STREAM Freight transport 2016

Emissions of freight transport modes

Topsector Logistiek

CE Delft

Committed to the Environment

LEAN & GREEN

STREAM Freight transport 2016

Emissions of freight transport modes – Version 2

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Foreword

This report was commissioned by Connekt on behalf of Topsector Logistiek and overseen by a steering party comprising representatives of Connekt, the Stimular Foundation, Milieu Centraal and the Foundation for Climate Friendly Procurement and Business (SKAO). We would like to thank the members of the steering party for their contribution to preparation of this report.

In the course of this study, two workshops were also held with participants from key branch organisations representing the Dutch transport sector (TLN, EVO, BLN, EICB, KNVR, KNV), the Netherlands Environmental Assessment Agency (PBL), the Dutch ministry of Infrastructure and Environment and steering party members. In preparing this report we received a wealth of useful feedback from these participants, for which we are very grateful.

The data in this report are based on the Dutch vehicle and vessel fleets.
This English version is a faithful translation of the original Dutch version *STREAM Goederenvervoer 2016*.

This 2nd version of STREAM Freight Transport 2016 has the following changes relative to Version 1:
- The particulate emissions (PMc) of short-sea shipping vessels have been adjusted upwards. Because of the SECA standards, the figures in STREAM for this vessel category are based on emissions for low-sulphur diesel (MGO). An analysis of recent sources (2016) points to MGO leading to higher emissions than assumed in the original version. This change impacts on all tables and figures referencing the particulate emissions of short-sea shipping.
- In Table 29, Table 30 and Table 31 the tank-to-wheel indices for CNG and LNG have been altered from 100 to 84, to correct a typing error.
- In Table 35 the particulate indices for 'HFO + scrubber' and 'LNG' have been altered, owing to the change in the particulate emissions of MGO-fuelled short-sea shipping.
- In Table 60 the well-to-tank particulate (PMc) and SO_2 emission factors have been altered, to correct a typing error.
- Several literature references have been replaced by more recent or direct sources (reporting the same information).

Contents

Terms and Abbreviations

CEMT	Conférence Européenne des Ministres de Transport.
CEMT I-VI	Waterway classes established by the CEMT, laying down maximum vessel dimensions for each class.
CNG	Compressed Natural Gas.
dwkt	Deadweight tonnage in kilotonnes: the total mass a shipping vessel can carry (load, fuel, ballast water).
dwt	Deadweight tonnage in tonnes: the total mass a shipping vessel can carry (load, fuel, ballast water).
GTL	Gas-to-Liquids, a high-quality 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.
HFO	Heavy fuel oil.
IMO	International Maritime Organisation.
kWh	Kilowatt-hour.
LHV	Long heavy vehicle (‘super-truck’)
LNG	Liquefied Natural Gas.
MGO	Marine Gas Oil.
MJ	Megajoules.
NO_X	Collective term for mono-nitrogen oxides (NO, NO_2 and NO_3). These lead to smog formation, environmental acidification and respiratory damage.
PM_{10}	Particulate matter with a diameter less than ten microns arising via combustion (PM_c) and wear and tear (PM_w) (abrasion of brake linings, rubber tyres and road surfaces) and posing a health risk when inhaled.
PM_c	PM_{10} emissions due to combustion.
PM_w	PM_{10} emissions due to wear and tear.
ppm	Parts per million.
SO_2	Sulphur dioxide emissions. These lead to smog formation and environmental acidification and can cause respiratory difficulties, irritation of the eyes and pulmonary problems.
TEU	Standard shipping container size expressing container volume: Twenty-feet Equivalent Unit.
tkm	Tonne-kilometre: a unit defining transport performance, expressed as transport of one tonne over a distance of one kilometre. The distance considered in the present context 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: 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: emissions arising during extraction, transport and refinery of fuels or during electric power generation and transmission. In line with IPCC protocols, the tank-to-wheel emissions of biofuels are taken to be zero. The net supply-chain emissions of biofuels have been included as well-to-tank emissions.
WTW	Well-to-wheel emissions: the sum total of well-to-tank and tank-to-wheel emissions.

Summary

Content

STREAM Freight Transport 2016 is a handbook providing emission factors per tonne-kilometre for road, rail, inland-waterway and short-sea transport.
For each of these transport modes the report gives representative average emission data suitable for exploratory (policy) analyses for which average data suffice. In addition, the report provides detailed factors with which emissions can be calculated for specific situations by users disposing over information on the types of vehicle or vessel employed and their mode of utilization (type of freight and class of waterway/road). Besides fleet-average emission factors for the year 2014, factors are also reported for individual vehicle technologies (such as Euro emission classes) and (alternative) fuels.

Besides the emission data, the report also provides extensive information on the sources and methods used.

The emission factors in this publication are not designed for direct comparison of transport modes. What they can be used for is comparison between various transport options, allowing for the particular distance travelled by each mode, for upstream and downstream transport and for freight transhipment.
This is illustrated with reference to several concrete cases.

