Framework Service Contract EEA/ACC/18/001/LOT 1

Methodology for GHG Efficiency of Transport Modes

Final Report

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Corrigendum: The results presented in this report are based on the use of a multiplier for aviation CO_2 emissions, to account for the additional radiative forcing effect of aircraft emissions at high altitude. In the report, this factor is applied to CO_2 emissions from international flights only (see p. 40). Following the finalisation of the report, clarification was made that the correction factor should be applied to all flights, which modifies the results concerning the average GHG efficiency of aviation. These updated results, together with the report's key results concerning other transport modes, are presented in the EEA Briefing No 01/2021.

Contents

1 Introduction and Overview

This section provides a short introduction into the motivation and objectives of the study and points out selected key messages.

1.1 Study objectives

This report conveys the final results and recommendations of the study “Methodology for GHG Efficiency of Transport Modes" conducted by Fraunhofer ISI and CE Delft on request of the European Environment Agency (EEA) between June and November 2020. The study objectives were to establish a robust and dynamic methodology for a continuous set of indicators for the transport sector, measuring and tracking the greenhouse gas efficiency in European transport. In this respect it continues the work done by EEA, the EC and other institutions in the past. Points of departure for this study include the EEA Greenhouse Gas Inventory (EEA 2020b), progress indicators in energy efficiency (EEA 2020d), Average CO_2 emissions from newly registered motor vehicles (EEA 2020a) or the European Union's regular updates on the external costs of transport (Schroten et al. 2019). The methodology developed reflects the current state of knowledge in emissions reporting, is designed to be replicable by the EEA, and is consistent across modes to enable comparison between modes.

The results obtained with the proposed method are valid for European boundaries in various geographical definitions and shall provide meaningful efficiency indicators per mode of transport to support strategic policy decisions. For the five modes of transport, road, rail, aviation, inland waterway transport, and maritime shipping, the methods are applied for EU-27 and EU-28 countries for the years 2014 to 2018. Per mode, indicators are provided in two levels of detail: a top level addressing the basic service types in passenger and freight transport, and a second level going more into detail of vehicle classes and fuel types.

Although the concept of emission monitoring, accounting and allocation of GHG emissions in transport has a long tradition, a number of caveats are still to be discussed or have recently appeared. These include top-down versus bottom-up approaches, the treatment of aviation emissions at high altitudes, treatment of data gaps or suitable boundaries of life cycle emission analyses.

The study managed to establish practicable computation methods and to identify suitable data sources for all modes of transport. However, certain data issues remain to be clarified for annual updates of the indicators. While the top level indicators in most cases can be computed with limited efforts, delving into details of vehicle classes and fuel types requires more resources and still bears some degree of uncertainty.

1.2 Structure and key messages

This report consists of three parts: general methodology (Chapter 2), methods and pilot results by mode (Chapters 3 to 7) and compiled pilot indicators and conclusions (Chapters 8 and 9). Here we provide a broad overview of the contents and overall results of the main sections of the report. We go more into detail with the results for pilot indicators and future outlook than with sheer methodological issues.

- Chapter 2 discusses basic methodological issues and presents core data relevant across all transport modes. Main issues are the scope of greenhouse gas impacts and the composition of the proposed levels in presenting the final GHG efficiency indicators.

- Chapters 3 to 7 discuss the five modes of transport (road, rail, aviation, inland navigation, and maritime shipping), develop estimation methods for the GHG indicators and present results by mode. The decomposition of total emission or fuel use data by vehicle types and transport markets, as well as the selection of timely and publicly available datasets constitute the main challenges in transforming the set of pilot indicators developed in this study into continuous updates by EEA. These challenges, however, remain specific to each mode of transport.

- Chapter 8 presents the compiled pilot indicators by level, transport market and fuel type. Top level indicators for passenger transport suggest that aviation and rail efficiency improved substantially by 11 % to 13 % over the period 2014 to 2018, while the specific GHG intensity of car travel only declined by 3 % and even a negative trend is observable with bus and coach. Freight transport efficiency rates show much wider differences than efficiency rates in passenger travel. Improvement rates on GHG emissions per tkm over the period 2014 to 2018 for the EU-27 are highest for air cargo (14 %) followed by rail freight (11 %). HGVs show a slight improvement of 3 % specific GHG emissions, while LDVs worsen by 2 % in EU-27.

- Chapter 9 finally concludes on the validity of results and provides an outlook for the further development and continuation of the indicators. The pilot indicators on a top level by transport mode are considered sufficiently robust across EU-27 and EU-28 countries. Issues for further methodological improvements include significant European monitoring of load factors in road transport in particular for LDVs, energy consumption and occupancy rates by train classes, the distribution of belly cargo in aviation and actual operations in inland navigation. Agreements for respective data collection with UIC or major national rail carriers, EUROCONTROL and CDNI could be considered.

This study is accompanied by data files per mode containing the inputs, computation rules and outputs for the GHG efficiency indicators for the five modes of transport.

2 General Methodology

2.1 Transport modes and vehicle types

The GHG efficiency in the transport sector may vary considerably between transport markets and vehicle categories. Transport markets denote passenger and freight services in their regional context, i.e. urban, rural, long-distance and extra-European trips and shipments. In these markets, GHG efficiency is driven by three factors: the energy intensity of fuels or electricity, vehicle power train technologies and load factors. The following characteristics per transport mode are addressed:

- Road: passenger car, bus and coach, light duty vehicles (LDV) and heavy goods vehicles (HGV). Powered two-wheelers and means of micro-mobility, such as electric scooters or e-bikes or cargo bikes, as well as conventional cycling and walking are not considered.

- Rail: passenger services are differentiated into conventional passenger trains, high speed rail and rail-based urban public transport by tram and metro. Freight services are not differentiated further.

- Aviation: civilian passenger and freight traffic are addressed. Military and small emitters (i.e. light aircraft, sport aircraft, helicopters) are disregarded.

- Shipping is differentiated between inland waterways (IWW) and maritime shipping, including short sea and ocean freight shipping, coastal passenger ferries and cruise liners.

The more detailed level of analysis will allow for differentiation by basic fuel types. There will be no detailed categorisation by vehicle sizes.

2.2 Geographical scope

The top level of analysis generates European figures by weighed country values for road, rail and IWW, and by using international data sources for aviation and maritime shipping. Results are shown as indicators for Europe as a whole and not for individual countries. The European scope, however, is kept flexible to allow adding or removing of single countries. In particular we allow for the removal of UK data. The methodology also allows the inclusion of non-EU countries like Norway and Switzerland.

National level data is used for internal calculations where needed, e.g. where European data is not reliable or not available with regular updates. Figures by country are not the expected outcome.

For transport across inner-European borders the two main possibilities for the accounting of emissions are:

- Territorial principle – accounting for all activities within a geographical / accounting territory, for this project this would be EU countries.

- Location principle – accounting for all activities of the residents of a country.

For aviation and maritime shipping the geographical scope shall be expanded beyond European territory in order to capture emissions of entire voyages. In many cases emissions occur outside national territories and as a result these emissions can become unaccounted for. A method to overcome this issue is to allocate emissions and transport performance equally between the country of origin and destination. This means that 50 % of the emissions are allocated to the country of origin and 50 % to the country of destination. This ensures that the entire voyage can be accounted for in emission calculations. However, in the case of calculating average GHG efficiency it is not necessary to allocate emissions to countries.

Transport markets or distance bands are part of the second level of analysis. This could be urban, national, European and international (i.e. extra-European) trips. These are relevant for meaningful comparisons and for the reporting of non-EU GHG emissions in European transport flows. Transport market definitions should be comparable between the different markets in the EU and for those transport modes which are relevant to the particular market. Market segments do therefore not necessarily represent all modes (e.g. urban transport will exclude shipping and aviation).

2.3 Scope of emissions

In this study we apply a well-to-wheel (WtW) approach to estimate specific GHG emissions from transport modes. This means that emissions from the exhaust (tank-to-wheel) as well upstream- or well-to-tank (WtT) emissions are included. WtT emissions originate from the extraction, transport and refinery of fuels, including fossil fuels and biofuels. For computing TtW emissions the energy content method applies.

The WtW approach is different from a full-scale life cycle analysis (LCA) as it does not consider the emissions from infrastructure and vehicle construction, maintenance, servicing and disposal associated to performing transport. The data availability is not sufficient to support a full-scale LCA approach. Further upstream and downstream processes like the production, disposal, recycling and reuse of vehicles and the construction, maintenance and operation of infrastructures are outside the scope of this study. This includes the emissions attributable to running airports and ports, or for the operations of traffic control systems.

The literature review indicated that most studies either present GHG emissions in CO_2 or use CO_2-equivalents (CO_2e). The latter shall be appropriate for the GHG efficiency indicators to be developed in this study. In this study CO_2e will be calculated using the global warming potential (GWP) as defined by the 4th IPCC study. Updated GWP from the 5th IPCC shall not be used as international reports tend to use GWP from the 4th IPCC study for consistency reasons.

The study also considers the latest insights in climate impacts of NO_X, black carbon and the effects of aerosols emitted by aircraft in high altitudes. The most recent information is provided by the European Aviation Safety Agency (EASA), which discusses non-CO_2 emissions in detail (European Commission 2020d). Following among others the Fourth IMO GHG study we do not include climate impacts of NO_X due to a lack of scientific consensus. Climate impacts of black carbon emissions are included for maritime shipping. For aviation emissions, a discussion is provided about the latest developments as well as a proposed CO_2e factor.

2.4 Time horizon

The pilot indicators presented in this study include the most recent years with sufficient data availability. Current data covers the period from 2014 to 2018 across all modes.

2.5 Levels of indicators, modes and transport markets

The assessment of the greenhouse gas efficiency of transport modes may have different objectives. First, this may be the tracking of general advances in efficiency by mode. For this purpose, a very broad structure of transport markets into passenger and freight is sufficient. Another intention may be to compare several transport alternatives. For this purpose a more detailed look into single vehicle types, service classes or even regional aspects is needed.

In order to serve these intentions, two levels of indicators are considered: the transport modes and the more detailed technology categories. The study puts most attention in the straightforward comparison of modes at the EU level of aggregation. At the top level, passenger and freight services are distinguished for rail, air and the waterborne modes. Only for road transport, basic vehicle types are differentiated.

For rail transport the energy source, electric and diesel traction, are differentiated on the top level as these types of traction constitute basic characteristics of the sector. For road transport, fuel types are differentiated at the second level only. For aviation, inland waterways and maritime shipping fuel types are not differentiated.

Typical transport markets are distinguished at the second level of indicators. We define transport markets by sector, i.e. passenger and freight, and by travel distance. This is urban, long distance European and extra-European trips or shipments. By the definition of transport markets the indicators allow a more appropriate comparison of GHG efficiencies where modes of transport really compete.

Table 2.1 shows the structure of top and second level indicators. Details of top and second level indicators are provided by the modal Chapters 3 to 7.

Table 2.1: Proposed structure of levels of indicators

Main mode	Top level indicators	Second level: Transport markets	Second level: fuel types
Road transport	Passenger cars Bus and coach HGV LDV	Urban Rural Highway	Diesel Petrol Electric
Rail transport	Passenger train (diesel and electric) Freight train (diesel and electric)	Conventional passenger (diesel and electric), High-speed rail (electric) Tram & metro (electric) Freight train	No further differentiation
Aviation	Civil passenger flights Belly and cargo flights	Domestic (European) / international passenger / cargo flights	Not applicable
Inland waterways	Freight inland waterway vessels	Bulk vessel (incl. container), tanker vessel and push boat	Not applicable
Maritime shipping	Freight maritime transport and passenger maritime transport	Passenger and RoPax ship; freight vessels for RoRo, general cargo, containers/RoRo cargo; carriers for bulk, vehicles, refrigerated cargo, combined goods, gas and LNG; chemicals and oil tankers.	Not applicable

Source: Fraunhofer ISI / CE Delft.

2.6 Cross-modal data

2.6.1 Emission factors for combustion fuels

This study takes a well-to-wheel (WtW) approach to estimate specific GHG emissions from transport modes. This means that emissions from the exhaust, i.e. tank-to-wheel (TtW) as well as upstream or well-to-tank (WtT) emissions, are included. WtT emissions originate from the extraction, transport and refinery of fuels, including fossil fuels and biofuels. TtW emissions can differ from the direct emissions of GHG as part of the fuel mix could be of biogenic origin, making them a renewable fuel with zero reported emissions. Currently transport biofuels are consistently applied in the fuel mix for road only.

The main source for the TtW and WtT factors for road transport are the recently updated JEC TtW and WtW reports (Prussi et al. 2020a; Prussi et al. 2020b). The JEC consortium consists of the European Commission’s Joint Research Centre (EC-JRC), EUCAR (European Council for Automotive Research and Development) and Concawe (the scientific body of the European Refiners’ Association for environment, health and safety in refining and distribution). The consortium periodically updates their joint evaluation of the well-to-wheel (WtW) energy use and greenhouse gas (GHG) emissions (emission factors), for a wide range of potential future powertrains and fuels options, within the European context. The JEC reports and annexes provide information about the TtW and WtT factors for fuel types at an EU level. It also provides information about the average energy content and WtT factors for the European mix of pathways for the production of biofuels.

The JEC reports do not investigate non-road fuels like kerosene and heavy fuel oil. The emission factors for these fuel types are based on a literature review. For maritime shipping the TtW is expressed in CO_2 per MJ. This value is calculated based on the carbon content of fuels from the European Union (EU) Monitoring, Reporting and Verification (MRV) regulation (ESSF 2017) and the energy density of fuels from the fourth IMO study. These values are used to calculate average efficiency in terms of MJ, the basis for calculation for WtT emissions. The WtT emission factors are based on the recent overview provided in Lindstad (2019). TtW and WtT emissions of kerosene factors are discussed in e.g. EXERGIA et al. (2015), Taskforce of Transportation and PBL (2020), CE Delft (2017), and El Takriti et al. (2017). The values provided by Bosch et al. (2017) represent up to date values that apply for the European situation.

Table 2.2: WtT and TtW emission factors for fuel components

Fuel type	TtW CO_2 content [gCO_2e/MJ]	TtW CO_2 emissions [gCO_2e/MJ]	WtT CO_2 emissions [gCO_2e/MJ]	WtW CO_2 emissions [gCO_2e/MJ]
Petrol fossil	73	73	19	92
Diesel fossil	73	73	17	90
LPG	65	65	8	73
CNG (EU mix)	56	56	12	68
LNG road	56	56	17	73
Ethanol - EU mix	71	0	52	123
Biodiesel EU mix (FAME)	76	0	39	115
HVO EU mix	71	0	30	101
Biodiesel (incl. HVO) - EU mix	75	0	37	112
Heavy fuel oil (HFO)	77	77	10	87
Marine gas oil (MGO)	75	75	14	89
Kerosene	73	73	14	88

Sources: Prussi et al. (2020a), Faber and Kleijn (2020), Lindstad (2019), Bosch et al. (2017).

Inland waterway transport (diesel) and aviation (kerosene) both rely on a single fuel type for propulsion. Road transport uses fossil petrol and diesel mixed with biofuels. Maritime shipping uses heavy fuel oils (HFO) and marine gas oils (MGO) for propulsion. The use of alternative fuels (e.g. LNG or methanol) in maritime shipping is still very limited and is therefore not considered for the WtT calculations. The share of biofuels for road transport is based on the final consumption data from Eurostat. Biodiesels in Europe are mainly fatty acid methyl ester (FAME) and hydrogenated vegetable oils (HVO). Based on Prussi et al. (2020a) we apply as European average mix a 83 % share for FAME and 17 % for HVO. Ethanol is the main biofuel mixed with fossil petrol fuel. For maritime shipping the mix between HFO and MGO is based on the final consumption in maritime shipping of heavy fuel oils and gas oil as reported by Eurostat. The specific values are shown in table 2.2.

The mix of fossil fuels and biofuels in road transport is reported by Eurostat fuel sales statistics. The average emission factor for maritime fuels is computed by the weighted share of their GHG emissions, where respective sales numbers for HFO and MGO are taken from Faber and Kleijn (2020) and Lindstad (2019). Kerosene emission factors are reported by Bosch et al. (2017). For the final estimate of the greenhouse impact of aviation, radiative forcing effects have to be considered on top (Chapter 5). For all other fuels the emission factors suggested by Prussi et al. (2020a) are applied.

Table 2.3: EU-27 fuel consumption of transport sector by category and year

Fuel sales, EU-28 [million t]	**2014**	**2015**	**2016**	**2017**	**2018**
Motor gasoline	62 242	61 878	62 201	62 651	62 735
Gas / diesel oil	174 298	178 728	183 821	186 243	187 323
Biogasoline	3 513	3 578	3 499	3 684	3 970
Biodiesel	11 297	11 219	11 167	12 084	13 561
Sales-weighted share of GHG emissions from marine fuels					
HFO	83 %	75 %	76 %	78 %	79 %
MGO	17 %	25 %	24 %	22 %	21 %

Source: Eurostat (2020) variable NRG_CB_OIL final consumption transport sector.

Factors for TtW and WtT emissions are computed as introduced below in table 2.4 and table 2.5 for EU-27 countries. In cases where sales numbers do not impact the mix of fuels, the values remain constant over the time period considered. The differences between countries are considered sufficiently minor, such that that EU-27 values are applied to EU-28.

Table 2.4: TtW emission factors by fuel mix, EU-27

TtW emissions [gCO_2e/MJ]	**2014**	**2015**	**2016**	**2017**	**2018**
Road petrol mix	69.48	69.39	69.49	69.32	69.03
Road diesel mix	68.74	68.88	69.01	68.74	68.26
LPG	65.40	65.40	65.40	65.40	65.40
Train IWT diesel	73.20	73.20	73.20	73.20	73.20
Maritime shipping	77.06	76.88	76.89	76.93	76.96
Kerosene	73.20	73.20	73.20	73.20	73.20

Source: compilation of Table 2.2 and Table 2.3.

According to the method for estimating final TtW emissions, WtT emissions are estimated by combining fuel component specific emission factors and sales by components. Table 2.5 provides the numbers for EU-27 (from 2020) for the years 2014 to 2018.

Table 2.5: WtT emission factors by fuel mix, EU-27

WtT emissions [gCO₂e/MJ]	2014	2015	2016	2017	2018
Road petrol mix	20.48	20.52	20.47	20.55	20.68
Road diesel mix	18.41	18.37	18.33	18.41	18.54
LPG	7.80	7.80	7.80	7.80	7.80
Train IWT diesel	17.20	17.20	17.20	17.20	17.20
Maritime shipping	10.41	10.78	10.75	10.68	10.62
Kerosene	14.30	14.30	14.30	14.30	14.30

Source: compilation of Table 2.2 and Table 2.3.

The share of upstream (WtT) emissions compared to direct combustion emissions varies significantly across fuels. The share is highest for road gasoline (30 %), LNG (29 %) and road diesel (27 %). LPG (12 %) and marine fuels (14 %), in contrast, show the lowest ration of upstream to combustion emissions.

2.6.2 GHG intensity of electricity production

For railways and for electrically powered road vehicles, the GHG intensity of national grid mixes are decisive. These can in single cases diverge from the actual GHG content of the energy consumed due to specific procurement contracts for renewable traction electricity. For instance rail carriers or fleet managers can purchase higher shares of renewable energies. Renewable energies may also be allocated to specific market segments of interest to customers, while more hidden segments have to bear the remaining GHG emissions. For instance Deutsche Bahn AG (DB AG) promote zero CO_2 emissions in high speed services, whereas their rail overall electricity mix consists of 39.9 % fossil sources (DB AG 2020). As information on these mechanisms is in most cases not publicly available on a European scale and needs critical verification we apply national grid emission factors to rail and electric road vehicles.

A different case is the use of additionally installed capacity of renewable energies, e.g. with smart homes for transport purposes. Their contribution to transport energy supply and climate impacts do not appear in national GHG reports and are thus not available for a top-down approach. In bottom-up approaches, the transport performance with additional power sources outside the general park of power plants may, however, be considered.

National grid emission factors are reported by EEA for EU-28 countries and Norway until 2017. Swiss emission factors are not reported in European sources and are thus set to the EU-28 average. This simplification is questionable as Switzerland relies heavily on hydropower and thus could positively impact the average European grid emission intensity.

The missing 2018 emission data is estimated using total electricity generation and total GHG emissions from energy industries in the EU-27 from EU Energy in Figures 2020 (European Commission 2020a). The respective reduction factor of -5.4 % has been applied to all countries alike. The final values are shown in table 2.6.

Table 2.6: GHG intensity of electricity generation [gCO$_2$e/kWh]

Country	2014	2015	2016	2017	2018
EU-27	310.0	310.5	298.4	295.7	279.8
EU-28	323.0	317.5	299.9	294.2	278.3
AT	92.5	107.64	95.6	104.0	98.4
BE	202.5	221.2	167.9	176.1	166.6
BG	463.3	474.5	449.6	486.2	460.0
CY	681.8	670.2	678.7	660.7	625.0
CZ	465.9	479.3	488.8	437.9	414.2
DE	483.3	453.8	450.3	418.8	396.2
DK	246.3	165.6	199.0	147.7	139.7
EE	992.3	934.8	917.3	922.4	872.6
EL	845.0	738.3	621.1	657.3	621.8
ES	279.9	318.2	266.1	304.3	287.9
FI	123.1	87.9	92.1	82.8	78.3
FR	49.8	52.2	58.0	67.2	63.6
HR	171.4	203.4	202.6	188.0	177.8
HU	256.8	257.5	248.4	253.0	239.3
IE	447.4	434.1	426.3	392.5	371.3
IT	252.2	278.1	257.2	258.8	244.8
LT	152.1	181.8	122.5	63.7	60.2
LU	195.4	136.6	70.8	65.2	61.7
LV	99.7	120.9	97.2	49.2	46.5
MT	738.1	679.6	673.7	441.8	417.9
NL	482.8	503.2	481.9	452.6	428.2
PL	800.7	775.7	765.4	755.7	714.9
PT	294.4	359.8	292.9	349.8	330.9
RO	319.7	337.6	297.8	262.5	248.3
SE	8.9	7.5	8.4	9.3	8.8
SI	212.1	250.0	248.4	248.3	234.9
SK	106.1	113.6	104.7	107.3	101.5
UK	422.9	370.3	299.7	268.5	254.0
NO	21.3	19.8	18.3	18.9	17.9

Source: European Commission (2020a) - until 2016 only; trend forecast for 2017/2018.

