cars are adjusted in the following way.

In the Danish fleet and mileage database kept by DTU Transport, the type approval fuel efficiency value based on the NEDC driving cycle (TA_{NEDC}) is registered for each single car. In the fleet and mileage database, type approval fuel efficiency values based on the WLTP driving cycle is converted into TA_{NEDC} values by using conversion factors from NEDC to WLTP established by JRC (2017).

Further, DTU Transport calculates a modified fuel efficiency value (FC_{inuse}) with the calculation function provided by COPERT 5 that better reflects the fuel consumption in real ("inuse") traffic conditions.

The FC_{inuse} function uses TA_{NEDC}, vehicle weight, engine size and regression coefficients by first registration year, as input parameters (EMEP/EEA, 2023). For each new registration year, i, fuel type, f, and engine size, k, number based average values of TA_{NEDC} and FC_{inuse} are summed up and referred to as $\overline{TA_{NEDC}}(i,f,k)$ and $\overline{TA_{inuse}}(i,f,k)$. For vehicle new registrations after 2014, regression coefficients are used for 2014.

The FC_{inuse} function has been developed from a vehicle database consisting of new registered cars from 2006-2014 (Tietge et al. 2017). Hence, as previously mentioned, The FC_{inuse} function is not able to account for the fuel gaps after 2014, between type approval and real-world fuel consumption as monitored by ICCT (Tietge et al., 2019).

To obtain $\overline{FC_{inuse}}(i,f,k)$ values for vehicle new registrations 2015-2022, the $\overline{FC_{inuse}}(i,f,k)$ values for 2014 are adjusted for the years 2015-2022[8] with an index function (indexed from 2014), C_{ICCT} (i, f), based on the reported ICCT fuel gap figures by fuel type for the new registration years 2014-2022.

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

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

[8] The ICCT monitoring report include new cars up to 2017. For new cars from 2018-2022, fuel gap figures are used for cars from 2017.
[9] The factors are derived from the Common Artemis Driving Cycle (CADC), with a 1/3 weight for each of the urban, rural and highway parts of CADC.

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

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

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 (2023b).

4.3.2 Adjustment for EGR, SCR and particle filters

In COPERT 5, emission factors are available for Euro V heavy duty vehicles using exhaust gas recirculation (EGR) and selective catalyst reduction (SCR) exhaust emission aftertreatment systems, respectively. The estimated new sales of Euro V diesel trucks equipped with EGR and SCR during the 2006-2010 time periods has been examined by Hjelgaard and Winther (2011). These inventory fleet data are used in the Danish inventory to calculate weighted emission factors for Euro V trucks in different size categories.

In 2008-2010, environmental zones have been introduced in the four largest Danish cities to bring down the particulate emissions from diesel fuelled heavy duty vehicles. Driving in these environmental zones prescribe the use of diesel particulate filters.

The Danish EPA has estimated the number of Euro I-III urban buses and Euro II-III trucks and tourist buses, which have been retrofitted with filters to fulfil the emission requirements in these environmental zones (Winther, 2011). It is assumed that the retrofitted filters are wall-flow diesel particle filters (DPF), and the particulate emissions from these retrofitted vehicles are effectively the same as the particulate emissions from Euro V vehicles all with preinstalled DPF's.

In 2009, a levy was introduced on light diesel vehicles without particle filters. To avoid this levy, many older diesel cars and vans have been retrofitted with open particle filters (also named free-flow or particle oxidation catalysts), regarded as the only technically feasible solution in this case. The particle emissions for these vehicles are expected to be 30 % lower than the particle emissions from the same Euro technology with no retrofitted filter.

In addition, since 2006, economical incitements have been given to private vehicle owners to buy Euro 4 diesel passenger cars and vans with preinstalled closed (wall-flow) diesel particle filters (DPF). The particulate emissions from these vehicles are similar to the particulate emissions for Euro 5 vehicles all with preinstalled DPF's.

From the Danish vehicle register, information exists of the number of diesel passenger cars and vans equipped with particle filters, no information is however, available on filter type.

The inventories assume that particle filter registered pre-Euro 4 vehicles have been retrofitted with open particle filters, and PM emission factors are reduced by 30 % compared to the PM emission factors from the same Euro technology with no retrofitted filter.

It is also assumed that all filter registered Euro 4 vehicles come with preinstalled DPFs, and PM emission factors are like the PM emission factors for Euro 5 vehicles. Although a few Euro 4 vehicles may be retrofitted with open particle filters, it's impossible to distinguish between filter types from vehicle register data. Nonetheless, any error introduced in the calculations under this assumption is very small.

The particle emission data for vehicles with filter installed are included in the Danish inventory by assuming that the particle emission factors for pre-Euro 4 vehicles (these vehicles are equipped with free-flow filters) are lowered by 30 % compared with the emission factors from the same Euro technology with no filter installed. For Euro 4 vehicles (these vehicles have DPF installed) the particle emission factors for Euro 5 vehicles are used in the emission inventories.

For all vehicle categories/technology levels not represented by measurements, the emission factors are produced by using reduction factors. The latter factors are determined by assessing the EU emission limits and the relevant emission approval test conditions, for each vehicle type and Euro class.

4.3.3 Adjustment for Euro 5 diesel passenger cars

In COPERT 5 emission factors are available for those Euro 5 diesel passenger cars for which engine control software has been installed to reduce the emissions, because of the diesel scandal.

The Euro 5 vehicles in question were brought to vehicle workshops during the vehicle recall program from 2016-2018. A short description of the recall program and the cars included is given below:

- Engine software was updated in 70,946 cars, evenly shared by 1/3 in each of the years 2016-2018
- Vehicle first registration years of the updated cars were between 2009-2016
- Engine sizes of the updated cars were < 1.4 l (9 %) and 1.4-2 l (91 %)

In DEMOS-Road, the fleet attributes for each year were distributed into first registration year-engine size categories, according to their fleet shares in the respective first registration year-engine size categories.

The number of included cars in the software update program was provided by the Danish Safety Technology Authority (Bonde, 2021) and engine size and model year information was provided by Volkswagen (Hjortshøj, 2021).

4.3.4 Adjustment for biofuel usage

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

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

4.3.5 Adjustment for deterioration

For Euro 1-6 gasoline and diesel[10] fuelled cars and vans, the emissions of NO_X, NMVOC and CO gradually increase due to catalyst wear and are, therefore, modified as a function of total mileage. Even though the emission curves may be serrated for the individual vehicles, on average, the emissions from catalyst cars stabilize after a given cut-off mileage is reached due to OBD (On Board Diagnostics) and the Danish inspection and maintenance programme.

For each year, y, and pollutant, i, the deterioration factors are calculated per first registration year, k, for each vehicle in layer j, by using deterioration coefficients and cut-off mileages, as given in EMEP/EEA (2023), for the corresponding layer j.

These deterioration factors are given by the equation:

$$DF_{k,i,j,y} = A_{i,j} \cdot \ MC_{k,i,j,y} + B_{i,j} \qquad (3)$$

where,

DF = the deterioration factor for a given cumulated mileage, MC, and pollutant i,

MC = the cumulated mileage of vehicles for which the correction is applied,

A_j = the degradation of the emission performance per kilometer for layer j,

B_j = the emission level of a fleet of brand-new vehicles for layer j.

Secondly, the aggregated deterioration factors per layer, are calculated by taking into account vehicle numbers and annual mileage levels per first registration year:

$$\mathrm{D}F_{i,j,y} = \frac{\sum_{k=FYear(j)}^{LYear(j)} DF_{k,i,y} \cdot N_{k,y} \cdot M_{k,y}}{\sum_{k=FYear(j)}^{LYear(j)} DF_{k,i,y} \cdot N_{k,y}} \qquad (4)$$

For N_2O and NH_3, COPERT 5 includes emission 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 (2023), 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

[10] For Euro 1 diesel cars and vans, adjustments due to wear only relate to NMVOC.

low sulphur level interval is assumed to be most representative. The deterioration factors are shown in Annex 6 for 2022.

4.4 Calculation method

4.4.1 Calculation of emissions and fuel consumption for hot engines

Emissions and fuel consumption results for operationally hot engines are calculated in DEMOS-Road for each year, layer and road type. DEMOS-Road uses the COPERT V detailed calculation methodology. The calculation procedure is to combine fuel consumption and emission factors (and deterioration factors for catalyst vehicles), number of vehicles, annual mileage levels and the relevant road-type shares given in Table 4.1. For non-catalyst vehicles this yields:

$$E_{j,k,y} = EF_{j,k,y} \cdot S_k \cdot N_{j,y} \cdot M_{j,y} \qquad (5)$$

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

For catalyst vehicles the calculation becomes:

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

4.4.2 Calculation of extra emissions and fuel consumption for cold engines

For cars and vans, extra emissions of NO_x, VOC, CH_4, CO, PM, N_2O, NH_3 and fuel consumption from cold start are calculated separately in DEMOS-Road, using the detailed calculation methodology and cold start emission factors from COPERT 5. For SO_2 and CO_2, the extra emissions are derived from the cold start fuel consumption results.

Each trip is associated with cold-start emissions that is assumed to occur during urban driving conditions. The number of trips is distributed evenly across the months. First, cold emission factors are calculated as the hot emission factor times the cold:hot emission ratio. Secondly, the extra emission factor during cold start is found by subtracting the hot emission factor from the cold emission factor. Finally, this extra factor is applied on the part of the total mileage driven during cold start for all vehicles in the specific layer.

The cold:hot ratios depend on the average trip length and the monthly ambient temperature distribution. The Danish temperatures for 2022 are given in Rubek et al. (2023). For previous years, temperature data are taken from similar reports available from The Danish Meteorological Institute (www.dmi.dk).

The cold:hot ratios are equivalent for gasoline fuelled passenger cars and vans, and for diesel passenger cars and vans, respectively, see EMEP/EEA (2023).

For conventional gasoline (pre-Euro 1) and pre-Euro 6 diesel vehicles the extra emissions become:

$$CE_{j,y} = \beta \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr - 1) \qquad (7)$$

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

For gasoline Euro 1-5 catalyst vehicles, the cold:hot ratio is also trip speed dependent. The ratio is, however, unaffected by catalyst wear. The Euro 1 cold:hot ratio is used for all Euro 1-5 catalyst technologies. However, to comply with the gradually stricter Euro 2-5 emission standards, the catalyst light-off temperature must be reached in even shorter periods of time for newer EURO 2-5 standards. Correspondingly, the β-factor for Euro 1 gasoline vehicles is reduced stepwise for Euro 2, 3, 4 and 5, with the β-reduction factor, β_{red}.

For gasoline Euro 1-5 catalyst vehicles, the cold extra emissions are found from:

$$CE_{j,y} = \beta_{red} \cdot \beta_{Euro\ 1} \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr_{Euro\ 1} - 1) \quad (8)$$

where β_{red} = the β reduction factor for Euro 2-5.

For Euro 6 vehicles, the cold extra emissions are found from:

$$CE_{j,y} = \beta_{red,Euro\ 6} \cdot \beta \cdot N_{Euro\ 6,y} \cdot M_{Euro\ 6,y} \cdot EF_{U,Euro\ 6,y} \cdot (CEr_{Euro\ 6} - 1) \quad (9)$$

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

For N_2O and NH_3, specific cold start emission factors are also proposed by COPERT 5. For catalyst vehicles, however, just like in the case of hot emission factors, the emission factors for cold start are functions of cumulated mileage (emission deterioration). The level of emission deterioration also relies on the content of sulphur in the fuel. The deterioration coefficients are given in EMEP/EEA (2023), 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.

4.4.3 Calculation of evaporative emissions from gasoline vehicles

For each year, evaporative emissions of hydrocarbons are calculated for hot and warm running loss, hot and warm soak and diurnal evaporation. The calculations in DEMOS-Road follow the Tier 2 approach in COPERT 5. The basic emission factors are season related (predefined by four ambient temperature intervals), for Danish climate conditions the temperature intervals [-5, 10], [0, 15] and [10, 25] °C are used. The emission factors are shown in more details in EMEP/EEA (2023).

Running loss emissions originate from vapour generated in the fuel tank while the vehicle is running. The distinction between hot and warm running loss emissions depends on engine temperature, i.e. the engine being either hot or cold. The emissions are calculated as annual mileage (broken down into cold and hot mileage totals using the β-factor) times the respective emission factors. For vehicles equipped with evaporation control (catalyst cars) only hot running loss emissions occur.

$$E_{j,y}^{R} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot ((1-\beta) \cdot HR + \beta \cdot WR) \quad (10)$$

Where E^R is running loss emissions, l_{trip} = the average trip length, and HR and WR are the hot and warm running loss emission factors, respectively.

Hot and warm soak emissions also occur for carburettor vehicles (no evaporation control), whereas for catalyst cars (evaporation control) only hot soak emissions occur. The soak emissions are calculated as number of trips (broken down into cold and hot trip numbers using the β-factor) times respective emission factors:

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

Where E^S is the soak emission, l_{trip} = the average trip length, and HS and WS are the hot and warm soak emission factors, respectively.

Average maximum and minimum temperatures per month are used in combination with diurnal emission factors to estimate the diurnal emissions from both carburettor and catalyst vehicles E^D:

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

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

4.4.4 Calculation of non-exhaust particulate emissions from road transport

The TSP, PM_{10}, $PM_{2.5}$, BC, heavy metal and PAH emissions arising from tyre and brake wear (SNAP 0707), and the TSP, PM_{10}, $PM_{2.5}$ and heavy metal emissions from road abrasion (SNAP 0708) are estimated as prescribed by the UNECE convention reporting format. The emissions are calculated in DEMOS-Road by multiplying the total annual mileage per vehicle category with the correspondent average emission factors for each source type. The calculation procedure is consistent with the COPERT 5 model approach used in DEMOS-Road to estimate the Danish national emissions coming from exhaust.

TSP tyre wear emission factors (mg/vkm) for different vehicle categories are taken from EMEP/EEA (2023). These tyre wear emission factors are further differentiated according to urban, rural and highway driving using relative trip speed correction functions from EMEP/EEA (2023).

From EMEP/EEA (2023) one gets that 60 % and 42 % of tyre wear TSP is emitted as PM_{10} and $PM_{2.5}$, respectively, thus enabling the calculation of PM_{10} and $PM_{2.5}$ emission factors (mg/vkm).

For brake wear and road abrasion the emission factors (mg/vkm) also come from EMEP/EEA (2023). The PM_{10} and $PM_{2.5}$ fractions of emitted TSP are 0.98 and 0.39 for brake wear, respectively, and 0.5 and 0.27 for road abrasion, respectively. The emission factors and total emissions for 2022 are shown in Annex 15. For all three non-exhaust sources, the non-exhaust emission factors for heavy metals are estimated using the content of heavy metals in worn material (emitted as TSP) given in EMEP/EEA (2023).

4.4.5 Energy balance between inventory and sales

The calculated fuel consumption in DEMOS-Road must equal the statistical fuel sale totals according to the UNFCCC and UNECE emissions reporting format. The statistical fuel sales for road transport are derived from the Danish Energy Authority data (see DEA, 2023).

For gasoline, the DEA sales data for road transport are adjusted at first, to account for e.g. non-road and recreational craft fuel consumption, which are not directly stated in the statistics. Please refer to chapter 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 bottom-up gasoline fuel consumption on Danish roads and total gasoline fuel sold.

For diesel, the DEA sales data for road transport are adjusted at first, to account for recreational craft fuel consumption, which are not directly stated in the statistics.

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

The diesel border sales (diesel used abroad) are allocated to truck-trailer and articulated trucks (TT/AT trucks) in two total vehicle weight categories, < 40 tonnes and > 40 tonnes, and coaches.

The distribution of the diesel used abroad is split into the three vehicle categories by using the relative fuel consumption used in Denmark by foreign TT/AT trucks (< 40 tonnes and > 40 tonnes) and coaches (calculated based on mileage driven in Denmark by foreign trucks (chapter 4) and corresponding fuel consumption factors).

The calculated "border" scaling factors of the TT/AT trucks and coaches in the model, i.e. the ratio between the total model fuel consumption (model fuel consumption in Denmark and model fuel consumption abroad) and the model fuel consumption in Denmark for these vehicle categories are shown in (Figure 4.3).

The total model fuel consumption for all vehicle categories is subsequently calculated in a first step, as the product of fuel consumption factors and corresponding total mileage, the latter being adjusted for mileage driven outside Denmark, as described above in the case of TT/AT trucks and coaches (adjusted bottom-up diesel fuel consumption).

Next, the percentage difference between the first step model diesel fuel consumption (adjusted bottom-up diesel fuel consumption) and the total diesel fuel sold in Denmark is used to scale fuel and emission results for all diesel vehicles regardless of vehicle category (Figure 4.3). The data behind the Figures 4.3 and 4.4 are also listed in Annex 8.

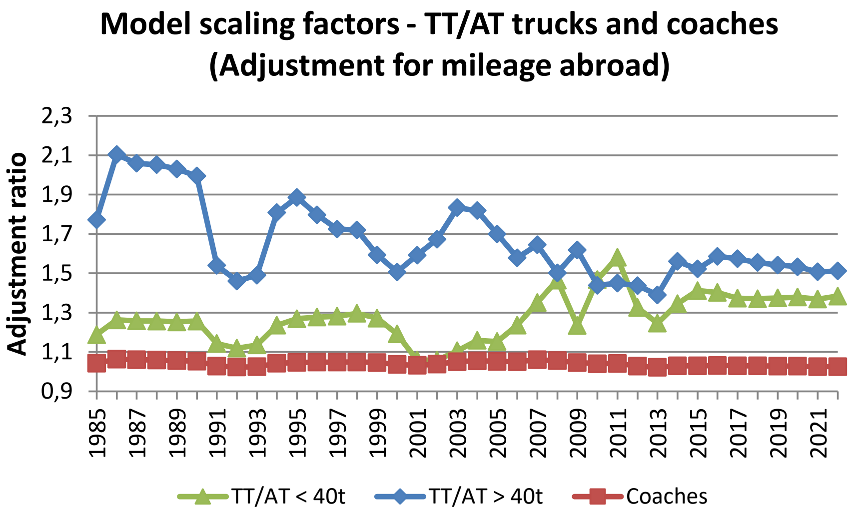


Figure 4.3 Fuel and emission adjustment ratios for TT/AT trucks and coaches: Bottom-up fuel consumption plus diesel used abroad vs bottom-up fuel consumption.

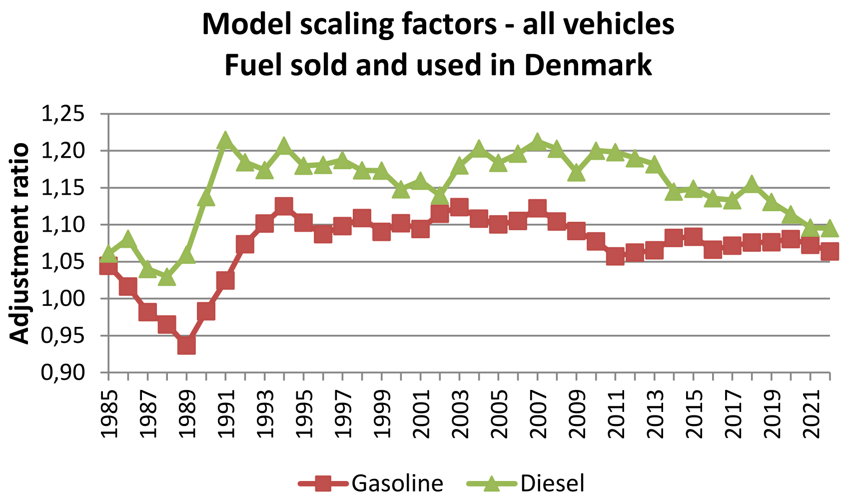


Figure 4.4 Gasoline and diesel fuel ratios (fuel and emission adjustment factors) regardless of vehicle category: Fuel sold and used in Denmark vs bottom-up fuel consumption used in Denmark

The reasons for the differences between DEA sales figures and bottom-up fuel estimates shown in Figure 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 1985-2022. The total fuel consumption and emissions are shown in Annex 8, per vehicle category and as grand totals, for 1985-2022 (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 2022.

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 (exhaust only), 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, bioethanol and biodiesel became available from a limited number of gas filling stations in Denmark, and today bioethanol and biodiesel (FAME) is added to all fuel commercially available. Following the IPCC guideline definitions, biofuels are in principle regarded as CO_2 neutral for the transport sector as such. A small part of carbon (and the associated CO_2 emissions) in biodiesel, however, have a fossil origin due to the use of fossil-derived methanol in the biodiesel production process. This is accounted for in the emission inventories by following the biodiesel fossil carbon content calculation methodology provided by Sempos (2019).

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 5 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:

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

Where:

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

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

The kilometer based average CO_2 emission factor is subsequently calculated as the product of the fuel related CO_2 emission factor from equation 13 and the energy based fuel consumption factor, $FC_{CO2,E}(BF0)$, derived from COPERT 5:

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

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

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

The fuel related CO_2 emission factors for neat gasoline, diesel, CNG and LPG, and for bio ethanol, biodiesel and bio CNG, and the aggregated CO_2 factors are shown in Table 3.3.7. For gasoline and compressed natural gas (CNG) the CO_2 emission factors are country specific. For gasoline, 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 (Energinet.dk, 2022). For liquefied petroleum gas (LPG), the emission factor source is EMEP/EEA (2023). For diesel the emission factor source is IPCC (2006) [11].

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	2017	2018	2019	2020	2021	2022
Neat diesel	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1
Neat gasoline	73	73	73	73	73	73	73	73	73	73	73	73	73	73	73	73	73	73
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	56.8	56.8	56.8	56.8	56.8	56.8
LPG	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8
Biodiesel	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Bio ethanol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bio CNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diesel avg.	74.1	74.1	74.1	74.1	74.0	74.1	71.8	69.7	69.5	69.5	69.6	69.6	69.8	69.9	69.5	69.5	69.5	69.9
Gasoline avg.	73	72.9	72.8	72.8	72.8	71.8	70.7	70.5	70.6	70.6	70.7	70.7	70.7	70.7	70.7	68.4	68.5	68.6
CNG avg.	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.2	55.1	53.8	52.7	51.1	47.6	44.4	38.2
	Biofuel share (BF%) of Danish road transport fuels																	
	1990-2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	0	0.09	0.14	0.12	0.20	0.66	3.2	5.2	5.4	5.4	5.3	5.3	5.2	5.1	5.4	6.5	6.5	6.0

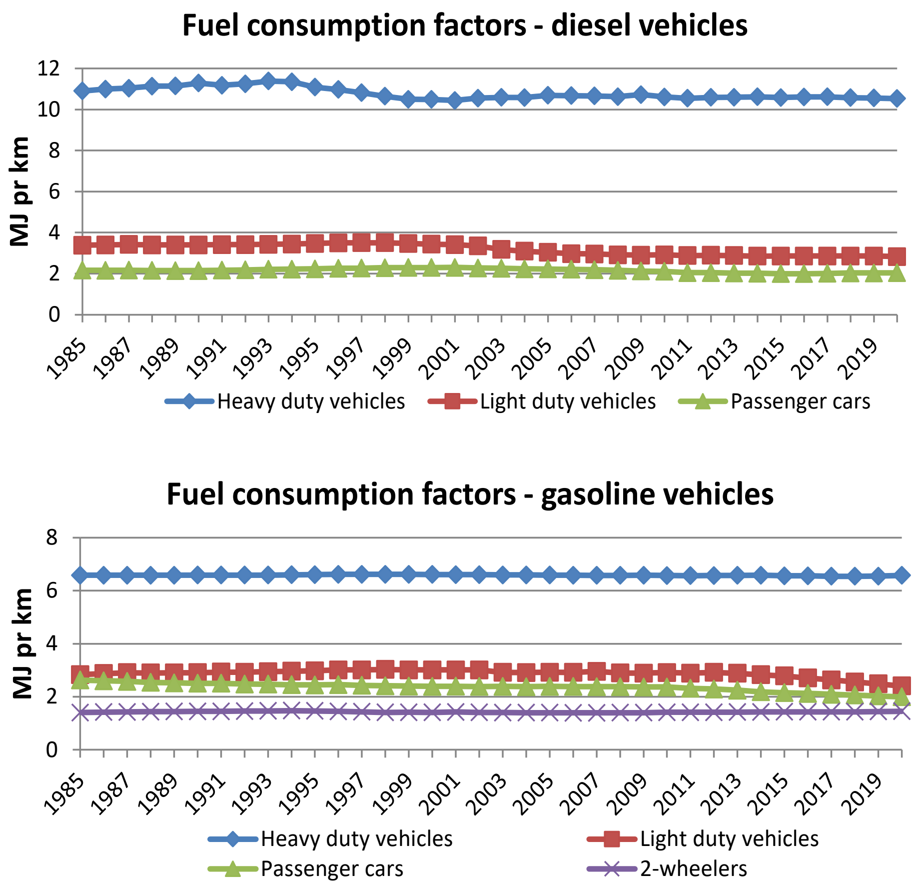


Figure 4.5 Km related fuel consumption factors per fuel type and vehicle type for Danish road transport (1985-2020).

[11] A country-specific emission factor for diesel used in road transportation is not during 2008-2016 is 74.1 kg/GJ, an EF identical to the IPCC (2006) default data. available from Danish refineries. Instead, the diesel EF for Danish stationary combustion is assessed, which is from the EU ETS. The average CO_2 EF of diesel burned in stationary Danish sources.

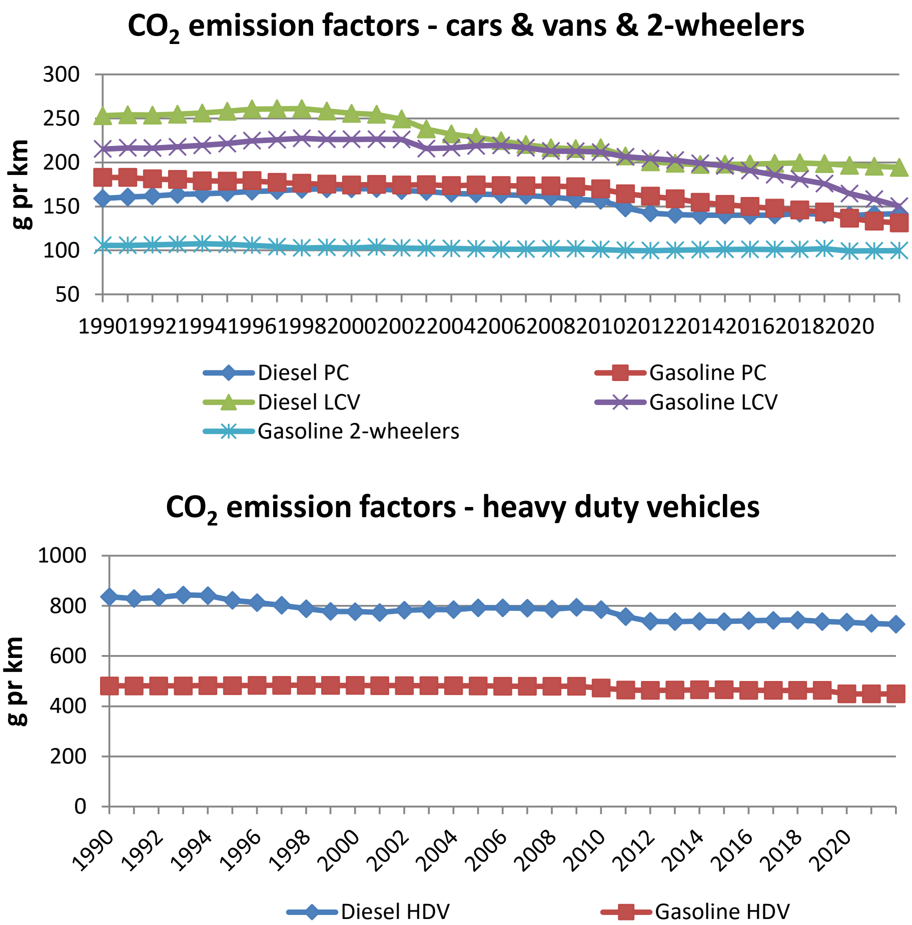


Figure 4.6 Km related CO_2 emission factors per vehicle type for Danish road transport (1990-2022).

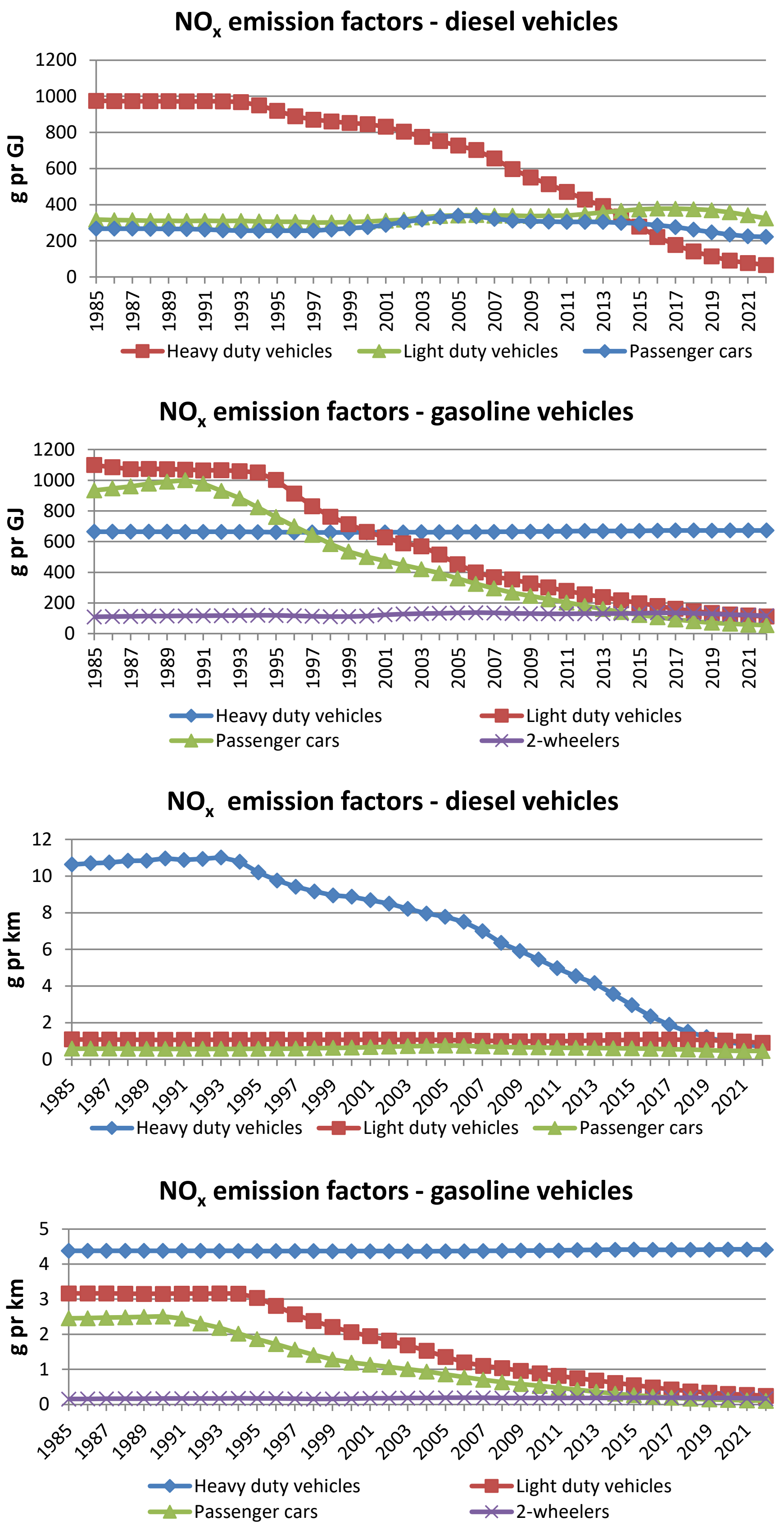


Figure 4.7 Fuel and km related NO_x emission factors per vehicle type for Danish road transport (1985-2022).

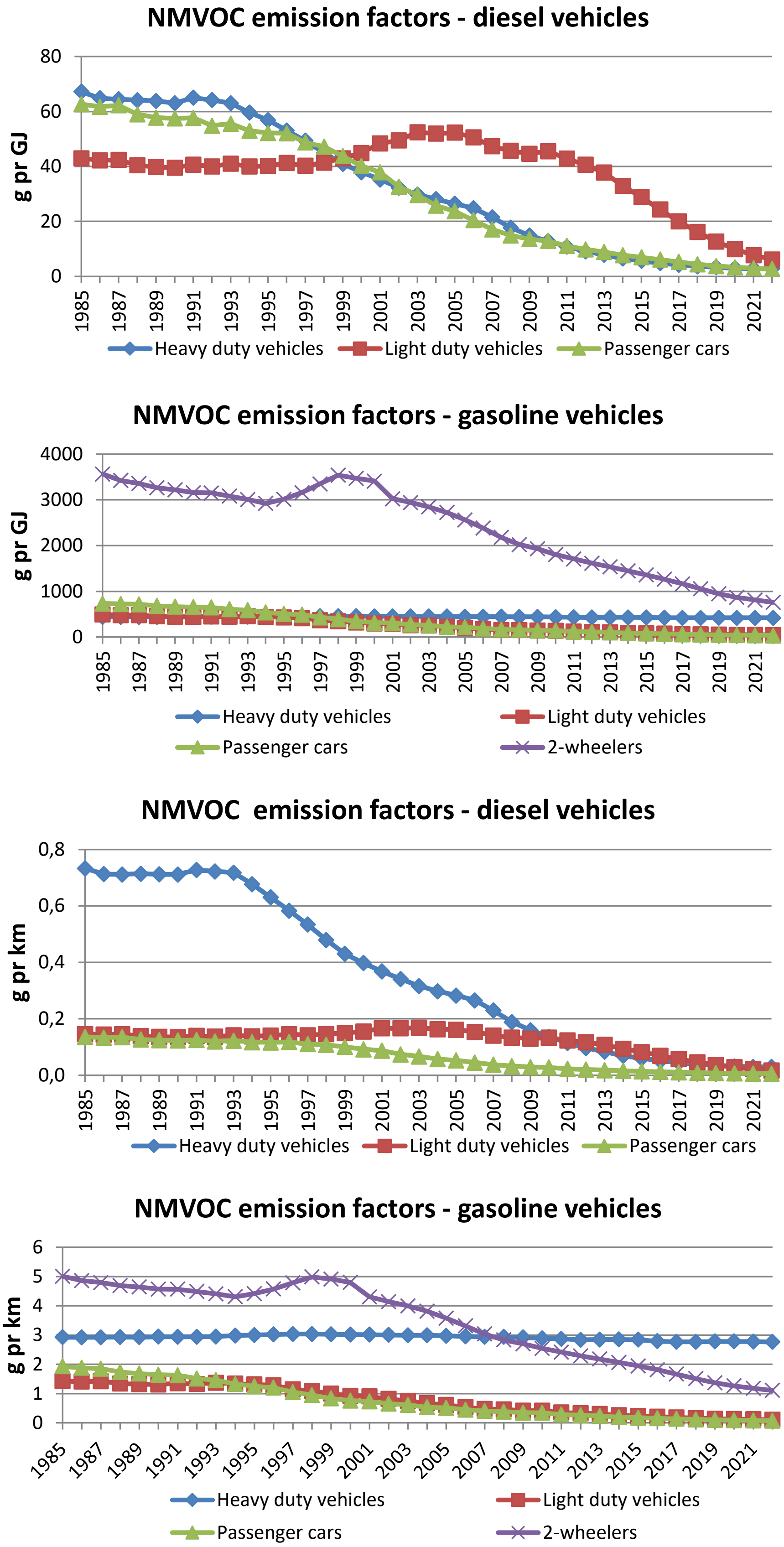


Figure 4.8 Fuel and km related NMVOC emission factors per vehicle type for Danish road transport (1985-2022).

