STREAM Freight Transport 2020

Emissions of freight transport modes

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Topsector Logistiek

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Contents

Terms and abbreviations

Abbreviation/Term	Definition
CCD	Cruise-climb-descent phase; Flight activities above 3,000 feet.
CEMT	Conférence Européenne des Ministres the Transport.
CEMT I-VI	Waterway classes established by the CEMT, laying down maximum vessel dimensions for each.
CH_4	Methane; greenhouse gas.
CNG	Compressed Natural Gas.
CO_2-eq	Carbon dioxide equivalent.
CO	Carbon monoxide.
DPF	Diesel Particle filter, to reduce particulate emissions.
dwkt	Deadweight tonnage: the total mass a shipping vessel can carry (load, fuel, ballast water) expressed in *kilotonnes*.
dwt	Deadweight tonnage: the total mass a shipping vessel can carry (load, fuel, ballast water), expressed in *tonnes*.
Emission factor	The amount of pollutant (including greenhouse gases) emitted per unit fuel, per kilometre or per tonne-km, with the latter always indicated.
EW	Empty Weight: the weight of an unladen vehicle.
GO	Guarantee of Origin
GT	Gross Tonnage; unit for expressing internal volumes of maritime vessels.
GTL	Gas-to-Liquids, a synthetic diesel oil made from natural gas.
GTW	Gross Tonne Weight: total vehicle weight, including load.
GVW	Gross Vehicle Weight: maximum permissible vehicle weight, including load.
HC	Hydrocarbons.
HFO	Heavy Fuel Oil.
HVO	Hydrotreated Vegetable Oil.
IMO	International Maritime Organisation.
kWh	Kilowatt-hour.
LNG	Liquefied Natural Gas.
LHV	Long Heavy Vehicle.
LTO	Landing-Take-Off cycle; Flight activities below 3,000 feet. Includes taxiing, take-off and landing.
LPG	liquefied petroleum gas
MDO	Marine Diesel Oil.
MGO	Marine Gas Oil.
MJ	Megajoule.
N_2O	Nitrous oxide; greenhouse gas.
NO_X	Collective term for mono-nitrogen oxides (NO, NO_2 and NO_3), emissions of which lead to smog formation, environmental acidification and respiratory damage.
PM	Particulate matter, in *STREAM* specifically PM_{10}.
PM_{10}	Particulate matter of diameter <10 microns, posing a health risk on inhalation.
PM_c	PM_{10} emissions due to fuel combustion.
PM_w	PM_{10} emissions due to wear and tear of brake linings, rubber tyres and road surfaces.
ppm	Parts per million.
SCR	Selective Catalytic Reduction, an exhaust gas treatment system to reduce NO_x emissions.

Abbreviation/Term	Definition
SO_2	Sulphur dioxide, emissions of which lead to smog formation and environmental acidification and can cause respiratory and pulmonary damage and irritation of the eyes.
TEU	Standard shipping container size expressing container volume: Twenty-feet Equivalent Unit.
tkm	Tonne-kilometre: unit of transport performance expressing transport of one tonne over one kilometre. The distance considered in *STREAM* is the total physical distance travelled in delivering the consignment. The tonne-kilometre thus expresses transport performance in terms of both distance and delivered weight.
TTW	Tank-to-wheel emissions (road & rail) or tank-to-wake emissions (shipping & aviation): emissions arising from fuel combustion during vehicle use. Under the heading 'TTW emissions' the tables in this report also include PM_w emissions occurring during vehicle use.
vkm	Vehicle-kilometre.
WTT	Well-to-tank emissions (road & rail) or well-to-wake emissions (shipping & aviation): emissions arising during extraction, transport and refinery of fuels or during electric power generation and transmission. In the case of biofuels, TTW emissions are taken to be zero, In line with IPCC protocols, and net supply-chain emissions cited under WTT.
WTW	Well-to-wheel emissions (road & rail) or well-to-wake emissions (shipping & aviation): the sum total of WTT and TTW emissions.
Load factor	Proportion of total vehicle load capacity taken up by the load in a laden vehicle, weighted over kilometres travelled.
(Capacity) Utilisation	Proportion of total vehicle load capacity used during laden and unladen trips, weighted over kilometres travelled.

Summary

Scope

STREAM Freight Transport 2020 is a handbook providing emission factors for greenhouse gases and the main air pollutants per tonne-kilometre for road, rail, inland waterway, maritime shipping and air transport. These emission factors are averages for the year 2018 and are representative for transport operations within the Netherlands or starting or ending there. For each transport mode, this document gives representative average emission factors suitable for exploratory (policy) analyses, when average data suffice, as well as detailed factors for calculating emissions in specific situations when data are available on individual vehicle or vessel types and how their mode of use (freight type, road or waterway class). Besides fleet-average emission factors for the year 2018, factors are also reported for various vehicle technologies (including Euro emissions classes) and (alternative) fuels. Extensive information is also provided on the data sources and methods employed.

These emission factors are not designed for directly comparing transport modes, this often being irrelevant (as with a van and an aircraft) or unfeasible (due to absence of infrastructure). Comparison is only feasible on transport corridors where alternative modes are indeed possible and where mode-specific distances are a key factor, though these may well be differently defined (as-the-crow-flies for aviation, distance driven/sailed for other modes). The *STREAM* emission factors can only be used for comparing logistical options if due allowance is made for mode-specific distances, upstream and downstream transport and transhipment. In Chapter 6 this is illustrated with several practical examples.

STREAM provides emissions factors for greenhouse gases (CO_2, CH_4 and N_2O, summed as CO_2-eq.) and the main transport air pollutants (PM_{10}, NO_x and SO_2). The exhaust and the wear-and-tear emissions (together known as Tank-to-Wheel or TTW emissions) are reported as well as the emissions occurring during extraction, production and transport/transmission of fuels and electricity (Well-to-Tank or WTT emissions). In the case of CO_2-eq. emissions, WTT and TTW emissions are both relevant for global warming impact. With air pollutants, the emissions site is of major relevance for health damage, emissions in densely populated areas posing more risk than emissions at sea, for example.

Besides detailing the WTT and TTW emissions deriving directly from use of the various transport modes, this new 2020 edition of *STREAM Freight* also quantifies how these compare with the emissions due to vehicle production and maintenance and roll-out of infrastructure. Given the increasingly important role of battery-electric vehicles, particular attention is given to the emissions associated with battery production.

Results

Chapter 2 provides a compact overview of emission factors per tonne-kilometre for the most representative vehicle and vessel categories. As these synopses show, the emission factors for each mode have a broad range, depending on the vehicle/vessel size (load capacity) and the type of freight carried (light, medium, heavy). In Chapter 3 the emission factors are reported in full detail.

The worked examples in Chapter 6 show that the comparative emissions of alternative modes in a given transport corridor depend not only on tonne-km emission factors, but also very much on overall distance and details of up- and downstream transport. In the examples, CO_2-eq. emissions are generally highest for road transport, but other modes may approach these values if these involve a lot of up- and downstream transport and a longer route needs to be taken. How modes compare with respect to emissions of exhaust particulates (PM_c) and NO_x differs considerably from case to case, with the highest emissions due to tractor-semitrailers, diesel trains, canal barges and short-sea shipping vessels, depending on vehicle/vessel size, transport distance and up- and downstream transport. Consistently, though, electrified trains have the lowest emissions.

For many modes, around 20% of aggregate lifecycle CO_2-eq. emissions are associated with the sum total of vehicle/vessel production and maintenance and infrastructure. For aircraft and larger ocean-going vessels this share is far lower (10% or less). With lighter road vehicles, the CO_2-eq. emissions due to vehicle production account for a relatively large share of the 20% figure. With rail and inland shipping, the CO_2-eq. emissions associated with infrastructure are more important.

With battery-electric road vehicles, battery production may well increase the CO_2-eq. emissions due to vehicle production twofold or more. The lower emissions during vehicle use mean the lifecycle CO_2-eq. emissions of battery-electric vehicles work out lower, however. With time this ‘edge’ will only increase, as the CO_2-eq. emissions of power generation continue to fall, with the same holding for battery production (partly for the same reason).

1 Introduction

1.1 Background

Under de acronym *STREAM* (Study on Transport Emissions for All Modes) CE Delft has now been publishing reports with transport emission factors for almost ten years. The emission factors from the *STREAM* studies are frequently used by policy-makers, industry, researchers and consultants for policy exploration and development on issues relating to modal shift, vehicle fleet renewal, (carbon) footprinting and other such matters.

The present study, *STREAM Freight Transport 2020*, an update of *STREAM Freight Transport 2016*, provides a comprehensive review of the emission factors of freight transport modes for the year 2018. This update was needed because European vehicle standards, fleet renewal, government policies and technological progress mean that transport emissions have changed since 2014, the reference year adopted in *STREAM 2016*. In addition, practical measurements on vehicles and vessels have shed new light on real-world emissions.

Besides reporting updated emission factors for a wide range of freight vehicles and vessels, *STREAM 2020* now includes emission factors for air freight carriage and a chapter on the emissions associated with vehicle production and maintenance and infrastructure.

Emission factors for passenger transport modes are reported in a separate publication, *STREAM Passenger Transport*, the most recent version of which was published in 2014.

1.2 Objective and scope

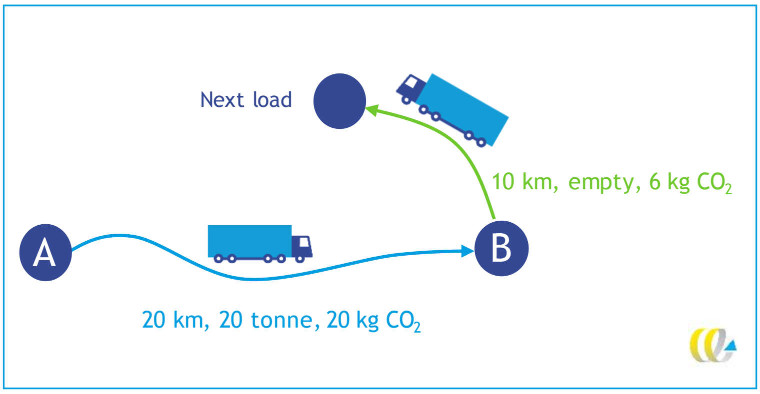
The aim of *STREAM* is to provide an up-to-date and accessible review of emission factors for key freight transport modes for use in (policy) analysis, intermodal comparison and (carbon) footprinting studies.

STREAM Freight Transport 2020 provides comprehensive lists of emission factors for greenhouse gases and key air pollutants per tonne-kilometre for the various modes of freight transport for the Netherlands for the year 2018. ‘For the Netherlands’ means the emission factors are typical for transport within the Netherlands or starting or ending there.

The sum total of emissions of both laden and unladen vehicles are related to transport performance expressed in tonne-kilometres: the product of load weight and the distance over which the load is carried (cf. Section 5.1 and text box on next page). Expressing emissions per tonne-kilometre:
- provides insight into how the emissions of various transport modes and technologies compare in specific situations;
- permits calculation of footprints of transport modes and technologies per tonne-kilometre.

Emissions per tonne-kilometre
Expressing emissions per tonne-kilometre establishes a direct relationship of emissions with transport performance, for a given trip the product of the weight transported (in metric tonnes) and the distance travelled (in km). While empty kilometres do not contribute to transport performance (tkm), they do contribute in the emission of empty trips to the next pick-up point or back to base. For each transport mode and vehicle category, the emission factors per tonne-kiloometre presented in *STREAM* are thus the averages of (averagely) laden and unladen trips.

For CO_2 emissions, this is illustrated by a 20-km delivery trip from A to B, emitting 20 kg CO_2, followed by a 10-km empty trip, emitting 6 kg CO_2.



Calculation of the CO_2 emission factor per tonne-km (tkm) is then as follows:
- physical tkm: 20 km*20 tonne + 10 km*0 tonne = 400 tkm;
- CO_2 emissions: 20 kg CO_2 + 6 kg CO_2 = 26 kg CO_2;
- emissions per tonne-kilometre: 26,000/400 = 65 g CO_2/tkm.

STREAM 2020 reports the key emission factors of relevance for climate and air-quality policy-makers. Emissions of the main greenhouse gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are expressed collectively as CO_2-equivalents[1]. The air-pollutant emissions considered are: mono-nitrogen oxides (NO_x), particulate matter (PM_{10}) and sulphur dioxide (SO_2). With PM_{10} a distinction is made between emissions due to fuel combustion (PM_c) and those due to wear and tear of brake linings, tyres, road surfaces, overhead wires and so on (PM_w).

For all emissions, insight is provided into both exhaust gas emissions (tank-to-wheel, or TTW emissions) and emissions associated with fuel extraction, production and transport and electricity production and transmission (well-to-tank, or WTT emissions). The particulate emissions due to the wear and tear of vehicles and infrastructure are also covered.

The emissions associated with infrastructure creation and vehicle manufacture and maintenance are not reported in the main tables, but discussed separately in Chapter 7, with an estimate of how they compare with the sum of the WTT and TTW emissions, the well-to-wheel, or WTW emissions.

Table 1 provides a summary of the emissions covered by the main tables of this report.

[1] The relative weighting of CH_4 and N_2O is discussed in Section 4.2. In the rest of this report "CO_2" should be taken as referring to CO_2-equivalents.

Table 1 - Emissions reported in *STREAM*

	Fuel combustion	Wear & tear	Fuel production, power generation, upstream transport
	TTW	(tyres, overhead wires, etc.)	WTT
CO_2-eq.	X	N.a.	X
NO_x	X	N.a.	X
PM_{10}	X	X	X
SO_2	X	N.a.	X

N.a.: not applicable. Wear and tear produces zero combustion products like CO_2, NO_x and SO_2.

The logistical parameters for the various types of freight transport can vary widely and, with them, emission factors. This report therefore distinguishes emission factors for two main categories of freight transport:
- bulk/packaged cargo;
- containers.

For these two basic types of transport, *STREAM* then distinguishes three weight categories: light, medium and heavy.[2]

Besides average emission factors for the year 2018, the study also provides emission factors for alternative fuels and vehicle technologies.

Several worked examples are also provided, to show how the emission factors can be used to compare transport modes in specific situations.

1.3 Using the emission factors

The emission factors reported in *STREAM Freight Transport 2020* can be used for a variety of purposes, the principal being policy analysis, intermodal comparison and (carbon) footprinting. They can be used to translate transport flow statistics in tonne-km directly into total emissions, for example.

Emission factors are provided for an extensive range of vehicle categories, freight types, fuels and road and waterway classes. Chapter 2 identifies the most representative factors for each transport mode.

When using these factors, it is important to be bear the following in mind:
- While the emission factors given are characteristic of the vehicle/vessel category concerned, when investigating specific cases it is important to ensure that the *STREAM* category selected is appropriately defined, particularly in terms of vehicle/vessel load capacity and load weight.

- While the *STREAM* emission factors are highly differentiated, they should still be regarded as default figures for analyses where detailed information is unavailable. A CO_2 footprint based on actual fuel consumption will always be preferable to a calculation based on tonne-kilometres and *STREAM* emission factors. Similarly, an analysis of air-pollutant emissions based on distance travelled and emission factors per kilometre will be more accurate than one based on tonne-km and emission factors per tonne-km.

2 These are defined in Section 3.1.

— Total emissions for a given trip are obtained by multiplying emission factors per tonne-km by the number of tonne-km, which should be based on the actual distance driven, sailed or flown, and not, for example, on the distance 'as the crow flies'[3] or the shortest route. As mentioned above, *STREAM* emission factors make due allowance for empty trips.

— If the emission factors are used for calculations on short delivery trips, it is important to bear in mind that tonne-km based on the shortest distance between origin and delivery site underestimates the actual tonne-km and thus also emissions. On these kinds of trips extra kilometres are unavoidable in combining delivery addresses.

— The emission factors can be used for comparing the footprints of transport alternatives in concrete situations. On their own, though, they are no basis for comparison between modes. When comparing alternatives, allowance needs to be made for the respective distances travelled and the upstream and downstream transport required for getting from origin to destination. This point is illustrated In Chapter 6.

— When comparing air-pollutant emissions, moreover, allowance needs to be made for where they occur, as this is what determines potential health damage. Particulate and NO_x emissions occurring in urban (especially city) environments (CE Delft; INFRAS; TRT; Ricardo, 2019) are substantially more harmful than those due to aviation and maritime shipping, which are out at sea or high in the atmosphere.

1.4 Differences from *STREAM 2016*

STREAM 2020 employs largely the same methodology as *STREAM 2016*, but taking 2018 as its reference year. The main changes relate to newly defined vehicle fleets and updated emission factors, as detailed in Chapter 8 and summarised below:

— More road vehicle categories are now distinguished, thanks to the more extensive data now available on vans in (Connekt, 2017). Four rather than two weight classes are now distinguished. The category used most frequently for freight transport (unladen weight 2-2.5 tonnes) is included in the tables with emission factors per tonne-km. For the other van categories, emissions are reported per vehicle-km, because these vehicles are also often used as a service vehicle, carrying tools rather than freight, for example.
— With inland shipping, the main change is use of more realistic sailing speeds based on real-world data. Particularly for small vessels on narrow waterways this means lower speeds and therefore lower emissions than in *STREAM 2016*.
— For rail transport, the main change is adjustment of train categories based on expert interviews and new publications (ProRail, 2019).
— For maritime shipping, the main change is an extension of overall scope, which now takes in not only coastal shipping but deep-sea shipping, too. Second, new data sources and a new methodology have now been used. *STREAM 2020* uses real-world data based on the EU-MRV dataset[4] and data compiled by the Royal Association of Netherlands Shipowners, KVNR.
— New in this edition are emission factors for aviation, distinguishing two types of aircraft: full-freight and belly-freight.

[3] Tonne-kilometres based on distance 'as the crow flies' are used specifically in analyses according to the COFRET method for allocating a carrier's emissions to delivery addresses.

[4] This dataset reports practical data on the CO_2 emissions of vessels >5,000 GT sailing to European ports in the framework of EU Regulation 2015/757 (EU, 2015b).

— For the first time, *STREAM 2020* now includes estimates for the so-called lifecycle emissions associated with vehicle production and maintenance, battery production and infrastructure.

1.5 Report outline

At the core of *STREAM 2020* are the emission factors per tonne-kilometre for the various categories of vehicle and vessel[5]. These are therefore presented prominently early on, since the main aim of *STREAM* is to provide an up-to-date and readily consultable review of freight transport emission factors.

Chapter 2 reports the most representative data for each basic mode of transport. These are a selection of the detailed data reported in Chapter 3, which provides data on more vehicle and vessel categories and types of load (light, medium, heavy), distinguishing road and waterway classes and air flight distances. For each mode, percentage indices are given for calculating the emission factors of alternatives fuels and technologies from the data in the basic tables.

Chapter 4 explains how the methodology and assumptions used to derive the data emission factors reported in Chapter 3.

Chapter 5 goes into the logistics data used for calculating the emission factors of the various transport modes.

Chapter 6 explains how the data can be used in specific situations.

Chapter 7 shows how the emissions arising during vehicle/vessel use compare with those associated with vehicle/vessel production and maintenance and infrastructure roll-out.

Chapter 8 comprises a brief discussion of the differences in emission factors between *STREAM 2020* and *STREAM 2016*.

Chapter 9, finally, presents a number of recommendations for further study.

In the appendixes additional information is provided for the various fuels, technologies and types of transport.

[5] With the exception of vans, for which emission factors are also reported per vehicle-kilometre.

2 Synopsis of results

2.1 Introduction

This chapter provides a concise synopsis of the updated *STREAM* emission factors *per tonne-kilometre*. Section 2.2 reports representative emission factors for each transport mode, while Section 2.3 reviews the ranges within which they lie. Section 2.4 then shows, for CO_2 emissions, how the emissions associated with infrastructure and vehicle production stand in relation to total lifecycle emissions.

This chapter is a condensed presentation of the results reported in the remainder of the document. For the definitions used here and further on, the reader is referred to the list of Terms and Abbreviations at the beginning of the document and the extensive descriptions in Chapters 3 and 4.

2.2 Representative emission factors

Table 2 and 3 present, for each transport mode, the tonne-km emission factors for the most representative vehicles and vessels and representative types of freight (light, medium, heavy) [6] carried. These vehicles and vessels represent the average, in many cases because they account for a major share of the respective transport movements:

- On the roads, large vans (2,000-2,500 kg unladen weight) are the vehicles in most frequent use. They generally carry a light load and are only sparsely loaded (based on data from Statistics Netherlands, CBS).
- On average, trucks carry a medium-weight load. Light and heavy tractor-semitrailer combinations account for almost 65% of truck km and 75% of tonne-km (CBS).
- In transport with lighter trucks (load capacity <20 t), used among other things for urban logistics, the medium-weight truck plays a major role.
- Rail freight carriage is dominated by electrified trains, but for shunting and on certain routes diesel locomotives are often used, mainly where overhead power is lacking. The weighted average emission factor for electric and diesel is given. It is predominantly heavy freight that is transported by rail. With respect to weight, the medium-length train (3,000 GTW full, average approx. 2,160 t) has been taken as representative for the average weight transported by rail (excl. container trains), based on the average train weights reported in (ProRail, 2019). With container transport, this is the long train (90 TEU[7]).
- In inland shipping almost 50% of freight is carried by two types of vessel: the Rhine-Herne canal vessel (M6) and the Large Rhine vessel (M8). It is generally heavy freight that is carried on the canals (RWS, Chartasoftware, 2015).
- The data in the EU-MRV database shows a 35-60 dwkt bulk carrier is a good approximation for the average deep-sea vessel, while for container transport this is the 8,000-12,000 TEU container ship. For short-sea transport a range of vessels are used. In terms of emissions per tonne-kilometre the General Cargo ship (10-20 dwkt) is representative of the average of these coastal vessels[8]. For container transport this is the 1,000-1,999 TEU container ship.

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[6] Based on analyses and sources from CE Delft (2016a) and TNO (2015b) for road, rail and inland shipping. See the definitions in Section 3.1.

[7] Unit of container size: Twenty-foot Equivalent Unit.

[8] Based on the number of vessels and capacity per vessel category (IMO, 2014).

— Long distance airplanes have a share of 84% in tonkm transported by air as is derived from the data supplied by Schiphol. The weighted-average of full freight (59%) and belly freight 41%) is representative for air freight transport.

The tables below report the most policy-relevant emission factors, viz. WTW greenhouse gas emissions (CO_2, CH_4 and N_2O expressed as CO_2-equivalents) and exhaust emissions (TTW) for particulates (PM_c) and NO_x. For land transport, the TTW emissions of PM_c and NO_x generally pose the greatest risk and are therefore more relevant for policymakers than the WTT emissions of these pollutants. While TTW emissions occur in or near built-up areas, where they impact human health more directly, WTT emissions are usually in less populated industrial areas where refineries, power stations and so on are located. With maritime shipping and aviation, it is the TWW emissions of PM_v and NO_x at ports and airports that have the greatest health impact.

The full data set of all the emission factors is provided in Chapter 3.

Table 2 - Representative emission factors per mode, bulk/packaged cargo transport

Mode	Vehicle/Vessel	Type of freight	CO_2 (g/tkm) (WTW)	PM_c (g/tkm) (TTW)*	NO_x (g/tkm) (TTW)*
Road	Van, empty weight 2,000-2,500 kg	Light	1,326	0.078	4.35
	Truck, medium-size	Med.-weight	256	0.015	1.40
	Tractor-semitrailer, light	Med.-weight	178	0.002	0.53
	Tractor-semitrailer, heavy	Med.-weight	88	0.002	0.22
Rail	Medium-length train (electric 73%: diesel 27%)	Heavy	12	0.001	0.05
Inland shipping	Rhine-Herne canal (RHC) vessel	Heavy	38	0.014	0.40
	Large Rhine vessel	Heavy	24	0.010	0.26
Maritime shipping	Short-sea: General Cargo 10-20 dwkt	Heavy	22	0.009	0.40
	Deep-sea: Bulk carrier 35-60 dwkt	Heavy	6.6	0.003	0.13
Aviation	Long-haul (average)	Light	544	0.015	1.98

* The emission factors for air pollutants provide no indication of the potential health damage associated with the various modes, which depends on where the emissions occur.

Table 3 - Representative emission factors per mode, container transport

Mode	Vehicle/Vessel	Type of freight	CO_2 (g/tkm) (WTW)	PM_c (g/tkm) (TTW)*	NO_x (g/tkm) (TTW)*
Road	Tractor-semitrailer, heavy (2 TEU)	Med.-weight	121	0.003	0.30
Rail	Long train (electric 73%: diesel 27%)	Med.-weight	18	0.0018	0.08
Inland shipping	Rhine-Herne canal (RHC) vessel (96 TEU)	Med.-weight	52	0.019	0.55
	Large Rhine vessel (208 TEU)	Med.-weight	32	0.013	0.34
Maritime shipping	Short-sea: 1,000–1,999 TEU container ship	Med.-weight	32	0.013	0.57
	Deep-sea: 8,000-11,999 TEU container ship	Med.-weight	12	0.005	0.23

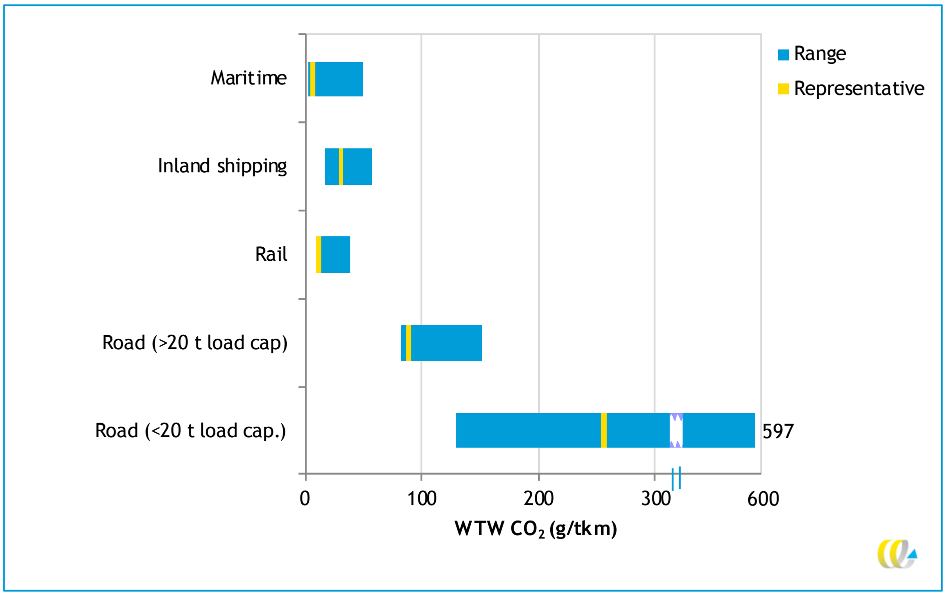
* The emission factors for air pollutants provide no indication of the potential health damage associated with the various modes, which depends on where the emissions occur.

2.3 Emission factor ranges

The emission factors reported for each mode are strongly dependent on the type of vehicle or vessel and the type of freight (light, medium-weight or heavy). This is illustrated in Figure 1 to 6 for the CO_2-eq., NO_x and PM_c emissions of both bulk/packaged cargo and container transport.[9] In each of the figures the representative values from Table 2 and 3 are shown in yellow. The blue bands indicate the extent to which the emission factors can vary, depending on the type of vehicle/vessel and freight (light, medium-weight, heavy) for the vehicles/vessels considered in Chapter 3. For inland shipping the average of the Rhine-Herne canal vessel and the Large Rhine vessel was taken.

The figures show the emission factors per tonne-kilometre for the transport modes concerned. It should be noted, though, that this does not mean these bars can be used for intermodal comparison. Modes can only be properly compared in specific cases, with due allowance being made for the distances travelled by the respective modes and the up- and downstream transport involved in getting from A to B. To illustrate this, in Chapter 6 three concrete examples are elaborated in which allowance is made for varying distances per mode and up- and downstream transport or multimodal transport.

Figure 1 – Ranges of CO_2 emission factors, bulk/packaged goods (WTW) (g/tkm)



[9] Vans and aircraft are not shown. Van emissions (CO_2, PM_c and NO_x) per tkm are disproportionally high, because these vehicles can transport only relatively small loads and are typically used for local delivery. Similarly, aircraft CO_2 emissions per tkm are disproportionally higher. Including these data in the figure would lead to a considerable loss of resolution.

Figure 2 - Ranges of CO_2 emission factors, container transport (WTW) (g/tkm)

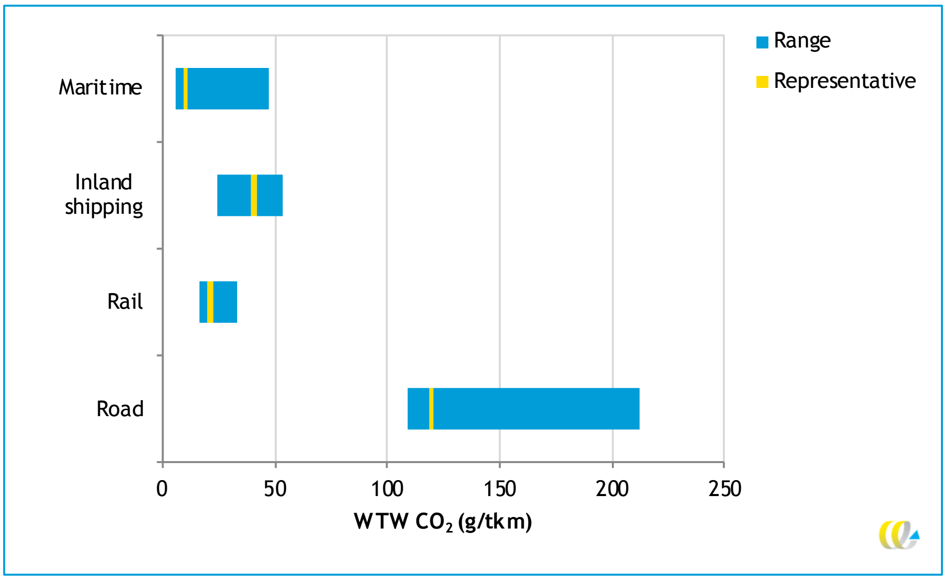


Figure 3 - Ranges of particulate (PM_c) emission factors, bulk/packaged goods (TTW) (g/tkm)

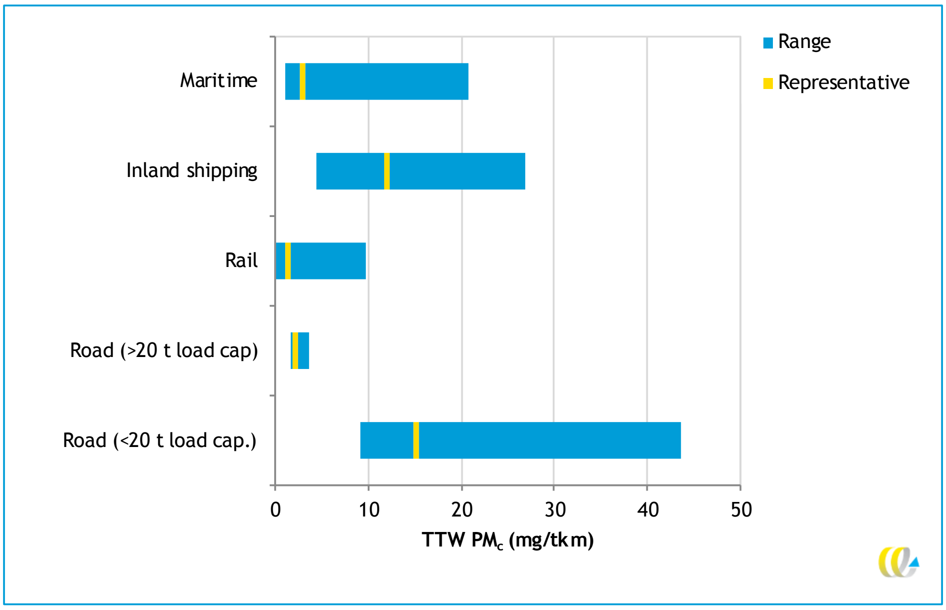


Figure 4 - Ranges of particulate (PM_c) emission factors, container transport (TTW) (g/tkm)

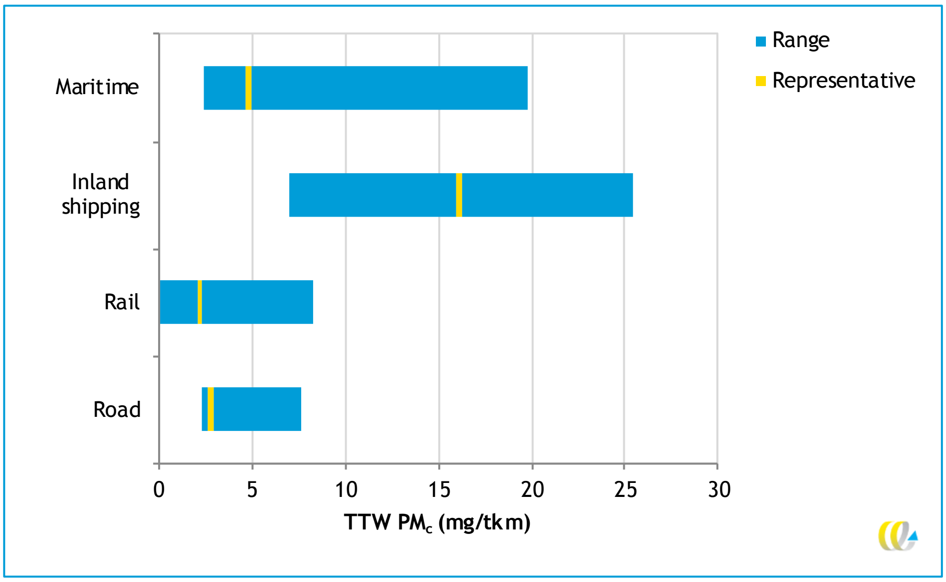


Figure 5 - Ranges of NO_x emission factors, bulk/packaged goods (TTW) (g/tkm)

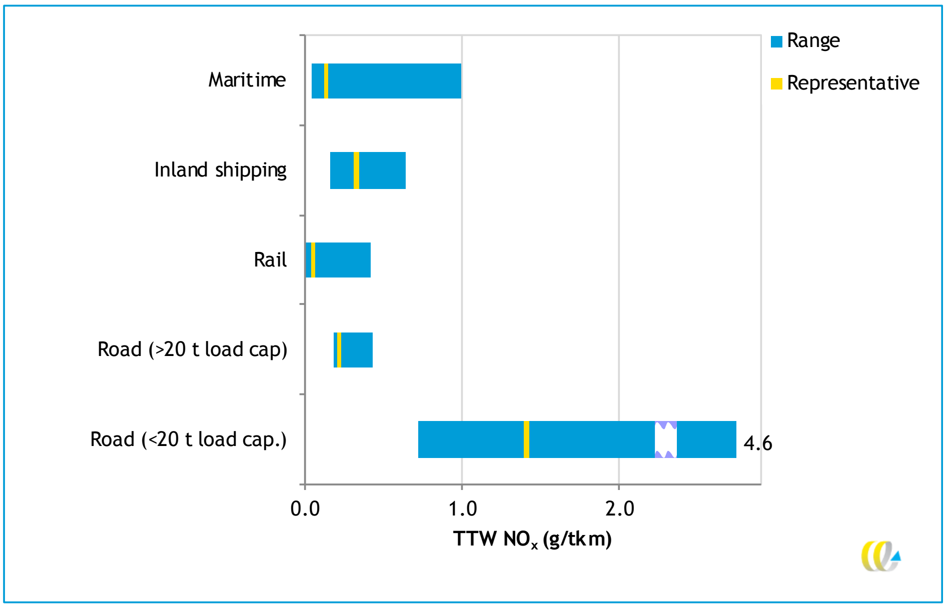
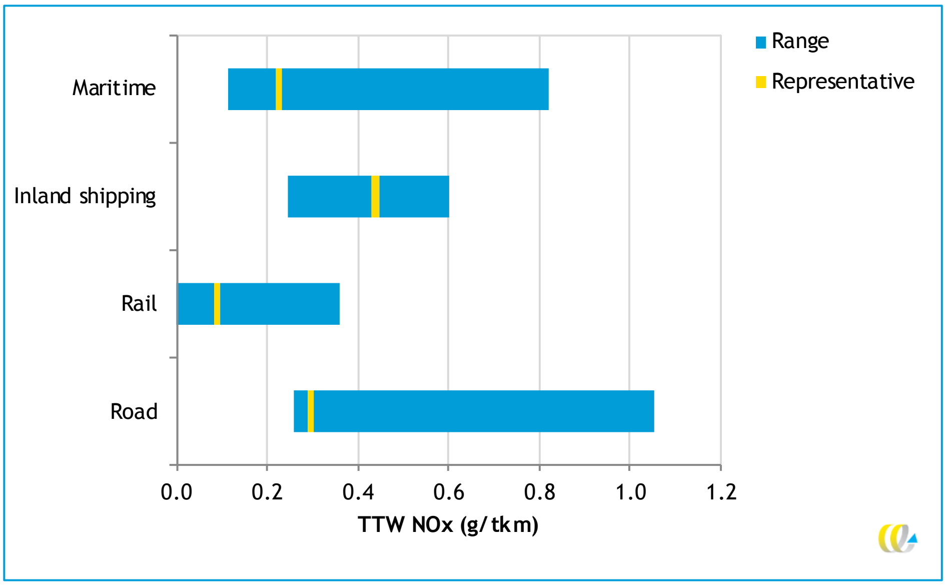


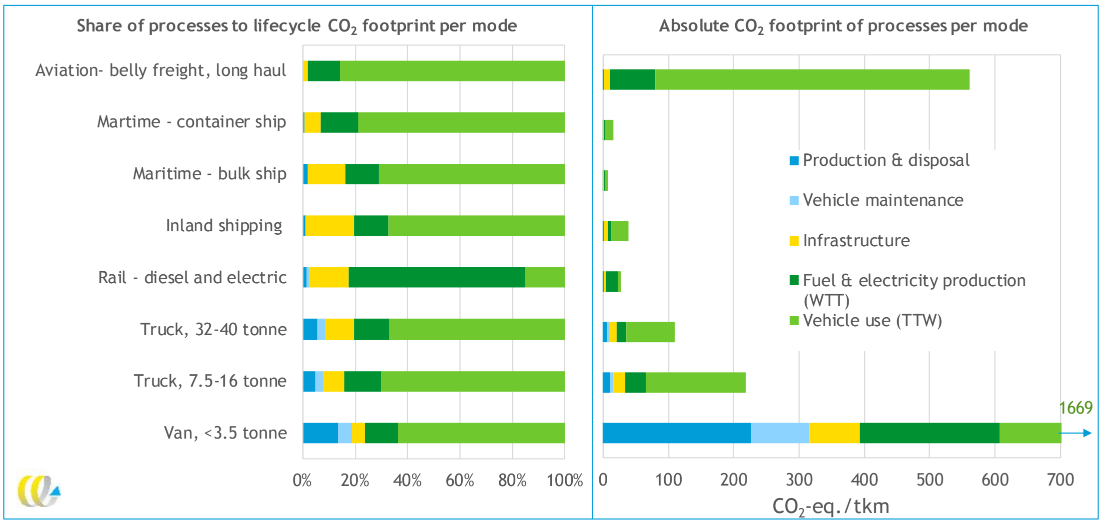
Figure 6 – Range of NO_x emission factors, container transport (TTW) (g/tkm)



2.4 Lifecycle emissions, including vehicle production and infrastructure

Chapter 7 discusses the emissions associated with infrastructure and vehicle production and maintenance, based on (Frischknecht, et al., 2016). Figure 7, below, shows how these emissions compare with TTW and WTT emissions. As can be seen, the TTW and WTT emissions - the core focus of *STREAM* - contribute the bulk of the overall, lifecycle CO_2 footprint: 80-90%, while the emissions associated with infrastructure and vehicle production and maintenance generally account for 10-20%. For aviation the latter figure is even lower, since aircraft WTW emissions are relatively high. For vans the figure is slightly higher, owing to the relatively high impact of vehicle production relative to the tonne-km during the vehicle's lifetime.

Figure 7 - Share of processes to lifecycle CO_2 footprint for each mode



Source: (Frischknecht, et al., 2016).

3 Detailed data per transport mode

3.1 Introduction

Compared with the data presented in Section 2.2, this chapter reports more far detailed emission factors per tonne-kilometre, distinguishing several road and waterway classes and providing insight into the full range of WTT emissions. A separate section is devoted to each transport mode, split into two subsections.

In the first, the fleet-average emission factors are given for bulk and packaged cargo, distinguishing between:
- light transport: appliances, furniture, mail, textiles, shaped products and suchlike (approx. <0.4 kg/litre loading area);
- medium-weight transport: food products, timber, paper, plastics, chemicals, metal products, cars, waste (approx. 0.4-1.3 kg/litre loading area);
- heavy transport: ores, minerals, coal, coke, oil (typically for liquids and load >1.3 kg/litre).

For aviation no distinction is made with regard to weight class. The emission factors are reported under ‘light transport’.

The second subsection gives the emission factors for container transport, again distinguishing three weight categories:
- light containers: 6 t/TEU[10];
- medium-weight containers: 10.5 t/TEU;
- heavy containers: 14 t/TEU.

In the tables, medium-weight transport is presented first, followed by light and then heavy transport. This has been done so the emissions factors for light transport are not read first, since these are less representative.

Inland and maritime shipping vessels as well as trains will usually be transporting a mix of light, medium-weight and heavy containers, with the average loaded container weighing 10.5 t/TEU. The emission factors for light and heavy containers are intended mainly for calculating emissions for a specific container load.

Besides the emission factors, the tables also report the capacity utilisation[11] and average load for the vehicle/vessel most representative of the transport category.

For each transport mode, a third subsection provides percentage indices for calculating how alternative fuels and technologies compare with the relevant baseline in terms of energy consumption and CO_2, PM_c and NO_x emissions. In each case an index is also given for the 2018 average (as reported in the main tables), allowing the emission factors for the alternative to be calculated from:

$$EF_{tkm-\,alt} = \frac{index_{alt}}{index_{2018\,av}} \times EF_{tkm-2018\,av}$$

[10] Unit of container size: Twenty-foot Equivalent Unit.

[11] Capacity utilisation is given by the load factor on a laden vehicle-km times the proportion of laden vehicle-km.

Where EF_{tkm} is the emission factor per tonne-km.

Although the emission factors reported in this chapter are extremely detailed, for any specific trip they make no allowance for the effects of weather conditions, driving style, specific speed and so on.

For vans, Subsection 3.2.1 reports emission factors per *tonne-km* that are representative for vehicles used for freight transport. In Subsection 3.2.3 emission factors per *vehicle-km* are additionally given for a broader category of vans. The reasoning behind this is that many vans are not used specifically for freight carriage (but in the construction or services industry), where a factor per tonne-km is not relevant.