The EEA figures on CO_2 efficiency of electricity production are based on total gross electricity generation, i.e. power outlet of the plants' main transformers. This output is finally related to the CO_2 emissions of fuel combustion in the power plant. From the power plant to the final consumers, however, grid losses due to network inefficiencies occur. These need to be added up to final energy consumption in order to capture induced total energy demand. the World bank estimates grid losses at 6 % in the EU-27 and 7 % in the UK for 2014 (World Bank Group 2020). More recent data is not available, so we consider this grid loss factor constant until 2018.

As for combustion fuels, fuels for electricity production have to be extracted, treated and distributed. The JRC well-to-wheel study estimates a range of these upstream emissions between 29.3 gCO_2e/kWh for high voltage, and 30.6 gCO_2e/kWh for low voltage power supply for EU-28 countries. This is 11 % of direct GHG emissions of electricity production. These upstream emissions are added to the direct emissions to remain consistent with the WtW approach taken for combustion fuels. Together with grid emission losses we receive 17.7 % additional upstream CO_2 emissions upon final energy consumption (FEC) related emissions.

3 Road Transport

Road transport is the least centralised of all means of transport. The routes are not bound to railways, air corridors or waterways. They are also independent from airports, harbours, stations or terminals. The very dense road network in Europe connects virtually every residential, corporate or public building. For that reasons, road transport also serves as a feeder or connecting mode for most rail, air or water transport. Additionally, both vehicle stocks and transport performance are dominated by privately owned cars and motorcycles. This makes the estimation and prediction of transport data very complex. It is mostly generated by surveys and representative traffic counts.

Road vehicle emissions strongly depend on topography, travel speed, traffic density and other operational factors. That is why emission test procedures such as the New European Driving Cycle (NEDC), the Worldwide harmonized Light vehicles Test Procedure (WLTP), Artemis or VECTO consist of multiple cycles for different environments (e.g. urban, rural, motorway) or velocity profiles (ACEA 2017; Boulter and McCrae 2007; TU Graz, TÜV Nord, ICCT, TNO, Heinz Steven 2017).

3.1 Assessment options

Road transport is characterised by a huge number of private actors, international operations and (to a limited extent) fuel tourism in border regions, and a variety of traffic situations and vehicle characteristics.

Top-down approaches for the development of emission factors depend on the availability of concise and complete databases on energy use, GHG emissions, transport activity, and transport performance in the desired scale and level of detail. Statistical data about GHG emissions of different sectors and traffic performance data is publicly available on an aggregated scale. However data gaps and high aggregation of data cause difficulties which increase with the level of detail needed.

Bottom-up emission factors are available for a variety of road vehicles for different propulsion systems, fuels and traffic situations (Notter et al. 2019). Those emission factors differ significantly among each other, partly even by an order of magnitude. In order to utilise this data on an aggregated scale, very detailed and exact traffic performance data is needed for the weighting of the different emission values. Additionally, emission factors predominantly are based on the transport activity (measured in vehicle kilometres (vkm)), rather than on the transport performance (measured in passenger kilometres (pkm) for passenger transport and tonne kilometres (tkm) for freight transport), where the focus of this study lies upon. Data on occupancy rates per country would be needed for conversion.

Publicly available traffic performance data is highly aggregated. In addition, emission factors are updated irregularly or in large intervals. This makes annual updates difficult. Data on occupancy rates is not available in the desired quality. For all those reasons a top-down approach was chosen for this report, based on emission and transport performance databases.

As emission databases focus on direct emissions, a bottom-up approach had to be chosen for electric vehicles, because for this category only indirect emissions are relevant.

Two principles may be applied for allocating emissions: the territorial principle and the location principle. The first one is applied in national GHG reporting and also in the fuel sales statistics, which are major sources for the top-down approach. Therefore the territorial principle also has to be applied for the traffic performance data, i.e. traffic performance within the borders of a country instead of the traffic performance of vehicles registered in the respective country. This differentiation is very important for cross border road traffic.

3.2 Total emission data

The EEA GHG inventory offers annual data delivered by the EU member states (EEA 2020b). Depending on the available national databases, different methods (tier 1 to tier 3) have been used for the data compilation. The total emission data is differentiated by road transport modes (1.A.3.b.i-v: cars, light duty trucks, heavy duty trucks and buses, motorcycles and other road transportation). A further differentiation by fuel types is available, but only fossil fuels (gaseous fuels, diesel oil, gasoline, LPG) are considered. The EEA GHG inventory only reports direct tank-to-wheel CO_2 equivalent (CO_2e) emissions excluding indirect land use changes (ILUC), while GHG emissions for electricity generation or cultivation and processing of biofuels are included in other sectors. The item “other fuels” covers fossil components of biofuels.

Another source for total emission data is the emission calculation tool COPERT, provided by Emisia SA. COPERT is made for simulating bottom-up emissions for national GHG reports to the UNFCCC (Emisia SA 2020). This tool is used by governments and agencies worldwide for the bottom-up calculation of GHG inventories. The total emission values calculated in COPERT are not considered as precise as the EEA GHG inventory, concerning the total emission data, but offer more details about vehicle categories, distance bands propulsion systems, and fuel types. Therefore it was used for differentiation purposes, such as the calculation of second level indicators, and data disaggregation (see paragraph below). The calculations with COPERT were performed by the project team of Fraunhofer ISI based on the European input datasets, which were bought from Emisia SA for this purpose.

3.3 Vehicle emission factors

COPERT provides GHG emission factors per vehicle category, segment, fuel type, emission standard and distance band, which were not used as such, but for the calculation of total emission data (see chapter 3.2).

Vehicle energy consumption factors for electric vehicles were taken from the EEA monitoring of CO_2 emissions from passenger cars (EEA 2020c). The factor of 17.7 % was for grid losses and upstream emissions, as described in chapter 2.6.2. In order to further improve the comparability to the top-down approach for fossil fuels, the consumption was increased by 20 % for real-world consumption and by 10 % for losses within the electric drivetrain. The mean electric consumption (given in Wh/km) of the cars sold in each were multiplied by the GHG intensity of electricity generation given in chapter 2.6.2, and then integrated from 2014 to 2018. As the stock of electric vehicles is still young and rapidly growing, and thus mainly consists of new vehicles, this approach is valid. In a last step, a European average was calculated (EU-27 and EU-28), weighed by the sales numbers of each country.

3.4 Transport activity data

Annual data about transport performance for both passenger (in pkm) and freight transport (in tkm) is available in the EU transport in figures - Statistical pocketbook and in Eurostat. The figures in this sources are reported by the Member States (European Commission 2020b).

Transport activity data for European countries differentiated by vehicle categories, distance bands, propulsion systems and fuel type was purchased from Emisia SA. National datasets were weighed and aggregated into separate datasets for EU-27 and EU-28. These detailed datasets were used for two purposes: the generation of second level indicators by providing the split between distance bands, propulsion systems and fuel types, and the disaggregation of the transport performance of LDV and HGV. Parallel to the total emission data, no absolute values from COPERT data were used for the GHG efficiency indicators.

Similarly to total emissions data, aggregated transport performance data complicate the calculation of GHG emission factors, as for road freight transport no difference is made between LDV and HGV. In order to provide differentiated GHG emission factors, it was necessary to calculate the distribution of emissions between LDV and HGV. Therefore the transport activity data in vehicle kilometres (vkm) from COPERT input datasets (see paragraph below) for LDV and HGV was multiplied with the average payload of each transport mode, which is 0.3 t for LDV (estimated average of numbers given in TU Graz (2019)), and 12 t for HGV (as used in VECTO (European Commission 2018)). The distribution of the resulting transport activity LDV and HGV was used for the disaggregation of the transport performance data from EU Transport in Figures - Statistical Pocketbook. However, data from different sources for load rates for LDVs and HGVs differ widely. In Schroten et al. (2019) 0.7 t for LDVs and 13.6 t for HGVs were assumed. It is not clear if transport performance in tkm makes sense for LDVs as these vehicles are also designed and used for passenger transport and include heavy equipment (e.g. tools etc.) or structures (e.g. seats, workbenches, mounts, etc.), which are not accounted for in the load factor.

3.5 Calculation method

Disaggregation of total emission data

Emission data of the EEA GHG inventory was retrieved from the Eurostat website (EEA 2020c). However, there is one particular shortcoming of this dataset, which complicated the calculation of the GHG emission factors in this study: The GHG emissions of HGVs and buses in the EEA inventory are given as an aggregate for heavy duty vehicles. For disaggregation, total emission data for all vehicle types was calculated in COPERT. For the distribution of GHG emissions between HGV and buses, the COPERT results were then applied on the EEA GHG inventory data.

Disaggregation of transport performance

Other than the disaggregation of the emissions HGV and buses, the disaggregation of the transport performance between LDVs and HGVs is associated with some uncertainties, as the occupancy rates derived from literature are not based on equally thorough empirical methods as the emission and transport performance databases. Another issue is that LDVs are not only used for freight transport, but also for transport of people and equipment. A possible workaround for this shortcoming, would be to drop the distinction between HGV and LDV and define an overall GHG efficiency indicator for freight transport in general.

Top level emission factors

The top level indicators include direct and indirect emissions. The direct emissions were obtained by dividing the total emission values by the transport performance value for each vehicle category, namely passenger cars, buses and coaches, LDVs, and HGVs. Emissions of biofuels are not included.

Indirect emissions also include two components: The WtT emissions of the diesel and petrol fuels, and emissions of the generation of electricity consumed in electric vehicles. In this study, only petrol, diesel, and electric vehicles are considered, as transport performance data is not available in COPERT for CNG and LPG. Biofuels, bi-fuel cars or PHEVs were not considered, due to uncertain assignment of emissions. In Section 2.6.1 factors between TtW and WtT emissions were defined for diesel and petrol. According to their share of the total transport activity, those factors were applied to the direct emissions, calculated beforehand. The emission factor for electric vehicles was applied according to their share of the total transport activity.

Vehicle energy consumption factors for electric vehicles were taken from the EEA monitoring of CO_2 emissions from passenger cars (EEA 2020c). The factor of 17.7 % was applied for grid losses and upstream emissions, as described in chapter 2.6.2. In order to further improve the comparability to the top-down approach for fossil fuels, the consumption was increased by 20 % for real-world consumption and by 10 % for losses within the electric drivetrain. The mean electric consumption (given in Wh/km) of the cars sold in each year were multiplied by the GHG intensity of electricity generation given in chapter 2.6.2, and then integrated from 2014 to 2018. As the stock of electric vehicles is still young and rapidly growing, and thus mainly consists of new vehicles, this approach is valid. In a last step, a European average was calculated (EU-27 and EU-28), weighed by the sales numbers of each country.

Second level emission factors

In order to obtain the second level indicators, namely emissions per distance band and propulsion system, detailed transport activity data from COPERT input data, as well as detailed GHG emission data form COPERT calculation results were used. With constant occupancy rates across distance bands and propulsion systems for each vehicle category, the calculation of second level indicators is possible on the basis of the emission values calculated in COPERT and the transport activity data from the COPERT input data. With this data, a global emission factor per vehicle category, as well as emission indicators for each distance band and propulsion system were calculated. As these emission indicators refer to the transport activity (in vkm) instead of transport performance (in pkm and tkm, respectively), for each second level indicator the percent deviation from the global emission factor was calculated and then applied to the top level indicator.

3.6 Results

The top level results for passenger and freight transport is given in table 3.1 and table 3.2, as well as the shares of TtW, WtT, and electricity in the total GHG emissions.

Table 3.1: Emission factors road passenger top level total and breakdown of WtT, electricity, and TtW components [gCO2e/pkm]

Regional entity	Vehicle category	Emission scope	2014	2015	2016	2017	2018
EU-27	Pass. cars	Total	147	146	145	145	143
EU-27	Buses	Total	71	73	75	81	80
EU-27	Pass cars	TtW	115	114	113	113	112
EU-27	Buses	TtW	56	57	59	64	63
EU-27	Pass cars	WtT	32	32	32	32	31
EU-27	Buses	WtT	15	15	16	17	17
EU-27	Pass. cars	Electricity	0.02	0.02	0.03	0.06	0.11
EU-28	Pass. cars	Total	145	144	144	143	141
EU-28	Buses	Total	85	87	90	95	95
EU-28	Pass. cars	TtW	113	113	112	112	110
EU-28	Buses	TtW	67	68	71	75	74
EU-28	Pass. cars	WtT	32	32	31	31	31
EU-28	Buses	WtT	18	18	19	20	20
EU-28	Pass. cars	Electricity	0.02	0.03	0.03	0.06	0.11

Source: Compilation from European Commission (2020b), Eurostat (2020), and COPERT database.

Table 3.2: Emission factors road freight top level total and breakdown of WtT, electricity, and TtW components [gCO2e/tkm]

Regional entity	Vehicle category	Emission scope	2014	2015	2016	2017	2018
EU-27	LDV	WtW	2145	2204	2225	2155	2187
EU-27	HGV	WtW	142	142	140	136	137
EU-27	LDV	TtW	1686	1733	1750	1695	1721
EU-27	HGV	TtW	112	112	110	107	108
EU-27	LDV	WtT	458	471	475	460	467
EU-27	HGV	WtT	30	30	30	29	29
EU-28	LDV	WtW	2161	2200	2210	2154	2171
EU-28	HGV	WtW	142	141	139	136	136
EU-28	LDV	TtW	1699	1730	1738	1695	1708
EU-28	HGV	TtW	112	111	110	107	107
EU-28	LDV	WtT	461	470	472	460	463
EU-28	HGV	WtT	30	30	30	29	29

Source: Own calculation with data from European Commission (2020b), Eurostat (2020), and COPERT database.

Occupancy rates for passenger transport and payload for freight transport were considered constant across distance bands and propulsion systems for each vehicle category:

- 1.6 passengers per passenger car (obtained by proportion between transport performance from European Commission (2020b) and transport activity from COPERT input data.

- 12 to 15 passengers per bus or coach (same method as for passenger cars)

  - EU-27, 2014 - 2016: 15 passengers
  - EU-27, 2017 - 2018: 14 passengers
  - EU-28, 2014 - 2016: 13 passengers
  - EU-28, 2017 - 2018: 12 passengers

- 0.3 t for LDV

- 12 t for HGV (see Section 3.4)

At this point a closer look at the influence of the occupancy rates on the GHG efficiency indicators of freight transport is possible. When the occupancy rates assumed by Schroten et al. (2019) as described in section 3.4 (0.7 t for LDVs and 13.6 t for HGVs) are used, the total indicator for HGVs changes only slightly from 137 to 142 gCO_2/tkm, while the total indicator for LDVs halves from 2187 to 1098 gCO_2/tkm. This strong dependency on relatively uncertain data raises the question of whether the distinction between LDVs and HGVs makes sense or if a cumulative indicator for road freight transport is more appropriate

Results for second level indicators in road transport for the years 2014 to 2018 by scope of emissions and regional boundary are presented in table 3.3 to table 3.6 by propulsion system and by distance band or transport market.

Table 3.3: Emission factors road passenger second level propulsion system [gCO2e/pkm]

Regional entity	Vehicle category	Propulsion system	2014	2015	2016	2017	2018
EU-27	Pass. cars	Petrol	153	154	154	153	149
EU-27	Pass. cars	Diesel	143	141	140	140	139
EU-27	Pass. cars	Electric	63	56	47	71	69
EU-27	Buses	Diesel	71	73	75	81	80
EU-28	Pass. cars	Petrol	151	152	152	150	148
EU-28	Pass. cars	Diesel	141	139	138	139	137
EU-28	Pass. cars	Electric	72	63	52	72	69
EU-28	Buses	Diesel	85	87	90	95	95

Source: Own calculation with data from European Commission (2020b), Eurostat (2020), and COPERT database.

Table 3.4: Emission factors road freight second level propulsion system [gCO2e/tkm]

Regional entity	Vehicle category	Propulsion system	2014	2015	2016	2017	2018
EU-27	LDV	Diesel	2155	2213	2231	2154	2179
EU-27	HGV	Diesel	142	142	140	136	137
EU-28	LDV	Diesel	2172	2209	2214	2152	2160
EU-28	HGV	Diesel	142	141	139	136	136

Source: Own calculation with data from European Commission (2020b), Eurostat (2020), and COPERT database.

Table 3.5: Emission factors road passenger second level distance bands [gCO2e/pkm]

Regional entity	Vehicle category	Distance bands	2014	2015	2016	2017	2018
EU-27	Pass. cars	Urban	191	190	189	189	187
EU-27	Pass. cars	Rural	120	120	119	119	117
EU-27	Pass. cars	Highway	138	136	135	135	132
EU-27	Buses	Urban	83	85	88	95	95
EU-27	Buses	Rural	61	61	63	67	66
EU-27	Buses	Highway	58	59	61	65	64
EU-28	Pass. cars	Urban	192	191	190	190	187
EU-28	Pass. cars	Rural	118	118	118	117	116
EU-28	Pass. cars	Highway	132	131	131	130	128
EU-28	Buses	Urban	105	107	112	118	118
EU-28	Buses	Rural	67	67	70	73	73
EU-28	Buses	Highway	60	62	64	68	67

Source: Own calculation with data from European Commission (2020b), Eurostat (2020), and COPERT database.

Table 3.6: Emission factors road freight second level distance bands [gCO$_2$e/tkm]

Regional entity	Vehicle category	Distance bands	2014	2015	2016	2017	2018
EU-27	LDV	Urban	2769	2838	2867	2780	2825
EU-27	LDV	Rural	1613	1655	1671	1619	1647
EU-27	LDV	Highway	2200	2254	2269	2180	2202
EU-27	HGV	Urban	193	196	195	190	195
EU-27	HGV	Rural	129	130	130	127	130
EU-27	HGV	Highway	130	128	123	117	117
EU-28	LDV	Urban	2722	2823	3074	3193	3493
EU-28	LDV	Rural	1671	1705	1715	1672	1687
EU-28	LDV	Highway	2236	2270	2277	2203	2207
EU-28	HGV	Urban	185	201	217	229	260
EU-28	HGV	Rural	131	132	132	129	131
EU-28	HGV	Highway	131	128	124	119	118

Source: Own calculation with data from European Commission (2020b), Eurostat (2020), and COPERT database.

4 Rail Transport

Rail traffic is characterised by common use of the same networks by passenger and freight services, besides a limited number of dedicated high-speed passenger lines and freight lines in some countries. Demand and performance data are held either by the - mostly national - infrastructure manager as well as by the private or public passenger and freight railway undertakings. Company data from infrastructure undertakings, energy providers and from railway undertakings are compiled by the international energy agency (iea) and the International Union of Railways (UIC). The completeness and consistency of the data is, however, rather challenging (iea / UIC 2017).

Energy use and GHG emissions of railways are strongly impacted by the rail services offered, load factors and the national electricity mixes. The GHG intensity of rail services per passenger and tonne kilometre thus differs widely between countries. This calls for a strong role of country data for the overall indicator methodology.

4.1 Assessment options

Specific GHG emissions in rail transport are estimated top-down by starting from total final energy consumption and fuel use. A bottom-up approach is not recommended as data on energy consumption and occupancy rates by train classes are not disclosed by all rail carriers and are thus not consistently available across Europe. Nevertheless, train-specific energy consumption and GHG emission data are needed to allocate total emissions to rail markets and types of rail services.

The estimation approach for GHG efficiency indicators in rail transport uses official and annually updated datasets in order to track changes in specific climate impacts per passenger and freight kilometre. Total GHG emissions of the railways by traction type are computed from final energy consumption in the railway sector published by Eurostat (Variable FC_TRA_Rail_E) and GHG emissions from diesel combustion available from the EU Transport in Figures statistical pocketbook 2020 and earlier editions (European Commission 2020b). The approach presented below takes a sequence of steps to allocate rough activity data, and to estimate GHG efficiency per passenger and tonne kilometre by market segment.

The approach is consistent with the iea / UIC Railway Handbook 2017 (iea / UIC 2017), but includes some challenges in the allocation of total GHG emissions to rail market segments and train classes. Company level data on train kilometres and energy efficiency from the RAILISA database (UIC 2020) provided by the International Union of Railways (UIC) is used. However, the data is either aggregated across rail markets, valid on the company level only or incomplete across countries. Therefore, general assumptions on train-specific energy consumption cannot be avoided.

The alternative would be to rely on GHG efficiency data per passenger or tonne kilometre and on average energy consumption data from literature. In contrast to road transport, where databases like HBEFA or COPERT are constantly updated, such information in the rail sector is rather static. Moreover, the engines in railcars and locomotives can be exchanged through their lifetime, the number and load of wagons can differ considerably between operators, and regional characteristics like track gradients or the number of tunnels (increasing locomotive energy demand by a factor two) are different. Average energy consumption figures per train, passenger or tonne kilometre thus are for this study less meaningful in rail than in road transport.

Exceptions to this general methodology need to be made for high-speed rail and urban public transport by tram and metro. Here, bottom-up estimates are needed despite the above described shortcomings as respective European databases on energy consumption or GHG emissions are missing. For all market segments activity data is provided by EU Transport in Figures (European Commission 2020b).

4.2 Total emission data

A number of different sources is available to estimate total energy use and GHG emissions from rail transport.

- Eurostat publishes annual final energy consumption of the railways for EU-28 countries and Norway, but excludes Switzerland. The data includes final energy demand from electricity and diesel combustion (Eurostat 2020).

- The EC's Transport in Figures Statistical Pocketbook (European Commission 2020b)reports total GHG emissions from railways. These refer to direct combustion emissions by passenger and freight diesel trains for EU-28 countries, Switzerland and Norway.