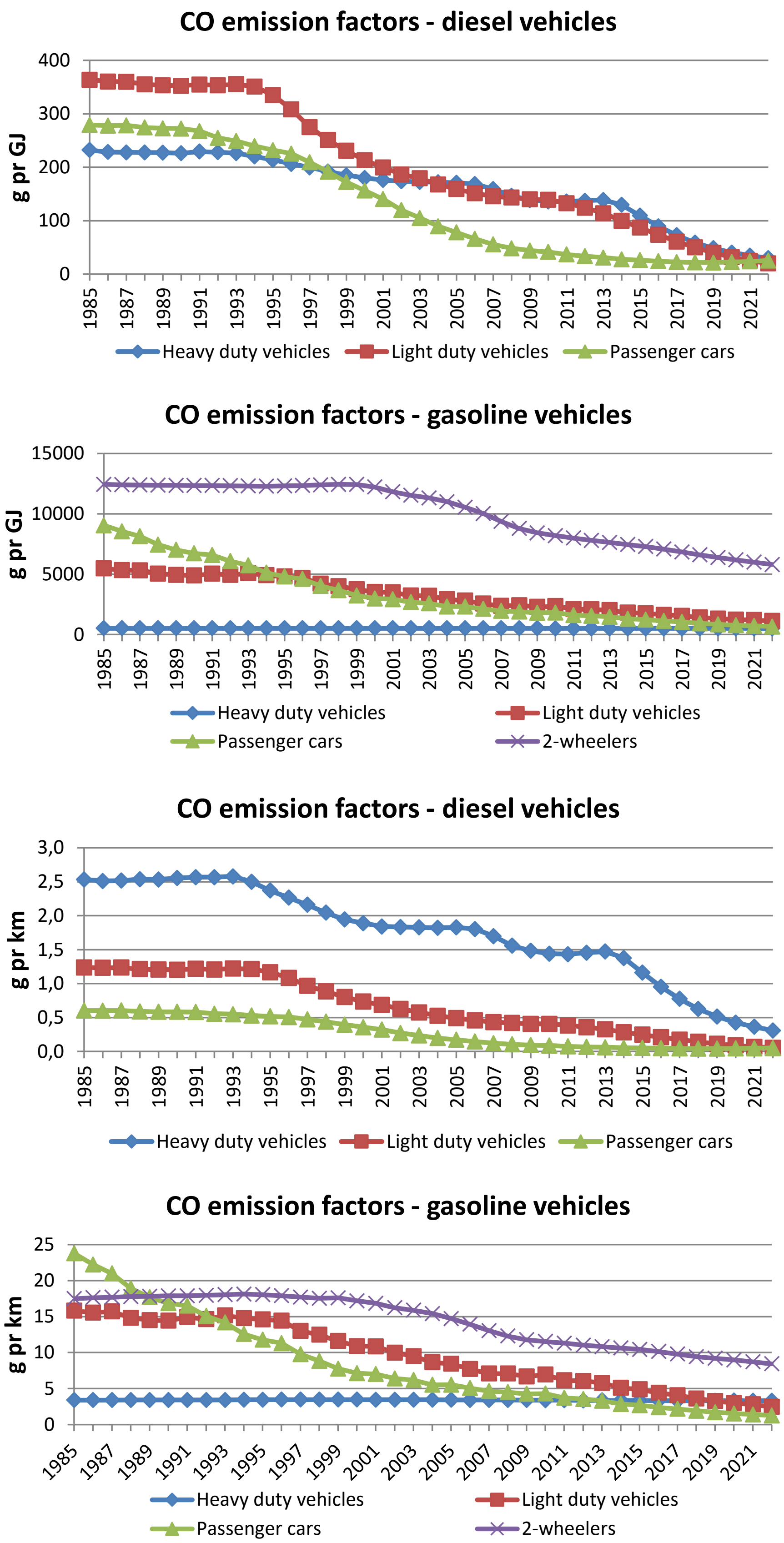
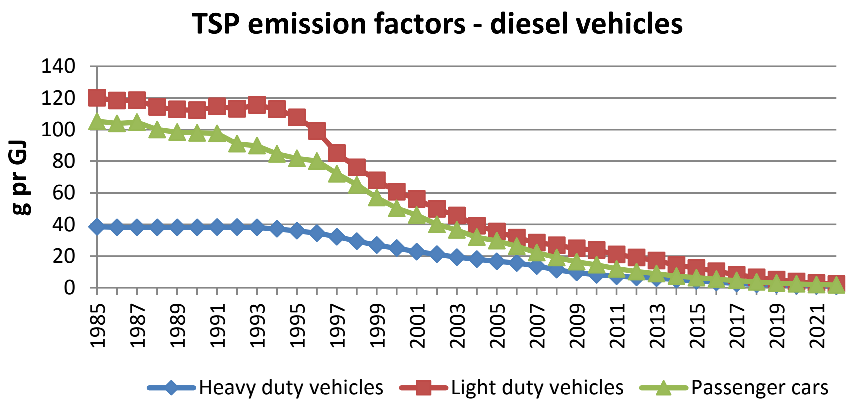
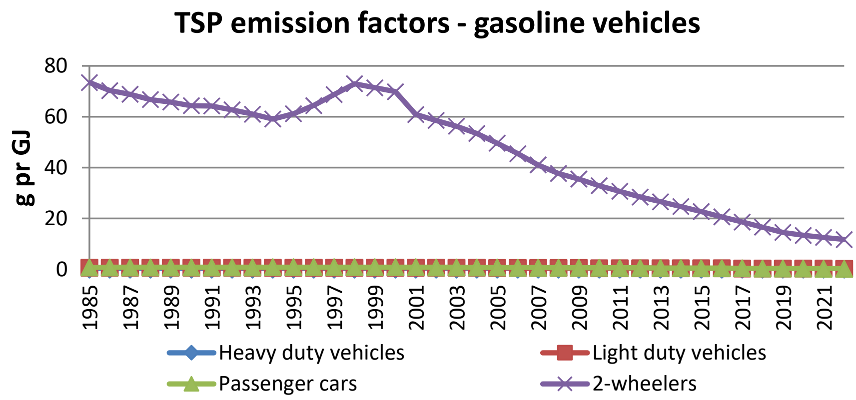
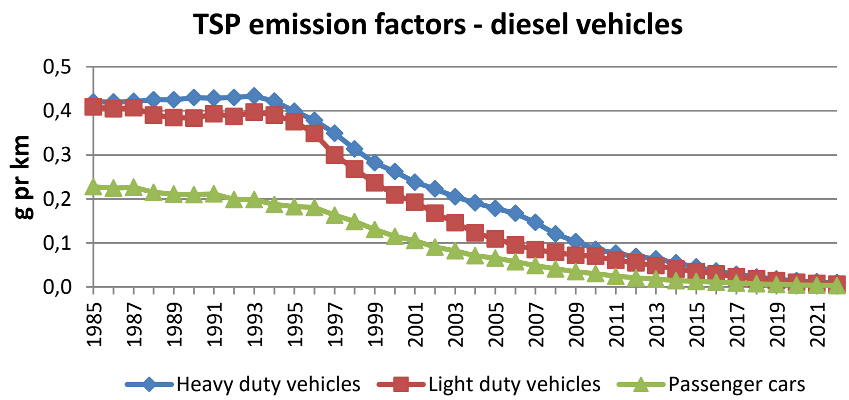


Figure 4.9 Fuel and km related CO emission factors per vehicle type for Danish road transport (1985-2022).







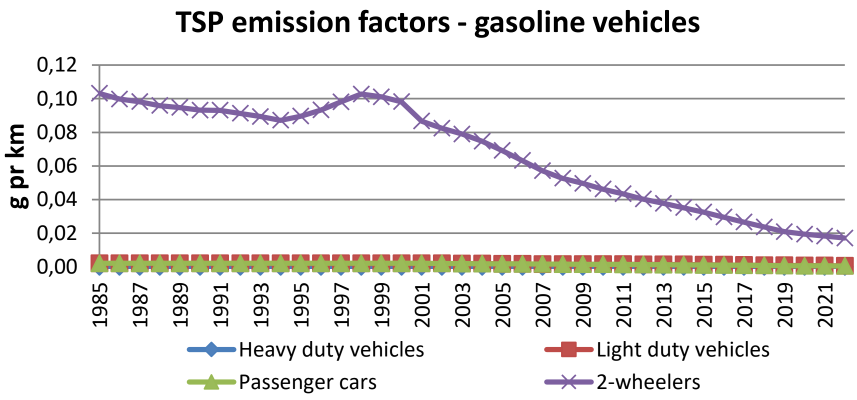


Figure 4.10 Fuel and km related TSP (exhaust only) emission factors per vehicle type for Danish road transport (1985-2022).

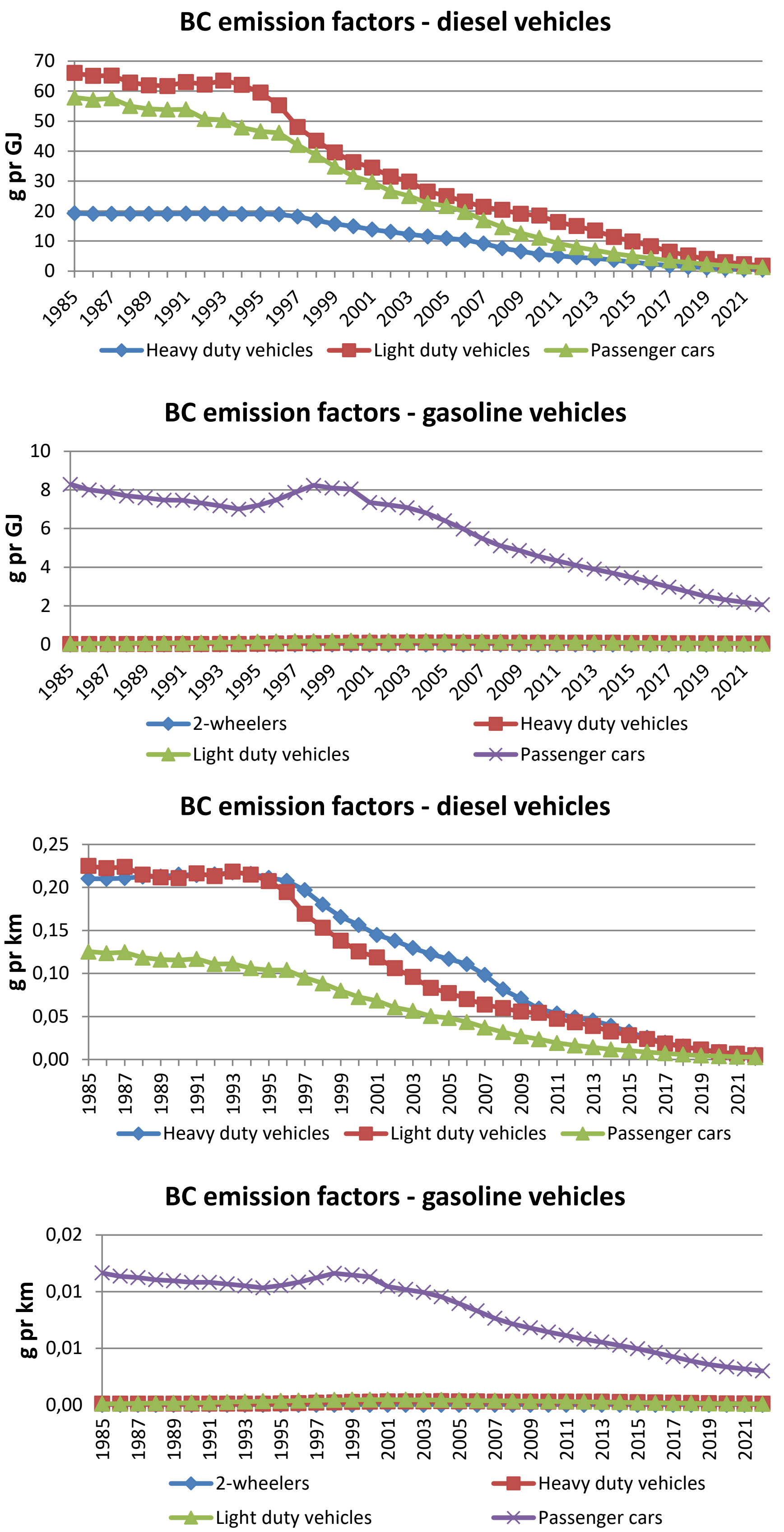


Figure 4.11 Fuel and km related BC emission factors per vehicle type for Danish road transport (1985-2022).

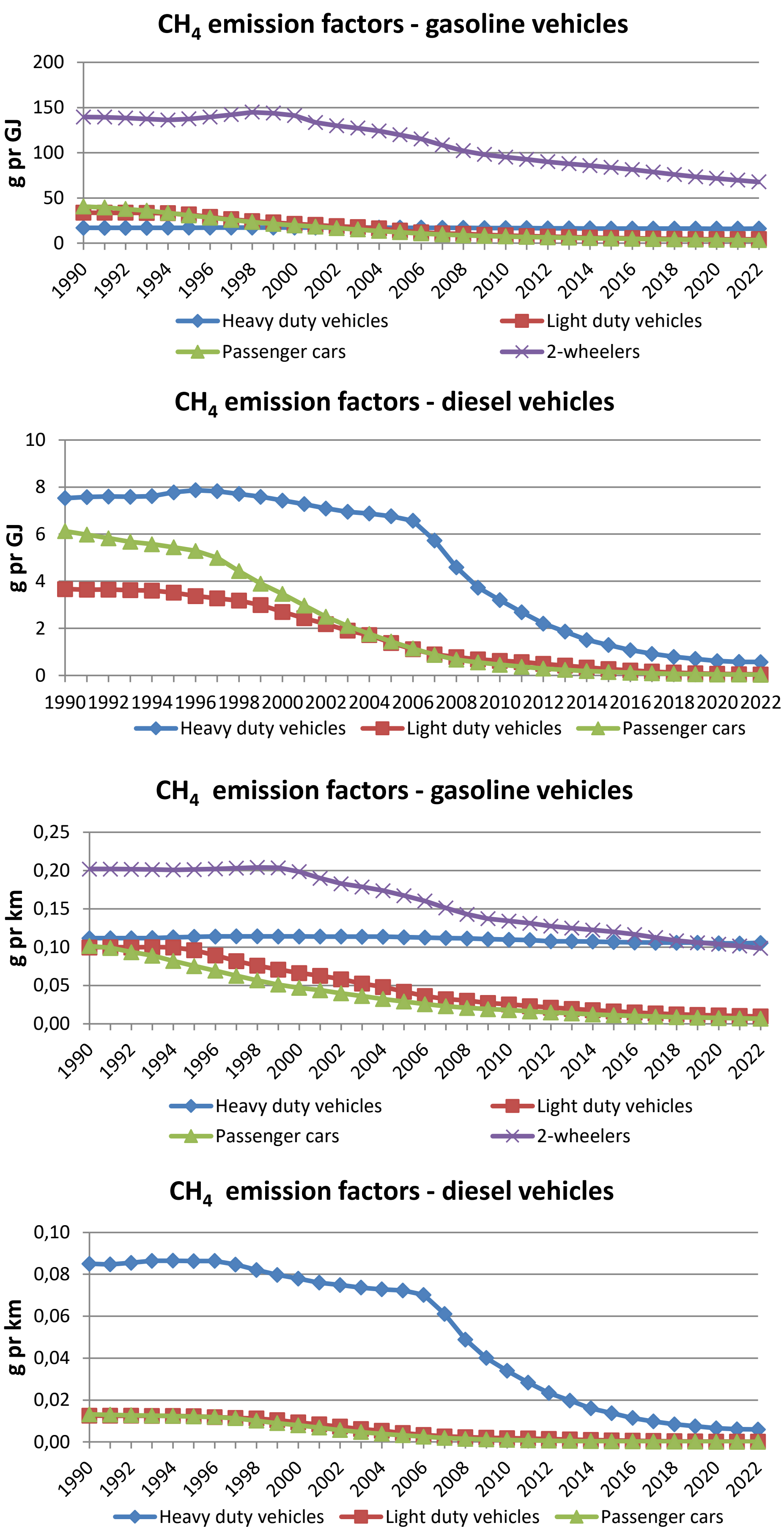


Figure 4.12 Fuel and km related CH_4 emission factors per vehicle type for Danish road transport (1990-2022).

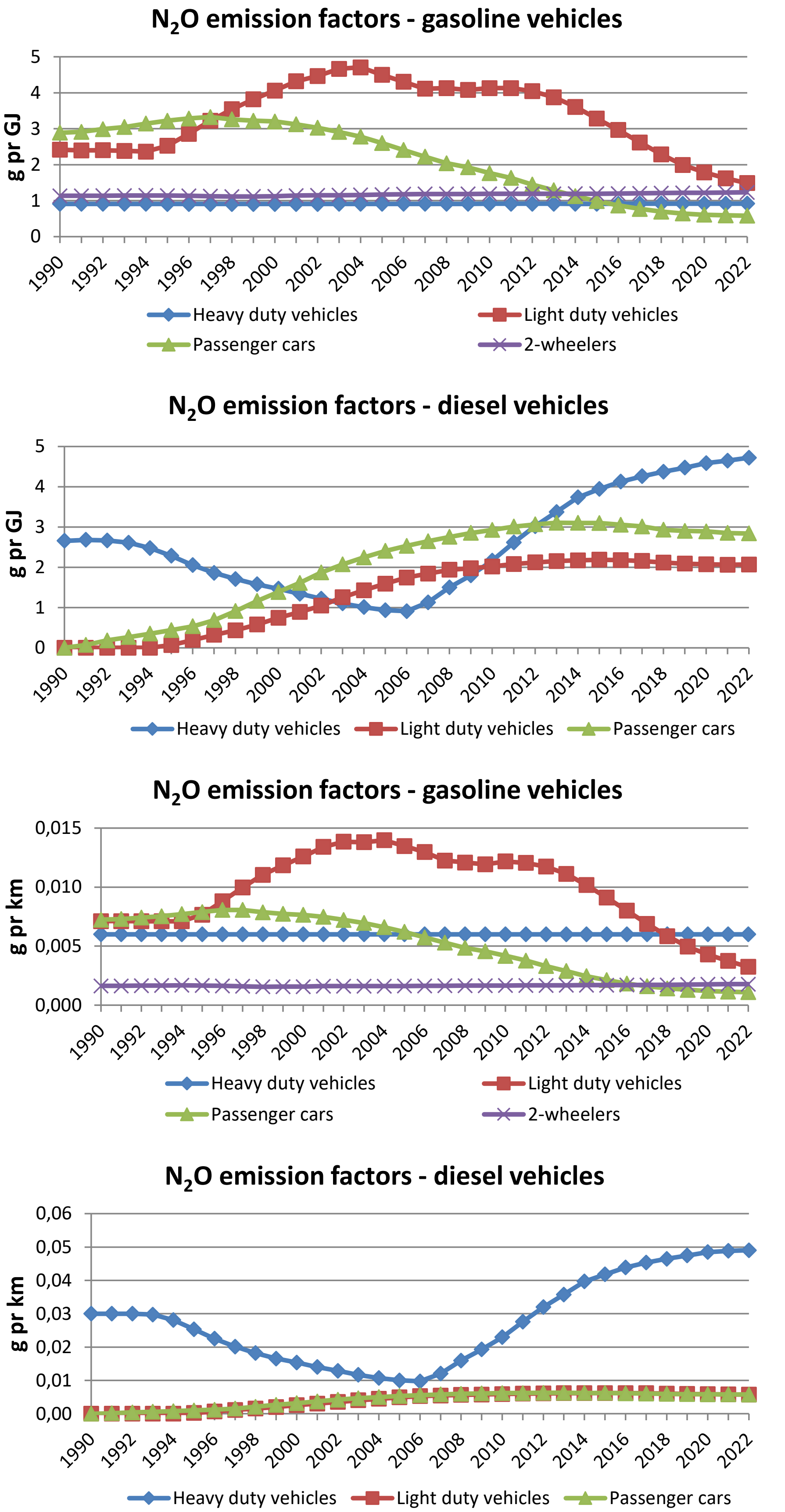


Figure 4.13 Fuel and km related N_2O emission factors per vehicle type for Danish road transport (1990-2022).

5 Input data and calculation methods for other mobile sources

The emission inventories for other mobile sources are divided into several sub-sectors: Civil aviation, national navigation, national fishing, railways, military, and non-road mobile machinery in agriculture, forestry, industry, commercial/institutional and residential.

The emission calculations are made for each sub-sector in the DEMOS model using the detailed method as described in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2023)[12].

5.1 Activity data

5.1.1 Air traffic

The activity data used in DEMOS-Aviation consists of air traffic statistics provided by the Danish Civil Aviation and Railway Authority and Copenhagen Airport. Fuel statistics for jet fuel consumption and aviation gasoline are obtained from the Danish energy statistics (DEA, 2023a).

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

In DEMOS-Aviation, each aircraft type is paired with a representative aircraft type, for which fuel consumption and emission data exist in the EMEP/EEA databank. As a basis, the type relation table is taken from the Eurocontrol AEM model, which is the primary source for the present EMEP/EEA fuel consumption and emission data. Supplementary aircraft types are assigned to representative aircraft types based on the type relation table already established in the previous version of DEMOS-Aviation (e.g. Winther, 2022a).

Additional aircraft types not present in the type relation table are identified by using different aircraft dictionaries and internet look-ups. 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 domes-

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

tic and international flights starting from Copenhagen Airport and other airports, respectively[13], in a time series from 2001-2022. The airport split is necessary to make due to the differences in LTO emission factors (cf. section 3.3.4).

The same type of LTO activity data for the flights for Greenland and the Faroe Islands are shown in Annex 10 also, further detailed into origin-destination airport pairs and associated flight distances. This level of detail meets the demand from UNFCCC to provide precise documentation for the part of the inventory for the Kingdom of Denmark being outside the Danish mainland.

The ideal flying distance (great circle distance) between the city-pairs is calculated by DCE in a separate database. The calculation algorithm uses a global latitude/altitude coordinate table for airports. In cases when airport coordinates are not present in DEMOS-Aviation, these are looked up on the internet and entered the database accordingly. In practise, the actual distance flown are longer than the great circle distance between two airports, and in addition, the LTO flight phase has an extent of 15 NM. This is adjusted for in DEMOS-Aviation, as explained in section 5.4.1.

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 Civil Aviation and Railway Authority. The assignment of representative aircraft types for Copenhagen Airport is done as described above. For the remaining Danish airports, representative aircraft types are not directly assigned. Instead, appropriate average assumptions are made relating to the fuel consumption and emission data part.

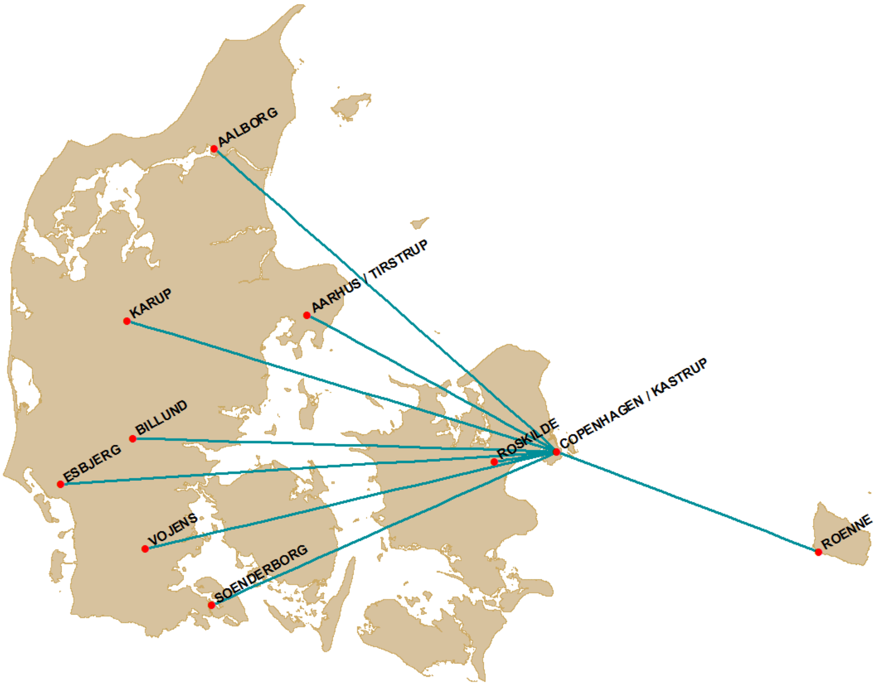
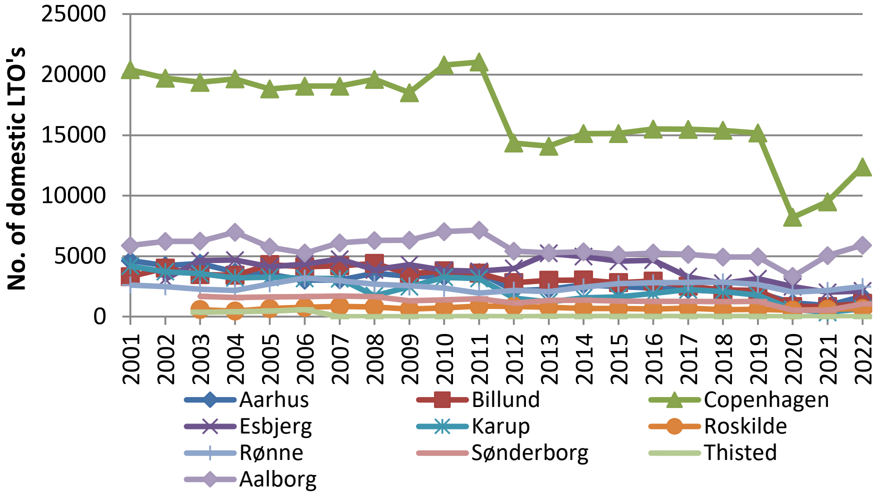


Figure 5.1 Most frequent domestic flying routes for large aircraft in Denmark.

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

Copenhagen Airport is the starting or end point for most of the domestic aviation made by large aircraft in Denmark (Figure 5.2; routes to Greenland/Faroe Islands are not shown). Even though many domestic flights not touching Copenhagen Airport are also reported in the flight statistics kept by the Danish Civil Aviation and Railway Authority, these flights, however, are predominantly made with small piston engine aircraft using aviation gasoline. Hence, the consumption of jet fuel by flights not using Copenhagen Airport is merely marginal.



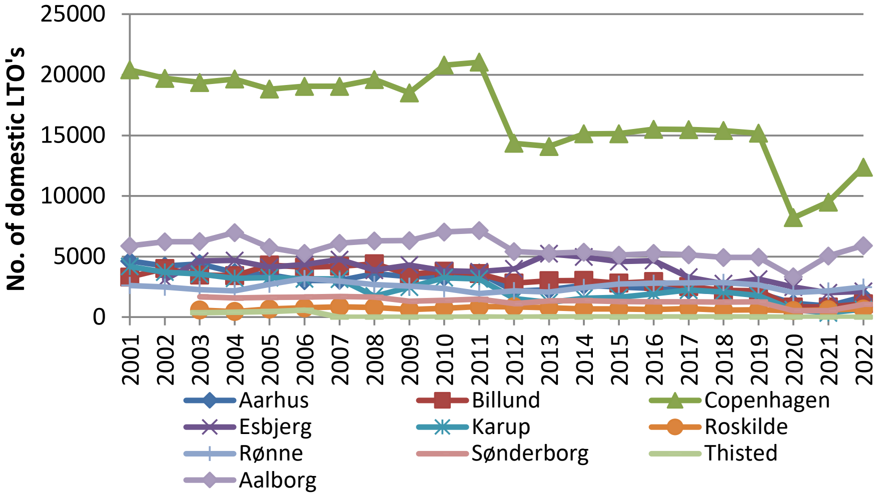


Figure 5.2 No. of LTO's for the most important airports in Denmark 2001-2022.

Figure 5.2 shows the number of domestic and international LTO's for Danish airports[14], in a time series from 2001-2022.

5.1.2 Non-road working machinery and equipment

Non-road mobile machinery is used in the agricultural, forestry, industrial, commercial/institutional and residential sectors, and the activity data are gathered from numerous sources. The activity data for non-road mobile machinery are described in the following together with activity data for recreational craft.

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

Detailed tractor fleet data for 2003-2020 and total numbers 1950-2002 for tractors in the Danish motor register are provided by Statistics Denmark (2021a, 2021b).

Total numbers for tractors (tractors in motor register and other tractors) for 1982-2005 are provided by Statistics Denmark (2021c). Total numbers for tractors (tractors in motor register and other tractors) for 1974-1981 are found in consecutive statistical publications e.g. Agricultural statistics 1974 (Statistics Denmark, 1975), as well as supplementary stock numbers per fuel type (diesel and gasoline).

Supplementary new sales data in kW classes are provided by the Association of Danish Agricultural Machinery Dealers for 1982-2018. Engine load factors and annual working hours for tractors come from Bak et al. (2003).

Number of forestry machines, engine size, annual working hours and average lifetimes are provided by the Danish Forest Association (Clemmensen, 2022).

For the most important types of building and construction machinery used in industry, annual new sales data for 1996 onwards has been provided by the Association of Danish Agricultural Machinery Dealers (Fasting, 2023).

Forklift sales data has been provided by the Association of Producers and Distributors of Forklifts in Denmark for 1976-2019. Further, WITS (World Industrial Truck Sales) and FEM (Federation European Material) forklift sales figures for Denmark in 2000-2022 as well as branch distribution information has been provided by Toyota Material Handling (Christensen, 2023).

For telescopic loaders, branch distribution information has been provided by Scantruck (Faurby, 2021).

The share of Stage IIIB and IV diesel engines used in the building and construction sector with preinstalled diesel particle filters, has been estimated in different engine size classes, based on questionnaire answers from the most important mobile machinery manufacturers and Danish machinery importers (Winther, 2022c).

From engine manufacturers engine load factors have been provided based on electronic engine power registrations (Sjøgren 2016; Mikkelsen 2016) in the case of building and construction machinery. Further, equipment size - engine size relations, equipment scrapping curves and annual working hours as a function of machinery age has been included in the model (Sjøgren 2016; Mikkelsen 2016; Brun 2018; Christensen 2018).

For the most important types of household and gardening machinery used in Commercial/Institutional and Residential, annual new sales data for 2006 onwards is provided by the Association for Industrial Technics, Tools and Automation (BITVA: Brancheforeningen for industriel teknik, værktøj og automation), see Gade (2023). Until 2018 new sales data was provided by the Dealers Association of Electric Tools and Gardening Machinery (LTEH: Leverandørforeningen for Transportabelt Elværktøj og Havebrugs-maskiner). Further, equipment size - engine size relations, equipment scrapping curves and annual working hours as a function of machinery age has been provided by LTEH (Nielsen and Schösser, 2016) and by Nielsen (2022) and Schösser (2022).

The total number of refrigerating units for long distance transport trucks has been estimated for 1990 and 2021 by Teknologisk Institut (1992, 2022). Based on these data, a linear development in the number of refrigerating units from 1990 to 2021 has been assumed. For distribution lorries, the total number of refrigerating units for distribution lorries has been estimated for 1990 by the Teknologisk Institut (1992), and a proportional increase in the number of units has been assumed based on the development in the number of Danish inhabitants from 1990 to 2022.

For a remaining group of non-road mobile machinery types with low emission contributions (e.g. pumps, generators, compressors), total stock numbers from 1990 to 2022 have been estimated based on 1990 stock numbers from Teknologisk Institut (1992, 1993) and a proportional development of the stock numbers with GDP. For these machinery types, load factors, engine sizes and annual working hours has been gathered by Winther et al. (2006).

The stock development from 1985-2022 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) and Winther (2023).

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

For agriculture, the total number of agricultural tractors and harvesters per year are shown in the Figures 5.3-5.4, respectively.

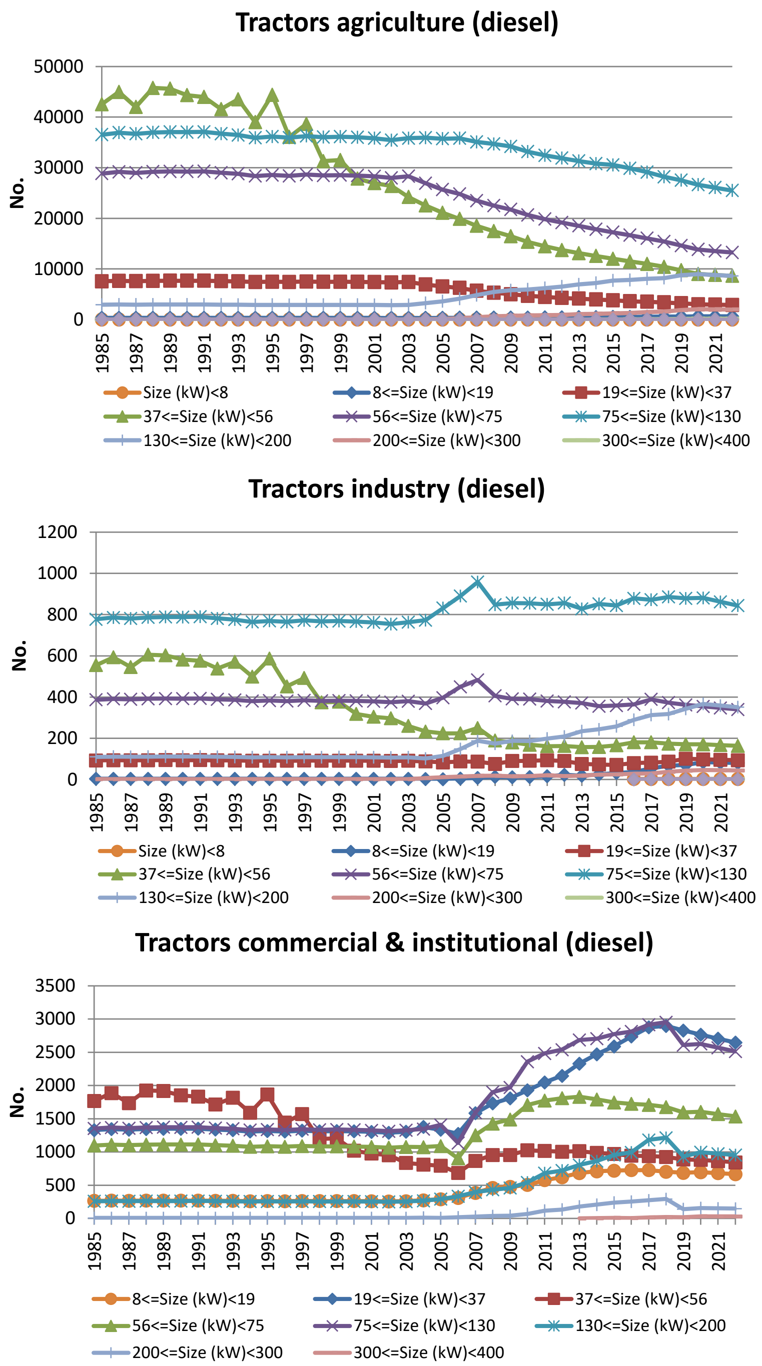


Figure 5.3 Total numbers in kW classes for tractors from 1985 to 2022.