3.2 Road transport

3.2.1 Fleet-average data for road transport of bulk/packaged goods

Table 4 – Emission factors per tkm, TTW and WTW, road transport, medium load, bulk/packaged goods, 2018

Vehicle cat.	Load	MJ/	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
/Road class	cap. (t)	tkm	CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Van, EW 2,000-2,500 kg												
Average	1.2	9.4	649.7	0.0039	0.050	2.8	0.044	857.3	0.89	0.08	3.10	0.044
Urban	1.2	10.4	721.2	0.0044	0.048	3.2	0.073	951.7	0.99	0.09	3.56	0.073
Rural	1.2	7.8	537.5	0.0032	0.030	2.4	0.037	709.2	0.73	0.06	2.64	0.037
Motorway	1.2	10.1	697.1	0.0042	0.062	2.9	0.039	919.8	0.95	0.10	3.24	0.039
Truck, GVW <10 t, no trailer												
Average	3.0	4.0	275.1	0.0017	0.026	2.738	0.067	362.7	0.375	0.040	2.87	0.067
Urban	3.0	5.4	376.3	0.0023	0.039	4.041	0.099	496.3	0.513	0.059	4.22	0.099
Rural	3.0	3.7	254.9	0.0015	0.025	2.450	0.052	336.1	0.347	0.038	2.57	0.052
Motorway	3.0	3.3	231.5	0.0014	0.020	2.191	0.057	305.3	0.316	0.032	2.30	0.057
Truck, GVW 10-20 t, no trailer												
Average	7.5	2.8	194.2	0.0012	0.015	1.404	0.026	256.1	0.265	0.025	1.50	0.026
Urban	7.5	4.0	279.0	0.0017	0.024	2.271	0.037	367.9	0.380	0.038	2.40	0.037
Rural	7.5	2.7	186.1	0.0011	0.014	1.208	0.020	245.4	0.254	0.024	1.30	0.020
Motorway	7.5	2.2	156.4	0.0009	0.011	1.053	0.022	206.2	0.213	0.019	1.13	0.022
Truck, GVW 10-20 t, with trailer												
Average	18.0	1.5	104.0	0.0006	0.010	0.768	0.012	136.9	0.141	0.015	0.82	0.012
Urban	18.0	2.2	152.8	0.0009	0.015	1.208	0.017	201.1	0.207	0.023	1.28	0.017
Rural	18.0	1.4	98.7	0.0006	0.009	0.698	0.009	129.8	0.133	0.014	0.74	0.009
Motorway	18.0	1.2	83.1	0.0005	0.007	0.588	0.010	109.4	0.112	0.012	0.63	0.010
Truck, GVW >20 t, no trailer												
Average	13.0	2.1	149.4	0.0009	0.007	0.975	0.015	196.6	0.202	0.015	1.04	0.015
Urban	13.0	3.4	237.6	0.0014	0.013	1.746	0.024	312.6	0.321	0.025	1.86	0.024
Rural	13.0	2.3	158.3	0.0009	0.008	1.117	0.013	208.3	0.214	0.016	1.19	0.013
Motorway	13.0	1.9	130.6	0.0008	0.006	0.785	0.014	171.8	0.176	0.013	0.85	0.014
Truck, GVW >20 t, with trailer												
Average	28.0	1.1	80.0	0.0005	0.002	0.286	0.007	105.2	0.108	0.006	0.32	0.007
Urban	28.0	2.0	137.6	0.0008	0.005	0.565	0.011	181.0	0.186	0.012	0.63	0.011
Rural	28.0	1.2	83.1	0.0005	0.002	0.331	0.006	109.3	0.112	0.007	0.37	0.006
Motorway	28.0	1.0	68.1	0.0004	0.002	0.218	0.007	89.6	0.092	0.005	0.25	0.007

Vehicle cat. /Road class	Load cap. (t)	MJ/ tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Tractor-semitrailer, light												
Average	15.7	1.9	135.5	0.0008	0.002	0.522	0.011	178.3	0.183	0.009	0.59	0.011
Urban	15.7	3.1	220.0	0.0013	0.005	1.185	0.018	289.4	0.297	0.017	1.29	0.018
Rural	15.7	2.2	151.5	0.0009	0.003	0.686	0.009	199.3	0.204	0.011	0.76	0.009
Motorway	15.7	1.8	124.3	0.0007	0.002	0.424	0.010	163.4	0.168	0.008	0.48	0.010
Tractor-semitrailer heavy												
Average	29.2	1.0	67.2	0.0004	0.002	0.215	0.004	88.4	0.091	0.005	0.25	0.004
Urban	29.2	1.9	135.6	0.0008	0.005	0.447	0.007	178.4	0.183	0.012	0.51	0.007
Rural	29.2	1.2	85.1	0.0005	0.003	0.266	0.004	111.9	0.115	0.007	0.31	0.004
Motorway	29.2	0.8	57.1	0.0003	0.002	0.184	0.004	75.1	0.077	0.005	0.21	0.004
LHV												
Average	40.8	0.9	64.9	0.0004	0.002	0.196	0.005	85.4	0.088	0.005	0.23	0.005
Urban	40.8	1.9	131.0	0.0008	0.004	0.407	0.007	172.3	0.177	0.011	0.47	0.007
Rural	40.8	1.2	82.2	0.0005	0.002	0.242	0.004	108.1	0.111	0.006	0.28	0.004
Motorway	40.8	0.8	55.6	0.0003	0.001	0.168	0.005	73.1	0.075	0.004	0.19	0.005

Table 5 - Emission factors per tkm, TTW and WTW, road transport, light load, bulk/packaged goods, 2018

Vehicle cat. /Road class	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Van, EW 2,000-2,500 kg												
Average	1.2	14.5	1005.1	0.0061	0.078	4.351	0.068	1326.3	1.374	0.129	4.83	0.068
Urban	1.2	16.1	1115.8	0.0067	0.075	5.017	0.113	1472.3	1.525	0.132	5.55	0.113
Rural	1.2	12.0	831.5	0.0050	0.047	3.722	0.057	1097.2	1.137	0.090	4.12	0.057
Motorway	1.2	15.6	1078.4	0.0065	0.097	4.540	0.061	1423.0	1.474	0.152	5.05	0.061
Truck, GVW <10 t, no trailer												
Average	3.0	6.5	452.8	0.0027	0.044	4.567	0.111	597.1	0.617	0.067	4.78	0.111
Urban	3.0	8.9	619.5	0.0037	0.065	6.748	0.163	816.9	0.845	0.097	7.04	0.163
Rural	3.0	6.0	419.6	0.0025	0.041	4.087	0.086	553.3	0.572	0.063	4.29	0.086
Motorway	3.0	5.5	381.2	0.0023	0.033	3.651	0.095	502.6	0.519	0.053	3.83	0.095
Truck, GVW 10-20 t, no trailer												
Average	7.5	4.2	290.5	0.0018	0.023	2.134	0.039	383.1	0.396	0.038	2.27	0.039
Urban	7.5	6.0	417.3	0.0025	0.036	3.455	0.056	550.2	0.569	0.058	3.65	0.056
Rural	7.5	4.0	278.4	0.0017	0.021	1.835	0.030	367.1	0.380	0.035	1.97	0.030
Motorway	7.5	3.4	233.9	0.0014	0.017	1.600	0.033	308.4	0.319	0.029	1.71	0.033
Truck, GVW 10-20 t, with trailer												
Average	18.0	2.2	152.5	0.0009	0.014	1.156	0.017	200.6	0.206	0.022	1.23	0.017
Urban	18.0	3.2	224.0	0.0013	0.022	1.820	0.024	294.8	0.303	0.034	1.92	0.024
Rural	18.0	2.1	144.6	0.0009	0.014	1.050	0.013	190.3	0.195	0.021	1.12	0.013
Motorway	18.0	1.7	121.9	0.0007	0.011	0.884	0.015	160.3	0.165	0.017	0.94	0.015
Truck, GVW >20 t, no trailer												
Average	13.0	3.2	221.9	0.0013	0.011	1.479	0.022	292.0	0.300	0.022	1.58	0.022
Urban	13.0	5.0	352.9	0.0021	0.019	2.652	0.035	464.2	0.476	0.037	2.82	0.035
Rural	13.0	3.3	235.1	0.0014	0.011	1.697	0.019	309.3	0.317	0.023	1.81	0.019
Motorway	13.0	2.8	193.9	0.0012	0.009	1.190	0.021	255.1	0.262	0.019	1.28	0.021
Truck, GVW >20 t, with trailer												
Average	28.0	1.6	115.7	0.0007	0.004	0.434	0.011	152.2	0.156	0.009	0.49	0.011
Urban	28.0	2.8	199.1	0.0012	0.007	0.858	0.016	261.9	0.268	0.017	0.95	0.016
Rural	28.0	1.7	120.3	0.0007	0.004	0.503	0.009	158.2	0.162	0.010	0.56	0.009

Vehicle cat. /Road class	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Motorway	28.0	1.4	98.6	0.0006	0.003	0.330	0.010	129.7	0.133	0.008	0.38	0.010
Tractor-semitrailer, light												
Average	15.7	2.8	197.3	0.0012	0.004	0.784	0.016	259.5	0.266	0.014	0.88	0.016
Urban	15.7	4.6	320.4	0.0019	0.008	1.780	0.026	421.4	0.432	0.024	1.93	0.026
Rural	15.7	3.1	220.6	0.0013	0.004	1.030	0.014	290.1	0.298	0.016	1.13	0.014
Motorway	15.7	2.6	180.9	0.0011	0.003	0.637	0.015	238.0	0.244	0.012	0.72	0.015
Tractor-semitrailer heavy												
Average	29.2	1.4	96.6	0.0006	0.003	0.326	0.006	127.0	0.130	0.008	0.37	0.006
Urban	29.2	2.8	194.9	0.0012	0.007	0.678	0.010	256.3	0.263	0.017	0.77	0.010
Rural	29.2	1.7	122.3	0.0007	0.004	0.403	0.006	160.9	0.165	0.010	0.46	0.006
Motorway	29.2	1.2	82.1	0.0005	0.002	0.278	0.006	107.9	0.111	0.007	0.32	0.006
LHV												
Average	40.8	1.3	93.4	0.0006	0.003	0.302	0.007	122.8	0.126	0.007	0.35	0.007
Urban	40.8	2.7	188.3	0.0011	0.006	0.627	0.011	247.6	0.254	0.016	0.72	0.011
Rural	40.8	1.7	118.2	0.0007	0.003	0.373	0.006	155.4	0.159	0.009	0.43	0.006
Motorway	40.8	1.1	79.3	0.0005	0.002	0.257	0.007	104.3	0.107	0.006	0.29	0.007

Table 6 - Emission factors per tkm, TTW and WTW, road transport, heavy load, bulk/packaged goods, 2018

Vehicle cat. /Road class	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Truck, GVW 10-20 t, no trailer												
Average	7.5	2.6	182.9	0.0016	0.01	1.3	0.024	241.1	0.25	0.02	1.40	0.024
Urban	7.5	3.8	262.6	0.0023	0.02	2.1	0.035	346.3	0.36	0.04	2.26	0.035
Rural	7.5	2.5	175.2	0.0015	0.01	1.1	0.019	231.1	0.24	0.02	1.22	0.019
Motorway	7.5	2.1	147.2	0.0013	0.01	1.0	0.021	194.1	0.20	0.02	1.06	0.021
Truck, GVW 10-20 t, with trailer												
Average	18.0	1.4	98.3	0.0008	0.01	0.7	0.011	129.3	0.13	0.01	0.77	0.011
Urban	18.0	2.1	144.4	0.0012	0.01	1.1	0.016	190.1	0.20	0.02	1.20	0.016
Rural	18.0	1.3	93.2	0.0008	0.01	0.7	0.009	122.7	0.13	0.01	0.70	0.009
Motorway	18.0	1.1	78.6	0.0007	0.01	0.6	0.009	103.4	0.11	0.01	0.59	0.009
Truck, GVW >20 t, no trailer												
Average	13.0	2.0	140.9	0.0012	0.01	0.9	0.014	185.3	0.19	0.01	0.98	0.014
Urban	13.0	3.2	224.0	0.0019	0.01	1.6	0.022	294.7	0.30	0.02	1.74	0.022
Rural	13.0	2.1	149.2	0.0013	0.01	1.0	0.012	196.3	0.20	0.01	1.12	0.012
Motorway	13.0	1.8	123.1	0.0011	0.01	0.7	0.014	161.9	0.17	0.01	0.79	0.014
Truck, GVW >20 t, with trailer												
Average	28.0	1.1	75.8	0.0007	0.00	0.3	0.007	99.7	0.10	0.01	0.30	0.007
Urban	28.0	1.9	130.4	0.0011	0.00	0.5	0.011	171.5	0.18	0.01	0.59	0.011
Rural	28.0	1.1	78.7	0.0007	0.00	0.3	0.006	103.6	0.11	0.01	0.35	0.006
Motorway	28.0	0.9	64.6	0.0006	0.00	0.2	0.007	84.9	0.09	0.01	0.23	0.007
Tractor-semitrailer, light												
Average	15.7	1.9	130.6	0.0011	0.00	0.5	0.010	171.8	0.18	0.01	0.56	0.010
Urban	15.7	3.0	212.1	0.0018	0.01	1.1	0.017	279.0	0.29	0.02	1.24	0.017
Rural	15.7	2.1	146.0	0.0013	0.00	0.7	0.009	192.1	0.20	0.01	0.73	0.009
Motorway	15.7	1.7	119.8	0.0010	0.00	0.4	0.010	157.5	0.16	0.01	0.46	0.010
Trekker-semitrailer, heavy												
Average	29.2	0.9	64.3	0.0006	0.00	0.2	0.004	84.6	0.09	0.01	0.23	0.004
Urban	29.2	1.8	129.8	0.0011	0.00	0.4	0.007	170.8	0.18	0.01	0.49	0.007

Vehicle cat. /Road class	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Rural	29.2	1.2	81.5	0.0007	0.00	0.3	0.004	107.2	0.11	0.01	0.29	0.004
Motorway	29.2	0.8	54.7	0.0005	0.00	0.2	0.004	71.9	0.07	0.00	0.20	0.004
LHV												
Average	40.8	0.9	62.2	0.0005	0.00	0.2	0.004	81.8	0.08	0.00	0.21	0.004
Urban	40.8	1.8	125.4	0.0011	0.00	0.4	0.007	165.0	0.17	0.01	0.44	0.007
Rural	40.8	1.1	78.7	0.0007	0.00	0.2	0.004	103.6	0.11	0.01	0.27	0.004
Motorway	40.8	0.8	52.8	0.0005	0.00	0.2	0.004	69.5	0.07	0.00	0.18	0.004

3.2.2 Fleet-average data for road container transport

Table 7 - Emission factors per tkm, TTW and WTW, road transport, medium load, containers, 2018

Vehicle cat. /Road class	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Truck, GVW >20 t, no trailer												
Average	1	2.3	161.1	0.0010	0.008	1.055	0.016	211.9	0.217	0.016	1.13	0.016
Urban	1	3.6	256.2	0.0015	0.014	1.890	0.025	337.0	0.346	0.027	2.01	0.025
Rural	1	2.4	170.7	0.0010	0.008	1.209	0.014	224.5	0.230	0.017	1.29	0.014
Motorway	1	2.0	140.8	0.0008	0.006	0.849	0.015	185.2	0.190	0.014	0.92	0.015
Truck, GVW >20 t, with trailer												
Average	2	1.3	92.5	0.0006	0.003	0.333	0.008	121.6	0.125	0.007	0.38	0.008
Urban	2	2.3	159.1	0.0009	0.005	0.658	0.013	209.2	0.215	0.013	0.73	0.013
Rural	2	1.4	96.1	0.0006	0.003	0.386	0.007	126.4	0.130	0.008	0.43	0.007
Motorway	2	1.1	78.8	0.0005	0.002	0.253	0.008	103.6	0.106	0.006	0.29	0.008
Tractor-semitrailer, heavy												
Average	2	1.3	91.9	0.0005	0.003	0.303	0.006	120.9	0.124	0.008	0.35	0.006
Urban	2	2.6	185.6	0.0011	0.007	0.630	0.010	244.1	0.250	0.016	0.72	0.010
Rural	2	1.7	116.5	0.0007	0.004	0.374	0.005	153.2	0.157	0.009	0.43	0.005
Motorway	2	1.1	78.1	0.0005	0.002	0.259	0.006	102.8	0.105	0.006	0.30	0.006
LHV												
Average	3	1.2	82.8	0.0005	0.002	0.259	0.006	108.9	0.112	0.006	0.30	0.006
Urban	3	2.4	167.0	0.0010	0.005	0.539	0.009	219.6	0.225	0.014	0.62	0.009
Rural	3	1.5	104.8	0.0006	0.003	0.320	0.005	137.9	0.141	0.008	0.37	0.005
Motorway	3	1.0	70.3	0.0004	0.002	0.221	0.006	92.5	0.095	0.005	0.25	0.006

Table 8 - Emission factors per tkm, TTW and WTW, road transport, light load, containers, 2018

Vehicle cat. /Road class	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_v	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Truck, GVW >20 t, no trailer												
Average	1	3.4	238.1	0.0014	0.012	1.599	0.024	313.2	0.321	0.024	1.71	0.024
Urban	1	5.4	378.6	0.0023	0.021	2.867	0.038	498.1	0.511	0.040	3.04	0.038
Rural	1	3.6	252.2	0.0015	0.012	1.834	0.020	331.8	0.341	0.025	1.95	0.020
Motorway	1	3.0	208.0	0.0012	0.010	1.286	0.023	273.7	0.281	0.020	1.38	0.023
Truck,GVW >20 t, with trailer												
Average	2	1.9	132.5	0.0008	0.004	0.505	0.012	174.2	0.179	0.011	0.57	0.012
Urban	2	3.2	227.9	0.0014	0.008	0.999	0.018	299.7	0.307	0.019	1.11	0.018
Rural	2	2.0	137.7	0.0008	0.004	0.586	0.010	181.0	0.186	0.011	0.65	0.010
Motorway	2	1.6	112.9	0.0007	0.003	0.384	0.012	148.4	0.152	0.009	0.44	0.012

Vehicle cat. /Road class	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_v	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Tractor-semitrailer, heavy												
Average	2	1.9	131.3	0.0008	0.004	0.457	0.009	172.7	0.177	0.011	0.52	0.009
Urban	2	3.8	265.0	0.0016	0.010	0.950	0.014	348.5	0.357	0.023	1.07	0.014
Rural	2	2.4	166.3	0.0010	0.005	0.565	0.008	218.7	0.224	0.014	0.64	0.008
Motorway	2	1.6	111.6	0.0007	0.003	0.389	0.009	146.7	0.150	0.009	0.44	0.009
LHV												
Average	3	1.7	118.2	0.0007	0.003	0.397	0.008	155.5	0.159	0.009	0.45	0.008
Urban	3	3.4	238.4	0.0014	0.008	0.826	0.013	313.6	0.322	0.020	0.94	0.013
Rural	3	2.1	149.7	0.0009	0.004	0.491	0.007	196.8	0.202	0.012	0.56	0.007
Motorway	3	1.4	100.5	0.0006	0.003	0.339	0.008	132.1	0.135	0.008	0.39	0.008

Table 9 - Emission factors per tkm, TTW and WTW, road transport, heavy load, containers, 2018

Vehicle cat. /Road class	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Truck, GVW >20 t, no trailer												
Average	1	1.8	126.8	0.0008	0.01	0.8	0.013	166.9	0.17	0.01	0.87	0.013
Urban	1	2.9	201.7	0.0012	0.01	1.5	0.020	265.3	0.27	0.02	1.55	0.020
Rural	1	1.9	134.4	0.0008	0.01	0.9	0.011	176.8	0.18	0.01	0.99	0.011
Motorway	1	1.6	110.8	0.0007	0.00	0.7	0.012	145.8	0.15	0.01	0.71	0.012
Truck, GVW >20 t, with trailer												
Average	2	1.1	74.7	0.0004	0.00	0.3	0.007	98.2	0.10	0.01	0.29	0.007
Urban	2	1.8	128.5	0.0008	0.00	0.5	0.010	169.0	0.17	0.01	0.57	0.010
Rural	2	1.1	77.6	0.0005	0.00	0.3	0.006	102.0	0.10	0.01	0.33	0.006
Motorway	2	0.9	63.6	0.0004	0.00	0.2	0.007	83.7	0.09	0.00	0.23	0.007
Tractor-semitrailer, heavy												
Average	2	1.1	74.4	0.0004	0.00	0.2	0.005	97.9	0.10	0.01	0.27	0.005
Urban	2	2.1	150.2	0.0009	0.01	0.5	0.008	197.6	0.20	0.01	0.56	0.008
Rural	2	1.3	94.3	0.0006	0.00	0.3	0.004	124.0	0.13	0.01	0.33	0.004
Motorway	2	0.9	63.2	0.0004	0.00	0.2	0.005	83.2	0.09	0.01	0.23	0.005
LHV												
Average	3	1.0	67.0	0.0004	0.00	0.2	0.005	88.2	0.09	0.01	0.23	0.005
Urban	3	1.9	135.2	0.0008	0.00	0.4	0.008	177.8	0.18	0.01	0.47	0.008
Rural	3	1.2	84.8	0.0005	0.00	0.2	0.004	111.6	0.11	0.01	0.28	0.004
Motorway	3	0.8	56.9	0.0003	0.00	0.2	0.005	74.9	0.08	0.00	0.20	0.005

3.2.3 Per-kilometre data for vans

Table 10 - Emission factors *per vehiclekilometer*, TTW and WTW, vans, 2018

Vehicle cat. /Road class	Load cap. (t)	MJ/km	TTW emissions (g/km)					WTW emissions (g/km)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Van, EW <1,500 kg												
Average	0.7	2.3	160.8	0.0010	0.017	0.9	0.017	212.2	0.2	0.03	1.003	0.017
Urban	0.7	2.8	196.7	0.0012	0.016	1.1	0.028	259.5	0.3	0.03	1.155	0.028
Rural	0.7	2.0	136.2	0.0008	0.010	0.8	0.014	179.7	0.2	0.02	0.859	0.014
Motorway	0.7	2.4	165.2	0.0010	0.021	1.0	0.015	218.0	0.2	0.03	1.047	0.015

Vehicle cat. /Road class	Load cap. (t)	MJ/km	TTW emissions (g/km)					WTW emissions (g/km)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Van, EW 1,500-2,000 kg												
Average	1.1	3.1	213.9	0.0013	0.019	1.1	0.017	282.2	0.3	0.03	1.178	0.017
Urban	1.1	3.4	237.4	0.0014	0.018	1.2	0.028	313.3	0.3	0.03	1.354	0.028
Rural	1.1	2.6	176.9	0.0011	0.012	0.9	0.014	233.4	0.2	0.02	1.005	0.014
Motorway	1.1	3.3	229.4	0.0014	0.024	1.1	0.015	302.8	0.3	0.04	1.232	0.015
Van, EW 2,000-2,500 kg												
Average	1.1	3.6	249.3	0.0015	0.019	1.1	0.017	329.0	0.3	0.03	1.195	0.017
Urban	1.1	4.0	276.7	0.0017	0.019	1.2	0.028	365.2	0.4	0.03	1.373	0.028
Rural	1.1	3.0	206.2	0.0012	0.012	0.9	0.014	272.1	0.3	0.02	1.019	0.014
Motorway	1.1	3.9	267.5	0.0016	0.024	1.1	0.015	352.9	0.4	0.04	1.251	0.015
Van, EW >2,500 kg												
Average	0.7	4.3	299.5	0.0018	0.019	1.1	0.017	395.2	0.4	0.03	1.220	0.017
Urban	0.7	4.8	332.4	0.0020	0.019	1.2	0.028	438.7	0.5	0.04	1.401	0.028
Rural	0.7	3.6	247.7	0.0015	0.012	0.9	0.014	326.9	0.3	0.02	1.040	0.014
Motorway	0.7	4.6	316.6	0.0019	0.024	1.1	0.015	417.8	0.4	0.04	1.272	0.015

3.2.4 Alternative fuels and technologies

The following tables report percentage indices for alternative fuels and technologies, compared with Euro 6 and Euro VI vehicles. For the alternative technologies, the emission factors per tonne-km can be calculated from the fleet-average factors reported in previous sections using the formula in Section 3.1. The indices are with respect to the emission factors for the average road class and may differ for specific road types. The first row shows the emission factors *per kilometre* for Euro 6d/VI as a reference value. Unless indicated in footnotes to the table, the indices also hold for similar vehicle categories.

Table 11 – Indices for alternative fuels and technologies, vans, empty weight 2,000-2,500 kg (indexed to Euro 6d = 100)

Fuel/technology	MJ/km	TTW emissions (g/km)			WTW emissions (g/km)		
		CO_2-eq	PM_c	NO_x	CO_2-eq	PM_c	NO_x
Diesel, Euro 6d	3.5	245	0.002	0.14	325	0,014	0,26
Index of average 2018 diesel rel. to Euro 6							
Diesel, average 2018	102%	102%	1264%	751%	102%	223%	456%
Index (Euro 6 = 100)							
Diesel, Euro 5	102%	102%	100%	1020%	102%	100%	603%
Diesel, Euro 6a	100%	100%	100%	223%	100%	100%	167%
Diesel, Euro 6d	100%	100%	100%	100%	100%	100%	100%
Diesel, plug-in hybrid, Euro 6	88%*	76%	180%	80%	86%	95%	87%
GTL, Euro 6	100%	104%	100%	100%	104%	103%	103%
Biodiesel, Euro 6, 97% FAME-3% HVO	100%	1%	100%	100%	15%	211%	122%
HVO, Euro 6	100%	1%	100%	100%	11%	211%	122%
CNG, Euro 6	97%	84%	228%	41%	73%	27%	30%
BioCNG, Euro 6	97%	5%	228%	41%	29%	51%	43%
Electric, average mix	47%**	0%	0%	0%	70%	54%	61%
Electric, wind/solar	47%**	0%	0%	0%	2%	0%	0%
Hydrogen	71%	0%	0%	0%	80%	328%	127%
Hydrogen, electrolysis with wind/solar/hydroelectric	71%	0%	0%	0%	7%	0%	0%

* 76% of MJ diesel, 12% electric; ** Tends towards 41% in urban traffic. For small vans (<1.5 t) this factor is 35% relative to diesel and the other indices are also 75% of the value given.

Table 12 - Indices for alternative fuels and technologies, medium-weight trucks (indexed to Euro VI = 100)

		TTW emissions (g/km)			WTW emissions (g/km)		
Fuel/technology	**MJ/km**	**CO_2-eq**	**PM_c**	**NO_x**	**CO_2-eq**	**PM_c**	**NO_x**
Diesel, Euro VI	7.55	529	0.009	1.769	696	0,036	2,0
Index of average 2018 diesel rel. to Euro VI							
Diesel, average 2014	108%	108%	489%	232%	108%	203%	217%
Index (Euro VI = 100)							
Diesel, Euro V	112%	112%	135%	225%	112%	117%	211%
Diesel, Euro VI	100%	100%	100%	100%	100%	100%	100%
Diesel, plug-in hybrid, Euro VI	89%*	80%	80%	80%	94%	89%	83%
GTL, Euro VI	100%	103%	100%	100%	104%	104%	101%
Biodiesel, Euro VI, 97% FAME-3% HVO	100%	2%	100%	100%	16%	198%	107%
HVO, Euro VI	100%	2%	100%	100%	11%	198%	107%
CNG, Euro VI	112%	96%	100%	74%	84%	28%	67%
BioCNG, Euro VI	112%	6%	100%	74%	34%	52%	71%
LNG, Euro VI	112%	96%	100%	74%	91%	51%	76%
BioLNG, Euro VI	112%	6%	100%	74%	36%	52%	71%
Electric, average mix	47%**	0%	0%	0%	71%	46%	17%
Electric, wind/solar	47%**	0%	0%	0%	2%	0%	0%
Hydrogen	71%	0%	0%	0%	81%	284%	36%
Hydrogen, electrolysis with wind/solar/hydroelectric	71%	0%	0%	0%	7%	0%	0%

* 80% of MJ diesel, 9% electric.

** Tends towards 41% in urban traffic.

Table 13 - Indices for alternative fuels and technologies, light and heavy tractor-semitrailers (indexed to Euro VI = 100)

	TTW	TTW emissions (g/km)			WTW emissions (g/km)		
Fuel/technology	**MJ/km**	**CO_2-eq.**	**PM_c**	**NO_x**	**CO_2-eq.**	**PM_c**	**NO_x**
Diesel, Euro VI*	12.87	901	0.013	1.634	1186	0,059	2,1
Index of average 2018 diesel rel. to Euro VI							
Diesel, average 2018	99%	99%	211%	175%	99%	123%	159
Index (Euro VI = 100)							
Diesel, Euro V**	H: 95% L: 98%	H: 95% L: 98%	H:270% L:112%	H: 121% L: 216%	H: 95% L: 98%	H: 133% L: 102%	H: 116% L: 201%
Diesel, Euro VI	100%	100%	100%	100%	100%	100%	100%
Diesel, plug-in hybrid, Euro VI	91%***	80%	80%	100%	97%	91%	103%
GTL, Euro V	100%	103%	100%	100%	104%	104%	102%
Biodiesel, Euro VI, 97% FAME-3% HVO	100%	2%	100%	100%	16%	202%	111%
HVO, Euro VI	100%	2%	100%	100%	11%	202%	111%
LNG, Euro VI	113%	97%	100%	50%	91%	49%	58%
BioLNG, Euro VI	113%	6%	100%	50%	36%	50%	51%
Electric, average mix	47%****	0%	0%	0%	70%	48%	29%
Electric, wind/solar	47%****	0%	0%	0%	2%	0%	0%
Hydrogen	71%	0%	0%	0%	80%	294%	59%
Hydrogen, electrolysis with wind/solar/hydroelectric	71%	0%	0%	0%	7%	0%	0%

* The reference vehicle is a heavy tractor-semitrailer; the indices also hold for light tractor-semitrailers, unless a distinction is made (see **).

** Separate NO_x and PM_c indices for light (L) and heavy (H) tractor-semitrailers.

*** 80% of MJ is diesel, 11% electric.

**** Decreases towards 41% in urban traffic.

3.3 Rail transport

3.3.1 Fleet-average data for rail transport of bulk/packaged goods

Table 14 - Emission factors per tkm, TTW and WTW, rail transport, medium load, bulk/packaged goods, 2018

Train cat.	Load cap.(t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Train, electric (approx. 73%)												
Med.-length (2,182t GTW)	1,715	0.08	-	-	-	-	0.0050	10.4	0.003	0.00035	0.0074	0.0050
Long (2,619t GTW)	2,058	0.07	-	-	-	-	0.0047	9.9	0.003	0.00034	0.0070	0.0047
Extra-long (2,993t GTW)	2,352	0.07	-	-	-	-	0.0046	9.7	0.003	0.00033	0.0068	0.0046
Train, diesel (approx. 27%)												
Med.-length (1,182t GTW)	1,715	0.21	14.4	0.00009	0.0047	0.20	0.0049	19.0	0.020	0.00542	0.2116	0.0049
Long (2,619t GTW)	2,058	0.20	13.7	0.00009	0.0045	0.19	0.0047	18.1	0.019	0.00516	0.2015	0.0047
Extra-long (2,993t GTW)	2,352	0.19	13.4	0.00008	0.0044	0.19	0.0045	17.7	0.018	0.00504	0.1968	0.0045

Table 15 - Emission factors per tkm, TTW and WTW, rail transport, light load, bulk/packaged goods, 2018

Train cat.	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Train, electric (approx. 73%)												
Med.-length (816t GTW)	945	0.16	-	-	-	-	0.0086	21.3	0.077	0.00073	0.0158	0.0086
Long (979t GTW)	1,134	0.14	-	-	-	-	0.0085	19.0	0.069	0.00065	0.0141	0.0085
Extra-long (1,118t GTW)	1,296	0.13	-	-	-	-	0.0080	17.5	0.063	0.00060	0.0130	0.0080
Train, diesel (approx. 27%)												
Med.-length. (816t GTW)	945	0.43	29.5	0.00018	0.0103	0.42	0.0096	39.0	0.040	0.01184	0.4340	0.0096
Long (979t GTW)	1,134	0.38	26.4	0.00016	0.0092	0.38	0.0086	34.8	0.036	0.01057	0.3876	0.0086
Extra-long (1,118t GTW)	1,296	0.35	24.3	0.00015	0.0085	0.35	0.0079	32.1	0.033	0.00973	0.3568	0.0079

Table 16 - Emission factors per tkm, TTW and WTW, rail transport, heavy load, bulk/packaged goods, 2018

Train cat.	Freight type	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
				CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Train, elektric (approx. 73%)													
Med,-length (2,841t GTW)	Tank wagons	1,940	0.071	-	-	-	-	0.0046	9.6	0.035	0.00033	0.0071	0.0046
Long (3,267t GTW)	Tank wagons	2,231	0.069	-	-	-	-	0.0045	9.3	0.034	0.00032	0.0069	0.0045
Medium-length (3,618t GTW)	Coal/ore	2,485	0.068	-	-	-	-	0.0044	9.1	0.033	0.00031	0.0068	0.0044
Long (4,549t GTW)	Coal/ore	3,124	0.065	-	-	-	-	0.0042	8.8	0.032	0.00030	0.0065	0.0042
Train, diesel (approx. 27%)													
Med,-length (2,841t GTW)	Tank wagons	1,940	0.193	13.3	0.000	0.00465	0.1895	0.0043	17.6	0.018	0.00534	0.1958	0.0043
Long (3,267t GTW)	Tank wagons	2,231	0.188	13.0	0.000	0.00453	0.1845	0.0042	17.1	0.018	0.00520	0.1907	0.0042
Med,-length (3,618t GTW)	Coal/ore	2,485	0.183	12.6	0.000	0.00441	0.1798	0.0041	16.7	0.017	0.00507	0.1858	0.0041
Long (4,549t GTW)	Coal/ore	3,124	0.176	12.2	0.000	0.00425	0.1730	0.0040	16.1	0.017	0.00488	0.1788	0.0040

3.3.2 Fleet-average data for rail transport of containers

Table 17 - Emission factors per tkm, TTW and WTW, rail transport, medium load, containers, 2018

Train cat.	Load cap. (TEU)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Train, electric (approx. 73%)												
Long (1,270t GTW)	90	0.11	-	-	-	-	0.0070	14.6	0.004	0.00050	0.0104	0.0070
Extra-long (1,481t GTW)	105	0.10	-	-	-	-	0.0064	13.3	0.004	0.00045	0.0094	0.0064
Train, diesel (approx. 27%)												
Long (1,270t GTW)	90	0.29	20.3	0.00013	0.0066	0.29	0.0069	26.8	0.028	0.00763	0.2979	0.0069
Extra-long (1,481t GTW)	105	0.27	18.4	0.00012	0.0060	0.26	0.0063	24.3	0.025	0.00694	0.2707	0.0063

Table 18 - Emission factors per tkm, TTW and WTW, rail transport, light load, containers, 2018

Train cat.	Load cap. (TEU)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Train, electric (approx. 73%)												
Long (988t GTW)	88	0.18	-	-	-	-	0.0114	23.8	0.007	0.00081	0.0168	0.0114
Extra-long (1,123t GTW)	100	0.16	-	-	-	-	0.0105	22.0	0.007	0.00075	0.0156	0.0105
Train, diesel (approx. 27%)												
Long (988t GTW)	88	0.48	33.0	0.00021	0.0107	0.47	0.0112	43.5	0.045	0.01242	0.4846	0.0112
Extra-long (1,123t GTW)	100	0.44	30.5	0.00019	0.0099	0.43	0.0103	40.2	0.042	0.01147	0.4477	0.0103

Table 19 - Emission factors per tkm, TTW and WTW, rail transport, heavy load, containers, 2018

Train cat.	Load cap. (TEU)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Train, electric (approx. 73%)												
Long (1,595t GTW)	96	0.08	-	-	-	-	0.0052	10.8	0.003	0.00037	0.0077	0.0052
Extra-long (1,795t GTW)	108	0.07	-	-	-	-	0.0048	10.1	0.003	0.00034	0.0071	0.0048
Train, diesel (approx. 27%)												
Long (1,595t GTW)	96	0.22	15.0	0.00009	0.0049	0.21	0.0051	19.8	0.021	0.00565	0.2205	0.0051
Extra-long (1,795t GTW)	108	0.20	14.0	0.00009	0.0045	0.20	0.0047	18.4	0.019	0.00525	0.2050	0.0047

3.3.3 Alternative fuels and technologies

The following tables report percentage indices for alternative power supply for electric trains and for alternative fuels and technologies relative to a locomotive complying with the current emission standard, Stage IIIb. For the alternative technologies, the emission factors per tonne-km can be calculated from the fleet-average factors reported in previous sections using the formula in Section 3.1. The first row shows the emission factors *per megajoule* for electric trains (Table 20) and *per kWh engine power* (Table 21) as a reference.

Table 20 - Indices for alternative power supply and overhead wires (indexed to average 2018 power = 100)

Power supply/technology	TTW emissions (g/MJ_e)			WTW emissions (g/ MJ_e)		
	CO_2-eq.	PM_c	NO_x	CO_2-eq.	PM_c	NO_x
Electricity, average (g/kWh-electric)	0.0	0.0	0.0	134.9	0.005	0.096
Index rel. to average electricity						
Electricity, average	100%	100%	100%	100%	100%	100%
Electricity, renewable, Dutch mix (wind/solar only)	100%	100%	100%	3%	0%	0%
Electricity, renewable, Dutch mix (wind/solar/biomass)	100%	100%	100%	7%	36%	19%
Overhead wires, 3 kV (rel. to 1.5 kV)	100%	100%	100%	80%	80%	80%

Table 21 - Indices for alternative fuels and technologies, diesel locomotives (indexed to Stage IIIb = 100)

Fuel/technology	TTW	TTW emissions (g/kWh*)			WTW emissions (g/kWh*)		
	MJ fuel/kWh*	CO_2-eq.	PM_c	NO_x	CO_2-eq.	PM_c	NO_x
Stage IIIb	8.8	608	0.025	4.000	802	0.06	4.29
Index t.o.v. Stage IIIb							
Stage IIIb	100%	100%	100%	100%	100%	100%	100%
Average 2018	100%	100%	763%	209%	100%	394%	201%
Stage V	100%	100%	100%	95%	100%	100%	96%
Stage IIIb HVO	100%	1%	80%	90%	11%	163%	94%

* Per kWh engine power, as per emission standards.

3.4 Inland shipping

3.4.1 Fleet-average data for inland-waterway transport of bulk/packaged goods

Table 22 - Emission factors per tkm, TTW and WTW, inland shipping, medium load, bulk/packaged goods, 2018

Vessel/ Waterway	Load cap.(t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Spits												
CEMT I	365	0.26	18.19	0.00011	0.015	0.27	0	23.97	0.025	0.016	0.28	0
CEMT Va	365	0.32	22.27	0.00013	0.016	0.32	0	29.35	0.030	0.017	0.33	0
CEMT VIb	365	0.36	24.89	0.00015	0.017	0.36	0	32.81	0.034	0.019	0.37	0
Waal	365	0.43	29.84	0.00018	0.021	0.43	0	39.33	0.041	0.022	0.44	0
Campine vessel												
CEMT II	617	0.25	17.17	0.00010	0.012	0.26	0	22.63	0.023	0.013	0.27	0
CEMT Va	617	0.37	25.52	0.00015	0.016	0.37	0	33.63	0.035	0.017	0.38	0
CEMT VIb	617	0.45	31.07	0.00019	0.019	0.46	0	40.96	0.042	0.021	0.47	0
Waal	617	0.45	31.62	0.00019	0.020	0.47	0	41.67	0.043	0.021	0.48	0
Rhine-Herne canal vessel												
CEMT IV	1,537	0.26	18.13	0.00011	0.009	0.25	0	23.90	0.025	0.010	0.26	0
CEMT Va	1,537	0.28	19.36	0.00012	0.009	0.26	0	25.51	0.026	0.010	0.27	0
CEMT VIb	1,537	0.36	25.27	0.00015	0.012	0.35	0	33.31	0.034	0.013	0.36	0
Waal	1,537	0.42	28.95	0.00017	0.014	0.40	0	38.16	0.039	0.016	0.42	0
Large Rhine vessel												
CEMT Va	3,013	0.17	12.15	0.00007	0.008	0.18	0	16.02	0.017	0.008	0.18	0
CEMT VIb	3,013	0.25	17.17	0.00010	0.009	0.24	0	22.62	0.023	0.010	0.25	0
Waal	3,013	0.26	18.13	0.00011	0.010	0.26	0	23.89	0.025	0.011	0.27	0
Class Va + 1 Europa II barge, wide												
CEMT VIb	5,046	0.33	22.68	0.00014	0.009	0.30	0	29.89	0.031	0.010	0.31	0
Waal	5,046	0.28	19.46	0.00012	0.008	0.26	0	25.65	0.026	0.009	0.27	0
4-barge push convoy												
CEMT VIb	11,181	0.17	12.07	0.00007	0.004	0.15	0	15.95	0.016	0.005	0.15	0
Waal	11,181	0.22	15.33	0.00009	0.005	0.19	0	20.23	0.021	0.006	0.20	0
6-barge push convoy, wide												
CEMT VIb	16,481	0.23	16.09	0.00010	0.005	0.20	0	21.21	0.022	0.006	0.20	0
Waal	16,481	0.18	12.56	0.00008	0.004	0.16	0	16.56	0.017	0.005	0.16	0

Table 23 - Emission factors per tkm, TTW and WTW, inland shipping, light load, bulk/packaged goods, 2018

Vessel/ Waterway	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Spits												
CEMT I	365	0.30	20.78	0.00013	0.020	0.34	0	27.39	0.028	0.021	0.35	0
CEMT Va	365	0.40	27.57	0.00017	0.021	0.40	0	36.34	0.038	0.022	0.41	0
CEMT VIb	365	0.46	32.14	0.00019	0.023	0.46	0	42.36	0.044	0.025	0.47	0
Waal	365	0.54	37.36	0.00022	0.026	0.54	0	49.24	0.051	0.028	0.56	0
Campine vessel												
CEMT II	617	0.28	19.55	0.00012	0.015	0.30	0	25.77	0.027	0.016	0.31	0
CEMT Va	617	0.46	31.84	0.00019	0.020	0.46	0	41.97	0.043	0.021	0.47	0
CEMT VIb	617	0.57	39.74	0.00024	0.025	0.59	0	52.38	0.054	0.027	0.60	0
Waal	617	0.62	43.00	0.00026	0.027	0.64	0	56.67	0.059	0.029	0.66	0

Vessel/ Waterway	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Rhine-Herne canal vessel												
CEMT IV	1,537	0.31	21.67	0.00013	0.012	0.31	0	28.56	0.029	0.013	0.32	0
CEMT Va	1,537	0.34	23.75	0.00014	0.012	0.33	0	31.30	0.032	0.013	0.34	0
CEMT VIb	1,537	0.48	33.28	0.00020	0.016	0.46	0	43.86	0.045	0.018	0.47	0
Waal	1,537	0.55	38.38	0.00023	0.018	0.54	0	50.58	0.052	0.020	0.55	0
Large Rhine vessel												
CEMT Va	3,013	0.22	15.08	0.00009	0.011	0.24	0	19.87	0.021	0.012	0.25	0
CEMT VIb	3,013	0.33	22.81	0.00014	0.013	0.32	0	30.06	0.031	0.014	0.33	0
Waal	3,013	0.36	24.85	0.00015	0.014	0.35	0	32.75	0.034	0.015	0.36	0
Class Va + 1 Europa II barge, wide												
CEMT VIb	5,046	0.40	27.91	0.00017	0.011	0.37	0	36.79	0.038	0.012	0.38	0
Waal	5,046	0.37	25.81	0.00016	0.010	0.34	0	34.02	0.035	0.011	0.36	0
4-barge push convoy												
CEMT VIb	11,181	0.21	14.37	0.00009	0.005	0.18	0	18.94	0.020	0.006	0.18	0
Waal	11,181	0.29	20.00	0.00012	0.007	0.25	0	26.36	0.027	0.008	0.26	0
6-barge push convoy, wide												
CEMT VIb	16,481	0.37	25.81	0.00016	0.008	0.31	0	34.02	0.035	0.010	0.33	0
Waal	16,481	0.25	17.38	0.00010	0.006	0.21	0	22.91	0.024	0.007	0.22	0

Table 24 – Emission factors per tkm, TTW and WTW, inland shipping, heavy load, bulk/packaged goods, 2018

Vessel/ Waterway	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Spits												
CEMT I	365	0.30	20.62	0.00012	0.016	0.30	0	27.18	0.028	0.017	0.31	0
CEMT Va	365	0.33	22.71	0.00014	0.016	0.32	0	29.93	0.031	0.017	0.33	0
CEMT VIb	365	0.37	25.54	0.00015	0.018	0.37	0	33.66	0.035	0.019	0.38	0
Waal	365	0.44	30.39	0.00018	0.021	0.44	0	40.06	0.041	0.023	0.46	0
Campibe vessel												
CEMT II	617	0.26	18.19	0.00011	0.014	0.28	0	23.97	0.025	0.014	0.29	0
CEMT Va	617	0.37	26.03	0.00016	0.016	0.38	0	34.30	0.035	0.018	0.39	0
CEMT VIb	617	0.45	31.18	0.00019	0.019	0.46	0	41.09	0.042	0.021	0.47	0
Waal	617	0.46	31.98	0.00019	0.020	0.47	0	42.15	0.044	0.022	0.49	0
Rhine-Herne canal vessel												
CEMT IV	1,537	0.27	18.91	0.00011	0.010	0.26	0	24.93	0.026	0.011	0.27	0
CEMT Va	1,537	0.28	19.85	0.00012	0.010	0.27	0	26.16	0.027	0.011	0.28	0
CEMT VIb	1,537	0.37	25.98	0.00016	0.012	0.36	0	34.25	0.035	0.014	0.37	0
Waal	1,537	0.41	28.57	0.00017	0.014	0.40	0	37.66	0.039	0.015	0.41	0
Large Rhine vessel												
CEMT Va	3,013	0.18	12.74	0.00008	0.008	0.18	0	16.79	0.017	0.008	0.19	0
CEMT VIb	3,013	0.25	17.57	0.00011	0.010	0.25	0	23.16	0.024	0.011	0.25	0
Waal	3,013	0.26	18.12	0.00011	0.010	0.26	0	23.88	0.025	0.011	0.27	0
Class Va + 1 Europa II barge, wide												
CEMT VIb	5,046	0.34	23.87	0.00014	0.009	0.32	0	31.46	0.032	0.011	0.33	0
Waal	5,046	0.29	19.90	0.00012	0.008	0.26	0	26.22	0.027	0.009	0.27	0

Vessel/ Waterway	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
4-barge push convoy												
CEMT VIb	11,181	0.18	12.61	0.00008	0.004	0.16	0	16.63	0.017	0.005	0.16	0
Waal	11,181	0.22	15.08	0.00009	0.005	0.19	0	19.87	0.021	0.006	0.19	0
6-barge push convoy, wide												
CEMT VIb	16,481	0.21	14.52	0.00009	0.005	0.18	0	19.14	0.020	0.006	0.19	0
Waal	16,481	0.19	13.07	0.00008	0.004	0.16	0	17.23	0.018	0.005	0.17	0

3.4.2 Fleet-average data for inland-waterway container transport

Table 25 - Emission factors per tkm, TTW and WTW, inland shipping, medium load, containers, 2018

Vessel/ Waterw.	Load cap. (TEU)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Neo Kemp (32-48 TEU)												
CEMT III	40	0.24	17.04	0.00011	0.014	0.27	0	22.46	0.023	0.014	0.28	0
CEMT Va	40	0.43	29.77	0.00019	0.018	0.43	0	39.24	0.041	0.020	0.44	0
CEMT VIb	40	0.52	36.34	0.00023	0.023	0.53	0	47.90	0.050	0.025	0.55	0
Waal	40	0.58	40.68	0.00026	0.025	0.60	0	53.62	0.055	0.028	0.62	0
Rhine-Herne canal vessel (96 TEU)												
CEMT IV	96	0.32	22.29	0.00014	0.012	0.32	0	29.38	0.030	0.013	0.33	0
CEMT Va	96	0.35	24.27	0.00015	0.012	0.34	0	31.99	0.033	0.014	0.35	0
CEMT VIb	96	0.49	33.90	0.00021	0.016	0.47	0	44.67	0.046	0.018	0.48	0
Waal	96	0.56	39.29	0.00025	0.019	0.55	0	51.78	0.054	0.021	0.57	0
Europa IIa push convoy (160 TEU)												
CEMT Va	160	0.40	27.80	0.00017	0.010	0.35	0	36.65	0.038	0.011	0.36	0
CEMT VIb	160	0.56	38.93	0.00024	0.014	0.49	0	51.31	0.053	0.016	0.51	0
Waal	160	0.60	41.67	0.00026	0.015	0.53	0	54.92	0.057	0.017	0.55	0
Large Rhine vessel (208 TEU)												
CEMT Va	208	0.22	15.03	0.00009	0.010	0.22	0	19.81	0.020	0.010	0.23	0
CEMT VIb	208	0.32	22.43	0.00014	0.012	0.31	0	29.57	0.031	0.013	0.32	0
Waal	208	0.35	24.16	0.00015	0.013	0.34	0	31.85	0.033	0.015	0.35	0
Extended Large Rhine vessel (272 TEU)												
CEMT Va	272	0.25	17.46	0.00011	0.008	0.24	0	23.01	0.024	0.009	0.25	0
CEMT VIb	272	0.31	21.83	0.00014	0.009	0.29	0	28.78	0.030	0.010	0.30	0
Waal	272	0.30	20.83	0.00013	0.008	0.27	0	27.45	0.028	0.009	0.28	0
Coupled: Europa II-C3l (348 TEU)												
CEMT Vb	348	0.21	14.75	0.00009	0.007	0.20	0	19.44	0.020	0.007	0.21	0
CEMT VIb	348	0.31	21.34	0.00013	0.008	0.28	0	28.12	0.029	0.009	0.29	0
Waal	348	0.29	20.40	0.00013	0.008	0.27	0	26.89	0.028	0.009	0.28	0
Rhinemax vessel (398-470 TEU)												
CEMT VIb	434	0.29	20.48	0.00013	0.008	0.26	0	26.99	0.028	0.009	0.27	0
Waal	434	0.27	18.72	0.00012	0.007	0.24	0	24.67	0.026	0.008	0.25	0

Table 26 - Emission factors per tkm, TTW and WTW, inland shipping, light load, containers, 2018

Vessel /	Load cap.		TTW emissions (g/tkm)					WTW emissions (g/tkm)				
Waterw.	(TEU)	MJ/tkm	CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Neo Kemp (32-48 TEU)												
CEMT III	40	0.34	23.39	0.00014	0.020	0.39	0	30.83	0.032	0.021	0.40	0
CEMT Va	40	0.61	42.69	0.00026	0.027	0.61	0	56.27	0.058	0.029	0.63	0
CEMT VIb	40	0.77	53.39	0.00032	0.033	0.78	0	70.37	0.073	0.036	0.81	0
Waal	40	0.86	59.72	0.00036	0.038	0.88	0	78.72	0.081	0.041	0.91	0
Rhine-Herne canal vessel (96 TEU)												
CEMT IV	96	0.45	31.43	0.00019	0.017	0.45	0	41.42	0.043	0.019	0.47	0
CEMT Va	96	0.51	35.81	0.00022	0.020	0.51	0	47.20	0.049	0.022	0.53	0
CEMT VIb	96	0.74	51.81	0.00031	0.025	0.71	0	68.29	0.070	0.027	0.73	0
Waal	96	0.87	60.29	0.00036	0.029	0.84	0	79.46	0.082	0.032	0.87	0
Europa IIa push convoy (160 TEU)												
CEMT Va	160	0.53	37.06	0.00022	0.014	0.47	0	48.85	0.050	0.016	0.49	0
CEMT VIb	160	0.79	55.05	0.00033	0.019	0.69	0	72.56	0.075	0.022	0.71	0
Waal	160	0.85	58.89	0.00035	0.021	0.75	0	77.62	0.080	0.024	0.78	0
Large Rhine vessel (208 TEU)												
CEMT Va	208	0.31	21.71	0.00013	0.017	0.35	0	28.62	0.030	0.018	0.36	0
CEMT VIb	208	0.49	33.91	0.00020	0.019	0.47	0	44.70	0.046	0.021	0.49	0
Waal	208	0.54	37.62	0.00023	0.021	0.53	0	49.58	0.051	0.023	0.55	0
Extended Large Rhine vessel (272 TEU)												
CEMT Va	272	0.36	24.73	0.00015	0.014	0.38	0	32.59	0.034	0.015	0.39	0
CEMT VIb	272	0.47	32.74	0.00020	0.014	0.44	0	43.15	0.045	0.015	0.45	0
Waal	272	0.46	32.32	0.00019	0.013	0.43	0	42.60	0.044	0.015	0.44	0
Coupled: Europa II-C3l (348 TEU)												
CEMT Vb	348	0.29	20.32	0.00012	0.009	0.28	0	26.79	0.028	0.010	0.29	0
CEMT VIb	348	0.45	31.35	0.00019	0.012	0.41	0	41.32	0.043	0.014	0.42	0
Waal	348	0.45	31.09	0.00019	0.012	0.41	0	40.97	0.042	0.014	0.42	0
Rhinemax vessel (398-470 TEU)												
CEMT VIb	434	0.43	29.69	0.00018	0.011	0.38	0	39.13	0.040	0.013	0.39	0
Waal	434	0.41	28.52	0.00017	0.011	0.37	0	37.59	0.039	0.012	0.38	0

Table 27 - Emission factors per tkm, TTW and WTW, inland shipping, heavy load, containers, 2018

Vessel/	Load cap.		TTW emissions (g/tkm)					WTW emissions (g/tkm)				
Waterw.	(TEU)	MJ/tkm	CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Neo Kemp												
CEMT III	40	0.21	14.78	0.00009	0.010	0.22	0	19.48	0.020	0.011	0.23	0
CEMT Va	40	0.37	25.43	0.00015	0.016	0.37	0	33.51	0.035	0.017	0.38	0
CEMT VIb	40	0.44	30.40	0.00018	0.019	0.45	0	40.07	0.041	0.021	0.46	0
Waal	40	0.49	34.29	0.00021	0.021	0.50	0	45.20	0.047	0.023	0.52	0
Rhine-Herne canal vessel (96 TEU)												
CEMT IV	96	0.27	18.84	0.00011	0.010	0.26	0	24.82	0.026	0.011	0.27	0
CEMT Va	96	0.29	20.30	0.00012	0.010	0.28	0	26.76	0.028	0.011	0.29	0
CEMT VIb	96	0.39	27.46	0.00017	0.013	0.38	0	36.19	0.037	0.015	0.39	0
Waal	96	0.46	31.94	0.00019	0.015	0.45	0	42.10	0.043	0.017	0.46	0

Vessel/ Waterw.	Load cap. (TEU)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Europa IIa push convoy (160 TEU)												
CEMT Va	160	0.36	24.90	0.00015	0.009	0.31	0	32.81	0.034	0.010	0.32	0
CEMT VIb	160	0.48	33.26	0.00020	0.012	0.42	0	43.83	0.045	0.014	0.44	0
Waal	160	0.51	35.54	0.00021	0.013	0.45	0	46.84	0.048	0.014	0.47	0
Large Rhine vessel (208 TEU)												
CEMT Va	208	0.19	13.08	0.00008	0.008	0.19	0	17.24	0.018	0.009	0.20	0
CEMT VIb	208	0.26	18.26	0.00011	0.010	0.26	0	24.06	0.025	0.011	0.27	0
Waal	208	0.28	19.24	0.00012	0.011	0.28	0	25.36	0.026	0.012	0.28	0
Extended Large Rhine vessel (272 TEU)												
CEMT Va	272	0.22	15.07	0.00009	0.006	0.20	0	19.86	0.021	0.007	0.21	0
CEMT VIb	272	0.26	17.90	0.00011	0.007	0.23	0	23.59	0.024	0.008	0.24	0
Waal	272	0.24	16.55	0.00010	0.006	0.22	0	21.82	0.023	0.007	0.22	0
Coupled: Europa II-C3l (348 TEU)												
CEMT Vb	348	0.18	12.72	0.00008	0.005	0.17	0	16.76	0.017	0.006	0.18	0
CEMT VIb	348	0.25	17.42	0.00010	0.007	0.23	0	22.95	0.024	0.008	0.24	0
Waal	348	0.24	16.50	0.00010	0.006	0.22	0	21.75	0.022	0.007	0.23	0
Rhinemax vessel (398-470 TEU)												
CEMT VIb	434	0.25	17.25	0.00010	0.006	0.22	0	22.73	0.023	0.007	0.23	0
Waal	434	0.22	15.17	0.00009	0.006	0.20	0	20.00	0.021	0.006	0.21	0

3.4.3 Alternative fuels and technologies

The following tables report percentage indices for alternative fuels and technologies for inland shipping relative to vessels with a CCNR2 engine (the 2018 standard for new engines). For the alternative technologies, the emission factors per tonne-km can be calculated from the fleet-average factors reported in previous sections using the formula in Section 3.1. The first row gives the emission factors *per kWh engine power*, to which air-pollutant standards are referenced.