- The GHG inventory by EEA provides direct emissions for the transport sector (1.A.3) and specifically for railways (1.A.3.c) from fuel combustion. The electricity sector reported in the database is only partly relevant for the railways as some rail operators run own power plants or buy varying shares of renewables for their services (EEA 2020b).

- Specific emissions from the railway sector have last been reported by iea and UIC in the Railway Handbook 2017 (iea / UIC 2017). This provides fuel combustion by fuel type, including WtT emissions of fuel production, and electric energy consumption by the main categories fossil, nuclear and renewable. Source data is provided by iea World Energy Statistics (iea 2019).

- The UIC Railisa database provides total diesel and electricity consumption by rail carrier and year. The data is rather incomplete, not checked for consistency and may contain double counts due to the overlap of rail carriers and holdings in the dataset (UIC 2020).

- Models like TREMOVE for DG Environment and TREMOD for Germany's national GHG reporting provide information on specific national electricity mixes (Allekotte et al. 2020; E3MLab/ICCS 2015). Energy consumption and GHG intensities per train or locomotive kilometre are estimated top-down from energy consumption and performance data provided by iea / UIC (2017) or by national railways. Allocations to individual train classes use technical specifications of rolling stock.

For total TtW GHG emissions from diesel traction we use data by countries provided in European Commission (2020b) and earlier editions. WtT emissions are added using the respective rail diesel emission factors from table 2.5. Here we assume equal emission factors across countries of 17.2 gCO_2e/MJ or 23 % of TtW emissions.

Total electricity-related GHG emissions are computed by subtracting diesel-related final energy use from total final energy consumption data provided by Eurostat (2020). Respective conversion factors are the national GHG intensities of electricity production (table 2.6), rail diesel TtW emission factors (table 2.2) and the energy content of diesel fuel.

4.3 Vehicle emission factors

Although the GHG efficiency indicators in rail transport are computed top-down, specific energy consumption and GHG emission factors are needed to allocate total emissions and to add missing market segments, i.e. urban tram and metro services.

Total emissions are allocated to passenger and freight services via train kilometres, weighted by average diesel and electricity consumption factors per train kilometre. This calculation step requires a number of assumptions, as energy use by train types are not reported by the railways. Basic data source is the RAILISA data base (UIC 2020).

4.3.1 Assigning train-km to traction type and market segment

Prepare RAILISA data

For 15 out of the EU-27 countries plus UK and Switzerland, RAILISA contains complete datasets on passenger and train kilometre by traction energy. Missing annual data are interpolated or extrapolated under consideration of pkm and tkm development. The relevant variables train kilometres on the network of the infrastructure manager. This includes all train movements by incumbent carriers and private competitors.

- RAILISA Variable 1208: Train-km diesel traction, passenger trains
- RAILISA Variable 1209: Train-km diesel traction, freight trains
- RAILISA Variable 1211: Train-km electric traction, passenger trains
- RAILISA Variable 1213: Train-km electric traction, freight trains

Complete datasets are available for Bulgaria, Greece, Spain, Finland, Croatia, Hungary, Italy, Lithuania, Latvia, Portugal, Romania, Sweden, Slovenia, Slovakia, the UK and Switzerland. Interpolation of missing RAILISA data was particularly required for the years 2014 and 2015. For Germany, data has been added from the TREMOD model description (Allekotte et al. 2020).

Complete total passenger and freight train movement data

Estimating traction type and market segment specific train kilometres starts from total train movements in passenger and freight transport. Total train kilometres on the networks of national infrastructure managers are provided by the RAILISA database for 28 out of 30 countries, but with different levels of completeness. Relevant variables are 1205 (passenger train-km) and 1206 (freight train-km). As for traction-specific train km, interpolation of the years 2014 and 2015 was needed for most countries. Missing intermediate years are filled by linear interpolation; missing final years are kept constant to the last available years with a maximum gap of three years.

For Denmark and the Netherlands datasets on train movements are missing completely. Here we derived train kilometres by activity data from European Commission (2020b) with average passenger and freight train occupancy rates from the RAILISA database (variables 5603 (pkm) and 6603 (global tkm, table 4.1).

Table 4.1: Average European train occupancy rates (EU-28 countries excluding DK and NL)

Segment	2014	2015	2016	2017	2018
Passengers / train	161.0	160.7	167.8	180.4	179.9
Tonnes / train	507.6	509.4	536.6	516.8	553.6

Source: Computed from UIC RAILISA database.

We assume the occupancy rates constant for electric and diesel traction. In particular for passenger transport this is problematic, but for the purpose of filling data for two countries only this simplification seems justified.

The average European occupancy rates over the 20 countries improved by 12 % in passenger services and 9 % in rail freight over the period 2014 to 2018. The occupancy rates cover all large countries in the EU-28 Member States plus Norway and Switzerland, but nevertheless show some fluctuation in average values.

Estimate share of electric and freight traction for missing countries

For the remaining countries without traction-specific train kilometre data, the share of electric traction in passenger and freight are estimated by a logarithmic function over the share of electrified tracks. The rationale behind estimating train movements from infrastructure characteristics is, that electrification is carried out on purpose by network operators to cater for more traffic. Thus we can expect a strong correlation between the share of pkm or tkm with electrified trains and the degree of network electrification. This interrelationship is different for passenger and freight markets.

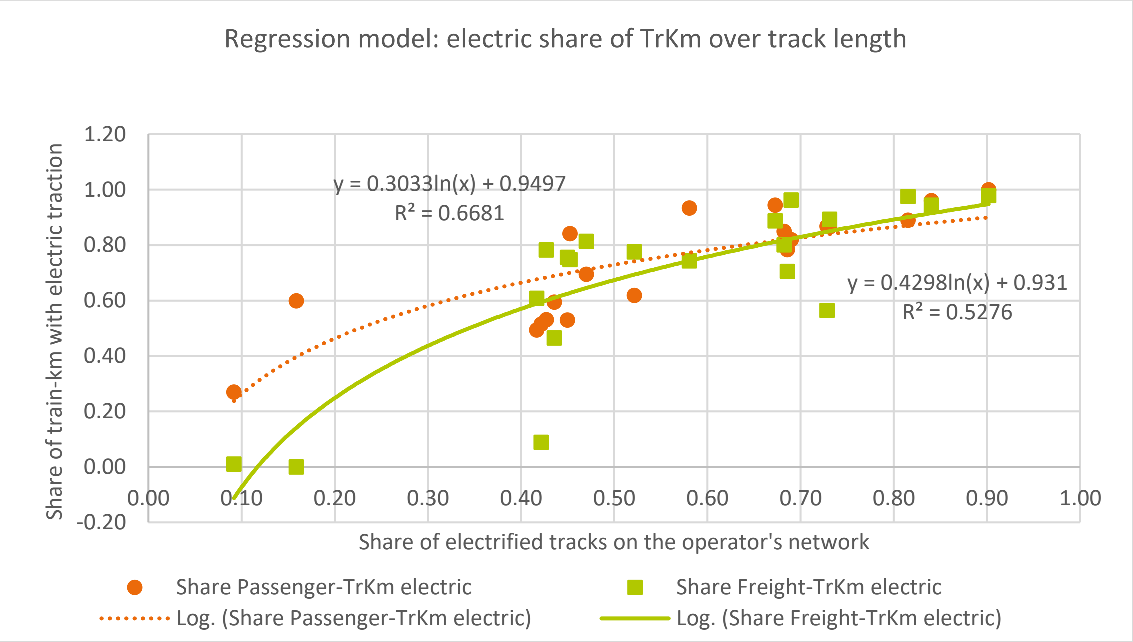
The share of electrified tracks is available from RAILISA, variables 1113 (length of tracks) and 1114 (length of electrified tracks). In cases where line-specific data is not available, track lengths are computed from line length with a double track line is equal to 2.5 single track line.

For 20 countries complete datasets for train-km and track electrification could be established. For Germany UIC RAILISA data was supplemented by TREMOD data (Allekotte et al. 2020). The best fit for passenger and freight data were logarithmic function of the form:

Equation: % electrified train-km = a * ln(% electrified tracks) + b.

The actual graph in figure 4.1 shows the slope, parameters and R² values of the fitting curves for passenger freight traffic. The graph also shows the parameters *a* and *b*.

Figure 4.1: Model estimation for pkm and tkm by traction type over network electrification



Source: Own computation with RAILISA and Tremod data.

The result of this calculation step is a complete dataset of train kilometres by traction type, market segment and country. This provides the basic data for allocating GHG emissions to passenger and freight services.

4.3.2 GHG emission factors

For the rail sector we apply a mixed bottom-up and top-down approach. Top level indicators, i.e. average passenger and freight GHG emissions use train-specific emission factors to allocate total emissions to the basic rail market segment. The second level indicators, in contrast, estimate average European GHG efficiency from specific emission factors per pkm and tkm.

Allocate total emissions to market segments

GHG emissions from electricity use and diesel combustion are allocated to passenger and freight markets using the share of train kilometres by traction type, weighted by average energy consumption. The energy consumption of trains changes with technical improvements and occupancy rates in passenger transport and loading factors or train lengths in freight transport. In order to track the GHG efficiency of rail services, fixed energy consumption factors should be avoided. However, constantly updated energy consumption figures are not published by the rail carriers and are thus not directly available in the RAILISA database.

We estimate the average electricity and diesel consumption of passenger and freight trains indirectly with RAILISA data on total electricity consumption (variable 8108) and total diesel use (variable 8105) for those railway undertakings, who also provide traction-specific passenger and freight kilometres. RAILISA provides suitable datasets for seven rail carriers from six countries: FGC (Spain), FS (Italy), MAV (Hungary), SZ (Slovenia), LG (Lithuania), and SBB and BLS (Switzerland). With a linear regression of energy consumption over train-km we receive the average energy consumption figures in table 4.2.

Table 4.2: Estimated final energy consumption factors by train type

Fuel	Market segment	2014	2015	2016	2017	2018
Diesel consumption [kg diesel / train-km]	Passenger train	(1.16)	(1.12)	1.04	(1.10)	0.95
	Freight train	(4.06)	(4.05)	4.04	(4.03)	4.02
Electricity consumption [kWh / train-km]	Passenger train	14.28	14.26	(13.67)	12.57	(12.64)
	Freight train	12.30	12.30	(12.30)	12.30	(11.11)

Source: Linear regression over RAILISA data.

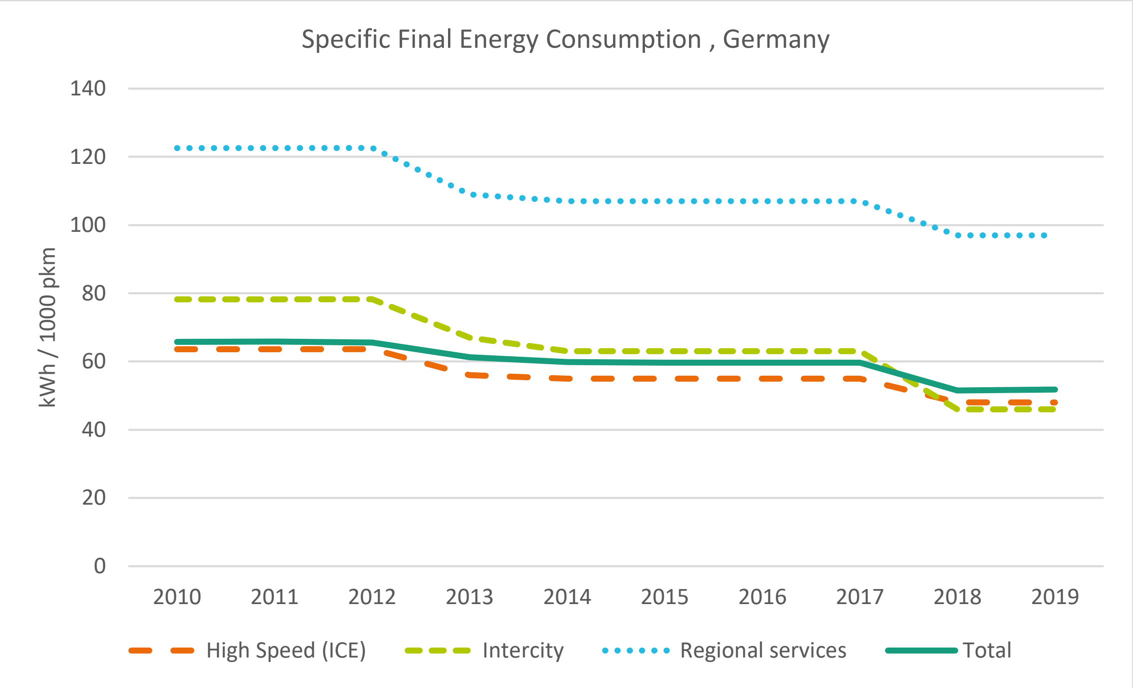
Numbers in brackets in table 4.2 indicate data based on 5 rail carriers or less. For diesel traction the results appear reliable with 0.95 and 4.02 kg diesel per train-km in the period 2016 to 2018. Regression results for electricity consumption, however, fluctuate significantly over the years as train categories vary more widely and because the large European rail carriers, namely DB and SNCF, do not provide data on energy consumption. Here we use 2017 and 2018 values, suggesting an energy consumption of 12.6 and 11.1 kWh per train-km in passenger and freight transport.

Overall, the application of the regression model can only approximate real consumption data. For regular updates of the GHG efficiency indicators it is recommended to conclude agreements with major rail carriers in Europe to provide actual figures year by year.

Specific energy consumption of high-speed trains

For computing the second level indicators, specific data on the energy use of high-speed trains, either by train-km or by pkm and tkm is needed. Regularly updated data on a European scale is, however not available. Energy efficiency data by broader passenger market segments long-distance and regional transport are published by some rail operators (e.g. (Deutsche Bahn 2020).

Figure 4.2: Energy efficiency of rail passenger services, Germany, 2010 to 2019



Source: Internal documentation by DB AG to Fraunhofer.

The energy efficiency in high-speed rail is dominated by two factors: the energy efficiency of rolling stock and occupancy rates. In particular occupancy rates vary strongly across countries. Therefore, German specific energy use per passenger km is not representative across Europe. In absence of better time series data we use the final energy consumption data by DB AG, provided for company sustainability reporting, e.g. according to the standards set by the Global Reporting Initiative GRI. In particular we use DB AG's sustainability assessment for Fraunhofer. These are not public but can be provided by DB AG on demand. For future updates of the indicator, agreements with rail carriers across Europe running high speed services are recommended. Relevant are LG (Spain), SNCF (France), FS (Italy), Thalys and Eurostar.

Specific GHG emissions by high speed and conventional (intercity and regional) rail services are estimated by multiplying the pkm-specific energy consumption with national GHG efficiencies of electricity generation. European averages are computed by weighting the national efficiency factor with passenger kilometres by high speed services from EU Transport in Figures (European Commission 2020b). The specific GHG emission factors of conventional rail services finally are received by subtracting total high-speed rail GHG emissions and pkm from the respective total for rail passenger transport.

Specific energy consumption of tram and metro services

In contrast to high-speed rail services, which are included in the top level indicator for rail passenger transport, urban tram and metro services are calculated on top of these. Again, comprehensive European data is not available. We thus exploit available national information.

- The German Federal Environment Agency (UBA) publishes GHG emissions per pkm for various transport services on an annual basis. For tram and metro services consumption data ranges between 1.09 (2014) and 0.90 (2018) MJ/pkm (Umweltbundesamt 2020a).

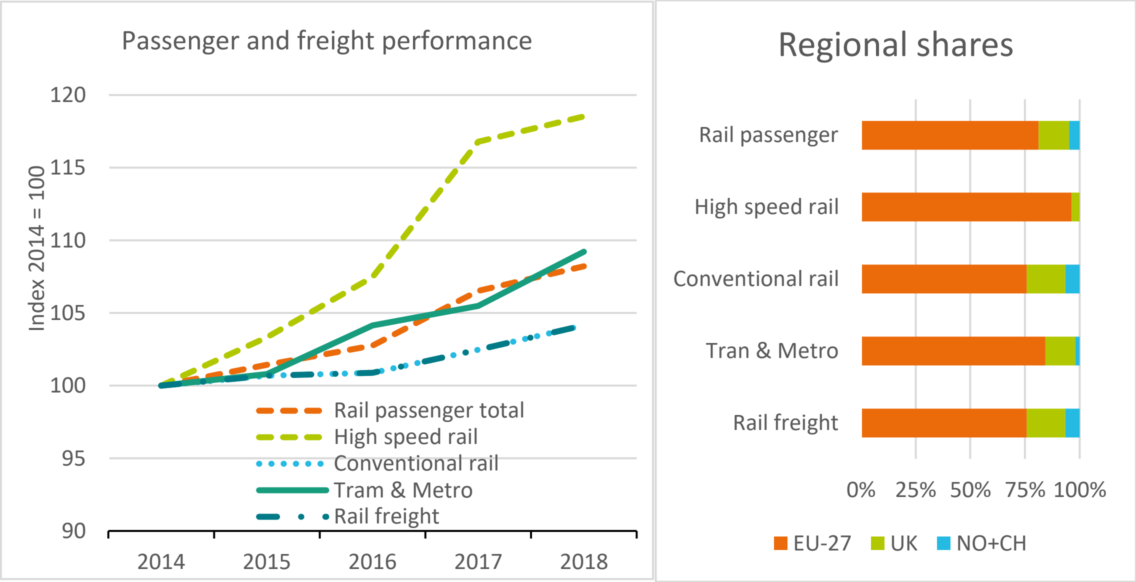
- Kenworthy (2020) finds energy efficiency rates in public transport of 1.10 MJ per pkm across 10 Swedish cities and 0.79 MJ per pkm in Freiburg (Germany) for 2015.

As the two sources find similar values, we apply the German values for Europe in the same manner as for high-speed rail. Differences by countries due to varying occupancy rates might be high, but respective European data on the energy efficiency in local tram and metro services is not available. National differences are thus only computed by the specific GHG intensity of electricity production.

4.4 Transport activity data

Top level efficiency indicators for rail are computed by dividing total direct and indirect combustion emissions and electricity emissions per sector by passenger and freight kilometres provided by EU Transport in Figures (European Commission 2020b). The dataset also provides separate figures for high-speed rail (HSR) and urban tram and metro services.

Figure 4.3: Demand structure of European railway services 2014 to 2018



Source: data compiled from European Commission (2020b).

High-speed rail shows by far the highest growth rates with +19 % in 2018 against 2014 in EU-27 countries. All rail passenger services as well as tram and metro grew by about 8 %, while conventional rail (intercity) and freight grew by 4 % only over this period.

EU-27 countries account for 76 % of passenger and 81 % of freight demand at EU-28 plus Norway and Switzerland in 2018. With 14 % of passenger and 18 % of tonne kilometres the UK plays a relevant role in both markets, whereas Norway and Switzerland contribute 5 % and 7 %

to rail transport activities. The high-speed market, however, shows a different pattern. Here the EU-27 countries hold 96 % of passenger kilometres. Remark: services with high-speed trains in countries without national high-speed carriers are commonly labelled as intercity services.

4.5 Calculation method

The detailed calculation steps from the original data sources to the final GHG efficiency indicators in rail transport are embedded in the above sections on total emissions, emission factors and demand data. Here we summarise the calculation method step-by-step:

1. Total emission data

- (1.1) Extract total energy consumption of rail from Eurostat, final energy consumption
- (1.2) Extract TtW diesel emissions from railways from EU Transport in Figures
- (1.3) Extract average CO_2 intensities from electricity production form EEA data
- (1.4) Transform total TtW Diesel emissions into diesel-related energy demand
- (1.5) Derive final electricity demand by subtracting TtW diesel-related energy demand from final energy consumption (Step 1.1)
- (1.6) Estimate WtT diesel emissions with WtT emission factors from the EU WtW study
- (1.7) Estimate upstream electricity emissions with WtT factors from the EU WtW study and grid losses from World Bank data

2. Allocate diesel and electricity emissions to broad train classes

- (2.1) Extract and complete train-km values by country, traction type and market segment form UIC RAILISA database
- (2.2) Extract shares of electrified tracks by country from UIC RAILISA database
- (2.3) Complete train-km by traction type and market segment with the logarithmic model from shares of electrified tracks
- (2.4) Review and if appropriate update passenger and freight electricity and diesel consumption factors from RAILISA data
- (2.5) Allocate diesel-related GHG emissions by weighting train-kilometres (2.3) with passenger and freight diesel consumption (2.4)
- (2.5) Allocate electricity-related GHG emissions by weighting train-kilometres (2.3) with passenger and freight electricity consumption (2.4)

3. Compute top level indicators

- (3.1) Extract passenger-km and tonne-km data from EU Transport in Figures
- (3.2) Divide electricity and diesel emissions per market segment (2.5 and 2.6) by the respective pkm and tkm data (3.1)
- (3.3) Compose total emission factors per market segment by diesel plus electricity related GHG emission factors (3.2)

4. Compute second level indicators for long-distance passenger rail

- (4.1) Derive specific energy consumption values per pkm for high-speed and intercity trains from railway undertakings' publications
- (4.2) Extract high-speed passenger kilometres from EU Transport in Figures
- (4.3) Assign electricity emissions in passenger transport to high-speed and remaining (intercity) services by weighting pkm with specific energy consumption (4.1)
- (4.4) Compute high-speed emission factors by dividing total high-speed electricity emissions (4.3) by respective pkm (4.2)
- (4.5) Compute intercity train emissions by dividing diesel emissions (2.5) plus resitual intercity electricity emissions (2.6 minus 4.4) by respective pkm (4.2)

5. Estimate additional emission factors for urban tram and metro

- (5.1) Compile data on specific energy consumption per pkm from TREMOD and - if possible - alternative sources.
- (5.2) Extract pkm for tram and metro from EU Transport in Figures
- (5.3) Compute average GHG emissions with GHG intensities of electricity production (1.3) and upstream emissions (1.7)

For details on calculation methods, parameters and sources Sections 4.1 to 4.4 are to be consulted.