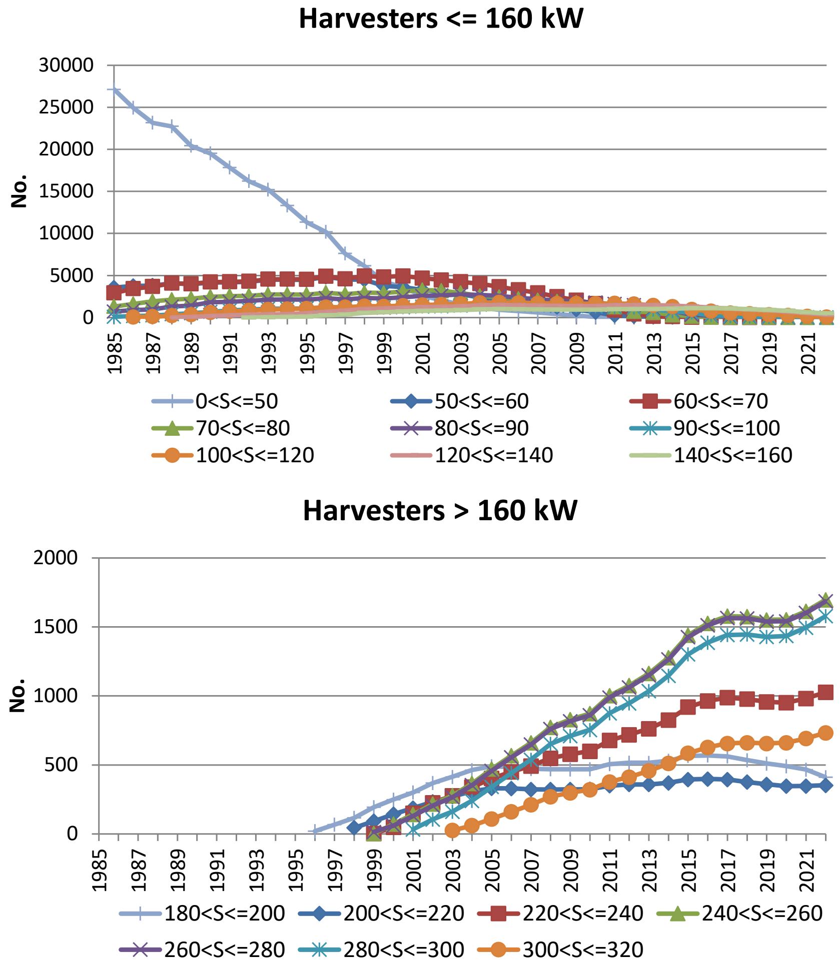
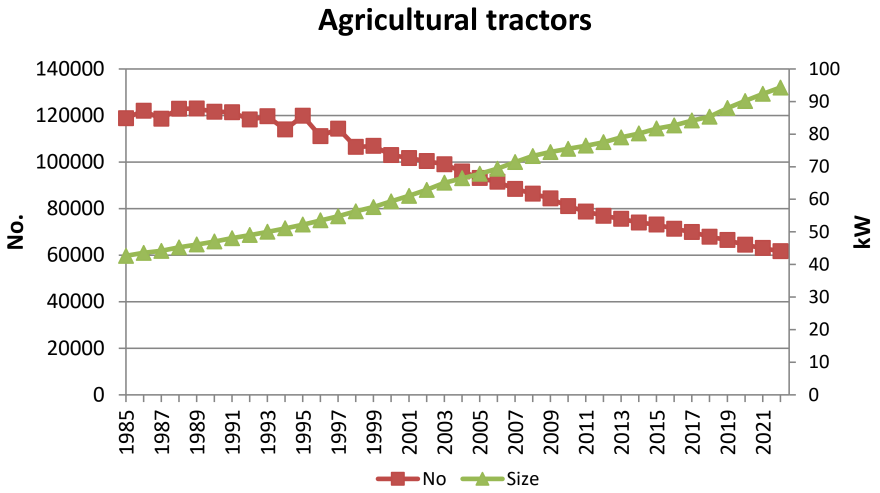


Figure 5.4 Total numbers in kW classes for harvesters from 1985 to 2022.

The tractor and harvester developments towards fewer vehicles and larger engines, shown in Figure 5.5, are very clear. From 1985 to 2022, tractor and harvester numbers decrease by around 48 % and 75 %, respectively, whereas the average increase in engine size for tractors is 121 %, and 395 % for harvesters, in the same period.



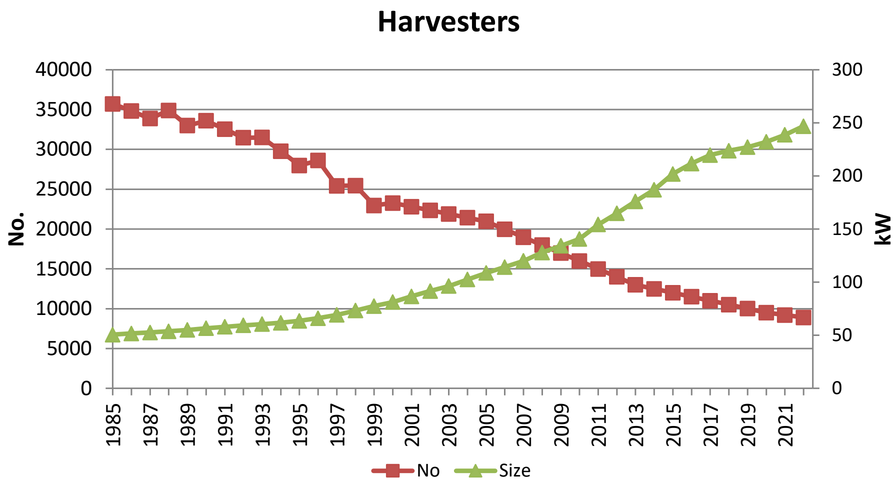


Figure 5.5 Total numbers and average engine size for tractors and harvesters from 1985 to 2022.

The most important non-road machinery types for industry are different types of construction machinery and forklifts. The Figures 5.6 and 5.7 show the 1985-2022 stock development for specific types of construction machinery and diesel and LPG forklifts. Due to lack of data, 1996-1999 average sales data for construction machinery is used for 1995 and back. It is, however, assumed that telescopic loaders first enter into use in 1986 (Jensen, Scantruck 2016). For most of the machinery types used in construction, there is an increase in machinery numbers from 1990 onwards, due to increased construction activities.

Reversely, substantial declines in total stock numbers are noted for diesel and LPG powered forklifts in Figure 5.7, especially during the last two decades. These stock decreases are due to the shift from combustion engines to battery electric powered forklifts in the industry and commercial and institutional sectors.

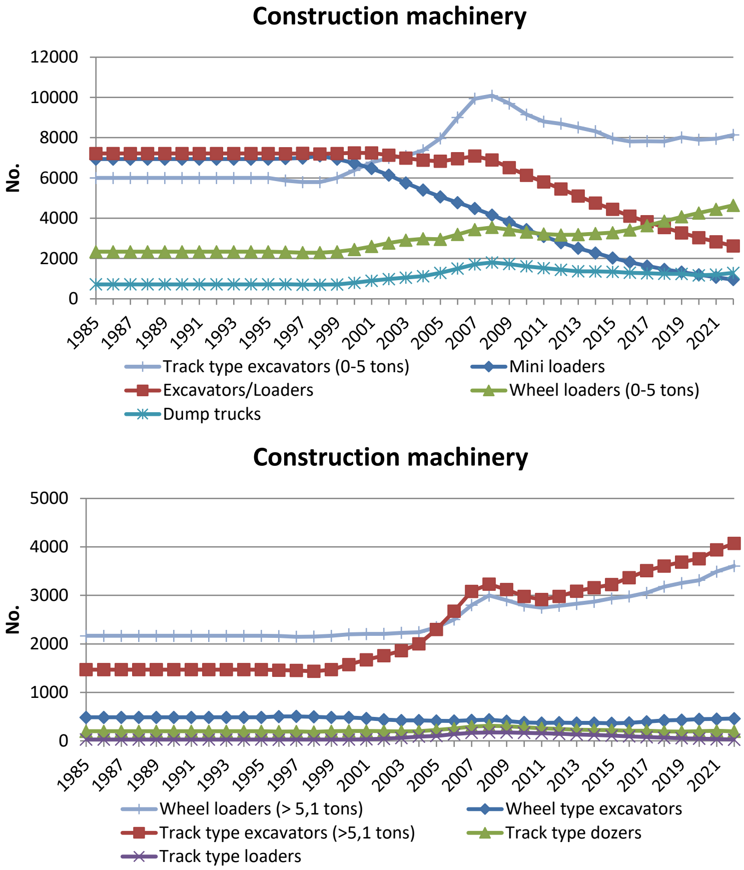


Figure 5.6 1985-2022 stock development for specific types of construction machinery.

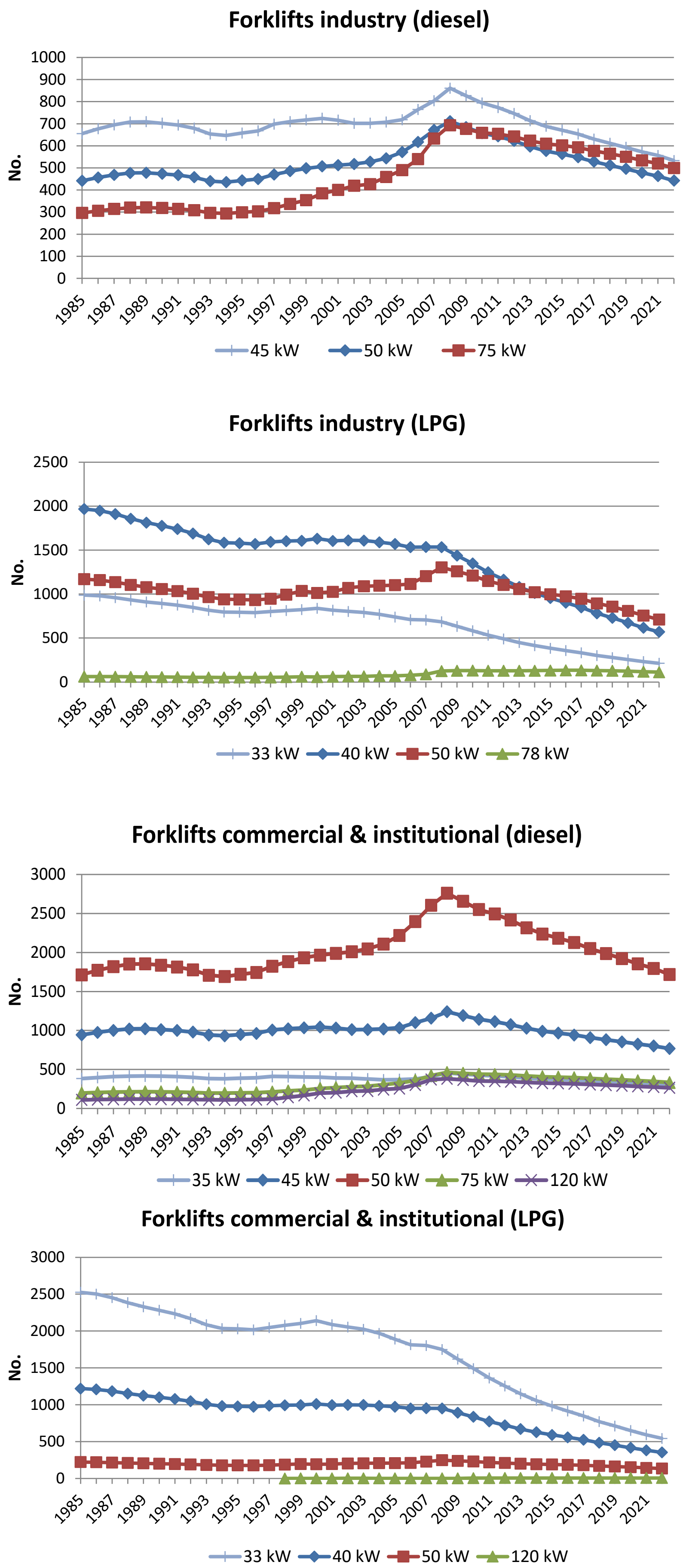
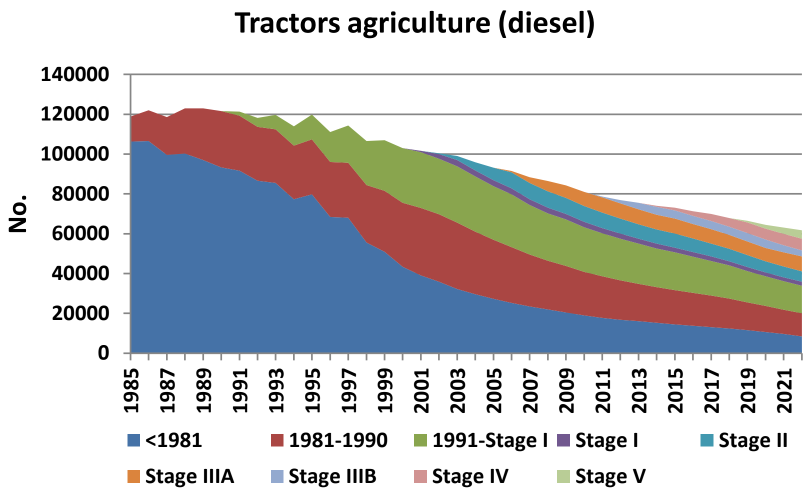


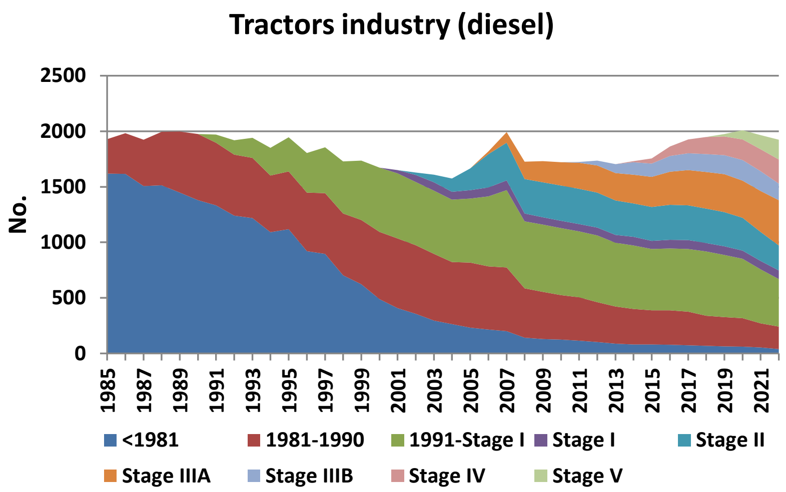
Figure 5.7 Total numbers of diesel and LPG forklifts in kW classes from 1985 to 2022.

Figure 5.8 shows the emission layer distribution for the total stock of tractors, harvesters, construction machinery (most important types, Figure 5.6) and diesel forklifts from 1990-2022.

The penetration of the different pre-Euro engine classes, and engine stages complying with the gradually stricter EU stage I-V emission limits is very visible from Figure 5.8.

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





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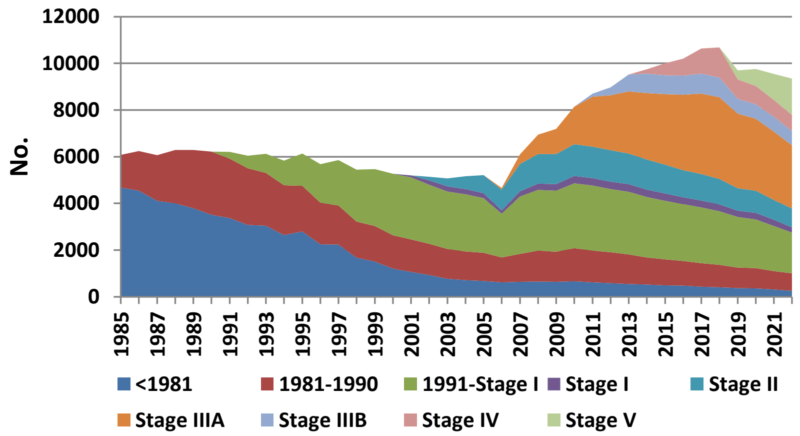
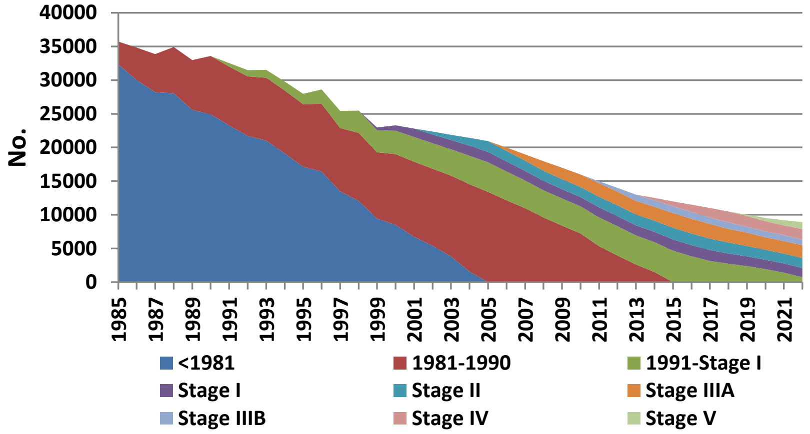
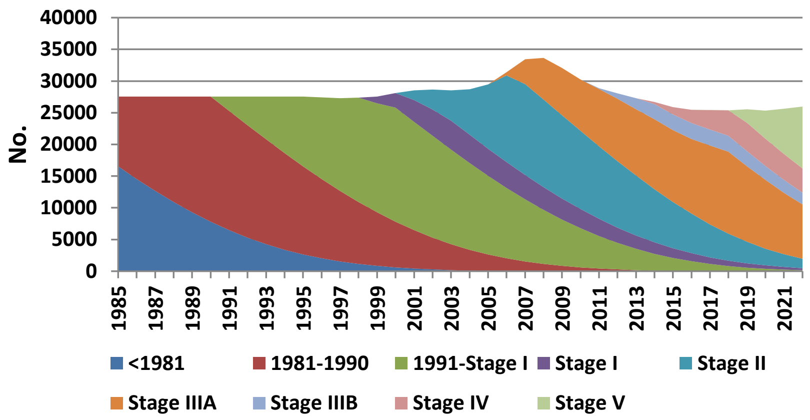
Tractors commercial & institutional (diesel)



Harvesters



Construction machinery



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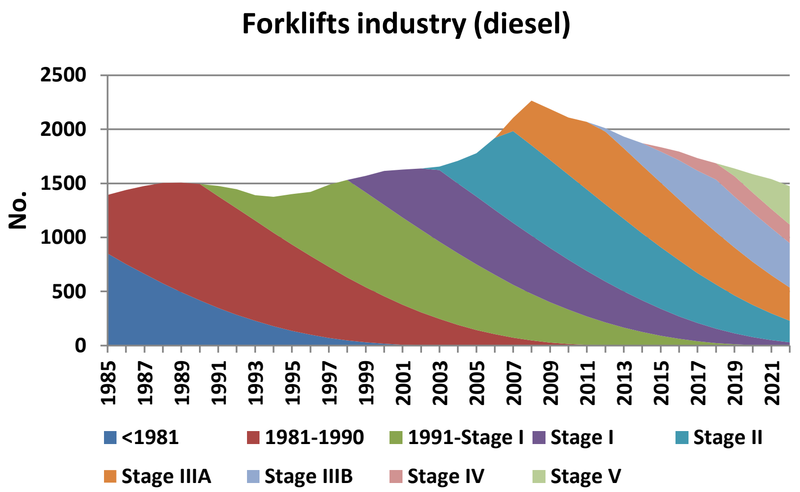


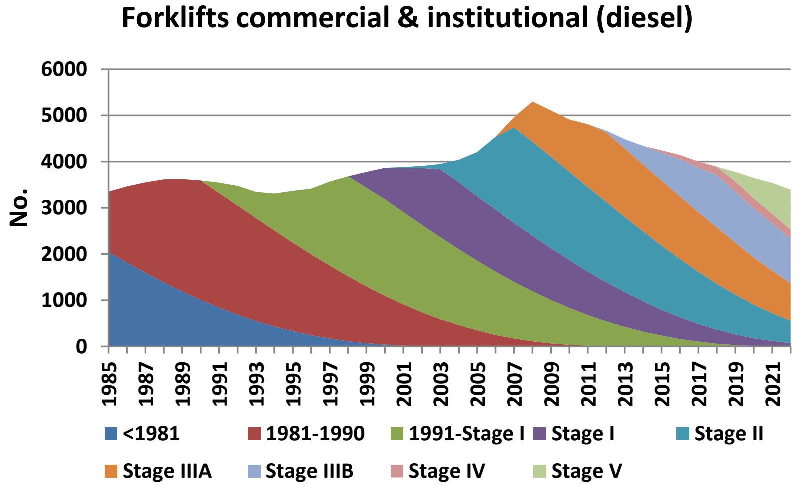


Figure 5.8 Layer distribution for tractors, harvesters, construction machinery and diesel forklifts (1985 to 2022).

The 1990-2022 stock development for the most important household and gardening machinery used in Commercial/Institutional and Residential is shown in Figure 5.9 (gasoline powered engine types only). In Figure 5.9, a substantial decline in the total number of gasoline powered machines is noted for many equipment types during the last 10 years. These stock number decreases are due to a large growth in new sales for electric powered machinery types, especially for battery electric chain saws, trimmers, hedge cutters, blowers and robotic lawn movers in the same period.

The activities made with private and professional equipment types are grouped into the Residential (1.A.4b) and Commercial/Institutional (1.A.4.a) inventory sectors, respectively.

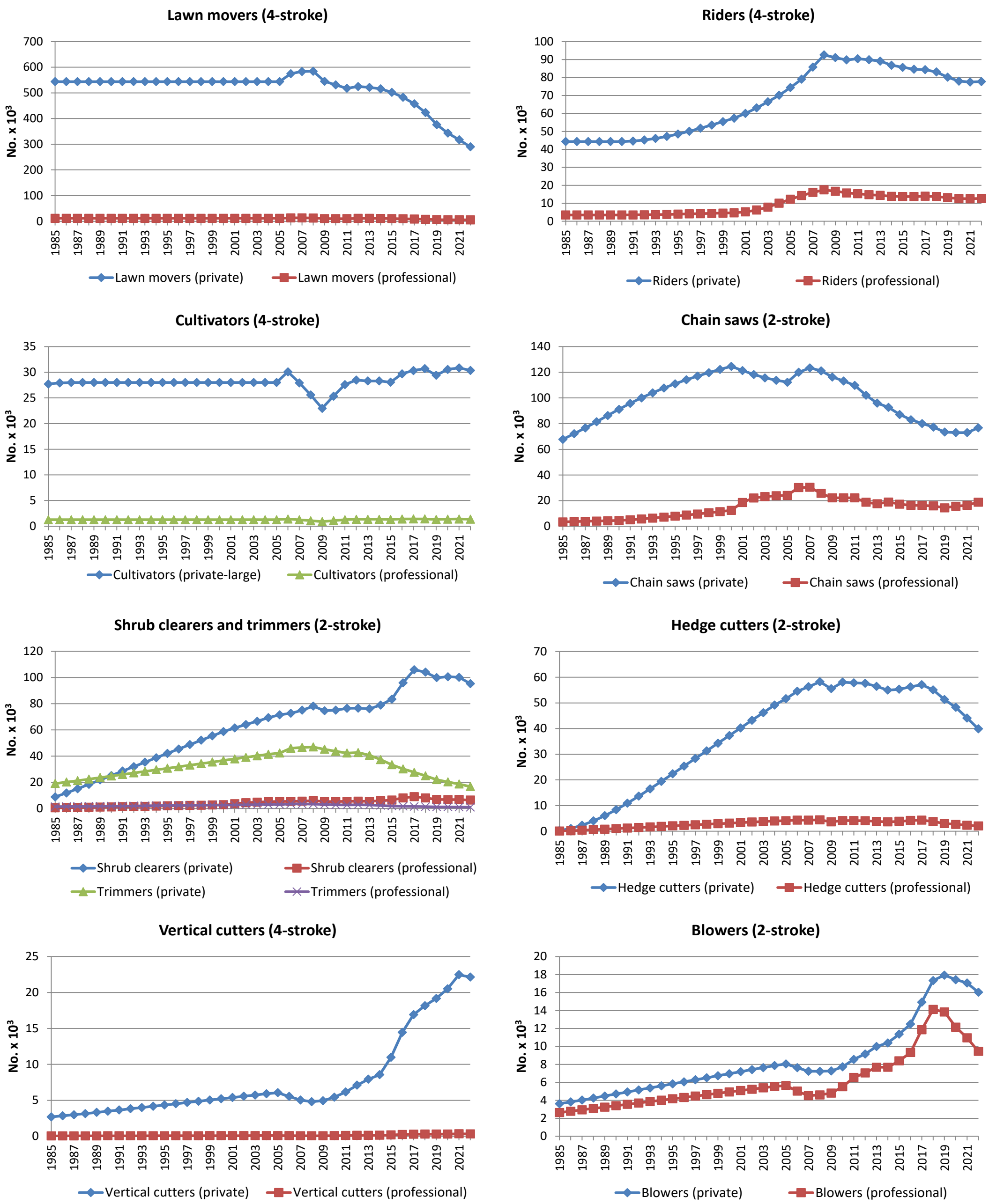


Figure 5.9 Stock developments 1985-2022 for the most important household and gardening machinery types.

The total stock development for the most important household and gardening machinery types is shown in Figure 5.10 split into 2-stroke and 4-stroke machinery for Residential (1.A.4b) and Commercial/Institutional (1.A.4.a). For the same stock division, the emission layer distribution is also shown in Figure 5.10. The penetration of new technologies occurs faster for working machinery in Commercial/Institutional (1.A.4.a) compared with Residential (1.A.4.b), due to the shorter maximum lifetimes for the working equipment used by professionals.

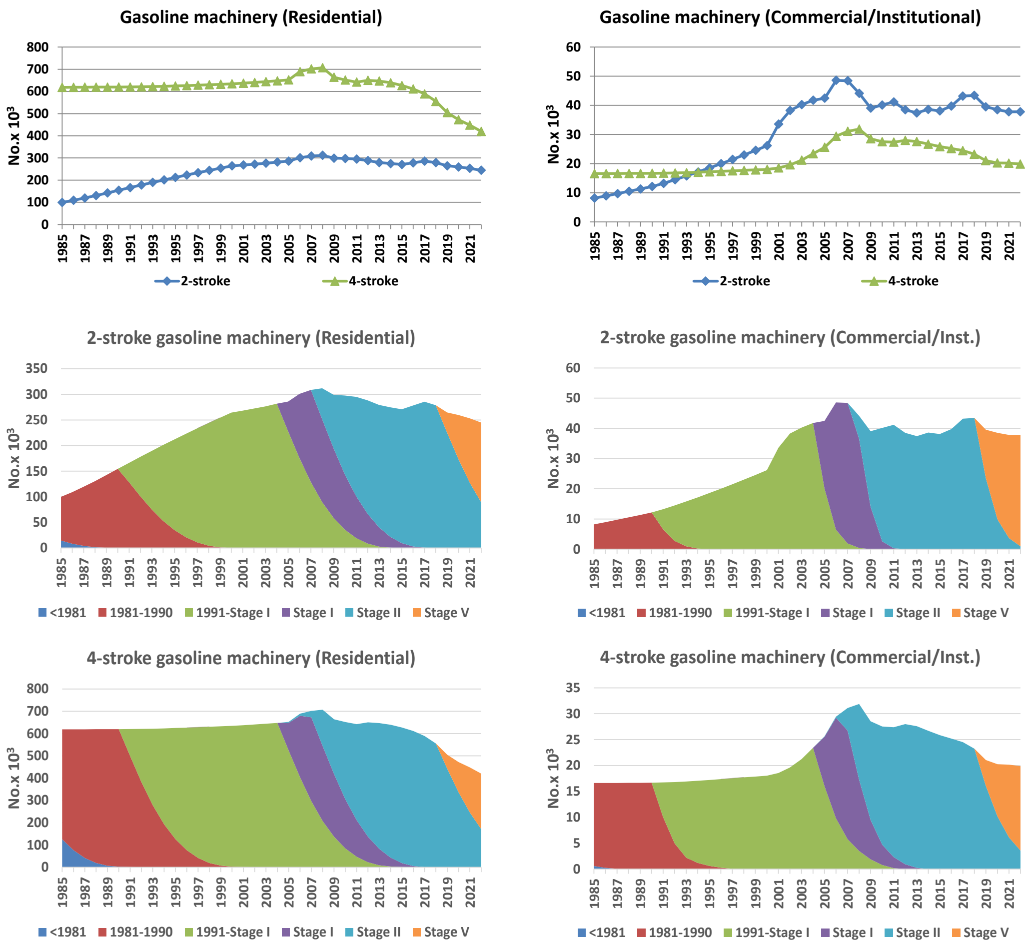


Figure 5.10 Layer distribution for the most important household and gardening machinery types split into Residential and Commercial/Institutional (1985-2022).

Figure 5.11 shows the development in numbers of different recreational craft from 1985-2022. 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 motorboats (< 27 ft.) and the engine sizes for sailing boats (<26 ft.), where the figures remain unchanged. A decrease in the total stock of sailing boats (<26 ft.) by 21 % and increases in the total stock of yawls/cabin boats and other boats (<20 ft.) by around 25 % are expected. Due to a lack of information specific to Denmark, the shifting rate from 2-stroke to 4-stroke gasoline engines is based on a German non-road study (IFEU, 2004).

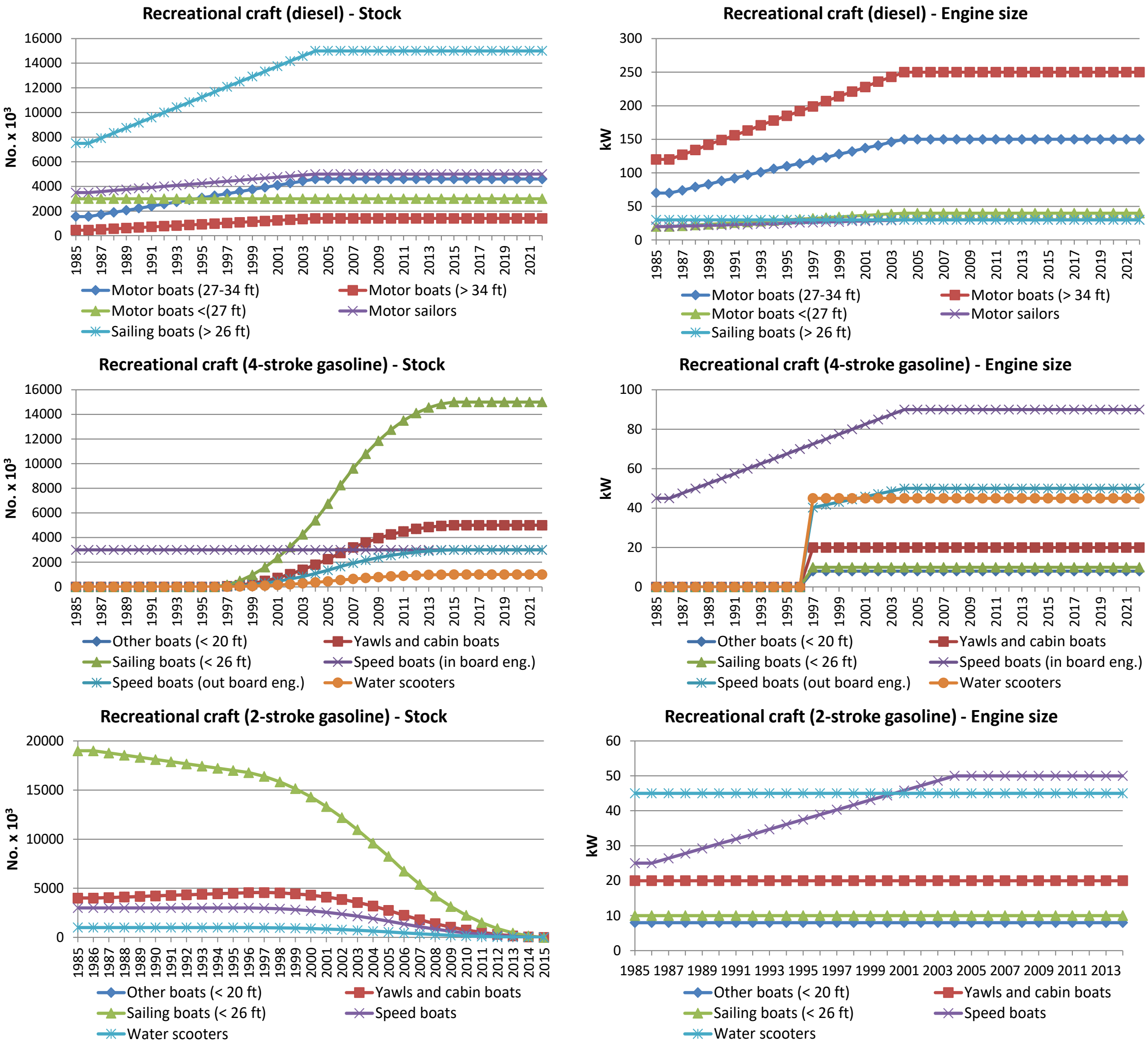


Figure 5.11 1985-2022 Stock and engine size development for recreational craft.