Table 28 - Indices for alternative fuels and technologies, inland shipping (indexed to CCNR2 = 100)

Fuel/technology	MJfuel/ kWh*	TTW emissions (g/kWh)			WTW emissions (g/kWh)		
		CO_2-eq.	PM_c	NO_x	CO_2-eq.	PM_c	NO_x
Diesel CCNR2 (g/kWh*)	8.0	597	0.2	7	775	0.23	7.26
Index of 2018 averages rel. to CCNR2							
Spits 2018	110%	110%	238%	140%	110%	222%	139%
Rhine-Herne canal vessel 2018	103%	103%	151%	122%	103%	145%	121%
Large Rhine vessel 2018	105%	105%	177%	129%	105%	168%	128%
Rhinemax vessel 2018	100%	100%	115%	110%	100%	113%	109%
Index of alternatives rel. to CCNR2							
Diesel CCNR2	100%	100%	100%	100%	100%	100%	100%
Stage V kW <300	103%	103%	50%	41%	102%	56%	44%
Stage V kW >300	95%	95%	8%	34%	96%	19%	37%
Diesel-electric CCNR2	100%	100%	100%	100%	100%	100%	100%
LNG, pilot <10% D	105%	104%	25%	25%	96%	26%	27%
LNG, dual-fuel, 20% D	105%	104%	50%	50%	96%	48%	51%
LNG, single-fuel, SI	105%	104%	10%	25%	96%	13%	27%
BioLNG, single-fuel, SI	105%	25%	10%	25%	47%	13%	58%
CCNR2 with HVO	100%	1%	80%	90%	11%	99%	91%

Fuel/technology	MJfuel/ kWh*	TTW emissions (g/kWh)			WTW emissions (g/kWh)		
		CO_2-eq.	PM_c	NO_x	CO_2-eq.	PM_c	NO_x
Stage V <300 kW met HVO	103%	1%	50%	41%	11%	73%	44%
Stage V >300 kW met HVO	95%	1%	8%	34%	10%	34%	37%
CCNR2 with GTL **	100%	96%	80%	90%	99%	83%	91%
CCNR2 with SCR **	100%	100%	90%	20%	100%	92%	24%
CCNR2 with DPF **	101%	100%	10%	100%	100%	25%	100%
CCNR2 with SCR/DPF **	101%	100%	10%	15%	100%	25%	19%

* Per kWh engine power, as per emission standards.

** These reduction percentages also hold when the alternative is used in a CCNR0 or CCNR1 engine compared with the engine without the measure. Few measurements on GTL are available; PM reduction varies from 15-60%.

3.5 Maritime shipping

As of 1 January 2020, maritime vessels must use low-sulphur diesel fuel (max. 0.5% S) or other means to reduce sulphur emissions by at least as much (e.g. scrubbers, LNG). Despite this not yet being in force in the reference year 2018, the following tables are based on fuels with max. 0.5% S, to reflect the current situation.

3.5.1 Fleet-average data for maritime shipping, bulk/packaged goods

Table 29 – Emission factors per tkm, TTW and WTW, maritime shipping, medium/heavy load, bulk/packaged goods, 2018*

Vessel category	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Bulk carrier												
0-4,999 dwt	4,450	0.37	28.3	0.053	0.0144	0.61	0	34.9	0.088	0.0155	0.63	0
5,000-9,999 dwt	8,005	0.23	17.8	0.034	0.0092	0.39	0	22.0	0.056	0.0099	0.40	0
10,000-34,999 dwt	28,385	0.09	7.0	0.013	0.0036	0.17	0	8.6	0.022	0.0039	0.17	0
35,000-59,999 dwt	42,731	0.07	5.3	0.010	0.0027	0.13	0	6.6	0.017	0.0030	0.13	0
60,000-99,999 dwt	80,379	0.05	4.0	0.008	0.0021	0.10	0	5.0	0.013	0.0022	0.10	0
100,000-199,999 dwt	170,075	0.04	2.9	0.005	0.0015	0.07	0	3.6	0.009	0.0016	0.07	0
200,000+ dwt	221,009	0.03	2.4	0.004	0.0012	0.06	0	2.9	0.007	0.0013	0.06	0
General cargo ship												
0-4,999 dwt	3,552	0.32	24.5	0.04 6	0.0126	0.60	0	30.3	0.077	0.0136	0.61	0
5,000-9,999 dwt	7,966	0.25	19.1	0.036	0.0098	0.42	0	23.6	0.060	0.0106	0.43	0
10,000-19,999 dwt	13,116	0.23	17.5	0.033	0.0090	0.40	0	21.7	0.055	0.0098	0.40	0
20,000+ dwt	30,528	0.13	10.3	0.019	0.0053	0.25	0	12.7	0.032	0.0057	0.25	0
Oil tanker												
0-4,999 dwt	3,357	0.40	31.0	0.059	0.0157	0.38	0	38.3	0.097	0.0170	0.39	0
5,000-9,999 dwt	7,428	0.38	29.6	0.056	0.0153	0.41	0	36.6	0.093	0.0165	0.42	0
10,000-19,999 dwt	15,262	0.24	18.8	0.036	0.0097	0.26	0	23.3	0.059	0.0105	0.27	0
20,000-59,999 dwt	43,288	0.11	8.2	0.015	0.0042	0.12	0	10.1	0.026	0.0046	0.13	0
60,000-79,999 dwt	73,202	0.07	5.1	0.010	0.0026	0.09	0	6.3	0.016	0.0028	0.09	0
80,000-119,999 dwt	110,775	0.06	4.6	0.009	0.0024	0.08	0	5.7	0.015	0.0026	0.08	0
120,000-199,999 dwt	157,137	0.05	3.5	0.007	0.0018	0.06	0	4.4	0.011	0.0020	0.07	0
200,000+ dwt	310,100	0.02	1.9	0.004	0.0010	0.04	0	2.3	0.006	0.0010	0.04	0

* SO_2 emissions based on use of low-sulphur fuel, as mandatory since 2020.

Table 30 – Emission factors per tkm, TTW and WTW, maritime shipping, light load, bulk/packaged goods, 2018*

Vessel category	Load cap. (t)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
General cargo ship												
0-4,999 dwt	3,552	0.53	40.6	0.077	0.0208	1.00	0	50.2	0.127	0.0225	1.02	0
5,000-9,999 dwt	7,662	0.44	34.0	0.064	0.0175	0.75	0	42.0	0.106	0.0190	0.76	0
10,000-19,999 dwt	13,987	0.33	25.8	0.049	0.0133	0.58	0	31.8	0.080	0.0144	0.59	0
20,000+ dwt	26,917	0.18	13.9	0.026	0.0072	0.33	0	17.2	0.043	0.0078	0.34	0

* SO_2 emissions based on use of low=sulphur fuel, as mandatory since 2020.

3.5.2 Fleet-average data, maritime shipping, containers

Table 31 – Emission factors per tkm, TTW and WTW, maritime shipping, medium load, containers, 2018*

Vessel category	Load cap. (TEU)	MJ/tkm	TTW emissions (g/tkm)									
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Container ship												
0-999 TEU	810	0.50	38.3	0.072	0.0198	0.82	0	47.4	0.120	0.0214	0.84	0
1,000-1,999 TEU	1,395	0.33	25.5	0.048	0.0132	0.57	0	31.5	0.080	0.0142	0.58	0
2,000-2,999 TEU	2,537	0.25	19.2	0.036	0.0099	0.44	0	23.7	0.060	0.0107	0.45	0
3,000-4,999 TEU	4,119	0.19	14.9	0.028	0.0077	0.36	0	18.5	0.047	0.0083	0.36	0
5,000-7,999 TEU	6,200	0.15	11.7	0.022	0.0061	0.29	0	14.5	0.037	0.0065	0.29	0
8,000-11,999 TEU	9,244	0.12	9.3	0.018	0.0048	0.23	0	11.5	0.029	0.0052	0.24	0
12,000-14,499 TEU	13,625	0.08	6.3	0.012	0.0033	0.16	0	7.8	0.020	0.0035	0.16	0
14,500-19,999 TEU	17,546	0.07	5.3	0.010	0.0027	0.13	0	6.5	0.016	0.0029	0.13	0
20,000+ TEU	20,563	0.06	4.7	0.009	0.0024	0.11	0	5.8	0.015	0.0026	0.11	0

* SO_2 emissions based on use of low=sulphur fuel, as mandatory since 2020.

Table 32 – Emission factors per tkm, TTW and WTW, maritime shipping, light load, containers, 2018*

Vessel category	Load cap. (TEU)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Container ship												
0-999 TEU	810	0.87	67.1	0.127	0.0346	1.44	0	82.9	0.210	0.0374	1.47	0
1,000-1,999 TEU	1,395	0.58	44.6	0.084	0.0230	1.00	0	55.1	0.139	0.0249	1.02	0
2,000-2,999 TEU	2,537	0.44	33.5	0.063	0.0173	0.78	0	41.4	0.105	0.0187	0.79	0
3,000-4,999 TEU	4,119	0.34	26.2	0.049	0.0135	0.62	0	32.3	0.082	0.0146	0.63	0
5,000-7,999 TEU	6,200	0.27	20.5	0.039	0.0106	0.51	0	25.4	0.064	0.0114	0.52	0
8,000-11,999 TEU	9,244	0.21	16.3	0.031	0.0084	0.41	0	20.2	0.051	0.0091	0.41	0
12,000-14,499 TEU	13,625	0.14	11.0	0.021	0.0057	0.27	0	13.7	0.035	0.0062	0.28	0
14,500-19,999 TEU	17,546	0.12	9.2	0.017	0.0048	0.23	0	11.4	0.029	0.0051	0.23	0
20,000+ TEU	20,563	0.11	8.2	0.016	0.0042	0.20	0	10.2	0.026	0.0046	0.20	0

* SO_2 emissions based on use of low-sulphur fuel, as mandatory since 2020.

Table 33 – Emission factors per tkn, TTW and WTW, maritime shipping, heavy load, containers, 2018*

Vessel category	Load cap. (TEU)	MJ/tkm	TTW emissions (g/tkm)					WTW emissions (g/tkm)				
			CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Container ship												
0-999 TEU	810	0.36	27.5	0.052	0.014	0.596	0	34.0	0.087	0.015	0.607	0
1,000-1,999 TEU	1,395	0.24	18.3	0.035	0.010	0.415	0	22.6	0.058	0.010	0.422	0
2,000-2,999 TEU	2,537	0.18	13.7	0.026	0.007	0.322	0	17.0	0.043	0.008	0.327	0
3,000-4,999 TEU	4,119	0.14	10.7	0.020	0.006	0.258	0	13.3	0.034	0.006	0.262	0
5,000-7,999 TEU	6,200	0.11	8.4	0.016	0.004	0.210	0	10.4	0.027	0.005	0.213	0
8,000-11,999 TEU	9,244	0.09	6.7	0.013	0.003	0.169	0	8.3	0.021	0.004	0.171	0
12,000-14,499 TEU	13,625	0.06	4.5	0.009	0.002	0.113	0	5.6	0.014	0.003	0.115	0
14,500-19,999 TEU	17,546	0.05	3.8	0.007	0.002	0.094	0	4.7	0.012	0.002	0.095	0
20,000+ TEU	20,563	0.04	3.4	0.006	0.002	0.081	0	4.2	0.011	0.002	0.083	0

* The reported SO_2 emissions are based on use of low=sulphur fuel, as mandatory since 2020.

3.5.3 Alternative fuels and technologies

The following tables report percentage indices for alternative fuels and technologies, compared with vessels with Tier II engines (the current standard) burning HFO/MDO with no more than 0.5% sulphur. For the alternative technologies, the emission factors per tonne-km can be calculated from the fleet-average factors reported in previous sections using the formula in Section 3.1. Specific average indices (I_{av}) can be used for the various categories of vessel (Bulk Carrier, General Cargo, etc.). The first row shows the emission factor *per kWh engine power* as a reference value.

Table 34 – Indices for alternative fuels and technologies, maritime shipping (indexed to Tier II = 100%)

Fuel/technology	MJ/kWh*	TTW emissions (g/kWh*)				WTW emissions (g/kWh*)			
		CO_2-eq.	PM_c	NO_x	SO_2	CO_2-eq.	PM_c	NO_x	SO_2
HFO/MDO (0.5% S) Tier II	7.8	601.7	0.3	11.2	1.8	743.7	0.3	11.5	2.5
Index of HFO/MDO (0.5% S), average rel. to HFO/MDO (0.5% S), Tier II									
HFO/MDO average 2018 (0,5% S)	100%	100%	100%	109%	100%	100%	100%	108%	100%
Bulk carrier, average	96%	96%	100%	120%	100%	96%	100%	119%	99%
General cargo ship, average	96%	96%	100%	117%	100%	96%	100%	116%	99%
Oil tanker, average	112%	112%	100%	95%	100%	112%	101%	95%	103%
Container ship, average	96%	96%	100%	118%	100%	96%	100%	118%	99%
Index of alternatives rel. to HFO/MDO (0.5% S), Tier II									
HFO/ MDO Tier II (0.5% S)	100%	100%	100%	100%	100%	100%	100%	100%	100%
HFO/MDO Tier III (0.5% S)	100%	100%	100%	27%	100%	100%	100%	29%	100%
MDO Tier II (0.1% S)	103%	101%	77%	100%	20%	103%	79%	100%	45%
HFO + scrubber, Tier II (0,5% S)	102%	104%	100%	100%	100%	97%	169%	98%	100%
LNG (SI, Lean-burn)	103%	98%	10%	36%	0,1%	95%	12%	37%	0,2%
LNG (dual-fuel, manifold injection)	103%	98%	68%	36%	0,1%	95%	66%	37%	0,2%
LNG (direct diesel injection)	103%	80%	68%	36%	0,1%	80%	66%	37%	0,2%
BioLNG (SI, Lean-burn)	103%	0%	10%	36%	0,1%	28%	12%	36%	2%

* kWh engine power. Value taken as reference because emission standards are thus defined.

3.6 Aviation

3.6.1 Fleet-average data

Table 35 reports the emission factors for aircraft transporting light-weight goods.
The factors are for both full-freight aircraft and passenger aircraft carrying belly freight

Table 35 - Emission factors, TTW and WTW, aviation, light load, 2018

Aircraft category	Flight phase	Load cap. (t)*	Unit	MJ	TTW emissions					WTW emissions				
					CO_2-eq.	SO_2	PM_c	NO_x	PM_w	CO_2-eq.	SO_2	PM_c	NO_x	PM_w
Belly-freight aircraft														
Short-haul	Whole flight	21.4	MJ/tkm & g/tkm	9.9	712	0.22	0.028	3.78	0.0184	910	1.20	0.078	4.2	0.0184
	CCD phase	21.4	MJ/tkm & g/tkm	7.8	564	0.18	0.022	2.93	0.018	720	0.95	0.062	3.2	0.018
	LTO phase	21.4	MJ/t & g/t	1,732	124,812	39	3.7	584	8.29	159,460	211	13	654	8.29
Medium-haul	Whole flight	53.7	MJ/tkm & g/tkm	6.7	483	0.15	0.018	2.37	0.0008	617	0.82	0.053	2.6	0.0008
	CCD phase	53.7	MJ/tkm & g/tkm	6.2	446	0.14	0.017	2.21	0.001	570	0.75	0.049	2.5	0.001
	LTO phase	53.7	MJ/t & g/t	1,759	126,698	40	2.6	706	3.31	161,869	214	12	777	3.31
Long-haul	Whole flight	59.6	MJ/tkm & g/tkm	6.2	448	0.14	0.017	2.33	0.0003	572	0.76	0.049	2.6	0.0003
	CCD phase	59.6	MJ/tkm & g/tkm	6.0	435	0.14	0.017	2.24	0.0003	556	0.74	0.048	2.5	0.0003
	LTO phase	59.6	MJ/t & g/t	1,838	132,442	42	2.6	788	2.98	169,209	224	12	863	2.98
Full-freight aircraft														
Short-haul	Whole flight	56.4	MJ/tkm & g/tkm	15.2	1,095	0.35	0.039	5.86	0.0087	1.399	1.85	0.118	6.5	0.0087
	CCD phase	56.4	MJ/tkm & g/tkm	10.4	752	0.24	0.030	4.19	0.009	960	1.27	0.083	4.6	0.009
	LTO phase	56.4	MJ/t & g/t	2,069	149,029	47	4.2	722	5.95	190,400	252	15	806	5.95
Medium-haul	Whole flight	105.9	MJ/tkm & g/tkm	6.0	435	0.14	0.016	1.93	0.0005	556	0.73	0.047	2.2	0.0005
	CCD phase	105.9	MJ/tkm & g/tkm	5.6	404	0.13	0.015	1.78	0.0005	516	0.68	0.044	2.0	0.0005
	LTO phase	105.9	MJ/t & g/t	1,491	107,400	34	2.3	511	2.30	137,215	181	10	572	2.30
Long-haul	Whole flight	110.8	MJ/tkm & g/tkm	5.7	411	0.13	0.014	1.72	0.0003	525	0.69	0.044	2.0	0.0003
	CCD phase	110.8	MJ/tkm & g/tkm	5.5	398	0.13	0.014	1.67	0.0003	508	0.67	0.042	1.9	0.0003
	LTO phase	110.8	MJ/t & g/t	1,536	110,676	35	2.3	510	2.14	141,400	187	10	572	2.14

* Including passenger load capacity for belly-freight aircraft.

3.6.2 Alternative fuels

Table 36 reports percentage indices for biokerosene, based on Hydrotreated Vegetable Oil (HVO). The emission factors per tonne-km of the alternative fuel can be calculated from the fleet-average factors reported in previous sections using the formula given in Section 3.1. The first row shows the average 2018 emission factors *per MJ fuel* as a reference value.

Table 36 - Relative emissions of biokerosene

		TTW emissions (g/MJ fuel)				WTW emissions (g/MJ fuel)			
Fuel	**MJ/kWh**	**CO_2-eq.**	**PM_c**	**NO_x**	**SO_x**	**CO_2-eq.**	**PM_c**	**NO_x**	**SO_x**
Average 2018	-	72.0	0.002	0.40	0.02	92.0	0.007	0.44	0.1
Index of alternatives rel. to kerosene									
Kerosene, average 2018	-	100%	100%	100%	100%	100%	100%	100%	100%
Biokerosene	-	1%	100%	100%	1%	11%	146%	102%	21%

4 Emission data: description and assumptions

4.1 Introduction

This chapter sets out the assumptions and computational methods used to derive the emission factors reported in Chapter 3. In Section 4.2 we first discuss the general assumptions and methods used in calculating the emissions per tonne-kilometre. Sections 4.3 (road), 4.4 (rail), 4.5 (inland shipping), 4.6 (maritime shipping) and 4.7 (aviation) set out the specific assumptions and methods for each mode in detail. Section 4.8 deals with upstream (WTT) emissions per megajoule. The chapter concludes, in Section 4.9, with a discussion of factors to account for transhipment. The logistics data on which the per tonne-km factors are based are described in Chapter 5.

4.2 General methodology

The emission factors in Chapters 2 and 3 are expressed as emissions per tonne-kilometre (EF_{tkm}). The tonne-km is a unit of transport performance expressing transportation of one tonne of freight over a distance of one kilometre. The distance considered in *STREAM* is the actual distance travelled in delivering the goods.[12] The tonne-km thus indicates the transport performance expressed in terms of both distance and delivered weight (see also Sections 1.2 and 1.3). With container transport it is only the weight of the container contents that is included in the tonne-km over which the emission factor is calculated and not the weight of the container itself. The container's weight does affect fuel and energy consumption, though, and this effect is included.

For all emissions, we report on both exhaust emissions: 'tank-to-wheel' or TTW emissions, and total 'well-to-wheel' or WTW emissions, which also factor in the emissions occurring during fuel extraction, production and transport and electrical power generation: the 'well-to-tank' or WTT emissions.

The CO_2 emissions in the tables in the previous chapters are aggregated CO_2-equivalent (CO_2-eq.) emissions, with emissions of methane (CH_4) and nitrous oxide (N_2O) expressed in CO_2-eq. using the GWP factors shown in Table 37. In the case of methane, allowance is made for its oxidation (Muñoz & Schmidt, 2016), which means the GWP works out 2.5 times higher than in the IPCC's Fifth Assessment Report.

Table 37 – GWP (Global Warming Potential) factors for methane and nitrous oxide

Greenhouse gas	Global Warming Potential (100 years)
Carbon dioxide (CO_2)	1
Methane (CH_4)	30.5
Nitrous oxide (N_2O)	265

Source: (IPCC, 2014; Muñoz & Schmidt, 2016).

[12] For monitoring purposes (Key Performance Indicators) and benchmarking the distance 'as the crow flies' is sometimes used in the definition of a tonne-kilometre.

The methodology adopted for calculating TTW emission factors differs from mode to mode and depends on the type of data employed, as explained in the following sections. For each mode, the first subsection indicates how TTW emissions per tonne-km were calculated, while the subsequent subsections go into fuel/energy consumption, TTW emissions and the emissions associated with alternative fuels and technologies.

WTT emission factors per tonne-km ($EF(WTT)_{tkm}$) were calculated using the same method for each mode and are directly proportional to fuel consumption (as also holds for CO_2). They were calculated from the energy consumption index (E_{tkm}), explained per mode in each second subsection, and the WTT emissions per megajoule fuel ($EF(WTT)_{MJ}$), reported in Section 4.8 and obtained from Formula 1, below.

$$\boldsymbol{EF(WTT)_{tkm} = E_{tkm} \times EF(WTT)_{MJ}} \qquad (1)$$

4.3 Road transport

4.3.1 Methodology

Emissions (and energy consumption) per tonne-kilometre (EF_{tkm}) were calculated from the average emissions per vehicle-kilometre (EF_{vkm}) and the vehicle's average load ($Tonne_{av}$) over fully laden and empty trips, according to:

$$\boldsymbol{EF_{tkm} = \frac{EF_{vkm}}{Tonne_{av(1)}}} \qquad (2)$$

EF_{vkm}

For road transport, average emissions per vehicle-kilometre (EF_{vkm}) were calculated from the emission factors for empty (EF_{empty}) and maximally loaded ($EF_{max\ full}$) vehicles according to a linear relationship:

$$\boldsymbol{EF_{vkm} = EF_{empty} + \frac{Tonne_{av(2)}}{Cap} \times \left(EF_{max\,full} - EF_{empty}\right)} \qquad (3)$$

The average emission per km then depends on the vehicle's average capacity utilisation ($Tonne_{av(2)}/Cap$), the average weight over full and empty trips as a percentage of the vehicle's maximum load capacity, as explained in more detail below. Subsection 4.3.2 explains our calculation of per-km energy consumption of full and empty vehicles and cites the data sources used for this purpose, while Subsection 4.3.3 reports the per-km emission factors.

$Tonne_{av}$

For bulk/packaged goods, the average tonnage over laden and empty kilometres (*$Tonne_{av}$*) was calculated from the vehicle's freight capacity (*Cap*), the average load factor on laden trips (*%tonne*) and the percentage of laden kilometres (*$\%vkm_{laden}$*), according to:

$$\boldsymbol{Tonne_{av(1\&2)}} = \boldsymbol{Cap} \times \%\boldsymbol{tonne} \times \%\boldsymbol{vkm_{laden}} \tag{4}$$

Data on vehicle freight capacity, average load factor and average percentage laden kilometres for each vehicle category are reported in Chapter 5, distinguishing between light, medium and heavy transport.

For container transport, the average tonnage over laden and empty kilometres was calculated from container capacity (*CapTEU*), average percentage use of container slots (*%TEU*) and average container load (*$tonne/TEU_1$*) or container weight (*$tonne/TEU_2$*), according to:

$$\boldsymbol{Tonne_{av(1)}} = \boldsymbol{CapTEU} \times \%\boldsymbol{TEU} \times \boldsymbol{tonne/TEU_1} \tag{5a}$$

$$\boldsymbol{Tonne_{av(2)}} = \boldsymbol{CapTEU} \times \%\boldsymbol{TEU} \times \boldsymbol{tonne/TEU_2} \tag{5b}$$

STREAM distinguishes light, medium-weight and heavy containers. For calculating EF_{tkm} in Formula 2 $Tonne_{av(1)}$ is used, with the empty weight of the container *not* included. For calculating EF_{vkm} in Formula 3 $Tonne_{av(2)}$ is used, with the weight of the container now included. The load indices used for container transport are reported in Chapter 5.

Vehicles

The road vehicle categories included in *STREAM 2020* are defined in Table 38. These definitions are in line with the emission factors used in (Task Force on Transportation, 2020). Truck freight capacities and empty weights are from (TNO, 2015b; TNO, 2013). Empty weights of light and heavy tractor-semitrailers were estimated using CBS fleet data. As those figures indicate, the tractor unit is around 7 tonnes and the empty weight of the semi-trailer 7-9 tonnes. The vehicle definitions for vans are from (Connekt, 2017).

Table 38 - *STREAM* road transport vehicle definitions

	Load capacity (tonne)	Empty weight, EW (tonne)	Gross Vehicle Weight, GVW (tonne)
Van, EW <1.5 t	0.7	1.25	1.95
Van, EW 1.5-2 t	1	1.8	2.8
Van, EW 2-2.5 t	1	2.2	3.2
Van, EW >2.5 t	0.7	2.8	3.5
Truck, GVW <10 t	3	4.5	7.5
Truck, GVW 10-20 t	7.5	8.5	16
Truck, GVW 10-20 t, with trailer	18	15	33
Truck, GVW >20 t	13	15	28
Truck, GVW >20 t, with trailer	28	18	46
Tractor-semitrailer, light	15.7	13.7	29.4
Tractor-semitrailer, heavy	29.2	15.7	44.9
LHV	40.8	19.2	60

4.3.2 Energy consumption

The energy consumption of trucks and tractor-semitrailers is based on the CO_2 factors reported in (Task Force on Transportation, 2020) per road class (urban, non-urban, motorway). This source distinguishes seven standard classes of truck: small, medium and large, the latter two with and without a trailer, and light and heavy tractor-semitrailers. The energy consumption of the four categories of van is based on the road class-average CO_2 emission reported in (Connekt, 2017). These average consumption figures were used for calculating the factors for each road class, based on the ratios between the CO_2 factors per road class and the road class-average CO_2 emission from (Task Force on Transportation, 2020). The emission factors for Long Heavy Vehicles (LHV) were modelled with reference to a tractor-semitrailer based on TML (2008) and TRL (2008) (see Table 90, Appendix B).

The CO_2 emission factors used hold for an average vehicle with an average load (in mass terms). In order to distinguish the energy consumption at different load factors, the emission factors for empty (EF_{empty}) and fully laden vehicles ($EF_{max\ full}$) were calculated from the average emission factors according to Formulae 6 and 7.

$$\boldsymbol{EF_{empty} = EF_{av-load} - difCO_2 \times Load_{av}} \tag{6}$$

$$\boldsymbol{EF_{max\ full} = EF_{av-load} + difCO_2 \times (Capacity - Load_{av})} \tag{7}$$

This calculation used the $difCO_2$ factors in Table 39, expressing the relationship between vehicle weight and per-km CO_2 emission.

Table 39 - Variation in CO_2 emission (g/km) per tonne load ($difCO_2$), road freight

Vehicle	Increase/decrease of CO_2/km with load increase/decrease (Δ (g CO_2/km)/Δ tonne)
Vans	18.5
Trucks & Tractor-semitrailers	13.25

Source: Vans: (TNO, 2015a). Trucks & Tractor-semitrailers: (CBS, 2014).

The calculation used the road class-average CO_2 factors of the vehicles concerned. Differentiation according to road class was carried out by applying the same ratio between the CO_2 factors per road class and the average to the road class-average CO_2 factors for full and empty vehicles. Energy consumption was then calculated by dividing the CO_2 emission factors (g/km) by the CO_2 content of fossil diesel on which the CO_2 emission factors are based (74.3 g CO_2/MJ). The energy consumption of empty and (fully) laden vehicles is reported in Table 40.

Table 40 - Energy consumption of road transport vehicles per road class and vehicle category, 2018 (range: empty to 100% full)

	Vehicle category	Urban	Rural	Motorway
Energy consumption (MJ/km)	Van, EW <1.5 t	2.6-2.8	1.9-2.1	2.5-2.0
	Van, EW 1.5-2 t	3.4-3.7	2.6-2.8	3.3-3.0
	Van, EW 2-2.5 t	4.0-4.3	3.0-3.2	3.9-4.0
	Van, EW >2.5 t	4.8-5.0	3.6-3.7	4.6-4.0
	Truck, GVW <10 t	5.5-6.2	3.7-4.2	3.4-3.8
	Truck, GVW 10-20 t	10.9-13.0	7.3-8.7	6.1-7.3
	Truck, GVW 10-20 t, with trailer	13.3-18.4	8.6-11.9	7.2-10.0
	Truck, GVW >20 t	15.7-19.4	10.5-12.9	8.6-10.7
	Truck, GVW >20 t, with trailer	17.9-26.7	10.8-16.1	8.9-13.2
	Tractor-semitrailer, light	15.1-19.6	10.4-13.5	8.5-11.1
	Tractor-semitrailer, heavy	21.2-31.4	13.3-19.7	8.9-13.2
	LHV	28.6-42.3	18.0-26.6	12.1-17.8

4.3.3 Emission data

Emission factors for CO_2, CH_4, N_2O and SO_2

The CO_2, CH_4, N_2O and SO_2 emission factors (g/km) were calculated directly from per-km energy consumption by multiplying these by the factors per megajoule (MJ) diesel reported in Table 41. The resultant per-km emission factors for CO_2 and SO_2 are shown in Table 42. The factors for SO_2 were calculated using the average sulphur content of diesel (10 ppm), under the assumption that 95% of the sulphur is converted to SO_2 (Task Force on Transportation, 2020).

Table 41 - CO_2, CH_4, N_2O and SO_2 emission factors per MJ diesel, road freight

	CO_2 (g/MJ)	CH_4 (mg/MJ)	N_2O (mg/MJ)	SO_2 (g/MJ)
Diesel van	68.9	0.66	1.47	0.42
Diesel truck	68.9	0.45	4.02	0.42

Source: (Task Force on Transportation, 2020). For CO_2 the share of biodiesel is factored in; see Section 4.8.

Table 42 - CO_2 and SO_2 emission factors (g/km) per road class (range: empty to 100% full)

	Vehicle category	Urban	Rural	Motorway
CO_2 (g/km)	Van, EW <1.5 t	195-209	135-145	163-176
	Van, EW 1.5-2 t	236-256	176-191	228-247
	Van, EW 2-2.5 t	275-294	205-219	266-284
	Van, EW >2.5 t	331-345	247-257	320-333
	Truck, GVW <10 t	376-429	254-290	231-264
	Truck, GVW 10-20 t	753-895	503-597	422-501
	Truck, GVW 10-20 t, with trailer	917-1,266	592-817	498-688
	Truck, GVW >20 t	1,083-1,338	722-892	595-735
	Truck, GVW >20 t, with trailer	1,235-1,839	746-1111	611-911
	Tractor-semitrailer, light	1,041-1,352	716-930	587-763
	Tractor-semitrailer, heavy	1,461-2,160	917-1356	615-909
	LHV	1,973-2,916	1,238-1,830	831-1,228

	Vehicle category	Urban	Rural	Motorway
SO_2 (mg/km)	Van, EW <1.5 t	1.18-1.27	0.82-0.88	0.99-1.07
	Van, EW 1.5-2 t	1.44-1.55	1.07-1.16	1.39-1.5
	Van, EW 2-2.5 t	1.67-1.79	1.25-1.33	1.62-1.73
	Van, EW >2.5 t	2.01-2.09	1.5-1.56	1.95-2.02
	Truck, GVW <10 t	2.28-2.61	1.55-1.77	1.4-1.6
	Truck, GVW 10-20 t	4.58-5.44	3.06-3.63	2.57-3.05
	Truck, GVW 10-20 t, with trailer	5.57-7.7	3.6-4.97	3.03-4.18
	Truck, GVW >20 t	6.59-8.14	4.39-5.42	3.62-4.47
	Truck, GVW >20 t, with trailer	7.51-11.18	4.53-6.75	3.72-5.54
	Tractor-semitrailer, light	6.33-8.22	4.35-5.66	3.57-4.64
	Tractor-semitrailer, heavy	8.88-13.13	5.58-8.24	3.74-5.53
	LHV	11.99-17.73	7.53-11.13	5.05-7.46

Besides the CO_2 from diesel combustion there are also limited CO_2 emissions from urea use in vehicles with a selective catalytic reduction (SCR) unit. This CO_2 is a urea reaction product. The average emissions per vehicle category were calculated using the emission factors and shares of kilometres reported in (Task Force on Transportation, 2020) and are shown in Table 43.

Table 43 - Fleet-average CO_2 emissions (g/km) due to urea use (averages of Euro emission classes)

Vehicle category	Urban	Rural	Motorway	Average
Van, EW <1.5 t	0	0	0	0
Van, EW 1.5-2 t	0	0	0	0
Van, EW 2-2.5 t	0	0	0	0
Van, EW >2.5 t	0	0	0	0
Truck, GVW <10 t	1.1	0.8	0.8	0.8
Truck, GVW 10-20 t	2.3	1.5	1.4	1.6
Truck, GVW 10-20 t, with trailer	3.4	2.3	2.0	2.2
Truck, GVW >20 t	3.5	2.9	2.4	2.6
Truck, GVW >20 t, with trailer	6.2	3.9	2.8	3.3
Tractor-semitrailer, light	2.0	1.3	1.2	1.3
Tractor-semitrailer, heavy	5.9	3.9	3.1	3.6
LHV	7.9	5.2	4.2	4.8

Emission factors for PM_c, NO_x and PM_w

For PM_c (particulates due to fuel combustion) and NO_x (nitrogen oxides) emission factors are based on the data per Euro class and road class reported in (Task Force on Transportation, 2020). This source also provides data on the percentage share of kilometres of each Euro emission class and road class per vehicle category. These are reported in Additional tables Table 88and 91, respectively, in Appendix B. These data were used to calculate the average emission factors by road class and the road class-average emission factors.

To convert the emission factors for the three categories of van in (Task Force on Transportation, 2020) to the four categories used in *STREAM*, the matrix in Table 89 in Appendix B was used.

Particulate emissions due to wear and tear (PM_w) comprise emissions from abrasion of tyres, brake linings and road surfaces and were calculated based on the emission factors in (Task Force on Transportation, 2020). With tyre abrasion, due allowance was made for the number of tyres per vehicle category. Around 5% of the particulate matter from wear and tear of tyres and road surfaces consists of PM_{10}. For brake lining abrasion this is about 50%.

It was assumed that the emission factors (*EF*) for full and empty vehicles are a linear function of energy consumption (*EC*), according to:

$$ECfull / ECempty = EFfull / EFempty * \varepsilon \qquad (8)$$

Here, ε is a factor between 0 and 1 that differs for the various air pollutants as well as per Euro emission class and indicates the emission increase. The NO_x emission factor for Euro IV-VI was assumed to be independent of the load carried, as was the PM_c emission factor for Euro VI. The factors are shown in Table 44.

Table 44 - Factor ε for relative change in air-pollutant emissions relative to energy consumption

Euro emission class	NO_x	PM_c	PM_w
Euro 0-III	0.75	0.5	1
Euro IV-V	0	0.5	1
Euro VI	0	0	1

Calculation by CE Delft based on (IFEU; INFRAS; IVE, 2014).

What the table shows is that for Euro 0-V vehicles, for example, a 1% increase in energy consumption leads to a proportional 1% increase in wear-and-tear particulates (PM_w), but only a 0.5% increase in combustion particulates (PM_c). With Euro VI vehicles, PM_c emissions are independent of the load carried (ε=0).

The emission factors for Long Heavy Vehicles (LHV) are modelled on the heavy tractor-semitrailer, as in (CE Delft, 2011) (see Table 90, Appendix B).

The resultant per-km emission factors are reported in Table 45. Using the road class distributions from Table 91 (Appendix B) and the figures for average load, the road class-average emissions per tonne-kilometre reported in Section 3.2 were calculated.

Table 45 - SO_2, PM_c , NO_x and PM_w emission factors per road class and 2018 vehicle category (range: empty to fully laden)

Emission factor	Vehicle category	Urban	Rural	Motorway
PM_c (mg/km)	Van, EW <1.5 t	15.99-16.78	10.17-10.67	20.88-21.91
	Van, EW 1.5-2 t	18.3-19.21	11.57-12.14	23.73-24.9
	Van, EW 2-2.5 t	18.3-19.21	11.57-12.14	23.73-24.9
	Van, EW >2.5 t	18.3-19.21	11.57-12.14	23.73-24.9
	Truck, GVW <10 t	40.56-43.32	25.5-27.22	20.72-22.12
	Truck, GVW 10-20 t	68.14-74.05	39.58-42.96	31.11-33.75
	Truck, GVW 10-20 t, with trailer	97.4-114.75	59.32-69.88	48.45-57.04
	Truck, GVW >20 t	62.56-68.85	36.69-40.29	28.92-31.73
	Truck, GVW >20 t, with trailer	46.4-53.76	25.25-29.05	19.74-22.57
	Tractor-semitrailer, light	28.59-29.48	15.17-15.75	11.14-11.6
	Tractor-semitrailer, heavy	59-68.75	31.57-36.94	20.63-24.01
	LHV	71.13-82.89	38.06-44.53	24.87-28.94

Emission factor	Vehicle category	Urban	Rural	Motorway
NO_x (g/km)	Van, EW <1.5 t	1.06-1.07	0.79-0.8	0.97-0.98
	Van, EW 1.5-2 t	1.24-1.25	0.92-0.93	1.12-1.13
	Van, EW 2-2.5 t	1.24-1.25	0.92-0.93	1.12-1.13
	Van, EW >2.5 t	1.24-1.25	0.92-0.93	1.12-1.13
	Truck, GVW <10 t	4.22-4.35	2.55-2.65	2.28-2.38
	Truck, GVW 10-20 t	6.53-6.81	3.46-3.64	3.02-3.18
	Truck, GVW 10-20 t, with trailer	8.08-9.1	4.65-5.28	3.91-4.45
	Truck, GVW >20 t	8.67-9.14	5.55-5.84	3.88-4.13
	Truck, GVW >20 t, with trailer	6.05-6.36	3.55-3.73	2.31-2.47
	Tractor-semitrailer, light	6.29-6.29	3.64-3.64	2.25-2.25
	Tractor-semitrailer, heavy	5.72-6.22	3.4-3.7	2.34-2.57
	LHV	7.63-7.5	4.54-4.46	3.12-3.1
PM_w (mg/km)	Van, EW <1.5 t	27.5-29.59	13.94-15	14.79-15.91
	Van, EW 1.5-2 t	27.46-29.71	13.92-15.06	14.76-15.97
	Van, EW 2-2.5 t	27.54-29.48	13.96-14.95	14.81-15.85
	Van, EW >2.5 t	27.77-28.91	14.08-14.65	14.93-15.54
	Truck, GVW <10 t	99.55-113.67	52.84-60.33	57.86-66.06
	Truck, GVW 10-20 t	102.13-121.31	55.01-65.34	60.81-72.23
	Truck, GVW 10-20 t, with trailer	100.81-139.21	54.98-75.92	61.28-84.62
	Truck, GVW >20 t	109.42-135.2	59.68-73.74	66.51-82.18
	Truck, GVW >20 t, with trailer	101.86-151.7	56.7-84.44	64-95.33
	Tractor-semitrailer, light	86.12-111.85	45.78-59.46	50.18-65.17
	Tractor-semitrailer, heavy	78.14-115.51	42.92-63.45	48.06-71.04
	LHV	113.66-168.02	62.43-92.29	69.9-103.32

4.3.4 Alternative fuels and technologies

For road transport, the options for alternative fuels and technologies differ depending on vehicle category. Chapter 3 reports percentage indices for the alternatives for a van, a medium-sized truck (10-20 t GVW) and a heavy tractor-semitrailer, which can be used to calculate their emissions relative to a new 2018 Euro VI vehicle.

The following alternative fuels and technologies are considered here:
- diesel Euro 5/V and Euro 6/VI, distinguishing Euro 6A and 6D for vans;
- plug-in hybrid Euro 6/VI;
- GTL (Gas-To-Liquid) Euro 6/VI;
- biodiesel Euro 6/VI, average mix of 97% FAME and 3% HVO (NEa, 2019);
- HVO Euro 6/VI;
- CNG and LNG Euro 6/VI;
- electric and hydrogen.

Table 46 shows the energy consumption of these fuels and technologies compared with Euro VI vehicles (the standard for new vehicles in 2018), as applicable for the vehicle in question. The relative emissions of each alternative were calculated using the CO_2, SO_2 and WTT emission factors from Section 4.8. The assumptions and data sources used for determining energy and (relative) TTW emissions of PM_c and NO_x are summarised in Table 47.

Table 46 – Energy consumption of alternative fuels and technologies, road transport (indexed to diesel = 100)

Fuel/technology	Van	Truck	Tractor-semi-t.
Diesel Euro 5/V	102	112	95
Diesel Euro 6/VI*	100	100	100
Diesel Plug-in hybrid (Euro 6/VI)	88*	89*	91*
GTL Euro 6/VI	100	100	100
Biodiesel Euro 6/VI (97% FAME-3% HVO)	100	100	100
HVO Euro VI	100	100	100
CNG (Euro 6/VI)	97	112	-
BioCNG (Euro 6/VI)	97	112	-
LNG (Euro 6/VI)	-	112	113
BioLNG (Euro 6/VI)	-	112	113
Electric	47 (35)*	47	47
Hydrogen	71	71	71

* For small vans the index factor is 35, the same as for cars.

Table 47 – Assumptions and data sources for energy consumption and air-pollutant emissions of alternative fuels and technologies, road transport

Fuel/technology	Assumptions, energy consumption	Assumptions, air-pollutant emissions
Diesel Euro 5/V	Comparison with Euro 6/VI based on (Task Force on Transportation, 2020), with practical test data. While newer engines are generally slightly more efficient, this makes no difference for Euro VI tractor-semitrailers.	Based on data in (Task Force on Transportation, 2020).
Plug-in hybrid	Share of electric for vans (24%) based on data in (Task Force on Transportation, 2020). For trucks a 20% share assumed.	Hybrid vehicles running fully electric have zero local emissions.
GTL	Energy consumption for GTL Euro VI assumed same as for diesel Euro VI (cf. (TNO, 2017)).	For Euro VI, no reduction (cf. (Shell, 2020) and others). For Euro III to V, GTL generally major improvement on standard diesel: approx. 10-20% NO_x reduction, 20% PM_c reduction (TNO & CE Delft, 2014; Shell, 2020; TNO, 2017).
Biodiesel	Energy consumption assumed same as for normal diesel. TTW CO_2 emission taken as zero.	For Euro VI, NO_x and PM_c emissions assumed same as for normal diesel (TNO, 2017). For Euro V and older, NO_x emissions approx. 25% higher for FAME and up to 10% lower for HVO. PM_c emissions 20% lower for HVO, 60% lower for FAME (TNO & CE Delft, 2014; TNO, 2017).
(bio)CNG and LNG	According to recent data (INFRAS, 2019a) energy consumption of CNG Euro 6 vans between 10% more and 10% less than comparable Euro 6 diesel, depending on model; the average of zero change was therefore taken. Older CNG vehicles (Euro 5 or lower) use more fuel than comparable diesel, owing in part to weight of gas tank. CNG and LNG Euro VI trucks burn 12-13% more fuel than a Euro VI diesel (INFRAS, 2019a).	While CNG/LNG give lower emissions, with introduction of Euro 6/VI the difference from diesel is less pronounced, with in some cases even an increase. Relative emission factors based on (Task Force on Transportation, 2020). BioCNG and bioLNG have same air-pollutant emissions as CNG and LNG.