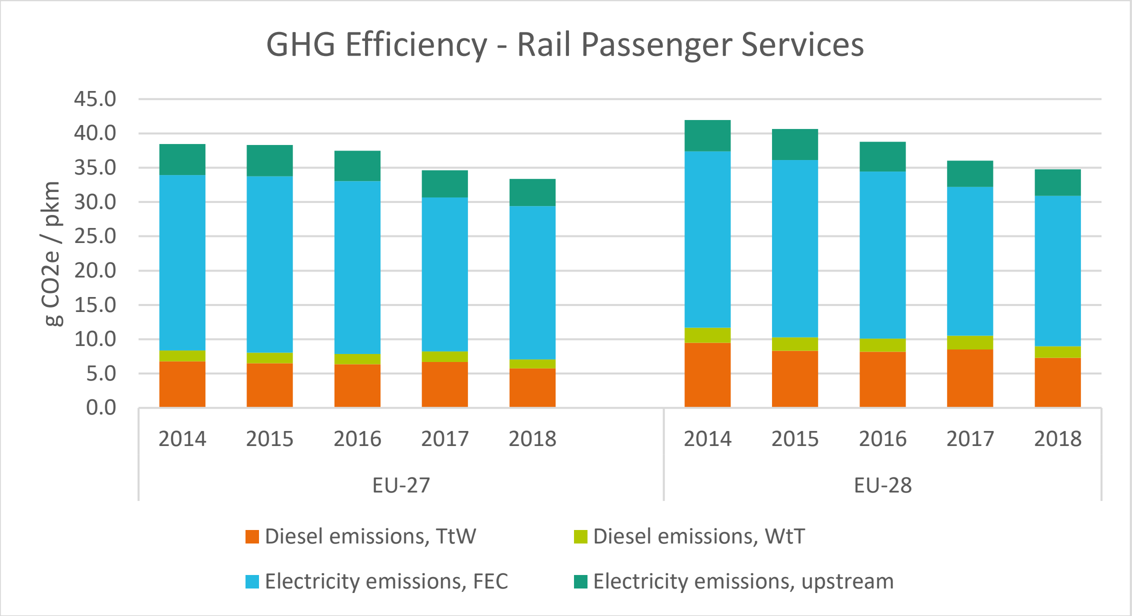
4.6 Results

In the following, top and second level GHG efficiency indicators for rail passenger and freight services are presented and are briefly discussed. Data is provided for the years 2014 to 2018 for EU-27 and EU-28. As essential data for Switzerland was missing during the computations, the extended regional scope of EU-28 plus Norway and Switzerland is not presented.

4.6.1 Top level indicators for railways

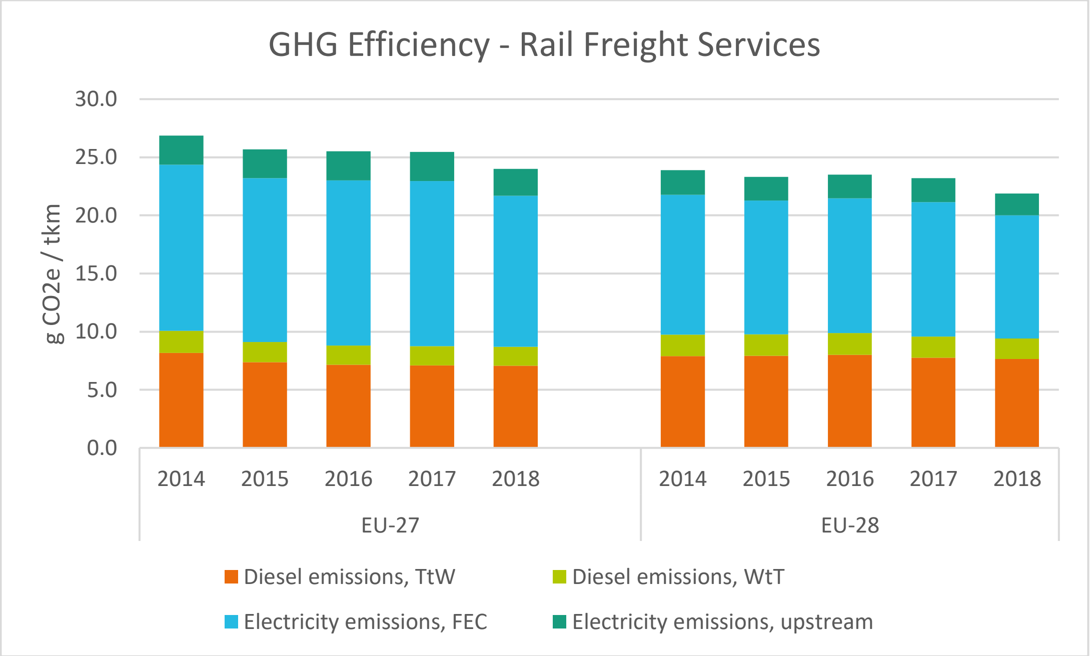
Top level efficiency indicators for rail are computed by dividing total direct and indirect combustion emissions and electricity emissions per sector by passenger and freight kilometres. This provides the breakdown per passenger and tonne kilometre by emission components for all long-distance passenger services in figure 4.4 in and freight trains in figure 4.5. Using top-down calculations, it is not possible to provide statements on only diesel and only electrical powered train services. Results suggest a drop in average emissions of 13 % in passenger rail and 11 % in freight transport in EU-27 countries between 2014 and 2018. Including the UK the index is -17 % and -11 %. The results show the progressing trend to replace diesel by electric traction. The decline in diesel content per passenger and tonne kilometre (-16 % to -17 %) is stronger than the effect of the reduction in the CO_2 content of power generation (-12 % to -13 % in EU-27 countries). Only in UK rail freight transport electricity generation improvements seem to dominate the slope of the GHG efficiency indicator.

Figure 4.4: Top level GHG efficiency indicators, rail passenger 2014 - 2018



Source: own calculations.

Figure 4.5: Top level GHG efficiency indicators, rail freight, 2014 - 2018



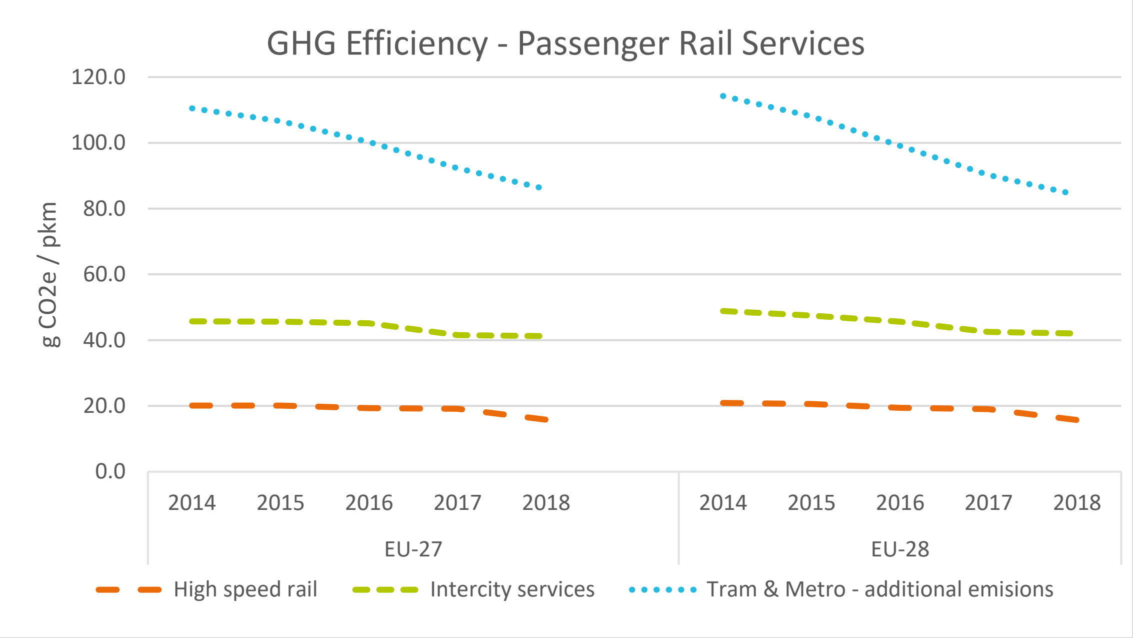
Source: own calculations.

4.6.2 Second level indicators for the railways

The second level indicators for rail transport differentiate passenger services further into high-speed rail and conventional intercity services. In addition to the top level indicators, which show the GHG efficiency in regional and long distance services, the second indicator level adds figures on urban tram and metro services. Total final energy consumed by high-speed rail is part of total rail passenger energy demand. The efficiency indicators of conventional and high-speed services thus mutually impact one another. In contrast, urban tram and metro services do not consume national rail traction power and are thus independently added. Results for EU-27 and EU-28 are shown in figure 4.6.

The considerably high values for urban tram and metro systems might seem surprising at first. However, the structure of the results is in line with the estimates on GHG intensities provided by the German Environment Agency (Umweltbundesamt 2020b) from the TREMOD model (Allekotte et al. 2020). We can explain this as in urban and regional transport dense train schedules are funded and required by public service obligations even in off-peak times and in sparsely populated regions in order to ensure accessibility. In long distance rail, line densities and rolling stock can be adapted better to actual spatial and temporal demand patterns.

Figure 4.6: Second level GHG efficiency indicators, rail passenger, 2014 - 2018



Source: own calculations.

High-speed rail and urban tram and metro services show a much steeper decline in GHG intensities (-21 % in EU-27 / -22 % in EU-28) than conventional rail services (-10 % / -4 %). This can be explained by the strong demand growth in these segments (compare the results above with figure 4.3) and the consequentially better occupancy rates on the one hand, and by their sole electricity propulsion on the other hand. In contrast to the stable emission factors of diesel traction, reductions in the GHG-intensity of power generation support the GHG efficiency of these modes.

5 Aviation

Aviation, just like shipping, presents a particular set of issues in measurement, reporting and policy development for GHG mitigation. It is a global industry and the majority of emissions take place in international air space. It is therefore necessary to distinguish between domestic or EU internal emissions and international emissions. One result of this is that national reporting to the UNFCCC does not fully account for aviation emissions. Member countries are required to report international aviation bunkers as a ‘memo item’, but this is not added to national totals.

A further issue for analysis is the differentiation between passenger and freight transport in civil aviation. While there are considerable numbers of purely freight aircraft, the majority of air cargo is carried in the belly of passenger aircraft on scheduled passenger flights.

5.1 Assessment options

5.1.1 Top-down vs. bottom-up

Aviation benefits from the detailed control systems and certification requirements for large aircraft flights. Data for Europe is compiled by EUROCONTROL and is accepted as a standard for European analysis. The EUROCONTROL modelling system (FEIS) uses the EUROCONTROL Advanced Emissions Model (AEM). This has been developed implementing a flight-by-flight bottom-up approach. It has been used in previous EEA publications on aviation emissions (EUROCONTROL 2016).

Aviation data is comprehensive. As described above, EUROCONTROL has data by individual flight for civilian flights and the EUROCONTROL AEM includes travel demand and emissions coefficients. The AEM calculates aviation emissions for domestic and international flights. Therefore, the bottom-up approach is used for aviation emissions. The EMEP/EEA air pollutant emission inventory guidebook 2019 (EMEP/EEA 2019) includes top-down approaches for aggregated calculations. Differentiation between freight and passenger loads is available for the EU. The EUROCONTROL IMPACT model is used to calculate national and international aviation activity, CO_2 and NO_X emissions (EASA 2019).

An alternative calculation is presented in ICCT (2020). These calculations also use bottom-up data and the commercially available PIANO model of aviation activity and emissions. The methodology is the same as for the EUROCONTROL AEM and IMPACT models, allowing for the different phases of a flight, individual flight records and data on aircraft characteristics and average load factors.

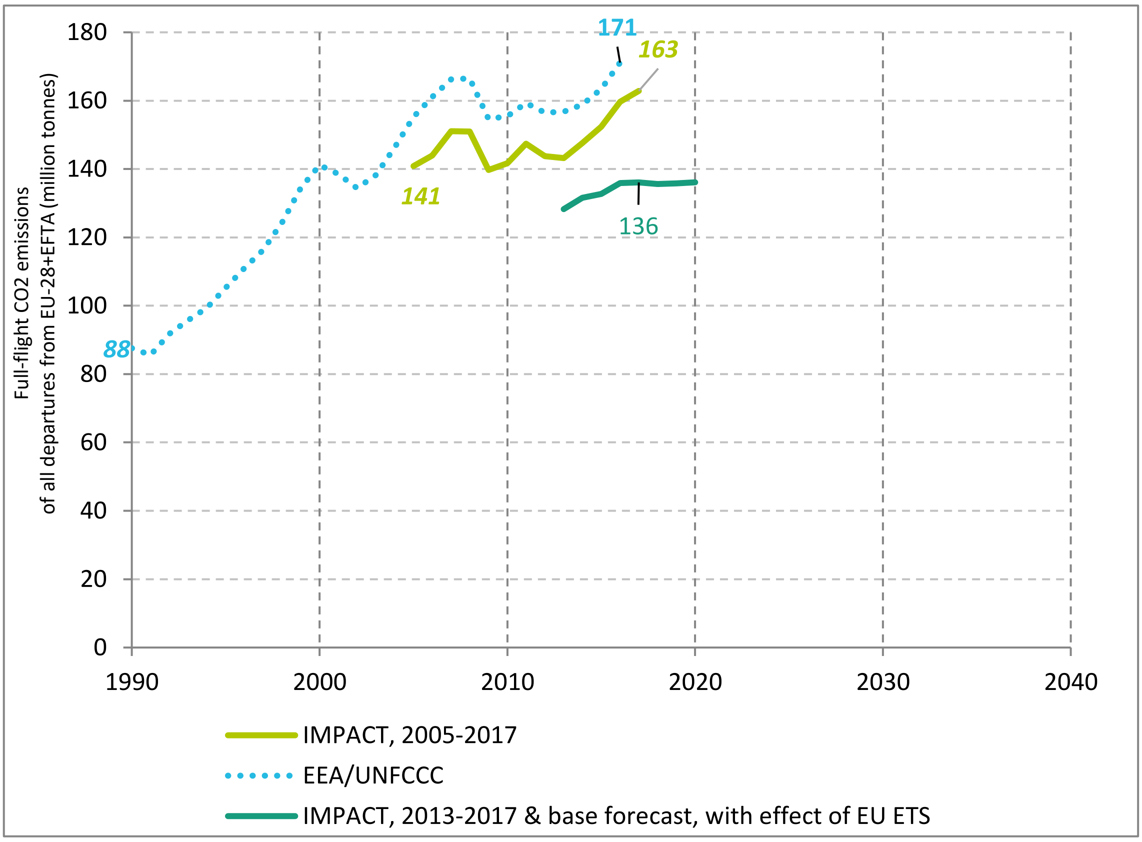
Therefore, the state of the art in aviation modelling is to use the bottom-up method of calculation. It is recommended that, in order to match the standards of national emissions reporting, the bottom-up methodology should be used. Since access to the detailed bottom-up data from EUROCONTROL was not available, data from different sources was combined to calculate an assessment. Global passenger domestic and international emissions and pkm for 2018 by country are available from ICCT (2020), as well as a distribution into passenger, belly cargo and cargo aircraft for the global total emissions and activity. EASA (2019) table 1.3 includes the pkm for 2017 and 2014 for the EU-28. EUROCONTROL provided times series data by country for emissions from passenger flights.

5.1.2 Allocation procedures

In order to address the issue of GHG emissions outside national airspace, both the EUROCONTROL FEIS and ICCT (2020) use the departures method of allocation. GHG emissions from a flight are allocated to the country from which the flight originates.

Note that different sources arrive at different results for total emissions, even when using the same methodology. This is shown in figure 5.1 which compares historical data from three different sources, including the EUROCONTROL IMPACT model and the UNFCCC reporting. As these sources both use detailed methods, widely reported in the scientific literature, it is recognised that there is considerable uncertainty in the evaluation of historical data on aviation emissions.

Figure 5.1: European aviation emissions from EASA (2019)



Source: EASA (2019).

5.2 Total emission data

EUROCONTROL has developed a comprehensive data system and emissions accounting methodology. This is the Fuel Burn and Emissions Inventory System (FEIS) procedure, which uses the AEM for large civil aircraft. The small emitters tool (SET) is available for emissions from small airlines and light / sport aircraft. Emissions from military aviation are not included in the reporting procedure (EUROCONTROL 2016, 2019).

EMEP/EEA (2019) and Whiteley (2018) identified three possible levels of analysis: Tier 1 calculations use the quantity of fuel sold for aviation purposes, Tier 2 calculations are performed if it is possible to obtain information on the number of LTO cycles per type of aircraft but there is no information available on the distances flown in the en-route stage, Tier 3 calculations use actual individual flight data and sum the results of all flights to calculate total emissions. The AEM implements Tier 3 bottom-up calculations for the FEIS (EUROCONTROL 2016). EASA (2019) reports data from the EUROCONTROL IMPACT model using this methodology. ICCT (2019) reports passenger flight emissions by country, including the EU-28 and EU-27.

5.3 Vehicle emission factors

The ICAO AEED database is used for aircraft emissions factors in the AEM model. The EU BADA database is used to calculate emissions in the en-route stage of a flight. The ICAO database for taxi-in and taxi-out times is supplemented by the EUROCONTROL Central Office for Delay Analyses (CODA) database for some European airports (EUROCONTROL 2016).

A further important question is the radiative forcing effect of aviation emissions. Unlike other modes, aviation emissions in cruise are emitted to the upper troposphere or stratosphere and may have an extra effect on atmospheric processes such as cloud formation The ‘Radiative Forcing Index’ (RFI) has been used in the literature to account for theses effects, but remains a controversial subject of scientific debate. Jungbluth and Meili (2019) review the recent literature and identify five approaches, which find values of RFI from 1 to 2.7. For emissions in the upper atmosphere, RFI factors range between 1 and 8.5. They recommend an overall RFI of 2, and for emissions in the upper atmosphere an RFI of 5.2. An important question is therefore whether EEA reporting and assessment should consider only GHG emissions or radiative forcing as well. The AEM calculates GHG emissions only (EUROCONTROL 2016). The most recent report on aviation emissions (European Commission 2020d) points out that RFI is not an appropriate measure:

> “The metric ‘Radiative Forcing Index’ (RFI) introduced by the IPCC (1999) to illustrate aviation’s net current-day non-CO_2 radiative impacts, relative to its historical and current day CO_2 radiative impacts was never designed to be an emissions metric and has been widely misused as such, despite scientific literature, including the IPCC Fifth Assessment Report (Myhre et al. 2014) pointing this out.” (European Commission 2020d)

Therefore, the RFI is NOT used in the calculations. The measure argued to be relevant for climate change issues is Global Warming Potential (GWP over 100 years. The European Commission (2020d) uses a net GWP-weighted emissions factor for net CO_2 equivalent of 1.7

and this is used for international aviation in the calculations. The available data for domestic aviation is for short distance flights. The radiative effects of aviation are reviewed in European Commission (2020d) section 2.2.2. The most significant effects are estimated to be Contrail cirrus, short term ozone increase through NO_x and CO_2 emissions. The impacts of Contrails and NO_x occur at high altitudes, in the stratosphere. Therefore the GWP weighting factor radiative impact and therefore the GWP is most strongly dependent on emissions at higher altitudes and domestic flights have a relatively large proportion of emissions at lower altitudes. To include these factors, the GWP factor is not applied to domestic flights.

5.4 Transport activity data

Calculations of transport activity and emissions are made with the AEM. The EUROCONTROL inventory system uses the PRISME database of all commercial flights and the characteristics of the aircraft types used. The FEIS procedure uses OAG and Innovata scheduled flight data for flights outside Europe. The Eurostat distance matrix (distances between airports) and tables on pkm and tkm between the main airports of the individual member states and their main partner airports could be used to calculate tkm and pkm for all EU flights (EUROCONTROL 2016).

5.5 Calculation Method

ICCT (2020) 2018 data by country and the EU for pkm and CO_2 emissions, together with the global distribution of CO_2 emissions and pkm, belly cargo and freight tkm was used as the basis for the calculations.

The transport activity data was constructed from ICCT (2020) for passenger activity and emissions data for 2018. The freight data was scaled from global ICCT (2020) data on passenger and freight activity. The time series activity data was scaled from the EUROCONTROL IMPACT model time series data for CO_2 emissions for the EU.

5.6 Results

While the EUROCONTROL FEIS accounting system and AEM model for large civilian aircraft represent the state of the art in aviation emissions modelling, they were not available for this project and the detailed data on passenger time series activity data and aviation freight is not publicly available. Therefore, a simplified estimation method combining ICCT (2020) and table 5.1. EUROCONTROL data on time series passenger aviation emissions for the EU were used to construct passenger and freight aviation emissions data for the EU from 2014 to 2018. The calculated GHG efficiencies were compared to changes in fuel efficiency for passenger aviation reported in EASA (2019) and found to be similar. Freight data is only available as a global aggregate for 2018 and more detailed data for EU time series was scaled using a combination of the ICCT (2020) distribution of emissions between passenger and freight and by assuming a similar change in emissions efficiency to passenger aviation. This avoids the requirement for time series data on aviation freight activity (tkm).

Table 5.1 to table 5.4 report the level 1 (EU totals for the EU-27 and EU-28) and the level 2 (division into domestic i.e. intra EU and international i.e. to or from outside EU) emissions, activity and resulting GHG efficiencies (CO_2 emissions per pkm and tkm).

The most reliable data is for 2018, where the global totals for pkm and tkm are available. The EUROCONTROL time series data for passenger flights and CO_2 emissions shows a decrease in flights from 2014-2017 and then an overall increase in flights between 2014 and 2018. This is a different pattern to CO_2 emissions, which increase continuously over this period.

Table 5.1: Emission factors aviation passenger top level total and breakdown of TtW, WtT, and GWP components [gCO₂e/pkm]

Regional entity	Flight category	Emission scope	2014	2015	2016	2017	2018
EU27	Passenger	Total	142	131	123	120	126
EU27	Passenger	TtW	96	89	84	83	84
EU27	Passenger	WtT	19	18	17	17	17
EU27	Passenger	GWP	26	24	22	21	25
EU28	Passenger	Total	150	138	130	127	133
EU28	Passenger	TtW	96	89	84	83	84
EU28	Passenger	WtT	19	18	17	17	17
EU28	Passenger	GWP	35	32	29	28	31

Source: own computation.