5.1.3 National navigation

National navigation includes the activities made by domestic ferries, fuel sold in Denmark and used for freight transport between Denmark and Greenland or the Faroe Island, and fuel used for the remaining part of the traffic between two Danish ports.

Table 5.1 lists the most important domestic ferry routes (regional ferries) in Denmark in the period 1990-2022. For these ferry routes and the years 1990-2005, the following detailed traffic and technical data have been gathered by Winther (2008): Ferry name, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size, share of annual trips and sailing time (single trip).

For 2006-2022, the above mentioned traffic and technical data for specific ferries have been provided by Nielsen (2022) in the case of Mols-Linien (Sjællands Odde-Ebeltoft, Sjællands Odde-Århus, Kalundborg-Århus, Køge-Rønne, Tårs-Spodsbjerg), by Jørgensen (2017) for Færgen A/S (Køge-Rønne, Tårs-Spodsbjerg, Kalundborg-Samsø), by Kruse (2015) for Samsø Rederi (Hou-Sælvig), by Mortensen (2015) for Færgeselskabet Læsø (Frederikshavn-Læsø) and by Eriksen (2017) for Ærøfærgerne (Svendborg-Ærøskøbing). For

Esbjerg/Hanstholm/-Hirtshals-Torshavn traffic and technical data have been provided by Dávastovu (2010).

Table 5.1 Regional ferry routes in the Danish inventory.

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

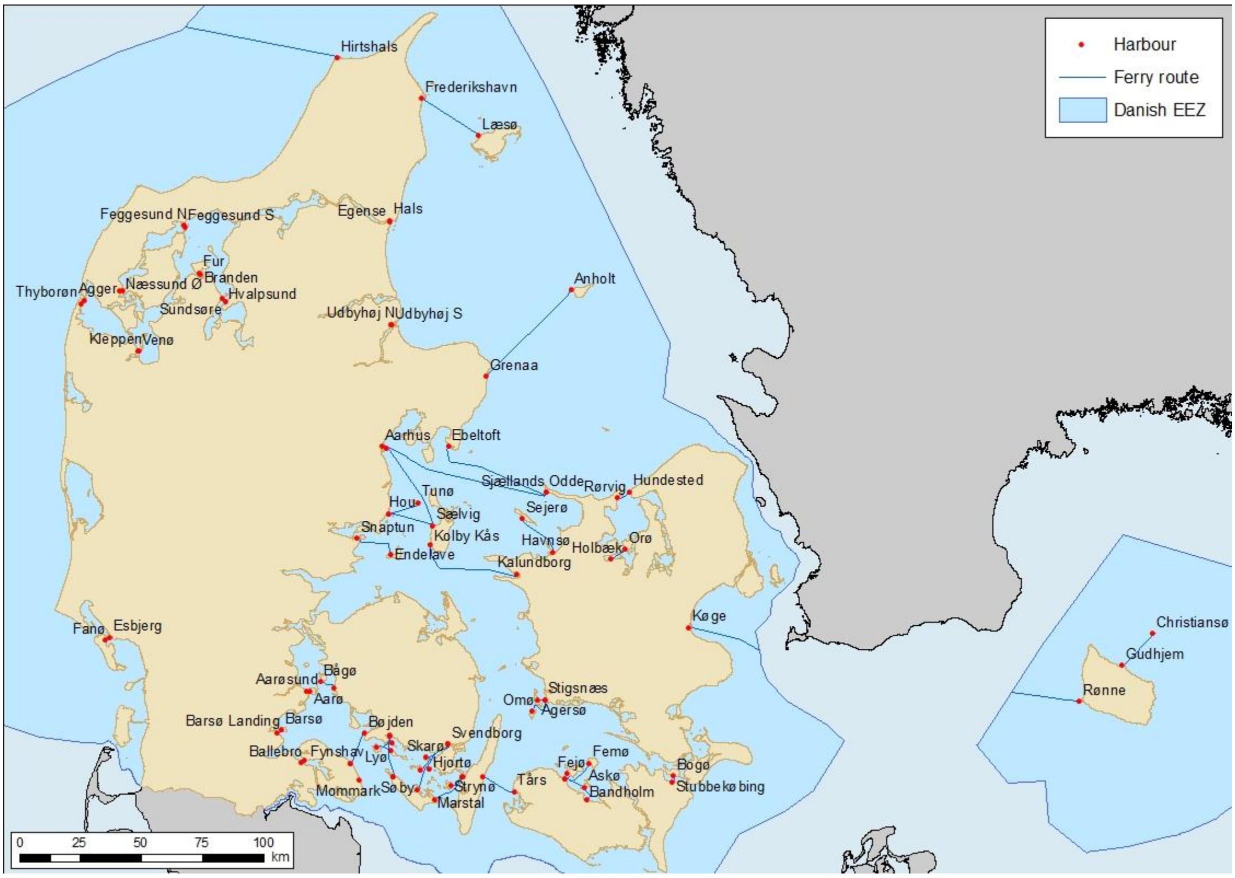


Figure 5.12 Domestic ferry routes in Denmark (2022).

Table 5.2 lists the small ferry routes (island and short cut ferries) included in the Danish inventory for the period 1990-2022. For these ferry routes and the years 1990-2022, the following detailed traffic and technical data have been gathered by Rasmussen (2017) and Andersen (2019): Ferry name, engine size (MCR), engine year, share of annual trips and sailing time (single trip). Supplementary data for engine type, fuel type and average load factor is provided by Kristensen (2017).

Table 5.2 Small ferry routes in the Danish inventory.

Ferry service	Service period
Assens-Baagø	1990+
Ballebro-Hardeshøj	1990+
Bandholm-Askø	1990+
Barsø Landing-Barsø	2018+
Branden-Fur	1990+
Bøjden-Fynshav	1990+
Esbjerg-Fanø	1990+
Feggesund overfart	1990+
Fejø-Kragenæs	1990+
Femø-Kragenæs	1990+
Frederikssund-Roskilde	1999-2000
Fåborg-Avernakø-Lyø	1990+
Fåborg-Søby	1990+
Grenaa-Anholt	1990+
Gudhjem-Christiansø	2015+
Hals-Egense	1994+
Havnsø-Sejerø	1990+
Holbæk-Orø	1990+
Horsens-Endelave	1990+
Hov-Tunø	1990+
Hundested-Rørvig	1990+
Hvalpsund-Sundsøre	1990+
Kastrup-Rønne	1990
Kleppen-Venø	1990+
Korsør-Lohals	1990+
Kragenæs-Askø	2020+
København-Århus	1992-1993
Næssund overfart	1990+
Rudkøbing-Marstal	-2013
Rudkøbing-Strynø	1990+
Stigsnæs-Agersø	1990+
Stigsnæs-Omø	1990+
Stubbekøbing-Bogø	1990+
Svendborg-Skarø-Drejø	1990+
Sælvig-Aarhus	2021+
Søby-Fynshav	2009+
Søby-Mommark	-2009
Thyborøn-Agger	1990+
Udbyhøj Nord - Udbyhøj Syd	2017+
Aarø-Aarøsund	1990+

The number of round trips per ferry route from 1990 to 2022 is provided by Statistics Denmark (2023a). Figure 5.12 show all ferry routes in use in 2022 (Esbjerg/Hanstholm/Hirtshals-Torshavn not shown).

For all ferry routes, detailed data in terms of ferry name, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size, number of trips and sailing time (single trip) is shown in Annex 12 for the years 1985-2022. 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.

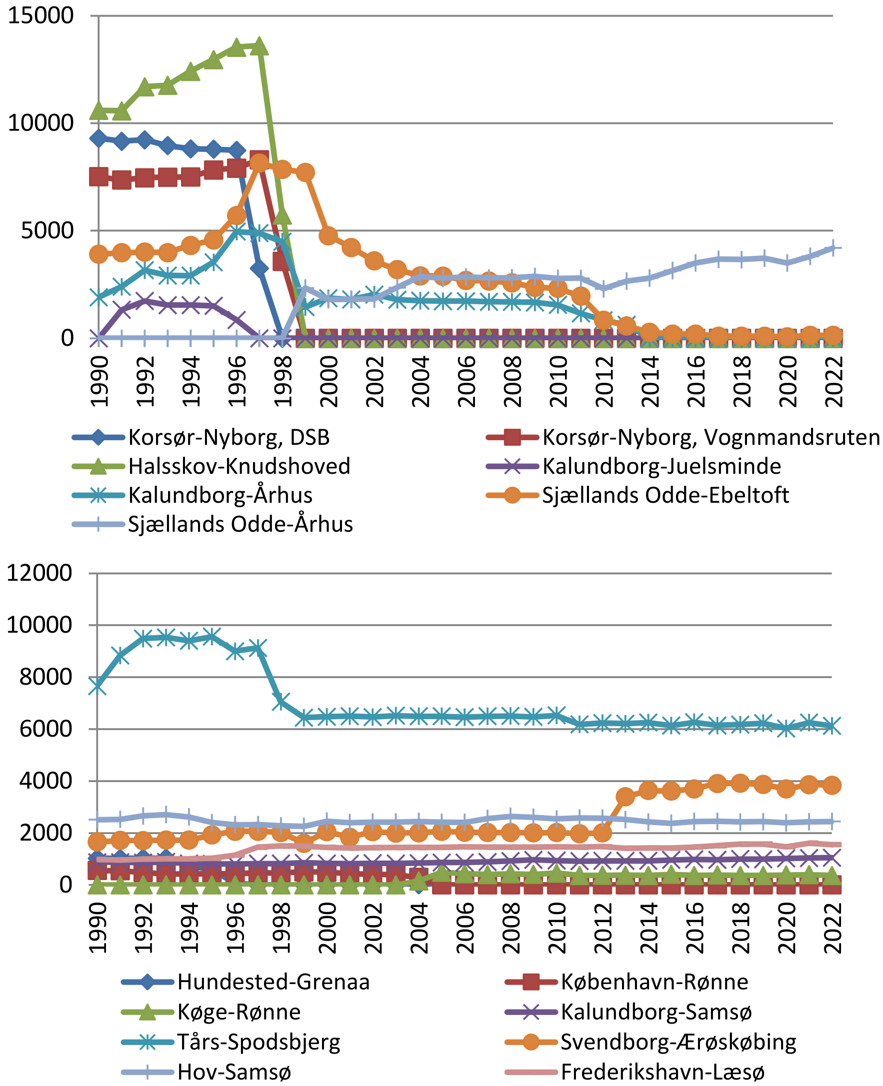


Figure 5.13 No. of round trips for the most important ferry routes in Denmark 1990-2022.

It is seen from Table 5.1 (and Figure 5.13) that several ferry routes were closed in the period from 1996-1998, mainly due to the opening of the Great Belt Bridge (connecting Zealand and Funen) in 1997. Hundested-Grenaa and Kalundborg-Juelsminde was closed in 1996, Korsør-Nyborg (DSB) closed in 1997, and Halsskov-Knudshoved and Korsør-Nyborg (Vognmandsruten) was closed in 1998. The ferry line København-Rønne was replaced by Køge-Rønne in 2004 and from 1999, a new ferry connection was opened between Sjællands Odde and Århus.

The fuel sold for freight transport by Royal Arctic Line between Aalborg (Denmark) and Greenland is included under other national sea transport in the Danish inventories. In this case all fuel is being bought in Denmark (Rasmussen, 2023). The fuel used by freight transport between Denmark and the Faroe Islands (Eimskip) is bought outside Denmark (Helgason, 2023). Hence, this fuel consumption is not included in the Danish inventories at all.

Fuel used for the remaining part of the traffic between two Danish ports, other national sea transport, is taken as the difference between 1) DEA national fuel sales for national sea transport minus fuel consumption at Danish offshore installations (offshore reduced fuel sales[15]) and 2) the bottom-up calculated fuel consumption for Danish ferries[16].

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

The LNG fuel calculated for Danish ferries differ from the LNG fuel sales for national navigation reported in the DEA fuel statistics. Subsequently, an inventory fuel balance is made to account for the total LNG fuel sold reported in the DEA fuel statistics.

5.1.4 National Fishing

For fishing vessels, electronic log data for 1985-2020 are provided by the Danish Fisheries Agency (Hernov, 2021) and for 2021-2022 by Aarhus University (Andersen, 2023) for each fishing trip made by Danish registered fishing vessels.

The log data register the following: Vessel registration number, build year, type, overall length (OAL), gross tonnes (GT), total installed engine power (kW) and hours at sea.

Average engine load factors (%) are taken from Winther and Martinsen (2020) based on data provided by Hanstholm Fisheries Association (Amdissen, 2020).

Figure 5.14 show hours at sea for the Danish fishing vessels split into OAL classes for the years 1990-2022.

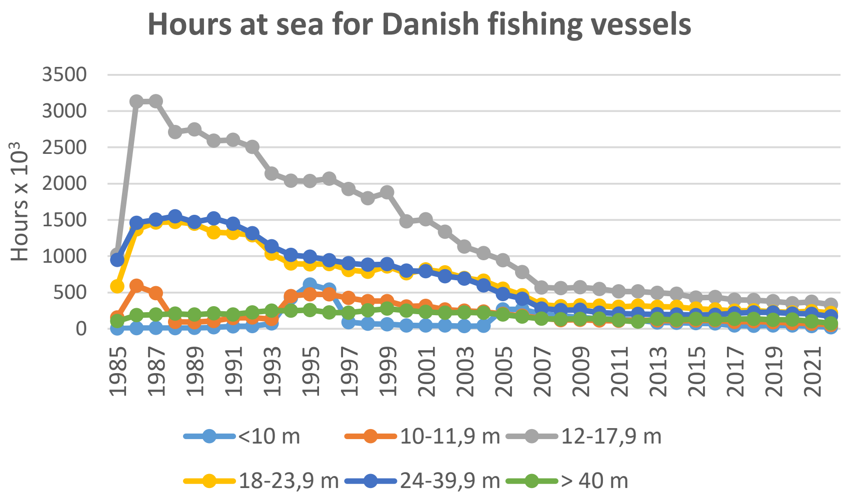


Figure 5.14 Total hours at sea for Danish fishing vessels 1990-2022.

[15] The diesel fuel sold to "offshore installations" are reported as sold for national navigation by the reporting oil companies in the energy statistics.
[16] A small amount of GTL is used by a few island and short-cut ferry lines from 2018 onwards. In energy units, this fuel is a part of the total fuel consumption for ferries subtracted from total DEA statistical fuel sales. For national navigation, the latter statistics only comprise diesel fuel as a liquid fuel.

5.1.5 Railways

The activity data for railways used in the DEMOS-Rail model consists of the total energy use for Danish railways activities from 1985-2022 provided by DEA (2023a). In addition, data for train km, train litra km, passenger km or occupancy rates and train litra service weight[17] are gathered from various sources:

- For regional and intercity trains, using diesel or electricity as a fuel depending on litra type, train km, train litra km and passenger occupancy rates are provided by Danish State Railways (DSB) for the period 2019-2022 (Mølgård, 2023).
- Urban trains ("'S-tog") are electric, and train km and passenger km data are taken from Statistics Denmark (2023b). Train litra km are estimated based on train km and supplementary data from DSB annual reports, e.g. Årsrapport 2022 (DSB, 2023).
- Metro trains are also electric, and train km, train litra km and passenger km data are provided by Metro (Fredericks, 2023).
- Private railways lines mainly use diesel, although a few lines are electrified. Train km, train litra km and passenger km data are provided by the Danish Civil Aviation and Railway Authority (Schelde, 2023), and data splits into litra sub types are provided by the private railway companies.
- Train service weight data for the different train litra types are gathered from relevant web pages (e.g. www.jernbanen.dk) and the weight of a passenger is set to 70 kg.
- Train km, train litra km and train litra performance weight (train litra service weight + total weight of passengers at average occupancy) are used to calculate the total train tonnes km.

For several private railway companies, the following data has been collected for each railway line operated by the companies: Litra type, litra new sales year, Euro emission level, fuel type, fuel consumption factors, number of seats/standing rooms, and percentage distribution of annual litra km driven per litra type (Hjortsø, 2022; Hansen, 2022; Jensen, 2022). For railway lines not able to provide data, and for the earliest years in the time series in general, supplementary data has been gathered from relevant web pages (e.g. www.jernbanen.dk).

Figure 5.15 show train litra km and tonnes train km for DSB, private railways and S-tog and Metro per litra type in 2022.

[17] Train service weight: The weight of the train including 2/3 load of supply (fuel etc.) and staff (Jernbaneleksikon jernbaneordbog jernbane leksikon ordbog (jernbanen.dk)

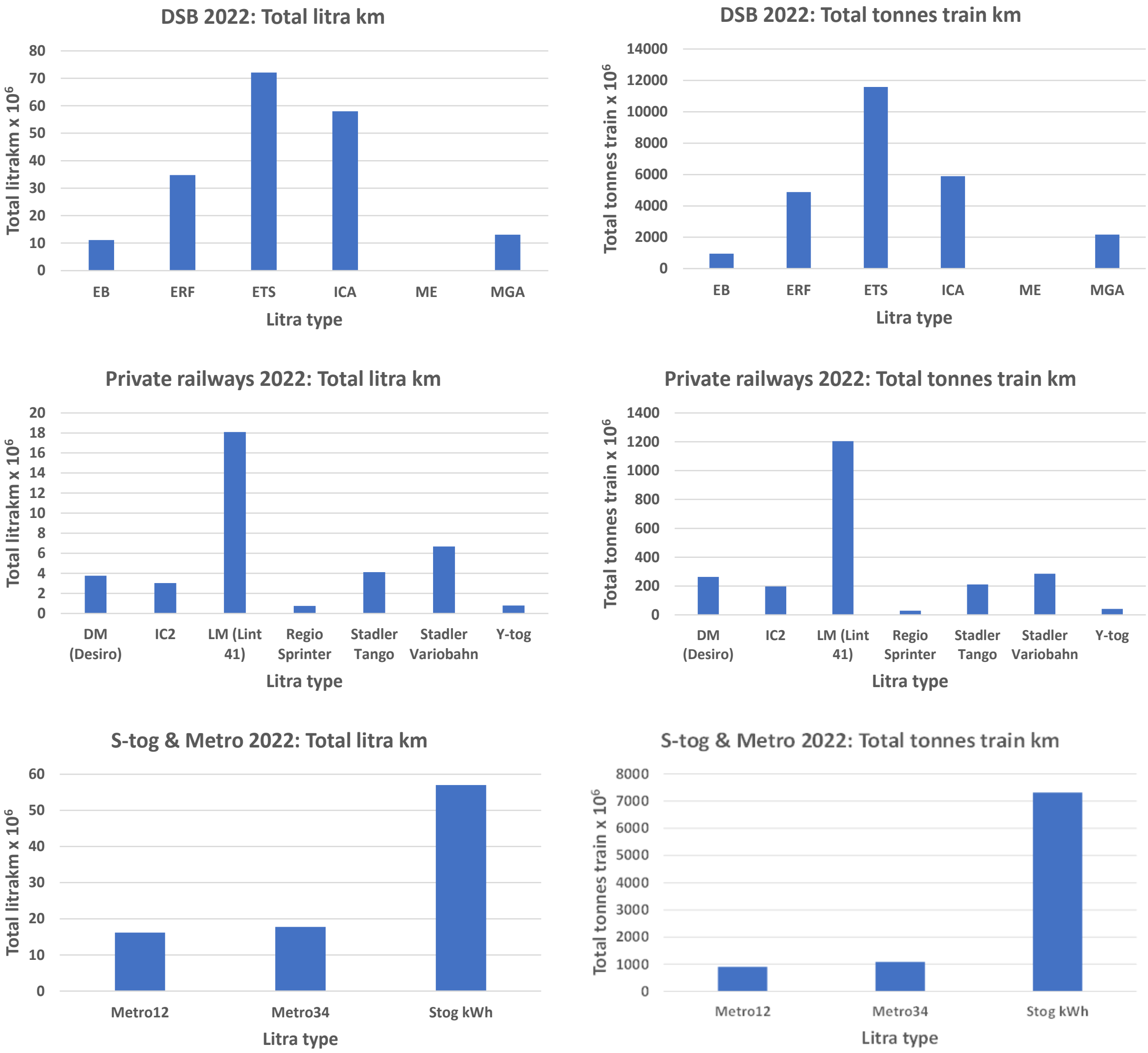


Figure 5.15 Train litra km and tonnes train km for DSB, private railways and S-tog and Metro per litra type in 2022.

In railways, the predominant part of diesel is used by DSB. For 2019-2022, the bottom-up calculated fuel consumption for DSB and private railway companies is subtracted from total diesel fuel sold, and the residual amount of fuel is allocated to DSB. For 1985-2018, the bottom-up calculated fuel consumption for private railway companies[18] is subtracted from total diesel fuel sold for railways in the DEA energy statistics, and the residual amount of fuel is allocated to DSB.

For railways, train litra km and tonnes train km for DSB, private railways and S-tog and Metro per litra type is shown in Annex 13 for the years 1985-2022.

5.1.6 Military

The activity data for military activities consists of fuel consumption information from DEA (2023).

[18] A small amount of GTL is used by private railways from 2018 onwards. In energy units, this fuel is a part of the total fuel consumption for railways subtracted from total DEA statistical fuel sales. For railways, the latter statistics only comprise diesel fuel as a liquid fuel.

5.1.7 International navigation

The activity data for international navigation consists of fuel consumption information from DEA (2023a).

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 to follow the IPCC guidelines, the fuel estimated for the ferry routes Esbjerg/Hanstholm/Hirtshals-Torshavn, and fuel bought by Royal Arctic Line is transferred from international sea transport to national sea transport in fuel sales, prior to inventory fuel input.

For all sectors, fuel consumption figures are given in Annex 15 for the years 1990 and 2022 in CollectER format, and fuel consumption time series are given in Annex 16 in CRF and NFR 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 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.

For gasoline non-road mobile machinery, the directive 2002/88 distinguishes between Stage I and II hand-held (SH) and not hand-held (NS) types of machinery (Table 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 non-road mobile machinery, EU directive 2016/1628 relate to diesel non-road mobile machinery other than agricultural tractors (Table 5.3) and railways machinery (Table 5.7) and gasoline non-road mobile 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 mobile machinery.

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

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

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

Table 5.4 Overview of the EU emission directives relevant for gasoline fuelled non-road machinery.

	Category	Engine size [ccm]	CO [g per kWh]	HC [g per kWh]	NO_X [g per kWh]	$HC+NO_X$ [g per kWh]	Impl. 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 $CO \leq 20.6$ g/kWh and $(HC+NOx) \leq 2.7$ g/kWh.

For recreational craft, Directive 2003/44 comprises the Stage 1 emission legislation limits for diesel engines, and for 2-stroke and 4-stroke gasoline engines, respectively. The CO and VOC emission limits depend on engine size (kW) and the inserted parameters presented in the calculation formulas in Table 5.5. 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 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 direvtive 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.

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

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

1. For engines of a type or model for which the date of manufacture of the first individual production model was before 1 January 1996, and for which the production date of the individual engine was before 1 January 2000.
2. For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 1996, or for individual engines with a production date on or after 1 January 2000.
3. For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2004.
4. For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2008, or for individual engines with a production date on or after 1 January 2013.
5. For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2014.

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

The limit values for NO_x are given by the formulae in Table 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 "www.easa.europa.eu/domains/environment/icao-aircraft-engine-emissions-databank" 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 is submitted on or after 1 January 2023;
- **All propeller-driven aeroplanes**, including their derived versions, of greater than 8,618 kg maximum take-off mass, for which the application for a type certificate was submitted on or after 1 January 2020;
- **Derived versions of non-CO_2-certified subsonic jet aeroplanes** of greater than 5,700 kg maximum certificated take-off mass for which the application for certification of the change in type design is submitted on or after 1 January 2023;
- **Derived versions of non-CO_2 certified propeller-driven aeroplanes** of greater than 8,618 kg maximum certificated take-off mass for which the application for certification of the change in type design is submitted on or after 1 January 2023;
- **Individual non-CO_2-certified subsonic jet aeroplanes** of greater than 5,700 kg maximum certificated take-off mass for which a certificate of airworthiness is first issued on or after 1 January 2028; and
- **Individual non-CO_2-certified propeller-driven aeroplanes** of greater than 8,618 kg maximum certificated take-off mass for which a certificate of airworthiness is first issued on or after 1 January 2028.

Emission standards of non-volatile Particulate Matter (nvPM) mass and number for jet engines of rated thrust greater than 26.7 kN were adopted by the ICAO Council in March 2020. The emission standards are applicable from 1 January 2023 onwards to new type and in-production engines with rated thrust greater than 26.7 kN. The emission standards are explained in more details on the ICAO website https://www.icao.int/environmental-protection/Pages/LAQ_TechnologyStandards.aspx.

The new emission standards replace the SN standard for engines of rated thrust greater than 26.7 kN. Given that the nvPM standards are not applicable to engines of rated thrust less or equal to 26.7 kN, these smaller engines will still need to comply with the SN standard.

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

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

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

- 17 g per kWh, $n < 130$ RPM
- $45 \times n^{-0.2}$ g per kWh, $130 \leq n < 2000$ RPM
- 9.8 g per kWh, $n \geq 2000$ RPM

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

- Tier I: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2000 and prior to 1 January 2011 (initial regulation).
- Tier II: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2011.
- Tier III[19]: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2016 operating in the North American ECA (Emission Control Area) or the United States Caribbean Sea ECA and diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2021 operating in the Baltic Sea and North Sea ECA.

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

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

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 per kWh	n < 130
	$45 \cdot n^{-0.2}$ g per kWh	130 ≤ n < 2000
	9,8 g per kWh	n ≥ 2000
Tier II	14.4 g per kWh	n < 130
	$44 \cdot n^{-0.23}$ g per kWh	130 ≤ n < 2000
	7.7 g per kWh	n ≥ 2000
Tier III	3.4 g per kWh	n < 130
	$9 \cdot n^{-0.2}$ g per kWh	130 ≤ n < 2000
	2 g per kWh	n ≥ 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) and outside SECAs.

Table 5.10 Current legislation in relation to marine fuel quality.

Legislation		Heavy fuel oil		Gas oil	
		S- %	Impl. 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 SECAs	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	SECAs	1	01.03.2010		
	SECAs	0.1	01.01.2015		
	Outside SECAs	3.5	01.01.2012		
	Outside SECAs	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 per tonnes.nm[20]). 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+).

[20] nm: nautical mile.

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 soon.

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

5.3 Fuel consumption and emission factors

The SO_2 emission factors are fuel related and rely on the sulphur contents given in the relevant EU fuel directives or in the Danish legal announcements. However, for jet fuel the default factor from IPCC (2006) is used. For ferries operated by Mols Linjen fuel sulphur data from fuel suppliers are used from 2017 onwards, and for small ferries fuel sulphur data from fuel suppliers are used in all inventory years.

Road transport diesel is assumed to be used by engines in military, railways (apart from railway lines using GTL) and recreational craft. Road transport gasoline is assumed to be used by non-road working machinery and recreational craft. Hence, these types of machinery have the same SO_2 emission factors, as for road transport. For GTL a fuel sulphur content of 5 ppm is used based on fuel supplier's information.

Time series of fuel sulphur contents for the relevant fuel types and their references are listed in Annex 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 for other fuels than diesel, LNG, LPG and GTL are country-specific and come from Fenhann and Kilde (1994). For diesel the CO_2 emission factor is taken from IPCC (2006). For LNG, the CO_2 emission factor is estimated by the Danish gas transmission company, Energinet.dk, based on gas analysis data (Energinet.dk, 2022). For LPG, the emission factor source is EMEP/EEA (2023).

A country-specific emission factor for diesel used in road transportation is not available from Danish refineries, instead, the diesel EF for stationary combustion is used, which is from EU ETS. The average CO_2 EF of diesel burned in stationary sources during 2008-2016 is 74.1 kg/GJ, identical EF to the IPCC default data.

For GTL the CO_2 emission factor comes from Winther (2022b).

The N_2O emission factors are taken from the EMEP/EEA guidebook; EMEP/EEA (2023) for road transport and non-road mobile machinery, and IPCC (2006) for national sea transport and fisheries as well as aviation.

For all mobile sources, the emission factor source for NH_3, PAH and PCB is the EMEP/EEA guidebook (EMEP/EEA, 2023).

For BC, the emission factor source is Comer et al. (2017) for national sea transport and fisheries, apart for ferries using GTL. In this case BC emission factors for marine diesel is used due to lack of data. The BC emission factors for the remaining inventory categories come from (EMEP/EEA, 2023).

The heavy metal emission factors related to fuel combustion for road transport and other mobile sources originate from Winther and Slentø (2010), except for national sea transport and fisheries. For the latter two mobile sectors, the heavy metal emission factor source is the EMEP/EEA guidebook (EMEP/EEA, 2023). For civil aviation jet fuel, no heavy metal emission factors are proposed due to lack of data.

For HCB, the emission factors come from Nielsen et al. (2014).

The non-exhaust emission factors for railways wear of contact lines (TSP, PM_{10}, $PM_{2.5}$ and Cu), rails and train wheels (TSP, PM_{10} and $PM_{2.5}$) and brakes (TSP, PM_{10}, $PM_{2.5}$, Cr and Ni), are taken from Vanherle et al. (2021). The latter source also provides the non-exhaust emission factors for tyre and brake wear (TSP, PM_{10} and $PM_{2.5}$) for domestic and international civil aviation. For aircraft tyre wear, the non-exhaust emission factors for heavy metals are estimated using the content of heavy metals in road transport tyres.

In the case of military ground equipment, due to lack of fleet/activity and emission data, aggregated emission factors for gasoline and diesel are derived from total road traffic emission results. For piston engine aircraft using aviation gasoline, emission factors from (EMEP/EEA, 2023) are used.

For non-road machinery in agriculture, forestry, industry, commercial/institutional and residential, and for recreational craft, the fuel consumption, NO_x, VOC, CO and TSP emission factors are derived from various European measurement programs; see IFEU (2004, 2009), Notter and Schmied (2015) and Winther (2023). For non-road machinery equipped with particle filters (DPF), TSP emission factors come from ICCT (2016). The NMVOC/CH_4 split is taken from IFEU (2009).

For railways, fuel consumption, NO_x, VOC, CO and TSP emission factors are derived from specific Danish emission measurements from the Danish State Railways (Mølgård, 2023). For private railway lines, fuel consumption, NO_x, VOC, CO, TSP and BC emission factors are estimated for the different train type technologies using diesel or GTL. The NMVOC emission factors for railways are derived from the VOC emission factors using a NMVOC/CH_4 split, based on expert judgement.

For national sea transport and fisheries, the fuel consumption and NO_x emission factors predominantly come from the engine manufacturer MAN Energy Solutions, as a function of engine production year. The CO and VOC emission factors come from the Danish TEMA2015 emission model (Ministry of Transport, 2015). TSP emission factors are provided by IMO (2015), whereas the PM_{10} and $PM_{2.5}$ size fractions are obtained from MAN Energy Solutions.

Specifically for the ferries used by Mols Linjen, fuel consumption, NO_x, VOC and CO emission factors are provided by Kristensen (2008), originating from engine measurements (Hansen et al., 2004; Wismann, 1999; PHP, 1996). Complimentary emission factor data for new ferries is provided by Kristensen (2013) and engine load specific emission data is provided by Nielsen (2022).

For island and short-cut ferries using GTL, fuel consumption, NO_x, VOC, CO and TSP emission factors are taken from Winther (2022a).

For the LNG fueled ferry in service on the Hou-Sælvig route, fuel consumption factors are provided by Kruse (2015) and NO_x, NMVOC, CO and TSP emission factors are taken from Bengtsson et al. (2011).

For marine engines using diesel or residual oil, VOC/CH_4 splits are taken from EMEP/EEA (2023).

For national sea transport, international sea transport and fisheries, total fuel consumption and aggregated emission factors per fuel type are shown Annex 12 for the years 1985-2022. Total fuel consumption and emission factors per ferry per route are also shown Annex 12 for 2022. For fisheries as well, total engine MWh's produced, total fuel consumption, fuel balance factors and emission factors are shown in Annex 12 for 1985-2022.

The source for aviation (jet fuel) fuel consumption and emission factors is the EMEP/EEA guidebook (EMEP/EEA, 2023). For a number of different representative aircraft types, the EMEP/EEA guidebook comprises fuel flow and NO_x, CO and VOC emission indices for the four LTO modes and distance-based fuel consumption and emission factors for cruise. For auxiliary power units (APU), ICAO (2020) is the data source for APU load specific fuel consumption NO_x, CO and VOC emission factors for different APU aircraft groups to be linked with the different representative aircraft types. VOC/CH_4 splits for aviation are taken from EMEP/EEA (2023).

For all sectors, emission factors are given in CollectER format in Annex 15 for 2022. Table 5.12 shows the emission factors for SO_2, NO_X, NMVOC, CO, NH_3, TSP and BC in CollectER format used to calculate the emissions from other mobile sources in Denmark.

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 (2022).