Fuel/technology	Assumptions, energy consumption	Assumptions, air-pollutant emissions
	As CNG and LNG produce less CO_2, there is a net CO_2-eq. reduction.	
Electric	Relative energy consumption of electric trucks and tractor-semitrailers (47%) based on electric/diesel comparisons in several sources (INFRAS, 2019a; Huismans, 2018; T&E, 2020a; JEC, 2020). Same value taken for large vans, and 35% for small vans, the figure for cars, based on (INFRAS, 2019a). For further background, see Appendix B.	Electric trucks and tractor-semitrailers have zero local air-pollutant emissions.
Hydrogen	Energy consumption assumed 1.5 times higher for hydrogen fuel-cell vehicles than for electric, based on 60% fuel-cell efficiency and 10% energy loss during battery charging for electric, so on balance losses 50% greater for hydrogen (Concawe, 2020; T&E, 2020a).	Hydrogen fuel cells have zero local air-pollutant emissions.

These are the assumptions on which the road vehicle emission factors per reported in Subsection 3.2.4 are based. Emissions for the reference (diesel Euro 6/VI) are given there in g/km, with percentage indices relative to Euro 6/VI for the alternative fuels and technologies.

4.4 Rail transport

4.4.1 Methodology

Emissions (and energy consumption) per tonne-kilometre (EF_{tkm}) were calculated from the average emissions per vehicle-kilometre (EF_{vkm}) and the vehicle's average load ($Tonne_{av}$) over fully laden and empty trips, according to:

$$EF_{tkm} = \frac{EF_{vkm}}{Tonne_{av}} \tag{9}$$

EF_{vkm}

The average emissions per vehicle-kilometre were calculated from the average energy consumption per km (see Subsection 4.4.2) and emission factors per megajoule energy consumption (see Subsection 4.4.3).

$Tonne_{av}$

For bulk/packaged goods, the average tonnage over laden and empty kilometres ($Tonne_{av}$) was calculated from vehicle freight capacity (Cap), the average load factor on laden trips ($\%tonne$) and the percentage of laden kilometres ($\%vkm_{loaded}$), according to:

$$Tonne_{av} = Cap \times \%tonne \times \%vkm_{laden} \tag{10a}$$

Data on vehicle freight capacity, average load factor and average percentage laden kilometres for each vehicle category are reported in Chapter 5, distinguishing between light, medium and heavy transport.

For container transport, the average tonnage over laden and empty kilometres was calculated from container capacity (*CapTEU*), average percentage use of container slots (*%TEU*) and average container load (*tonne/TEU*), according to:

$$\boldsymbol{Tonne_{av} = CapTEU \times \%TEU \times tonne/TEU} \tag{10b}$$

STREAM distinguishes light, medium-weight and heavy containers. The empty weight of the container is not included in the calculation of average tonnage. The load indices used for container transport are reported in Chapter 5.

Vehicles

The train categories included in *STREAM 2020* are defined in Table 48, with a distinction made between transport of bulk/packaged goods and containers. The following basic assumptions were made:
- On international routes the maximum permitted train length (incl. locomotive) is 650 metres, but since early 2020 twenty 740-m container trains have been running weekly in the Netherlands (ProRail, 2019). The former are referred to here as “long”, the latter as “extra-long”, which In *STREAM* have also been modelled for transport of bulk and packaged goods, light and medium-weight.
- Heavily laden trains are pulled by more than one locomotive, while empty trains use just one (CE Delft, 2008). The loc characteristics used in *STREAM* are given in Appendix C.
- The table reports GTW: the sum of the empty train weight, excluding locomotive(s), and the load. In 2018 the average train GTW in the Netherlands was 1,527 t (average of laden and empty); see Appendix C. On the Betuwe line this average was 1.831 t (average of laden and empty) and on the Oldenzaal (Twente) and Venlo (Limburg) border crossings 1.148 t and 1.517 t, respectively. In 2018 capacity on the Betuwe line was restricted (for construction of a third track between Zevenaar and Oberhausen) and some of these freight movements were diverted via Oldenzaal and Venlo, thus using the all-purpose, ‘mixed’ network instead of the Betuwe line (ProRail, 2019).
- The loads for which the train categories are used are detailed in Appendix C.

Table 48 - *STREAM* train category definitions

Train category	Train length (m)	Load capacity (tonne or TEU)	GTW, loaded (tonne)	No. of locs (-)	No. of wagons (-)
Bulk/packaged goods					
Light transport					
Medium-length	543	945	816	1	35
Long	648	1,134	979	1	42
Extra-long	738	1,296	1,118	1	48
Medium-weight transport					
Medium-length	508	1,715	2,182	1	35
Long	624	2,058	2,619	2	42
Extra-long	736	2,450	2,993	2	50
Heavy transport					
Medium-length	540	1,940	2,841	2	40

Train category	Train length (m)	Load capacity (tonne or TEU)	GTW, loaded (tonne)	No. of locs (-)	No. of wagons (-)
Long	616	2,231	3,267	2	46
Extra-heavy transport					
Medium-length	498	2,485	3,618	2	35
Long	635	3,124	4,549	3	44
Containers					
Light transport					
Long	635	88	988	1	44
Extra-long	719	100	1,123	1	50
Medium-weight transport					
Long	626	90	1,270	1	36
Extra-long	727	105	1,481	1	42
Heavy transport					
Long	650	96	1,595	1	32
Extra-long	729	108	1,795	1	36

Table 49 reports the tonne-km carried on the three basic elements of the Dutch rail grid in 2018, with the split between electric (66-80%) and diesel (34-20%). In that year the overall average for the Netherlands worked out at 73% electric and 27% diesel. This is the split adopted used in *STREAM 2020*. On the Betuwe line the share of electric is far higher than on the (Rotterdam) Harbour Line and 'mixed network'. Because of work on the third track in 2018 (see above), tonne-km on the Betuwe line was 13% down compared with 2017, with an attendant increase on the 'mixed network'. In the coming years the average share of electric in the Netherlands may increase as tonne-km move from the 'mixed network' back to the Betuwe line. On the Harbour Line the share of diesel is higher than on the Betuwe line because it is used more for shunting, for which a diesel locomotive is always used.

Table 49 – Tonne-kilometres, rail freight, with electric-diesel split

	Tonne-km (billion) (ProRail, 2019)	Share of electric (ProRail, 2020)	Share of diesel (ProRail, 2020)	Tonne-km, electric (billion) (calculated)	Tonne-km, diesel (billion) (calculated)
Betuwe line	4.0	95%	5%	3.8	0.2
Harbour line	2.0	67%	33%	1.3	0.7
'Mixed' network	7.5	50-75%	50-25%	*4.7	**2.8
Total	**13.5**	**73%**	**27%**	**9.8**	**3.7**

* Calculated using 62.5%.

** Calculated using 37.5%.

4.4.2 Energy consumption

Rail freight energy consumption was calculated in the same way as in *STREAM Freight Transport 2016* (CE Delft, 2016b) and is based on the methodology described in EcoTransit (IFEU; INFRAS; IVE, 2019), which has been validated with practical data.

From the methodology it can be derived that per-kilometre electrical power consumption (*EC* (MJ_e/vkm)) is a function of total train weight (GTW), including the weight of the wagons but excluding that of the locomotive, according to:

$$EC\ (MJE/vkm) = 4.23 \times GTW\ 0,38$$ - for GTW <2.200 ton
$$EC\ (MJE/vkm) = 0,035 \times GTW$$ - for *GTW >2.200 ton* (11)

Based on engine efficiency, for diesel trains a factor 2.7 was applied (2.7 MJ diesel delivers the same engine power as 1 MJ electricity). For diesel, energy consumption (MJ_{diesel}/vkm) was then calculated as follows:

$$EC\ (MJdiesel/vkm) = 11.4 \times GTW\ 0,38$$ - for GTW <2.200 ton
$$EC\ (MJdiesel/vkm) = 0,095 \times GTW$$ - for GTW >2.200 ton (12)

In *STREAM 2016* it was assumed that per-km energy consumption fell by 2% between 2009 (*STREAM 2011* reference year) and 2014 (*STREAM 2016* reference year). Based on UIC data from August 2019 (UIC, 2019) that assumption has been changed:
- For electric freight trains energy consumption has been falling roughly linearly since 2005, at a rate of 2.5% per annum. A 9.6% reduction between 2014 and 2018 was therefore assumed.
- For diesel freight trains there is no observable trend either up or down, so no reduction factor was applied.

The UIC data and trends are shown graphically in Appendix C.

Calculation of *GTW*

To calculate energy consumption, the gross tonnage (*GTW*) of the loaded wagons was determined for the various categories of train. For bulk/packaged cargo, the weight of laden (GTW_l) and empty (GTW_e) trains was established using the wagon specifications in Table 50 and the load factors reported in Chapter 5, according to:

$$GTW_b = AW \times (BG \times CapW) + AW \times GW$$
$$GTW_l = AW \times GW \qquad (13)$$

where:
NW = number of wagons (see Table 50)
LF = load factor (see logistics data in Chapter 5)
CapW = wagon load capacity (see Table 50)
WW = wagon weight (see Table 50).

For container transport it was assumed that the train is always laden and GTW_l was calculated from the wagon specifications in Table 50 according to:

$$GTW_b = AW \times TEUcap \times BTC \times (LPT + GLC) + AW \times GW \qquad (14)$$

where:
TEUcap = TEU capacity per wagon (see Table 50)
TCU = TEU capacity utilisation (see Chapter 5)
LPT = load per TEU: average of full and empty containers ($tonne/TEU_1$) (see Chapter 5)
WEC = weight of empty container (see Chapter 5).

Table 50 – Rail wagon specifications in *STREAM* (DBSchenker Rail AG, 2009; Hungaria RailCargo, sd)

	Wagon weight (GW) (tonne)	Wagon load capacity (CapW or TEUcap) (tonne or TEU)	Wagon length (m)
Bulk/packaged goods			
Light goods	12.5	27.0	15.0
Medium-weight goods	22.8	49.0	14.0
Tank wagons	23.5	48.5	12.6
Coal/ore transport	33.8	71.0	13.2
Containers			
Light goods	12.5	2.0	14.0
Medium-weight goods	16.3	2.5	16.9
Heavy goods	20.0	3.0	19.7

Calculation of energy consumption

Using the GTW indices for full and empty trains, the respective energy consumption figures were calculated. These were then weighted according to the share of laden versus unladen kilometres reported in Section 4.1. The resultant energy consumption figures are shown in Table 51.

Table 51 – Energy consumption (MJ/vkm), rail freight

Train category	MJ_e/vkm	MJ_{diesel}/vkm
Bulk/packaged goods		
Light transport		
Medium-length train	48	129
Long train	51	138
Extra-long train	54	146
Medium-weight transport		
Medium-length train	60	163
Long train	65	175
Extra-long train	74	199
Heavy transport		
Medium-length train	75	201
Long train	83	226
Extra-heavy transport		
Medium-length train	91	245
Long train	110	296
Containers		
Light transport		
Long train	54	145
Extra-long train	56	152
Medium-weght transport		
Long train	59	159
Extra-long train	63	169
Heavy transport		
Long train	64	174
Extra-long train	67	182

4.4.3 Emission data

Emission factors per kilometre rail transport were calculated from per-km energy consumption using the emission factors per megajoule electricity or diesel in Table 52. The emission factors reported in *STREAM Freight Transport 2016* for NO_x and PM_c have been revised, with the others remaining unchanged, based on the sources cited. The new factors for NO_x and PM_c derive from an analysis of estimated fleet composition in the Netherlands (CE Delft, 2020c), based on (diesel) locomotive year-of-build, the determining factor for these emissions. This analysis led to the DB Cargo emission factors cited in (IFEU; INFRAS; IVE, 2019) being taken as most representative for the Dutch situation.

Table 52 – Emission factors per megajoule, rail freight

	Diesel (g/MJ_{diesel})	Electric ($g/MJ_{electric}$)	Source
CO_2	68.9	-	(Task Force on Transportation, 2020) with a % bio; see Section 4.8
SO_2	0.0004	-	(Task Force on Transportation, 2020)
PM_c	0.0225	-	(IFEU; INFRAS; IVE, 2019)
NO_x	0.9837	-	(IFEU; INFRAS; IVE, 2019)
PM_w	0.0235	0.0647	(CE Delft, 2014)
CH_4	0.0050	-	(Task Force on Transportation, 2020)
N_2O	0.0006	-	(Task Force on Transportation, 2020)

4.4.4 Alternative fuels and technologies

In the case of rail, there is already a basic distinction between two alternatives: electric and diesel. The emission factors for electricity in Chapter 3 are based on the average Dutch production mix, which means no allowance has been made for allocation of any outside procurement or own production of renewable power (see text box in Section 4.8). With renewable power, energy consumption and TTW emissions remain the same as for average electricity. WTT emissions are based on the emission factors for green power in Section 4.8.

Besides using renewably sourced power, energy can also be saved by increasing the voltage on the overhead wires from 1.5 kV (on the existing rail network, excl. the Betuwe line) to 3 kV. Studies show that this can reduce energy consumption and therefore WTT emissions by around 20% (Arcadis, 2013).

Under the Non-Road Mobile Machinery (NRMM) Directive 97/68/EC, locomotive diesel engines have had to satisfy the Stage IIIa standard since 2007/2009 and the Stage IIIb standard since 2012 (EC, 1998). Table 20 shows how the fleet average and the Stage V standard coming into force in 2021 score relative to the current Stage IIIb standard. The average is far higher than the current standard, because there are still many locs with older engines in the fleet. The real-world emissions of Stage IIIB and V locs were taken equal to the emission standards. For Stage IIIb locs running on HVO, PM_c emissions were taken as 80% of those of standard diesel and NO_x emissions as 90%, based on the impact of GTL (qualitatively similar to HVO) on the emissions of inland shipping engines (VIA Donau, 2015).

4.5 Inland shipping

4.5.1 Methodology

Emissions (and energy consumption) per tonne-kilometre (EF_{tkm}) were calculated from the average emissions per vessel-kilometre (EF_{vkm}) and the vessel's average load ($Tonne_{av}$) over fully laden and empty trips, according to:

$$EF_{tkm} = \frac{EF_{vkm}}{Tonne_{av}} \tag{15}$$

EF_{vkm}

The average emissions per kilometre were calculated from the average energy consumption per km (see Subsection 4.5.2) and emission factors per kilowatt-hour engine consumption (see Subsection 4.5.3).

$Tonne_{av}$

For bulk/packaged goods, the average tonnage over laden and empty kilometres ($Tonne_{av}$) was calculated from vessel weight capacity (*Cap*), average load factor on laden trips (*%tonne*) and percentage of laden kilometres ($\%vkm_{laden}$), according to:

$$Tonne_{av} = Cap \times \%tonne \times \%vkm_{laden} \tag{16a}$$

Data on vessel capacity, average load capacity and average percentage laden kilometres for each vessel category are reported in Chapter 5, distinguishing between light, medium and heavy transport.

For container transport, the average tonnage over laden and empty kilometres was calculated from container capacity (*CapTEU*), average percentage use of container slots (*%TEU*) and average container load (*tonne/TEU*), according to:

$$Tonne_{av} = CapTEU \times \%TEU \times tonne/TEU \tag{16b}$$

STREAM distinguishes light, medium-weight and heavy containers. The empty weight of the container is not included in the calculation of average tonnage. The load indices used for container transport are reported in Chapter 5.

Vessels

The inland shipping vessels included in *STREAM* are defined in Table 53. The figures for rated engine capacity are based on STC-NESTRA; RebelGroup; EICB (2015) and RWS-DVS (2011).

Table 53 – *STREAM* inland shipping vessel definitions

	Vessel type	AVV class	Load capacity (tonne)	Engine capacity (kW)
Bulk/packaged cargo				
Spits	Motorised	M1	365	200
Campine vessel	Motorised	M2	617	275
Rhine-Herne canal vessel	Motorised	M6	1,537	840
Large Rhine vessel	Motorised	M8	3,013	1,500
Class Va + 1 Europa II barge, wide	Coupled	C3b	5,046	2,300
4-barge push convoy	Push convoy	BII-4	11,181	3,500
6-barge push convoy, wide	Push convoy	BII-6b	16,481	3,500
Container ships				
Neo Kemp (32-48 TEU)*	Motorised	M3	850	400
Rhine-Herne canal vessel (96 TEU)	Motorised	M6	1,537	840
Europa IIa push convoy (160 TEU)	Push convoy	BIIa	2,708	1,400
Large Rhine vessel (208 TEU)	Motorised	M8	3,013	1,500
Extended Large Rhine vessel (272 TEU)	Motorised	M9	3,736	2,500
Coupled Europa II C3l (348 TEU)	Coupled	C3l	4,518	2,300
Rhinemax vessel (398-470 TEU)*	Motorised	M12	6,082	2,600

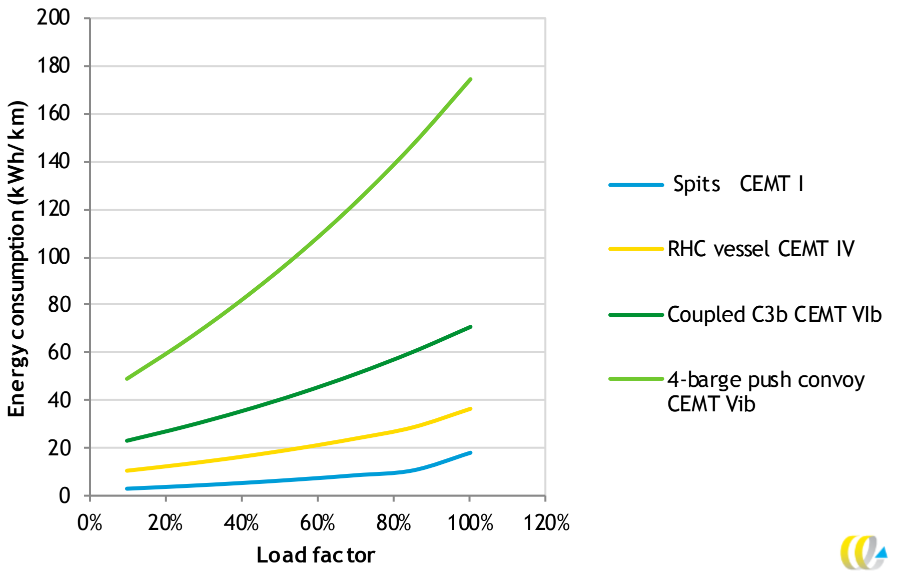
* The number of layers of containers and thus transport capacity depends on available bridge clearance. For Neo Kemp vessels a range is given, for two or three layers of containers, for Rhinemax vessels for four or five.

4.5.2 Energy consumption

Methodology

For inland shipping, all emission factors per vessel-kilometre were calculated from per-km energy consumption, using emission factors per kilowatt-hour (see Subsection 4.5.3). Per-km energy consumption was modelled with the Dutch Emissions Register model, described in (AVV, 2003), which estimates energy consumption based on waterway parameters (depth, width, flow), vessel parameters (length/width, full and empty vessel draught) and operational parameters (sailing speed, load). Load factor affects draught and thus energy consumption. The relationship between load factor and energy consumption is illustrated in Figure 8 for a combination of several types of vessel and waterway (CEMT class).

Figure 8 - Influence of load factor on energy consumption, inland shipping



The vessel parameters used for modelling the categories of vessel distinguished in *STREAM* are reported in Appendix D. Sailing speeds, differentiated according to waterway class and load status (laden vs. empty), are the figures used for the Emissions Register (Emissieregistratie, 2018), which are measured with *Rijkswaterstaat* AIS transponders and compiled by Statistics Netherlands (CBS).

With the model, energy consumption can thus be calculated for the various types of vessel on the respective waterway classes, distinguishing between full and empty trips. For rivers, an additional distinction is made between upstream and downstream trips.

Average energy consumption per kilometre (kWh/km) was then calculated by weighting the energy consumption on laden (EC_{laden}) and empty (EC_{empty}) trips using the share of laden ($\%km_{laden}$) and empty kilometres ($1- \%km_{laden}$), according to:

$$\boldsymbol{EC_{av}} = \%\boldsymbol{km_{laden}} \times \boldsymbol{EC_{laden}} + (\boldsymbol{1} - \%\boldsymbol{km_{laden}}) \times \boldsymbol{EC_{empty}} \tag{17}$$

The share of laden kilometres used for the calculation is reported in Chapter 5. For rivers, the relative share of laden vs. empty kilometres was additionally broken down into upstream and downstream, under the assumption that laden kilometres are divided 50-50 between the two.

Finally, the model outcome was increased by 6% to account for use of bow thruster motors (estimate by CE Delft based on (Emissieregistratie, 2012)).

A correction was also made for engine load. Every engine has an optimum load at which there is maximum use of fuel energy for thrust and thus optimum fuel burn. At both lower and higher engine loads, relatively more fuel is burned per kWh. Here, engine load is calculated by dividing the average power demand of the specific vessel category on a specific waterway class by the rated engine capacity for the vessel, as defined in Table 53.

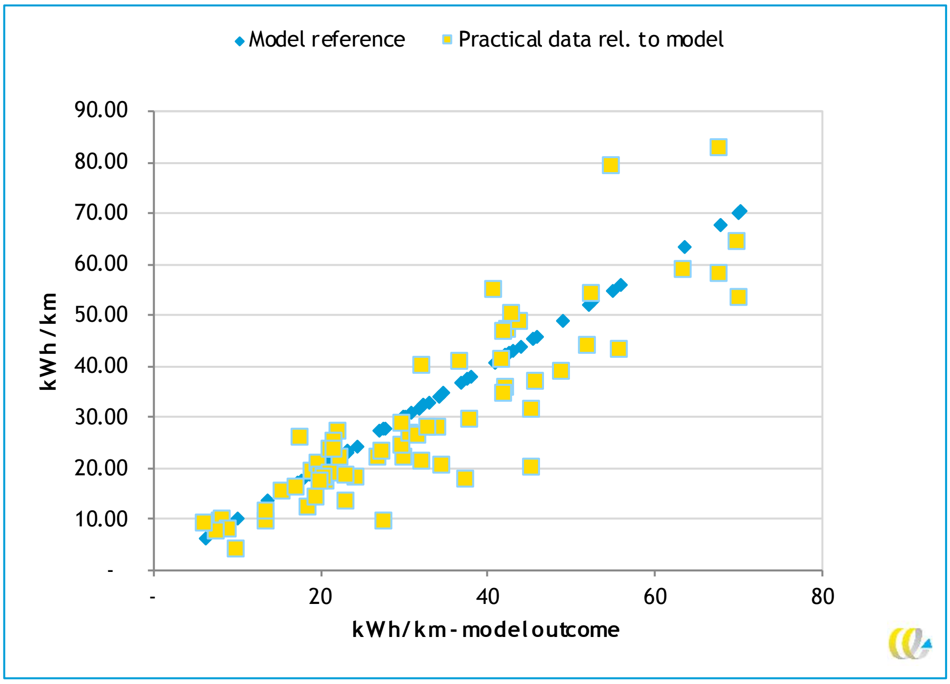
The correction factors for engine load are based on (Emissieregistratie, 2018). Their application increases energy consumption on trips involving low or very high power demand.

Besides engine load, fuel burn also varies according to engine year-of-build, new engines using relatively less fuel than older models (Emissieregistratie, 2018). Using the construction-year data in (STC-NESTRA; RebelGroup; EICB, 2015), a weighted average fuel burn figure was calculated for each vessel category. Fuel consumption has thus been corrected for engine age for each category of vessel.

Validation

The modelling results were validated using practical data on 100 inland waterway vessels compiled by BLN Schuttevaer. In Figure 9 these annual average real-world data are plotted against the model data for the same vessels (for further details, see Appendix D). As can be seen, on average the model predicts energy consumption fairly accurately, although in individual cases consumption may deviate substantially.

Figure 9 - Energy consumption, inland shipping: real-world data versus modelling outcome



Modelling results

The model was used to calculate the energy consumption of the most commonly used types of vessel. The results for transport of bulk/packaged goods are shown in Table 54 and for container transport in Table 55.

Table 54 – Motor power consumption (kWh/km) and diesel fuel consumption (MJ/km), inland shipping, bulk/packaged goods

Vessel category (designated class)	Waterway class	Motor energy consumption (kWh/km)			Diesel consumption (MJ/km)*		
		Light	Med.-weight	Heavy	Light	Med.-weight	Heavy
Spits (M1)	CEMT I	8	10	12	37	50	58
	CEMT Va	10	13	13	49	61	64
	CEMT VIb	12	14	15	57	68	71
	Waal	14	17	18	67	82	87
Campine vessel (M2)	CEMT II	12	16	18	58	79	85
	CEMT Va	20	24	25	95	117	121
	CEMT VIb	25	30	30	119	143	146
	Waal	27	31	32	129	147	153
Rhine-Herne canal vessel (M6)	CEMT IV	34	44	46	161	210	222
	CEMT Va	37	47	49	177	224	234
	CEMT VIb	51	61	63	247	293	302
	Waal	60	70	71	288	335	339
Large Rhine vessel (M8)	CEMT Va	47	61	64	228	291	306
	CEMT VIb	71	85	88	343	410	424
	Waal	80	90	93	384	433	447
Class Va + 1 Europa II barge, wide (C3b)	CEMT VIb	146	187	197	699	898	945
	Waal	139	165	170	668	791	814
4-barge push convoy (BII-4)	CEMT VIb	166	223	231	798	1,070	1,111
	Waal	236	283	283	1,135	1,360	1,358
6-barge push convoy, wide (BII-6b)	CEMT VIb	442	438	396	2,123	2,101	1,899
	Waal	299	341	361	1,435	1,639	1,734

* Diesel consumption calculated using specific fuel consumption of 205 g diesel/kWh (see Section 4.5.3) and 42.7 MJ/kg for energy density of (100% fossil) diesel.

Table 55 - Motor power consumption (kWh/km) and diesel fuel consumption (MJ/km), inland shipping, container transport

Vessel category (TEU capacity) (designated class)	Waterway class	Motor power consumption (kWh/km)			Diesel consumption (MJ/km)*		
		Light	Med.-weight	Heavy	Light	Med.-weight	Heavy
Neo Kemp (32-48 TEU) (M3)	CEMT III	11	14	16	52	66	79
	CEMT Va	19	24	28	94	113	134
	CEMT VIb	24	29	34	117	140	162
	Waal	28	33	38	133	159	183
Rhine-Herne canal vessel (96 TEU) (M6)	CEMT IV	29	36	42	140	174	203
	CEMT Va	33	40	46	160	190	219
	CEMT VIb	48	56	62	231	267	296
	Waal	57	65	72	273	310	345
Europa IIa push convoy (160 TEU) (BII-1)	CEMT Va	57	75	93	276	362	448
	CEMT VIb	85	106	125	410	507	598
	Waal	93	114	132	447	545	636
Large Rhine vessel (208 TEU) (M8)	CEMT Va	44	53	64	210	255	306
	CEMT VIb	68	79	89	328	380	427
	Waal	78	87	96	373	419	459
Extended Large Rhine vessel (272 TEU) (M9)	CEMT Va	65	81	96	313	387	461
	CEMT VIb	86	101	114	414	483	547
	Waal	87	98	107	416	470	516
Coupled: Europa II C3l (348 TEU) (C3l)	CEMT Vb	69	87	104	329	418	498
	CEMT VIb	106	126	142	508	605	681
	Waal	107	123	136	513	589	655
Rhinemax vessel (398-470 TEU) (M12)	CEMT VIb	125	152	175	599	730	842
	Waal	122	140	156	587	674	751

* Diesel consumption calculated using specific fuel consumption of 205 g diesel/kWh (see Section 4.5.3) and 42.7 MJ/kg for energy density of (100% fossil) diesel.

4.5.3 Emission data

The CO_2, SO_2, N_2O and CH_4 emission factors are all directly proportional to engine diesel consumption, for which Task Force data were taken (Task Force on Transportation, 2020). Based on a specific fuel consumption of 205 g diesel per kWh for inland shipping vessels (based on (Emissieregistratie, 2018), emission factors per megajoule were converted to factors per kWh (Table 56).

Table 56 - Emission factors for CO_2, N_2O, CH_4 and SO_2 per kilowatt-hour, inland shipping

Emission factor	g/kWh	Calculated as
CO_2	599	205 g diesel/kWh x 2.919 g CO_2/kg diesel
N_2O	0.0173	205 g diesel/kWh x 0.085 g N_2O/kg diesel
CH_4	0.061	205 g diesel/kWh x 0.30 g CH_4/kg diesel
SO_2	0.0036	205 g diesel/kWh x 0.018 g SO_2/kg diesel

The NO_x and PM_c emission factors depend on vessel construction year and the emission standards in force at the time. Since 2003 NO_x and PM_c emissions have been regulated under standards set by the Central Commission for Navigation of the Rhine (CCNR, 2000; 2001) and later under EU Directive 2004/26. Based on these regulations, a distinction can be made between engines from before 2003 (CCNR0), engines from 2003-2006 (CCNR1) and engines from 2007 or later (CCNR2). Stage V engines under EU Directive 2016/1628 (EU, 2016), mandatory since 2019/2020, were not yet relevant in 2018.

The average emission factors for the construction-year classes are shown in Tabel 57. The values are based on the construction-year-indexed emission factors given in the EMS protocol in the Dutch Emissions Register for inland shipping (Emissieregistratie, 2018).

Tabel 57 – Emission factors for NO_x and PM_c per construction-year class (CCNR class), inland shipping

Construction year	CCNR class	NO_x	$PM_{2.5}$	Fuel consumption (g/km)
1900-1974	N.v.t.	10.8	0.57	235
1975-1979	N.v.t.	10.6	0.57	230
1980-1984	N.v.t.	10.4	0.57	225
1985-1989	N.v.t.	10.1	0.475	220
1990-1994	N.v.t.	10.1	0.38	220
1995-2002	N.v.t.	9.4	0.285	205
2003-2007	CCNR1	9.2	0.285	200
2008-2018/2019	CCNR2	7	0.19	200
2019-20xx	Stage V L1 <300 kW	2.9	0.09	205
2020-20xx	Stage V L2 >300 kW	2.4	0.0143	190

The percentage distribution of vessels over construction years was taken from the European project 'Prominent'[13]. In 2018, the *STREAM* reference year, ship owners replacing engines generally opted for a CCNR2 model rather than the considerably dearer (as well as hard-to-find) Stage V engine. For this reason we assumed that newly installed engines are CCNR2 up to and including 2018.

Table 58 – Distribution of vessels over construction years, inland shipping

Share per vessel category	1974	1975-1979	1980-1984	1985-1989	1990-1994	1995-2002	2003-2007	2008-2015	>2015
Spits	26%	18%	12%	11%	2%	3%	14%	9%	5%
Campine vessel	17%	3%	9%	12%	6%	3%	39%	8%	3%
Neo Kemp	17%	3%	9%	12%	6%	3%	39%	8%	3%
Rhine-Herne canal vessel	9%	1%	1%	3%	2%	8%	35%	40%	0%
Large Rhine vessel	15%	2%	4%	7%	4%	4%	37%	24%	4%
Extended Large Rhine vessel	0%	0%	0%	0%	0%	0%	39%	60%	0%
Rhinemax vessel M12	0%	0%	0%	0%	0%	1%	29%	69%	1%
4-barge push convoy	0%	0%	0%	0%	0%	0%	5%	36%	59%
6-barge push convoy, wide	0%	0%	0%	0%	0%	0%	5%	36%	59%
Class Va + 1 Europa II barge, wide	0%	0%	0%	0%	0%	0%	39%	60%	0%

[13] As the Dutch fleet accounts for a major share of the North European fleet with which the Prominent project is concerned, the distribution reported there can justifiably be used for the Dutch fleet.

From these data on vessel distribution over construction year and emission factors per year, a weighted average emission factor was determined for each vessel category. The resultant figures are shown in Table 59. Vessel categories with, on average, older engines have a higher fuel consumption and associated emissions as well as higher PM_c and NO_x emissions owing to older engines having less emission abatement provisions.

Table 59 – Weighted average emission factors for vessel categories (g/kWh), inland shipping

Vessel category	CO_2	SO_2	PMv	NO_x	N_2O	CH_4
Spits	699	0.0040	0.48	9.82	0.019	0.066
Campine vessel	676	0.0038	0.41	9.55	0.018	0.064
Neo Kemp	676	0.0038	0.41	9.55	0.018	0.064
Rhine-Herne canal vessel	651	0.0037	0.30	8.54	0.017	0.062
Large Rhine vessel	664	0.0038	0.35	9.02	0.018	0.063
Extended Large Rhine vessel	635	0.0036	0.24	7.89	0.017	0.060
Rhinemax vessel M12	635	0.0036	0.23	7.68	0.017	0.060
4-barge push convoy	684	0.0039	0.40	9.19	0.018	0.065
6-barge push convoy, wide	635	0.0036	0.21	7.11	0.017	0.060
Class Va + 1 Europa II barge, wide	635	0.0036	0.21	7.11	0.017	0.060

Since low as well as very high engine loads give relatively high emissions (Emissieregistratie, 2018) the above emission factors need to be corrected for engine load. Using the power demand determined in Subsection 4.3.2 and the rated engine capacity data in Table 53 for each vessel category, an average power demand figure was determined. Based on the power used, the correction factors in (Emissieregistratie, 2018) were applied.

4.5.4 Alternative fuels and technologies

Several alternative fuels and technologies are already in use in the current inland shipping fleet. Since 2007 new engines have had to comply with the CCNR2 standard or the equivalent Phase IIIA standard under the EU's Non-Road Mobile Machinery Directive 97/68/EC (EC, 1998). The Phase V emission standard in force for new engines since 2019/2020 is not relevant for *STREAM*.
LNG is a good alternative for vessels with high annual fuel burn, the lower fuel costs making investment in an LNG engine worthwhile. There are several options:
— LNG, single-fuel, SI: spark ignition engines burning only LNG;
— LNG, pilot, <10%D: dedicated dual-fuel engines suitable for burning both diesel and LNG, with ignition kick-started by 'pilot injection' of about 3% diesel;
— LNG, dual-fuel, 20%D: dual-fuel engines (often retrofitted diesel engines) burning around 20% diesel in addition to LNG.

GTL (Gas-To-Liquid) is an option for reducing the air-pollutant emissions of (older) engines that requires no further engine modifications.

Two add-on technologies are also often applied:
— SCR, Selective Catalytic Reduction, to reduce NO_x emissions;
— DPF, Diesel Particle Filter, to reduce particulate emissions.

Table 28 (Subsection 3.4.3) reviews the percentage indices used for the above fuels and technologies relative to vessels with a CCNR2 engine, the 2018 standard for new engines.

For CCNR2, the first row gives an absolute value for emissions per kWh engine power[14]. Table 60 summarises the impact of the fuels and technologies on energy consumption and air-pollutant emissions and the data sources used. The other relative emissions were calculated using the figures for relative fuel consumption and the CO_2, SO_2 and WTT emission factors in Section 4.8.

Table 60 – Assumptions and data sources for energy consumption and air-pollutant emissions of alternative fuels and technologies, inland shipping

Fuel/technology	Assumptions, energy consumption	Assumptions, air-pollutant emissions
Diesel, Stage V	Engines with rated power <300 kW and ≥300 kW use different technologies for meeting the different emission standards. Based on (Emissieregistratie, 2018) 5% lower energy consumption than CCNR2 assumed for engines ≥300 kW and 3% more for <300 kW.	Stage V emission standards are far stricter than for CCNR2 and Stage IIIa. Emissions (reduction) based on (Emissieregistratie, 2018).
Diesel-electric	Diesel-electric motors use inherently more diesel per unit energy output because of greater internal energy losses in the drivetrain. If two generators are used or one variable-speed generator, energy efficiency can be improved by optimising engine loads. Whether there are gains will also depend on route characteristics. As an average, energy consumption assumed unchanged (TNO, 2018b).	As with energy consumption, air-pollutant emissions for diesel-electric (CCNR) taken same as for CCNR2 diesel. For Stage V diesel-electric there may be gains relative to Stage V-diesel, since more optimal engine loading improves SCR and DPF performance (TNO, 2018b).
(bio-)LNG, pilot injection <10%D LNG, dual-fuel, 20%D LNG, single-fuel, SI	LNG engines have approx. 5% higher energy consumption (in MJ), but CO_2 emissions per MJ fuel are lower (cf. Section 4.8) (TNO, 2015d).	PM_c and NO_x emission reductions based on (TNO, 2015d), (VIA Donau, 2015) and (CE Delft, 2015a) and highest for LNG single-fuel, SI and lowest for dual-fuel, 20%D.
HVO CCNR2 HVO Stage V GTL CCNR2	Fuel quality of HVO and GTL is comparable. Fuel consumption (MJ diesel/kWh) assumed same as for diesel (cf. (VIA Donau, 2015)).	HVO and GTL have lower NO_x (10%) and PM_c (20%) emissions when used in CCNR2 engines (VIA Donau, 2015; Shell, 2020). As with Euro 6 road-vehicle engines, for Stage V engines burning GTL and HVO emissions assumed unchanged.
SCR/DPF CCNR2	SCR and DPF have virtually no impact on fuel consumption, but 1% increase assumed for DPF because of back-pressure (VIA Donau, 2015).	SCR reduces NO_x emissions by 80% on average, but may be more or less depending on urea dosing and tuning. Too much urea can lead to unwanted NH_3 emissions. SCR also cuts PM_c emissions by approx. 10%, and DPF by 90% on average (VIA Donau, 2015).

[14] The metric to which air-pollutant emission standards are indexed.

4.6 Maritime shipping

STREAM 2020 includes not only short-sea but also deep-sea shipping, which means factoring in not only the standards for Sulphur Emission Control Area (SECA)[15] in the North Sea and Baltic, but also those in force on the open seas. As of 1 January 2020, new regulations issued by the International Maritime Organisation, IMO, mean that ocean-going vessels must burn low-sulphur diesel fuel oil (max. 0.5% S), and otherwise use alternative means (e.g. scrubbers, LNG) to reduce sulphur emissions by at least as much. Even though these regulations were not yet in force in the reference year 2018, they was been taken on board in *STREAM 2020*. Low-sulphur HFO has such a major impact on PM_c and SO_2 emissions that to ignore the new circumstances would leave the reported data with little relevance for today.

4.6.1 Methodology

Emissions per tonne-kilometre (EF_{tkm}) were calculated from energy consumption per tonne-kilometre (E_{tkm}) and emission factors per MJ fuel (EF_{MJ}), according to:

$$\boldsymbol{EF_{tkm} = E_{tkm} \times EF_{MJ}} \qquad (18)$$

with E_{tkm} being calculated for each category of vessel by dividing total annual energy consumption (E_{year}) by total annual tonne-kilometres tkm_{year}, according to:

$$\boldsymbol{E_{tkm} = \frac{E_{year}}{tkm_{year}}} \qquad (19)$$

The categories of ocean-going vessel are based on the type of cargo and ship size according to the categories distinguished in *STREAM 2016* (CE Delft, 2016b) and in the 4th IMO GHG Study (IMO, 2020) for bulk carriers, general cargo vessels, oil tankers and container ships.

4.6.2 Energy consumption

Since 1 January, 2018 ships over 5,000 t Gross Tonnage[16] taking on or discharging cargo or passengers in ports in the European Economic Space must monitor and report CO_2 emissions and other relevant data, with monitoring, reporting and verification (MRV) in line with EU Regulations 2015/757 and 2016/2071.

The *STREAM* calculations of energy consumption per tonne-km are for vessels with a Gross Tonnage (GT) over 5,000 t, based on these data. For lighter vessels, data provided by Dutch shipowners for the database maintained by KVNR, the Royal Association of Netherlands Shipowners, were used (KVNR, 2018). This means there are differences in both calculation method and data source compared with *STREAM 2016*. While those calculations were based on more theoretical data from the 3rd IMO GHG Study, *STREAM 2020* uses the data recorded and reported by shipowners for the EU-MRV and KVNR databases.

For each vessel the EU-MRV database (EMSA, 2018) reports:
a total annual fuel consumption (tonnes);
b average annual fuel consumption per tonne-kilometre (kg/tkm)[17];

[15] Fuel sulphur content in SECA may not exceed 0.1%.
[16] Gross Tonnage is is a nonlinear measure of a ship's overall internal volume
[17] The database uses nautical miles (nm) rather than km, also for tonne-km. 1 nm = 1.852 km.

c average annual fuel consumption per kilometre (kg/km).

Allowing derivation of the following:
- annual tonne-kilometres carried (a/b);
- annual kilometres sailed (a/c).

These data are linked via the vessel's IMO number to the data in Clarksons World Fleet Register (Clarksons, 2020), allowing vessel size (dwt) to be added to the data set and thus dwt-kilometres (*DWT-km*) to be calculated.

Based on annual fuel consumption (*Fuel*) and the tonne-kilometres (*tkm*) for the ships (*s*) in a given category (*cat*) the average energy consumption (MJ/tkm) per category was calculated from:

$$E_{tkm(cat)} = \frac{\sum_{s-cat}(Fuel_{s} \times 1000 \times ED_{s})}{\sum_{s-cat}(tkm_{s})} \tag{20}$$

where *ED* is the energy density of the fuel in MJ/kg. As the EU-MRV database does not report the type of fuel used (MGO or HFO), for all vessels over 5,000 t GT the average of HFO (41.0 MJ/kg) and MGO (42.7 MJ/kg) was taken: 41.9 MJ/kg [18].

Besides energy consumption, the average capacity utilisation of each vessel category was also calculated, by dividing the total tonne-km for the category by total dwt-km (see Chapter 5). Vessels with >100% or <10% utilisation were not included.

As mentioned above, for vessels <5,000 t dwt the KVNR database was used, from which the following data were taken:

a size class (in dwt);
b fuel consumption, *with type of fuel*;
c distance sailed.

Allowing derivation of:
- dwt-kilometres per vessel (d·f).

From the above data the average energy consumption (in MJ/tkm) was calculated, again using Formula 20, but now distinguishing fuel type (HFO, MGO, LNG), as reported. Tonne-km cannot be derived directly from the data and was calculated using Formula 21, under the assumption that vessels <5,000 dwt (*cat1*) have the same utilisation as the next category (*cat2*) in the EU-MRV database. The total tonne-km of vessels <5,000 dwt (*tkm*) was then calculated from the dwt-kilometres (D*WTkm*) and utilisation (*Util*) according to Formula 21.

$$\sum_{s-cat1}(tkm_{s}) = \sum_{s-cat1}(DWTkm_{s}) \times Util_{cat2} \tag{21}$$

For maritime shipping *STREAM 2020* no longer distinguishes medium-weight and heavy freight, partly because it was already apparent in the previous version that there is little difference between the two categories. In the category of general cargo, light transport is still distinguished, though, for which purpose only transport with >50% utilisation was taken from the database.

[18] Fuel energy density is treated in Section 4.8.

In its reporting of tonne-km container transport, the EU-MRV database uses the load weight inclusive of the container. The calculated emissions per tonne-km were therefore corrected using a factor 9.6/7.6, the ratio between the weight of an average container including and excluding container weight (see Chapter 5).

4.6.3 Emission data

Emissions of CO_2, N_2O, CH_4 and SO_2 per megajoule

The emission factors (in g/MJ) for CO_2, N_2O and CH_4 and SO_2 depend directly on fuel burn and fuel type, but have been assumed independent of engine type. The emission factors for low-sulphur HFO and MDO are given in Table 61. The 4th IMO GHG Study (IMO, 2020) states that in 2018 the maritime shipping fuel mix was approximately 65-75% HFO, 22-32% MDO and 3% LNG. MDO is used mainly in auxiliary engines and in SECA areas. With the new limits on sulphur dioxide emissions now in force, the share of MDO is likely to rise and emissions were therefore indexed to the average of HFO and MDO. This assumption is above all pertinent to SO_2. The average emission factors adopted in *STREAM* for maritime shipping are shown in the bottom row of Table 61.

Table 61 – Fuel consumption dependent emission factors (per MJ), maritime shipping

	CO_2 (g/MJ)	CH_4 (mg/MJ)	N_2O (mg/MJ)	SO_2 (g/MJ)
HFO (0.5% S)	75.95	7.0	2.0	0.24
MDO (0.1% S)	75.08	7.0	2.0	0.05
Average (50% HFO, 50% MDO)	75.52	7.0	2.0	0.15

Source: (Task Force on Transportation, 2020); SO_2 emissions calculated using cited sulphur content.

PM_c and NO_x emissions depend not only on fuel burn and fuel type, but also on engine type (main engine, auxiliary engine, boiler). (MARIN, 2019) reports detailed emission factors by engine type, age category and fuel type, and these figures have been adopted here.

Fuel sulphur content is particularly important for PM_c emission factors, since sulphur is a major source of secondary particulates. Table 62 reports construction-year-weighted emission factors (in g/kg fuel) for PM_c by fuel and engine type, plus the average figure adopted here for all vessels, the reasoning being that the major uncertainties regarding fuel composition in the context of the low-sulphur standards make it next to impossible to make distinctions according to vessel category.

Table 62 – PM_c emission factors, by engine type and average (g/kg fuel), maritime shipping

	Main engine	Aux. engine	Boiler	Source
HFO (0.5% S)	2.49	2.49*	N.a.	Calculated by interpolation of emission factors for HFO (1% S), MDO (0.2%) and MDO (0.1%) in (MARIN, 2019) and (MARIN, 2014) and average share in fuel burn by construction-year class from (EMSA, 2018).
MDO (0.1% S)	1.38	1.27	0.7	(MARIN, 2019) and average share in fuel consumption by construction-year class from (EMSA, 2018).
Average		1.7		Calculated based on average ratio between fuel burn of main engine, auxiliary engine and boiler from (IMO, 2020) and 50:50 ratio between HFO and MDO.

* Assumed equal to main engine.

The NO_x emissions of these vessels are likewise dependent on engine type (main engine, auxiliary engine, boiler), but also on the IMO emission standard the engine has had to satisfy since the year 2000. Engines from 2000-2010 must meet the Tier I standard, those post-2010 the Tier II standard. On 1 January, 2016 so-called NECAs (NO_x emission control areas) were introduced in North America, where ships must satisfy Tier III standards.

Based on an average distribution of fuel burn across construction years according to the EU-MRV database (EMSA, 2018) and the emission factors by Tier level and construction-year class from (MARIN, 2019), average NO_x-emission factors were calculated for each of the three engine types (Table 63). Then, based on the ratio between the annual energy burn of the respective engine types per vessel class, the average NO_x emission factor (in g/kg fuel) was calculated. For this ratio, use was made of the fuel burn data for each engine type cited in the 4th IMO GHG Study (IMO, 2020). For NO_x then, in contrast to PM_c, a distinction was made between the various vessel categories, because the relative amount of fuel burned in the boiler has a major impact on the average NO_x emission factor (in g NO_x/kg fuel), while NO_x emissions are independent of sulphur content. Oil-tanker boilers account for a far greater share of fuel burn than in the other vessels, for instance, because boiler heat is also used to keep the crude oil fluid in transport. The size class-differentiated NO_x emission factors used to calculate emission factors per tonne-km are shown in Table 64.

Table 63 - NO_x emission factors by engine type (g/kg fuel), maritime transport

	Main engine	Aux. engine	Boiler	Source
NO_x	86	46	3.5	Based on emission factor by construction year (MARIN, 2019) and average share of fuel burn by construction year from (EMSA, 2018)

Table 64 - NO_x emission factors (g/kg fuel) by vessel type and size class, maritime transport

Vessel type	Size class	NO_x emission factor (g/kg fuel)
Average	Average	68
Bulk carrier	Average	79
	0-4,999 dwt	71
	5,000-9,999 dwt	71
	10,000-34,999 dwt	79
	35,000-59,999 dwt	78
	60,000-99,999 dwt	77
	100,000-199,999 dwt	81
	200,000+ dwt	82
General cargo ship	Average	76
	0-4,999 dwt	80
	5,000-9,999 dwt	71
	10,000-19,999 dwt	73
	20,000+ dwt	77
Oil tanker	Average	54
	0-4,999 dwt	40
	5,000-9,999 dwt	45
	10,000-19,999 dwt	45
	20,000-59,999 dwt	48
	60,000-79,999 dwt	56
	80,000-119,999 dwt	54
	120,000-199,999 dwt	59
	200,000+ dwt	69
Container ship	Average	77

Vessel type	Size class	NO_x emission factor (g/kg fuel)
	0-999 TEU	69
	1,000-1,999 TEU	72
	2,000-2,999 TEU	75
	3,000-4,999 TEU	77
	5,000-7,999 TEU	80
	8,000-11,999 TEU	80
	12,000-14,499 TEU	80
	14,500-19,999 TEU	79
	20,000+ TEU	77

Source: Calculated based on Table 63 and shares by engine type in (IMO, 2020).