Table 5.2: Emission factors aviation freight top level total and breakdown of TtW, WtT, and GWP components [gCO₂e/tkm]

Regional entity	Flight category	Emission scope	2014	2015	2016	2017	2018
EU27	Freight	Total	973	897	843	823	834
EU27	Freight	TtW	622	577	545	535	545
EU27	Freight	WtT	124	115	109	107	109
EU27	Freight	GWP	227	205	189	181	179
EU28	Freight	Total	967	893	840	823	834
EU28	Freight	TtW	618	574	543	535	545
EU28	Freight	WtT	124	115	109	107	109
EU28	Freight	GWP	225	204	188	181	179

Source: own computation.

The CO_2 efficiency for the EU-28 is calculated to be 84.44 gCO_2 / pkm (passenger) and 545.31 gCO_2 /tkm (freight) in 2018. There are only slight variations in the 2018 results between the EU-27 and the EU-28 and between total, international and domestic efficiencies. A significant result is that the level of domestic aviation emissions are only slightly below international emissions for the EU in the ICCT (2020) data. The same distribution is assumed for freight.

Table 5.3: Emission factors aviation second level passenger distance bands [gCO_2e/pkm]

Regional entity	Flight category	Regional scope	2014	2015	2016	2017	2018
EU27	Passenger	Domestic EU	117	111	108	109	101
EU27	Passenger	International	163	151	143	140	143
EU28	Passenger	Domestic EU	118	112	109	110	102
EU28	Passenger	International	159	144	133	128	143

Source: own computation.

Table 5.4: Emission factors aviation second level freight distance bands [gCO_2e/tkm]

Regional entity	Flight category	Regional scope	2014	2015	2016	2017	2018
EU27	Freight	Domestic EU	750	695	656	645	655
EU27	Freight	International	1173	1088	1027	1009	1035
EU28	Freight	Domestic EU	747	693	656	646	658
EU28	Freight	International	1169	1085	1027	1011	1030

Source: own computation.

6 Inland waterway transport

Transport occurring on inland waterways, by vessels not equipped to sail on maritime waters, differs significantly in nature from maritime shipping. Inland waterway vessels are a lot smaller in size and their operation is limited to rivers and canals. Unlike most maritime transport inland waterway transport can be substituted by rail or road transport. Inland waterway transport is therefore considered as a separate category from maritime shipping.

Inland waterway transport is focussed in several countries with high shares in transport performance. Germany (35 %), Netherlands (35 %), Romania (9 %), Belgium (8 %) and France (4 %) make up for 93 % of the inland waterway transport market in 2018 (Eurostat 2020). Therefore using data from a selection of national sources could result in a reliable GHG indicator for the European Union. The calculation of an average European GHG efficiency indicator for inland waterway transport is not straightforward. The main issue for inland shipping is a mismatch between the level of activity data and emission data at a European level.

6.1 Assessment options

As discussed there is a mismatch between the available activity data and emission data. This is because total GHG emissions of inland waterway transport are not reported under a single category at a European level. Emissions are included under inland navigation which also includes emissions from inland maritime shipping. At the same time the transport activity presented on Eurostat does not include inland maritime vessels. Therefore there is no transport activity data available for inland navigation with the same scope as the reported GHG data. Simultaneously no GHG data is reported specifically for non-maritime inland waterway transport with a similar scope as the transport activity data.

The abovementioned issues mean that sources currently do not report weighted GHG indicators for inland shipping. Sources calculating European emissions from inland shipping often rely on estimated average emission factors. Also, comparisons of bottom-up and top-down methods have not been pursued before. In this study we have found a solution for this problem and we have constructed a reliable methodology to calculate GHG efficiency indicators using fuel sales data.

6.2 Total emission data

Total emissions for inland waterways are not found easily. As mentioned above, CO_2 reporting for inland shipping falls under the same IPCC guidelines as maritime shipping. This means that emissions from inland waterway transport are reported together with maritime shipping under shipping emissions. As a result the total emission data of solely inland waterway transport are not reported by European sources.

Therefore we have looked at national sources which report GHG emissions from inland waterway transport. Belgium, France, and the Netherlands report emissions from inland waterway transport. However the information is not easy to locate and the data quality is questionable. Some countries report CO_2 emissions on national territory whereas others report emissions based on fuel sold. The emissions from sold fuels cannot be combined with emissions on national territories as CO_2 emissions often occur outside countries where fuel is bunkered. Combining emissions on a territorial basis with emissions on a fuel sold basis would result in double counting or underestimation. In conclusion, it is not possible to construct a complete overview of CO_2 emissions based on national sources.

An alternative option is to calculate total GHG emissions based on fuel sales. However fuel sales data is, for reasons similar to GHG emission reports, not available at a European level. As discussed above national sources are not satisfactory as well. A solution is provided by using data collected as part of the "Convention on the Collection, Deposit and Reception of Waste Generated during Navigation on the Rhine and other Inland Waterways" (CDNI) agreement. This agreement concerns the collection, deposit and reception of waste generated during navigation on the Rhine and other inland waterways. Vessels bunkering fuels in the countries where the CDNI agreement applies (Belgium, France, Luxembourg, Germany, the Netherlands, and Switzerland) pay a fee for each tonne of fuel bunkered. The amount of fuels bunkered are monitored in a dataset (SPE-CDNI dataset). Inland waterway transport in Europe can be categorized in two operating regions. The Rhine and adjacent rivers (for which the CDNI agreement applies) and the Danube. Not many vessels operate regularly in both regions. As a result the total fuel consumption data in the CDNI region can be matched with the transport activity data of countries where the CDNI agreement applies. Inland waterway transport in the CDNI countries consists of about 83 % of the European market in terms of transport activity. In conclusion the best available source for the calculation for total GHG emissions is the fuel sales data from the CDNI.

6.3 Vehicle emission factors

Vehicle emissions factors can be helpful to calculate GHG emissions if detailed transport activity is available. Several sources report emission factors for inland waterway shipping. The so called AVV model (Bolt 2003) is used to predict the energy use and emissions of inland vessels on various fairway. This model is used by several studies including the Taskforce of Transportation (Geilenkirchen 2020; CE Delft 2020) and de Vlaamse milieumaatschappij. These studies differentiate emissions based on vessel type and fairway size. However, activity data used by these studies are not publicly available and do not align with the European situation.

There are other studies, for example the Smart Freight Centre (2020), that report emission factors that are differentiated towards vessel types. These results are often based on European research projects like PROMINENT (Stichting Projecten Binnenvaart 2016) and CLINSH (Povincie Zuid-Holland 2020; Stichting Projecten Binnenvaart 2016). PROMINENT differentiates fuel consumption by several fleet families. The underlying fuel consumption data is also based on fuel sale information from Western-European countries from the CDNI agreement. However, as these European studies are not being updated, the results will become outdated. Therefore, using vehicle emissions factors is in this case not helpful for the calculation of weighted efficiency indicators.

6.4 Transport activity data

Transport activity for inland waterway transport is often expressed in tonne-kilometres. There are a few sources that report transport performance data for Europe. Aggregated data for European countries is available via the Statistical Pocketbook or Eurostat. Eurostat also reports transport performance for liquid bulk, dry bulk and container transport by both self-propelled barges and push boats for all European countries where inland waterway transport occurs. Transport activity data is however not differentiated towards size classes. Therefore, the transport activity data does not match the vessel types distinguished by the studies reporting emission factors.

Other sources that report transport activity data are European research project (Povincie Zuid-Holland 2020; Stichting Projecten Binnenvaart 2016) and earlier publications, as well as the Central Commission for the Navigation of the Rhine (CCNR). The European studies do report activity data on a more detailed level. However, the results of these studies are not being updated and become outdated quickly. The CCNR does not differentiate many vessel classes and only focusses on the Rhine region. Emissions from this region are not available.

The Dutch inland waterway model BIVAS does contain detailed transport performance data by vessel type. However, it is not straightforward to extract this information and the model only focusses on the Netherlands and main fairways in Belgium and Germany. In total about 56 % of European transport activity is included in BIVAS.

6.5 Calculation method

As discussed, the main issue for inland shipping is a mismatch at the level of activity data and emission data available for Europe. The abovementioned issues are responsible for a lack of public sources that currently do report weighted GHG indicators for inland shipping. Also, comparisons of bottom-up and top-down methods have not been pursued before. Using fuel sales data from the CDNI agreement we have constructed an indication of total GHG emissions in Europe from inland waterway transport. With this data we can calculate total fuel consumption in the most relevant European countries (about 83 % of the market), which can used as proxy for the entire European area. Unfortunately, fuel sales data before the year 2019 is no longer available, and as a result no historical efficiency indicators have been calculated.

In order to generate complete GHG emissions and transport performance five additional steps are required:

1. The vessel types and scope from the transport data form Eurostat and the fuel consumption data from CDNI have to match. For the Eurostat data this means aggregating data towards three vessel types (dry bulk, liquid bulk and push boats). Also, transport data has to be aggregated for the CDNI countries.

2. From the fuel consumption data, vessels have to be selected that are involved in transportation of dry bulk, liquid bulk or push barges. This means excluding vessels like

work boats, recreational vessels and passenger vessels for which no transport performance is available.

3. The fuel consumption of selected vessels provides insight in the fuel consumption in the CDNI countries belonging to the transport performance in these countries. These figures can be used to calculate average GHG efficiency in CDNI countries. In the Danube region mostly push barges are used with below average GHG emissions. Therefore, the average efficiency indicators is based on vessel types used on the entire European waterways, rather than just the CDNI countries.

4. The previous steps resulted in transport volumes (in tkm) and fuel use (in litres) for the entire European inland waterway fleet. This step converts the fuel from litres towards energy (MJ). This ensures that TtW and WtT emissions can be calculated.

5. The last calculation step involves dividing the total CO_2e emissions by the transport performance in order to calculate average efficiency indicators.

Using this method average efficiency indicators for the European inland waterway sector can be calculated based on actual fuel consumption. The results are available for 2019 and can be replicated for future years.

Calculating transport performance

Eurostat distinguishes six categories for transport data: dry bulk, liquid bulk and container for both self-propelled barges and barges not self-propelled. Liquid bulk and container are not transported often via non self-propelled barges and therefore we include these volumes with dry bulk. Furthermore, as we discuss in step 2, fuel consumption from container vessels is partly included under dry bulk vessels in the CDNI data. Therefore we cannot distinguish container transport as a separate category and have to combine it with dry bulk. As a result we have transport volumes for the following for classes:

- dry bulk and container vessels;
- liquid bulk vessels;
- push boats (non self-propelled barges).

The first step is to calculate transport volumes for the abovementioned categories using Eurostat transport figures. Besides the individual countries we calculate total transport figures for the countries where the CDNI agreement applies.

Calculating fuel consumption

The anonymised fuel consumption data from the CDNI is available for individual vessels. For each vessel information is provided about the vessel type. Information about the country of origin, year of built, tonnage and dimensions is also available for most vessels. The type of vessels include abovementioned cargo vessels but also vessels which are not used for commercial transport or for which no activity data is available. These vessels are for example: working boats, pleasure boats or passenger ships. For the other vessel types, subtypes have to be combined. The CDNI category general cargo ships includes vessels that transport dry bulk and containers. As a result it is not possible to differentiate specific GHG emissions for these type of vessels. It is important to note that the categorisation of vessel types involves some uncertainty as it is done by several national authorities. The vessel types which can attributed to the transport volumes of Eurostat are shown in table 6.1.

Table 6.1: Division of vessel types CDNI to categories

Dry bulk vessels (incl. container)	Liquid bulk vessels	Push boats
General cargo ship	Tank vessel	Push barge cargo
Container ship	Bunker boat	Lighter
Roll on roll ship		Pontoon cargo
Other cargo ship		Push barge tank
Bulk transport barge		Tank lighter
		Pontoon tank
		Push boat
		Push tug

Source: Eurostat.

Scaling up to European totals

The fuel consumption from these vessel types can be aggregated to be in line with the categories considered in Eurostat. This results in fuel use figures by inland waterway vessels in the CDNI countries. By considering the transport performance in the Danube region the fuel consumption figures can be increased in order to account for inland waterway transport in all European countries.

Calculation of total GHG emissions

The previous step has resulted in fuel consumption in litres for the inland waterway sector in Europe. The results have to be converted to energy (MJ) in order to apply the TtW and WtT CO_2e factors. Table 6.2 provides an overview of the fuel characteristics used for the conversion. Currently no biofuels are mixed with diesel used by inland waterway transport. It is important to note that this might change in the future.

Table 6.2: Density and energy content of diesel

Parameter	Fossil diesel
Fuel density [kg/litre fuel]	0.832
Energy content [MJ/kg fuel]	43.1

Source: EC (2020) - JEC Well to wheel report.

Average efficiency indicators

The last step involves dividing the previously calculated TtW and WtT CO_2e emissions by the transport performance in order to generate the average efficiency indicators.

The SPE-CDNI data is not stored for multiple years. Therefore, the emissions from previous years could not be derived from the CDNI data. The development of the average GHG efficiency is therefore based on results from the Netherlands and Germany. GHG emissions in the Netherlands are reported by the Dutch statistical agency, while for Germany the results are taken from Allekotte et al. (2020). Using the transport efficiencies reported on Eurostat average GHG efficiency for Germany and the Netherlands have been calculated. The development of average GHG efficiency is used to calculate an estimate for the relative development of average GHG efficiency in Europe. Germany and the Netherlands cover about 70 % of GHG emissions from inland waterways. This approach thus results in a reliable estimate of average GHG efficiency between 2014 and 2019. It is however not possible to distinguish the GHG efficiency development towards vessel types.

The relative development of average GHG efficiency is shown in table 6.3. Between 2014 and 2018 the average efficiency in both countries has increased. The results show a decrease for 2019. The results are highest in 2018 which is due to low water levels in that year. As a result many vessels could not sail fully loaded and as a result the efficiency in that year decreased.

Table 6.3: Development of average GHG efficiency 2014 - 2019

Country	2014	2015	2016	2017	2018	2019
Germany	94 %	97 %	94 %	97 %	100 %	100 %
Netherlands	97 %	98 %	98 %	100 %	100 %	100 %
European average	96 %	97 %	96 %	98 %	100 %	100 %

Source: own compilation.

6.6 Results

The WtW CO_2e for inland waterway transport in Europe are shown in table 6.4. Biofuels are currently not regularly applied in inland waterway transport. Therefore, the carbon content of inland waterway fuel has remained constant between 2014 and 2019. The differences in WtW emissions are therefore due to differences in average energy efficiency.

The level of emissions in 2019 are based on actual fuel consumption data. The results show that push boats and dry bulk vessels have significantly lower emissions than tanker vessels. Tanker vessels often have to cool and heat their cargo which requires energy which results in higher GHG emissions. Also, in tanker vessels relatively less space is available for carrying cargo due to layout requirements for among others various pipes and tubes. Both issues contribute to a higher average GHG emissions of tanker vessels.

Due to data limitations historical energy efficiency can only be provided for the entire fleet. The results are based on results from Germany and the Netherlands which together make up about 70 % of the European inland waterway transport volumes. The results show a relative decrease up to 2018 in average GHG efficiency. In 2019 the average GHG efficiency is considerably better. This increase is not likely the result of the use of less environmentally friendly technology. Operational factors are instead a more logical explanation for the improvement in average GHG efficiency.

An important factor for the average GHG efficiency is the type and size of vessels which are applied. Larger vessels carry goods more efficiently and thus have higher GHG efficiency. Between 2014 and 2019 the transport of coal between the Netherlands and Germany has reduced by about 40 %. Coal is generally transported by large vessels with a high average GHG efficiency. The reduction in coal transport does thus contribute to a decrease in the overall average GHG efficiency between 2014 and 2018.

Another large factor of influence are low water levels on inland waterways which limit the maximum carrying capacity of inland waterway vessels. 2018 was a year with low waters levels and vessels could only transport part of their regular loading levels. As a result the average GHG emissions in 2018 were higher than in previous years. Besides the loading factor the average GHG efficiency is influenced by the type of fairway and the sailing speed. Therefore it is difficult to pinpoint the exact reason for the differences in average GHG efficiency between 2014 and 2018.

Table 6.4: WtW emissions inland waterway transport

Gram CO_2e/tkm	2014	2015	2016	2017	2018	2019
Dry bulk including container						25.6
Tanker						53.7
Push Boat						24.2
Total	31.97	32.56	32.11	32.93	33.44	31.6

Source: own compilation.

Calculating average efficiency indicators for inland waterway transport in Europe is a novel exercise. There are several data limitations concerning the CO_2e reporting for inland waterway transport. Using private fuel consumption data from the CDNI agreement we have been able to construct a reliable method for calculating average GHG efficiency. The data is based on actual bunkered fuels and allows the differentiation of efficiency indicators for three vessel types. It is possible to repeat this exercise annually with limited effort. However, data limitations do not allow an overview of historical fuel consumption. The historical trend for the entire inland waterway transport is therefore based on national figures from Germany and the Netherlands. The results show that operational forces have a large impact on development of the average GHG efficiency.

For future updates it is recommended to contact CDNI timely. It takes some time before the data request is processed. Furthermore, it is important to know that the main purpose of the fuel consumption data is not monitoring or reporting. Therefore, elements not essential to the functioning of CDNI agreement are less accurate. This means that vessel information is occasionally incomplete or inaccurate. Also historical data is not saved for a long period of time. Abovementioned issues could improve in the future due to increased demand for accurate GHG reporting.

7 Maritime Shipping

Maritime transport occurs over longer distances and a large portion of the emissions occurs outside national territories. Most of the emissions are the result of freight transport, although passenger transport in the form of cruises or ferries is significant as well. The global aspect of maritime shipping means that information is at times limited, especially in the case of total emissions and transport demand. Also fuel sales provide little information about the geographic allocation of GHG emissions as many vessels bunker in countries where fuel is cheap.

7.1 Assessment options

Many vessels and companies operate in maritime shipping. Many individual stakeholders are involved and information about energy consumption, transport performance and GHG emissions is not available centrally. However, the introduction of the EU MRV Regulation (European Commission 2020c) ensured that CO_2 emissions of about 90 % of European maritime transport is reported.

Most studies include emissions from all sources of GHG on board of vessels. This includes engines used for propulsion but also auxiliary engines, boilers and other sources of emissions. Several studies include emissions from extraction, transport and refinery of oil products as well. As these are similar for all combustion fuels and are proportional to fuel use, their inclusion in WtW figures per pkm or tkm is straight-forward. Average efficiency indicators for maritime shipping can be calculated by combining literature insights about WtW emissions with CO_2 emissions and transport data from the EU MRV dataset.

7.2 Total emission data

The GHG emissions – including CO_2, CH_4 and N_2O, expressed in CO_2e – of global shipping have increased from 977 Mt in 2012 to 1,076 Mt in 2018. This is an increase of 9.6 %. The total CO_2 emissions increased by 9.3 %, from 962 Mt in 2012 to 1,056 Mt in 2018. Maritime transport was in 2018 responsible for 2.89 % of the global GHG emissions (MEPC 2020).

Besides greenhouse gas emissions, ships' emissions also have an impact on the air quality and human health. Emissions which impact on the air quality are SO_2, NO_X, PM and black carbon. Fuel type and quality and the engine type and combustion process influence the amount of these emissions.

- EU MRV – EU Monitoring, Reporting and Verification of CO_2 emissions is a data collection programme for maritime vessels that started on 1 January 2018. Transport data is provided for the individual vessels. The EU scheme focusses on CO_2 emissions from shipping activities to, from and within the EU area. Ships over 5,000 gross tonnage (GT), which is a nonlinear measure of a ship's overall internal volume, calling at EU ports fall under the Regulation. Data collection takes place on a per voyage basis. The reported CO_2 emissions, together with additional data (e.g. cargo, energy efficiency parameters), are to be verified by independent verifiers and sent to a central database, managed by the European Maritime Safety Agency (EMSA). The aggregated ship emission and efficiency data is published by the EC since June 2019 and will be updated every consecutive year. EMSA (2020) estimates that ships over 5,000 GT emit over 90 % of the CO_2 emissions from maritime vessels visiting Europe. As a result the emissions in the EU MRV dataset do not include all maritime shipping emissions. The emissions of smaller vessels are not being monitored and therefore the exact GHG emissions from these vessels is unknown. The EC has estimated that these vessels contribute about 10 % of total maritime emissions (EMSA 2020) . Based on the 4th GHG study from the IMO we also find that the emissions of the vessel classes below 5,000 GT are about 10 %. Given the data limitations it seems sensible to calculate the total emissions by increasing the total emissions by 10 %.

- Another option is the use of the 4th IMO GHG studies (Faber and Kleijn 2020) which provides GHG emissions from global maritime transport. The latest edition of the IMO study reports GHG emissions between 2012 and 2018 of global shipping, as well as an outlook until 2050. The method used in the 4th IMO GHG study to provide GHG emissions is called a voyage-based method. The emission factors are specified for vessel types and are based on extensive modelling in combination with actual measurements. These emissions do however apply in a global setting, but are differentiated between domestic and international emissions. A significant change in the fuel mix has occurred in the last years, which is taken into account. Depending on the ship type and size, there are differences in the share of emissions across different phases of the operation such as at sea, during manoeuvring, at anchorage or at berth. The 4th IMO GHG study provides a breakdown of GHG emissions across these different phases of operation per ship type.

7.3 Vehicle emission factors

The amount of emissions differs between vessel types because of the design, the requirements (e.g. cooling / heating installations) as well as the operational profile of the ship. The required speed and amount of time at different phases of the operation, such as at sea and at berth, can have significant influence on the emissions. The ship size also has a large impact on the amount of emissions. Larger ships generally transport more cargo which has the result that the total emissions will be higher, but that emissions per tonne nautical mile will be lower compared to smaller ships.