					Emission factors [g per GJ, kg/GJ (CO_2)]									
SNAP ID	Category	Fuel type	Tier level	CH_4 % of VOC	CH_4	CO_2	N_2O	SO_2	NO_X	NMVOC	CO	NH_3	TSP	BC
080100	Military	Diesel	Tier 1	8.1	0.30	74.10	3.61	0.44	165.93	3.43	26.50	1.44	1.48	1.01
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 3	3.7	0.86	74.10	2.24	0.47	413.55	22.31	66.01	0.20	3.93	2.55
080200	Railways	GTL	Tier 3	3.7	1.41	71.10	2.24	0.23	281.57	36.66	179.96	0.20	2.83	1.84
080300	Recreational craft	Bio ethanol	Tier 3	2.7	10.85	0.00	1.61	0.00	516.75	384.89	7060.69	0.11	4.29	0.21
080300	Recreational craft	Biodiesel	Tier 3	2.4	2.28	4.20	2.97	0.00	549.62	92.82	339.27	0.17	48.05	17.78
080300	Recreational craft	Diesel	Tier 3	2.4	2.28	74.10	2.97	46.84	549.62	92.82	339.27	0.17	48.05	17.78
080300	Recreational craft	Gasoline	Tier 3	2.7	10.85	73.00	1.61	0.46	516.75	384.89	7060.69	0.11	4.29	0.21
080402	National sea traffic	Diesel	Tier 3	2.0	1.25	74.10	1.87	21.17	1190.49	61.26	112.74	0.00	20.17	3.49
080402	National sea traffic	GTL	Tier 3	2.0	1.07	71.10	1.74	0.23	781.16	52.55	130.08	0.00	11.13	5.58
080402	National sea traffic	LNG	Tier 3	74.0	263.14	56.80	3.96	0.00	161.63	92.45	269.39	0.00	8.51	0.22
080402	National sea traffic	Residual oil	Tier 3	2.0	1.35	78.00	1.95	48.90	1797.31	66.04	195.48	0.00	91.50	4.85
080403	Fishing	Diesel	Tier 3	2.0	1.14	74.10	1.83	46.84	1128.55	55.81	154.11	0.00	21.17	4.39
080404	International sea traffic	Diesel	Tier 1	2.0	1.28	74.10	1.87	46.84	1521.18	62.92	176.34	0.00	24.38	2.36
080404	International sea traffic	Residual oil	Tier 1	2.0	1.42	78.00	1.96	48.90	1989.00	69.49	194.76	0.00	100.69	4.52
080501	Air traffic, Dom. < 3000 ft.	AvGas	Tier 1	2.0	8.62	73.00	2.00	22.83	71.70	422.10	18219.00	1.60	10.00	1.50
080501	Air traffic, Dom. < 3000 ft.	Jet fuel	Tier 3	10.0	1.51	72.00	8.79	22.99	284.63	13.56	198.53	0.00	1.94	0.88
080502	Air traffic, Int. < 3000 ft.	Jet fuel	Tier 3	10.0	1.91	72.00	4.36	22.99	303.63	17.22	196.98	0.00	2.84	1.44
080503	Air traffic, Dom. > 3000 ft.	Jet fuel	Tier 3	0.0	0.00	72.00	2.30	22.99	314.60	6.54	103.94	0.00	2.39	1.36
080504	Air traffic, Int. > 3000 ft.	Jet fuel	Tier 3	0.0	0.00	72.00	2.30	22.99	297.26	5.09	60.97	0.00	4.55	2.41
080600	Agriculture	Bio ethanol	Tier 3	12.2	151.62	0.00	1.62	0.00	107.87	1094.55	18700.38	1.51	30.55	1.53
080600	Agriculture	Diesel	Tier 3	2.4	0.77	74.10	3.58	0.47	243.21	31.38	237.29	0.20	20.75	12.53
080600	Agriculture	Gasoline	Tier 3	12.2	151.62	73.00	1.62	0.46	107.87	1094.55	18700.38	1.51	30.55	1.53
080700	Forestry	Bio ethanol	Tier 3	6.0	240.84	0.00	0.46	0.00	54.79	3754.76	17915.98	0.09	82.19	4.11
080700	Forestry	Diesel	Tier 3	2.4	0.36	74.10	3.71	0.47	53.33	14.68	174.67	0.21	2.14	1.42
080700	Forestry	Gasoline	Tier 3	6.0	240.84	73.00	0.46	0.46	54.79	3754.76	17915.98	0.09	82.19	4.11
080800	Industry	Bio ethanol	Tier 3	3.6	40.81	0.00	1.22	0.00	121.08	1106.62	26586.50	0.08	22.68	1.13
080800	Industry	Diesel	Tier 3	2.4	0.73	74.10	3.51	0.47	216.01	29.67	209.74	0.20	13.87	9.96
080800	Industry	Gasoline	Tier 3	3.6	40.81	73.00	1.22	0.46	121.08	1106.62	26586.50	0.08	22.68	1.13
080800	Industry	LPG	Tier 3	5.0	1.75	64.80	3.50	0.00	139.81	33.20	13.98	0.21	0.70	0.03
080900	Household and gardening	Bio ethanol	Tier 3	2.3	50.88	0.00	1.16	0.00	84.10	2148.94	29871.91	0.09	40.81	2.04
080900	Household and gardening	Gasoline	Tier 3	2.3	50.88	73.00	1.16	0.46	84.10	2148.94	29871.91	0.09	40.81	2.04
081100	Commercial and institutional	Bio ethanol	Tier 3	4.1	36.58	0.00	1.29	0.00	66.15	852.22	33393.58	0.09	16.15	0.81
081100	Commercial and institutional	Diesel	Tier 3	2.4	0.79	74.10	3.50	0.47	251.83	32.31	230.57	0.20	15.36	10.64
081100	Commercial and institutional	Gasoline	Tier 3	4.1	36.58	73.00	1.29	0.46	66.15	852.22	33393.58	0.09	16.15	0.81
081100	Commercial and institutional	LPG	Tier 3	5.0	1.75	64.80	3.50	0.00	139.81	33.20	13.98	0.21	0.70	0.03
080501	Air traffic, Dom. < 3000 ft.	AvGas	Tier 1	2.0	8.62	73.00	2.00	22.83	71.70	422.10	18219.00	1.60	10.00	1.50
080501	Air traffic, Dom. < 3000 ft.	Jet fuel	Tier 3	10.0	1.33	72.00	5.57	22.99	280.07	11.97	230.45	0.00	1.65	0.58
080502	Air traffic, Int. < 3000 ft.	Jet fuel	Tier 3	10.0	1.83	72.00	3.21	22.99	320.82	16.51	205.98	0.00	2.09	0.72
080503	Air traffic, Dom. > 3000 ft.	Jet fuel	Tier 3	0.0	0.00	72.00	2.30	22.99	327.63	3.59	61.08	0.00	2.63	0.81
080504	Air traffic, Int. > 3000 ft.	Jet fuel	Tier 3	0.0	0.00	72.00	2.30	22.99	349.73	3.40	43.23	0.00	3.19	1.02

References. CO_2: Country-specific, Energinet.dk (LNG), EMEP/EEA (LPG), IPCC (diesel), Winther (2022, GTL). N_2O: EMEP/EEA. CH_4: Railways: Danish State Railways, DCE; Agriculture/Forestry/Industry/Household-Gardening: IFEU (2004, 2009, 2014), Notter and Schmied (2015); National navigation/Fishing/International navigation: Ministry of Transport (2015), 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 (fuel, NO_x, CO, NMVOC and TSP): Danish State Railways; Agriculture, forestry, industry, household gardening and recreational craft (fuel, NO_x, CO, VOC and TSP): IFEU (2004, 2009, 2014), Notter and Schmied (2015), ICCT (2016); National navigation/National fishing/International navigation: MAN Energy Solutions (fuel, NO_x), Ministry of Transport (2015) (CO, NMVOC), IMO (TSP), specific data from Mols Linjen (fuel, NO_x, CO, NMVOC, TSP) & LNG emission factors (NO_x, CO, NMVOC, TSP) from Bengtsson et al. (2011) & GTL emission factors (fuel, NO_x, CO, NMVOC, TSP) from Winther (2022a); Aviation (fuel, NO_X, CO, NMVOC, TSP): EMEP/EEA.

5.3.1 Adjustment for deterioration and transient engine loads 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 factors for deterioration and engine transient loads 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.

5.3.2 Adjustment for engine load for marine engines

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

For a few ferries operated by Mols Linjen actual engine loads and engine load specific emission data provided by Nielsen (2022) is used to calculate precise sfc and emission factors of NO_x, CO and VOC.

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 (2023), the fuel consumption and emission factors for the full LTO cycle are estimated for each of the representative aircraft types used in the Danish inventory.

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

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

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:

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

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, 0.7 and 2.2 minutes are used as defined by ICAO (ICAO, 1995). For taxi in and taxi out, specific times-in-modes data are provided by Eurocontrol for the airports present in the Danish inventory. The taxi times-in-modes data are shown in Annex 3.B.10 for the years 2001-2022.

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 (2020) is the data source for APU load specific fuel flows (kg per s) and emission rates (g per kg fuel) for different APU aircraft groups (characterised by seating capacity and age). APU times-in-modes for arrival, start-up, boarding and main engine start are also provided by ICAO (2020), whereas push back time intervals are taken from an emission study made in Copenhagen Airport (Ellermann et al., 2011; Winther et al., 2015).

For each representative aircraft type, the calculated fuel consumption and emission factors per LTO are shown in Annex 10 for Copenhagen Airport and other airports (aggregated) for 2022. 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 (2023) per representative aircraft type. Data interpolations or extrapolations are made – in each case determined by the actual flown distance between the origin and the destination airports.

The actual flown distance between two airports can be derived as a function of the great circle distance (GCD) between the airports in question, also taking into account the extent of the LTO flight phase (15 NM = 27.78 km), which is a constant for all aircraft types. The relation between actual distance and GCD flown is taken from the German TREMOD AV model (Knörr et al., 2012).

For GCD <= 100 NM (<= 185.2 km), 60 km is added to the great circle distance (GCD) to find the actual distance flown. For GCD > 100 NM (>185.2 km), 4 % additional flown distance is added for the part of GCD > 100 NM (>185.2 km). In both cases, 15 NM (=27.78 km) from the LTO flight phase is subtracted from the actual flown distance, to find the actual flown distance during cruise:

- Actual flown cruise distance (GCD <= 185.2 km) = GCD + 60 km – 27.78 km
- Actual flown cruise distance (GCD > 185.2 km) = (GCD – 185.2 km) x 1,04 + 185.2 km + 60 km – 27.78 km.

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

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

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

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

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

Non-exhaust TSP, PM_{10} and $PM_{2.5}$ emissions for aircraft tyre wear and brakes during landing for all flights are calculated in DEMOS-Aviation, as a function of aircraft MTOM (Maximum Take Off Mass).

Total aircraft MTOM per airport per year support the calculations. Emission factors reported as 0.223 gPM_{10}/tonnes MTOM for brake wear and 0.253 gPM_{10}/tonnes MTOM for tyre wear are taken from Vanherle et al. (2021).

PM_{10}/TSP and $PM_{2.5}$/PM_{10} size ratios of 0.98 and 0.4 for brakes and 0.6 and 0.7 for tyres, respectively, are taken from EMEP/EEA (2023) reported for road transport non-exhaust PM, due to lack of relevant PM size fraction data for aircraft non-exhaust PM. The similar assumption for the $PM_{2.5}$/PM_{10} ratios has been made by Underwood et al. (2010) for Heathrow Airport.

Annex 10 shows the average fuel consumption and emission factors per representative aircraft type for cruise flying, as well as total distance flown, for 2020[21]. The factors are split between Copenhagen Airport and other airports and distinguish between domestic and international flights.

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

The overall fuel precision (fuel balance) in the model is 0.95 in 2022, 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 Civil Aviation and Railway Authority. Due to lack of aircraft type specific LTO data, fuel consumption and emission factors derived for domestic LTO's in Copenhagen Airport is used for all LTO's in other airports. In a next step, the total fuel consumption for cruise (true cruise fuel consumption) is found year by year as the statistical fuel consumption total minus the calculated fuel consumption for LTO.

For each inventory year, intermediate cruise fuel consumption figures 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.

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

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:

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

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

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

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

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.

As a part of some engine manufacturer's emission reduction strategy, a part of the Stage IIIB and IV machines used in building and construction are equipped with preinstalled closed (wall-flow) particle filters (DPF), and hence have low particle emissions. This particle filter effect on particle emissions needs to be taken into account in the calculations, since the baseline emission factors for TSP more aligns with EU emission legislation limits, and these emission limits do not necessarily require particulate filters in order to be met.

The particle reduction factor, F_{dpf}, for any given machinery type, engine size and engine age in year X, depends on the share of engines with preinstalled closed particle filters, in the different size classes and emission levels:

$$F_{dpf,i,j,k}(X) = \frac{(1-S_{y,z}) \cdot EF_{y,z} + S_{y,z} \cdot EF_{dpf,y,z}}{EF_{y,z}} \quad (23)$$

Where F_{dpf}, = particle reduction factor, S = Share of engines with preinstalled DPF's, i = machinery type, j = engine size, and k = engine age. This emission reduction factor relates to PM and BC emissions from Stage IIIB and IV diesel engines with preinstalled DPF's[22]. The emissions from all other non-road machines are not affected by this adjustment.

The final calculation of fuel consumption and emissions in year X for a given machinery type, engine size and engine age, is the product of the expressions 19-23:

$$E(X)_{i,j,k} = E_{Basis}(X)_{i,j,k} \cdot TF(X)_{i,j,k} \cdot (1 + DF(X)_{i,j,k}) \cdot F_{dpf,i,j,k}(X) \quad (24)$$

The evaporative hydrocarbon emissions from fuelling are calculated as:

$$E_{Evap,fueling,i} = FC_i \cdot EF_{Evap,fueling} \quad (25)$$

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

For tank evaporation, the hydrocarbon emissions are found from:

$$E_{Evap,tank,i} = N_i \cdot EF_{Evap,tank,i} \quad (26)$$

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

5.4.3 National navigation and international navigation

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

$$E(X) = \sum_i N_i \cdot T_i \cdot S_{i,j} \cdot P_i \cdot LF_j \cdot LAF_j \cdot EF_{k,l,y} \quad (27)$$

[22] The particle emission adjustment relating to Stage IIIB and IV engines equipped with DPF's also significantly affects BC emissions, since closed particle filters very efficiently reduce BC from the exhaust.

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, other national sea transport and international navigation, the emissions are calculated using a simplified approach:

$$E(X) = \sum_i EC_{i,k} \cdot EF_{k,l,y} \quad (28)$$

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

The emission factor inserted in (28) 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:

$$EF_{k,l,y} = \frac{\sum_{year=X}^{year=X-LT} EF_{k,l}}{LT_{k,l}} \quad (29)$$

5.4.4 National fishing

For fishing vessels, the fuel consumption and emissions in year X, are calculated as:

$$E(X) = \sum_i T_i \cdot P_j \cdot LF_j \cdot LAF_j \cdot EF_{k,l,y} \quad (30)$$

Where E = fuel consumption/emissions, T = sailing time per fishing trip in hours, P = engine size in kW, LF = engine load factor, LAF = engine load adjustment factor, EF = fuel consumption/emission factor in g per kWh, i = fishing trip no., j = fishing vessel registration no., k = fuel type, l = engine type, y = engine year.

5.4.5 Railways

The fuel consumption and emissions in year X, for DSB (Danish State Railways, 2019-2022) and private railway lines (all years) are calculated as:

$$E(X) = \sum_i EF_{i,j,k} \cdot S_{i,j} \cdot M_{i,j} \quad (31)$$

Here E = fuel consumption/emission, EF = fuel consumption/emission factor in g per train litra km, S = litra type share of total train litra km, M = total train litra km, i = railway line, j = litra type and k = fuel type (diesel, GTL or electricity).

As explained in section 5.1.5, in Danish railways, the predominant part of diesel is used by DSB. For 2019-2022, the bottom-up calculated fuel consumption for DSB and private railway companies is subtracted from total diesel fuel sales reported in the statistics (DEA, 2023), and the residual amount of fuel is allocated to the residual group “other railways traffic”. For 1985-2018, the bottom-up calculated fuel consumption for private railway companies[23] is subtracted from the statistical fuel sales (DEA, 2023), and the residual amount of fuel is allocated to the residual group “DSB and other railways traffic”. For the residual groups “other railways traffic” and “DSB and other railways” average emission factors for DSB are used in the following calculations.

The emissions for DSB and other railways traffic in 1985-2018, and other railways traffic in 2019-2022 are calculated as:

$$E(X) = FC(X) \cdot EF(X) \quad (32)$$

Where E = fuel consumption/emissions, FC = fuel consumption, EF = emission factor in g per kg fuel.

Non exhaust TSP, PM_{10}, $PM_{2.5}$ and Cu emissions for the wear of contact lines for electric trains (regional and intercity, urban and metro, light rail), TSP, PM_{10} and $PM_{2.5}$ emissions for the wear of rails and train wheels (all train types) and TSP, PM_{10}, $PM_{2.5}$, Cr and Ni emissions from train brakes (all trains) are also calculated in DEMOS-Rail.

The emissions are calculated as the product of train litra km, train litra performance weight (train litra service weight + total weight of passengers at average occupancy) and emission factors (g/train tonnes km).

$$E(X) = \sum_i EF_{i,j,k} \cdot S_{i,j} \cdot M_{i,j} \cdot (SW_{i,j} + PW_{i,j}) \quad (33)$$

Here E = fuel consumption/emission, EF = fuel consumption/emission factor in g per train tonnes km, S = litra type share of total train litra km, M = total train litra km, SW = train service weight, PW = total weight of passengers at average occupancy, i = railway line, j = litra type and k = fuel type.

5.4.6 Military

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

$$E(X) = FC(X) \cdot EF(X) \quad (34)$$

where E = emission, FC = fuel consumption and EF = emission factor.

The calculated emissions for other mobile sources are shown in CollectER format in Annex 15 for the years 1990 and 2022 and as time series 1985-2022 in Annex 16 (NFR format).

5.5 Energy balance

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.

[23] The small amount of GTL calculated for private railways is treated as diesel in this fuel balance, since only diesel and the consumption of electricity is reported for railways in the national statistics.

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

5.5.1 National navigation

Fuel used for the remaining part of the traffic between two Danish ports, other national sea transport, is taken as the difference between 1) DEA national fuel sales for national sea transport minus fuel consumption at Danish offshore installations (offshore reduced fuel sales[24]) and 2) the bottom-up calculated fuel consumption for Danish ferries in DEMOS-Navigation.

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

5.5.2 National fishing

For fisheries, the calculation methodology is activity based with a fuel balance, and input fuel data is in principle the diesel fuel sold for fisheries reported by DEA.

For years when diesel fuel calculated for national navigation are higher than the "Offshore reduced" fuel sold for national navigation, diesel is transferred from fisheries to national navigation in the inventories.

Incorrectly reported gasoline and heavy fuel oil for fisheries is transferred to recreational craft (reported under "Other") and national navigation, respectively.

According to the DEA, in some cases inaccurate costumer specifications are made by the oil suppliers, which result in sector misallocation in the sales statistics between national 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 are also the reason for heavy fuel oil being reported for fisheries in the DEA statistics. No engines installed in fishing vessels use heavy fuel oil, even though a certain amount of heavy fuel oil is listed in the DEA numbers for some statistical years (H. Amdissen, Danish Fishermen's Association, personal communication, 2006).

[24] According to the Danish Energy Authority, the latter diesel fuel sales are reported as sold for national navigation by the fuel sales reporting oil companies.

5.5.3 Non-road machinery and recreational craft

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

For gasoline, the DEA residential sector, together with the DEA sectors mentioned for diesel and LPG, contribute to the non-road fuel consumption total. In addition, a certain amount of fuel is transferred from DEA road transport to outbalance the bottom-up fuel consumption calculated in DEMOS-NRMM.

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

5.5.4 Road transport

The bottom-up diesel and gasoline estimate for recreational craft is subtracted from road transport and grouped in the "Other" inventory category together with military activities.

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

5.5.5 Classification of domestic and international aviation and navigation for Denmark

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

Aviation

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

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

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

Navigation

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

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

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

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

6 Fuel consumption and emissions

6.1 Fuel consumption

Table 6.1 shows the fuel consumption for domestic transport based on DEA statistics for 2022 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 1985-2022 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 2022 in Annex 15 (CollectER format).

Road transport has a major share of the fuel consumption for mobile sources. In 2022, this sector's fuel consumption share is 81 %, while the fuel consumption shares for Off road agriculture/forestry, Manufacturing industries (mobile) and National navigation are 5 %, 4 % and 3 %, respectively. For the remaining sectors, the total fuel consumption share is 7 %.

Table 6.1 Fuel consumption (PJ) for domestic mobile sources in 2022 in CRF sectors.

CRF ID	Fuel consumption (PJ)
Manufacturing industries/Construction (mobile)	8.8
Civil aviation (Domestic)*	1.6
Road transport: Passenger cars	85.0
Road transport: Light duty vehicles	21.9
Road transport: Heavy duty vehicles	52.6
Road transport: Mopeds & motorcycles	1.0
Railways	2.1
National navigation (Shipping)	6.6
Commercial/Institutional: Mobile	2.4
Residential: Household and gardening (mobile)	0.4
Agriculture/Forestry/Fishing: Off-road agriculture/forestry	9.2
Agriculture/Forestry/Fishing: National fishing	5.1
Other. Mobile	2.6
Road transport total	160.5
Other mobile total	38.9
Domestic total	199.3
Civil aviation* (International)	30.1
Navigation (international)	20.5

*Grouped according to UNFCCC reporting definitions

From 1985 to 2022, diesel (sum of diesel and biodiesel) and gasoline (sum of neat gasoline and bio ethanol) fuel consumption has changed by 70 % and -16 %, respectively (Figure 6.1), and in 2022 the fuel consumption shares for diesel and gasoline were 70 % and 28 %, respectively (not shown). Other fuels only have a 2 % share of the domestic mobile sources 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 mobile source 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[25].

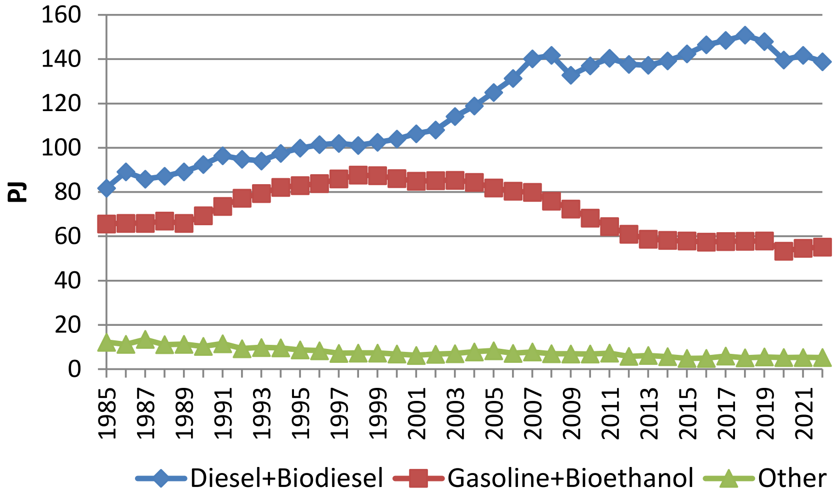


Figure 6.1 Fuel consumption per fuel type for domestic mobile sources 1985-2022.

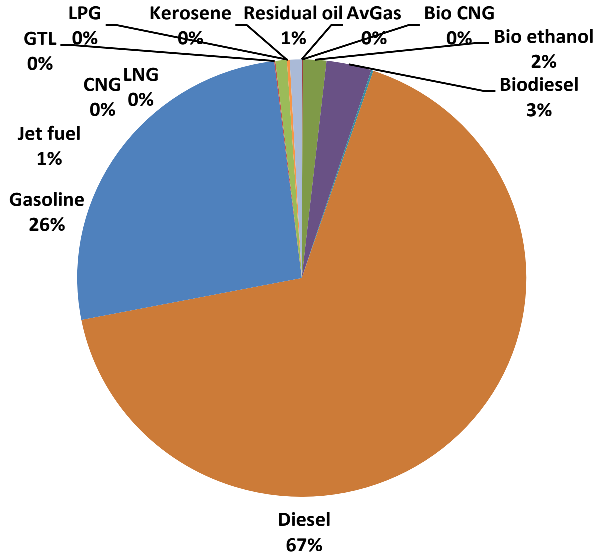


Figure 6.2 Fuel consumption share per fuel type for domestic mobile sources in 2022.

6.1.1 Road transport

As shown in Figure 6.3, the fuel consumption for road transport[26] has generally increased until 2007, except from a small fuel consumption decline noted in 2000. Reduced traffic causes significant fuel consumption declines in 2008-2009 during the global financial crisis, and in 2020 during the periods with COVID-19 lock down and social restrictions in the Danish society. The fuel consumption development is due to a decreasing trend in the use of gasoline

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

[26] The sum share of bioethanol and biodiesel in the gasoline and diesel fuel blends for road transport is 5.0 %, in 2022.

fuels from 1999 to 2013 combined with a steady growth in the use of diesel until 2007, and from 2014 to 2018. Within sub-sectors, passenger cars represent the most fuel-consuming vehicle category, followed by heavy-duty vehicles, light duty vehicles and 2-wheelers, in decreasing order (Figure 6.4). The largest fuel consumption impact related to COVID-19 is noted for passenger cars.

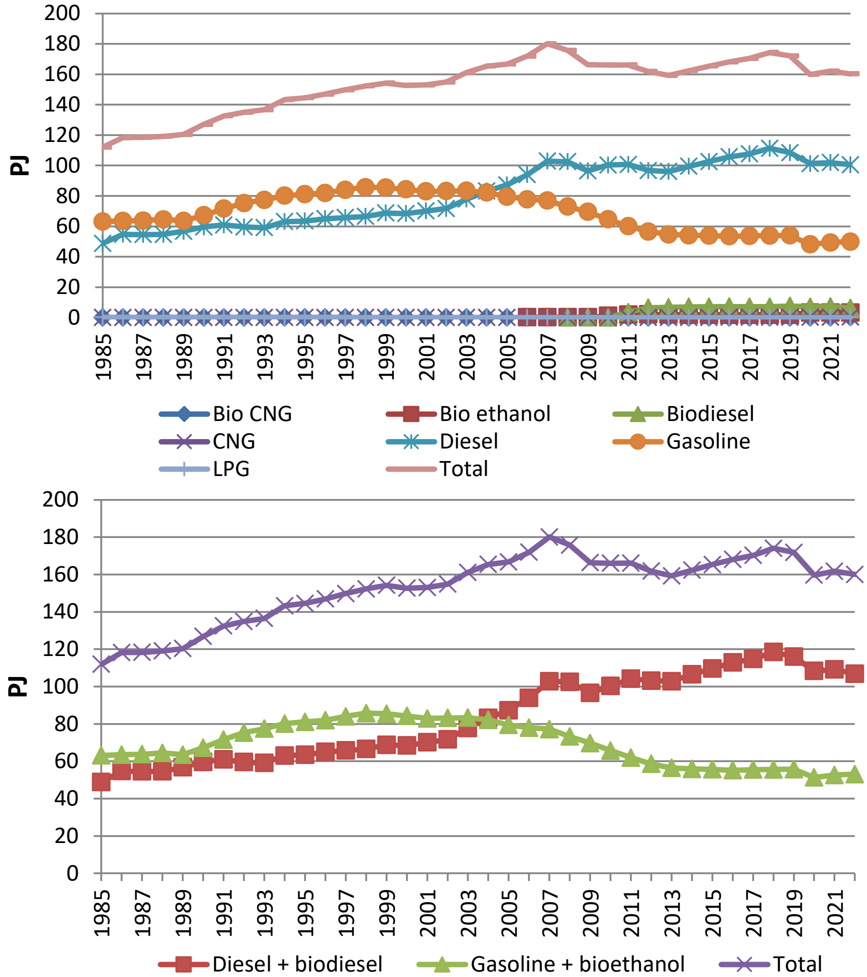


Figure 6.3 Fuel consumption per fuel type and as totals for road transport 1985-2022.

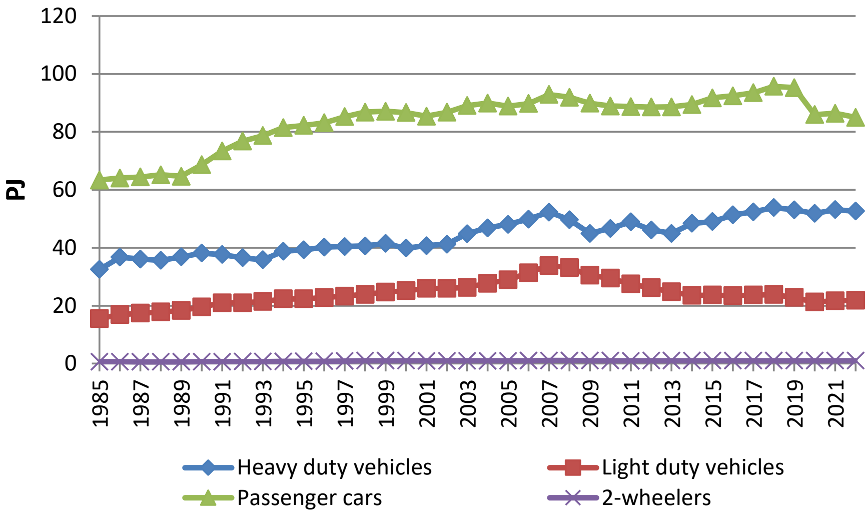


Figure 6.4 Total fuel consumption per vehicle type for road transport 1985-2022.

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 until 2018, while declines in the fuel consumption for trucks and buses (heavy-duty vehicles) are noted for 2008-2009, 2012-2013 and 2019-2020, and fuel consumption reductions for light duty vehicles are noted for 2008-2014 and 2019-2020.

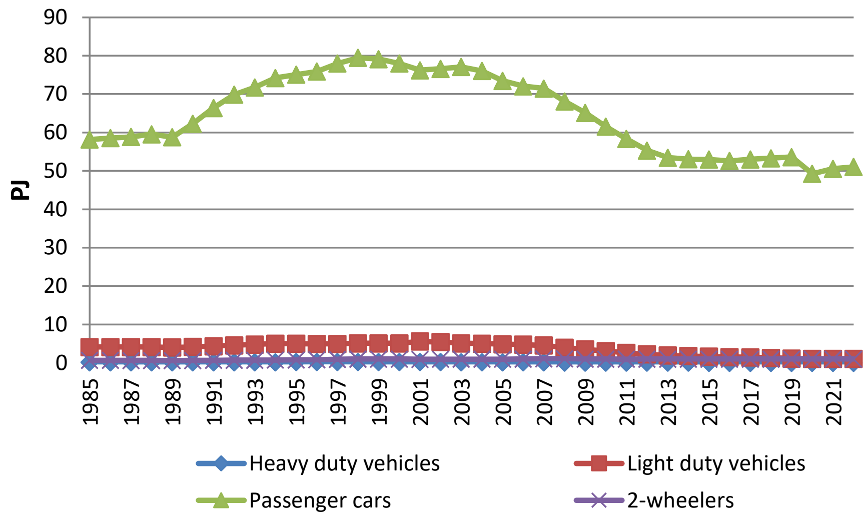


Figure 6.5 Gasoline fuel consumption per vehicle type for road transport 1985-2022.

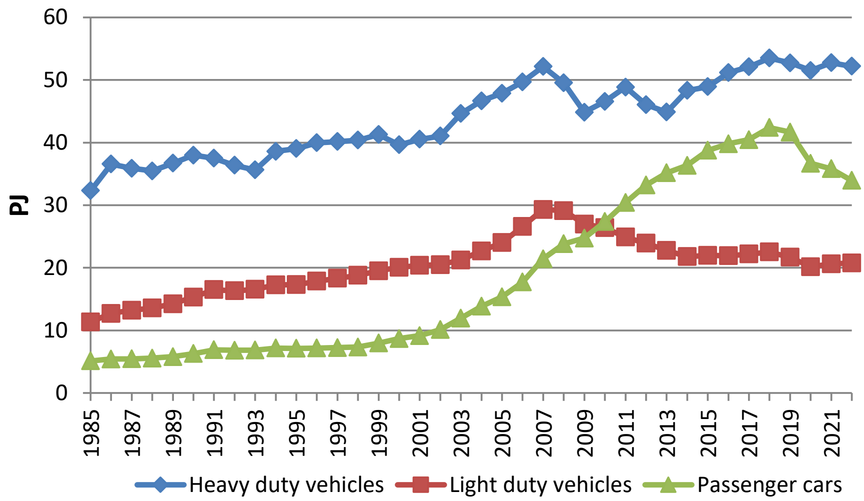


Figure 6.6 Diesel fuel consumption per vehicle type for road transport 1985-2022.

In 2022, fuel consumption shares for gasoline passenger cars, diesel heavy-duty vehicles, diesel passenger cars and diesel light duty vehicles were 32, 32, 21 and 13 %, respectively (Figure 6.7).

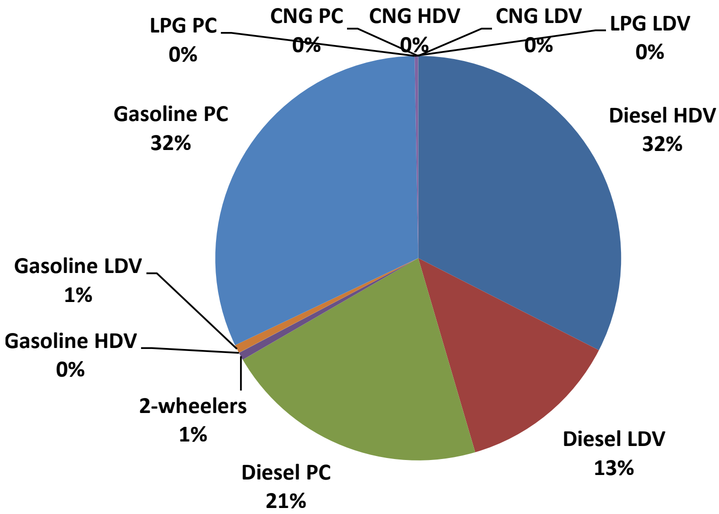


Figure 6.7 Fuel consumption share (PJ) per vehicle type for road transport in 2022.

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 1985-2022 time series are shown per fuel type in Figures 6.9-6.12 for diesel, gasoline, residual oil and jet fuel, and liquefied natural gas (LNG) and gas-to-liquid (GTL) manufactured from natural gas, respectively.

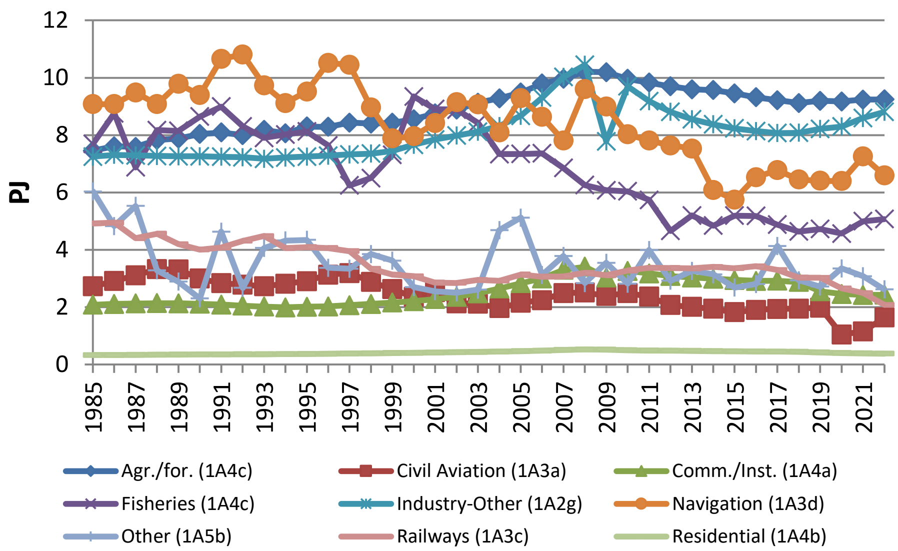


Figure 6.8 Total fuel consumption in CRF sectors for other mobile sources 1985-2022.