4.6.4 Alternative fuels and technologies

As explained in the previous section, for maritime shipping a 50:50-mix of MDO (0.1% S) and HFO (0.5% S) was assumed. Taking this fuel mix and Tier II engines as a reference, Section 3.5.3 reports the relative emissions of the following alternative fuels and technologies:

- Tier II and III engines: the Tier classes define NO_x emission standards laid down by the IMO. Engines of ships built after 2011 must satisfy the Tier II standard. Tier III will apply when NECAs (NO_x Emission Control Areas) come into force in the North Sea and Baltic in 2021, as is already the case in North American waters.
- MDO (0.1% sulphur): MDO is a lighter grade of diesel fuel oil often used in auxiliary engines and in NECA areas. Its lower sulphur content means PM_c and SO_2 emissions are lower than for HFO.
- HFO (2.7% sulphur) with a scrubber to reduce SO_2 in the exhaust, permitting continued use of higher-sulphur HFO.
- LNG single/dual fuel: given their high fuel consumption, LNG is an appealing, cost-saving option for seagoing vessels. Single-fuel, lean-burn LNG engines have spark ignition, dual-fuel engines compression ignition, using diesel for ignition. Two variants of the latter are considered: manifold injection and direct cylinder injection, with lower methane emissions.

The assumptions made with respect to energy consumption and air pollutant TTW emissions of these alternative fuels and technologies are summarised in Table 65. CO_2, SO_2 and WTT emissions are derived from energy consumption and the fuel emission factors given in Section 4.8.

Table 65 - Assumptions and data sources for energy consumption and air-pollutant emissions of alternative fuels and technologies, maritime shipping

Fuel/Technology	Assumptions, energy consumption	Assumptions, air-pollutant emissions
Tier II & III, HFO/MDO	Energy consumption of Tier II and III assumed equal to average, based on (MARIN, 2019).	For Tier II engines (emission standard in force since 2011) on average 10% lower NO_x emission than the average (MARIN, 2019). Tier III engines (emission standard since 2016) have approx. 73% lower NO_x emissions than Tier II (IMO, 2020). Tier standards have no effect on other air-pollutant emissions.
MDO (0.1% S)	+3% energy consumption assumed.	Lower sulphur content means lower PM_c (23%) and SO_2 emissions (80%) (MARIN, 2019).
HFO (2.7% S) + Scrubber	+2% energy consumption assumed for caustic soda pumps (CE Delft, 2015a)	Scrubber assumed to give same SO_2 and PM_c emissions as HFO with 0.5% S. Composition of PM_c may differ, however.
(bio)LNG	+3% energy consumption assumed, due to LNG engines being a little less efficient than diesel engines (TNO, 2015d).	PM_c emissions of LNG single-fuel (SI, lean-burn) taken as 0.03 g/kWh = 90% lower than for diesel; duel-fuel as 0.2 g/kWh = 32% reduction (TNO, 2015d). For all LNG options, NO_x emissions taken as 4 g/kWh = 72% lower than for diesel (TNO, 2015d).

4.7 Aviation

Aviation was not yet included in *STREAM Freight Transport 2016* and the methodology adopted in *STREAM 2020* is therefore new. For this mode of transport no differentiation has been made as to cargo weight, with all cargo taken to be basically "light".

4.7.1 Methodology

Average emissions per kilometre were calculated using data from flights flown to and from Schiphol in 2018. This data set was provided by Schiphol Airport and covers all incoming and outgoing flights in that year, giving IATA aircraft type, load factor (passengers and cargo[19]) and airport-to-airport distance. From these data, fuel burn, CO_2 emissions and air-pollutant emissions were calculated. For full-freight aircraft, which often make a stop-over landing, load factors were used to correct for cargo already on board: 53% for short-haul, 73% for medium-haul and 75% for long-haul flights, based on (IFEU; INFRAS; IVE, 2019) and (BEIS, 2020).

Emissions per tonne-kilometre (EF_{tkm}) were calculated from energy consumption per tonne-km (E_{tkm}) and emission factors per MJ fuel (EF_{MJ}), according to:

$$\boldsymbol{EF_{tkm} = E_{tkm} \times EF_{MJ}} \qquad (22)$$

[19] Only the cargo loaded or unloaded at Schiphol is known, not any cargo already on board.

with energy consumption per tonne-km (E_{tkm}) per aircraft category being calculated by dividing total annual energy consumption (E_{year}) by total annual tonne-km (tkm_{year}), according to Formula 23, and annual energy consumption derived from CO_2 emissions (cf. Subsection 4.7.2).

$$\boldsymbol{E_{tkm}} = \frac{\boldsymbol{E_{year}}}{\boldsymbol{tkm_{year}}} \tag{23}$$

In terms of freight carriage, two aircraft types are distinguished: full-freight and belly-freight, the former carrying freight only, the latter primarily a passenger aircraft, with freight optional. In terms of distance, three classes of flight are distinguished: short-haul (<1,500 km), medium-haul (1,500-6,000 km) and long-haul (>6,000 km). Most European flights are short-haul. This segmentation is such that the average emission factor is most representative for the segment concerned (cf. Figure 10 in Subsection 4.7.2).

As explained in the text box, *STREAM* does *not* include the climate impact of non-CO_2 emissions[20].

Climate impacts of non-CO_2 aviation emissions

In the case of aviation, global warming impact involves not only CO_2, methane (CH_4) and nitrous oxide (N_2O) emissions but several other factors, too, in particular contrails, NO_x emissions and impacts on cloud cover. These occur mainly at altitudes over 9,000 metres. Although the effects of these non-CO_2 emissions are more local and shorter-lasting, the impact is nonetheless significant. In 2005 it was estimated that 40% of the climate impact (radiative forcing) of aviation is due to aviation CO_2 in the atmosphere and 60% to non-CO_2 effects (EEA; EASA: EUROCONTROL, 2019). These percentages refer to the impact of atmospheric CO_2 levels and so cannot be translated directly to the relative impact of non-CO_2 and CO_2 emissions. This is a hotly debated issue and the effects of aviation-induced cloudiness (AIC), in particular, are hard to assess. In many methodologies the CO_2 emissions of the flight or the cruise phase are multiplied by a factor 2 (INFRAS, 2019b). Because of the uncertainty in the quantification of the effect and to keep the scoping of the CO_2-equivalent clear for all modalities, in *STREAM 2020* it has been opted to *exclude* these non-CO_2 emissions, merely mentioning them in this text box.

4.7.2 Energy consumption and CO_2 emissions

Energy consumption per tonne-km was derived from CO_2 emissions per tonne-km using a factor 71.5 g CO_2/MJ (cf. Section 4.8). Based on the annual CO_2 emissions of each category of aircraft ($CO_{2\text{-}a}$) and the tonne-km (tkm) of the aircraft (a) in the given category (cat) the average energy consumption of each category ($E_{tkm(cat)}$) was calculated as follows:

$$\boldsymbol{E_{tkm(cat)}} = \frac{\sum_{a-cat}(\boldsymbol{CO_{2-a}} \times \frac{1}{71.5})}{\sum_{v-cat}(\boldsymbol{tkm_a})} \tag{24}$$

To calculate the energy consumption and CO_2 emissions of the six different categories, use was made of the Small Emitters Tool (SET), with a fixed split being adopted for belly freight to allocate emissions to passengers versus cargo. The tonne-km of each aircraft category can be derived directly from the Schiphol database, which reports both flight distance (as-the-crow-flies) and tonnage.

[20] CH_4 and N_2O *are* included.

CO_2 emissions and energy consumption using Small Emitters Tool

The Small Emitters Tool (SET), administered by EUROCONTROL, calculates fuel burn and CO_2 emissions over the entire flight. It was developed for calculating the emissions of smaller airlines[21] with an obligation to record intra-European flights in connection with EU ETS emission allowances.

The SET algorithm is built around the actual fuel burn of various types of aircraft flying under a range of conditions (EUROCONTROL, 2020). This means that real-world fuel burn on specific flights may deviate somewhat from SET-modelled values, because of differences in weight (passengers vs. cargo), meteorological conditions (wind) or ATC (air-traffic control) delays, for example. As the SET has been used for a large number of flights, however, it is not anticipated that such individual deviations will confound the overall picture.

The most recent (2019) version of the SET was used for the calculations. To plug in the Schiphol data, IATA aircraft types had to be converted to ICAO types. In addition, a correction had to be made for the fact that aircraft rarely if ever fly the shortest route between two airports. This detour distance, a standard feature in the SET, was set at 95 km. With the SET, flight data per aircraft type and distance were converted to fuel consumption and CO_2 emissions for each combination of aircraft type and distance.

Allocation to passengers and freight

The SET output was then used to calculate average energy consumption and CO_2 per tonne-km using Formula 24. For full-freight aircraft this is straightforward, because 100% of fuel burn can be allocated to the cargo carried. Belly-freight aircraft carry both passengers and freight, though, so energy consumption and CO_2 emissions must be allocated accordingly.

At first sight, freight carriage on passenger aircraft might be seen merely as an extra bonus, as the flight would occur anyway for the passengers. The freight volumes routinely carried on passenger flights are substantial, however: in the Netherlands around 60% of total air freight in 2018, according to CBS data. Given its routine nature and the volumes concerned, it cannot be seen merely as a ‘bonus’, then, and so it would be wrong to allocate all the emissions to passengers.

There are various options for allocation across freight and passengers. The first is to allocate emissions on an economic basis. While theoretically of interest, in practice this requires information that is not publicly available, including the actual cost of passenger and freight transport and the prices paid. A second option is to assume 100 kg for an average passenger (incl. luggage), in line with European Standard EN16258, and then allocate the energy consumption associated with the CO_2 emissions according to the total weights of cargo and passengers. This method, used in (IFEU; INFRAS; IVE, 2019), often leads to a relatively low share of passengers in aviation fuel burn and CO_2 emissions, however. A third option is therefore to take 100 kg for an average passenger (incl. luggage) and assume a further 50 kg for each seat. It makes no difference whether or not the seat is actually occupied; this 50 kg per seat covers the weight of the on-board provisions for passengers (seats, toilets, catering, service staff). This is the method used in the ICAO Carbon Emissions Calculator Methodology (ICAO, 2017) and by the ICCT (2019) and is laid down in recommended practice 1678 issued by IATA (2014).

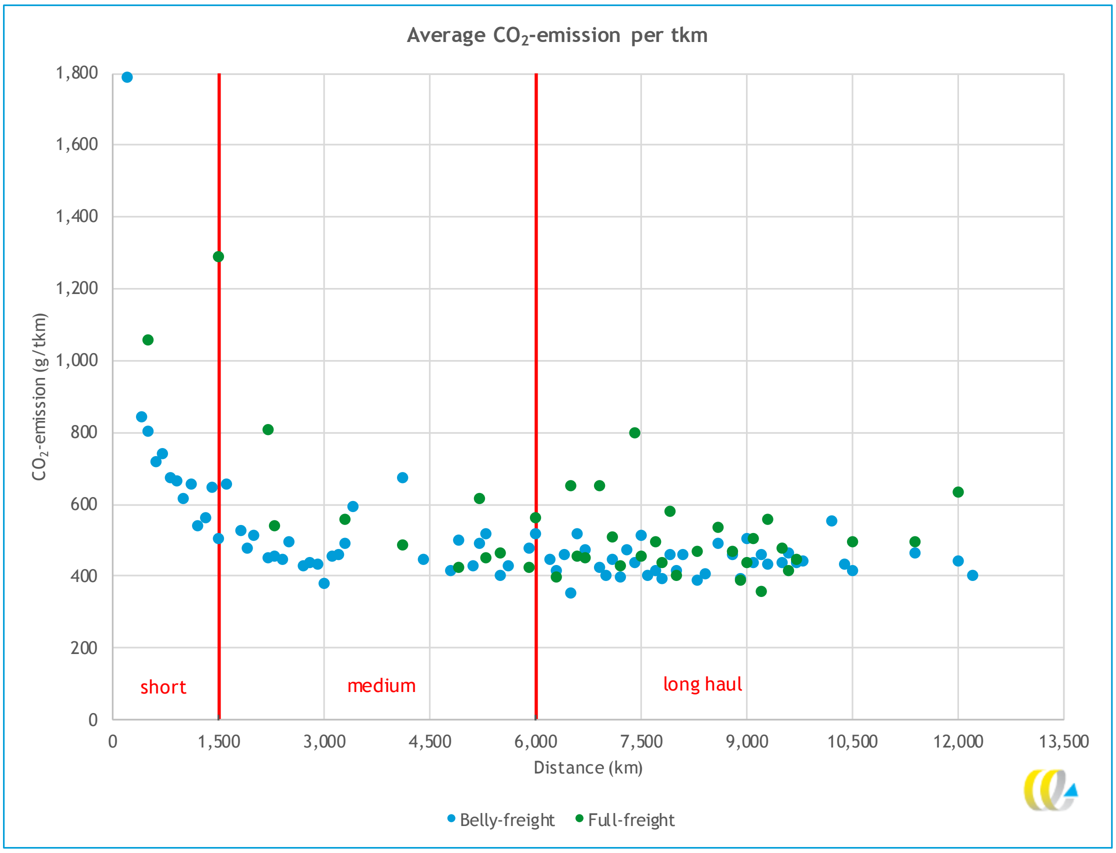
[21] In the EU ETS legislation a smaller airline is defined as one that either (i) flies less than 243 flights per 4-month period for three successive periods, or (ii) has total annual CO_2 emissions below 25,000 t/a (NEa, 2020).

STREAM 2020 adopts the last of these methods. The energy consumption allocated with cargo was calculated from the average number of passengers per flight (*#Pax*), number of seats per flight (*#seats*) and cargo weight per flight (G_{cargo}), according to Formula 25.

$$E_{cargo-flight} = E_{total\ flight} \times \frac{G_{cargo}\ (kg)}{G_{cargo}\ (kg) + \#Pax \times 100 + \#seats \times 50} \qquad (25)$$

The results for the three categories of flight distance distinguished: short, medium and long haul (aggregated within distance bins of 100 km) are shown in Figure 10, indicating the boundaries between them. It is for these three distances that average emission factors are reported in Chapters 2 and 3.

Figure 10 - CO_2 emission per tonne-km by flight distance, belly-freight and full-freight aircraft



4.7.3 Emission data

Aviation CO_2 emissions were discussed in the previous subsection. Air-pollutant emissions are not linked directly to fuel burn but depend on engine type and engine thrust. At the higher thrust used for take-off, these emissions are far higher than during cruising or descent. In addition, there are major differences across engine types. As aircraft manufacturers like to leave engine choice up to customers, aircraft models do not consistently have the same type of engine. To calculate the air-pollutant emissions of the six different aircraft categories, use was made of the Aviation Emissions Calculator of the European Environment Agency (EEA, 2019), combined with the cargo/passenger split explained in Subsection 4.7.2.

Aviation Emissions Calculator

For every aircraft and distance flown, the EEA Aviation Emissions Calculator calculates (among other things) emissions of NO_x, SO_x, H_2O, CO, HC, nvPM[22], vPM[23] and total PM. Given the wide variation in engine type, even for a single aircraft model, the EEA has modelled emissions on the basis of the engine type most commonly used in each model in 2015. The emissions of a two-engined Airbus A320 are based on 3CM026 engines, for example, this being the commonest configuration in 2015.

The data used here for calculating emissions derive from actual flights to and from Schiphol in 2018. While the aircraft used on each of these flights is known, the precise engine configuration is not. It was therefore opted to use the commonest configuration for each aircraft model in the Aviation Emissions Calculator. One drawback of this choice is that several newer aircraft models included in our dataset are absent in the Calculator, however, such as the A380 and models from the A320neo family. This meant that for a small fraction of flights no air-polluting emissions could be calculated, as reported in Table 66. Given the small numbers involved, however, this will have little impact on the emissions reported per tonne-kilometre.

Table 66 – Percentage of flights for which no air-pollutant emissions could be calculated

	Belly freight	Full freight
Short-haul	2.5%	0.2%
Medium-haul	6.7%	0%
Long-haul	3.8%	0.05%

The Aviation Emissions Calculator gives a breakdown between Landing and Take-Off (LTO) and Climb, Cruise and Descent (CCD) emissions (both in kg), the former occurring below 3,000 feet, the latter above. In the tables this distinction is maintained, since air-polluting emissions at high altitudes remain there and have no direct human health impact, while LTO emissions sink and do have an impact. When assigning a value to these emissions, therefore, only the LTO emissions should be taken.

In the Aviation Emissions Calculator LTO emissions are calculated in two ways: using the ICAO default LTO cycle, and with an LTO cycle characteristic of a busy European airport in 2015. These differ in the time spent on successive LTO phases. *STREAM* takes the LTO cycle characteristic of a busy European airport, of which Schiphol is clearly an example. This cycle is six seconds faster than the ICAO default cycle, which means emissions are slightly lower.

The Aviation Emissions Calculator sets a maximum flight distance for each aircraft type. The Schiphol data show, however, that a handful of aircraft types are used for long-haul flights beyond the limit set in the Calculator. For these flights, air-pollutant emissions were calculated by determining the marginal emission per CCD kilometre and using this to

[22] Non-volatile PM.

[23] Volatile PM.

multiply up the additional kilometres and add these emissions to those given by the Calculator.

To calculate the air-polluting emissions per tonne-km we need to know the fraction of tonne-km below 3,000 feet. Taking 15° as average climb angle (Boeing, 2009) and 3.2° as average descent angle (Trax, 2016), the (horizontal) distance flown per LTO event is around 25 km. This can be used to derive the average emission per tonne-km for the whole flight, the LTO portion and the CCD portion.

Alternative fuels and technologies

The International Civil Aviation Organization (ICAO) has drawn up international emission standards – the CAEP standards – to which new aircraft engines must conform. For NO_x these are defined for the LTO cycle and have been steadily tightened since their introduction in 1986 (CAEP1) to the current CAEP8 standard set in 2011. In 2020 additional standards were introduced for PM_c and CO_2 (EASA, 2019; Peeters & Melkert, 2018). The majority of today's aircraft satisfy the CAEP8 standaard.

In contrast with other transport modes, aviation currently makes little if any use of alternative fuels or technologies on any significant scale. To meet climate targets, biokerosene is probably the most promising short-term option. This fuel is similar to Hydrotreated Vegetable Oil, HVO (Peeters & Melkert, 2018) on which its fuel-dependent emissions have here been based (cf. Section 4.8). Fuel burn and PM_c and NO_x emissions have been taken to be comparable with those of regular kerosene jet fuel.

4.8 Fuels and electricity

Fuels

This section discusses the fuel emission factors used for obtaining emissions per tonne-km from energy consumption per tonne-km. Table 68 reports these factors for conventional fuels and Table 69 for alternative fuels. These tables show both TTW emission factors, directly related to fuel burn (CO_2 via carbon content and SO_2 via sulphur content), and WTT emission factors, which by definition are also directly proportional to fuel burn. It is only the emission factors of methane (CH_4) and nitrous oxide (N_2O) included in the TTW CO_2-eq. emissions that are governed not only by fuel burn but also by vehicle drive technology, which differs per mode. In a number of cases, therefore, CO_2-eq. emission factors have been differentiated according to mode or vehicle type.

The values cited for fuel density and calorific value and the resultant TTW-emission factors for CO_2, CO_2-eq. and SO_2 are taken from (Task Force on Transportation, 2020) and (Task Force on Transportation, 2019). Where figures were lacking, additional sources or assumptions were used, as follows:
- The CO_2 emission factors for HFO and MDO are based on (IMO, 2020), which has the same factors as cited in EU Regulation 2015/757 for reporting shipping emissions. They are therefore in line with international methods.
- The SO_2 emission factors for biodiesel are based on (AQB, 2018), those for HVO on (Neste, 2016).
- The SO_2 emissions of LPG have been assumed equal to those of CNG.

- The vehicle- and vessel-specific CH_4 and N_2O emissions for (bio)CNG and (bio)LNG are based on (TNO, 2015d).
- The CH_4 and N_2O-emission factors of GTL (as elements of CO_2-eq.) have been taken equal to those of diesel.
- The fuel characteristics of HVO and GTL are from (TNO, 2018a), those of CNG and LNG from (TNO, 2015d) and (LNG24, 2015).

The WTT CO_2 emission factors are based on the WTW factors laid down in the European Fuel Quality Directive (FQD) (EU, 2015a), for use by fuel suppliers and others, including the Netherlands Emission Authority (NEa) (NEa, 2019), for computing emission cuts due to alternative fuels. The WTT emission factors were calculated as the difference between the TTW and WTW factors given in the directive. The figures thus derived are in line with an earlier JRC study commissioned by the European Commission (JRC, 2014b).[24] Figure 11 shows how the WTW emissions are built up for diesel, petrol (gasoline) and HFO. For these three fuels, crude oil production and refinery contribute most to WTW emissions.

The shares of biofuel in diesel (5%) and petrol (4%) and the emission factors for the average biofuel mix are based on the fuel volumes in (NEa, 2019). The CO_2 emission factors for biofuels make no allowance for the emissions from indirect land use (ILUC). According to the data and indices in (NEa, 2019) ILUC is relevant for petrol substitutes only and inclusion would lead to an extra 14.1 g CO_2/J, meaning petrol substitutes would work out at 29.4 g CO_2/MJ. With biodiesel and biogas, produced exclusively from waste, there is no ILUC involved. Overall, ILUC has been ignored in *STREAM 2020*, given that the magnitude of impacts is still being debated. The FQD contains provisions for reducing ILUC, moreover.

For WTT CO_2 emissions, a number of additional assumptions were made and sources used to complete the data set:
- For GTL, the WTT emission factor is based on (JRC, 2014a) and the WTW (and TTW) emission factors on LNG, as cited in the FQD (EU, 2015a).
- For HFO (3.5% S), the WTT emission factor is based on the value cited in (JRC, 2014b).
- For MDO and kerosene, the WTT emission factors were taken slightly lower than for diesel, based on (JRC, 2014b), owing *inter alia* to lower transport emissions (cf. Figure 11), and coming to 20 g CO_2-eq./MJ. That MDO and kerosene WTT emissions are close to those for diesel is confirmed by other sources (BEIS, 2020; IFEU; INFRAS; IVE, 2020).
- For low-sulphur HFO a reliable data source is lacking. TTW emissions will be higher than for HFO (3.5% S), owing to the extra energy needed for desulphurisation, but lower than for MDO. WTT emissions have been taken as the average of HFO and MDO.

Figure 11 - WTW emissions reported in (JRC, 2014b); OPGEE = Oil Production Greenhouse gas Emissions Estimator

WTW marginal refining emissions + OPGEE production emissions			
[$gCO_{2\ eq}$/MJ final fuel]	DIESEL	GASOLINE	HFO
1) production emissions from OPGEE including transport of crude	11.0	10.8	10.5
3) refining emissions	8.6	7.0	2.2
4) transport of product	1.1	1.2	0
5) combustion emissions	73.2	73.4	80.6
Total emissions	**93.9**	**92.4**	**93.3**

[24] As *STREAM 2020* was being completed a new JEC study was published with updated values, which are generally slightly lower (by 2 g/MJ = 10%).

In *STREAM 2016*, WTT air pollutant emission factors were based on Ecoinvent[25]. In *STREAM 2020* these have again been adopted, supplemented as necessary with values from Ecoinvent 3.5 (Wernet, et al., 2016).

Electricity

STREAM works with the average electricity production mix in the Netherlands, including the share of renewables, which are therefore not treated separately (for more on this, see following text box). For alternative fuels and technologies, though, we do report the emissions associated with electricity based on the Dutch renewable production mix (wind/solar/biomass), both with and without biomass.

Electric vehicles have zero direct emissions, only upstream emissions due to power generation and production/transport of power-station fuel. Power-plant emissions are based on a recent study of the Dutch electricity mix in 2018 (CE Delft, 2020a) that calculates the emissions associated with the entire chain from fossil resource extraction up to and including power generation. For low and medium voltage power supply, figures were adjusted upwards by 3% and 1.2%, respectively, for conversion and grid transmission losses.

Two approaches for electricity

The emission factors calculated in *STREAM* are based on the domestic Dutch electricity *production mix*, supplemented by the imports required when demand exceeds supply. An alternative approach is to proceed from the Dutch *trade mix*. In that case the mix is determined by the Guarantees of Origin (GOs) associated with the electricity supplied in the Netherlands. This means, for example, that green electricity from Norway for which the GOs have been bought by Dutch power companies is also included in the Dutch mix. From this perspective, companies purchasing GOs for the electricity they use can count these as “zero-emission” (with upstream emissions for bio-energy only).

In this study we have opted to base calculations on the Dutch *production mix*, motivated in part by the fact that a GO generally costs only a fraction of the additional cost of wind or solar subsidised under the Dutch SDE renewable energy incentive scheme. It can thus be reasoned that it is the Dutch taxpayer who is paying most of the additional costs by way of the SDE subsidy.

In contrast to *STREAM 2016*, the CO_2 emission factors for solar and wind power now include the CO_2 emissions of photovoltaic cell and wind turbine production, based on (CE Delft, 2020a). This is because of the relatively short service life of both cells and turbines (compared with a coal-fired power station). If these were not included, the emissions would be near-zero. For other forms of electricity, infrastructure-related emissions are negligible, because of the long service life of the technology.

As no emission factors for PM_c, NO_x or SO_2 are provided In (CE Delft, 2020a), these were calculated from the data underpinning the study, which are based on Ecoinvent 3.5 (Wernet, et al., 2016), though with two important updates:
- The emissions of coal-, biomass- and gas-fired power stations have been adjusted based on the 2017 figures reported for Dutch power stations under European legislation (EEA, 2020)[26], as shown in Table 67.
- The maritime shipping emissions for coal transport are based on the emissions of a 60,000-99,999 dwt bulk carrier, as reported here in *STREAM 2020*.

[25] The emissions associated with infrastructure are not included in the Ecoinvent calculations.

[26] Industrial Reporting under the EU Industrial Emissions Directive 2010/75/EU and European Pollutant Release and Transfer Register Regulation (EC) No. 166/2006.

Table 67 – Power station emissions (mg/kWh power output)

	SO_2 (mg/kWh)	NO_x (mg/kWh)	PM (mg/kWh)
Coal-fired	128.507	208.269	7.410
Biomass-fired	58.786	233.904	2.120
Gas-fired, cogeneration	0.109	108.424	0.278
Gas-fired, non-cogeneration	0.144	142.663	0.366

Table 68 and 69 report the emission factors for both fuels and electricity.

Table 68 – Emission factors (g/MJ) of fuels and electricity for freight transport, 2018

Fuel	Application	Density (kg/litre)	Cal. value (MJ/kg)	TTW (g/MJ)			WTT (g/MJ)			
				CO_2-eq.	CO_2	SO_2	CO_2-eq.	NO_x	PM	SO_2
Diesel, fossil	(various)	0.84	43.2	NG	72.5	0.00044	22.6	0.032	0.003	0.098
Biodiesel, NL blend 2018 (97% FAME, 3% HVO)	(various)	0.88	37.0	NG	-	0.000377	13.5	0.050	0.008	0.026
Diesel, NL blend 2018 (5% biodiesel, MJ/MJ)	Cars[a]			69.5						
	Vans			69.3						
	Trucks	0.84	42.8	70.0	68.9	0.00044	22.1	0.033	0.004	0.094
	Inland shipping			69.6						
	Rail			69.2						
Electricity (av. mix)	Road/rail (med.-voltage)	N.a.	N.a.	-	-	-	134.9	0.096	0.005	0.040
	Road (low-voltage)	N.a.	N.a.	-	-	-	137.3	0.097	0.005	0.041
HFO (3.5% S [b])	Maritime shipping	0.97	41.0	78.2	77.5	1.07	12.7	0.031	0.003	0.092
HFO (0.5% S [b])	Maritime shipping	0.97	41.0	78.2	77.5	0.24	16.4	0.031	0.003	0.094
MDO (0.1% S [b])	Maritime shipping	0.84	42.7	75.8	75.1	0.05	20.0	0.032	0.003	0.096
HFO (0.5% S [b])/MDO, av.	Maritime shipping	-	41.9	77.0	76.3	0.15	18.2	0.031	0.003	0.095
Kerosene	Aviation	0.8	43.5	72.0	71.5	0.023	20.0	0.041	0.005	0.099

NG: Not given; values are vehicle-specific.

N.a. Not applicable

[a] Not relevant for freight transport, but cited as a reference.

[b] This is the maximum fuel sulphur content.

Table 69 – Emission factors (g/MJ) of alternative fuels and green electricity for freight transport, 2018

Fuel	Application	Density (kg/litre)	Cal. value (MJ/kg)	TTW (g/MJ)			WTT (g/MJ)			
				CO_2-eq.	CO_2	SO_2	CO_2-eq.	NO_x	PM	SO_2
Petrol	Petrol (fossil)	0.750	43	-	73.0	0.00045	20.30	0.041	0.004	0.126
	Petrol substitutes (av.)	0.748	27	-	-	0.00045	29.40[e]	0.160	0.029	0.205
	Vans (blend, 4% bio)	0.750	42	70.9	70.2	0.00045	20.86[e]	0.049	0.006	0.131
LPG	Vans	0.536	45	67.0	66.7	0.00020	6.9	0.045	0.003	0.039
	Trucks			67.5						
HVO	Trucks	0.785	44	1.1	-	0.00023	9.40	0.050	0.008	0.026
	Inland/maritime shipping			0.7						
CNG	Vans	0.167	38	60.1	56.5	0.00020	9.20	0.006	0.0001	0.0003
	Trucks			60.1						
BioCNG	Vans	0.167	38	3.6	-	0.00020	24.00	0.016	0.001	0.006
	Trucks			3.6						
LNG	Road	0.45	49	60.1	56.5	0.00020	14.40	0.027	0.001	0.0004
	Inland/maritime shipping (lean-burn or dual-fuel, 3% diesel)			73.5						
	Maritime shipping (dual-fuel, direct-injection, <10% MGO)			58.2						
BioLNG	Road	0.45	49	3.6	-	0.00020	25.60	0.016	0.001	0.006
	Inland/maritime shipping (lean-burn or dual-fuel, <10% diesel)			17.9						
	Maritime shipping (dual-fuel, direct-injection,<10% MGO)			1.7						
GTL	Trucks	0.78	44	72.0	70.9	0.00020	23.40	0.036	0.004	0.111
	Inland shipping			71.6						
Hydrogen [a]	Fuel cell	-	120	-	-	-	104.30	0.134	0.019	0.133
Green hydr. [b]	Fuel cell	-	120	-	-	-	9.10	0.0001	0.00001	0.0001
Green electr. [c]	Battery	-	N.a.	-	-	-	9.87	0.018	0.002	0.005
Green electr., no biomass [d]	Battery	-	N.a.	-	-	-	4.55	0.00003	0.000005	0.00004

[a] Produced by steam reforming; [b] Using non-biomass renewables (wind, solar); [c] Dutch mix of biomass, wind & solar; [d] Dutch mix without biomass;

[e] Including ILUC, values for petrol substitutes and blend come to resp. 43.5 and 21.7 g/MJ using method in (NEa, 2019).

4.9 Transhipment

With multimodal transportation, the emissions associated with loading and unloading operations can make a sizable contribution to the overall transport footprint. Particularly when comparing two transport variants, one involving more transhipment than the other, it is important to factor in these emissions.

Data on the energy consumption associated with transhipment have been taken from (IFEU; INFRAS; IVE, 2014) and for containers from (TNO, 2016c), as follows:

- container transfer, per move[27] 4.4 kWh/TEU (52.2 MJ_e/TEU)
- transfer of liquid load 0.4 kWh/t (1.4 MJ_e/t)
- transfer of bulk load 1.3 kWh/t (4.7 MJ_e/t)
- transfer of other load 0.6 kWh/t (2.2 MJ_e/t)

For the emission factors of cranes and other machinery involved in transhipment, the figures reported in Table 70 were used in *STREAM*. The factors for diesel are based on (TNO, 2016c), for electric on those given in the previous section, with 10% electromotor efficiency losses assumed.

Table 70 – Average emission factors (g/kWh) for mobile machinery, 2018

	CO_2-eq.	NO_x	PM_c	SO_2
Diesel	779	3.16	0.17	0.005
Electric	549	0.39	0.02	0.164

[27] On average, 3-4 moves per container transfer (offloading/parking/reloading).

5 Logistics data

5.1 Introduction

As explained in Chapter 4, vehicle load capacity and capacity utilisation go a long way to determining emissions per tonne-kilometre. Capacity utilisation is defined as the load factor on loaded kilometres multiplied by the percentage share of loaded vehicle-kilometres. Load factor is the proportion of total vehicle load capacity taken up by the load in a laden vehicle, weighted over kilometres travelled.

While load factor has only a limited effect on emissions per *vehicle*-kilometre, it knocks on significantly in *tonne*-kilometre terms. When fully laden, trucks burn around 20% more fuel than when semi-laden (50%), but tonne-km are doubled. As a result, emissions per tonne-km decrease by 40%. In principle, this holds for all transport modes. While empty trips leave tonne-km transport performance unchanged, they do contribute to emissions, thus adding to overall emissions per tonne-km.

In *STREAM* it has been opted to express transport performance in tonne-kilometres. In principle a different measure could have been adopted, such as volume-km (m^3-km), package-km or pallet-km. The tonne-km unit can be used in a broad range of contexts, though, and is widely recognised by players on all sides.

Having made this choice, though, it is important to distinguish between types of freight. A low load factor does not necessarily mean a vehicle is being inefficiently used. A vehicle fully laden with feathers will always have a lower load factor than one half-laden with coal. In the case of inland shipping, water level and waterway depth are also key factors in how full a vessel can be loaded. Effective capacity at low water levels may be less than maximum capacity at high levels (the capacity reported here). For container ships on waterways with low bridges, high water may in contrast mean containers can be stacked less high.

The load factors reported in this study are therefore not intended to make any judgment on transport efficiency, but designed purely for calculating the emission factors per tonne-km for the various modes. For loaded kilometres, too, it holds that these should not be used to pronounce on whether or not vehicles or vessels are being efficiently utilised. For some types of transport (coal, for instance) it is simply unfeasible to make the return trip loaded. Generally speaking, freight with a high load factor (like coal) is associated with fewer laden kilometres, freight with a low load factor often with more.

The logistics data used for transport of bulk/packaged goods are given In Section 5.2, those for container transport in Section 5.3. The tonnages used for container transport refer solely to the weight of the container contents. The weight of the container itself is thus not included in transport performance. In calculating fuel consumption, however, the weight of the container *is* factored in. In calculations on container transport for all transport modes an average container load (tonne/TEU) and average share of empty containers have been used. While in reality there will be differences between the various modes, for comparison on equal footing average values have been used throughout.

The logistical parameters used in *STREAM* are based on the following sources:
- (Bundesamt, 2014) – road transport;
- (Destatis, 2015) – rail, inland shipping;
- (EU-MRV dataset, 2020) – maritime shipping;
- (Statline (CBS), 2020) – all modes;
- (CE Delft, 2011) - all modes;
- (IFEU, Infras, IVE, 2014) – logistical parameters for containers.

The parameters from these statistics are not always complete for all the categories of vehicle and vessel distinguished in *STREAM* and have therefore been supplemented with estimates of our own. The logistical parameters adopted were then put to branch organisations and carriers in a consultation round. Based on their response and the data subsequently obtained the parameters were then finalised, as shown in the tables making up the rest of this chapter.

5.2 Bulk/packaged goods

Table 71 - Logistical parameters for light, medium and heavy loads, bulk/packaged goods, all vehicle/vessel categories

Vehicle/vessel category	Load capacity (tonne)	Medium load			Light load			Heavy load		
		Load factor	Laden km	Utilisation	Load factor	Laden km	Utilisation	Load factor	Laden km	Utilisation
Road transport										
Van, EW 2,000-2,500 kg	1.2	41%	79%	32%	27%	27%	27%	N.a.	N.a.	N.a.
Truck, GVW <10 t, no trailer	3.0	48%	73%	35%	76%	76%	76%			
Truck, GVW 10-20 t, no trailer	7.5	52%	75%	39%	21%	21%	21%	64%	65%	42%
Truck, GVW 10-20 t, with trailer	18.0	52%	75%	39%	28%	28%	28%	64%	65%	42%
Truck, GVW >20 t, no trailer	13.0	52%	75%	39%	75%	75%	75%	64%	65%	42%
Truck, GVW >20 t, with trailer	28.0	52%	75%	39%	21%	21%	21%	64%	65%	42%
Tractor-semitrailer, light	15.7	52%	65%	34%	30%	30%	30%	64%	55%	35%
Tractor-semitrailer, heavy	29.2	65%	70%	46%	85%	85%	85%	80%	60%	48%
LHV	40.8	65%	70%	46%	26%	26%	26%	80%	60%	48%
Rail transport										
Medium-length train	*See Table 72	80%	60%	48%	40%	80%	32%	98%	55%	54%
Long train		80%	60%	48%	40%	80%	32%	98%	55%	54%
Extra-long train		80%	60%	48%	40%	80%	32%	98%	55%	54%
Inland shipping										
Spits vessel	365	75%	70%	53%	45%	75%	34%	90%	60%	54%
Campine vessel	617	75%	70%	53%	45%	75%	34%	90%	60%	54%
Rhine-Herne canal vessel	1,537	75%	70%	53%	45%	75%	34%	90%	60%	54%
Large Rhine vessel	3,013	65%	85%	55%	40%	87%	35%	80%	70%	56%
Class Va + 1 Europa II barge, wide	5,046	65%	85%	55%	40%	87%	35%	80%	70%	56%
4-barge push convoy	11,181	65%	85%	55%	40%	87%	35%	80%	70%	56%
6-barge push convoy, wide	16,481	65%	85%	55%	40%	87%	35%	80%	70%	56%

<table>
<tr><th rowspan="2">Vehicle/vessel category</th><th rowspan="2">Load capacity (tonne)</th><th colspan="3">Medium load</th><th colspan="3">Light load</th><th colspan="3">Heavy load</th></tr>
<tr><th>Load factor</th><th>Laden km</th><th>Utilisation</th><th>Load factor</th><th>Laden km</th><th>Utilisation</th><th>Load factor</th><th>Laden km</th><th>Utilisation</th></tr>
<tr><td colspan="11">Maritime shipping</td></tr>
<tr><td>Bulk carrier, 0-4,999 dwt</td><td>4,450</td><td rowspan="2">N.a.</td><td rowspan="2">N.a.</td><td rowspan="2">N.a.</td><td rowspan="2">N.a.</td><td rowspan="2">N.a.</td><td rowspan="2">N.a.</td><td rowspan="2">NC</td><td rowspan="2">NC</td><td>54%</td></tr>
<tr><td>Bulk carrier, 5,000-9,999 dwt</td><td>8,005</td><td>54%</td></tr>
<tr><td>Bulk carrier, 10,000-34,999 dwt</td><td>28,385</td><td rowspan="5">N.a.</td><td rowspan="5">N.a.</td><td rowspan="5">N.a.</td><td rowspan="17">N.a.</td><td rowspan="17">N.a.</td><td rowspan="17">N.a.</td><td rowspan="17">NC</td><td rowspan="17">NC</td><td>64%</td></tr>
<tr><td>Bulk carrier, 35,000-59,999 dwt</td><td>42,731</td><td>65%</td></tr>
<tr><td>Bulk carrier, 60,000-99,999 dwt</td><td>80,379</td><td>55%</td></tr>
<tr><td>Bulk carrier, 100,000-199,999 dwt</td><td>170,075</td><td>61%</td></tr>
<tr><td>Bulk carrier, 200,000+ dwt</td><td>221,009</td><td>55%</td></tr>
<tr><td>General cargo ship, 0-4,999 dwt</td><td>3,552</td><td rowspan="4">NC</td><td rowspan="4">NC</td><td>31%</td><td>52%</td></tr>
<tr><td>General cargo ship, 5,000-9,999 dwt</td><td>7,966</td><td>31%</td><td>52%</td></tr>
<tr><td>General cargo ship, 10,000-19,999 dwt</td><td>13,116</td><td>33%</td><td>46%</td></tr>
<tr><td>General cargo ship, 20,000+ dwt</td><td>30,528</td><td>40%</td><td>50%</td></tr>
<tr><td>Oil tanker, 0-4,999 dwt</td><td>3,357</td><td rowspan="8">N.a.</td><td rowspan="8">N.a.</td><td rowspan="8">N.a.</td><td>40%</td></tr>
<tr><td>Oil tanker, 5,000-9,999 dwt</td><td>7,428</td><td>47%</td></tr>
<tr><td>Oil tanker, 10,000-19,999 dwt</td><td>15,262</td><td>46%</td></tr>
<tr><td>Oil tanker, 20,000-59,999 dwt</td><td>43,288</td><td>51%</td></tr>
<tr><td>Oil tanker, 60,000-79,999 dwt</td><td>73,202</td><td>60%</td></tr>
<tr><td>Oil tanker, 80,000-119,999 dwt</td><td>110,775</td><td>53%</td></tr>
<tr><td>Oil tanker, 120,000-199,999 dwt</td><td>157,137</td><td>56%</td></tr>
<tr><td>Oil tanker, 200,000+ dwt</td><td>310,100</td><td>73%</td></tr>
</table>

* Load capacity differs per weight category because different wagon combinations are used.

N.a.: Not applicable: vehicle/vessel not used for this type of freight.

NC: Not calculated: for these vehicles/vessels, only utilisation estimated.

Table 72 - Load capacity of trainload combinations, bulk/packaged goods

Load	Use	Train length	Load capacity (tonne)
Light	Grain	Medium-length	945
	Neobulk	Long	1,134
	Neobulk	Extra-long	1,296
Medium	Neobulk	Medium-length	1,715
	Neobulk	Long	2,058
	Neobulk	Extra-long	2,352
Heavy	Tank wagons	Medium-length	1,940
	Tank wagons	Long	2,231
Extra-heavy	Coal/ore	Medium-length	2,485
	Coal/ore	Long	3,124

Table 73 - Belly-freight aircraft loads, bulk/packaged goods

	Total load, incl. passengers (tonne)	Cargo load (tonne)
Short-haul	21	0
Medium-haul	39	5
Long-haul	57	11

Table 74 - Full-freight aircraft loads, bulk/packaged goods

	Average capacity (tonne)	Utilisation
Short-haul	56	53%
Medium-haul	106	73%
Long-haul	111	75%

5.3 Container transport

Table 75 - Load capacity and average slot utilisation, container transport

Vehicle/vessel category	Load capacity (TEU)	Average slot utilisation[28]
Road transport		
Heavy truck, >20 t, no trailer	1	70%
Heavy truck, >20 t, with trailer	2	70%
Tractor-semitrailer	2	70%
LHV	3	70%
Rail transport		
Long train	88/90/96*	80%
Extra-long train	100/105/108*	80%
Inland shipping		
Neo Kemp (32-48 TEU)	40	75%
Rhine-Herne canal vessel (96 TEU)	96	75%
Europa IIa push convoy (160 TEU)	160	75%
Large Rhine vessel (208 TEU)	208	75%

[28] Including return transport and empty containers.

Vehicle/vessel category	Load capacity (TEU)	Average slot utilisation[28]
Extended Large Rhine vessel (272 TEU)	272	75%
Coupled: Europa II-C3l (348 TEU)	348	75%
Rhinemax vessel (398-470 TEU)	434	75%
Maritime shipping		
Container ship, 0-999 TEU	810	NC
Container ship, 1,000-1,999 TEU	1,395	NC
Container ship, 2,000-2,999 TEU	2,537	NC
Container ship, 3,000-4,999 TEU	4,119	NC
Container ship, 5,000-7,999 TEU	6,200	NC
Container ship, 8,000-11,999 TEU	9,244	NC
Container ship,12,000-14,499 TEU	13,625	NC
Container ship, 14,500-19,999 TEU	17,546	NC
Container ship, 20,000+ TEU	20,563	NC

* Load capacity for light, medium and heavy loads; differs per weight category because different wagon combinations are used.

NC: Not calculated: the data sources used report average tonne-km, which were used here for calculation.

Table 76 – Load factors, loaded kilometres and capacity utilisation for light, medium and heavy loads, all container modes

Container transport	Light	Medium	heavy
Percentage laden containers	72%	72%	72%
Percentage empty containers	28%	28%	28%
Load weight per laden TEU*	6 t/TEU	10.5 t/TEU	14.5 t/TEU
Empty container weight per TEU*	1.90 t/TEU	1.95 t/TEU	2.00 t/TEU
Calculated values			
Av. load per TEU (full and empty container), with container [a] (*tonne/TEU$_2$*)	6.2 t/TEU	9.6 t/TEU	12.5 t/TEU
Av. load per TEU (full and empty container), without container [b] (*tonne/TEU$_1$*)	4.3 t/TEU	7.6 t/TEU	10.5 t/TEU

* Based on (IFEU; INFRAS; IVE, 2014).

[a] (Load weight per laden TEU · Percentage laden) + Empty container weight/TEU.

[b] Load weight per laden TEU · Percentage laden.

5.4 Vans

Table 77 – Load capacity, load factors, loaded km and utilisation for use of vans for varying purposes (based on CBS data)

Use	Vehicle category (empty weight)	Load cap. (tonne)	Load factor excl. tools	Load factor incl. tools	Laden km	Utilisation
Construction	Van <1,500 kg	0.7	7%	17%	100%	17%
Construction	Van 1,500-2,000 kg	1.1	7%	20%	100%	20%
Construction	Van 2,000-2,500 kg	1.1	9%	29%	100%	29%
Construction	Van >2,500 kg	0.8	42%	64%	100%	64%
Service	Van <1,500 kg	0.7	5%	16%	100%	16%
Service	Van 1,500-2,000 kg	1.1	7%	21%	100%	21%
Service	Van 2,000-2,500 kg	1.1	9%	24%	100%	24%
Service	Van >2,500 kg	0.7	33%	46%	100%	46%
Goods	Van <1,500 kg	0.7	18%	18%	69%	12%
Goods	Van 1,500-2,000 kg	1.1	8%	8%	77%	6%
Goods	Van 2,000-2,500 kg	1.1	26%	26%	78%	20%
Goods (transport firms)*	Van 2,000-2,500 kg	1.2	46%	46%	70%	32%
Goods	Van >2,500 kg	0.7	28%	28%	78%	22%
Mail	Van <1,500 kg	0.7	13%	13%	73%	10%
Mail	Van 1,500-2,000 kg	1.1	12%	12%	78%	10%
Mail	Van 2,000-2,500 kg	1.2	27%	27%	76%	21%
Mail	Van >2,500 kg	0.6	40%	40%	80%	32%
Average	Van <1,500 kg	0.7	7%	16%	95%	16%
Average	Van 1,500-2,000 kg	1.1	7%	19%	96%	19%
Average	Van 2,000-2,500 kg	1.1	15%	26%	92%	24%
Average	Van >2,500 kg	0.7	33%	41%	87%	36%

* This category is a subcategory of goods in general and particular for vans owned by transport & storage firms (most commonly a 2.0-2.5 t van). These are the figures used in Table 4 for medium-weight loads. For light loads (Tabel 2 and 5), the values for Mail were taken.

6 Intermodal comparisons

6.1 Introduction

To illustrate how the *STREAM* emission factors (for the year 2018) can be used for calculation purposes, in this chapter we consider several practical cases, as was done in previous editions of *STREAM*. The Rotterdam-Duisburg, Amsterdam-Regensburg and Rotterdam-Lithuania examples are parallel to those in *STREAM 2016*, while Kenia-Utrecht is new and includes a segment of air transport, which is new in *STREAM 2020*.

To calculate the emissions associated with a particular transport operation requires information under four headings:
- transport distance;
- up- and downstream transport;
- logistics data
- transhipment.