The following sources are relevant when it comes to vessel emission factors:

- The abovementioned 4th GHG studies provides emission factors for various units including among others tonne nautical miles, passenger nautical miles as well as ship nautical miles (NM). The availability of various vessel classes makes this a good option for emission factors.

- The EU MRV dataset provides emissions per tonne nautical mile or passenger nautical mile for individual vessels above 5,000 GT visiting Europe. The EU MRV is based on monitored annual data reports. The dataset also allows calculations of aggregated emission factors using the yearly fuel consumption. Ships can be compared with each other or grouped in a certain ship type category.

- Some sources provide emission factors based on contact with local shipping authorities (CE Delft 2020).

7.4 Transport activity data

Maritime shipping is a global operation and, as a result, a lot of the transport activity occurs in international waters. Unlike for inland forms of transport, maritime activity data is not reported on a national scale. However, the activity level of individual vessel types is available. And the recently released EU MRV dataset can provide even more detailed information on a European level:

- Total transport demand can be derived from the EU MRV dataset where the annual fuel consumption, the annual fuel consumption per nautical mile and the annual fuel consumption per tonne nautical mile is provided at individual vessel level. The number of nautical miles and tonne nautical miles can be calculated based on this data. For vessels below 5,000 GT, which are not included the EU MRV dataset, the transport demand has to be added. The transport demand can be calculated using the estimated CO_2 emissions and the average transport performance of vessels below 5,000 GT from the 4th IMO study.

- Eurostat and the Statistical Pocketbook do not provide transport demand data other than the throughput of tonnes and passengers. The 4th IMO GHG study can be used to estimate transport demand as transport demand per vessel type is available. Calculating the emissions based on the throughput of tonnes and passengers is however very uncertain as it is uncertain which vessel types are used. At the same time it makes sense that the distribution of vessels activity in Europe differs from the global situation. This makes the use of the 4th IMO GHG study for European results not the preferred option.

7.5 Calculation method

The best results for maritime shipping can be derived by applying bottom-up calculations using the EU THETIS-MRV dataset for the main GHG calculations. This dataset is preferred over the 4th IMO dataset because it provides detailed emissions and transport performance specifically for Europe whereas the 4th IMO study is global. In order to generate complete GHG emissions and transport performance five additional steps are required:

1. Vessels below 5,000 GT are not included in the EU MRV dataset. In order to have a complete overview of maritime shipping emissions the CO_2 emissions of these vessels have to be included. The EC estimates that emissions from vessels below 5,000 GT contribute about 10 % of total emissions (EMSA 2020). A crosscheck done in this study shows that 10 % is a sensible estimate. Therefore the total CO_2 emissions from the EU MRV dataset are increased by 10 % in order to account for emissions from vessels below 5,000 GT.

2. The total transport performance can be derived from the EU MRV dataset. The total transport performance has to be increased in order to account for transport work from vessels below 5,000 GT. The average performance of smaller vessels can be derived from the 4th IMO study

3. The emissions of other greenhouse gasses have to be calculated based on total CO_2 emissions and fuel mix (based on 4th IMO study)

4. The climate impact of black carbon has to be included (based on the 4th IMO study)

5. WtT emission factors based on the fuel mix have to be added in order to create WtW emission factors

These calculation steps result in WtW GHG indicators for maritime shipping. The calculation steps will be shown in more detail below. The results can be presented for average freight vessels, average passenger vessels as well as the following vessel types:

- passenger ship;
- RoPax ship;
- RoRo ship;
- gas carrier;
- bulk carrier;
- general cargo ship;
- vehicle carrier;
- chemical tanker;
- container ship;
- refrigerated cargo carrier;
- container / RoRo cargo ship;
- oil tanker;
- combination carrier;
- LNG carrier;
- other ship types.

Further differentiations are possible by combining the EU MRV dataset with a vessel characteristics dataset e.g. World Fleet Register - Clarkson's). However, doing so was not feasible within the framework of the current study.

Calculating total CO_2 emissions

The EU MRV dataset (2018 edition) contains three columns of interest for total CO_2 emissions. The 2019 edition is similar in layout but is at this moment not finalised. First of all it provides annual CO_2 emissions from European voyages for individual vessels. For vessels that transport both passenger and freight (RoPax ferries) total CO_2 values have been assigned to passenger and freight. This split has been performed by vessel owners and is either based on mass or area following the methodology defined in EN 16258:2012. Summarising the results of these columns, by vessel type, results in total annual CO_2 emissions from all voyages to/from Europe.

These CO_2 emissions have to be increased by 10 % in order to account for emissions from vessels below 5,000 GT.

Calculating total transport work

The average energy efficiency of vessels is provided for several ship types and categories. It is not possible to calculate an average energy efficiency as the relative contribution differs between vessels. For instance, larger vessels carry more loads and have higher annual CO_2 emissions. Therefore it is necessary to calculate transport performance of the individual vessels. This can be done by dividing total CO_2 emissions by above-mentioned average energy efficiency. For RoPax the specific freight and passenger emissions as well as average energy efficiency has to be used. The results are total transport performance in (nm, tnm, pnm) for individual vessels. Summarizing the results of these columns, by vessel type, results in total annual transport performance for the various vessel types. Multiplying with 1.852 ensures that the results are in kilometres rather than nautical miles. Based on the 4th IMO study we have derived the transport performance of vessels below 5,000 GT as seen in table 7.1. The average energy efficiency of freight vessels below 5,000 GT is estimated to be 91 g CO_2/tnm and 210 kg CO_2/nm per vessel. The correction for vessels below 5,000 GT results in an increase of vehicle km by 22.3 % and tkm by 1.2 %.

Table 7.1: Transport performance of vessels below 5,000 GT based on 4th IMO study

Vessel categories below <5,000 GT	Emissions Mt CO_2	gCO_2/tnm	kgCO_2/nm
Bulk carrier	3.7	37.9	111
Chemical tanker	14.8	68.5	152
Container	10	35.3	205
General cargo	18.9	36.5	69
Liquified gas tanker	1.58	46	224
Oil tanker	23.2	83.4	176
Other liquids tanker	1.5	134	400
Ferry-pax only	10.6	127.7	230
Cruise	7	316	255
Ferry-RoPax	9.1	270.7	193
Refrigerated bulk	1.9	190	190
RoRo	6.7	147	244
Vehicle	3.1	135	270

Source: compilation from Faber and Kleijn (2020).

Other GHG

The emissions of the climate gasses CH_4 and N_20 are engine type dependent and can be scaled on CO_2 emissions based on the results of the 4th IMO study. The 4th IMO study finds that the total contribution of CH_4 (0.52 %) and N_20 (1.45 %) is much small compared to CO_2 (98.03 %).

Black carbon

There is scientific consensus about the effect of black carbon emissions on climate change. The EU MRV dataset does not distinguish black carbon emissions but the 4th IMO GHG study does. In the 4th IMO study black carbon emissions vary as a function of fuel type (residual, such as HFO or distillate, such as MDO), engine stroke type (2-stroke or 4-stroke), and engine load. As this detailed information is not available from the EU MRV dataset we propose to use an average factor per CO_2 emissions based on the fleet average results found in the 4th IMO study. In the 4th IMO study the climate contribution of black carbon is estimated to be 6.85 %, while CO_2 contributes 91.32 %. The total contribution of GHG besides CO_2 including black carbon can be calculated by considering the total impact of CO_2 (91.32 %) in total CO_2e emissions. Since we know the emissions in CO_2 from step 2 we can calculate the contribution from other greenhouse gasses and black carbon simultaneously.

WtT emissions

In the final calculation step the additional climate burden from extracting, treating and distributing bunker fuels has to be added. The WtT emissions are based on the emissions by MJ fuel. The MJ fuel can calculated based on the CO_2 content of fuel (g CO_2/MJ) and total CO_2 emissions. Which for HFO and MGO are provided in table 7.2. Based on the fuel sales of HFO (fuel oil) and MGO (gasoil) to international and national navigation on Eurostat we can calculate the relative importance of both fuel types.

Table 7.2: CO_2 content marine fuels

Fuel type	gCO_2/kg fuel	MJ/kg fuel	gCO_2/MJ
HFO	3,114	40.2	77.46
MGO	3,206	42.7	75.08

Table 7.3: Relative contribution (in MJ) of fuel sold in EU-27

Fuel type	2014	2015	2016	2017	2018
HFO	83 %	75 %	76 %	78 %	79 %
MGO	17 %	25 %	24 %	22 %	21 %

Source: own compilation.

The abovementioned steps result in average GHG efficiency indicators from 2018 onwards. As the EU-MRV regulation did not apply before 2018 results for earlier years are based on the 4th IMO GHG study. The 4th IMO GHG study provides average GHG efficiency indicators for various vessel types between 2014 and 2018. The trend from these figures have been applied to the

2018 results of the EU MRV in order to calculate results for earlier years. Table 7.4 shows the relative development of average GHG efficiency for maritime vessel types compared to the average GHG efficiency in 2018. These results are based on figures provided by the 4th IMO study. The results show that between 2014 and 2018 the average GHG efficiency for most vessel types has improved. This historical trend is applied to the results from the earlier steps.

Table 7.4: Relative development of average GHG efficiency between 2014 and 2018

	2014	2015	2016	2017	2018
Passenger ship	99 %	101 %	101 %	99 %	100 %
RoPax ship	105 %	108 %	107 %	102 %	100 %
Other ship types	106 %	106 %	107 %	102 %	100 %
RoRo ship	105 %	103 %	100 %	99 %	100 %
Gas carrier	106 %	109 %	106 %	102 %	100 %
Bulk carrier	104 %	104 %	104 %	102 %	100 %
General cargo ship	104 %	108 %	110 %	103 %	100 %
Vehicle carrier	102 %	103 %	104 %	102 %	100 %
Chemical tanker	108 %	107 %	105 %	102 %	100 %
Container ship	106 %	105 %	105 %	103 %	100 %
Refrigerated cargo carrier	98 %	96 %	101 %	101 %	100 %
Container / RoRo cargo ship	105 %	103 %	100 %	99 %	100 %
Oil tanker	106 %	109 %	106 %	102 %	100 %
Combination carrier	106 %	106 %	107 %	102 %	100 %
LNG carrier	102 %	105 %	105 %	102 %	100 %

Source: own compilation.

7.6 Results

The top level indicators for maritime shipping are shown in Table 7.5. The results show an increase in average freight GHG efficiency between 2014 and 2018. This is partly due to an increase in energy efficiency. Also, changes in fuel types have an influence on the reduction in TtW and WtT emissions. Marine gas oil has slightly lower TtW emissions than HFO. However, WtT and WtW emissions of HFO are lower. In recent years the use of HFO relative to MGO has increased after a sudden drop in 2015. This contributes to a decrease of WtT and WtW emissions from 2015 to 2019. The average GHG efficiency for passenger transport has increased as well between 2014 and 2018. This is mainly due to improved average efficiency of ferry transport.

Table 7.5: Top level indicators maritime shipping WtW

	2014	2015	2016	2017	2018	2019
Total freight [gCO2e/tkm]	6.9	7.0	6.9	6.8	6.6	6.8
Total passenger [gCO2e/pkm]	62.1	63.9	63.4	61.4	60.7	36.8

Source: own compilation.

The detailed efficiency indicators are shown in table 7.6 and table 7.7. The results show that the average GHG efficiency of vessels solely aimed at passengers, mainly cruise vessels, is significantly lower than emissions from ferries. This is not surprising as cruise vessels offer very different facilities and are used for holiday purposes rather than transport per se.

Table 7.6: Second level indicators maritime passenger transport

gCO_2e/pkm	2014	2015	2016	2017	2018	2019
Passenger ship	318.5	325.3	324.4	319.3	320.8	312.2
RoPax ship	37.5	38.7	38.4	36.7	35.9	19.1
Total passenger	62.1	63.9	63.4	61.4	60.7	36.8

Source: own compilation.

The development of freight efficiency indicators is shown in table 7.7. The results show large differences in GHG efficiency between vessels. The main reason of these differences is due to differences in size and load factors of vessels. Fewer infrastructure restrictions to vessel size exist for maritime vessels compared to other modes of transport. As a consequence there are large differences in size and load factors among maritime vessels. There are significant efficiency advantages in the use of larger vessels that can lead up to almost 10 times higher average GHG efficiency for vessels transporting the same goods (Faber and Kleijn 2020). Vessel classes where on average vessels with a large scale are used have on average higher GHG efficiency. This can be for example seen by the low average emissions of oil tankers and bulk carriers. The use of larger vessels is however restricted by the availability of sufficient transport volumes, and for certain cargo types or routes the use of large vessels is not possible. Larger vessels also are less flexible and are generally used for specific routes.

Besides differences in scale the layout of vessels is important for the average GHG efficiency. Vessels which transport gas or chemicals often require more safety infrastructure on board which reduces the capacity for cargo. Also cooling and heating of cargo results in higher energy use and CO_2e emissions. Also vessels transporting vehicles or rolling equipment leave relatively much space unused. As a result the average efficiency of these vessels is lower. The relative contribution of these specialised vessels towards the total fleet is however limited. As a result the average GHG efficiency of maritime vessels is relatively high.

Between 2014 and 2019 the average GHG efficiency of many vessels has improved. The 4th IMO GHG provides several reasons for the improvement of average GHG efficiency. Firstly, the average ship size has increased between 2014 and 2019. Secondly there is a continued reduction in operating speeds which reduces fuel consumption. This reduction in operating speed is however not constant for all vessel types. Fluctuating market forces and responses by vessel operators influence operating speeds and through this also average GHG efficiency.

There are some vessel types which show unexpected large increases from 2018 to 2019. These increases are not due to changes in operation of these vessel types. The issues seem to concentrate on vessel types where it is difficult to determine the exact transport performance. For example for RoRo and RoPax vessels it is difficult to determine the weight of freight goods and for RoPax to divide GHG emissions between passengers and freight. Also many LNG carriers are powered by the LNG they are carrying. As a result the reported annual CO_2 emissions averages in the EU MRV dataset are subject to change, especially in the initial years of the monitoring programme. The trend for the years 2014 – 2017 is based on results from the 4th IMO study. For most vessel types the absolute values are comparable with the results presented in the IMO study. Only for RoPax, RoRo and LNG the results are different which most likely is due to the measurement of transport performance. Updates and improved consistency of the EU MRV data will lead to better comparable results between years.

Table 7.7: Second level indicators maritime freight transport

g/CO_2e per tkm	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
RoPax ship	4.5	4.7	4.6	4.5	4.3	6.5
Other ship types	23.7	23.7	23.9	22.8	22.3	23.8
RoRo ship	16.5	16.3	15.8	15.6	15.7	53.0
Gas carrier	20.6	21.3	20.8	19.9	19.5	18.4
Bulk carrier	4.6	4.7	4.7	4.5	4.5	4.4
General cargo ship	11.1	11.6	11.8	11.0	10.7	13.2
Vehicle carrier	36.4	36.8	37.4	36.6	35.8	33.6
Chemical tanker	9.7	9.7	9.5	9.2	9.0	10.2
Container ship	8.7	8.7	8.7	8.5	8.2	7.7
Refrigerated cargo carrier	17.7	17.4	18.2	18.2	18.0	25.2
Container / RoRo cargo ship	43.0	42.5	41.3	40.7	41.1	20.8
Oil tanker	4.3	4.4	4.3	4.1	4.1	4.1
Combination carrier	16.1	16.1	16.2	15.5	15.2	18.7
LNG carrier	11.2	11.5	11.5	11.2	10.9	21.9
Total freight	6.9	7.0	6.9	6.8	6.6	6.8

Source: own compilation.

Climate change is an urgent challenge confronting society and the demand for accurate GHG reporting has increased significantly. Since 2018 most maritime vessels visiting Europe have to monitor and report CO_2 emissions and transport performance. The results are published annually in the MRV THETIS dataset. This dataset is the ideal source for monitoring the average GHG efficiency of maritime vessels in Europe. The development of average GHG efficiency before 2018 is based on the 4th IMO study. The results show large differences in average GHG efficiency between vessel types which are due to average cargo sizes and vessel layouts. Furthermore, market forces and the reactions of vessel operators to market forces have a large influence on the year-to-year development of GHG efficiency.

It is important to be aware of developments in the maritime sector before drawing conclusions about the average GHG efficiency. Current trends of scale increases and especially reductions in operating speed could easily be reversed in the future. The influence of technical improvements and emissions reduction techniques on the year-to-year development of GHG efficiency is limited. Therefore, it is difficult to interpret the results without knowledge of recent developments in the sector.

It takes time before the MRV-THETIS datasets are finalised. GHG reports of all individual vessels have to be identified. At the time of writing there are still minor alterations done to the 2018 dataset. The 2019 dataset is published as well but the data still contains errors which at times result in different results compared to 2018. Therefore, the results for 2019 are not included in this report. These quality control issues are to be expected since the EU MRV programme is still quite new. It is thus important to keep in mind that changes might occur to the dataset after the initial release.

8 Pilot indicators for 2014 to 2018

Top and second level indicators on GHG efficiency per passenger and tonne kilometre have been derived for all five transport modes: road, rail, aviation, inland navigation and maritime shipping. The method for estimating the values is either based on individual country data (road, rail, inland waterways) or on European sources (aviation, maritime shipping). Except for maritime shipping the estimation approach allows to differentiate between the regional entities EU-27 and EU-28. In the following we present EU-27 data. An extended regional scope including non-EU countries like Norway and Switzerland is not displayed as for some transport modes decisive data is missing.

8.1 Top level indicators

Top level indicators show advances in the GHG efficiency of the main vehicle categories per mode of transport. For the years 2014 to 2018 we present the top level pilot indicators by passenger and freight transport for the EU-27.

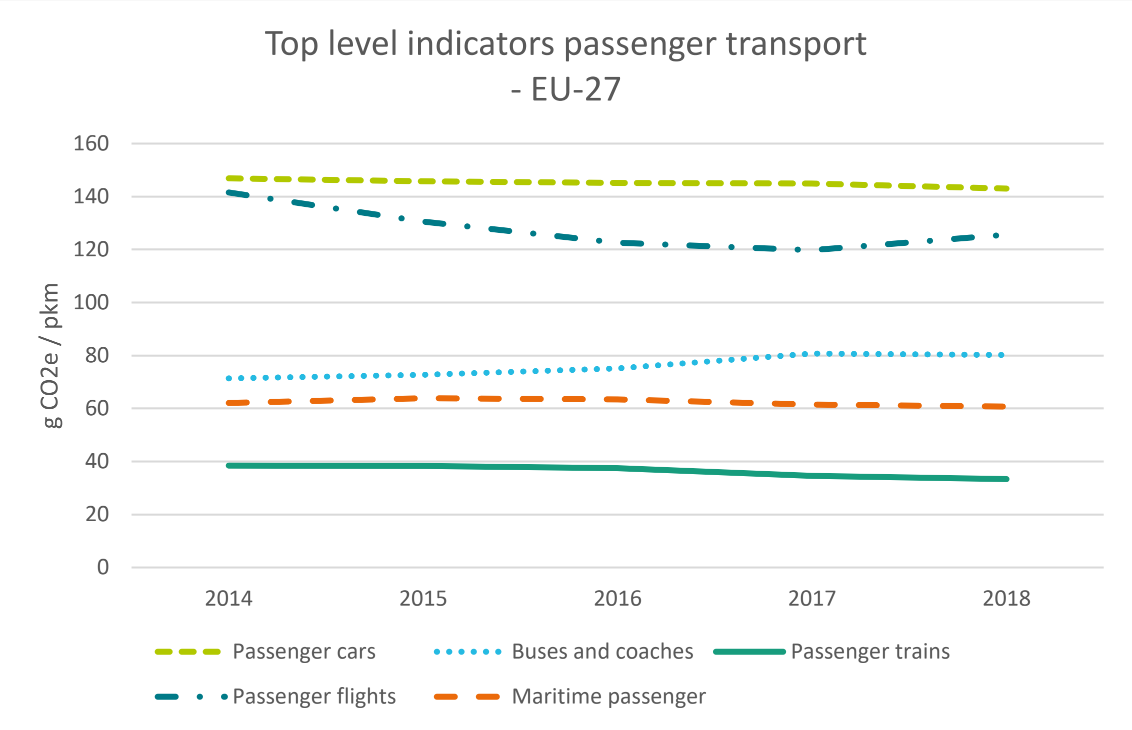
8.1.1 Top level indicators for passenger transport

For the main transport modes on a European scale we find that passenger cars and domestic aviation have the highest GHG emission factor per passenger kilometre. However, aviation efficiency improved substantially by 11 % over the period 2014 to 2018, while the specific GHG intensity of car travel declined by 3 % (Figure 8.1).

Rail travel (with an improvement of 13 %) shows a similar pattern to aviation, although the reasons for higher efficiency are different. While aviation profits from higher occupancy rates possibly pushed by low cost airlines, the rail sector made significant progress in replacing diesel with electric propulsion. The decarbonisation of electricity production accelerates the positive effect of the electrification of rail transport.