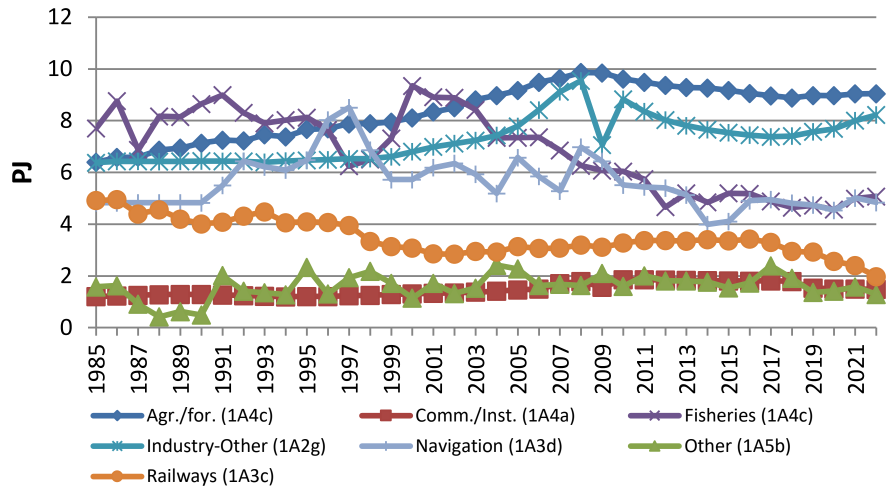


Figure 6.9 Diesel fuel consumption in CRF sectors for other mobile sources 1985-2022.

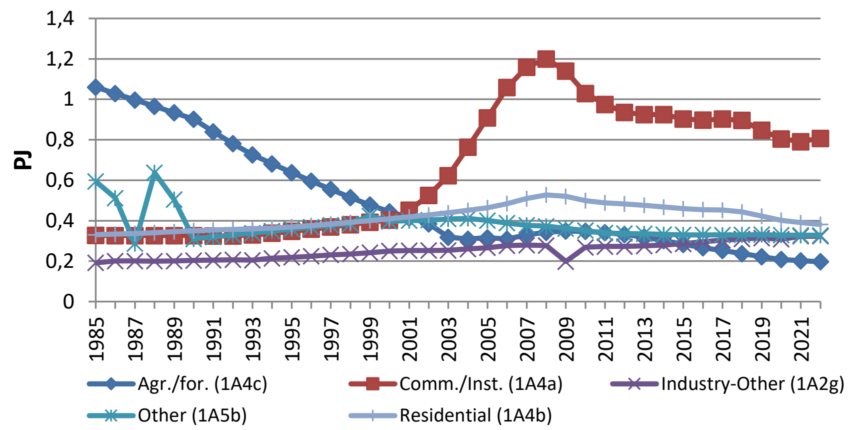


Figure 6.10 Gasoline fuel consumption in CRF sectors for other mobile source 1985-2022.

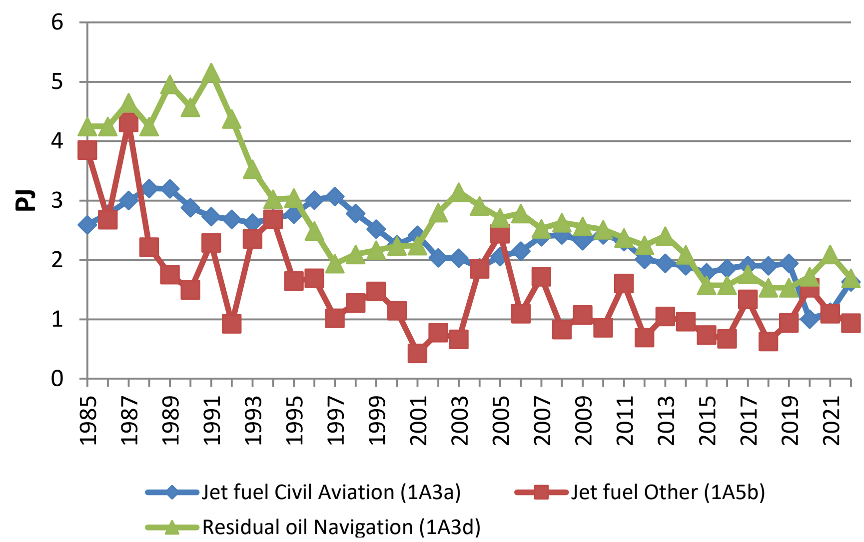


Figure 6.11 Residual oil and jet fuel consumption in CRF sectors for other mobile sources 1985-2022.

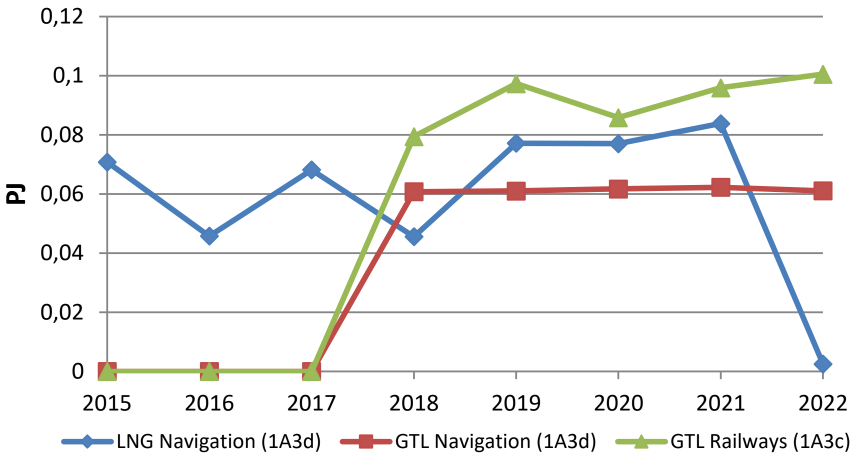


Figure 6.12 LNG and GTL fuel consumption in CRF sectors for other mobile sources 1985-2022.

For diesel, although the number of tractors and harvesters decrease in the entire period 1985-2020, the contemporary increase in the engine sizes of new sold machines makes the total fuel consumption grow until 2008. The turnover of old less fuel efficient machinery and the decline in the number of tractors and harvesters explain the total fuel consumption decrease from 2008 onwards. 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. The fuel efficiency improvements for new sold machinery are the main reason for total fuel consumption decline from 2010-2018. For fisheries, the development in fuel consumption reflects the activities in this sector.

The Navigation sector comprises national sea transport (fuel consumption between two Danish ports including sea travel directly between Denmark and Greenland/Faroe Islands). For national sea transport, the diesel fuel consumption curve reflects the combination of traffic and ferries in use for regional ferries. In 1998 and 1999, a significant decline in fuel consumption is apparent. The most important explanation here is the closing of ferry service routes in connection with the opening of the Great Belt Bridge in 1997. For railways, the gradual shift towards electrification explains the lowering trend in diesel fuel consumption 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 new sales of ATVs from the mid 2000s until 2011, followed by a decrease in new sales of ATVs from 2011 forward.

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

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

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

6.1.3 International transport

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

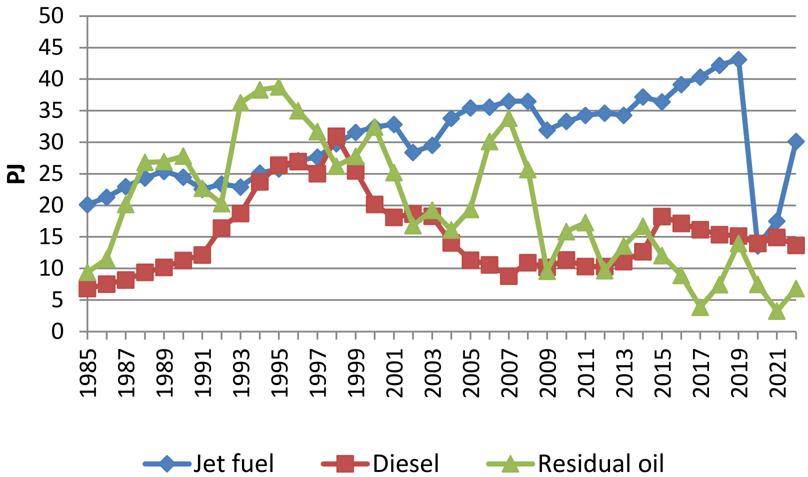


Figure 6.13 Bunker fuel consumption 1985-2022.

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 2022 in CRF sectors. The emission figures in time series 1990-2022 are given in Annex 16 (CRF format) and are shown for 1990 and 2022 in Annex 15 (CollectER format).

From 1990 to 2022, the road transport emissions of CO_2 and N_2O have increased by 19 and 44 %, respectively, whereas the emissions of CH_4 have decreased by 91 % (from Figures 6.14 - 6.16). From 1990 to 2022 the other mobile CO_2 emissions have decreased by 14 %, (from Figures 6.18 - 6.20).

Table 6.2 Emissions of CO_2, CH_4 and N_2O in 2022 for road transport and other mobile sources.

	CO_2 ktonnes	CH_4 tonnes	N_2O tonnes
Manufacturing industries/Construction (mobile)	648	20	30
Civil aviation (Domestic)	118	1	6
Road transport: Passenger cars	5873	180	126
Road transport: Light duty vehicles	1527	6	45
Road transport: Heavy duty vehicles	3668	43	248
Road transport: Mopeds & motorcycles	68	67	1
Road transport: Gasoline evaporation	0	0	0
Railways	154	2	5
National navigation (Shipping)	495	9	12
Commercial/Institutional: Mobile	175	31	7
Residential: Household and gardening (mobile)	26	19	0
Agriculture/forestry/fishing: Off-road agriculture/forestry	684	41	33
Agriculture/forestry/fishing: National fishing	376	6	9
Other, Mobile	185	8	7
Domestic total	13996	433	529
Road transport exhaust total	11135	296	420
Other mobile exhaust total	2861	137	109
Civil aviation (International)	2169	6	73
Navigation (International)	1547	27	39

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 2022, the respective emission shares were 53, 33, 14 and 0 %, 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 2022 emission shares for CH_4 were 61, 23, 14 and 2 % for passenger cars, 2-wheelers, heavy-duty vehicles and light-duty vehicles, respectively (Figure 6.17).

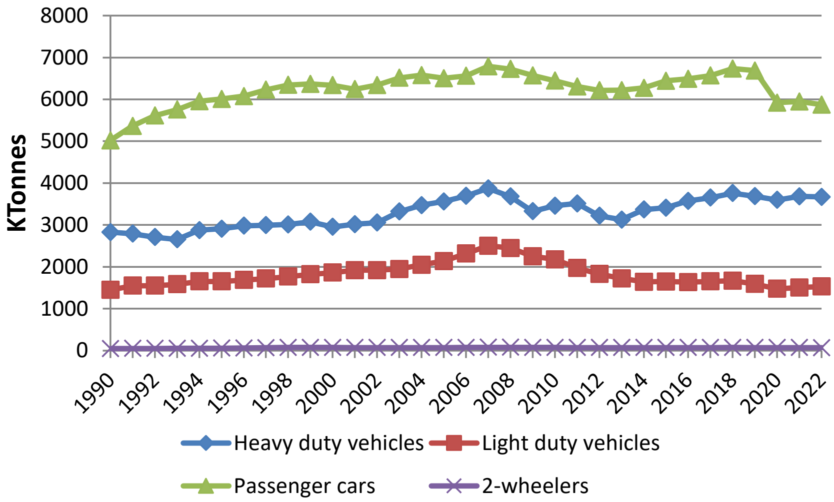


Figure 6.14 CO_2 emissions (k-tonnes) per vehicle type for road transport 1990-2022.

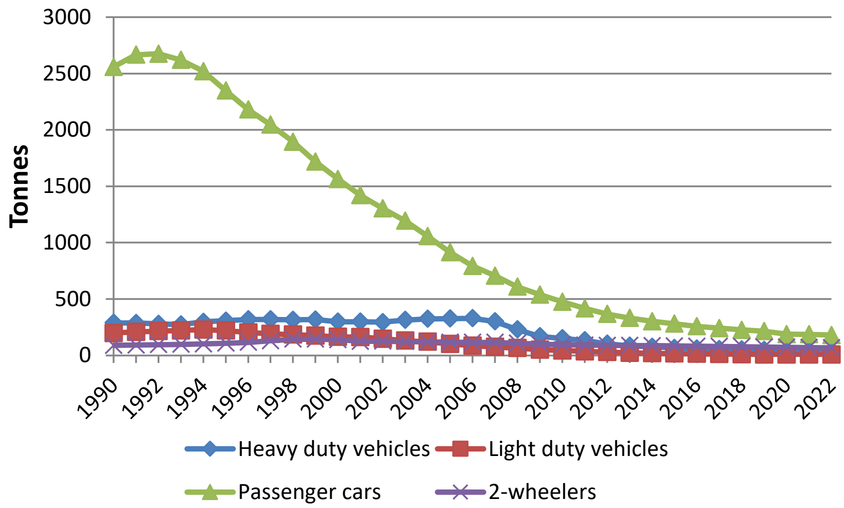


Figure 6.15 CH_4 emissions (tonnes) pr. vehicle type for road transport 1990-2022.

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 2022, emission shares for passenger cars, heavy and light-duty vehicles were 59, 30 and 11 %, of the total road transport N_2O, respectively (Figure 6.17).

Referring to the fifth IPCC assessment report, 1 g CH_4 and 1 g N_2O has the greenhouse effect of 28 and 265 g CO_2, respectively. Despite 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.

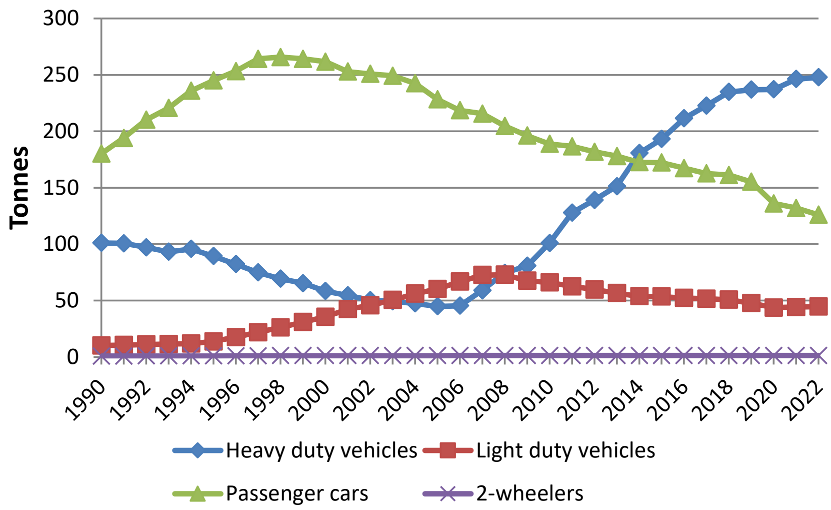


Figure 6.16 N_2O emissions (tonnes) per vehicle type for road transport 1990-2022.

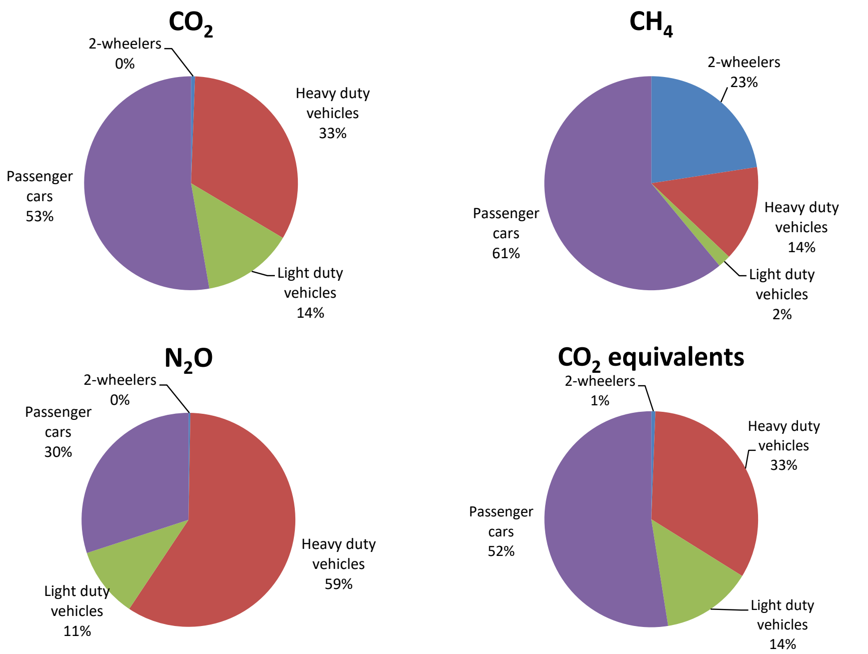


Figure 6.17 CO_2, CH_4 and N_2O emission shares and GHG equivalent emission distribution for road transport in 2022.

6.2.2 Other mobile sources

For other mobile sources, the highest CO_2 emissions in 2022 come from Agriculture/forestry/fisheries (1A4c), Industry-other (1A2g) and Navigation (1A3d), with shares of 37 %, 23 %, 17, respectively (Figure 6.21). The 1990-2021 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), Commercial/Institutional (1A4a), Industry-other (1A2g), and Residential (1A4b), see Figure 6.21. The emission shares are 34 %, 7 %, 23 %, 14 % and 14 %, respectively in 2022. For the remaining sectors the emission shares 6 % 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.

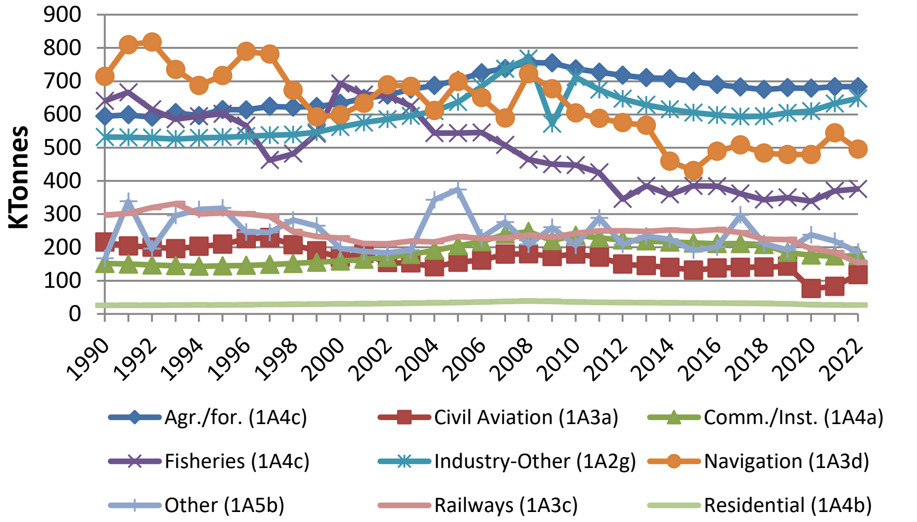


Figure 6.18 CO_2 emissions (ktonnes) in CRF sectors for other mobile sources 1990-2022.

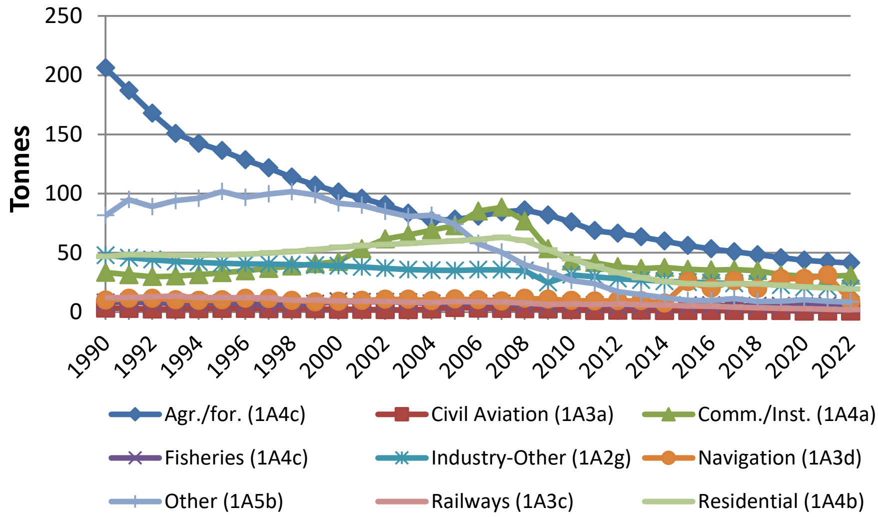


Figure 6.19 CH_4 emissions (tonnes) in CRF sectors for other mobile sources 1990-2022.

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).

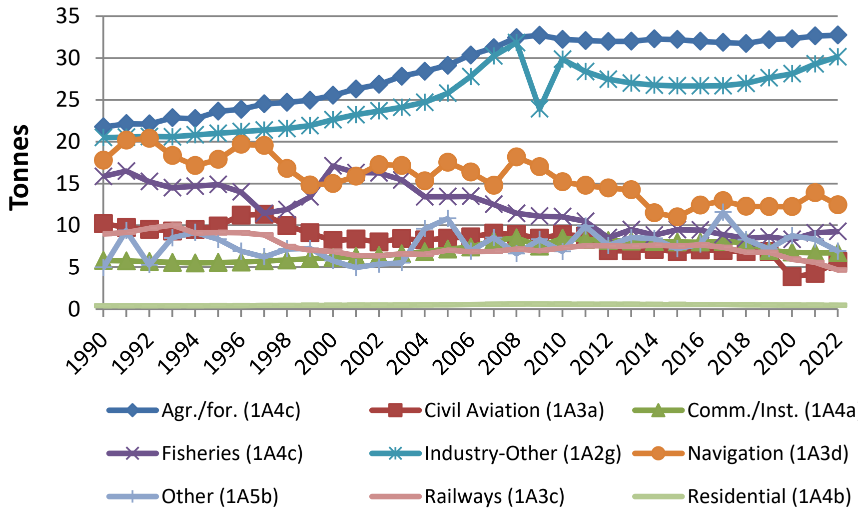


Figure 6.20 N_2O emissions (tonnes) in CRF sectors for other mobile sources 1990-2022.

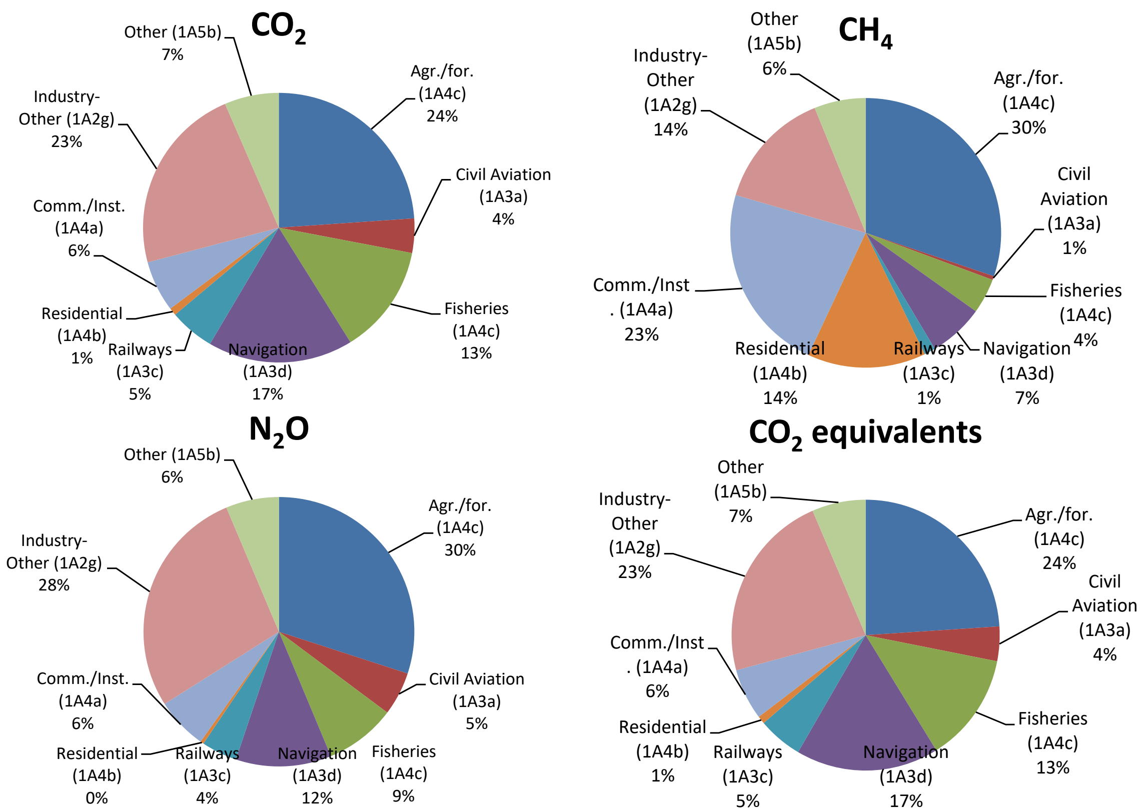


Figure 6.21 CO_2, CH_4 and N_2O emission shares and GHG equivalent emission distribution for other mobile sources in 2022.

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 2022 in NFR sectors. The emission figures in the time series 1985-2022 are given in Annex 16 (NFR format) and are shown for 2022 in Annex 15 (CollectER format).

From 1985 to 2022, the road transport emissions of SO_2, NO_X, NMVOC, CO, PM (exhaust emissions; all size fractions) and BC have decreased by 99, 78, 93, 92, 94 and 93 %, respectively (Figures 3.3.14-3.3.19), whereas the NH_3 emissions have increased by 1001 % during the same period (Figure 3.3.20).

For other mobile sources, the emission changes for SO_2, NO_X, NMVOC, CO, PM (exhaust emissions; all size fractions) and BC are -96, -47, -65, -35, -80 and -83 %, respectively (Figures 3.3.21-3.3.25). The NH_3 emissions have increased by 18 % during the same period (Figure 3.3.26).

Table 6.3 Emissions of SO_2, NO_X, NMVOC, CO, NH_3, TSP, PM_{10}, $PM_{2.5}$ and BC in 2022 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	1852	610	10320	2	122	122	122	82
Civil aviation (Domestic)	38	511	13	280	0	4	4	4	2
Civil Aviation (Domestic): Tyre and brake wear	0	0	0	0	0	1	0	0	0
Road transport: Passenger cars	37	10369	2016	34367	593	74	74	74	46
Road transport:Light duty vehicles	10	6854	180	1626	49	49	49	49	37
Road transport:Heavy duty vehicles	23	3499	155	1627	45	51	51	51	28
Road transport: Mopeds & motorcycles	0	115	749	5712	1	12	12	12	2
Road transport: Gasoline evaporation	0	0	1339	0	0	0	0	0	0
Road transport: Brake wear	0	0	0	0	0	673	660	263	18
Road transport: Tyre wear	0	0	0	0	0	954	572	401	146
Road transport: Road abrasion	0	0	0	0	0	1213	606	328	0
Railways	1	846	48	149	0	8	8	8	5
Railways: Train brake wear	0	0	0	0	0	112	112	56	0
Railways: Train contact wire wear	0	0	0	0	0	3	3	1	0
Railways: Train wheel and rail wear	0	0	0	0	0	251	251	126	0
National navigation (Shipping)	185	8852	412	885	0	253	251	249	25
Commercial/Institutional: Mobile	1	448	741	27308	0	36	36	36	16
Residential: Household and gardening (mobile)	0	32	819	11388	0	16	16	16	1
Agriculture/forestry/fishing: Off-road agriculture/forestry	4	2115	632	5766	2	186	186	186	108
Agriculture/forestry/fishing: National fishing	238	5723	283	781	0	107	106	106	22
Other, Mobile	66	1013	244	2880	1	51	51	51	19
Domestic total	606	42229	8239	103088	694	4176	3171	2138	556
Road transport exhaust total	70	20837	4438	43331	688	186	186	186	112
Road transport non exhaust total	0	0	0	0	0	2840	1839	991	164
Other mobile exhaust total	536	21392	3802	59756	5	783	780	778	281
Other mobile non exhaust total	0	0	0	0	0	367	366	183	0
Civil aviation (International)	692	10206	155	1931	0	98	98	98	36
Civil Aviation (International): Tyre and brake wear	0	0	0	0	0	5	4	2	0
Navigation (International)	975	34395	1335	3743	0	1021	1010	1005	63

6.3.1 Road transport

The stepwise lowering of the sulphur content in diesel fuel has caused 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 2022 shares for SO_2 emissions and fuel consumption for passenger cars, heavy-duty vehicles, light-duty vehicles and 2-wheelers are the same in each case: 53, 33, 14 and 0 %, respectively (Figure 6.29).

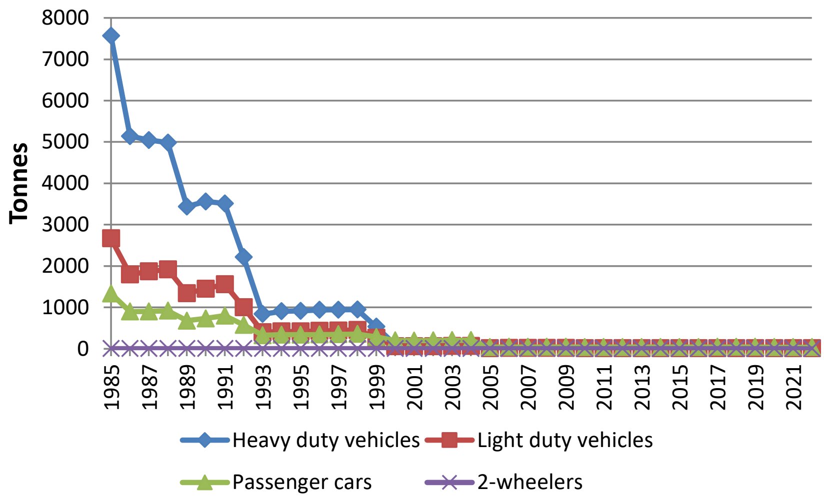


Figure 6.22 SO_2 emissions (tonnes) per vehicle type for road transport 1985-2022.

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 2, 3, 4 and 5 private cars (introduced in 1997, 2001, 2006 and 2011, respectively).

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

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

For heavy duty vehicles until Euro III, the real traffic NO_x emissions are not reduced in the order as intended by the EU emission legislation. Most markedly for Euro II engines, the emission factors are even higher than for Euro I due to the so-called engine cycle-beating effect. Outside the legislative test cycle stationary measurement points, the electronic engine control for heavy duty Euro II and III engines 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 in 2008 and 2009 and improved emission factors for Euro IV onwards causes the NO_x emissions for heavy duty vehicles to decrease significantly from 2008.

Exhaust particulate emissions from road transportation vehicles are well below $PM_{2.5}$. The emissions from light- and heavy-duty vehicles have significantly decreased since the mid-1990s due to gradually stricter EURO emission standards. In recent years until 2008 the environmental benefit of introducing gradually cleaner diesel private cars has been somewhat outbalanced by an increase in sales of new vehicles. After 2008, the PM emissions gradually become lower due to the increasing number of Euro 5 cars equipped with particulate filter sold in Denmark from 2006 onwards (Figure 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 4. As a result, the BC emission development becomes environmentally less positive than for TSP, until the introduction of Euro 5 vehicles, for which the installed particulate filters have very high removal rates of BC.

An undesirable environmental side effect of the introduction of catalyst cars is the increase in the emissions of NH_3 from the first two generations of catalyst cars (Euro 1 and 2) compared to conventional cars. The emission factors for later catalytic converter technologies are considerably lower than the ones for Euro1 and 2, thus causing the emissions to decrease from 2001 onwards (Figure 6.28).

The 2022 emission shares for passenger cars, heavy-duty vehicles, light-duty vehicles and 2-wheelers for NO_x (50, 33, 17 and 0 %), NMVOC (exhaust: 45, 4, 4 and 17 %), CO (79, 4, 4 and 13 %), PM (40, 28, 26 and 6 %), BC (32, 49, 19 and 0 %), and NH_3 (86, 7, 7 and 0 %), are also shown in Figure 6.29.

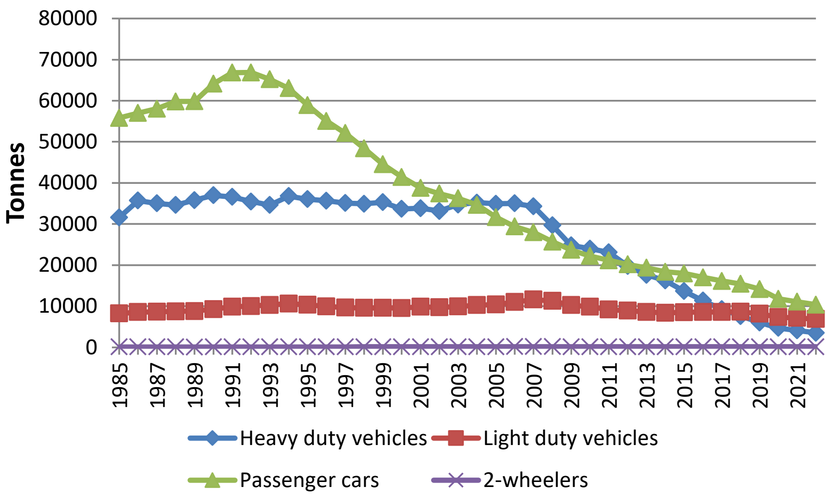


Figure 6.23 NO_X emissions (tonnes) per vehicle type for road transport 1985-2022.

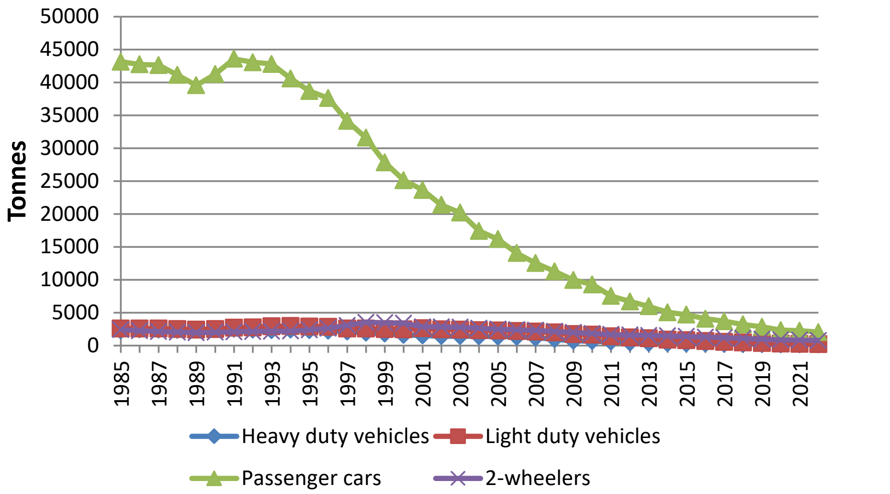


Figure 6.24 NMVOC emissions (tonnes) per vehicle type for road transport 1985-2022.