In the examples below, the total emissions per tonne freight are calculated for the corridor concerned. As the health damage due to NO_x and PMv$_5$ depends on where the pollutants are emitted, the results of these case studies cannot be used to pronounce on the NO_x and PMvimpacts of the various transport options. Additionally, the radiative forcing resulting from aircraft emissions is due to more than just CO_2 emissions (see the text box in Subsection 4.7.1). For information on the adverse impacts of transport emissions the reader is referred to (CE Delft; INFRAS; TRT; Ricardo, 2019).

6.2 Example 1: Rotterdam-Duisburg

The first example evaluates transport of a medium-weight container from Rotterdam to Duisburg, a case involving little upstream or downstream transport. The comparison includes the impact on emissions per tonne downstream transport to Essen and Dortmund. The distances for the various modes are summarised in Table 78. The results are shown in Figure 12 to 15 for CO_2, SO_2, PM_c and NO_x, respectively.

Table 78 - Distances, Rotterdam-Duisburg example; downstream transport by truck-semitrailer

	Rotterdam-Duisburg		Rotterdam-Essen		Rotterdam-Dortmund	
	Main leg (km)	Down-stream (km)	Main leg (km)	Down-stream (km)	Main leg (km)	Down-stream (km)
Tractor-semitrailer, heavy	240 (0:12:88)*	0	266 (0:11:89)*	0	290 (1:11:88)*	0
Train, electric, medium-length	241	0	241	26 (8:0:92)*	241	63 (6:6:87)*
Train, diesel, medium-length	241	0	241	26 (8:0:92)*	241	63 (6:6:87)*
Extended Large Rhine vessel (272 TEU)	253	0	253	26 (8:0:92)*	253	63 (6:6:87)*
Rhinemax vessel (434 TEU)	253	0	253	26 (8:0:92)*	253	63 (6:6:87)*

* Urban : rural : motorway.

Figure 12 - CO_2 emissions per tonne for medium-weight container transport, Rotterdam-Duisburg example

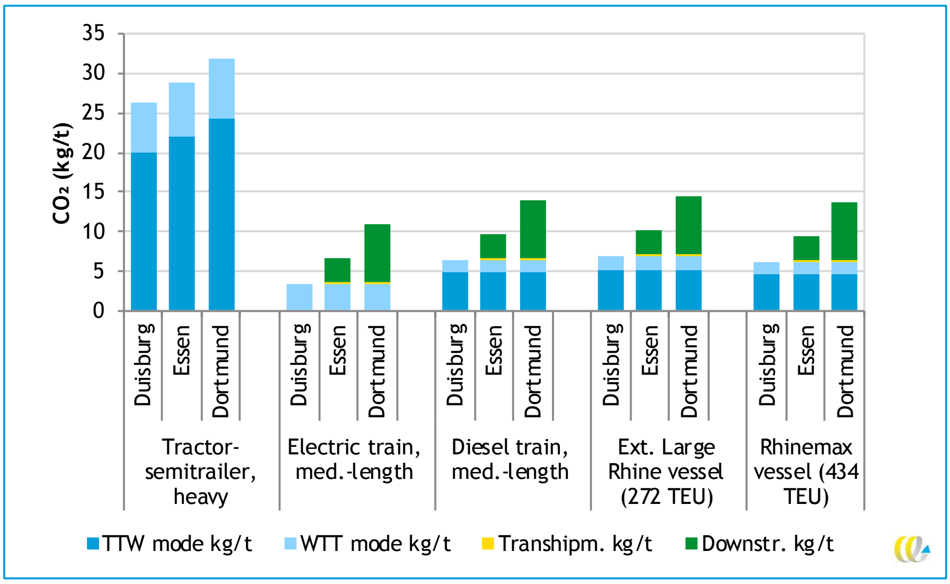


Figure 13 - SO_2 emissions per tonne for medium-weight container transport, Rotterdam-Duisburg example

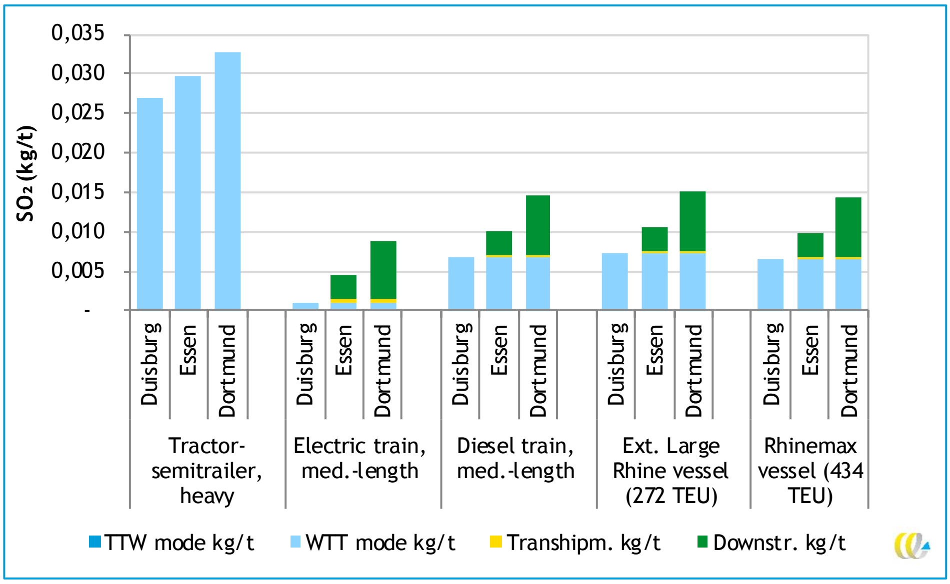


Figure 14 - PM_c emissions per tonne for medium-weight container transport, Rotterdam-Duisburg example

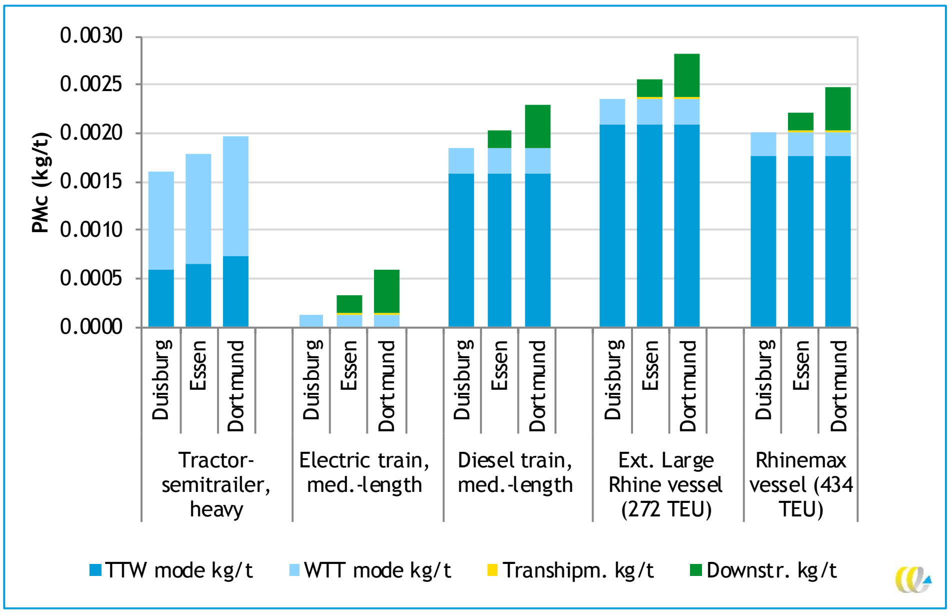
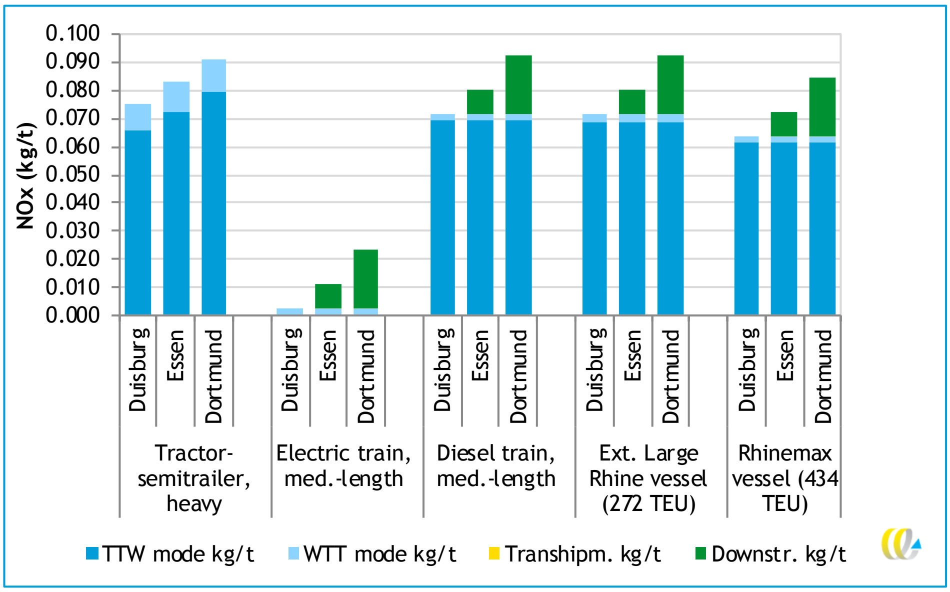


Figure 15 - NO_x emissions per tonne for medium-weight container transport, Rotterdam-Duisburg example



6.3 Example 2: Amsterdam-Regensburg

The second example is transportation of steel from Amsterdam to Regensburg. The impact of downstream transport on emissions per tonne has been taken on board by including the alternative destination of Munich. The distances for the various modes are summarised in Table 79. The results are shown in Figure 16 to 19 for CO_2, SO_2, PM_c and NO_x, respectively

Table 79 - Distances, Amsterdam-Regensburg example; downstream transport by truck-semitrailer

	Amsterdam-Regensburg		Amsterdam-München	
	Main leg (km)	Downstream (km)	Main leg (km)	Downstream (km)
Tractor-semitrailer, heavy	759 (0:0:100)*	0	832 (0:0:100)*	0
Train, electric, long	788	0	868	0
Train, diesel, long	788	0	868	0
Rhine-Herne canal vessel	1,047	0	1,047	141 (0:1:99)*
Large Rhine vessel	1,047	0	1,047	141 (0:1:99)*

* Urban : rural : motorway.

Figure 16 - CO_2 emissions per tonne for heavy bulk transport, Amsterdam-Regensburg example

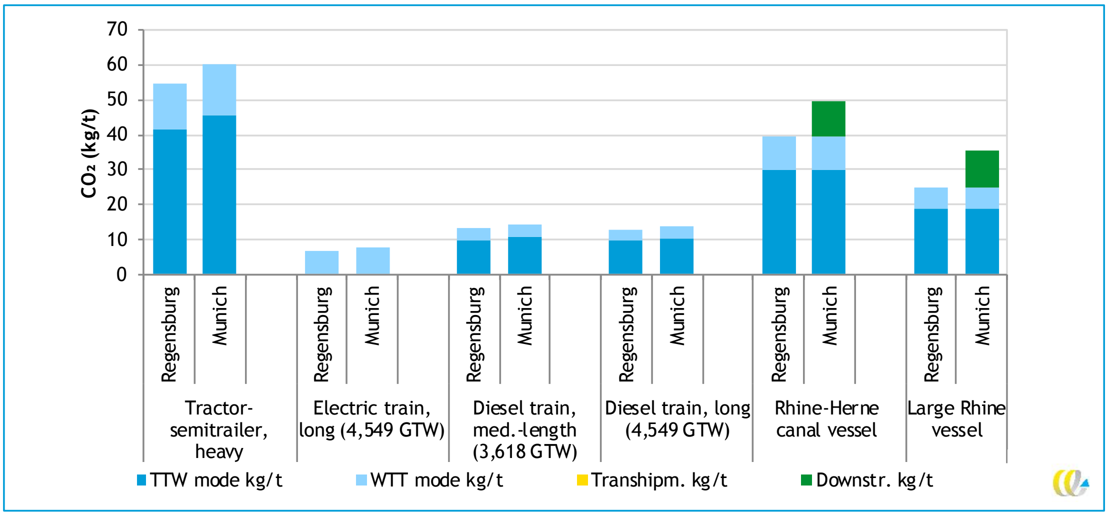


Figure 17 - SO_2 emissions per tonne for heavy bulk transport, Amsterdam-Regensburg example

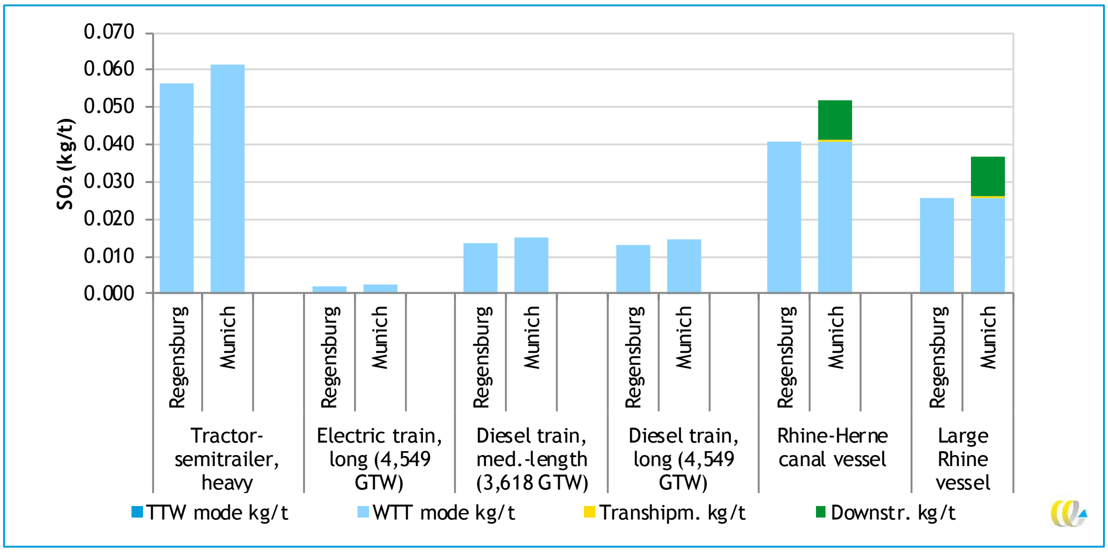


Figure 18 - PM$_c$ emissions per tonne for heavy bulk transport, Amsterdam-Regensburg example

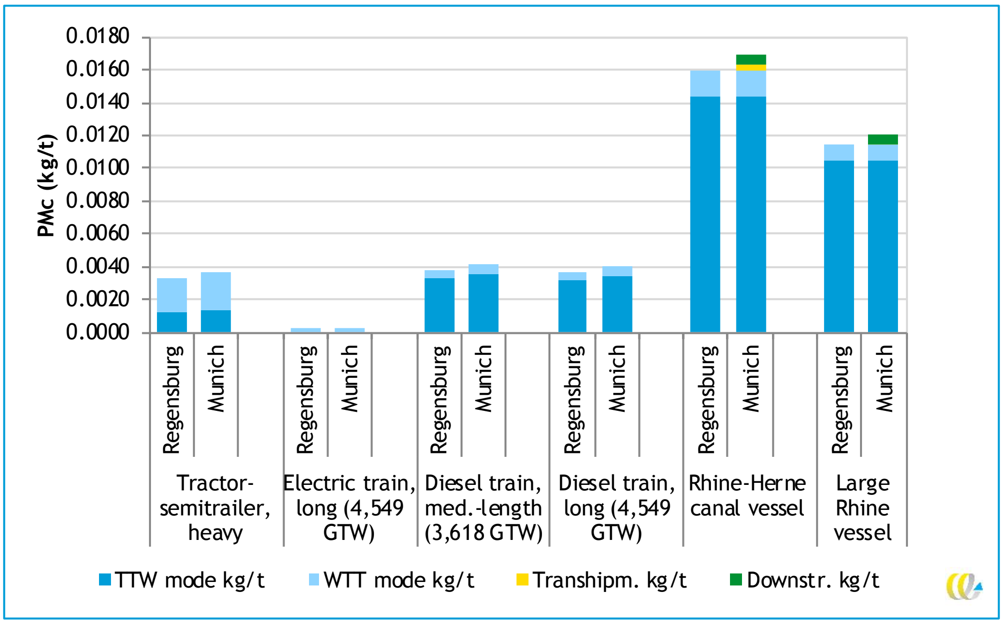
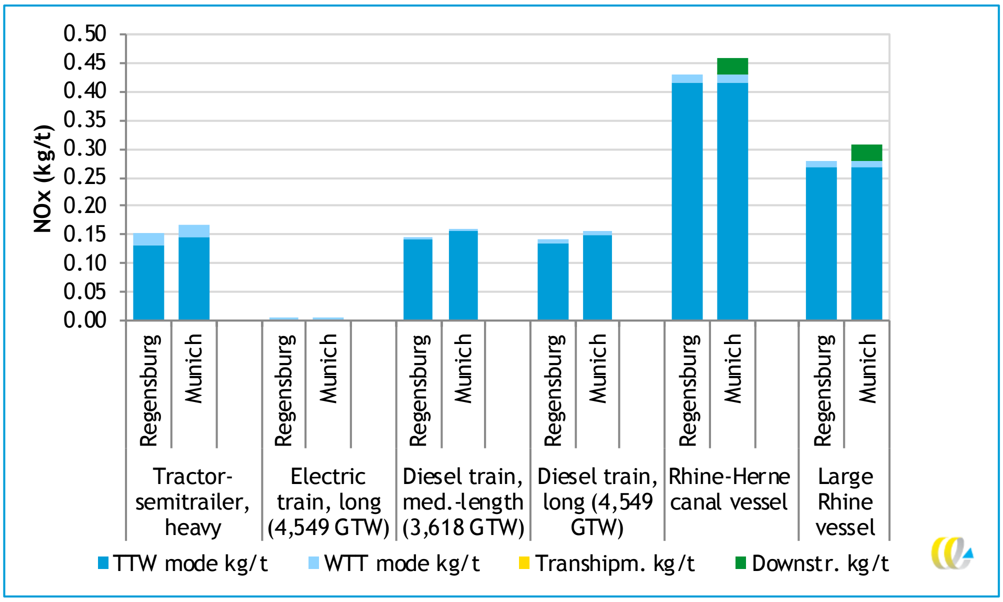


Figure 19 - NO$_x$ emissions per tonne for heavy bulk transport, Amsterdam-Regensburg example



6.4 Example 3: Rotterdam-Lithuania

The third example is transport of a medium-weight container from Rotterdam to Lithuania, with two destinations considered: Klaipeda and Sestokai. Klaipeda is an international seaport with a weekly shipping service to and from Rotterdam. Sestokai has a railway station and lies on the TEN-T Rail Freight Corridor 8 (Rotterdam-Kaunas) (Priority Project 27).

This example not only illustrates the differences between transport modes, but also includes a multimodal option: transport from Rotterdam to Kiel, by either road or rail, followed by sea transport from Kiel to Klaipeda. For legibility, the distinction between TTW and WTT has been omitted. The distances for the various options are summarised in Table 80. The results are shown in Figure 20 to 23 for CO_2, SO_2, PM_c and NO_x, respectively.

Table 80 - Distances, Rotterdam-Lithuania example

	Rotterdam-Klaipeda			Rottterdam-Sestokai		
	Road (km)	Rail (km)	Sea (km)	Road (km)	Rail (km)	Sea (km)
Tractor-semitrailer, heavy	1,821 (0:0:100)*			1,532 (0:1:99)*		
Train, electric, medium-length	309** (2:2:96)*	1,638			1,638	
Container ship (feeder)			1,314	309** (2:2:96)*		1,314
Multimodal: Tractor-semitrailer/ Container ship (feeder)	616 (1:1:98)*		744	N.a.		
Multimodal: Train, medium-length)/Container ship (feeder)		614	744			

* Urban : rural : motorway.

** Downstream transport.

Figure 20 - CO_2 emissions per tonne for medium-weight container transport, Rotterdam-Lithuania example

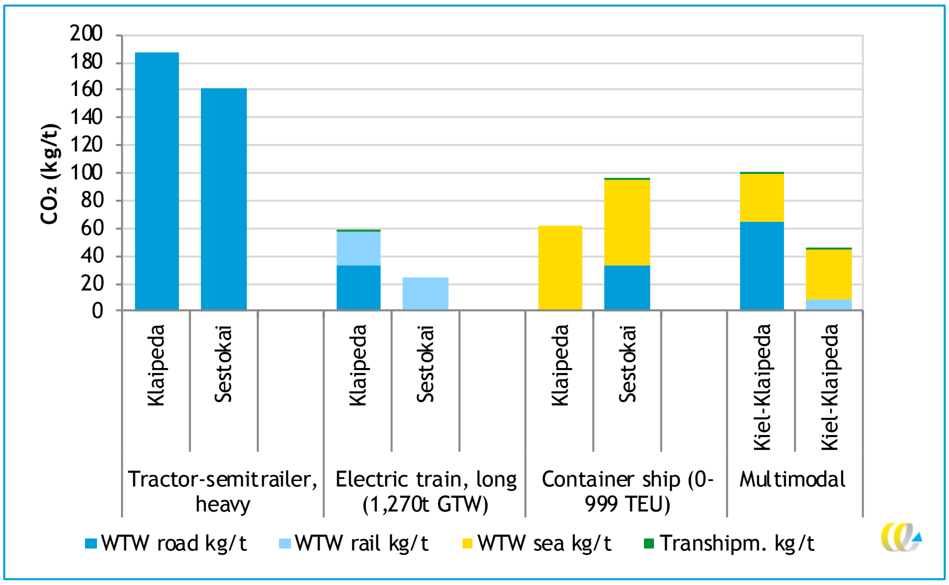


Figure 21 - SO_2 emissions per tonne for medium-weight container transport, Rotterdam-Lithuania example

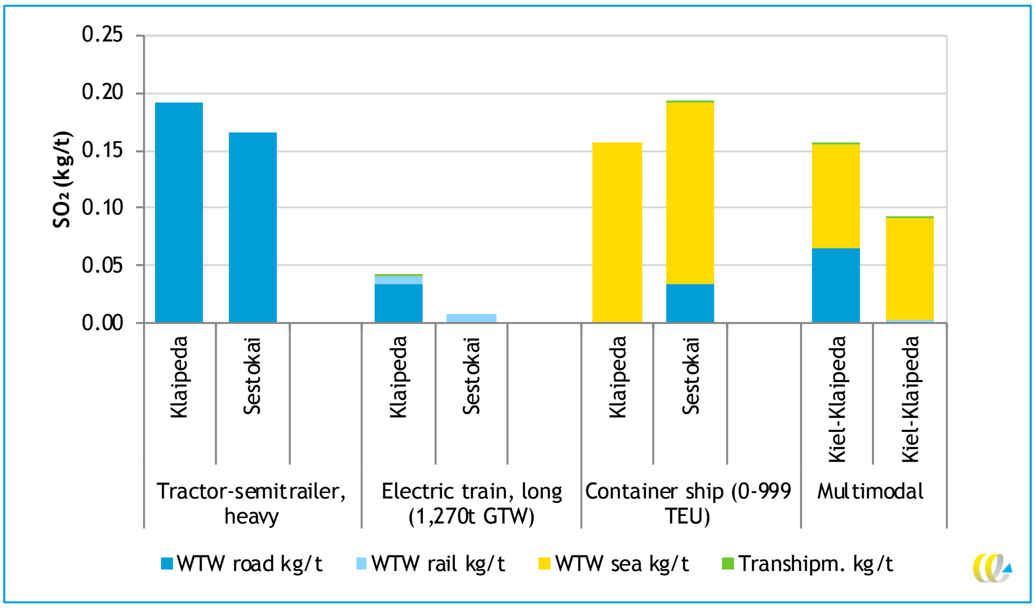


Figure 22 - PM_c emissions per tonne for medium-weight container transport, Rotterdam-Lithuania example

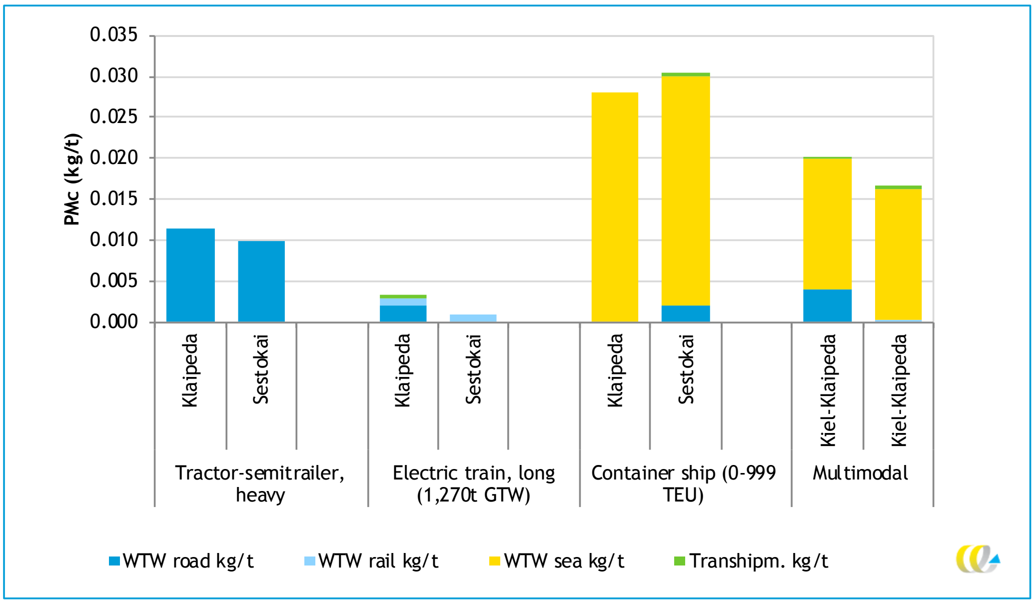
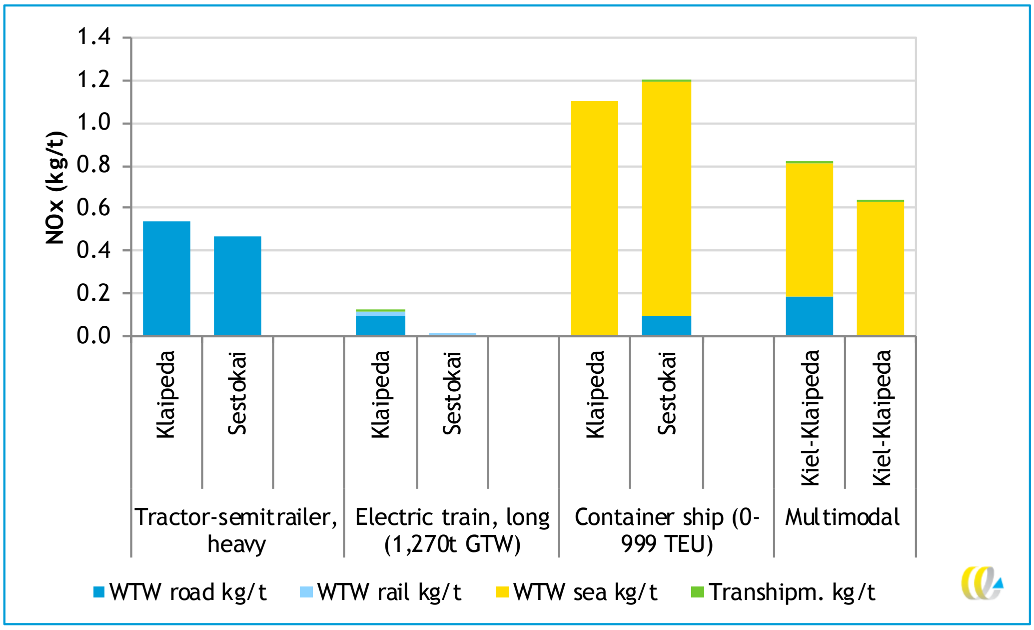


Figure 23 - NO_x emissions per tonne for medium-weight container transport, Rotterdam-Lithuania example



6.5 Example 4: Kenya-Utrecht

The fourth example is transportation of pineapples from Kenya (Thika) to Utrecht. Pineapples stop ripening after being picked, so ripe fruit needs to be eaten within a few days and flown out by air. Alternatively, the fruit can picked a little earlier, which affects the taste but means it can be transported by sea. Both cases involve multimodal transport. For upstream road transport in Kenya the data for the Netherlands have been taken, as Kenyan data were lacking. For legibility, the distinction between TTW and WTT has been omitted. The distances for the various modes are summarised in Table 81. The results are show in Figure 24 to 27 for CO_2, SO_2, PM_c and NO_x, respectively.

Table 81 - Distances, Kenya-Utrecht example; downstream transport by truck-semitrailer

	Kenia-Utrecht	
	Main leg (km)	Downstream (km)
Belly-freight aircraft, long-haul	6,684	108 (4:60:44)*
Full-freight aircraft, long-haul	6,684	108 (4:60:44)*
Container ship, 8,000-11,999 TEU	11,569	628 (4:536:88)*

* Urban : rural : motorway.

Figure 24 - CO_2 emissions per tonne for light transport, Kenya-Utrecht example

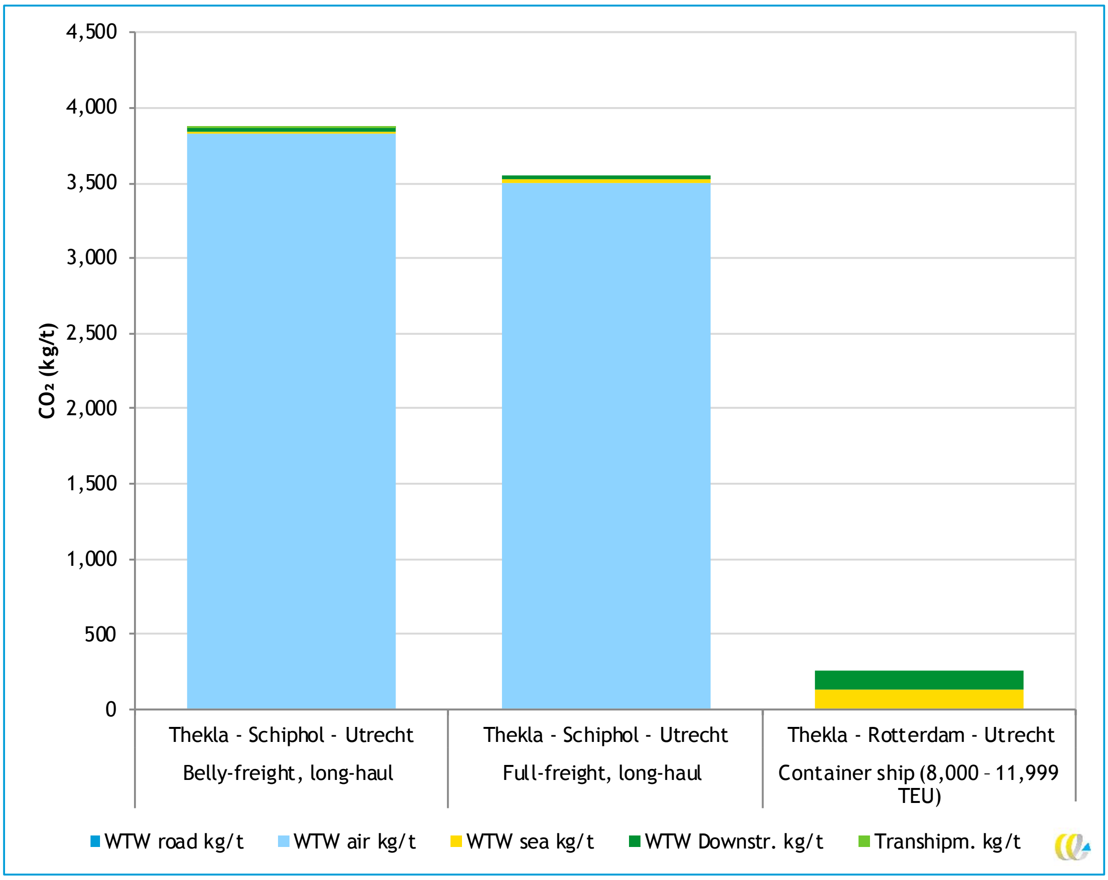


Figure 25 - SO_2 emissions per tonne for light transport, Kenya-Utrecht example

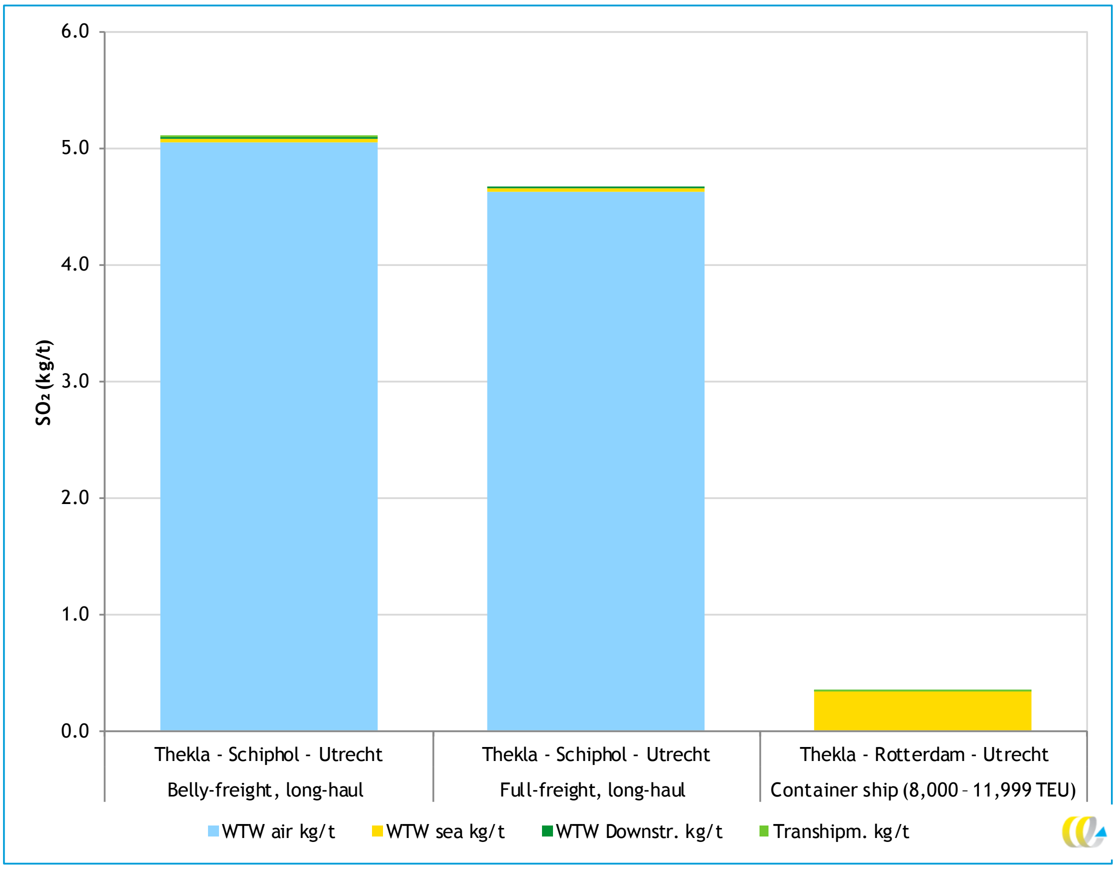


Figure 26 - PM_c emissions per tonne for light transport, Kenya-Utrecht example

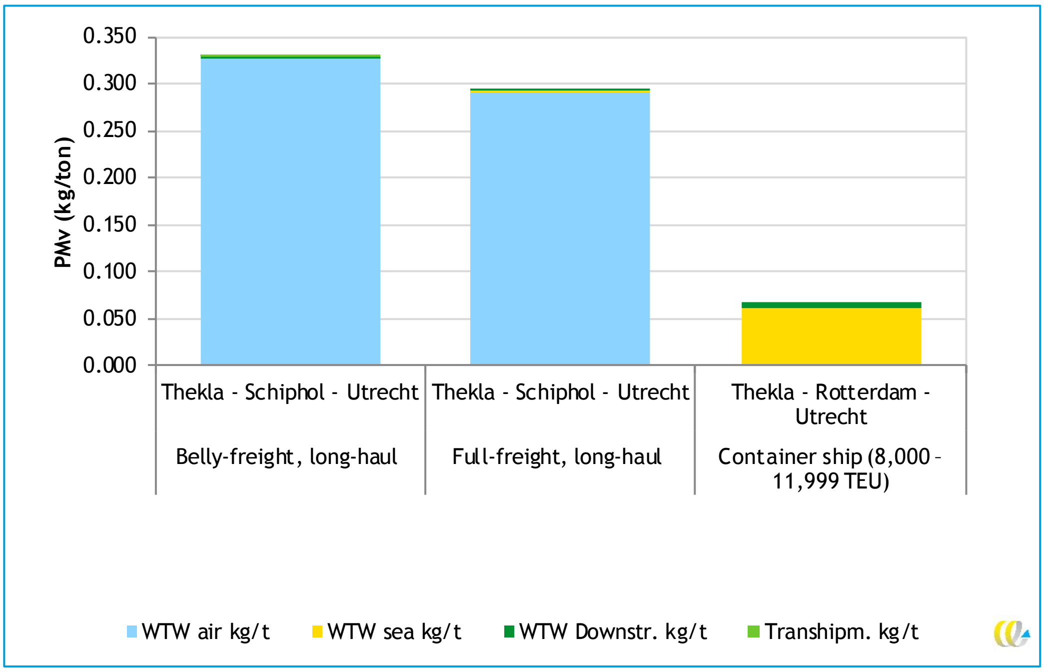
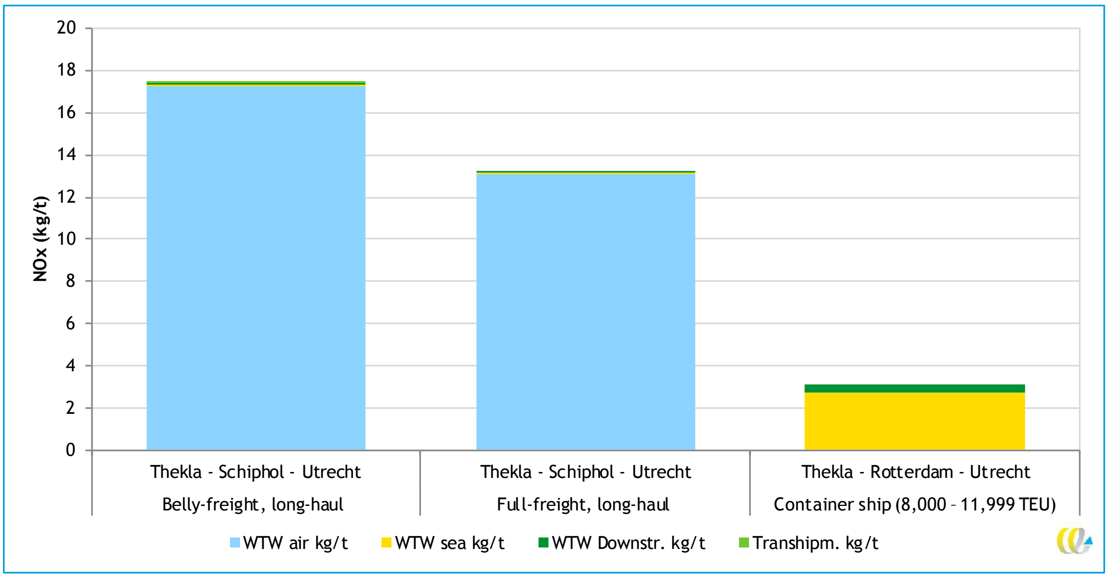


Figure 27 - NO_x emissions per tonne for light transport, Kenya-Utrecht example



6.6 Conclusion

The examples calculated with the 2018 data show that comparative performance of the various modes (in kg emissions per tonne carried) depends not only on emission factors per tonne-km, but also to a substantial degree on the distances involved and the amount of upstream and downstream transport. In all the examples except the last, road transport CO_2 emissions are highest, but as the Amsterdam-München case shows, if the distance covered by inland shipping is relatively long and there is also downstream transport, these CO_2 emissions may approach those due to road transport. The CO_2 emissions associated with electric rail transport are generally lowest.

Well-to-wheel SO_2 emissions are dominated by well-to-tank emissions and are therefore a function of fuel consumption. These emissions consequently exhibit the same pattern across transport modes as CO_2 emissions.

How the transport modes score relative to one another with respect to particulate (PM_c) and NO_x emissions differs considerably from case to case. Depending on the example, the highest emissions alternate between tractor-semitrailer, diesel train, inland-waterway or short-sea, depending on vehicle/vessel size, distance and up- and downstream transport. In all cases, electric rail scores lowest.

7 Lifecycle emissions of vehicles and infrastructure

As explained in Chapter 1, the emission factors reported in the previous chapters are for emissions occuring during vehicle use[29], and thereforedo not include the emissions associated with infrastructure and vehicle manufacture. The latter emissions are drawing growing attention in debates on the greenest forms of transport, however. In comparisons of rail and air transport, for example, the argument is often heard that rail infrastructure makes a significant contribution to total lifecycle emissions. Similarly, in the context of electric vehicles the emissions due to battery production are often cited.

This chapter therefore discusses the CO_2 emissions due to infrastructure and vehicle production and how these compare with those due to vehicle energy consumption. Because of the increasingly important role of electric vehicles in the transport sector, the main focus is on the CO_2 emissions of battery production. Already there are a range of electric vans and trucks on the market and several electrically powered inland shipping vessels have come off the drawing board and look set to come into service by the end of 2020.
The Netherlands Aerospace Centre (NLR) has also set up a 'Living Lab Electric Flight'.

First, in Section 7.1, we review the literature on the contribution of infrastructure and vehicle manufacture and maintenance to the total lifecycle emissions of freight transport. Section 7.2 explores in greater depth the impact of battery production on the lifecycle emissions of road vehicles. In Section 7.3, finally, conclusions are drawn and recommendations made to develop a set of emission factors specifically for the Netherlands that capture the impact of infrastructure and vehicle production and maintenance.

7.1 Share of infrastructure and vehicle production in lifecycle emissions

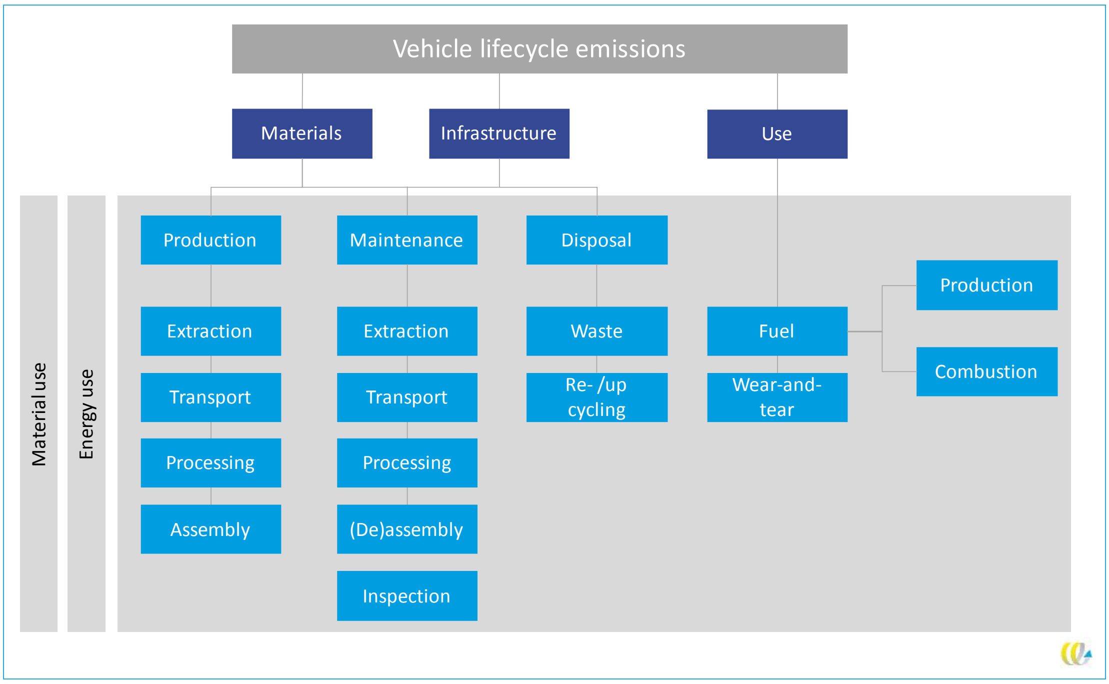
7.1.1 Lifecycle assessment

Lifecycle assessment, or LCA, is a methodology used to estimate the emissions associated with a process or product 'from the cradle to the grave'. In the case of vehicles, this means assessing the environmental impact of all the emissions occurring from resource extraction all the way through to vehicle disposal and encompassing the vehicle production process, logistical operations associated with production, vehicle use and maintenance and infrastructure creation.

The following figure shows the LCA elements involved in the case of transport, distinguishing between materials, infrastructure and vehicle use. The lifecycle emissions are determined by the sum total of material and energy use all the way along the supply chain. This includes machinery use during vehicle production and maintenance, for example.

[29] In this chapter "vehicles" should be taken to include shipping vessels and aircraft.

Figure 28 - Elements of lifecycle vehicle emissions



The emissions of vehicle production per (tonne-)kilometre are calculated by 'writing off' the sum total of production emissions over the total (tonne-)kilometrage during a vehicle's service life. The emissions per (tonne-)km attributable to vehicle production thus depend not only on the production process (and the assumptions made in characterising it), but also on (assumptions regarding) the service life of the vehicle itself as well its component parts.

Infrastructure is used by multiple vehicles for multiple years. To calculate the emissions attributable to infrastructure per vehicle-km or tonne-km, total infrastructure emissions are therefore divided over all years and users. In the case of road infrastructure, for example, users range from motorcycles to heavy trucks. Given the very different characteristics of these vehicles, allocation factors are used to assign the infrastructure emissions across vehicles accordingly. The assumptions made in the process may differ from country to country as well as across the literature.

7.1.2 Emissions due to vehicle production and infrastructure

Desk study

There are a number of LCA studies on transport that are relevant for *STREAM* and were reviewed for the present analysis; see Table 82. Only two of these have information on all the topics of interest for all transport modes in the context of vehicle and infrastructure lifecycles and report data per tonne-kilometre: Ecoinvent (2010) and Frischknecht et al. (2016).

Ecoinvent is a database with information on the emissions of thousands of products, including production and maintenance processes. Frischknecht et al. (2016) use the Ecoinvent data, but adjusting it based on specific assumptions for each vehicle category. The results have been compiled into a dataset called Mobitool. Compared with the other sources, the lifecycle emissions in Mobitool provide the clearest breakdown into the contributions of infrastructure, vehicle production, maintenance and use. In addition, the vehicle categories correspond largely to those adopted in *STREAM* and figures are reported for CO_2, NO_x and PM emissions. Mobitool is thus the most complete source and serves as the basis for the remainder of this chapter. The other sources contain information that overlaps partly with the categories employed in Ecoinvent (2010) and Frischknecht et al. (2016).

A brief description of the sources cited in Table 82 is provided in Appendix E. Direct comparison between the sources is not always feasible, because the emissions are not always expressed per tonne-kilometre. Nor do all the sources provide information on every step of the lifecycle, which means total lifecycle emissions are unknown. For a comparison to be feasible, assumptions would need to be made about issues like annual kilometrage, vehicle lifetime and total freight carried during that lifetime. The assumptions underlying the calculations would also have to be compared, viz. those on issues like vehicle weight, the details of vehicle production and the allocation factor for infrastructure.