A negative trend is observable with buses and coaches. Here the per pkm emissions increased by 12 % from 2014 to 2018. This is due to declining occupancy rates on long-distance buses. Low cost airlines and ridesharing offers for private cars may play a role here, as well as the rising number of long-distance bus connections

Figure 8.1: Top level indicators for passenger transport 2014 - 2018

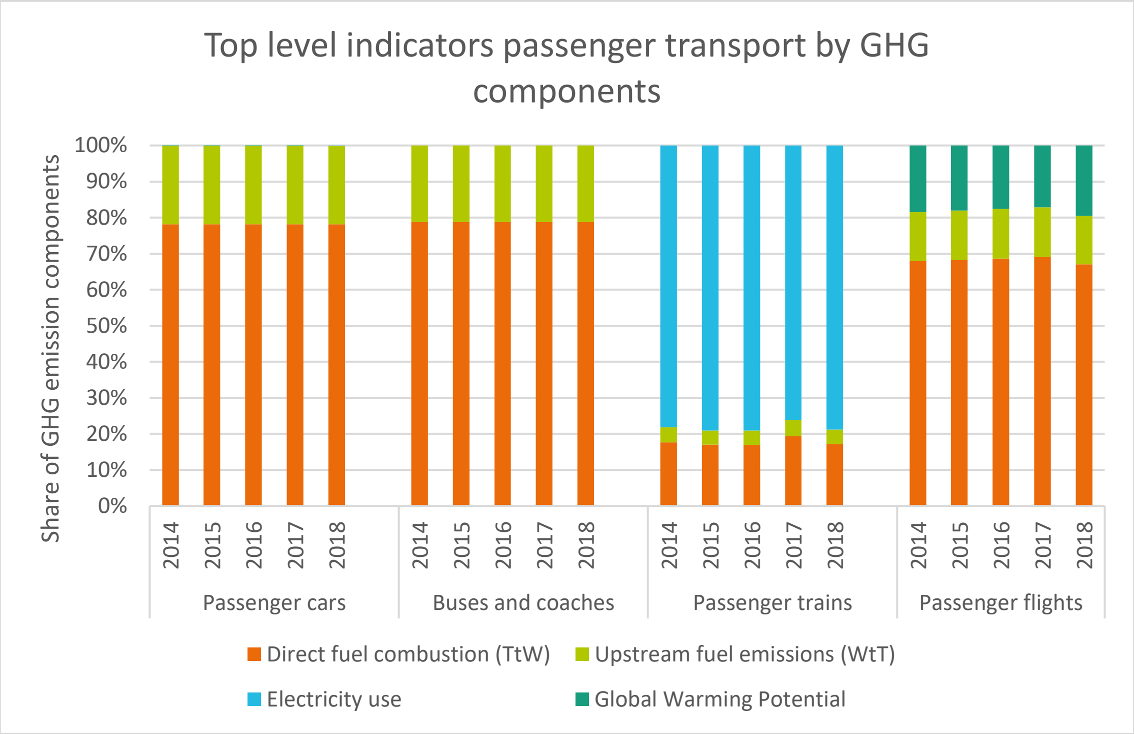


Source: own calculation.

Figure 8.2 shows the structure of GHG emissions per pkm by emission components. Electric propulsion dominates rail passenger services with 79 % of GHG emissions - with increasing tendency. But also in road passenger transport electric propulsion systems play an increasing role. The share of electricity-related GHG emissions is still at 0.08 % in 2018 in the EU-27 but has increased by 700 % since 2014. This is despite a considerable drop in the GHG intensity of electricity production during that period.

An important part of the climate impacts of air travel is due to so-called non-CO_2 emissions at high altitudes, the so-called radiative forcing effect. The radiative forcing index is controversially debated, but with an additional GWP of 1.7 we adopt the most recent scientific evidence currently available.

Figure 8.2: Top level indicators for passenger transport, EU-27, 2014-2018, share of GHG components



Source: own computation.

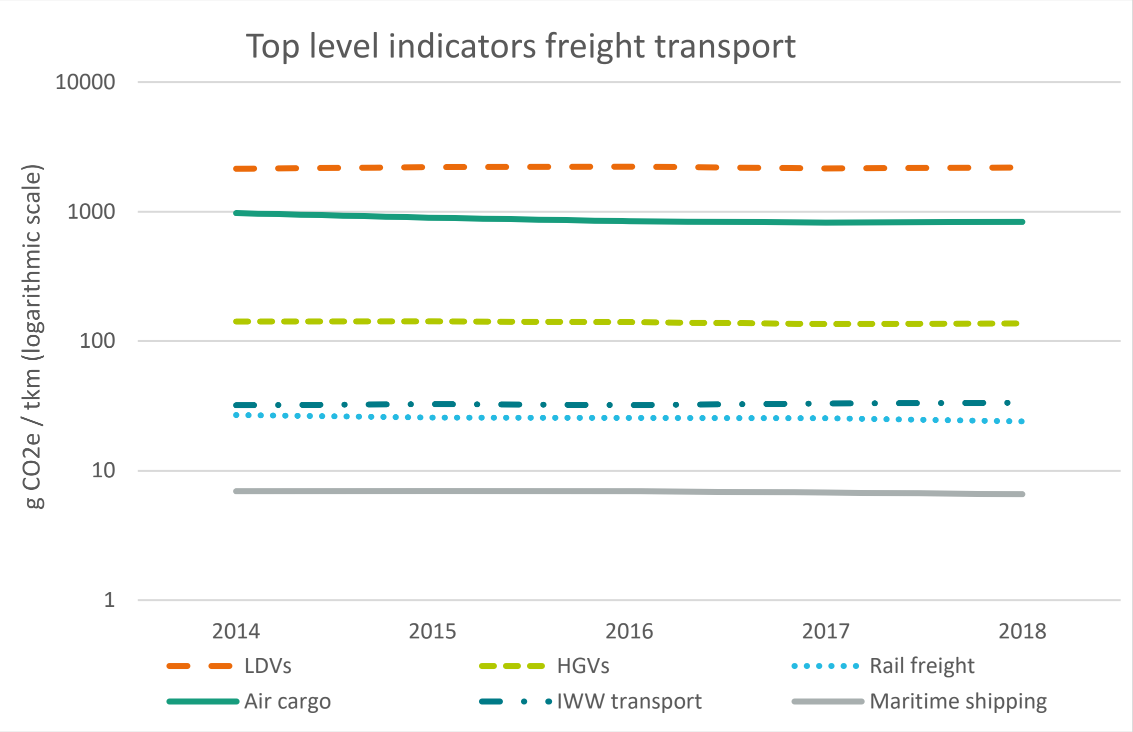
8.1.2 Top level indicators for freight transport

Freight transport efficiency rates show much wider differences than efficiency rates in passenger travel. Emission factors in air freight and for LDVs are about 16 times above those for heavy goods vehicles. This is because LDVs are commonly used for other purposes than transporting goods and thus show, relative to their vehicle mass and fuel consumption, rather low load factors. This issue is discussed in section 3.4. Air freight, in contrast, is characterised by high value and time critical goods. Here, transport time considerations dominate and the GHG efficiency of the transport chain is correspondingly low. In both cases, however, it is difficult to correctly split emissions between passenger and freight transport.

On the other end of the scale we see maritime shipping with 5 %, rail with 18 % and inland navigation with 24 % of the average per tkm GHG emissions of HGVs. The difference between rail and LDV values is large. In order to reflect this, we use a logarithmic scale for the efficiency values in Figure 8.3.

Improvement rates on GHG emissions per tkm over the period 2014 to 2018 for the EU-27 are highest for air cargo (14 %) followed by rail freight (11 %). HGVs show a slight improvement of 3 % specific GHG emissions, while LDVs worsen by 3 % in EU-27.

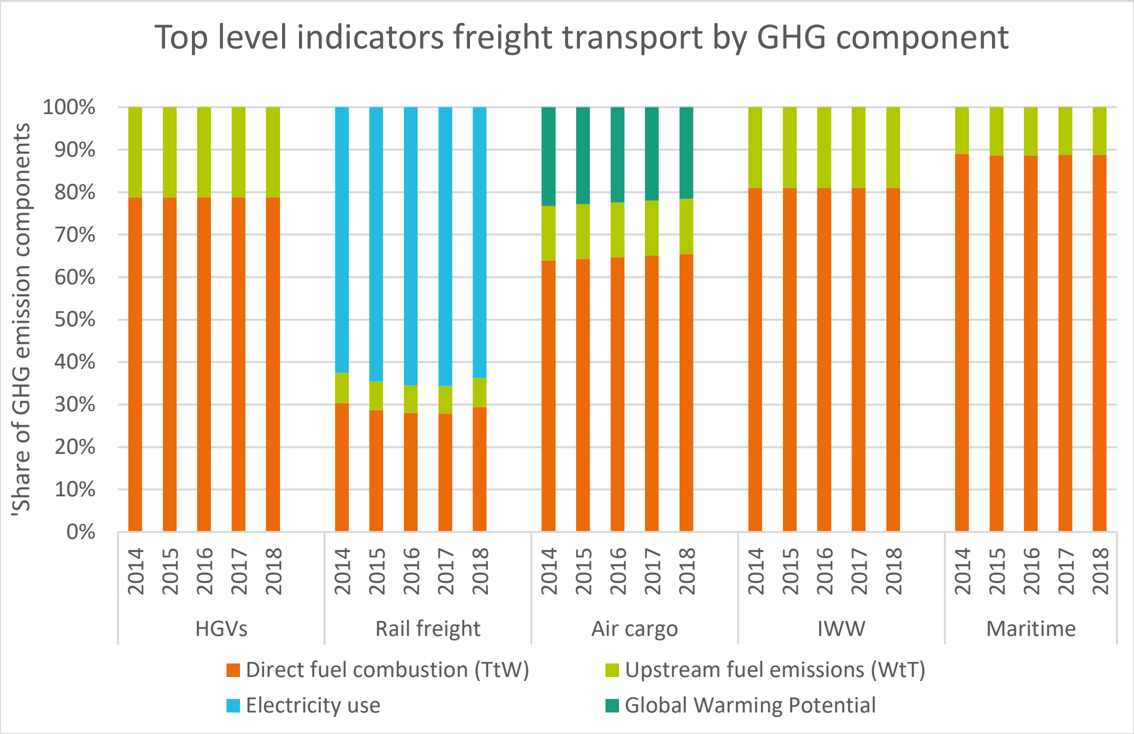
Figure 8.3: Top level indicators for freight transport, EU-27, 2014-2018



Source: own computation.

Figure 8.4 displays the relevance of the components, which the GHG indicators are composed of. Here we see the slowly increasing dominance of electric traction in rail transport, which is currently responsible for more than 60 % of rail freight GHG emissions. This trend will lead to increasingly higher GHG efficiencies in future years, due to the rise in green electricity production. The figure also suggests that electrification in road freight transport does not yet have a relevant influence.

Figure 8.4: Top level indicators for freight transport, EU-27, 2014-2018, share of GHG components



Source: own computation.

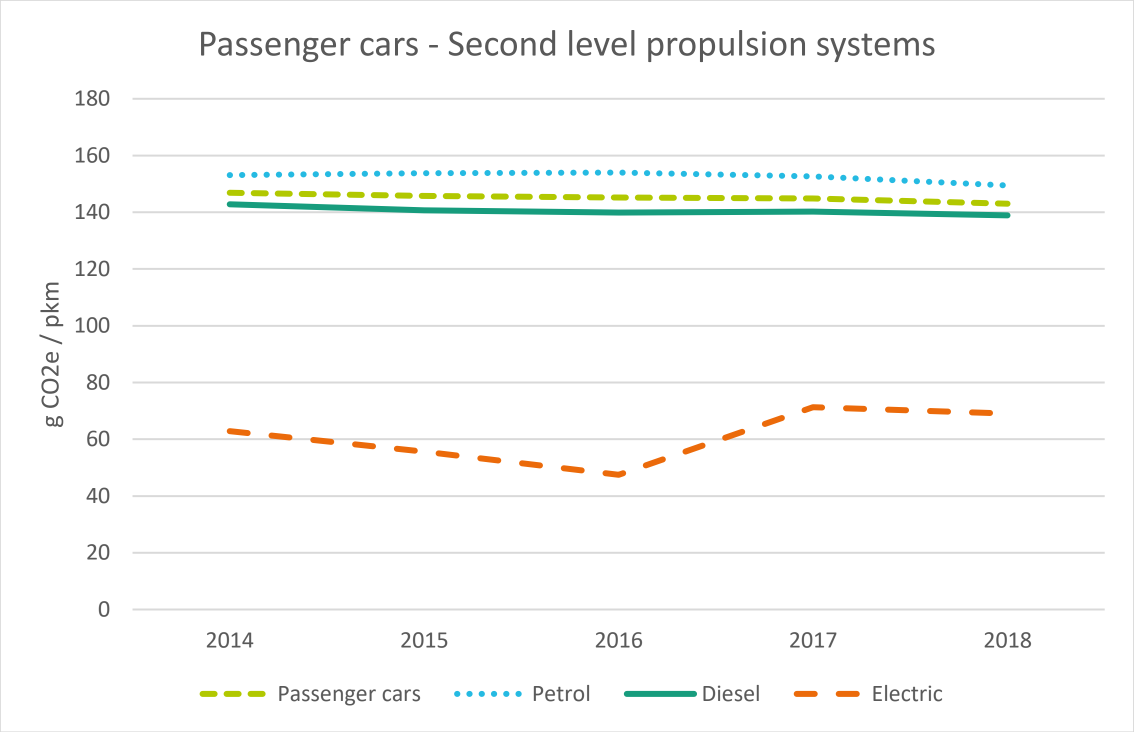
8.2 Second level indicators

At the second level of indicators we added more detail concerning vehicle classes and fuel types. In the following we present a selection of potential assessments on the second level. Further details can be found in the respective methodological chapters of this study.

8.2.1 Fuels and propulsion systems in road transport

Only for road modes we differentiate according to different propulsion systems. In Figure 8.5 the results are shown. In 2017 an increase of GHG emissions from electric cars can be observed, which is mostly due to a increased electicity consumption of new registered vehicles, while the the decrease of the GHG intensity of European electricity generation is lower than in the years before and after, especially in countries with a higher share of electric vehicles.

Figure 8.5: Second level indicators, fuels and propulsion systems in passenger cars, EU-27, 2014-2018



Source: own computation.

8.2.2 *Specific transport markets and distance bands*

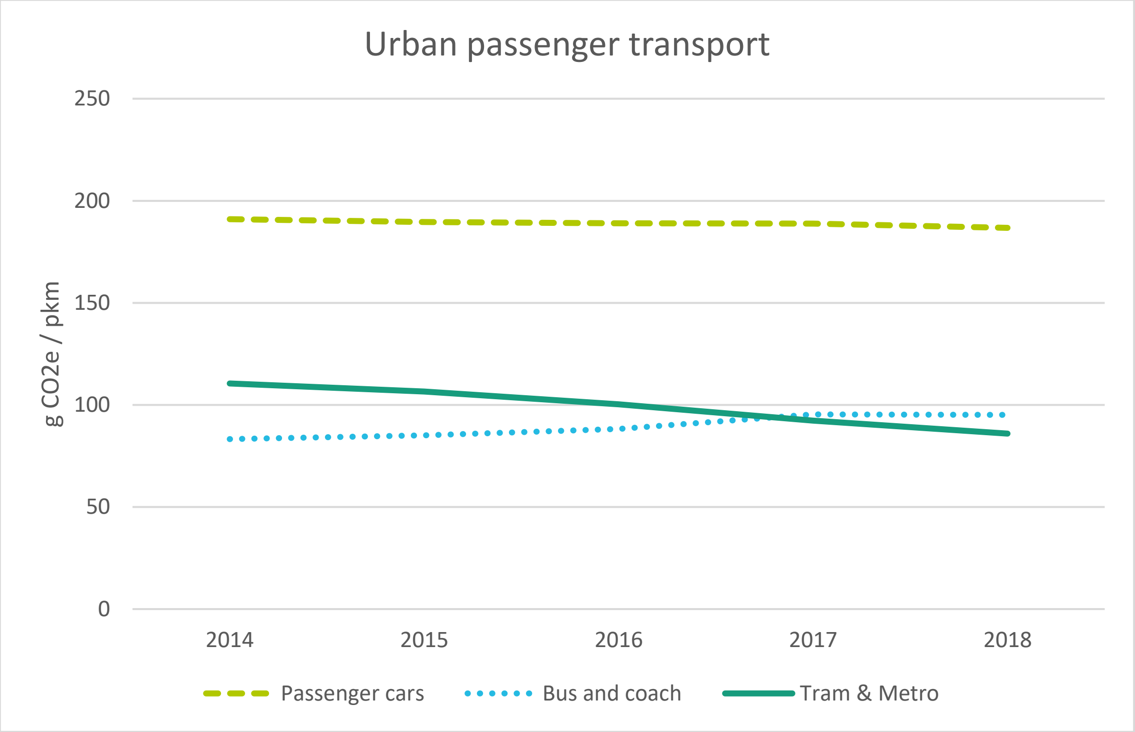
The comparison of transport modes needs to happen in comparable transport markets. In this chapter two transport markets are exemplarily discussed: urban and long distance passenger transport. For the intermodal comparison, second level emission factors are used.

For urban passenger transport, emission factors for passenger cars and busses are considered only for urban road transport. They are compared to the tram and metro emission factors taken from the rail transport section.

For long distance or inter-urban passenger transport we compare the second level GHG indicators of five means of transport: cars, coaches, high-speed train, aviation and ferry.

The results for urban passenger transport are presented in figure 8.6. The figure indicates that in the rather short period covered by the pilot indicators, tram services clearly improved due to advances in electricity production, while urban bus increased their GHG emissions per pkm due to decreasing occupancy rates.

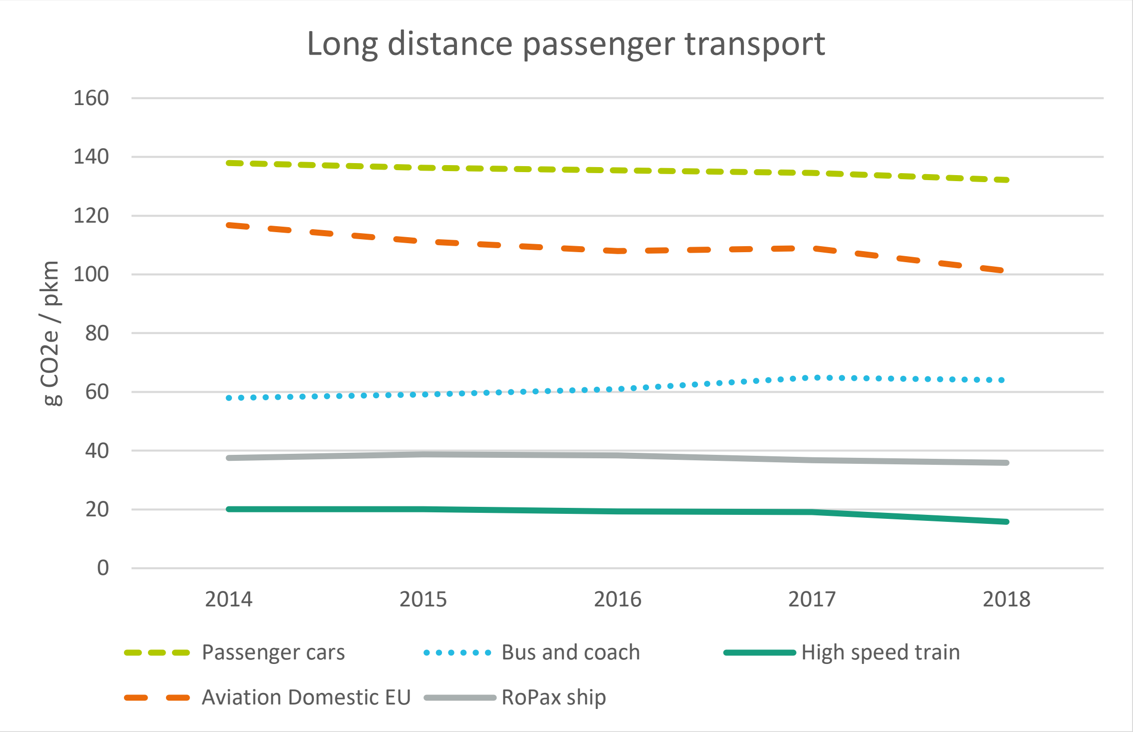
Figure 8.6: Second level indicators, urban passenger transport, EU-27, 2014-2018



Source: own computation.

For inter-urban travel, interestingly the specific GHG emissions per pkm are led by car travel with around 132 g CO_2e/pkm, followed by aviation with only 101 g CO_2e/pkm in 2018 in EU-27 countries. Inter-city coach shows increasing GHG emission rates. RoPax ships range between rail and bus transport and (Figure 8.7).

Figure 8.7: Second level indicators, inter-urban passenger transport, EU-27, 2014-2018



Source: own computation.

9 Conclusions and Recommendations

This final section takes a look at the robustness of the data and the methods behind the calculation methods for road, rail, aviation, IWW and maritime shipping GHG efficiency indicators. In both cases we propose improvements and discuss requirements in case the pilot indicators will be regularly updated by EEA.

9.1 Data quality issues

Road. With the annually updated COPERT model, data on road transport performance and energy use is readily available by country and traffic situation. The model does, however, not contain information on vehicle load factors. Although a number of studies and national investment planning manuals suggest specific load factors in passenger and commercial freight transport, a regular annual monitoring of occupancy rates in passenger transport and freight vehicle load factors is missing.

This is particularly relevant for light duty vehicles, which are often not loaded to their full permissible weight or are used for other purposes than transporting goods. Tonne kilometres finally appears to be a not very significant indicator for the intensity of use for LDVs and tracking of average load factors is rather challenging. Future issues of a GHG efficiency indicator could use emissions per vehicle kilometre or a global road freight indicator instead.

Rail. The processing of rail demand and supply data proved to be particularly challenging for two reasons: the incompleteness of some decisive data items for the big European rail carriers (BE, NL, FR, DE) and the required match between national data provided by infrastructure managers and company data of the railway undertakings. This is challenging in freight traffic where some companies are reporting on global rather than on domestic freight movements. For the final indicators some national data, e.g. from railways' corporate responsibility reports, could be used to supplement the UIC data used so far.

Despite the availability of a rich database on rail energy use and activities provided by the International Union of Railways, the computation logic for specific GHG emissions in rail transport involve a series of steps to estimate electricity and diesel use in passenger and freight services. This complex calculation logic for allocating total emissions to passenger and freight rail market segments is needed because statistically significant and annually updated passenger occupancy rates, freight load factors and energy consumption factors by train class are not provided by the majority of European rail carriers.

The railways and national GHG reporting offices in national environmental agencies should have the required data available. Moreover, most companies publish relevant information through their sustainability reporting schemes or annual reports, but data on energy use or GHG emissions is not provided systematically to international organisations. Getting access to these sources would save considerable resources and simplify the computation of the GHG efficiency indicators significantly.