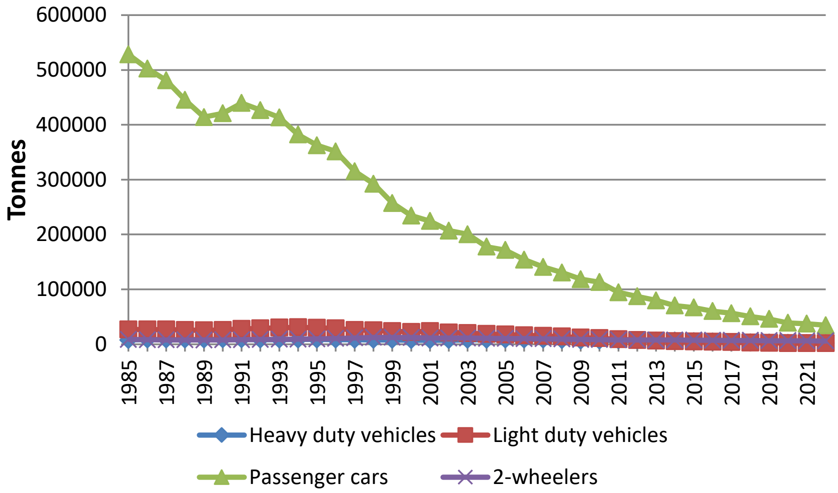


Figure 6.25 CO emissions (tonnes) per vehicle type for road transport 1985-2022.

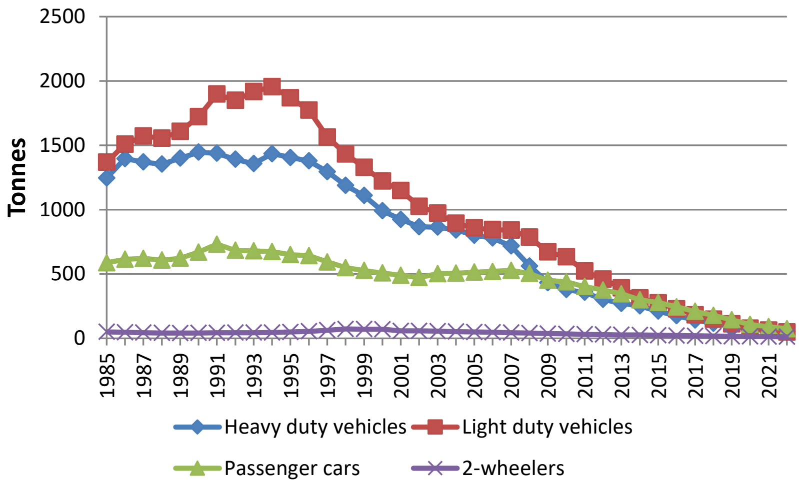


Figure 6.26 PM emissions (tonnes) per vehicle type for road transport 1985-2022.

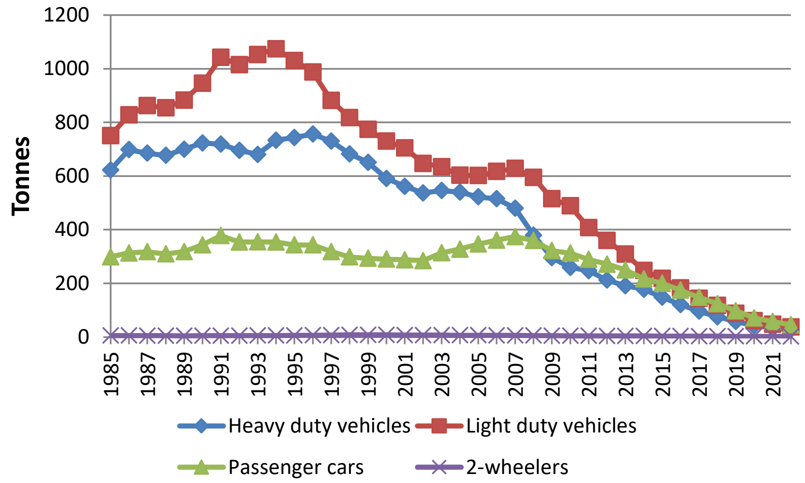


Figure 6.27 BC emissions (tonnes) per vehicle type for road transport 1985-2022.

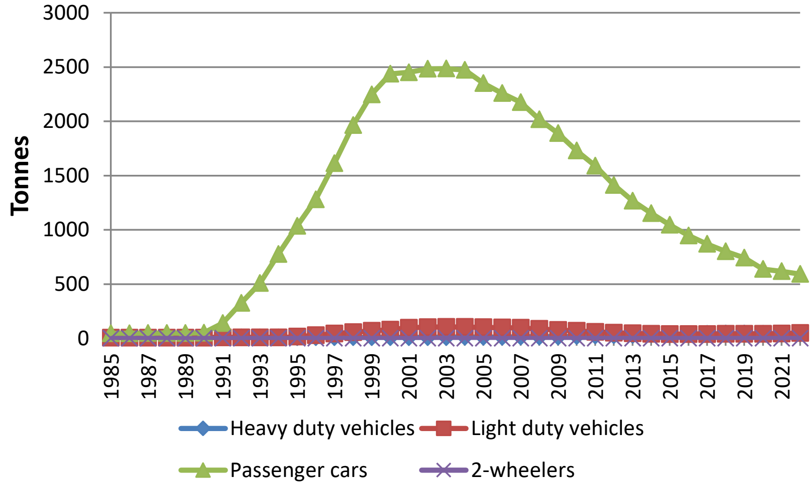


Figure 6.28 NH_3 emissions (tonnes) per vehicle type for road transport 1985-2022.

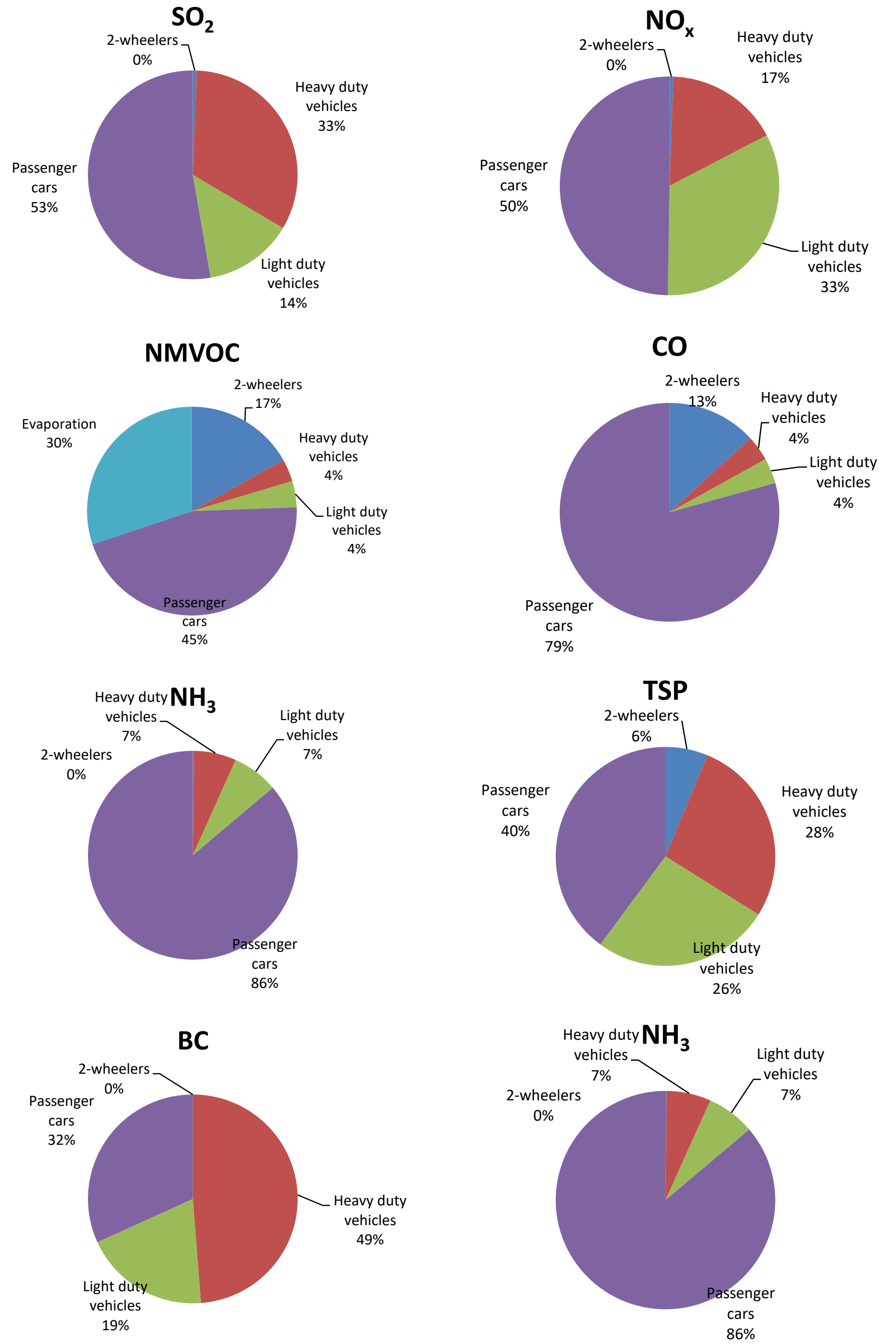


Figure 6.29 SO_2, NO_X, NMVOC, CO, NH_3, PM and BC emission shares per vehicle type for road transport in 2022.

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

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

In Table 6., the non-exhaust TSP, PM_{10}, $PM_{2.5}$ and BC emissions for road transport are shown for 2022 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. For brake wear, passenger cars caused the highest emissions in

2022, followed by light-duty vehicles, trucks, buses and 2-wheelers. In the case of tyre wear and road abrasion, passenger cars caused the highest emissions in 2022, followed by trucks, light-duty vehicles, buses and 2-wheelers.

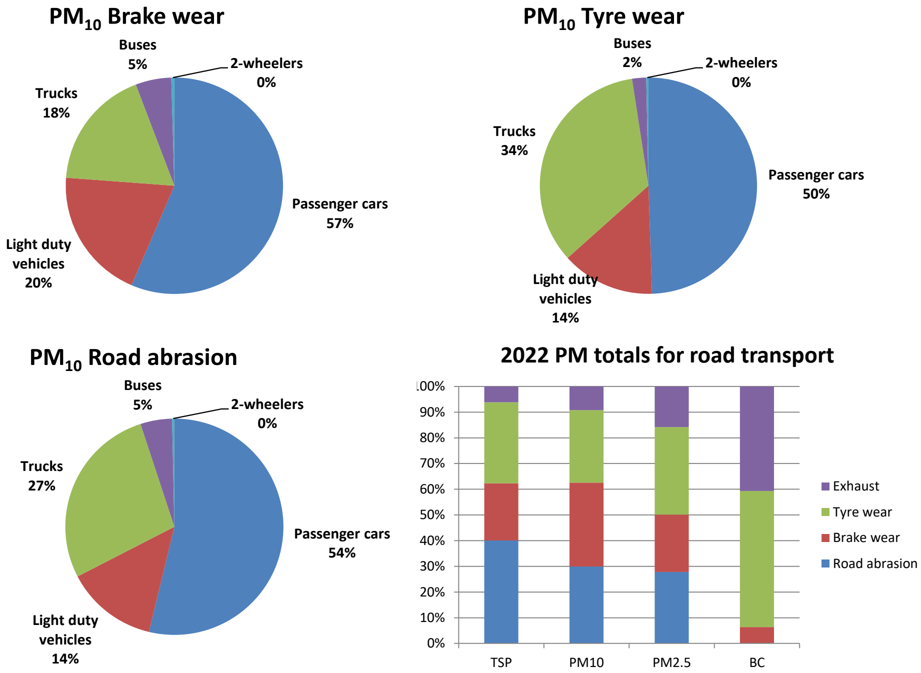


Figure 6.30 Brake and tyre wear and road abrasion PM_{10} emission shares and PM and BC exhaust/non-exhaust distributions for road traffic in 2022.

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 6, 9, 16 and 41 %, respectively, in 2022. For brake and tyre wear and road abrasion the TSP shares are 22, 32 and 40 %, respectively. The same three sources have PM_{10} shares of 33, 28 and 30 %, respectively, $PM_{2.5}$ shares of 22, 34, 28 %, and BC shares of 6, 53 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.

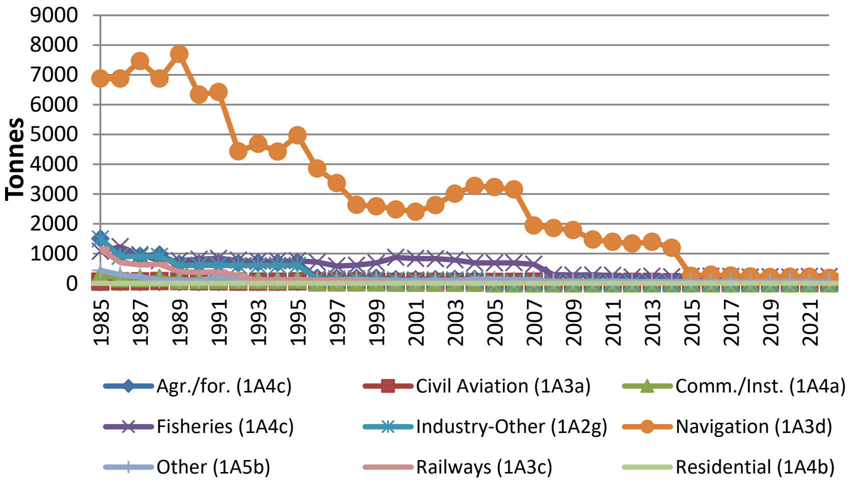


Figure 6.31 SO_2 emissions (ktonnes) in NFR sectors for other mobile sources 1985-2022.

NO_X emissions mainly come from diesel machinery, and the most important sources are Navigation (1A3d), Agriculture/forestry/fisheries (1A4c) and Industry (1A2f), as shown in Figure 6.32. The 2022 emission shares are 41, 37 and 9 %, respectively (Figure 6.38). Minor emissions come from the sectors Other (1A5), Railways (1A3b), Civil Aviation (1A3a), Commercial/Institutional (1A4a) and Residential (1A4b).

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

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

For agricultural and forestry machines, the diesel fuel consumption increases from 1985 to 2008 and is then followed by a decrease from 2009 onwards (Figure 6.9). The NO_x emission performance for non-road diesel machinery is characterized by somewhat higher NO_x emission factors for 1991-stage I machinery, and gradually improved emission performance for stage I and onwards emission technology levels entering the stock since the late 1990s. Consequently, the total NO_x emissions for agriculture/forestry increase up to 2001, and then reduces from 2003 onwards.

The NO_x emissions for industrial non-road machinery decline from 1985-2022. The emission reductions are, however, mostly pronounced from 2009 onwards. The NO_x emission development from 1985 to 2022 for industrial non-road machinery is the product of a rather constant fuel consumption from 1985-1999, a fuel consumption increases from 2000 to 2008, and a fuel consumption decrease from 2009 onwards (Figure 6.9), in combination with a development in NO_x emission factors as explained for agricultural machinery. For industrial non-road machinery, the NO_x emission impact from the global financial crisis becomes very visible for 2009.

For railways, the gradual shift towards electrification explains the declining trend in diesel fuel consumption and NO_X emissions for this transport sector until 2001.

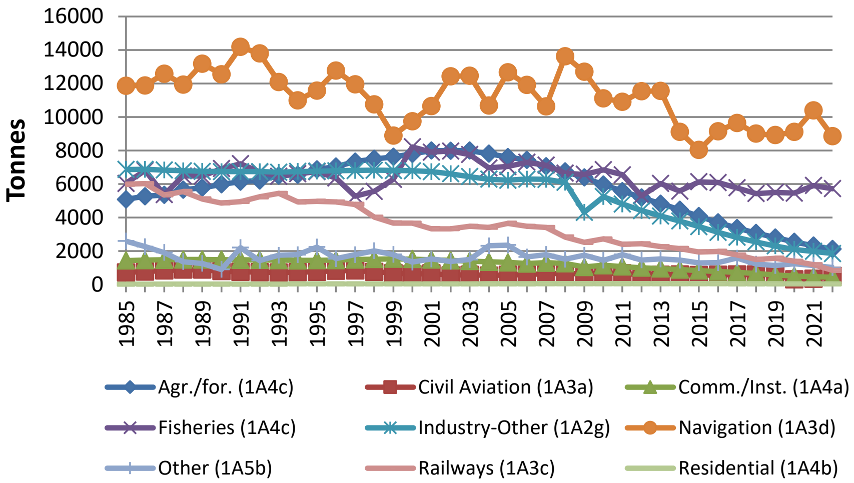


Figure 6.32 NO_X emissions (tonnes) in NFR sectors for other mobile sources 1985-2022.

The 1985-2022 time series of NMVOC and CO emissions are shown in Figures 6.33 and 6.34 for other mobile sources. The 2022 sector emission shares are shown in Figure 6.38. For NMVOC, the most important sectors are Agriculture/forestry/fisheries (1A4c), Residential (1A4b), Commercial/Institutional (1A4a) and Industry (1A2g), with 2022 emission shares of 24, 22, 20 and 16 %, respectively.

The same four sectors also contribute with most of the CO emissions. For Commercial/Institutional (1A4a), Residential (1A4b), Industry (1A2g) and Agriculture/forestry/fisheries (1A4c) the emission shares are 46, 19, 17 and 11 %, respectively. Minor NMVOC and CO emissions come from Navigation (1A3d), Railways (1A3c), Civil Aviation (1A3a) and Other (1A5).

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

As shown in Figure 6.38, for other mobile sources the largest TSP contributors in 2022 are Agriculture/forestry/fisheries (1A4c), Navigation (1A3d) and Industry (1A2f) with emission shares of 38 %, 32 % and 15 %, respectively. The remaining sectors: Railways (1A3c), Civil aviation (1A3a), Other (1A5), Commercial/Institutional (1A4a) and Residential (1A4b) represent only minor emission sources.

The 1985-2022 TSP emissions for navigation and fisheries are determined by the fuel consumption fluctuations in these years, and the development of the emission factors, which to a major extent is a function of the fuel type and fuel sulphur content.

For agriculture/forestry non-road machinery, the TSP emissions development from 1985-2022 are also determined by the development of fuel consumption and emission factors. The diesel fuel consumption increases from 1985 to 2008 followed by a decrease from 2009 onwards (Figure 6.9), whereas the emission factors are gradually reduced during the whole period. Consequently, the total TSP emissions for agriculture/forestry are quite constant until 1990, and then reduced from 1991 onwards.

The TSP emissions for industrial non-road machinery decline from 1985-2022. The latter emission development is the product of gradually reduced emission factors throughout the period, in combination with a rather constant fuel consumption from 1985-1999, which later increases from 2000 to 2008 followed by a fuel consumption decrease from 2009 onwards (Figure 6.9). For industry, the TSP emission impact from the global financial crisis becomes very visible for 2009.

The TSP emission explanations for railways are the same as for NO_x (Figure 6.32).

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

The amounts of NH_3 emissions calculated for other mobile sources are very small. The largest emission sources are Agriculture-/forestry/fisheries (1A4c), Industry (1A2f), Other (1A5b) and Railways (1A3c), with emission shares of 39 %, 32 %, 13 % and 8 %, respectively.

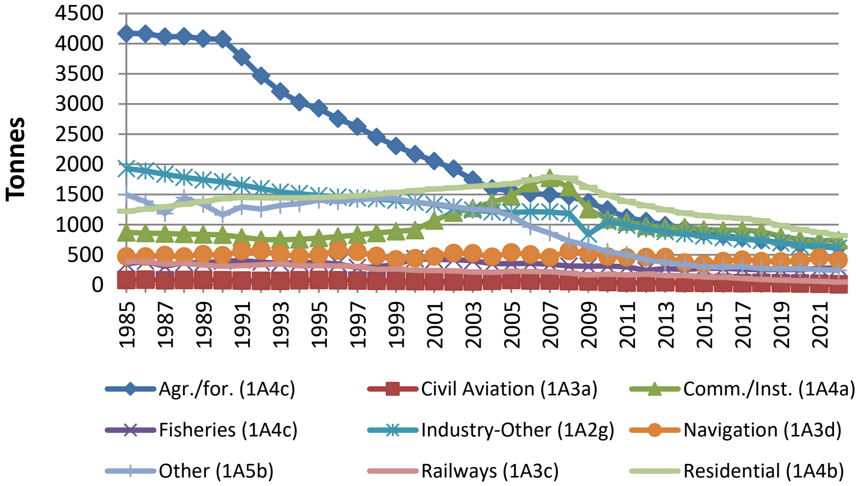


Figure 6.33 NMVOC emissions (tonnes) in NFR sectors for other mobile sources 1985-2022.

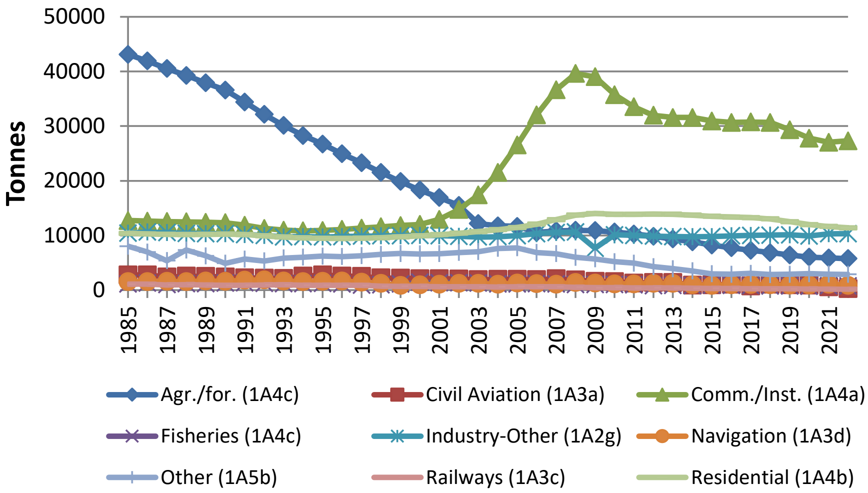


Figure 6.34 CO emissions (tonnes) in NFR sectors for other mobile sources 1985-2022.

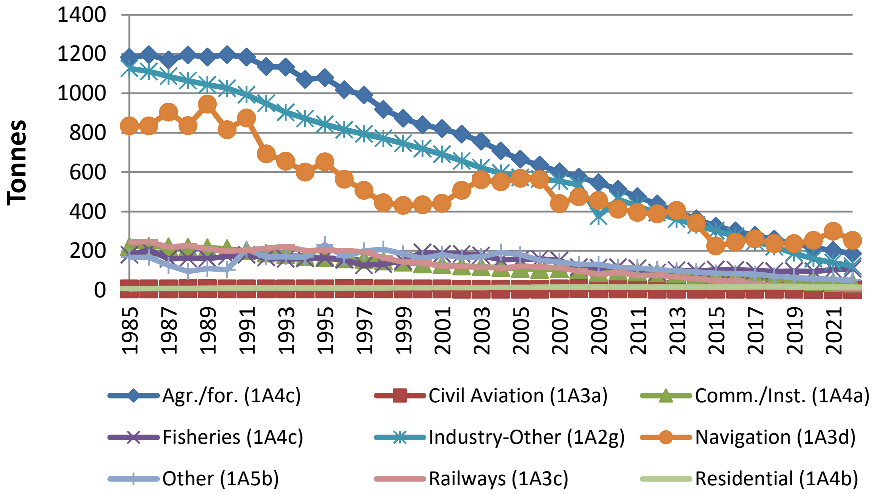


Figure 6.35 TSP emissions (tonnes) in NFR sectors for other mobile sources 1985-2022.

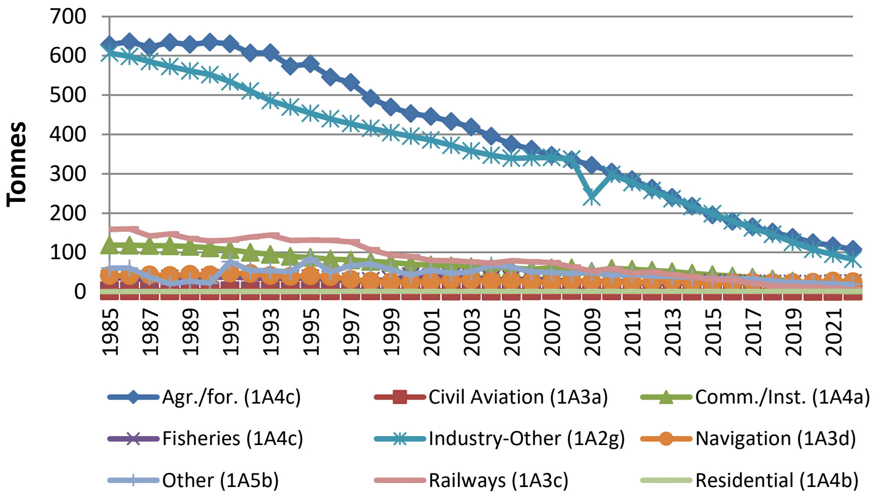


Figure 6.36 BC emissions (tonnes) in NFR sectors for other mobile sources 1985-2022.

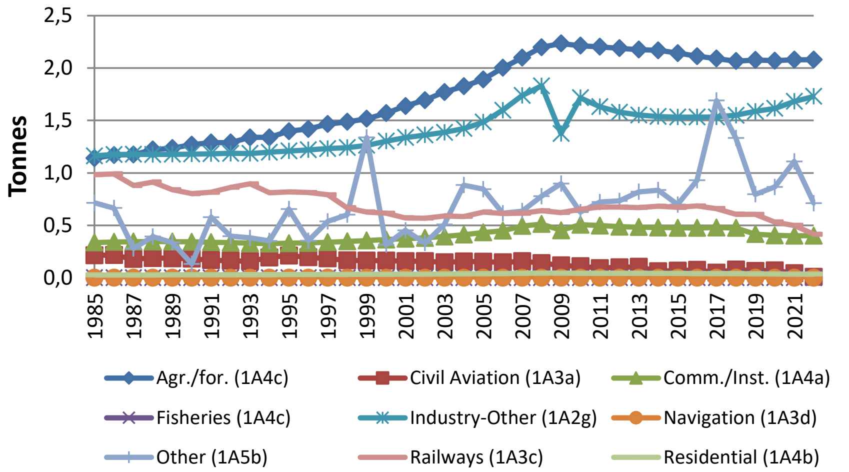


Figure 6.37 NH_3 emissions (tonnes) in NFR sectors for other mobile sources 1985-2022.

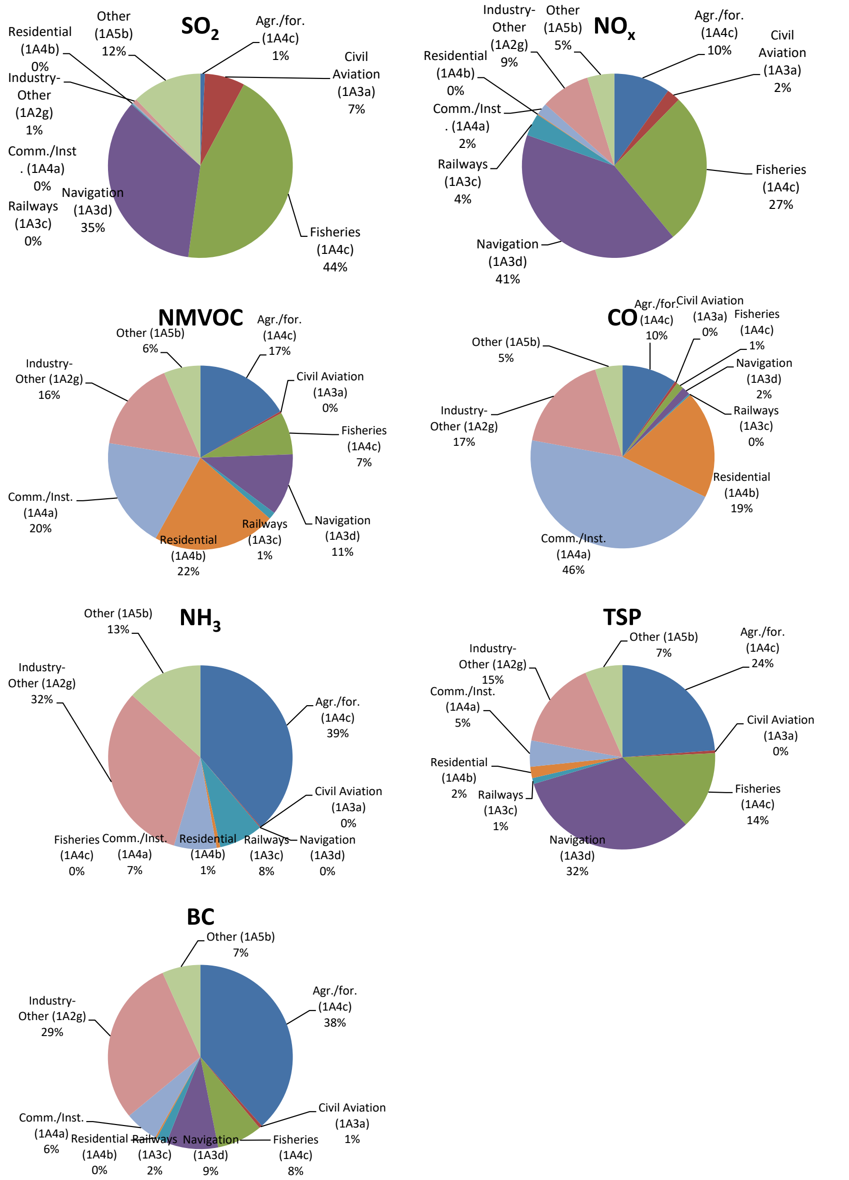


Figure 6.38 SO_2, NO_X, NMVOC, CO, NH_3, PM and BC emission shares per vehicle type for other mobile sources in 2022.

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

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

In Table 6.3, the non-exhaust TSP, PM_{10} and $PM_{2.5}$ emissions for railways and civil aviation are shown for 2022 in NFR sectors. The activity data and emission factors are also shown in Annex 15.

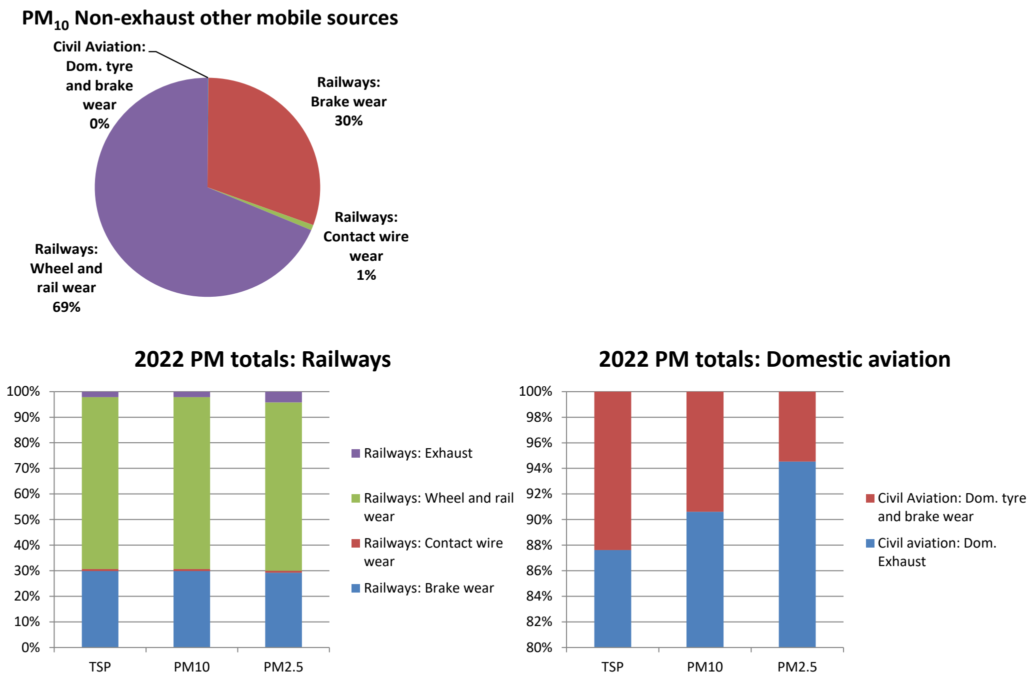


Figure 6.39 Non-exhaust PM_{10} emission shares for domestic civil aviation and railways, and PM exhaust/non-exhaust distributions for civil aviation and railways in 2022.

For PM_{10}, the non-exhaust emissions coming from train wheel and rail wear, brake wear and contact wire wear make up 69 %, 30 % and 1 % of the total non-exhaust emissions for other mobile sources. For railways, the exhaust emissions of TSP, PM_{10}, $PM_{2.5}$ make up 2 %, 2 % and 4 %, respectively, of the total TSP, PM_{10}, $PM_{2.5}$ emissions from railways. For civil aviation, the exhaust emissions of TSP, PM_{10}, $PM_{2.5}$ make up 42 %, 49 % and 64 %, respectively, of the total TSP, PM_{10}, $PM_{2.5}$ emissions from civil aviation.

6.4 Heavy metals

In Table 6.4, the heavy metal emissions for road transport and other mobile sources are shown for 2022 in NFR sectors. The emission figures in the time series 1990-2022 are given in Annex 16 (NFR format) and are shown for 1990 and 2022 in Annex 15 (CollectER format).

Table 6.4 Heavy metal emissions in 2022 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	329
Civil aviation (Domestic)	0	0	0	0	0	0	73	0	0
Civil Aviation (Domestic): Tyre and brake wear	0	0	0	20	0	0	3	0	8
Road transport: Passenger cars	0	28	55	88	13	30	117	0	5590
Road transport:Light duty vehicles	0	5	16	12	3	5	28	0	967
Road transport:Heavy duty vehicles	0	7	27	19	6	7	43	0	1436
Road transport: Mopeds & motorcycles	0	0	0	0	0	0	0	0	23
Road transport: Gasoline evaporation	0	0	0	0	0	0	0	0	0
Road transport: Brake wear	0	6	77	55636	0	74	7226	13	11654
Road transport: Tyre wear	0	2	3	15	0	24	77	19	10434
Road transport: Road abrasion	0	0	24	12	0	19	57	0	92
Railways	0	0	1	1	0	0	2	0	77
Railways: Train brake wear	0	0	1117	0	0	2235	0	0	0
Railways: Train contact wire wear	0	0	0	2902	0	0	0	0	0
Railways: Train wheel and rail wear	0	0	0	0	0	0	0	0	0
National navigation (Shipping)	26	2	13	26	4	1250	20	39	95
Commercial/Institutional: Mobile	0	0	1	1	0	1	2	0	94
Residential: Household and gardening (mobile)	0	0	0	0	0	0	0	0	18
Agriculture/Forestry/Fishing: Off-road agriculture/forestry	0	2	6	4	1	2	10	0	347
Agriculture/Forestry/Fishing: National fishing	6	1	5	6	4	8	12	24	59
Other, Mobile	0	0	1	1	0	0	2	0	68
Domestic total	33	56	1353	58750	33	3658	7682	96	31292
Road transport exhaust total	1	40	98	120	22	43	188	0	8017
Road transport non exhaust total	0	8	104	55663	0	117	7360	33	22180
Other mobile exhaust total	32	8	33	45	11	1263	131	63	1087
Other mobile non exhaust total	0	0	1117	2923	0	2235	3	0	8
Civil aviation (International)	0	0	0	0	0	0	0	0	0
Civil Aviation (International): Tyre and brake wear	0	0	0	180	0	0	24	0	69
Navigation (International)	99	8	46	99	13	5027	65	131	310

The heavy metal emission estimates for road transport exhaust are based on a national research study made by Winther and Slentø (2010). The latter study calculates among other the exhaust related emissions from the vehicle fuel and engine oil.