Table 82 - Literature studied for *STREAM 2020*

Source	Transport mode	Publ. year	LCA	Vehicle production	Infra-structure	Conven-tional	Electric
(Ecoinvent; PSI ESU, 2007)	All modes	2013	Yes	Yes	Yes	Yes	Yes (rail)
(Frischknecht, et al., 2016) (Mobitool)	All modes	2016	Yes	Yes	Yes	Yes	Yes (rail)
(AEA; CE Delft; TEPR; TNO, 2012)	All modes	2012	No	Yes	Yes	Yes	No
(CE Delft, 2018)	All modes	2018	No	Nee	Yes	Yes	Yes
(CE Delft, 2020b)*	Road	2020	Yes	Yes	Yes	Yes	Yes
(Soriano & Laudon, 2012)	Road	2012	Yes	Yes	No	Yes	Yes
(Yang, et al., 2018)	Road	2018	Yes	Yes	Yes	Yes	Yes
(NMRI, 2014)	Mar. shipping	2014	Yes	Yes	No	Yes	No
(Université Liege, 2017)	Rail	2017	No	No	Yes	Yes	Yes
(UIC, 2016)	Rail	2016	No	No	Yes	Yes	No

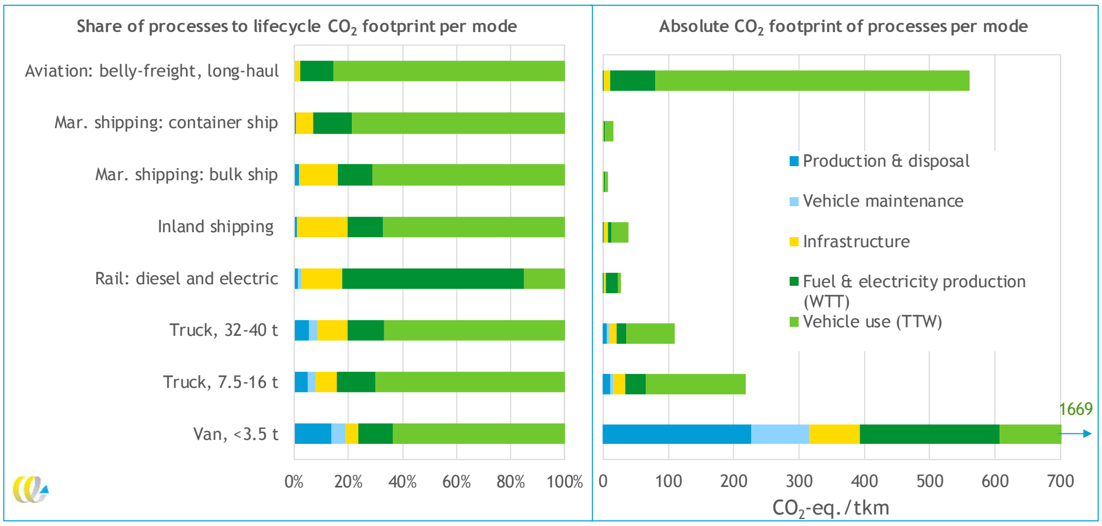
* This source is concerned with passenger transport rather than freight transport.

As *STREAM 2020* was being completed, another important new LCA study was published on road vehicles (Ricardo, 2020). This was not included in the present analysis, but appears to be largely in line with the Mobitool data.

Emissions due to vehicle production and infrastructure

Based on the Mobitool data, Figure 29 provides a graphic synopsis of the CO_2 emissions associated with each phase of the lifecycle for key vehicle categories, in both percentage and absolute terms. In all cases the bulk of the CO_2 emissions derive from the energy consumption for vehicle propulsion (TTW + WTT), with a minimum share of 80% in total life-cycle CO_2 emissions. In absolute terms, the emissions due to vehicle production and maintenance and infrastructure are highest for road vehicles and aviation, owing mainly to the relatively low tonne-km performance over aircraft and truck lifetime compared with rail and (inland and maritime) shipping. Infrastructure emissions are high for road transport because of tonne-km performance, but also because of the extent of the road grid compared with the infrastructure networks for the other modes. While not applying across the board for aviation, short-haul flights (within Europe) do have relatively high infrastructure CO_2 emissions, since they make comparatively frequent use of the infrastructure relative to kilometres flown. With long-haul flights, this is obviously less true.

Figure 29 – Share of processes in lifecycle CO_2 emissions for key vehicle categories (Frischknecht, et al., 2016)



In relative terms, infrastructure emissions contribute more to rail and inland shipping than with the other modes, thanks to the low CO_2 emissions due to energy consumption. With aviation, production, disposal and maintenance make a negligible contribution to total lifecycle emissions, because of the far higher WTW emissions per tonne-km. The results for NO_x and PM are reported in Appendix E.

7.2 Impact of battery production on lifecycle CO_2 emissions of electric vehicles[30]

Electric vehicles are becoming an increasingly important element of the future transport system. To meet the terms of the Paris Climate Accord and their transposition in the Dutch national climate agreement will require a substantial increase in zero-emission vehicles. The past decade has seen rapid growth of battery-electric vehicles. Batteries have become twice as light per unit capacity and can store more energy than ten years ago. They were almost three times more expensive then than they are today and had a three to ten times shorter lifespan. Given the major efforts currently being invested in battery development, these improvements are set to continue in the coming years. As an example, tests are now underway with a new type of battery weighing 75% less for the same energy content (Kesseler, 2020).

In the road transport sector there are already a range of electric vans as well as several trucks on the market and on the roads (CBS, 2020). Series production of electric trucks is expected by 2025 (see text box below), which means an increase in the number on the roads. There are also plans for battery-electric barges, with the batteries carried in containers on a (smaller) container vessel.

[30] For this section Auke Hoekstra contributed source material and a critical review.

Batteries in road freight transport

The number of electric trucks in the Dutch fleet is still limited. On 1 January, 2020 there were 193 in all, most of them box trucks, with 20 tractor units. For urban distribution there are various models on the market with a range of 200-300 km, and these are expected to be in series production within a few years. With heavy-duty, 40-t trucks, though, we are generally talking about converted vehicles with a very low range (100-200 km) for this class of truck. Most such trucks do 500-800 km a day, making the usefulness of a vehicle with a 100-km range very limited. Tesla is testing several prototypes with an 800-km range and claims to have several thousand pre-orders. Production has been postponed to 2021, however (Volvo, sd; Tesla, 2020a; Lambert, 2020).

Developments in the field of battery capacity and electric powertrains are improving costs. A study for the Port of Rotterdam Authority by EVConsult and ZEnMo has calculated that gradual replacement of part of the fleet by electric trucks will soon be economically viable, provided they are consistently used in their optimum range. Although the additional cost of batteries is still very high, this is soon set to change. The powertrain also needs to be redesigned to take full advantage of the potential it offers for weight reduction (up to 3.5 tonnes) (Sloten, et al., 2019). A battery-electric truck with a range of over 900 km is expected to become cost-efficient within 12 years (Sloten, et al., 2019). In ELaadNL, (2019) three scenarios predict that the Total Cost of Ownership for E-trucks in urban logistics will become attractive between 2023 and 2026. The number of trucks used in urban logistics is estimated at 30,000 out of a total of 143,000 trucks registered (ELaadNL, 2019). Transport & Environment (2017) also conclude that heavy E-trucks will eventually become technically feasible in the EU and be both economically viable and environmentally benign.

A key aspect of battery-electric trucks is battery weight, since this could reduce the amount of freight that can be carried. However, EU regulations stipulate that zero-emission trucks may be 1-2 tonnes heavier than their conventional counterparts (EU, 2019). In the near future, a 40-t E-truck with a range of 400 km will have a 700 kWh battery weighing around 3.5 tonnes, assuming a weight-to-power ratio the same as in a state-of-the-art car, viz. 5 kg/kWh (Hoekstra, 2020). At the moment, it is generally regular trucks that are being converted to E-trucks, with the fuel engine being replaced but the powertrain left intact. In a newly manufactured E-truck the electric motor will be installed between the axles and a dedicated powertrain used, a configuration potentially 2.7 tonnes lighter (Verbruggen, et al., 2018). Battery weight is thus projected to decline in the coming years and, combined with EU regulations, this could mean an 800-km E-truck with little if any loss of load capacity.

7.2.1 Lithium-ion batteries: an introduction

At the moment the Lithium-ion (Li-ion) battery is the type most commonly used in road freight vehicles. For other modes different battery types are under consideration, but there is little information available. Use of Li-ion batteries in transport settings is a relatively recent development that only really took off around the turn of the century. As outlined above, battery development is moving fast. At the same time a debate is unfolding about the impact of battery production on total lifecycle CO_2 emissions. In this section the various developments are considered in more detail and their present and future impact on freight transport and CO_2 emissions discussed.

While there is little specific information at present on the impact of battery production on the lifecycle CO_2 emissions of trucks, much can be deduced from what we know about this issue in connection with battery-electric cars. The main factors affecting the lifecycle CO_2 emissions are the following:

- The carbon footprint of battery production derives mainly from production of battery cells. These are no different for heavy or light vehicles, simply applied in greater numbers per battery pack. Emissions per kWh battery production are therefore comparable for trucks and cars.

- The precise emissions depend on battery composition. A 2012 study by Chalmers University looked at LFP batteries in (hybrid) trucks, while there has been increasing talk over the past few years of using NCA or NCM batteries, which are lighter. All three are Li-ion batteries, but differing in composition, resulting in different emissions. Hao et al. (2017) report that the emissions associated with production of a 28-kWh battery are higher for LFP than for NCM (Soriano & Laudon, 2012).
- A truck makes more intensive use of its battery than a passenger car. While a truck will generally utilise its entire battery range in the course of a day, this is not usually the case with a car. Every new charging cycle means more savings on fuel and thus CO_2 emissions and costs compared with running on diesel. The ecological and financial payback time is therefore shorter for trucks than for cars, because of the higher charging frequency.
- In trucks the battery packs and other components are larger than in cars, making prototype construction and testing relatively expensive, while the market for truck batteries is smaller. This means the overhead costs of truck battery production are likely to be higher than those for car batteries. This is not expected to have any major impact on the carbon footprint of battery production, though, because the cells are no different from those used in cars and other smaller vehicles.

The following subsections discuss the CO_2 emissions associated with battery production and battery life, allowing conclusions to be drawn about lifecycle impacts per tonne-kilometre.

7.2.2 The carbon footprint of battery production

On 7 May, 2018 the European Commission presented its agenda for safe, clean and connected mobility (EC, 2018), one element of which is a strategic action plan for battery development and production. To underpin this action plan, in the context of the Ecodesign Directive a study on the carbon emissions of battery production was carried out, looking specifically at the case of battery-electric trucks. The study calculated a value of 114 kg CO_2-eq. per kWh battery capacity (see Table 83) (EC, 2019; Vito/Energyville; Viegand Maagoe, 2019).

In recent years there have also been numerous studies focusing on the production of cars and other light-weight vehicles (Emilsson, 2019; Hao, et al., 2017; T&E, 2020b). These studies report a range of CO_2 emissions for battery production: 61-106 kg CO_2-eq./kWh (Emilsson, 2019), 96-109 kg CO_2-eq./kWh (Hao, et al., 2017) and 86 kg CO_2-eq./kWh (T&E, 2020b); see also Table 83. A striking feature of these studies is the theoretical approach adopted and the explicit mention of lack of practical data. Another study reports a value of 75 kg CO_2-eq./kWh. (A. Hoekstra, 2020). Tesla recently released an impact report on the company's so-called Giga Factories, the world's largest electric car production facility, reporting that battery production there was accompanied by 87 kg CO_2-eq./kWh in 2017 and 77 kg CO_2-eq./kWh in 2019 (Tesla, 2020b).

All these studies state that battery production carbon emissions depend heavily on the following factors:
- The energy mix used: using renewables leads to significantly lower emissions.
- The location: production in China emerges as the most polluting, with US and European production causing around 50% lower emissions owing to less carbon-intensive electricity production.
- The production facility: conditions and procedures differ from plant to plant, while scaling-up leads to major emission cuts.

The figures reported for the CO_2 emissions associated with battery production thus vary according to the source, as summarised in in Table 83.

Table 83 – Values reported for CO_2-eq. emissions of Li-ion battery production

Source	Battery production emissions (kg CO_2-eq./kWh)
(Emilsson, 2019)	61-106
(Hao, et al., 2017)	96-109
(Hoekstra, 2019)	75
(T&E, 2020b)	86
(Vito/Energyville; Viegand Maagoe, 2019)	114
(Tesla, 2020b)	87 (2017); 77 (2019)

Transport & Environment recently presented a tool for comparing the lifecycle carbon emissions of battery-electric cars with their diesel and petrol counterparts (T&E, 2020b). The background information that comes with the tool states that allowance was made for the use of differing electricity mixes for production at various locations (Sweden, Poland, China) and that many studies report conservative values. As Table 83 shows, the value adopted by Transport & Environment is more or less the average of the other values reported. It is also within the range given in Tesla's impact report.

7.2.3 Battery life

A key factor determining battery-related carbon emissions per km or tonne-km is battery life, given that aggregate emissions must be divided by total (ton-)km performance in the course of that lifetime. In this context a distinction can be made between calendar aging and capacity fade. Calendar aging means the battery reaches the end of its service life because of its age and the fact that it has not been fully utilised. With capacity fade, the battery reaches end-of-life as a consequence of the number of times it has been fully charged, i.e. gone through the full charge-discharge cycle. This is best explained with a numerical example; see the following text box (Battery University, 2019).

Difference in battery life based on range

Suppose two battery-electric cars A and B with respective ranges of 500 km and 250 km each drive 250,000 km until reaching vehicle's end-of-life. This means:

- car A's battery has 250,000 / 500 = 500 full charge-discharge cycles
- car B's battery has 250,000 / 250 = 1,000 full charge-discharge cycles.

This means that after 250,000 km, car A's battery has lost relatively less of its battery capacity than car B's. In principle, then, a higher battery capacity comes with a longer battery life. In practice, though, this need not always be the case. If the vehicle is less frequently used, calendar aging will be the determining factor and the battery will deteriorate and reach end-of-life because of aging without its full capacity having been utilised.

If a battery is always fully charged this will accelerate the capacity fade process. More frequent charging in small bursts and charging only to the kWh required for a particular trip increases overall service life. Ultra-fast charging shortens battery life, though, particularly if the battery is cold. Charging and using a cold battery lowers capacity and therefore shortens service life. The ideal temperature for batteries is room temperature.

In the past, car lithium batteries often lasted no more than 500 cycles. Today, battery packs in new vehicles are expected to last 1,500–3,000 cycles before 20% of the capacity is lost and in 2030 this is projected to have risen to 5,000-10,000 cycles (Hoekstra, 2019). This means greater mileage per battery lifetime. For the present we have assumed that batteries last 1,500 cycles and that for freight vehicles calendar aging is less important than capacity fading, owing to intensive battery use.

7.2.4 Comparison of conventional and electric road freight vehicles

In this section we analyse the contribution of battery production CO_2 emissions to the total lifecycle emissions of electric vehicles. To this end we make a comparison with conventional vehicles taken largely from Mobitool: a small and a large electric delivery van, a truck and a tractor-semitrailer (Frischknecht, et al., 2016). The small van is not cited directly in Mobitool, but was approximated using their data for large vans. The small van was included in the analysis because this type of vehicle is already widely available and differs from heavier vehicles in its consumption characteristics relative to diesel (cf. Subsection 3.2.4).

The share of battery production in vehicle lifetime emissions was calculated for the following electric vehicle models (existing or announced), which are similar in size to the Mobitool vehicles:
- Renault Kangoo Maxi ZE 33 (35 kWh);
- Toyota PROACE Electric (75 kWh);
- DAF LF Electric (235 kWh);
- Tesla Semi (1.000 kWh).

For the service life of the electric vehicles the same values were taken as for their conventional counterparts and for the battery production CO_2 emissions the value of 86 kg CO_2-eq./kWh cited in the recent Transport & Environment study (T&E, 2020b).[31] The basic data and assumptions for each vehicle are summarised in Table 84.

Table 84 - Data and assumptions for comparison of electric road freight vehicles

	Small van (EW 1.6 t)	Large van (EW 2.2 t)	Truck	Truck-semitrailer
Assumptions, CO_2 battery emissions				
Vehicle model	Renault Kangoo	Toyota PROACE Electric	DAF LF Electric Innovation Truck	Tesla Semi Truck
Development stage	on the market	on the market	on the market	Under development
Use	City logistics	City logistics	City logistics	Long-distance
Maximum freight capacity (t)	0.74	1.3	12	23
Average load per trip (t)	0.11	0.2	5.8	11.6
Battery pack capacity (kWh)	35	75	235	1000
Battery range (km)	max 170	max 330	max 235	max 800
Theoretical battery life (cycles)	1,500 (2018) 5,000 (2030)	1,500 (2018) 5,000 (2030)	1,500 (2018) 5,000 (2030)	1,500 (2018) 5,000 (2030)
Vehicle life (km)	250,000	350,000[b]	700,000	900,000
No. of batteries per vehicle life[a]	1 (2018) 1 (2030)	1 (2018) 1 (2030)	2 (2018) 1 (2030)	1 (2018) 1 (2030)
Battery production emissions per kWh capacity (kg CO_2-eq./kWh)	86 (2018) 60 (2030)			
Battery production emissions per tkm (g CO_2/tkm)	108 (2018) 22.5 (2030)	48 (2018) 10 (2030)	10 (2018) 2.1 (2030)	8.2 (2018) 1.7 (2030)

31 (Ricardo, 2020) reports a similar value of 90 kg/kWh.

	Small van (EW 1.6 t)	Large van (EW 2.2 t)	Truck	Truck-semitrailer
Assumptions, WTW emissions				
Electricity consumption (kWh/km)	0.22	0.40	1.3	1.6
Energy consumption, diesel reference (Mobitool) (kWh diesel/km)	0.64	0.86	2.8	3.4
Lifetime vehicle emissions per kWh (year of manufacture 2018 & 2030) (g CO_2/kWh)	82 (max. 137) (2018) 14 (max. 27) (2030)			

[a] No. of batteries calculated by dividing no. of cycles required during vehicle lifetime (lifetime/75% max. range) by max. no. of cycles (1,500). If a 2nd battery is needed, a longer battery life of 3,000 cycles was assumed.

[b] A conservative assumption: for this model 1.000.000 km is guaranteed.

In calculating the sum total lifecycle emissions, the figures reported in Frischknecht et al. (2016) with respect to the following were used for both conventional and electric vehicles:
- vehicle manufacture and disposal;
- vehicle maintenance;
- infrastructure.[32]

Since Mobitool only has data on a large van (EW 2.0-2.5 ton), the lifecycle emissions of the small van were calculated as being proportional based on vehicle weight and lifetime tonne-km performance. For electric vehicles, battery production emissions were then added.

For the large van and the two types of truck, fuel consumption is based on Mobitool (Frischknecht, et al., 2016), for the small van on the data in Table 10 in Subsection 3.2.3. The WTT CO_2 emissions of diesel and electric were calculated using the emission factors in Section 4.8 and Subsection 3.2.4, respectively. It was assumed that 5% more biodiesel is added to the diesel blend over vehicle life (though not in the maximum variant), while 82 g CO_2/MJ[33] was taken as the average emission of the (2018) electricity mix over vehicle lifetime and 137 g CO_2/MJ as a maximum.

Besides calculating lifecycle carbon emissions for 2018, estimates were also made for 2030 using projected figures for power-generation and battery-production emissions for that year. For the former an average of 13.7 CO_2/MJ and a maximum of 27.4 g CO_2/MJ were assumed (with the 2030 mix).[33] Battery production emissions were assumed to fall to 60 kg/kWh, with the number of battery cycles rising to 5,000. Diesel vehicles were taken to be 30% more efficient than today's vehicles in 2030[34], with 5% more biodiesel in the blend.

Figure 30 to 33 show how the vehicles in Table 84 compare with conventional vehicles in terms of lifecycle carbon emissions. As can be seen, a 2018 electric vehicle gives a 33-44% CO_2 reduction over its lifetime (with a minimum of 15-23% if there is no improvement in the electricity mix). In 2030 this reduction is far greater: an estimated 40-70%, depending on the share of renewables in the electricity mix.

[32] The impact of charging infrastructure was not calculated, but is likely to be relatively insignificant.

[33] For the 2018 vehicle an average of 137 g CO_2/MJ was taken in 2018 and 27.4 g CO_2/MJ in 2030 (based on (PBL, 2019)), for the 2030 vehicle 27.4 g/MJ as maximum in 2030 and half this as average over vehicle lifetime.

[34] Based on the EU target of a 30% improvement in truck efficiency in 2030. For vans the same figure was taken.

The conclusion is that the extra emissions due to battery production do not weigh up against the emission cuts during vehicle use. On balance there is a clear reduction in carbon footprint as batteries improve, battery production become more efficient and power generation emissions fall, which can only increase as we move towards 2030.

Figure 30 - Lifecycle emissions, small van, conventional and electric, 2018 and 2030

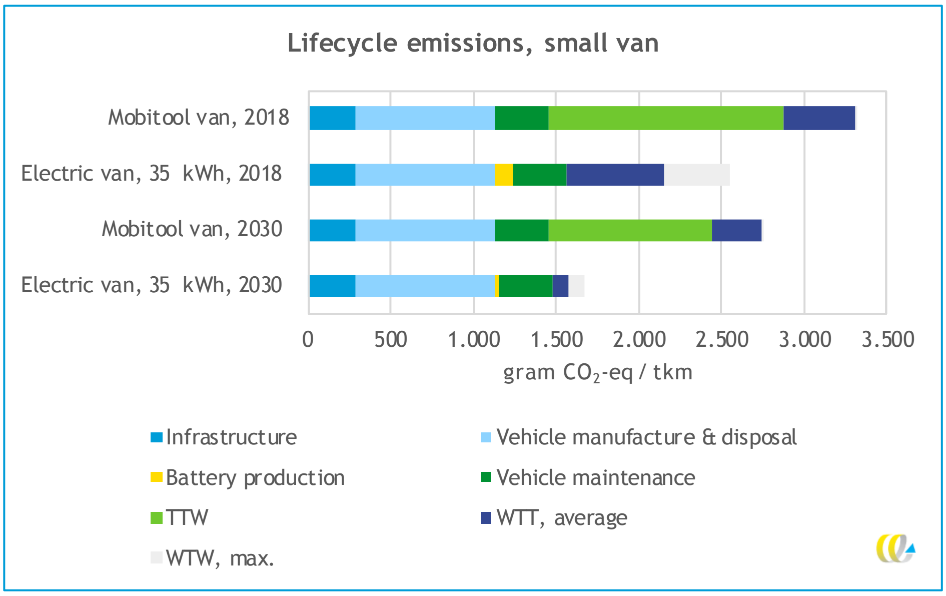


Figure 31 - Lifecycle emissions, large van, conventional and electric, 2018 and 2030

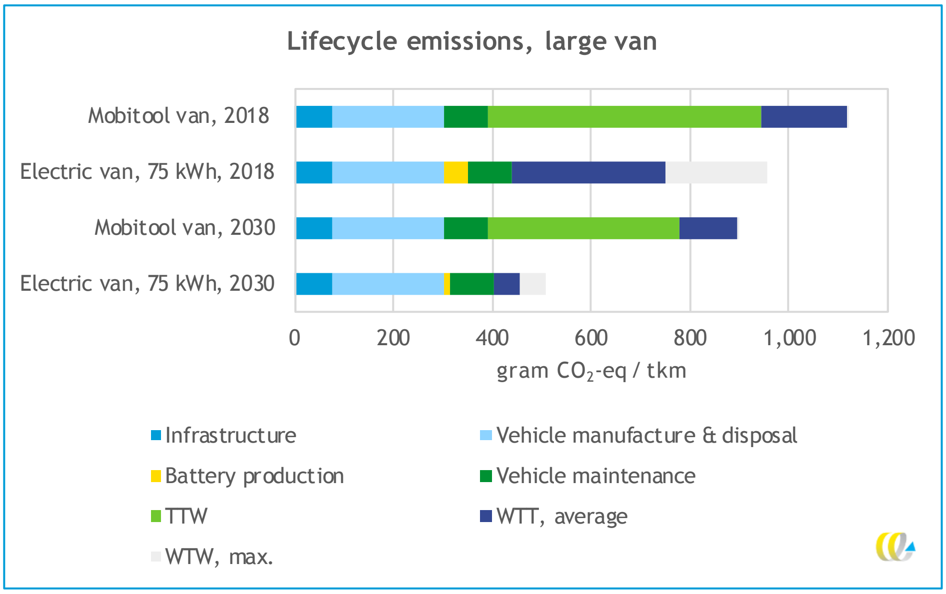


Figure 32 - Lifecycle emissions, truck, conventional and electric, 2018 and 2030

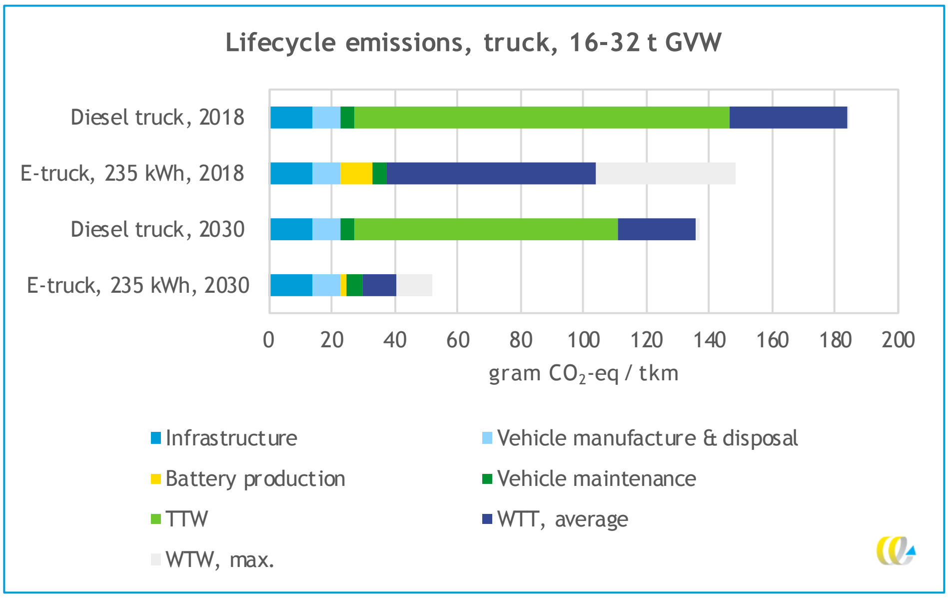
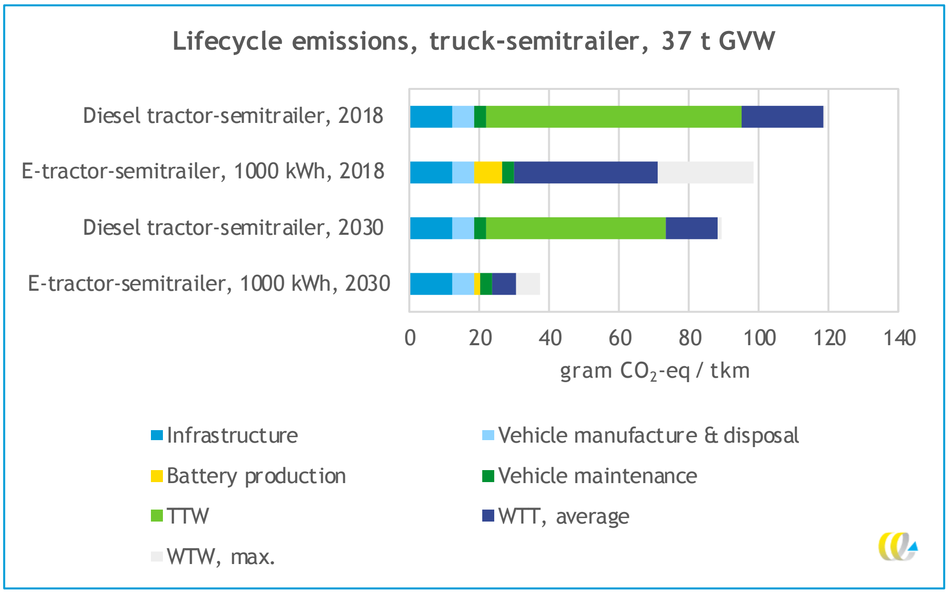


Figure 33 - Lifecycle emissions, tractor-semitrailer, conventional and electric, 2018 and 2030



The above comparison has focused on the share of battery production in lifecycle carbon emissions, since this is expected to make the greatest contribution. The comparison makes no allowance for any reduction in the CO_2 emissions of vehicle manufacture, vehicle maintenance and infrastructure as we move ahead to 2030. Such reductions will not differ significantly for diesel and electric vehicles, though. Nor was allowance made, with electric vehicles, for the probably lower maintenance emissions and additional (but low) infrastructure emissions due to charging stations compared with diesel vehicles.

In these calculations the impact of service-life extension has been included for battery production only. Longer battery life may well increase the service life of the vehicle itself, reducing emissions per tonne-km. For additional calculations on this point, see Appendix E.

Electrification of inland shipping

It is not just truck manufacturers that are pursuing battery-electric powertrains as a future option; barge operators are also investigating their potential. This year (2020) Combined Cargo Terminals (CCT) took the first fully electric inland shipping vessel intro service. The vessel, the Alphenaar, is now being used full-time for carrying Heineken bottled beer from Alphen aan den Rijn to Moerdijk, from where it is goes on to Rotterdam and Antwerp to be transported around the world. The vessel uses battery packs installed in containers that can be swapped as self-contained units and can be rented rather than purchased (Nieuwsblad Transport, 2020; AD, 2020; Nedcargo, sd).

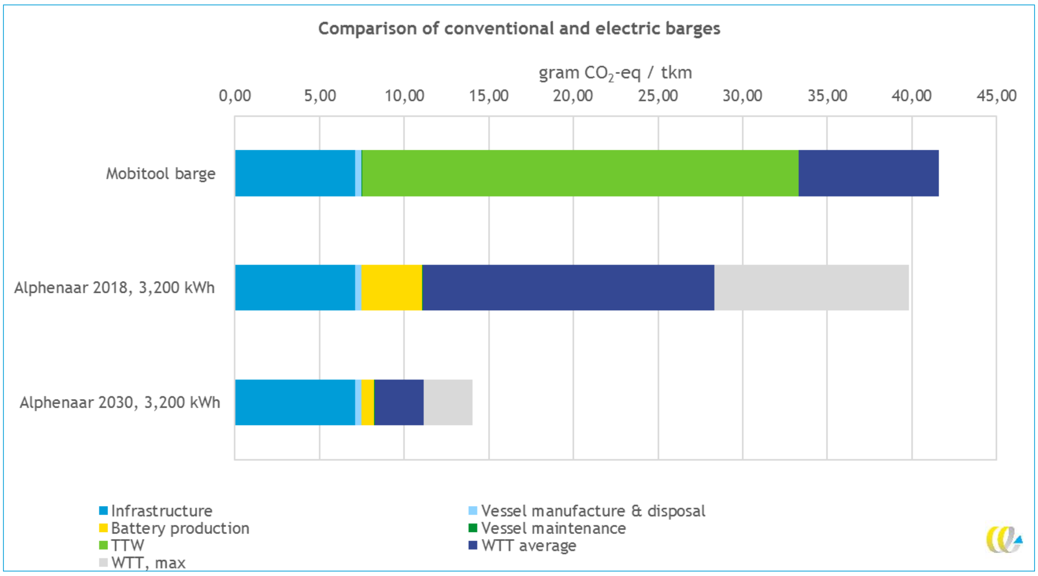
For propulsion the Alphenaar needs two battery containers, together providing 3,200 kWh of power, enough for 50–100 kilometres. The battery pack weighs 20–22 tonnes, around 1.1% of the 1,850 ton vessel's load capacity (104 TEU) (Modulair Energie Concept, 2019; Concordia DAMEN, sd).

To illustrate the battery's impact on total lifecycle CO_2 emissions, a first-pass analysis was made of the CO_2 impact of this barge if it had been in operation in 2018 and for new-build in 2030 compared with a 2018 diesel vessel. The Alphenaar is similar to the barge in Mobitool (Frischknecht, et al., 2016), with 2,000 t load capacity and on average 1,030 t utilisation (Figure 34). For the comparison the same service life was assumed, in km terms, as the Mobitool vessel: 3,357,500 km (Messmer & Frischknecht, 2016). For the average load, the same value as Mobitool was again taken: 1,030 t. For the comparison the same method was used as for road transport, assuming that the battery provides 54% of the energy otherwise delivered by diesel.[35] For the per-kWh carbon footprint of battery production the same value was taken as for road transport in 2018 and 2030.[36] For the CO_2 emissions of the vessel itself an average figure over twelve years starting in 2018 (Alphenaar 2018) and in 2030 (Alphenaar 2030) was assumed. Over the entire vessel lifetime (far more than 12 years) the emissions will on average be lower, however.

[35] Given the high efficiency of diesel engines for use in inland shipping, a relatively high energy consumption figure was taken from the literature for trucks (INFRAS, 2019a).

[36] For 2018 the same per-kWh CO_2 emissions (2018 value) were taken for all replacement batteries required in the course of the vessel's lifetime. This value is therefore an overestimate.

Figure 34 – Comparison of lifecycle CO_2 emissions of conventional and electric barges, 2018 and 2030



Emissions per tonne-km are 28 g CO_2-eq./tkm (max. 40 g/tkm) for the Alphenaar 2018 and 11 g CO_2-eq./tkm (max 14 g/tkm) for the Alphenaar 2030. Comparted with a conventional barge, with 42 g CO_2-eq./tkm, this is a reduction of 32% (min. 9%) for the 2018 vessel and 66% for the 2030 vessel. In 2018 battery production contributed 10% to total lifecycle emissions, falling to 6% in 2030. This reduction is due in part to the longer battery pack lifetime in 2030. Use of larger batteries will also mean a greater net reduction of the carbon footprint of inland shipping in the future.

7.3 Conclusions and recommendations

The previous sections set out the elements to be included in an LCA and quantified the emissions associated with battery production. A simplified analysis was also made of the lifecycle emissions of electric versus conventional vehicles/vessels. In this closing section we discuss the preliminary steps that need to be taken before a fully-fledged LCA can be performed for the Dutch situation. Appendix E describes the differences in LCAs for conventional and electric vehicles with reference to three studies.

7.3.1 Conclusions

The information required for performing an LCA is available for all the modes and in the previous sections the lifecycle emissions of each were compared based on (Frischknecht, et al., 2016). For every mode, the contribution of the CO_2 emissions due to infrastructure and vehicle production and maintenance is 10-20% of total lifecycle emissions. Only in the case of aviation is the figure lower, owing partly to the high CO_2 emissions of fuel burn. In absolute terms the emissions due to infrastructure and vehicle production and maintenance are highest for road transport and aviation.

For NO_x and PM_c the picture is more varied. With modes with relatively low NO_x and PM_c emissions due to fuel/energy consumption, (rail) infrastructure and vehicle production make up a large share of total lifecycle emissions. Particularly for PM_c this contribution may sometimes be pronounced (up to 70% for diesel trains), owing to the relatively high emissions of mobile machinery and use of coal-based power (abroad) for steel production.

For battery-electric vehicles it was shown that battery production leads to increased CO_2 emissions in the manufacturing phase, but to a reduction with respect to fuel production and in the use phase. On balance there is a net reduction in carbon footprint that will increase as battery production efficiency improves, battery life increases and electricity CO_2 emissions decline.

7.3.2 Recommendations

Rigorous, across-the-board comparison of the available data reported is hard, as calculation of CO_2 emissions per tonne-kilometre would mean making a range of assumptions. In addition, most sources do not report emissions data on every phase of the lifecycle. Only in Frischknecht et al. (2016) and Ecoinvent (2007) are these assumptions explicitly reported.

While the quantitative data cited in this chapter provide an rough indication, they were not specifically developed for the Dutch situation. Key parameters determining the CO_2 emissions associated with infrastructure include intensity of usage, number of bridges and tunnels, and maintenance status. To arrive at specific Dutch figures would require a dedicated LCA. The most obvious approach would be to use the data reported in Ecoinvent (2010), as Mobiltool does, making adjustments for the Dutch situation. Battery-electric vehicles can also be modelled more specifically, adjusting for differences in the production process of the vehicle itself and the infrastructure it requires.

In the context of the Dutch Climate Agreement and the CO_2 reduction targets for 2030 and 2050, the abatement potential of electrifying the entire road vehicle fleet can then be calculated. The emission factors reported in this chapter are per tonne-kilometre and can serve as an approximation. The same methodology can also be adopted to calculate factors for other road vehicle categories. For road transport as well as for other modes, additional electrification concepts can be examined, such as overhead wires for road transport and other types of battery for shipping, for example.

8 Comparison of results with *STREAM Freight 2016*

STREAM Freight 2020 takes 2018 as its reference year. While the main contours of the methodology remain the same as in the previous edition, *STREAM Freight 2016*, there have been a number of changes, which are explained below.

8.1 Road transport

For road transport, the differences in methodology compared with 2016 are as follows:

- The two van categories in *STREAM 2016* have been broken down into fouras there are now more data available on vans thanks to a study by Connekt (2017). With 3.5 tonnes as the maximum permitted weight of a loaded van, the largest category (>2.5 t EW) has a relatively low load capacity. These vehicles are used mainly for transporting bulky items Table 85 compares the 2016 and 2020 categories.

Table 85 – Road freight vehicle categories, *STREAM 2016* and *STREAM 2020*

STREAM 2016	Load capacity	*STREAM 2020*	Load capacity
Van, <2 t	0.7	Van, EW <1.5 t	0.7
		Van, EW 1.5-2 t	1
Van, >2 t	1.2	Van, EW 2-2.5 t	1
		Van, EW >2.5 t	0.7
Truck, GVW <10 t, no trailer	3	Truck, GVW <10 t, no trailer	3
Truck, GVW 10-20 t, no trailer	7.5	Truck, GVW 10-20 t, no trailer	7.5
Truck, GVW 10-20 t, with trailer	18	Truck, GVW 10-20 t, with trailer	18
Truck, GVW >20 t, no trailer	13	Truck, GVW >20 t, no trailer	13
Truck, GVW >20 t, with trailer	28	Truck, GVW >20 t, with trailer	28
Tractor-semitrailer, light	16	Tractor-semitrailer, light	16
Tractor-semitrailer, heavy	29	Tractor-semitrailer, heavy	29
LHV	41	LHV	41

- Emission factors have been updated based on the latest version of the Task Force on Transportation's report (2020), which, among other things, gives higher figures for the NO_x factors for Euro 6 vehicles compared with *STREAM* 2016, based on practical measurements.
- There are several methodological changes in Task Force on Transportation, (2020). These include more specific mileages and road classes for the vehicle categories. Vehicle fleet composition has also been adjusted to the situation in 2018. The lower Euro classes now have a significantly lower presence, giving lower average air-pollutant emissions. The changes in road class distribution relate mainly to trucks, which now do more kilometres on rural roads and less on motorways and urban roads.
- Sales of new light-weight vans have been falling for years compared with heavier vans. This means average van weight has increased and, with it, average van emissions.
- In *STREAM 2020* pre-Euro vehicles have also been included, as "Euro 0", giving an increase in the emissions of this group of vehicles and the fleet-average as a whole. In *STREAM 2016* pre-Euro vehicles were not included.

There are several differences in the results compared with *STREAM 2016*. The new fleet composition means trucks and tractor-trailers have a slightly different energy demand (MJ/km). For trucks the figure is lower, because Euro V and VI are more efficient than Euro III and IV. Euro VI and Euro V tractors scarcely differ in efficiency, if at all. In certain situations, changes in road class distribution and fleet composition mean higher energy consumption. Truck NO_x emissions are substantially lower, as there are now more Euro V and Euro VI trucks in the fleet. For the same reason, PM_c emissions are considerably lower than in *STREAM 2016*. For vans, more specific data have been used. The vans used for transportation are relatively large and have higher per-km energy consumption than reported in *STREAM 2016*, leading to higher per-km CO_2 and NO_x emissions. Emissions of PM_c work out lower, though, owing to the difference in fleet composition. Van emissions per tonne-km remain much the same as in *STREAM 2016*.

8.2 Rail transport

For rail freight, the most important update relative to *STREAM 2016* is a change in train categories based on interviews with experts and a new study (ProRail, 2019):
- For packaged/bulk freight, medium-length, long and extra-long trains are now defined.
- For container transport, long and extra-long trains are now defined, the former 650 m long, the latter 740 m.
- For bulk freight, a new extra-heavy category has been added representing coal and ore transport. The type of freight carried by each train is reported in Appendix C.

The following additional changes have been made in *STREAM 2020*:
- The NO_x emission factor is now 0.984 g/MJ (0.978 g/MJ in *STREAM 2016*).
- The PM_c emission factor is now 0.023 g/MJ (0.027 g/MJ in *STREAM 2016*).
- Based on new UIC data (UIC, 2019), electric trains now have lower energy consumption in kWh per tkm.
- The tkm electric/diesel split on the Dutch rail grid has been determined, permitting better assessment of the weighted average of diesel and electric.

The changes in train categories make direct comparison between *STREAM 2016* and *STREAM 2020* tricky. Broadly speaking, however, the results remain largely unchanged, though use of relatively longer trains means improved efficiency per tkm. In addition, use of slightly lower NO_x and PM_w emission factors means a slight reduction in these emissions.

8.3 Inland shipping

For inland shipping there have been a number of adjustments based on new data and new studies. The main changes are as follows:
- Inland shipping sailing speeds have been updated using practical data compiled by Statistics Netherlands (CBS) based on AIS data measured with *Rijkswaterstaat* transponders in July 2015. For smaller vessels on smaller waterways, in particular, speeds are now considerably lower. On certain routes, speeds may prove higher. The differences from *STREAM 2016* are reported in Table 100 to 103 in Appendix D.
- Based on new counts of vessel category per waterway class, certain vessel-waterway combinations are now more representative
  - The 6-barge push convoy (long) has been replaced by ditto (wide).
  - For Coupled: Europa II-C3l, waterway class Vb has been taken instead of Va.
- Based on several studies (STC-NESTRA; RebelGroup; EICB, 2015) an average rated engine capacity has been assumed for each vessel category, predicated on the condition that

power demand never exceeds this capacity. Because of the changes in sailing speeds, this is no longer the case anywhere, though.

- Emission factors have been updated based on the latest issue of the EMS Protocol. Compared with *STREAM 2016*, NO_x emission factors have been adjusted based on TNO measurements in ships' plumes (Emissieregistratie, 2018). This means the NO_x factors for CCNR2 engines are higher than in *STREAM 2016*.
- In line with the latest issue of the EMS Protocol (Emissieregistratie, 2018) correction factors for engine load have now been applied to fuel consumption and the emission factors for NO_x, PM_c, VOC, methane and CO. A lower engine load gives relatively higher emissions per kWh engine capacity owing to suboptimum engine operation. The load on a ship's engine was calculated by comparing power demand with engine load on the route concerned and then comparing this demand with the rated engine capacity for each vessel category. An M1 vessel carrying an average load on a CEMT1 canal uses 13% of its engine capacity, on average, which means 140% higher NO_x emissions per KWh. In absolute terms, though, the lower power demand means less NO_x.
- As a result of this change, the energy demand and emissions of inland shipping vessels are now different from those in *STREAM 2016*. For smaller vessels, in particular, sailing speeds are now lower, giving lower engine loads and a parallel reduction in emissions. At the same time, the use of emission correction factors for suboptimal engine loads means higher emissions compared with *STREAM 2016*. Whether this leads on balance to an increase or decrease in energy consumption and emissions depends on the vessel category and waterway class concerned.

8.4 Maritime shipping

For maritime shipping, the first key change concerns the scope. While *STREAM 2016* covered only short-sea shipping, *STREAM 2020* includes deep-sea shipping, too. This means due allowance had to be made not only for the Sulphur Emission Control Areas (SECA) in the North Sea and Baltic, where fuel oil may contain at most 0.1% S, but also for the standards in force since 1 January, 2020 on the high seas. Since then, deep-sea vessels must burn low-sulphur fuel oil, with at most 0.5% S, or reduce sulphur emissions to at least an equivalent degree by other means (e.g. scrubbers, LNG). Even though this regulation was not yet in force in 2018, *STREAM 2020*'s reference year, it has been taken on board because of its major impact on emissions and a desire to avoid emission factors being directly outdated.

The second important change concerns the literature consulted and the methodology employed. In *STREAM 2016* the 3rd IMO GHG Study was used as a modelling basis for calculating values for emissions and energy consumption per tonne-km. For *STREAM 2020* practical data could be used, as these are available from ships docking at EU ports, which under EU Regulation 2015/757 must then report CO_2 emissions per tkm. These data, held in the so-called EU-MRV database, were used in tandem with data from Clarksons Research Portal. As the EU-MRV database only has data on ships over 5,000 GT, for lighter vessels practical figures from the Royal Association of Netherlands Shipowners, KVNR, were used.

These changes in sources and methodology give the following main differences in results:
- In *STREAM 2020* average vessel tonnage (expressed as dwt) within a tonnage class was calculated using data from the EU-MRV database. Generally speaking, average tonnage remains roughly the same as in *STREAM 2016*. However, the 10-20 dwkt General cargo ship is now significantly smaller (by 40%), leading to higher emission factors, while the 0-5,999 dwt oil tanker is significantly larger (by 70%), leading to lower factors.
- Energy consumption (in MJ/tkm) and CO_2 and air-pollutant emissions per tkm are now generally lower for the bulk carriers, oil tankers and container ships than in *STREAM 2016*, owing to the lower figures for energy consumption per tkm deriving from the EU-MRV database. In practice the larger container ships, in particular, prove to have lower energy consumption per tkm than previously estimated. Contrary to estimates in *STREAM 2016*, capacity utilisation in certain larger vessel categories in fact decreases slightly. For the General cargo vessel, energy consumption has now been taken higher, with a resultant increase in CO_2 and air-pollutant emissions.
- PM_c and SO_2 emissions per unit fuel are a little higher than in *STREAM 2016* because of the change in scope. Calculations are now based on a higher average fuel sulphur content, not on the 0.1% S based solely on the North Sea and Baltic SECA.
- On average, NO_x emissions per unit fuel are now slightly lower, owing to fleet renewal.
- The values for energy consumption and emissions are derived from fuel consumption data. Because both the EU-MRV and the KVNR database report real-world values for fuel consumption, distance sailed and cargo tonnage, we deem the *STREAM 2020* results to be more reliable than those of *STREAM 2016*, which derived from theoretical energy consumption and emission values.

8.5 Aviation

Aviation is a new addition to *STREAM 2020*.

8.6 Upstream emissions

In *STREAM 2020* the upstream CO_2 emissions of fuels are based largely on (NEa, 2019), which uses the emission factors given in the Implementing Directive of the Fuel Quality Directive (FQD), based in turn on studies by JRC and JEC. In *STREAM 2016* these emissions were based on the (still) most recent JRC study (JRC, 2014a) (JRC, 2014b) and the values cited there are still in good agreement with those in (NEa, 2019).

The upstream air-pollutant emissions of fuel production remain unchanged. For electricity production, the CO_2 emission factor in *STREAM 2020* remains virtually the same, while air-pollutant emissions are now slightly lower.

9 Recommendations for further study

STREAM Freight 2020 provides an overview of average transport emission factors based on the fleets of vehicles and vessels in operation in the Netherlands in 2018. It would be useful to look ahead to the future – to 2025, 2030 and beyond – based on projections of fleet renewal. Over this period, further growth of electric and possibly also hydrogen-fuelled vehicles is set to have a game-changing impact.

There is still limited practical data on battery-electric trucks as well as considerable spread in the values reported for energy consumption relative to diesel trucks. It is recommended to update these data in the years ahead as new practical data come in.

In the coming years more practical data are also expected to become available on inland shipping, via monitoring programmes like CLINSH, for example. In particular, more recent and complete barge sailing speeds would help improve the current results. To this end, new measurements are needed, based on AIS, for instance.

10 Literature

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A Fuel and electricity emission factors

STREAM Freight 2020 reports emission factors for fuel and electricity per MJ. Here they are given in the units more commonly encountered: per litre, kWh or kg fuel/energy carrier.