The treatment of high-speed rail and urban tram and metro services remains a challenge. Data is scattered or not disclosed by rail companies, which necessitates a rough bottom-up approach. In this report we have solved this with German energy use data. Agreements with Eurostat, UIC or UITP on a regular monitoring of these specific markets would help making the GHG efficiency indicators more reliable in the European context.

Aviation has a very clearly defined and scientifically accepted methodology for emissions assessment. The aviation industry also has very detailed data that enables a bottom-up analysis of activity, emissions and emissions efficiency. Aviation analysis is in principle simplified, because the technologies and aircraft used are homogeneous across all countries. The majority of large civil aircraft in Europe are Boeing, Airbus or Embraer models, whose specifications are known and publicly available.

Data exists on every individual flight for large commercial aircraft. Data on the technical details of aircraft types and fuel used is publicly available. However, only a very limited selection of the activity and emissions data is publicly available, even from public organisations such as EUROCONTROL. Data on freight tkm and associated emissions is more limited than for passenger activity.

This implies that if the EEA requires analysis beyond the published reports, it will be necessary to bring industry stakeholders together in specific projects. If the EEA wishes to publish regular updates of assessments, it may be most efficient to enter into framework agreements with the most important stakeholders.

IWW. Calculating average efficiency indicators for inland waterway transport in Europe is a novel exercise. Using private fuel consumption data from the CDNI agreement we have been able to construct a reliable method for calculating average GHG efficiency. However, data limitations do not allow an overview of historical fuel consumption. For future updates it is recommended to contact CDNI early in a project plan, as it takes some time before the data request is processed.

Maritime shipping. The MRV THETIS dataset is the ideal source for monitoring the average GHG efficiency of maritime vessels in Europe. The development of average GHG efficiency before 2018 is based on the 4th IMO study. The results show large differences in average GHG efficiency between vessel types which are due to average cargo sizes and vessel layouts. Furthermore, market forces and behavioural trends have a large influence on the year-on-year development of GHG efficiency.

9.2 Potential methodological improvements

Total emissions are generally available by the national reporting mechanisms. In most cases data is aggregated and provided by Eurostat, EEA or the European Commission. Difficult in most cases is their more detailed allocation to transport market segments, i.e. to passenger and freight transport. In most cases the respective methodological difficulties cannot be solved with current data.

Road. A particular challenge is the division of freight performance in tkm for LDVs and HGVs. LDVs are used for multiple purposes, including the transport of people. Moreover, they usually carry goods which are more defined by their value or volume. Tonne kilometre might thus not be the most appropriate unit for expressing their energy or GHG efficiency. Other measures, such as vehicle kilometres, could be discussed (see above). However, this raises the issue of how to compare LDVs with other modes of freight transport. In principle, a volume measure, calculated from the nominal or actual tonnes of payload and typical densities in tonnes/m^3 might be considered. This would be a topic for further research, if LDV emissions are considered significant.

Rail. The allocation of total emissions and energy consumption to rail markets was carried out by an indirect approach using a regression model. This is not easy to replicate and may report energy consumption factors by train type less accurately than real market observations. Although the regression analyses does not need to be repeated each year, for further updates of the methodology it is recommended to apply real consumption figures from major European rail carriers. This could go along with a thorough analysis of national and private rail carriers' social responsibility reports to track specific occupancy rates and load factors, as well as their actual electricity mix.

Aviation. The distribution of emissions between passengers and belly cargo in passenger aircraft is a complex issue that has not yet been fully addressed. Emissions can be allocated by weight, if the weight of passengers and the weight of cargo is known. However, this requires an agreed method of accounting. Relevant questions are: how should passenger luggage be assigned? Should the total aircraft emissions assigned to passengers include the whole of the aircraft’s structural weight and operating weight (crew and fuel), with belly freight only being assigned the marginal emissions due to the extra weight of belly cargo (and the consequent increase in fuel carried)? Or should the aircraft weight and fuel be assigned to passengers and belly cargo in proportion to the weight of passengers compared to the weight of belly cargo?

The issue of the impact of aircraft emissions at high altitude and the assessment of the GWP for aviation is still not solved. The value of GWP = 1.7 adopted in this report should be reviewed when new estimation methods are developed e.g. (Lee et al. 2021).

IWW. Private fuel consumption data from the CDNI agreement is not intended for GHG reporting. Therefore, elements not essential to the functioning of CDNI agreement are less accurate. This means that vessel information is occasionally incomplete or inaccurate. The results show that operational factors have a large impact on development of the average GHG efficiency. This indicates that more data on actual operations of IWW vessels could improve the reliability of the emissions calculations.

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11 Abbreviations and Country Codes

11.1 Abbreviations

AEED	Aircraft Engine Emissions Databank
AEM	Advanced Emissions Model
ASTRA	Assessment of Transport Strategies (model)
BADA	(EUROCONTROL) Base of aircraft data
BEV	Battery electric vehicle
CCNR	Central Commission for the Navigation of the Rhine
CDN	Convention on the collection, deposit and reception of waste generated during navigation on the rhine and other inland waterways
CH_4	Methane
CDNI	Convention on the Collection, Deposit And Reception of Waste Generated during Navigation on the Rhine and other Inland Waterways
CNG	Compressed natural gas
CO_2	Carbon dioxide
CO_2e	CO_2 equivalent
CODA	(EUROCONTROL) Central Office for Delay Analyses
CSR	Corporate sustainability reporting
DB AG	Deutsche Bahn Aktiengesellschaft
EC	European Commission
EEA	European Environment Agency
EMEP	European Monitoring and Evaluation Programme
ERA	European Railway Agency
EU	European Union
EU-27	EU Member States as of 1 February 2020
EU-28	EU Member States as of 1 July 2013
FEIS	Aviation Fuel Use and Emission Inventory System
FCEV	Fuel cell electric vehicle
FEC	Final energy consumption
g	Gramme
GDP	Gross domestic product
GHG	Greenhouse Gas(es)
GRI	Global Reporting Initiative
GT	Gross tonnage
Gt	Gigatonne
GWP	Global warming potential
HGV	Heavy goods vehicle
HFO	Heavy fuel oil
HSR	High speed rail
HVO	Hydrotreated vegetable oil
ICAO	(UN) International Civil Aviation Organisation
iea	International Energy Agency
ICE	Inter-City Express
ILUC	Indirect land use change
IMO	International Maritime Organisation
IPCC	International Panel on Climate Change

IWT	European Inland Waterway Transport Platform
IWW	Inland waterway transport
JRC	(EC) Joint Research Centre
JRC-IET	(EC) JRC Institute for Energy and Transport
JEC	JEC (JRC-Eucar-Concawe)
kg	Kilogramme
LCA	Life cycle assessment
LDV	Light duty vehicle
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LTO	Landing and take-off cycle
MGO	Marine gas oil
MHEV	Mild hybrid electric vehicle
MJ	Megajoule
MRV	(EU) Monitoring, Reporting and Verification Reporting (of CO_2)
N_2O	Nitrous oxide
NEDC	New European Driving Cycle
nm	Nautical miles
NOx	Nitrogen oxides (NO and NO_2)
PHEV	Plug-in hybrid electric vehicle
pkm	Passenger kilometres
pnm	Passenger nautical miles
PRISME	Pan European Repository of Information Supporting the Management of European Air Traffic Management (EATM)
PT	Public Transport
PtX	Power-to-X (vehicle or infrastructure)
RAILISA	RAIL Information System and Analyses
RFI	Radiative Forcing Index
RoPax	Roll On/Roll Off + passengers
RoRo	Roll on Roll off
RPK	Revenue passenger kilometres
SET	Small Emitters Tool
t	Tonne (metric tonne)
tkm	Tonne kilometres
tnm	Ton nautical miles
TtW	Tank to wheel/Tank to wake
UIC	International Union of Railways
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
vkm	Vehicle kilometres
Wh	Watthours
WLTP	Worldwide harmonized Light vehicles Test Procedure
WtT	Well-to-tank
WtW	Well-to-wheel/Well-to-wake

11.2 Country Codes

AT	Austria
BE	Belgium
BU	Bulgaria
CH	Switzerland
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece (EU code)
ES	Spain
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	The Netherlands
NO	Norway
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom

12 Annex: Results by Mode

12.1 Accompanying MS Excel calculation tables

Table 12.1: Overview of accompanying calculation tables

File Name	Description and use
EEA-GHG-Efficiency_Top-2nd-level -Indicators.xlsx	• Aggregation of GHG efficiency indicators of all transport modes • Intermodal comparisons • Set of figures
EEA-GHG-Indicators_ROAD_Results.xlsx	• GHG efficiency indicators for road transport • Calculation steps • Implemented formulas for calculation of GHG indicators for coming years, based on updated input
EEA-GHG-Indicators_RAIL_Results.xlsx	• GHG efficiency indicators for rail transport • Calculation steps • Implemented formulas for calculation of GHG indicators for coming years, based on updated input
EEA-GHG-Indicators_AVIATION_Results.xlsx	• GHG efficiency indicators for aviation transport • Calculation steps • Implemented formulas for calculation of GHG indicators for coming years, based on updated input
EEA-GHG-Indicators_IWT_Results.xlsx	• GHG efficiency indicators for IWT transport • Calculation steps • Implemented formulas for calculation of GHG indicators for coming years, based on updated input
EEA-GHG-Indicators_MARITIME_Results.xlsx	• GHG efficiency indicators for IWT transport • Calculation steps • Implemented formulas for calculation of GHG indicators for coming years, based on updated input

12.2 Output tables

Table 12.2: Emission factors road passenger top level total and breakdown of WtT, Electricity, and TtW components [gCO_2e/pkm]

Regional entity	Vehicle category	Emission scope	2014	2015	2016	2017	2018
EU-27	Pass. cars	Total	147	146	145	145	143
EU-27	Buses	Total	71	73	75	81	80
EU-27	Pass cars	TtW	115	114	113	113	112
EU-27	Buses	TtW	56	57	59	64	63
EU-27	Pass cars	WtT	32	32	32	32	31
EU-27	Buses	WtT	15	15	16	17	17
EU-27	Pass. cars	Electricity	0.02	0.02	0.03	0.06	0.11
EU-28	Pass. cars	Total	145	144	144	143	141
EU-28	Buses	Total	85	87	90	95	95
EU-28	Pass. cars	TtW	113	113	112	112	110
EU-28	Buses	TtW	67	68	71	75	74
EU-28	Pass. cars	WtT	32	32	31	31	31
EU-28	Buses	WtT	18	18	19	20	20
EU-28	Pass. cars	Electricity	0.02	0.03	0.03	0.06	0.11

Source: Compilation from European Commission (2020b), Eurostat (2020), and COPERT database.

Table 12.3: Emission factors road freight top level total and breakdown of WtT, Electricity, and TtW components [gCO_2e/tkm]

Regional entity	Vehicle category	Emission scope	2014	2015	2016	2017	2018
EU-27	LDV	Total	2145	2204	2225	2155	2187
EU-27	HGV	Total	142	142	140	136	137
EU-27	LDV	TtW	1686	1733	1750	1695	1721
EU-27	HGV	TtW	112	112	110	107	108
EU-27	LDV	WtT	458	471	475	460	467
EU-27	HGV	WtT	30	30	30	29	29
EU-28	LDV	Total	2161	2200	2210	2154	2171
EU-28	HGV	Total	142	141	139	136	136
EU-28	LDV	TtW	1699	1730	1738	1695	1708
EU-28	HGV	TtW	112	111	110	107	107
EU-28	LDV	WtT	461	470	472	460	463
EU-28	HGV	WtT	30	30	30	29	29

Source: Own calculation with data from European Commission (2020b), Eurostat (2020), and COPERT database.

Table 12.4: Emission factors road passenger second level propulsion system [gCO_2e/pkm]

Regional entity	Vehicle category	Propulsion system	2014	2015	2016	2017	2018
EU-27	Pass. cars	Petrol	153	154	154	153	149
EU-27	Pass. cars	Diesel	143	141	140	140	139
EU-27	Pass. cars	Electric	63	56	47	71	69
EU-27	Buses	Diesel	71	73	75	81	80
EU-28	Pass. cars	Petrol	151	152	152	150	148
EU-28	Pass. cars	Diesel	141	139	138	139	137
EU-28	Pass. cars	Electric	72	63	52	72	69
EU-28	Buses	Diesel	85	87	90	95	95

Source: Own calculation with data from European Commission (2020b), Eurostat (2020), and COPERT database.

Table 12.5: Emission factors road freight second level propulsion system [gCO$_2$e/tkm]

Regional entity	Vehicle category	Propulsion system	2014	2015	2016	2017	2018
EU-27	LDV	Diesel	2155	2213	2231	2154	2179
EU-27	HGV	Diesel	142	142	140	136	137
EU-28	LDV	Diesel	2172	2209	2214	2152	2160
EU-28	HGV	Diesel	142	141	139	136	136

Source: Own calculation with data from European Commission (2020b), Eurostat (2020), and COPERT database.

Table 12.6: Emission factors road passenger second level distance bands [gCO$_2$e/pkm]

Regional entity	Vehicle category	Distance bands	2014	2015	2016	2017	2018
EU-27	Pass. cars	Urban	191	190	189	189	187
EU-27	Pass. cars	Rural	120	120	119	119	117
EU-27	Pass. cars	Highway	138	136	135	135	132
EU-27	Buses	Urban	83	85	88	95	95
EU-27	Buses	Rural	61	61	63	67	66
EU-27	Buses	Highway	58	59	61	65	64
EU-28	Pass. cars	Urban	192	191	190	190	187
EU-28	Pass. cars	Rural	118	118	118	117	116
EU-28	Pass. cars	Highway	132	131	131	130	128
EU-28	Buses	Urban	105	107	112	118	118
EU-28	Buses	Rural	67	67	70	73	73
EU-28	Buses	Highway	60	62	64	68	67

Source: Own calculation with data from European Commission (2020b), Eurostat (2020), and COPERT database.

Table 12.7: **Emission factors road freight second level distance bands [gCO$_2$e/tkm]**

Regional entity	Vehicle category	Distance bands	2014	2015	2016	2017	2018
EU-27	LDV	Urban	2769	2838	2867	2780	2825
EU-27	LDV	Rural	1613	1655	1671	1619	1647
EU-27	LDV	Highway	2200	2254	2269	2180	2202
EU-27	HGV	Urban	193	196	195	190	195
EU-27	HGV	Rural	129	130	130	127	130
EU-27	HGV	Highway	130	128	123	117	117
EU-28	LDV	Urban	2722	2823	3074	3193	3493
EU-28	LDV	Rural	1671	1705	1715	1672	1687
EU-28	LDV	Highway	2236	2270	2277	2203	2207
EU-28	HGV	Urban	185	201	217	229	260
EU-28	HGV	Rural	131	132	132	129	131
EU-28	HGV	Highway	131	128	124	119	118

Source: Own calculation with data from European Commission (2020b), Eurostat (2020), and COPERT database.

Table 12.8: **Emission factors rail passenger top level total and breakdown of WtT, Electricity, and TtW components [gCO$_2$e/pkm]**

Regional entity	Transport category	Emission scope	2014	2015	2016	2017	2018
EU-27	Pass. train	Total	38.45	38.30	37.49	34.62	33.35
EU-28	Pass. train	Total	41.93	40.67	38.77	36.04	34.79
EU-27	Pass. train	Diesel TtW	6.79	6.51	6.36	6.69	5.74
EU-28	Pass. train	Diesel TtW	9.48	8.34	8.20	8.52	7.27
EU-27	Pass. train	Diesel WtT	1.58	1.52	1.48	1.56	1.34
EU-28	Pass. train	Diesel WtT	2.21	1.94	1.91	1.98	1.69
EU-27	Pass. train	Electric	30.07	30.27	29.65	26.37	26.28
EU-28	Pass. train	Electric	30.24	30.38	28.65	25.54	25.82

Source: own calculations.

Table 12.9: **Emission factors rail freight top level total and breakdown of WtT, Electricity, and TtW components [gCO_2e/tkm]**

Regional entity	Transport category	Emission scope	2014	2015	2016	2017	2018
EU-27	Freight train	Total	26.87	25.69	25.52	25.45	23.99
EU-28	Freight train	Total	23.89	23.31	23.51	23.19	21.89
EU-27	Freight train	Diesel TtW	8.16	7.38	7.15	7.10	7.06
EU-28	Freight train	Diesel TtW	7.90	7.93	8.02	7.76	7.64
EU-27	Freight train	Diesel WtT	1.90	1.72	1.66	1.65	1.64
EU-28	Freight train	Diesel WtT	1.84	1.85	1.87	1.81	1.78
EU-27	Freight train	Electric	16.80	16.60	16.71	16.70	15.29
EU-28	Freight train	Electric	14.16	13.54	13.62	13.62	12.47

Source: own calculations.

Table 12.10: **Emission factors rail second level passenger train categories [gCO_2e/pkm]**

Regional entity	Train category	2014	2015	2016	2017	2018
EU-27	High speed train	20.06	20.09	19.31	19.14	15.80
EU-27	Conventional train	45.69	45.66	45.12	41.57	41.22
EU-27	Tram&Metro	110.52	106.65	100.25	92.25	85.96
EU-28	High speed train	20.90	20.55	19.41	19.04	15.72
EU-28	Conventional train	48.86	47.44	45.62	42.48	42.00
EU-28	Tram&Metro	114.25	108.02	99.09	90.21	84.20

Source: own calculations.

Table 12.11: Emission factors aviation passenger top level total and breakdown of TtW, WtT, and GWP components [gCO_2e/pkm]

Regional entity	Flight category	Emission scope	2014	2015	2016	2017	2018
EU27	Passenger	Total	142	131	123	120	126
EU27	Passenger	TtW	96	89	84	83	84
EU27	Passenger	WtT	19	18	17	17	17
EU27	Passenger	GWP	26	24	22	21	25
EU28	Passenger	Total	150	138	130	127	133
EU28	Passenger	TtW	96	89	84	83	84
EU28	Passenger	WtT	19	18	17	17	17
EU28	Passenger	GWP	35	32	29	28	31

Source: own computation.

Table 12.12: Emission factors aviation freight top level total and breakdown of TtW, WtT, and GWP components [gCO_2e/tkm]

Regional entity	Flight category	Emission scope	2014	2015	2016	2017	2018
EU27	Freight	Total	973	897	843	823	834
EU27	Freight	TtW	622	577	545	535	545
EU27	Freight	WtT	124	115	109	107	109
EU27	Freight	GWP	227	205	189	181	179
EU28	Freight	Total	967	893	840	823	834
EU28	Freight	TtW	618	574	543	535	545
EU28	Freight	WtT	124	115	109	107	109
EU28	Freight	GWP	225	204	188	181	179

Source: own computation.

Table 12.13: Emission factors aviation second level passenger distance bands [gCO_2e/pkm]

Regional entity	Flight category	Regional scope	2014	2015	2016	2017	2018
EU27	Passenger	Domestic EU	117	111	108	109	101
EU27	Passenger	International	163	151	143	140	143
EU28	Passenger	Domestic EU	118	112	109	110	102
EU28	Passenger	International	159	144	133	128	143

Source: own computation.

Table 12.14: Emission factors aviation second level freight distance bands [gCO_2e/tkm]

Regional entity	Flight category	Regional scope	2014	2015	2016	2017	2018
EU27	Freight	Domestic EU	750	695	656	645	655
EU27	Freight	International	1173	1088	1027	1009	1035
EU28	Freight	Domestic EU	747	693	656	646	658
EU28	Freight	International	1169	1085	1027	1011	1030

Source: own computation.

Table 12.15: Emission factors IWT freight top level total and breakdown of TtW and WtT components [gCO2e/tkm]

Emission Scope	2014	2015	2016	2017	2018	2019
Total	32.0	32.6	32.1	32.9	33.4	31.6
TtW	25.9	26.4	26.0	26.7	27.1	25.5
WtT	6.1	6.2	6.1	6.3	6.4	6.0

Source: own computation.

Table 12.16: Emission factors IWT second level freight ship type [gCO2e/tkm]

Ship Type	2014	2015	2016	2017	2018	2019
Dry bulk						25.6
Tanker						53.7
Push boat						24.2

Source: own computation.

Table 12.17: Emission factors maritime transport top level [gCO2e/tkm]

Emission Scope	2014	2015	2016	2017	2018
Total	6.93	6.96	6.94	6.76	6.57
TtW	6.17	6.17	6.15	6.00	5.84
WtT	0.76	0.79	0.79	0.76	0.74

Source: own computation.

Table 12.18: Emission factors factors maritime passenger transport second level ship type [gCO2e/pkm]

Ship Type	2014	2015	2016	2017	2018	2019
Passenger ship	318.5	325.3	324.4	319.3	320.8	312.2
Ro-pax ship	37.5	38.7	38.4	36.7	35.9	19.1
Total passenger	62.1	63.9	63.4	61.4	60.7	36.8

Source: own computation.

Table 12.19: Emission factors factors maritime freight transport second level ship type [gCO2e/tkm]

Ship Type	2014	2015	2016	2017	2018	2019
Ro-pax ship	4.5	4.7	4.6	4.5	4.3	6.5
Other ship types	23.7	23.7	23.9	22.8	22.3	23.8
Ro-ro ship	16.5	16.3	15.8	15.6	15.7	53.0
Gas carrier	20.6	21.3	20.8	19.9	19.5	18.4
Bulk carrier	4.6	4.7	4.7	4.5	4.5	4.4
General cargo ship	11.1	11.6	11.8	11.0	10.7	13.2
Vehicle carrier	36.4	36.8	37.4	36.6	35.8	33.6
Chemical tanker	9.7	9.7	9.5	9.2	9.0	10.2
Container ship	8.7	8.7	8.7	8.5	8.2	7.7
Refrigerated cargo carrier	17.7	17.4	18.2	18.2	18.0	25.2
Container/ro-ro cargo ship	43.0	42.5	41.3	40.7	41.1	20.8
Oil tanker	4.3	4.4	4.3	4.1	4.1	4.1
Combination carrier	16.1	16.1	16.2	15.5	15.2	18.7
LNG carrier	11.2	11.5	11.5	11.2	10.9	21.9
Total freight	6.9	7.0	6.9	6.8	6.6	6.8

Source: own computation.