The heavy metal emissions originating from tyre, brake and road wear are based on emission factors from COPERT 5.

Apart from Pb, the emission factors only deviate to a less extent due to changes in fleet and mileage composition over the years; this brought relative changes in fuel consumption per fuel type, engine oil use and aggregated emission factors for brake, tyre and road wear.

The most important exhaust related emissions for road transport are Zn, Pb, Cu and Cr. the most important wear related emissions are Cu and Pb almost solely coming from tyre wear, and Zn from brake and tyre wear.

For other mobile sources, the most important exhaust related emission contributions are calculated for Ni, Se and As, coming from the use of marine diesel oil in fisheries and navigation and residual oil in navigation.

The most important wear related heavy metal emissions for other mobile sources comes from railways, namely Cu from train contact wire wear, and Cr and Ni from train brake wear.

The figures 6.40 and 6.41 show the exhaust related heavy metal emission distributions for all road transport sources split into vehicle categories, and for other mobile sectors, respectively.

For non-road mobile machinery in agriculture, forestry, industry, commercial/institutional and recreational, as well as military and railways, fuel related emission factors from road transport are used derived for the year 2009.

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

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

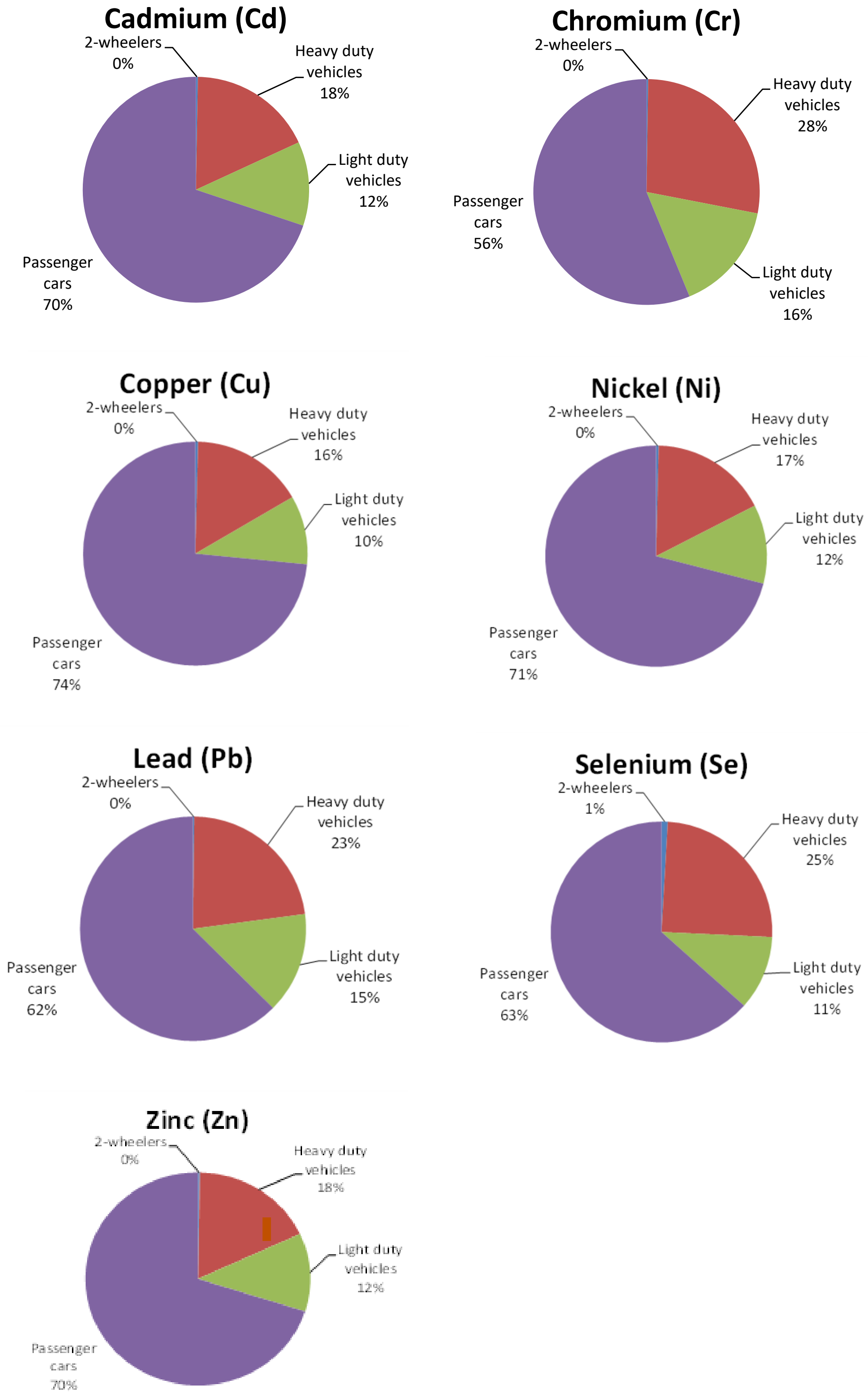


Figure 6.40 Exhaust related heavy metal emission shares for road transport in 2022.

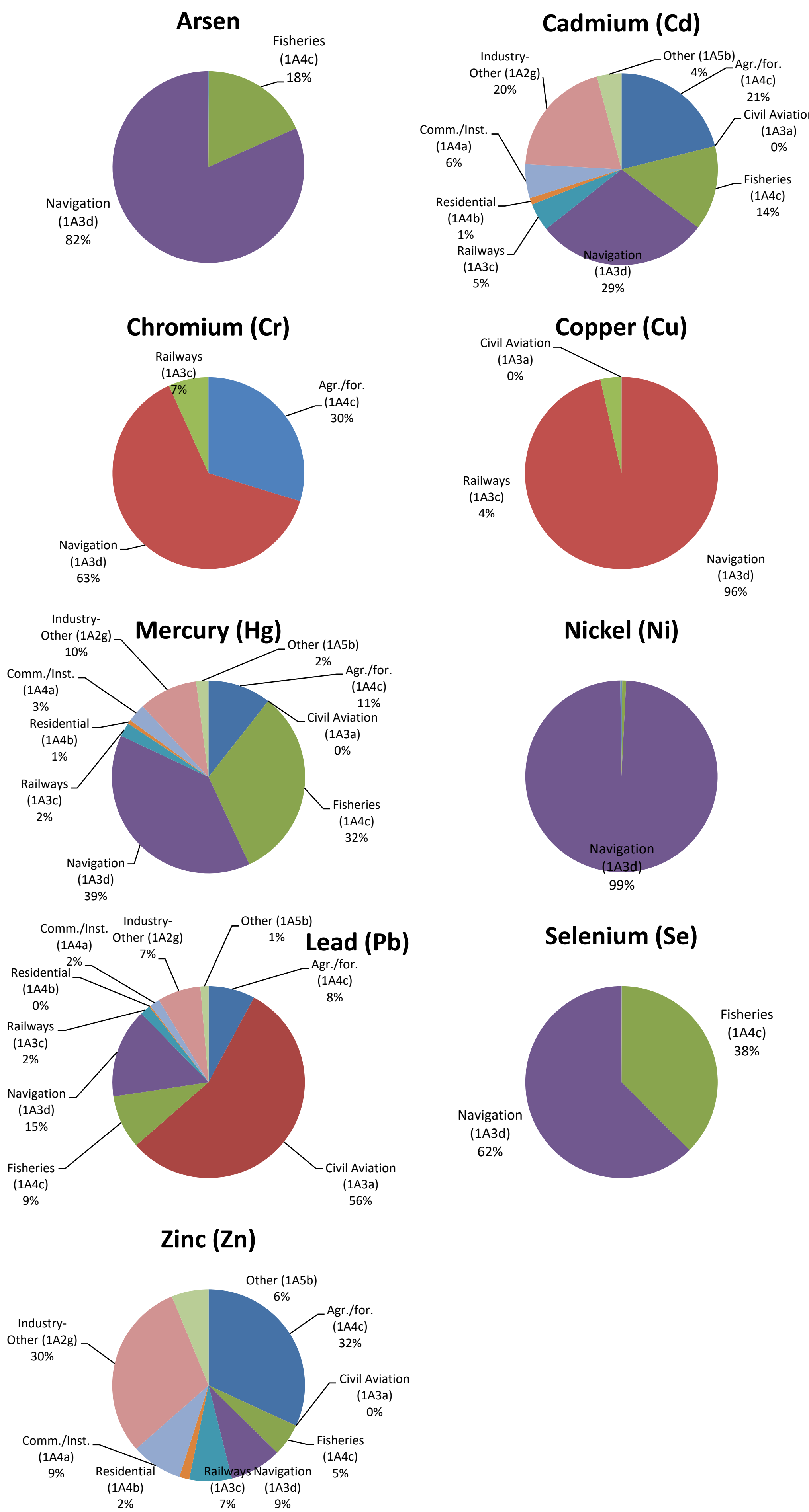


Figure 6.41 Exhaust related heavy metal emission shares for other mobile sources in 2022.

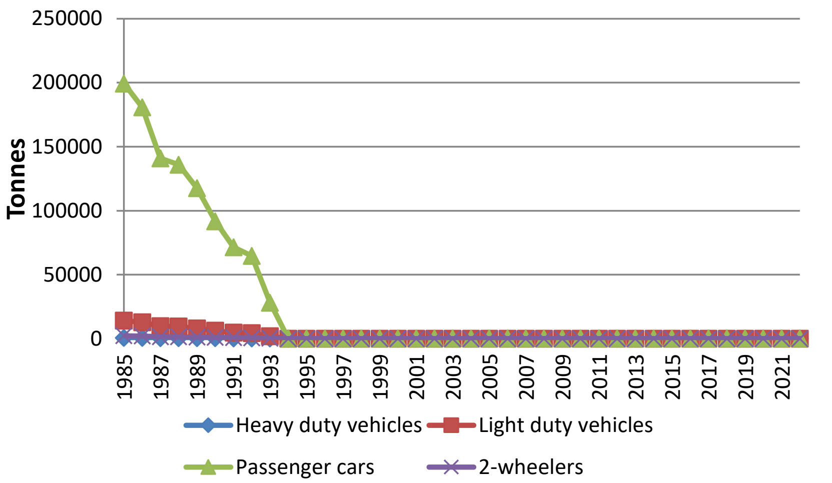


Figure 6.42 Exhaust related Pb emissions (kg) per vehicle type for road transport 1985-2022.

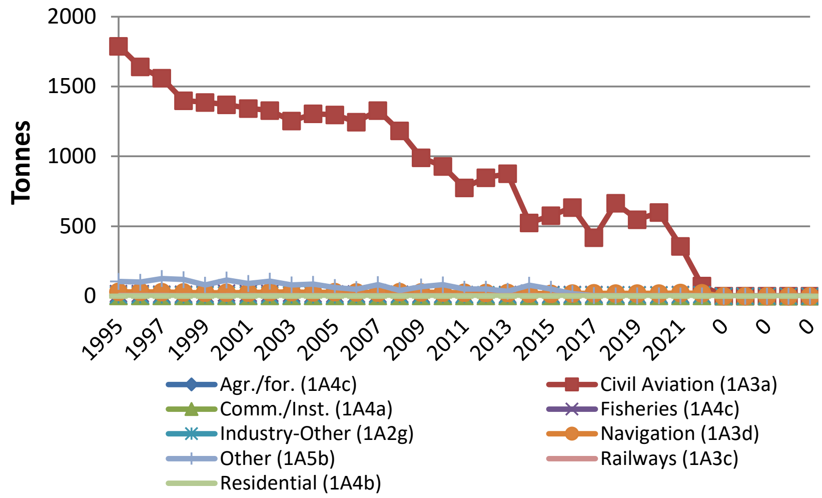


Figure 6.43 Exhaust related Pb emissions (kg) in NFR sectors for other mobile sources 1990-2022.

6.5 POP

Dioxins, HCB, PCBs and PAHs are categorized as POPs (persistent organic pollutants). In Table 6.5, the dioxin, PAH, HCB and PCB emissions for road transport and other mobile sources are shown for 2022 in NFR sectors. The emission figures in the time series 1990-2022 are given in Annex 16 (NFR format) and are shown for 1990 and 2022 in Annex 15 (CollectER format).

Table 6.5 Dioxin, PAH, HCB and PCB emissions in 2022 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	PCB
	g	g	kg	kg	kg	kg	g
Manufacturing industries/Construction (mobile)	0.051	0.007	4.26	4.10	2.14	2.25	0.004
Civil aviation (Domestic)	0.000	0.000	0.00	0.00	0.00	0.00	0.000
Civil Aviation (Domestic): Tyre and brake wear	0.000	0.000	0.00	0.00	0.00	0.00	0.000
Road transport: Passenger cars	0.209	0.036	41.95	32.22	37.29	37.21	0.082
Road transport: Light duty vehicles	0.128	0.012	14.75	11.56	13.16	12.30	0.015
Road transport: Heavy duty vehicles	0.321	0.055	27.37	30.59	4.52	7.03	0.003
Road transport: Mopeds & motorcycles	0.000	0.016	0.45	0.15	0.25	0.53	0.003
Road transport: Gasoline evaporation	0.000	0.000	0.00	0.00	0.00	0.00	0.000
Road transport: Brake wear	0.000	0.000	0.28	0.42	0.50	0.00	0.000
Road transport: Tyre wear	0.000	0.000	0.00	0.00	3.72	0.00	0.000
Road transport: Road abrasion	0.000	0.000	0.00	0.00	0.00	0.00	0.000
Railways	0.013	0.001	0.75	0.83	0.12	0.19	0.002
Railways: Train brake wear	0	0	0	0	0	0	0
Railways: Train contact wire wear	0	0	0	0	0	0	0
Railways: Train wheel and rail wear	0	0	0	0	0	0	0
National navigation (Shipping)	0.015	0.082	3.59	1.55	0.77	5.83	0.006
Commercial/Institutional: Mobile	0.009	0.005	0.93	0.80	0.47	0.59	0.002
Residential: Household and gardening (mobile)	0.000	0.002	0.08	0.03	0.04	0.09	0.001
Agriculture/forestry/fishing: Off-road agriculture/forestry	0.056	0.007	4.66	4.50	2.33	2.44	0.005
Agriculture/forestry/fishing: National fishing	0.010	0.061	3.25	1.52	0.76	5.98	0.004
Other, Mobile	0.008	0.003	0.76	0.69	0.38	0.44	0.002
Domestic total	0.820	0.288	103.08	88.96	66.46	74.89	0.128
Road transport exhaust total	0.658	0.119	84.52	74.51	55.21	57.07	0
Road transport non exhaust total	0	0	0.28	0.42	4.22	0	0
Other mobile exhaust total	0.162	0.169	18.28	14.03	7.03	17.82	0.025
Other mobile non exhaust total	0	0	0.00	0.00	0.00	0	0
Civil aviation (International)	0.000	0.000	0.00	0.00	0.00	0.00	0.000
Civil Aviation (International): Tyre and brake wear	0.000	0.000	0.00	0.00	0.01	0.00	0.000
Navigation (International)	0.051	0.256	10.13	4.72	2.53	17.52	0.017

For mobile sources, road transport displays the largest emission of dioxins and PAH. The dioxin emission share for road transport is 41 % of all mobile emissions in 2022, whereas Navigation and Agriculture/forestry-/fisheries have smaller shares of 28 and 24 %. For the different PAH components, road transport shares are around 80 % of total emissions for mobile sources. The remaining emissions almost solely come from Agriculture/forestry-/fisheries, Navigation and Industry with Agriculture/forestry/fisheries as the largest source.

Figures 6.44 and 6.45 show the dioxin and PAH emission distributions into vehicle categories and other mobile sectors, respectively.

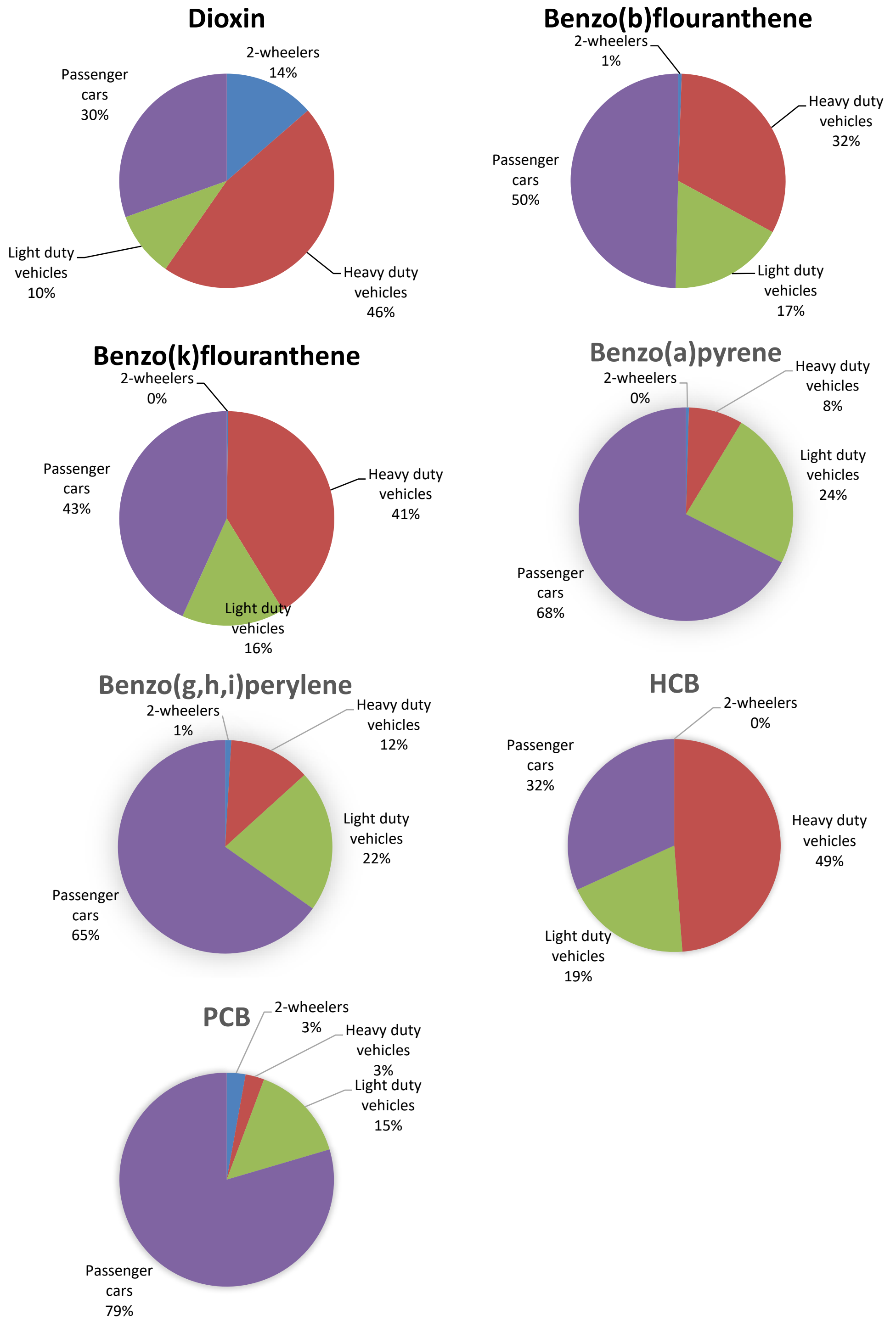


Figure 6.44 Dioxin, PAH, HCB and PCB emission shares for road transport in 2022.

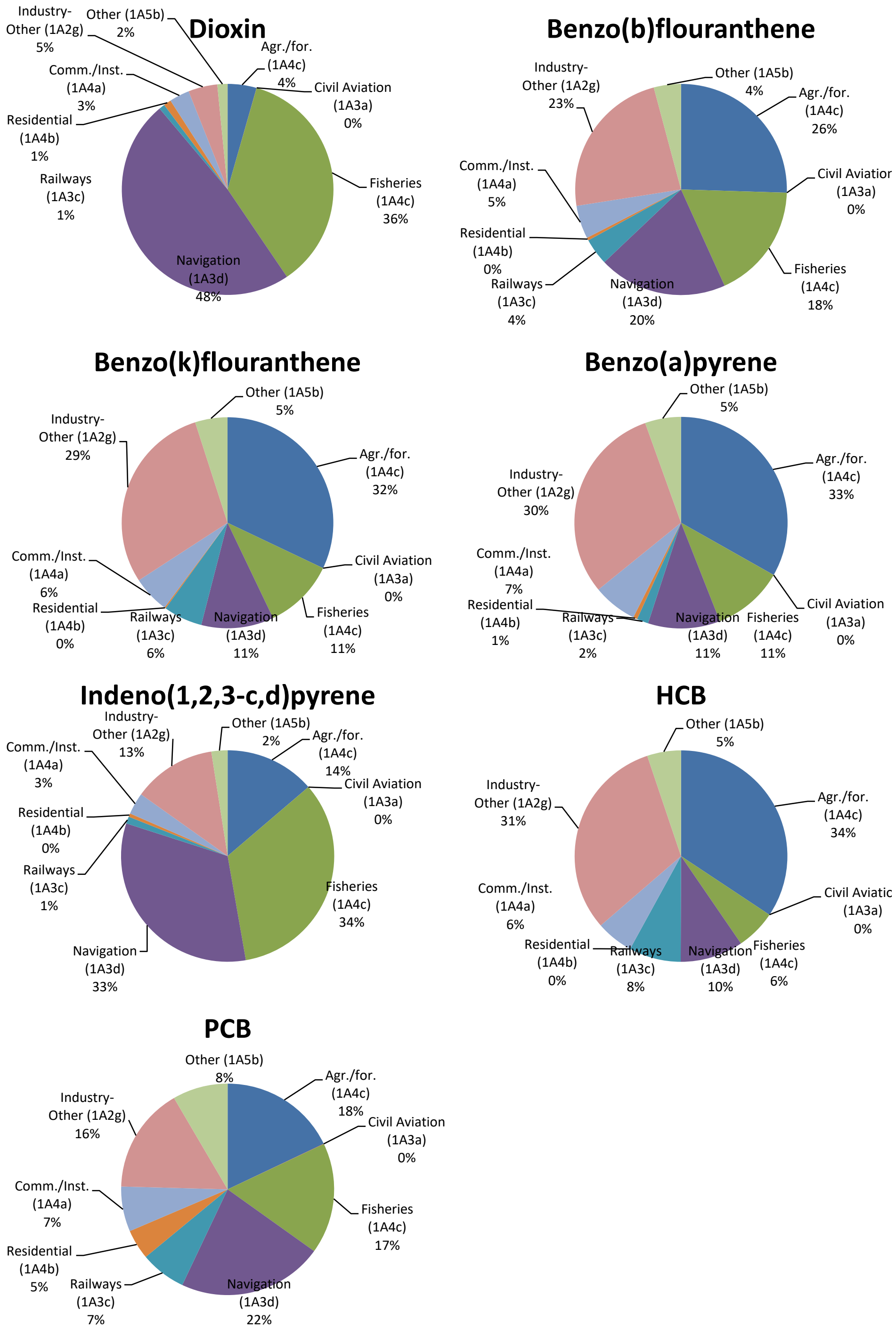


Figure 6.45 Dioxin, PAH, HCB and PCB emission shares for other mobile sources in 2022.

6.6 International transport

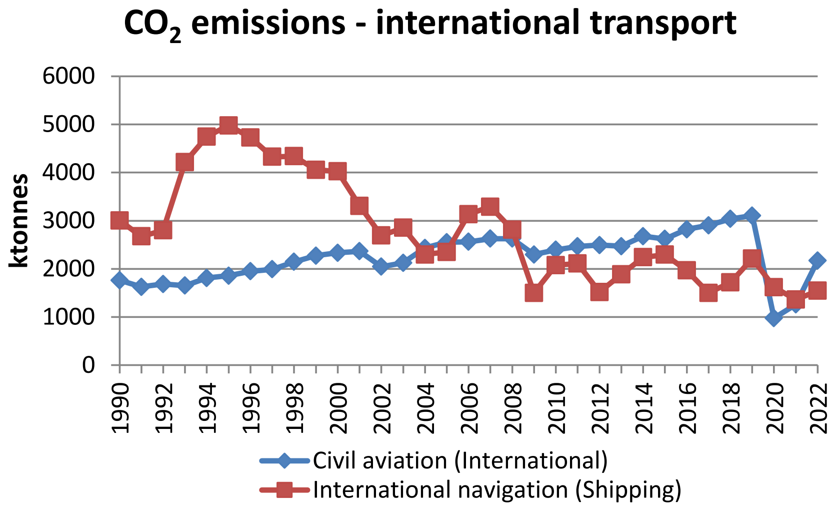
6.6.1 Emissions of CO_2, CH_4 and N_2O

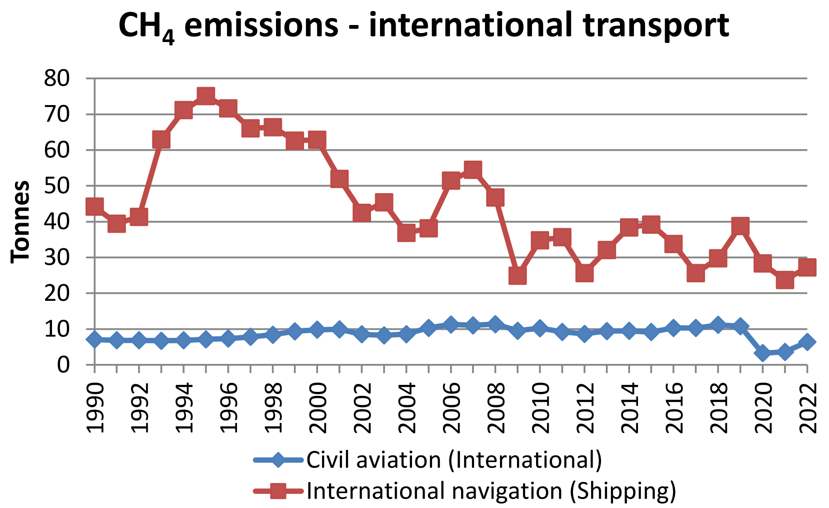
In terms of greenhouse gas emissions, the level of emissions from Danish bunker fuel consumption are 27 %, 8 % and 21 %, respectively, for CO_2, CH_4 and N_2O, compared with the emission total for domestic mobile sources in 2022.

The bunker emission totals of CO_2, CH_4 and N_2O are shown in Table 6.3 for 2022, split into sea transport and civil aviation. All emission figures in the 1990-2022 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 2022.

For further explanations of SO_2 and NO_x emissions from bunkers please refer to the Danish IIR report (Nielsen et al., 2023).

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 6.46 are like the fuel consumption development.





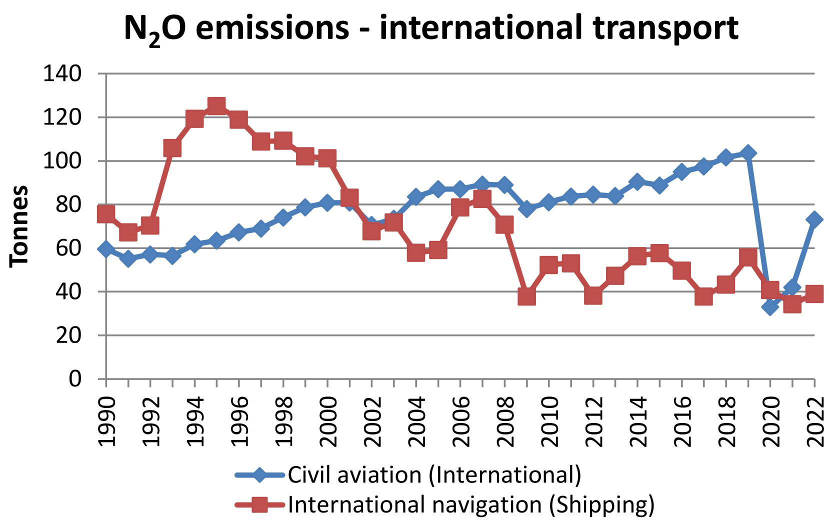


Figure 6.46 CO_2, CH_4 and N_2O emissions for international transport 1990-2022.

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 2022, split into sea transport and civil aviation. All emission figures in the 1985-2022 time series are given in Annex 16 (NFR format). In Annex 15, the emissions are also given in CollectER format for 2022.

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 6.47 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 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).

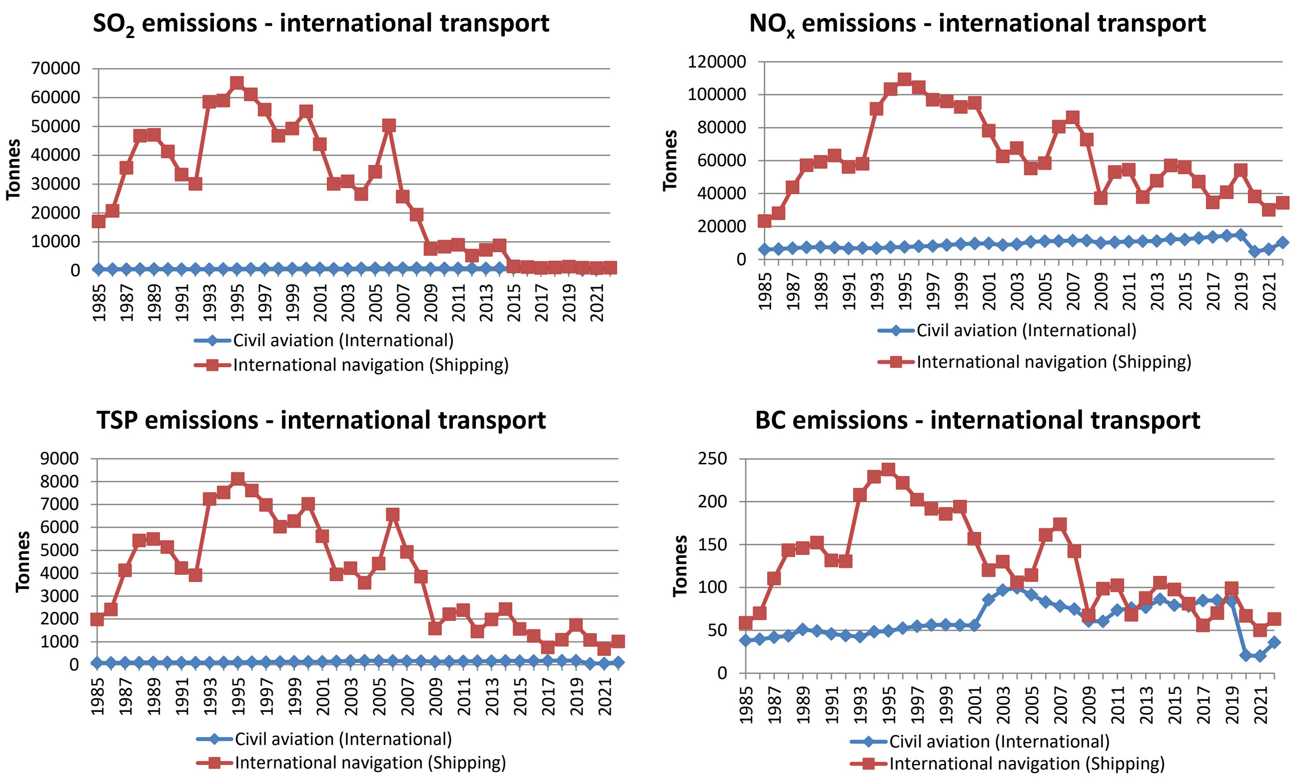


Figure 6.47 SO_2, NO_x, TSP and BC emissions for international transport 1985-2022.

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.

Table 7.1 Tier 1 Uncertainties for activity data, emission factors and total emissions in 2022 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 2022		4.9	30.3	97.6
Trend uncertainty		4.9	1.7	50.8

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 EMEP/EEA guidebook (EMEP/EEA, 2023). 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 for all emission components reported to the LRTAP Convention.

Table 7.2 Uncertainties for activity data, emission factors and total emissions in 2022 and as a trend.

	Emission factor uncertainties [%]		Emission uncertainties [%]	
Pollutant	Road	Other	Overall 2022	Trend
SO_2	50	50	46	1
NO_x	50	100	57	8
NMVOC	50	100	54	4
CO	50	100	62	9
NH_3	1000	1000	992	596
TSP	50	100	46	7
PM_{10}	50	100	48	4
$PM_{2.5}$	50	100	53	2
BC	50	100	57	2
Arsenic	1000	1000	825	89
Cadmium	1000	1000	867	191
Chromium	1000	1000	863	77
Copper	1000	1000	948	32
Mercury	1000	1000	748	111
Nickel	1000	1000	957	21
Lead	1000	1000	980	0
Selenium	1000	1000	741	181
Zinc	1000	1000	964	36
Dioxins	1000	1000	718	131
Benzo(b) flouranthene	1000	1000	842	169
Benzo(k) flouranthene	1000	1000	857	253
Benzo(a) pyrene	1000	1000	900	192
indeno(1,2,3-c,d) pyrene	1000	1000	798	144
HCB	1000	1000	827	220
PCB	1000	1000	827	16

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DANISH EMISSION INVENTORIES FOR ROAD TRANSPORT AND OTHER MOBILE SOURCES

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 1990-2022 the fuel consumption and CO_2 emissions for road transport increased by 26 and 19 %, respectively, and CH_4 emissions have decreased by 91 %. A N_2O emission increase of 44 % is related to the relatively high emissions from older gasoline catalyst cars. The 1985-2022 emission decrease for NO_x, NMVOC, CO, particulates (exhaust only: Size is below $PM_{2.5}$) and BC are 78, 93, 92, 94 and 93 %, respectively, due to the introduction of vehicles complying with gradually stricter emission standards. For SO_2 the emissions drop 99 % (due to reduced sulphur content in the diesel fuel), whereas the NH_3 emissions increased by 1001 % (due to the introduction of catalyst cars). For other mobile sources the calculated fuel consumption and emission changes for CO_2, CH_4 and N_2O were -14, -14, -69 and +3 %, from 1990 to 2022. The emissions of SO_2, NOX, NMVOC, CO, PM (all size fractions) and BC decreased by 96, 47, 65, 35, 80 and 83 %, respectively, from 1985 to 2022. For NH_3 the emissions increased by 18 % in the same period. Uncertainties for the emissions and trends were estimated.

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