Table 86 – Emission factors, fuels and electricity (cf. Table 68 for factors per MJ)

			TTW			WTT			
Fuel	**Use**	**Unit**	**CO_2-eq. kg/unit**	**CO_2 kg/unit**	**SO_2 g/unit**	**CO_2-eq. kg/unit**	**NO_x g/unit**	**PM g/unit**	**SO_2 g/unit**
Diesel	Diesel, fossil	Litre	NG	2.62	0.02	0.82	1.16	0.12	3.54
	Biodiesel, NL blend (97% FAME, 3% HVO)	Litre	NG	0.00	0.12	0.44	1.64	0.27	0.84
	Cars	Litre	2.50	2.47	0.02	0.80	1.18	0.13	3.39
	Vans	Litre	2.49	2.47	0.02	0.80	1.18	0.13	3.39
	Trucks	Litre	2.51	2.47	0.02	0.80	1.18	0.13	3.39
	Inland shipping	Litre	2.50	2.47	0.02	0.80	1.18	0.13	3.39
	Rail	Litre	2.48	2.47	0.02	0.80	1.18	0.13	3.39
Electricity	Rail (med.-voltage)	Kwh	0.00	0.00	0.00	0.486	0.34	0.02	0.15
	Road (low-voltage)	Kwh	0.00	0.00	0.00	0.494	0.35	0.02	0.15
HFO (3.5% S)	Maritime shipping	Litre	3.11	3.08	42.68	0.51	1.22	0.12	3.68
HFO (0.5% S)	Maritime shipping	Litre	3.11	3.08	9.70	0.65	1.24	0.13	3.75
MDO (0.1% S)	Maritime shipping	Litre	2.71	2.68	1.67	0.71	1.13	0.12	3.44
HFO (0.5% S)/ MDO average	Maritime shipping	kg	3.22	3.19	6.08	0.76	1.31	0.13	3.99
Kerosene	Aviation	Litre	2.51	2.49	0.79	0.70	1.41	0.18	3.44

NG: Not given; values are vehicle-specific.

Table 87 – Emission factors, alternative fuels and green electricity (cf. Table 69 for factors per MJ)

Fuel	Use	Unit	TTW CO_2-eq. kg/unit	TTW CO_2 kg/unit	TTW SO_2 g/unit	WTW CO_2-eq. kg/unit	WTW NO_x g/unit	WTW PM g/unit	WTW SO_2 g/unit
Petrol	Petrol (fossil)	Litre		2.35	0.0145	0.65	1.33	0.14	4.05
	Petrol substitutes (av.)	Litre		0	0.0091	0.88	3.24	0.60	4.14
	Vans (blend, 4% bio)	Litre	2.20	2.18	0.0143	0.66*	1.55	0.19	4.15
LPG	Vans	Litre	1,62	1,61	0,0049	0,17	1,08	0,08	0,95
	Trucks	Litre	1,63	1,61	0,0049	0,17	1,08	0,08	0,95
HVO	Trucks	Litre	0.04	0.00	0.0078	0.32	1.74	0.28	0.89
	Inland/maritime shipping	Litre	0.03	0.00	0.0078	0.32	1.74	0.28	0.89
CNG	Vans	Litre	0.38	0.36	0.0013	0.06	0.04	0.00	0.00
	Trucks	Litre	0.38	0.36	0.0013	0.06	0.04	0.00	0.00
BioCNG	Vans	Litre	0.02	0	0.0013	0.15	0.10	0.01	0.04
	Trucks	Litre	0.02	0	0.0013	0.15	0.10	0.01	0.04
LNG	Road	Litre	1.33	1.25	0.0045	0.32	0.59	0.02	0.01
	Inland/maritime shipping (lean-burn or dual-fuel, 3% diesel)	Litre	1.62	1.25	0.0045	0.32	0.59	0.02	0.01
	Maritime shipping (dual-fuel, direct-inj., <10% MGO)	Litre	1.28	1.25	0.0045	0.32	0.59	0.02	0.01
BioLNG	Weg	Litre	0.08	0	0.0045	0.56	0.36	0.02	0.13
	Inland/maritime shipping (lean-burn or dual-fuel, 3% diesel)	Litre	0.39	0	0.0045	0.56	0.36	0.02	0.13
	Maritime shipping (dual-fuel, direct-inj., 10% MGO)	Litre	0.04	0	0.0045	0.56	0.36	0.02	0.13
GTL	Trucks	Litre	2.47	2.43	0.0070	0.80	1.24	0.13	3.80
	Inland shipping	Litre	2.46	2.43	0.0070	0.80	1.24	0.13	3.80
Hydrogen[a]	Fuel cell	kg	0	0	0	12.52	16.04	2.28	15.94
Green hydr.[b]	Fuel cell	kg	0	0	0	1.09	0.01	0.00	0.01
Green electr. [c]	Battery	kWh	0	0	0	0.00	0.06	0.01	0.02
Green electr., no biomass[d]	Battery	kWh	0	0	0	0.02	0.00	0.00	0.00

* 0.69 including ILUC.

a Produced by steam reforming.

b Using non-biomass renewables (wind, solar).

c Dutch mix of biomass, wind & solar.

d Dutch mix without biomass.

B Road transport

B.1 Additional tables

Table 88 - Vehicle-kilometre distribution of Euro classes over vehicle categories, based on (Task Force on Transportation, 2020)

Euro class	Van <1.5 t	Van 1.5-2 t	Van 2-2.5 t	Van >2.5 t	Truck <10 t	Truck 10-20 t	Truck >20 t	Tractor light	Tractor heavy
Euro 0	0%	0%	0%	0%	3%	2%	0%	0%	0%
Euro I	0%	0%	0%	0%	0%	2%	0%	0%	0%
Euro II	1%	2%	2%	2%	7%	5%	4%	0%	0%
Euro III	9%	10%	10%	10%	10%	12%	14%	0%	11%
Euro IV	15%	13%	13%	13%	14%	10%	8%	0%	8%
Euro V	47%	49%	49%	49%	38%	28%	24%	25%	20%
Euro VI	27%	26%	26%	26%	28%	41%	50%	75%	61%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table 89 - Allocation of Task Force van categories (Task Force on Transportation, 2020) to *STREAM* van categories (empty weight, EW)

	Task Force category light (N1-I)	Task Force category med.-weight (N1-II)	Task Force category heavy (N1-III)
Van, EW <1.5 t	1%	27%	72%
Van, EW 1.5-2 t	0%	0%	100%
Van, EW 2-2.5 t	0%	0%	100%
Van, EW >2.5 t	0%	0%	100%

Table 90 - Ratio between LHV and tractor-semitrailer emission factors (g/km)

Emission	Emission factor ratio (g/km, LHV / g/km, tractor-semitr.)	Data source
CO_2/SO_2	1.35	TML, 2008/McKinnon, 2008
NO_x	1.33	TML, 2008/McKinnon, 2008
PMc	1.21	TML, 2008/McKinnon, 2008
PM_w (PM_{10} wear and tear)	See main text	Own calculations, depending on number of tyres, via Task Force 2016 methodology

Table 91 - Vehicle distribution over road class, based on (Task Force on Transportation, 2020)

Vehicle category	Urban	Rural	Motorway
Van, <2 t Van, >2 t	16%	32%	52%
Truck, <10 t	29%	33%	38%
Truck, 10-20 t Truck, 10-20 t, with trailer	19%	23%	58%
Truck, >20 t Truck, >20 t, with trailer	14%	18%	67%
Tractor-semitrailer, light Tractor-semitrailer, heavy LHV	5%	8%	87%

B.2 Relative energy consumption of battery-electric trucks

To quantify the energy consumption of battery-electric trucks relative to diesel, data sources were consulted that report these figures for the vehicle category and type of use adopted in *STREAM*: (INFRAS, 2019a; Huismans, 2018; T&E, 2020a; JEC, 2020). The figures reported in the first three of these sources are summarised in Table 92, Table 93 and Table 94, respectively. As can be seen, the data spread is substantial. While most sources report a figure of around 42% for a typical urban trip, values range from 39% to 58% for motorways and for the average reported by INFRAS.

Transport and Environment (T&E, 2017) compare electric and diesel by comparing the power-train losses involved. Using these data, *STREAM* calculates a value of 43% if a non-optimised battery-electric truck ('cab-over-engine') is compared with an average diesel truck and 52% when comparing an aerodynamically optimised model with an ultra-efficient diesel. As the T&E values show, it makes quite some difference whether or not state-of-the-art technology is assumed, on both the diesel and electric side. *STREAM* takes an intermediate value of 47%. This also seems a good median value from the other sources when the high truck mileage on motorways is borne in mind.

Table 92 - Relative energy consumption of electric and diesel trucks according to (INFRAS, 2019a)

	Motorway	Rural	Urban	Average (Germany)
Truck >7.5-12 t Euro VI	51%	51%	41%	50%
Truck <=7.5 t Euro VI	53%	53%	39%	51%
Tractor-semitrailer/truck >34-40 t Euro VI	59%	55%	41%	54%

Table 93 - Relative energy consumption of electric and diesel trucks according to (JEC, 2020)

	Motorway trip	Regional trip	City trip
Truck, 2016	58%	48%	42%
Truck, 2025	40%	45%	34%

Table 94 - Relative energy consumption of electric and diesel trucks according to (Huismans, 2018)

Road type	2020 (kWh/km)			2030 (kWh/km)		
	Diesel	Electric	Electric /diesel	Diesel	Electric	Electric /diesel
Motorway	3.37	1.53	45%	2.03	1.01	50%
Rural	4.45	1.74	39%	3.5	1.55	44%
Urban	4.92	2.02	41%	3.15	1.28	41%

C Rail transport

C.1 Additional tables

Table 95 - Locomotive parameters

	Length (m)	Weight (t)	Tractive effort (t)
Electric	18	88	1,800
Diesel	18	110	1,800

Loc. weight from (CE Delft, 2008), length and tractive power from online sources.

Table 96 - Freight type per train category

Train category	Light transport	Medium-weight transport	Heavy transport	Extra-heavy transport
Bulk/packaged goods				
Medium-length	Grain	Neobulk	Tank wagons	Coal/ore
Long	Neobulk	Neobulk	Tank wagons	Coal/ore
Extra-long	Neobulk	Neobulk	-	-
Containers				
Long	Containers	Containers	Containers	Containers
Extra-long	Containers	Containers	Containers	Containers

Table 97 - Average gross tonne weight (GTW) of Dutch trains on border crossings, incl. Betuwe line, 2018

Border crossing	No. of trains	Gross tonnage carried (Mt)	Average GTW per train
Oldenzaal-Bad Bentheim	6,100	7	1,148
Zevenaar-Emmerich	20,650	37.8	1,831
of which via 'mixed network'	*450*	*0.7*	*1,556*
of which via Betuwe line	*20,200*	*31.1*	*1,540*
Venlo-Kaldenkirchen	16,550	25.1	1,517
Eijsden-Visé	2,550	3.6	1,412
Rossendaal-Essen	8,050	8.8	1,093
Total/average for border crossings	**53,900**	**82.3**	**1,527**

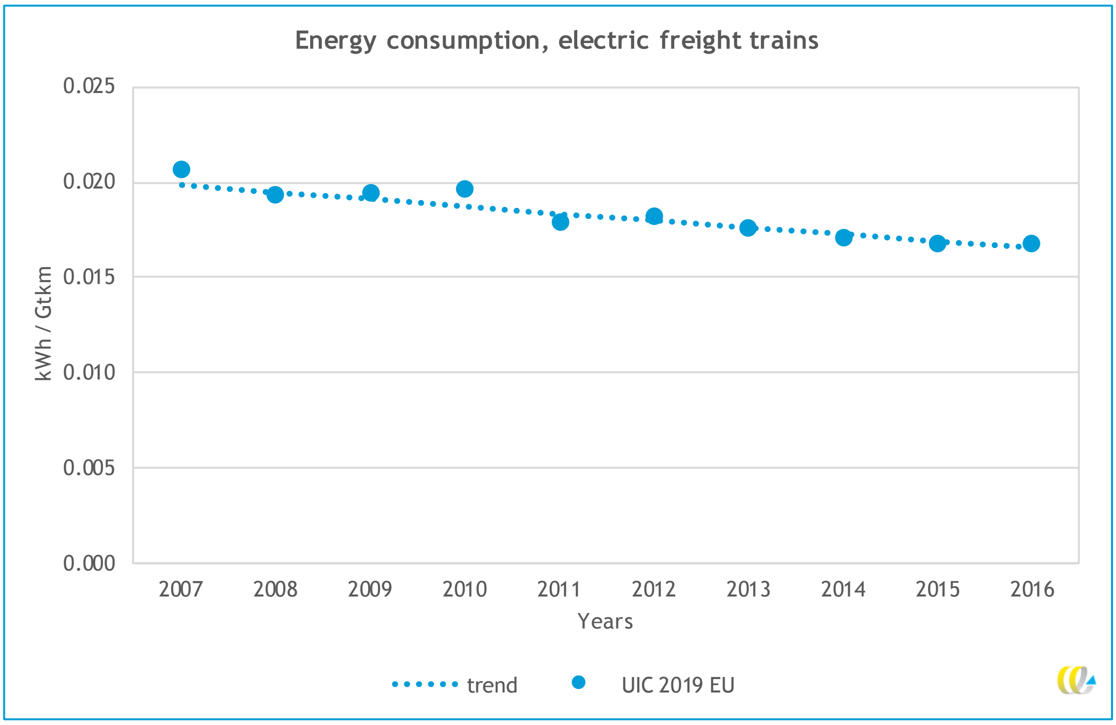
Source: (ProRail, 2019).

Table 98 - Percentage share of rail freight categories

Freight category	Share
Containers	43%
Coal	17%
Ore	14%
Bulk	11%
Steel	7%
Dry bulk	6%
Other	2%
Total (annual)	**100%**

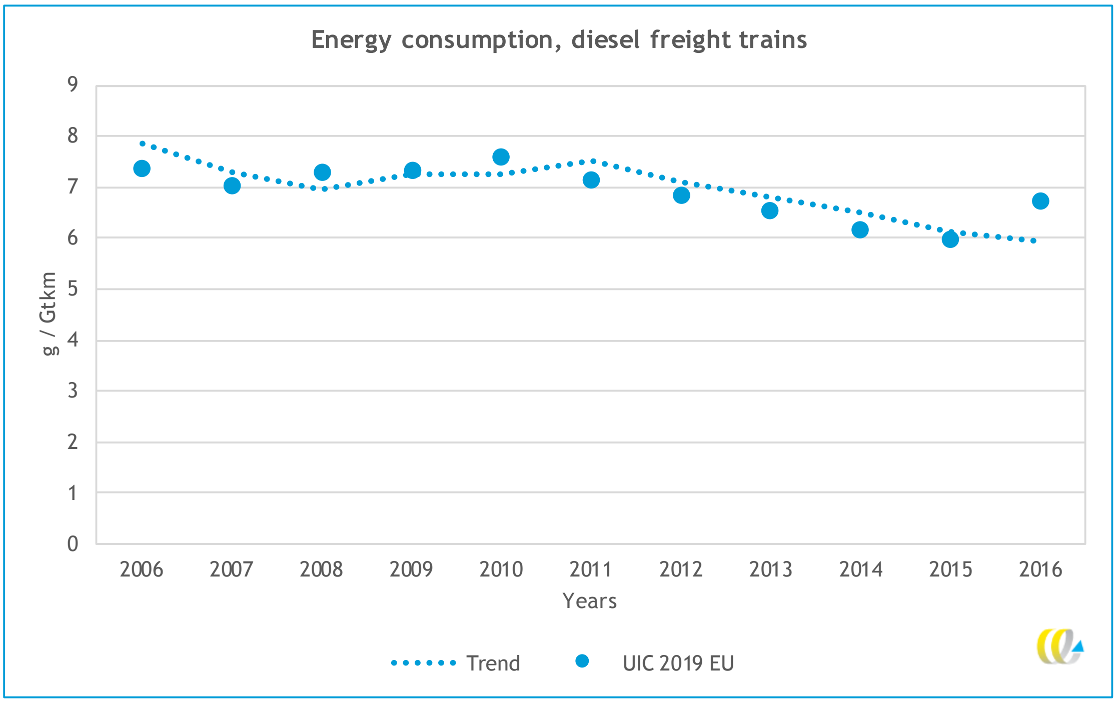
Source: (ProRail, 2017).

Figure 35 - Trend in energy consumption of electric freight trains (based on UIC data)



Source: (UIC, 2019).

Figure 36 - Trend in energy consumption of diesel freight trains (based on UIC data)



Source: (UIC, 2019).

D Inland shipping

D.1 Additional tables

Table 99 – Ship parameters used for modelling energy consumption

Vessel category	Load cap. (t)	Width (m)	Length (m)	Draught, full (m)	Draught, empty (m)
Bulk/packaged goods					
Spits	365	5.05	38.50	2.48	0.52
Campine vessel	617	6.60	55.00	2.60	0.60
Rhine-Herne canal vessel	1.537	9.50	85.00	2.90	0.75
Large Rhine vessel	3.013	11.40	110.00	3.30	0.95
Class Va + 1 Europa II barge, wide	5.046	22.80	110.00	3.75	0.95
4-barge push convoy	11.181	22.80	189.00	3.75	0.60
6-barge push convoy, wide	16.481	34.20	193.00	3.75	0.60
Containers					
Neo Kemp	850	7.20	67.00	2.54	0.70
Rhine-Herne canal vessel (96 TEU)	1.537	9.50	85.00	2.90	0.75
Europa IIa push convoy (160 TEU)	2.708	11.40	92.00	3.50	0.60
Large Rhine vessel (208 TEU)	3.013	11.40	110.00	3.30	0.95
Extended Large Rhine vessel (272 TEU)	3.736	11.40	135.00	3.50	1.00
Coupled Europa II C3l (348 TEU)	4.518	11.40	180.00	3.75	0.95
Rhinemax vessel	6.082	17.00	135.00	3.80	0.90

Source: CE Delft, based on (RWS-AVV, 2002), (RWS-DVS, 2011) and (TNO, 2014).

Table 100 – Sailing speeds, bulk ships, in *STREAM Freight 2016*

AVV class	Vessel category (designated class)	Waterway class	Speed, laden, upstr./both	Speed, laden, downstr.	Speed, unladen, upstr./both	Speed unladen, downstr.
M1	Spits	CEMT I	9	9	23	23
		CEMT Va	11	11	17	17
		CEMT VIb	11	11	16	16
		Waal	11	12	15	16
M2	Campine vessel	CEMT II	9	9	16	16
		CEMT Va	12	12	18	18
		CEMT VIb	12	12	17	17
		Waal	13	14	16	17
M6	Rhine-Herne canal vessel	CEMT IV	9	9	16	16
		CEMT Va	12	12	19	19
		CEMT VIb	14	14	19	19
		Waal	14	14	18	19
M8	Large Rhine vessel	CEMT Va	10	10	17	17
		CEMT VIb	14	14	19	19
		Waal	13	14	18	18
C3b	Class Va + 1 Europa II barge, wide	CEMT VIb	8	8	15	15
		Waal	11	11	15	16

AVV class	Vessel category (designated class)	Waterway class	Speed, laden, upstr./both	Speed, laden, downstr.	Speed, unladen, upstr./both	Speed unladen, downstr.
BII-4	4-barge push convoy	CEMT VIb	10	10	17	17
		Waal	12	11	16	17
BII-6b	6-barge push convoy, wide	CEMT VIc	N.a.	N.a.	N.a.	N.a.
		Waal	N.a.	N.a.	N.a.	N.a.

N.a. This combination was not included in *STREAM Freight 2016*.

Table 101 - Sailing speeds, bulk ships, in *STREAM Freight 2020*, based on practical AIS data

AVV class	Vessel category (designated class)	Waterway class	Speed, laden, upstr./both	Speed, laden, downstr.	Speed, unladen, upstr./both	Speed unladen, downstr.
M1	Spits	CEMT I	7	7	9	9
		CEMT Va	9	9	12	12
		CEMT VIb	10	10	13	13
		Waal	9	11	12	17
M2	Campine vessel	CEMT II	7	7	8	8
		CEMT Va	11	11	12	12
		CEMT VIb	13	13	14	14
		Waal	12	16	12	17
M6	Rhine-Herne canal vessel	CEMT IV	9	9	11	11
		CEMT Va	10	10	12	12
		CEMT VIb	14	14	15	15
		Waal	13	17	14	18
M8	Large Rhine vessel	CEMT Va	9	9	11	11
		CEMT VIb	13	13	14	14
		Waal	13	17	14	18
C3b	Class Va + 1 Europa II barge, wide	CEMT VIb	12	12	12	12
		Waal	11	15	16	17
BII-4	4-barge push convoy	CEMT VIb	10	10	11	11
		Waal	11	16	16	18
BII-6b	6-barge push convoy, wide	CEMT Vic	14	14	15	15
		Waal	10	17	16	18

Table 102 - Sailing speeds, container ships, in *STREAM Freight 2016*

Vessel category (designated class)	Waterway class	Speed, laden, upstr./both	Speed, laden, downstr.	Speed, unladen, upstr./both	Speed unladen, downstr.
Neo Kemp	CEMT III	9.2	9.2	15.1	15.1
	CEMT Va	12.2	12.2	17.4	17.4
	CEMT VIb	13.9	13.9	16.7	16.7
	Waal	13.2	14.3	17.1	17.5
Rhine-Herne canal vessel (96 TEU)	CEMT IV	9.3	9.3	15.7	15.7
	CEMT Va	12.1	12.1	18.5	18.5
	CEMT VIb	14.1	14.1	18.7	18.7
	Waal	14.1	14.1	18.3	18.5

Vessel category (designated class)	Waterway class	Speed, laden, upstr./both	Speed, laden, downstr.	Speed, unladen, upstr./both	Speed unladen, downstr.
Europa IIa push convoy (160 TEU)	CEMT Va	10.8	10.8	17.4	17.4
	CEMT VIb	12.8	12.8	17.2	17.2
	Waal	12.5	13.1	16.2	16.5
Large Rhine vessel (208 TEU)	CEMT Va	10	10	17.3	17.3
	CEMT VIb	13.6	13.6	19.2	19.2
	Waal	13.2	13.5	18	18.2
Extended Large Rhine vessel (272 TEU)	CEMT Va	10.5	10.5	18.3	18.3
	CEMT VIb	13.7	13.7	19.5	19.5
	Waal	12.5	13.6	18	18.1
Coupled Europa II C3l (348 TEU)	CEMT Vb	N.a.	N.a.	N.a.	N.a.
	CEMT VIb	11.7	11.7	18.2	18.2
	Waal	11.3	12	16.3	16.4
Rhinemax vessel (398-470 TEU)	CEMT VIb	14	14	18.5	18.5
	Waal	15.2	17.3	18.2	20.3

N.a.: This combination was not included in *STREAM Freight 2016*.

Table 103 - Sailing speeds, container ships, in *STREAM Freight 2020*, based on practical AIS data

Vessel category (designated class)	Waterway class	Speed, laden, upstr./both	Speed, laden, downstr.	Speed, unladen, upstr./both	Speed unladen, downstr.
Neo Kemp	CEMT III	7.2	7.2	8.1	8.1
	CEMT Va	10.7	10.7	11.7	11.7
	CEMT VIb	13.0	13.0	14.1	14.1
	Waal	12.0	15.9	13.1	17.6
Rhine-Herne canal vessel (96 TEU)	CEMT IV	9.0	9.0	10.5	10.5
	CEMT Va	10.0	10.0	11.7	11.7
	CEMT VIb	13.6	13.6	14.7	14.7
	Waal	13.5	17.3	13.6	18.1
Europa IIa push convoy (160 TEU)	CEMT Va	9.3	9.3	10.6	10.6
	CEMT VIb	12.8	12.8	13.1	13.1
	Waal	11.0	16.3	12.4	16.1
Large Rhine vessel (208 TEU)	CEMT Va	9.1	9.1	11.1	11.1
	CEMT VIb	13.4	13.4	14.4	14.4
	Waal	12.8	17.2	13.5	18.0
Extended Large Rhine vessel (272 TEU)	CEMT Va	10.4	10.4	9.7	9.7
	CEMT VIb	14.0	14.0	14.9	14.9
	CEMT Vb	12.6	16.6	14.0	18.0
Coupled Europa II C3l (348 TEU)	CEMT Vb	9.7	9.7	14.6	14.6
	CEMT VIb	13.6	13.6	14.7	14.7
	Waal	12.3	16.4	11.9	17.0
Rhinemax vessel (398-470 TEU)	CEMT VIb	14.1	14.1	14.4	14.4
	Waal	12.7	16.7	16.6	19.3

E Lifecycle emissions

E.1 Description of sources

Ecoinvent

Ecoinvent is a Swiss non-profit organisation that administers a ‘Life Cycle Inventory’ (LCI) database with information on the emissions associated with thousands of products, encompassing not only production processes but also maintenance. With the SimaPro software the data from this database can be retrieved and processed in a ‘Life Cycle Assessment’ (LCA) that allows the lifecycle emissions of a particular process or product to be established, ‘from cradle to grave’.

When it comes to transportation, the Ecoinvent database contains data on all the modes included in *STREAM* as well as on related infrastructure. For each transport mode the data are available for a range of geographical situations, such as Switzerland, Europe without Switzerland or the whole world. For certain modes information on specific countries is available.

Mobitool (Frischknecht, et al., 2016)

The Swiss platform Mobitool has developed the tool ‘Mobitool-Faktoren’ for reviewing vehicle emissions per mode. The tool is based on the LCA methodology and uses mainly the data from the Ecoinvent database. For defining a particular case, Mobitool applies a factor for scaling emissions and models. Thus, a vehicle is defined as follows:

$$vehicle_{mobitool} = vehicle_{ecoinvent} * \frac{vehicle\ weight_{mobitool}}{vehicle\ weight_{ecoinvent}}$$

and indirect emissions from electricity production as follows:

$$energy\ input_{mobitool} = energy\ input_{ecoinvent} * \frac{average\ consumption_{mobitool}}{average\ consumption_{ecoinvent}}$$

A parallel method is adopted to establish the direct emissions and the emissions associated with maintenance and infrastructure.

LCA on three passenger car models (CE Delft, 2020b)

This study performes lifecycle analyses for three cars in the C-segment differing in their power source: petrol, electric and hydrogen, comparing emissions and costs in 2020 and 2030. By 2030 the production process will have become more efficient and use predominantly renewable energy. The study does not include the end-of-life phase, because the recycling infrastructure is not yet in place. This phase is not anticipated to have any significant impact on total lifecycle emissions, though. Infrastructure is not included either, as this too is projected to have little effect on lifecycle emissions. This study has investigated differnces in lifecycle emissions of parts used for different three cars.

Review of transport GHG emission factors for the EIB (CE Delft, 2018)

The aim of this CE Delft study for the EIB was to update transport emission factors. This was done by reviewing a range of data sources and led to an update of WTW and TTW emission factors for selected modes. Correction factors were also computed for 2030 as a basis for new emission factors.

Comparative LCA of Electrified Heavy Vehicles in Urban Use (Soriano & Laudon, 2012)

This study evaluates two Volvo hybrid trucks for use in urban logistics and waste collection. Production of the Li-ion batteries for the powertrain has the greatest impact on lifecycle emissions. With regard to maintenance, only single battery replacement was modelled, for one of the hybrids. A large difference is reported between the emissions of the refuse truck and the delivery truck, for both the conventional vehicles and the hybrid variant. In both cases the refuse truck has lower emissions than the delivery truck.

Life Cycle Assessment of Commercial Delivery Trucks: Diesel, Plug-In Electric, and Battery-Swap Electric (Yang, et al., 2018)

Truck production is accompanied by emission of 8 kg CO_2-eq./kg vehicle. Vehicle lifetime is taken as 240,000 km, annual kilometrage as 14,728-30,000 km.

Development of LCA software for ships and LCI Analysis (NMRI, 2014)

This study models eight shipping vessels (bulk, tanker and container) to determine their lifecycle CO_2, NO_x and SO_x emissions. These LCAs take in production, use, dismantling and recycling. No mention is made of infrastructure.

Life Cycle Assessment of railway infrastructure in Belgium (Université Liege, 2017)

This study estimates the share of infrastructure in rail transport lifecycle emissions in Belgium. Tunnels and bridges are included, as is railway construction. Diesel and electric locomotives are distinguished.

Carbon Footprint of Railway Infrastructure (UIC, 2016)

This UIC study compares the CO_2 emission factors reported for railway infrastructure in various sources. It includes several case studies and distinguishes passenger and freight transport.

EU Transport GHG: Routes to 2050 II (AEA; CE Delft; TEPR; TNO, 2012)

This study assesses the carbon emissions of infrastructure, vehicle production and disposal for each main transport mode, taking in both freight and passenger transport.

E.1.1 Comparison of LCAs on conventional and electric vehicles

In this section the approaches adopted in the various LCAs on conventional and electric vehicles are compared.

(CE Delft, 2020b)

This study reports the differences between petrol-fuelled and electric cars. Table 104 presents a similar comparison, with some adjustments and additions for freight transport.

Table 104 - Differences between conventional and electric vehicles

Vehicle element	Conventional vehicles	Electric vehicles
Powertrain & transmission	– Combustion engine – Heavier powertrain (trucks)	– Electromotor – Lighter powertrain (trucks) – Yet to be determined (other modes)
Energy/power supply	– Fuel tank	– Li-ion battery (road transport) – Flow battery (inland shipping) – Modular battery container (inland shipping container ships) – Solid electrolyte battery (shipping) – Overhead lines (rail)
Electronics & wiring	– Little electronics	– Substantial electronics
Other changes	– N.a.	– Reinforced axles (trucks) – Yet to be determined (other modes)

(Ecoinvent, 2010)

Trains are the only electric freight vehicles included in this study. Table 105 summarises the differences emerging from the LCAs of diesel-powered and electric freight trains.

Table 105 - Differences and equivalencies between diesel and electric freight trains per tonne-kilometre

LCA phase	Diesel	Electric
Locomotive production	No difference	
Wagon production	No difference	
Locomotive maintenance	No difference	
Wagon maintenance	No difference	
Infrastructure	Same allocation factor	
Diesel fuel	0.0107 kg	0.000677 kg
Electricity	0 kWh	0.0478 kWh

Source: (Ecoinvent, 2010).

The contributions of production, maintenance and infrastructure to lifecycle emissions are the same for diesel and electric, for which the only difference is the diesel versus electrically powered locomotive. The wagons are the same in both cases and therefore also the share of infrastructure in lifecycle emissions. Given the different locomotives, though, it can be queried whether the figures for production and maintenance should be taken the same. As a result this study includes a small amount of diesel fuel for the electric train.

(Frischknecht, et al., 2016)

For freight transport, Mobitool makes no comparison between conventional and electric vehicles, except for rail, although it does do so for passenger cars, in principle making the same assumptions for both variants on such issues as service life. Table 106 summarises the assumptions made.

Table 106 – Differences between petrol and electric cars

Item	Petrol	Electric
Battery life	N.a.	100,000 km
Average consumption	7.5 l/100 km	20 kWh/100 km
Range	N.a.	165 km
Wear-and-tear emissions	100%	10%
Charging infrastructure	N.a.	Not included

Source: (Frischknecht, et al., 2016).

E.1.2 Comparison of Mobitool data with other data

Below we describe how the data from various sources used for calculating lifecycle CO_2 emissions differ from the Mobitool data (Frischknecht, et al., 2016). As specific sources are not available for every mode, only road, rail and maritime shipping are considered. For all modes it holds that the data are not geared to the specifics of Dutch freight transport; the emission factors reported are based on the international situation. This means the underlying assumptions needed to be validated for their applicability to the Netherlands.

Road transport

While data on road transport is the most widely available, the sources in question do not permit direct quantification of the share of each phase of the lifecycle in aggregate emissions. There are data gaps and assumptions are be made to determine emissions per tonne-kilometre.

Yang et al. (2018) compare diesel and electric variants of a van and a light truck (3.5–7.0 t). They calculate that the E-van has 69% lower lifecycle CO_2 emissions per tonne-km than the diesel van, but that these are 9.8% higher for the E-truck than the diesel. The figures reported by Yang et al. for the share of vehicle production are generally within the Mobitool range. The only exception is the E-van, production of which contributes slightly less than the diesel variant in absolute terms, but more in percentage terms, as its total lifecycle emissions work out lower. The shares of Wheel-To-Well (WTW) emissions are reasonably in line with the Mobitool data for both the diesel van and truck. While the share is lower for the E-variants, it is still relatively high, though, possibly in part because fossil electricity is assumed for China (cf. following section).

Table 107 – Comparison of shares of vehicle production and WTW in lifecycle emissions, road transport

Vehicle	Powertrain	Lifecycle emissions (excl. infrastr.) (g CO_2/tkm)	Share of vehicle prod. (excl. battery) (-)	Share of WTW emissions (-)
Mobiltool				
Van, <3.5 t	Diesel	1,592	14%	80%
Truck, 3.5-7.5 t	Diesel	482	7%	88%
Yang et al., 2018				
Van, <3.5 t	Diesel	745	10%	91%
	Electric	231	22%	59%
Truck, 3.5-7.0 t	Diesel	265	12%	84%
	Electric	291	13%	67%

(Soriano & Laudon, 2012) do the sums for two hybrid trucks: a refuse truck and a delivery truck, and report these having far lower lifecycle CO_2 emissions than their conventional counterparts. Although the figure is lower for the refuse truck in absolute terms, when converted to emissions per tkm there is less difference, since the delivery truck goes longer distances and carries heavier loads. The parameters of these hybrid vehicles prohibit one-to-one comparison with the Mobitool data.

Rail

For rail, two studies were consulted alongside the Mobitool data: (Université Liege, 2017) and (UIC, 2019), both of which assess the share of rail infrastructure in lifecycle emissions. The former looks specifically the Belgian situation, while the UIC study is more general. Table 108 summarises how their results compare with the Mobitool data on this issue. While all three sources discuss the influence of tunnels and bridges on aggregate emissions, the UIC study shows that their presence in large numbers may treble annual per-km CO_2 emissions. As can be seen in Table 108, the reported values are all within the same range.

Table 108 – Comparison of share of infrastructure in lifecycle emissions, rail

	g CO_2/tkm infrastructure	Share of infrastr. in lifecycle CO_2	mg PM/tkm infrastructure	Share of infrastr. in lifecycle PM
Mobiltool				
Diesel & electric	4.15	15%	4.82	38%
Electric	4.15	18%	4.82	46%
(Université Liege, 2017)				
Diesel	-	19%	-	23%
Electric	-	26%	-	42%
(UIC, 2019)				
Average	6-7	-	-	-

Maritime shipping

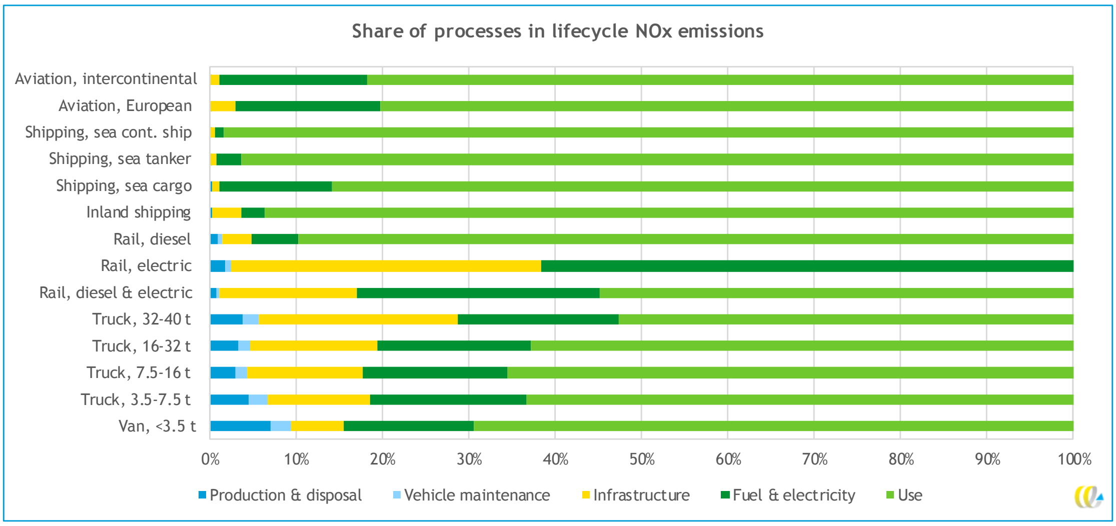
NMRI, (2014) reports on LCAs of eight deep-sea vessels. The construction phase of a 10,000-t ship contributes 15,000 t CO_2 to aggregate lifecycle emissions. Of these, 500 t are direct shipyard emissions, attributable to the sea trial (43%), cutting, welding and plate-forming (46%) and shipyard transport (11%). As Mobitool report shipbuilding emissions per tonne-km, direct comparison is precluded unless assumptions are made about lifetime tkm for the eight vessels in question. For the use phase, NMRI does reports emissions per tkm. Of these, 7% are due to fuel production, compared with Mobiltool's 15.2%.

E.2 Additional graphs on vehicle LCAs

The shares of the various phases in total lifecycle NO_x and PM emissions for the various modes according to the Mobitool dataset (Frischknecht, et al., 2016) are shown in Figure 37 and 38, respectively. As can be seen, for electric rail and road, infrastructure contributes more to lifecycle NO_x emissions than is the case for CO_2. With aviation, inland and maritime shipping and diesel rail, it contributes less. This is because the NO_x emissions are due largely to use of mobile machinery in road and railway construction, which are subject to less stringent emission standards than road vehicles, which means higher emissions per litre diesel than for road transport, but not other modes. With regard to the contribution of vehicle/vessel production/disposal and maintenance, it is striking that this is limited for the lifecycle NO_x emissions of inland and maritime shipping, though these phases make up a considerable share of lifecycle CO_2 emissions.

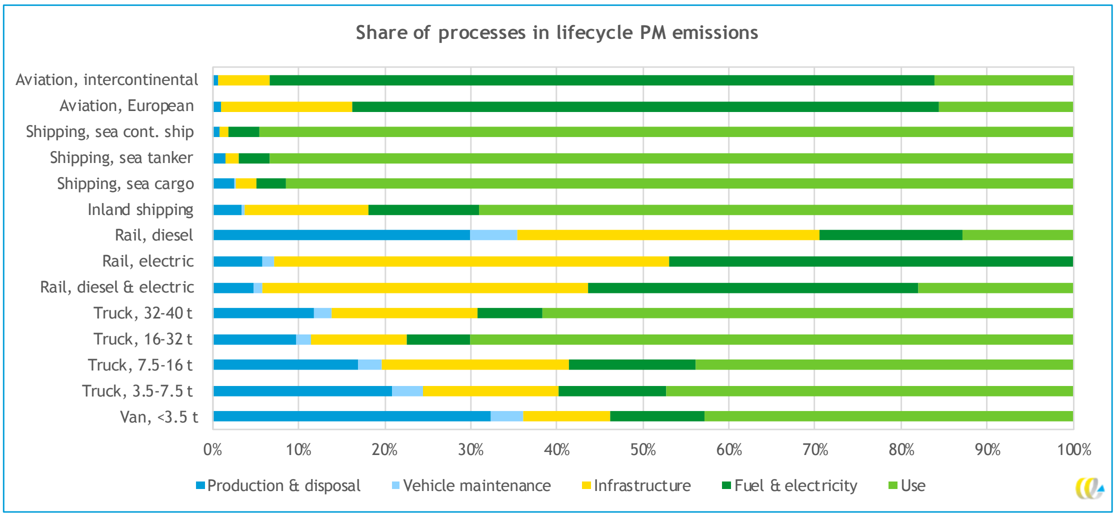
The share of infrastructure in lifecycle PM_c emissions is similar to the case for NOx, but more pronounced, while vehicle production/disposal and maintenance contribute far more than in the case of NO_x and CO_2, with this holding for all modes. Together with infrastructure, these account for almost half the lifecycle emissions in the case of vans and even more than half for full electric rail. The high share of vehicle production in lifecycle PM emissions is due above all to use of coal-based electricity in the steel production chain.

Figure 37 - Share of processes in lifecycle NO_x emissions, by transport mode



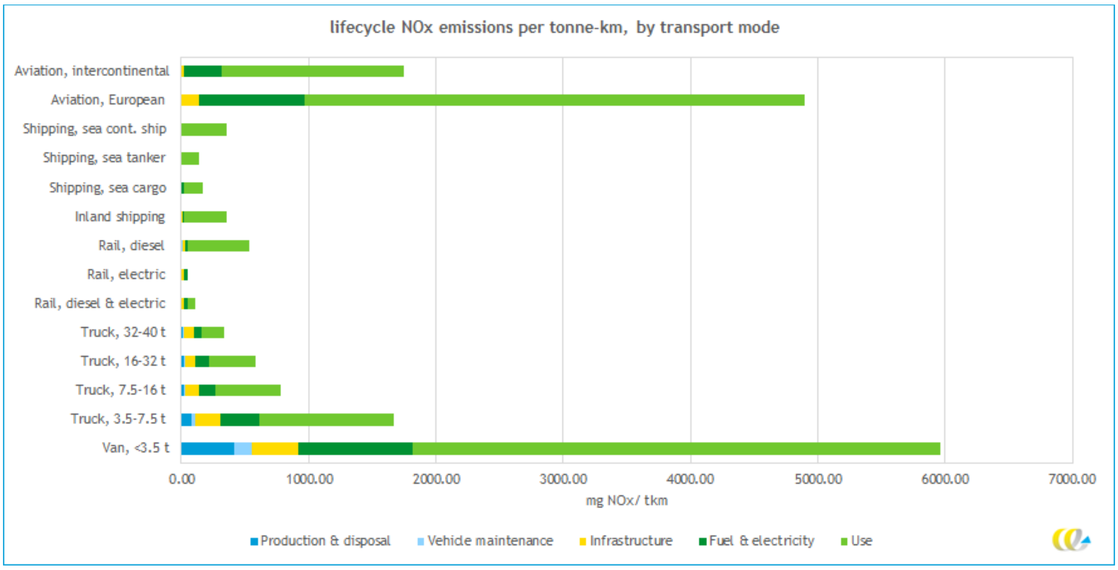
Source: (Frischknecht, et al., 2016).

Figure 38 - Share of processes in lifecycle PM_c emissions, by transport mode



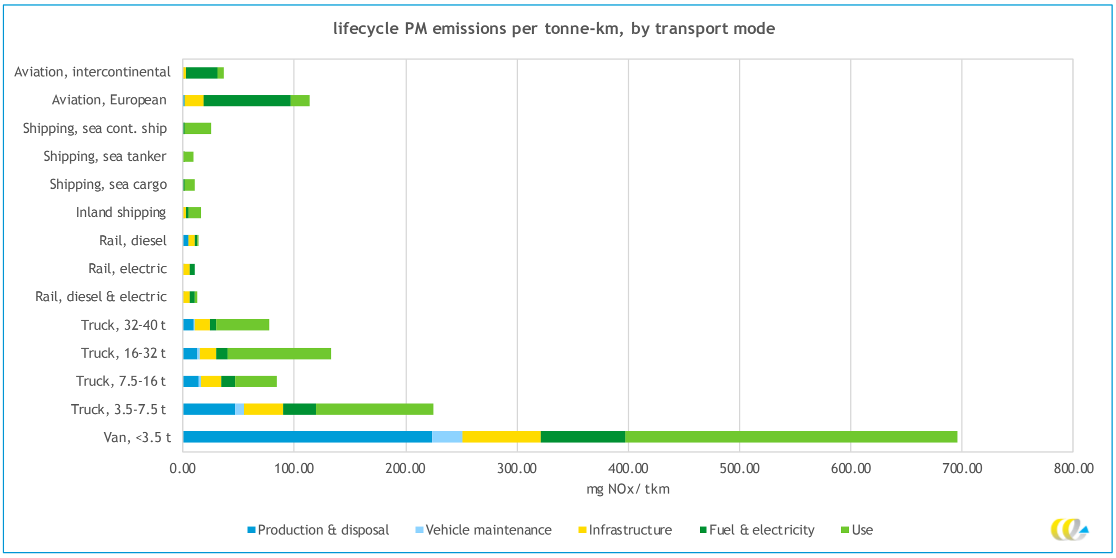
Source: (Frischknecht, et al., 2016).

Figure 39 - Lifecycle NO_x emissions per tonne-km, by transport mode



Source: (Frischknecht, et al., 2016).

Figure 40 - Lifecycle PM_c emissions by tonne-km, by transport mode

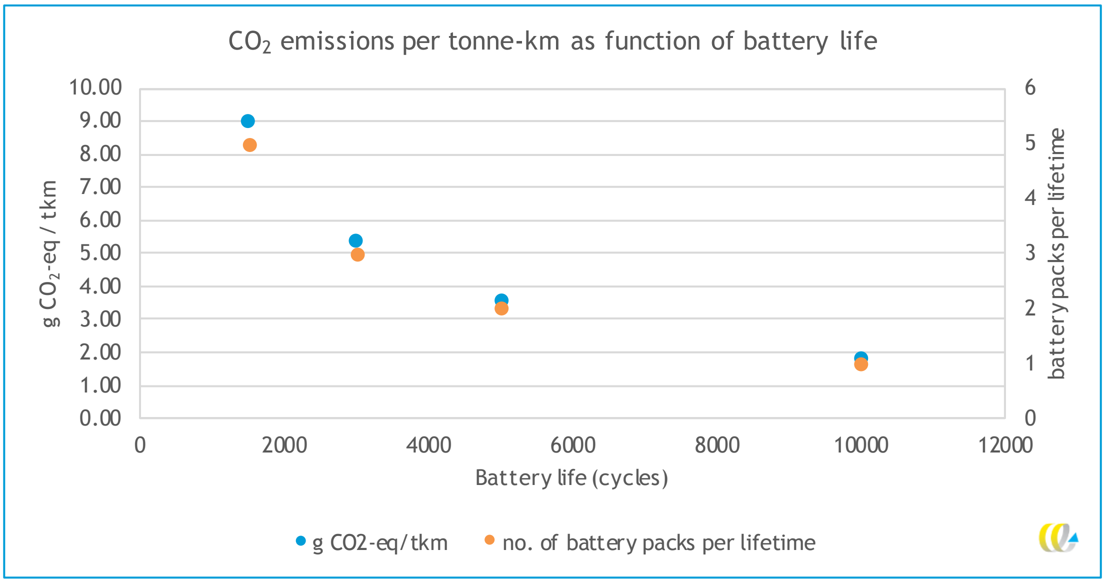


Source: (Frischknecht, et al., 2016).

E.3 Additional calculations on batteries

As discussed in Section 7.2, the service life of batteries is set to increase substantially in the coming years. The calculations in *STREAM 2020* take 1,500 cycles as the theoretical end-of-life (Hoekstra, 2019), a conservative value, as figures between 1,500 and 3,000 cycles are cited in the latest literature for the near future, rising to 5,000-10,000 cycles not too far hence. Figure 41 shows how CO_2 emissions per tonne-km are projected to decline as a function of battery life in the coming years.

Figure 41 - CO_2 emissions per tonne-km as function of battery life (DAF CF Electric Innovation Truck (load cap. 27 t)



STREAM calculates emissions due to battery production based on vehicle lifetime, which in some cases means allowing for one or more battery changes. An alternative approach is to base calculations on battery lifetime, which will mean lower emissions if this exceeds vehicle lifetime. Since *STREAM 2020* takes a conservative value of 1,500 cycles, with future projections rising to 10,000 by 2030, this will be ever more often the case.

E.4 Key variables in transport LCAs

In transport LCAs aiming to quantify vehicle emissions per tonne-km, the most important assumptions are generally those on the following issues:

- Vehicle lifetime: a longer lifetime, with more kilometres, reduces emissions per tkm.
- Average annual or total weight transported in vehicle lifetime.
- Annual kilometrage.
- Fleet composition per vehicle category.
- Infrastructure occupation (for establishing allocation factors).
- Percentages of tunnels and bridges in infrastructure.
- Infrastructure lifetime.
- Production locations: certainly for batteries, production emissions depend on plant location. To an extent, the same will hold for production of the rest of the vehicle.