STREAM provides emission factors for greenhouse gases (CO_2, CH_4 and N_2O, summed as CO_2-eq.) and the principal transport air-pollutants (PM_{10}, NO_x and SO_2). Besides both exhaust and wear-and-tear emissions, the emissions occurring during extraction, production and transport/transmission of fuel and electricity are also reported.

Results

An extensive overview of the emission factors is provided in Chapter 2.
The synopsis provided shows that emission factors for individual transport modes have a broad range, depending on the vehicle/vessel size (load capacity) and the type of freight being transported (light, medium, heavy).

As the concrete cases presented in Chapter 6 demonstrate, the comparative emissions of alternative transport modes on a given route depend not only on emission factors per tonne-kilometre, but also very much on the overall distance and amount of upstream and downstream transport.

In the cases discussed it is generally road transport that is associated with the highest CO_2 emissions, but other modes may also have similar emission levels if there is substantial up- and downstream transport and the routes taken by other modes are longer. How modes compare with respect to particulate and NO_x emissions differs considerably from case to case, with the highest emissions due to varying modes (tractor-semitrailer, diesel train, canal barge, coaster), depending on vehicle/vessel size, distance and up- and downstream transport. Consistently, though, the electric train has the lowest emissions.

1 Introduction

1.1 Background

Under de acronym STREAM (Study on Transport Emissions for All Modes) CE Delft has been publishing reports with transport emission factors for a number of 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 2016*, an update of *STREAM International Freight 2011*, provides a comprehensive review of the emission factors of freight transport modes for the year 2014. This update was needed because European vehicle standards, fleet renewal, government policies and technological progress mean that transport emissions have changed since 2009, the reference year adopted in *STREAM 2011*. In addition, measurements on road and rail vehicles and shipping vessels have given rise to new insights on practical, real-world emissions.

This report provides an update of the emission factors for freight transport modes. Emission indices for passenger transport modes are reported in a separate publication, *STREAM Passenger Transport*, the latest version of which dates from 2014.

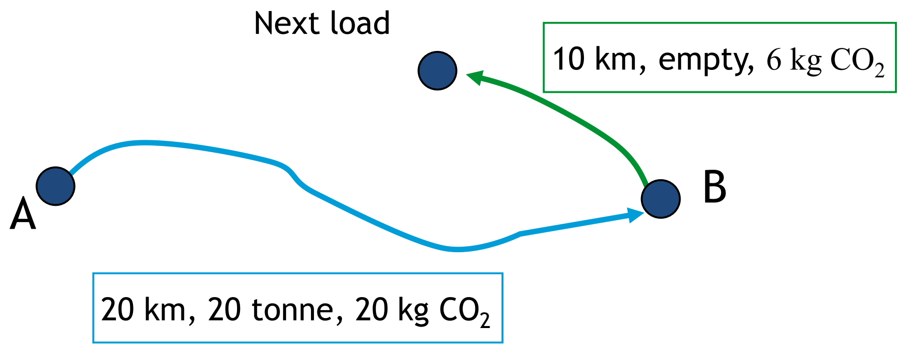
1.2 Objective and scope

This study has the following goal:

> *To provide an up-to-date and accessible review of the emission factors of modes of freight transport for (policy) analysis, intermodal comparison and (carbon) footprinting.*

STREAM Freight Transport 2016 provides a comprehensive review of the greenhouse gas emissions and principal air-pollutant emissions of the various modes of freight transport per tonne-kilometre for the Netherlands for the year 2014. The report relates the sum total of emissions of both loaded and empty vehicles to transport performance. Transport performance is expressed in tonne-kilometres, the product of load weight and the distance over which the load is carried (see also Section 4.2 and the text box on the next page). Expressing emissions per tonne-kilometre permits:
– insight into how the emissions of various transport modes compare; for particular transport operations;
– calculation of footprints per mode and technology based on tonne-kilometres.

Emissions per tonne-kilometre
Emissions per tonne-kilometre express the relationship between emissions and transport performance. This performance is indicated by multiplying, for each trip, the weight transported (in metric tonnes) by the distance travelled (in km). The calculated CO_2 emissions include all the CO_2 emissions associated with this transport performance, thus including the emissions deriving from both full and empty trips.
The emission factors presented in STREAM are based on average data per transport mode.
For an individual trip, the calculation can be illustrated as follows:



Calculation of CO_2 emissions per tonne-km:
- physical tonne-kilometres (tkm) = 20 km * 20 tonne = 400 tkm;
- CO_2 emissions = 20 kg CO_2 + 6 kg CO_2 = 26 kg CO_2;
- emissions per tonne-kilometre = 65 g CO_2/tkm (26,000/400).

STREAM calculations use the average of empty trips and average load per vehicle category. On the basis of tonne-kilometres (transported weight times distance from A to B) users of STREAM emission factors can estimate the total CO_2 emissions of the transport operation, including unavoidable empty runs.

In this report, climate emissions comprise emissions of the three main greenhouse gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), collectively expressed as CO_2-equivalents[1]. The air-pollutant emissions considered are: mono-nitrogen oxides (NO_x), fine particulates (PM_{10}), and sulphur dioxide (SO_2). For PM_{10} a distinction is made between emissions due to combustion (PM_c) and those due to wear and tear (PM_w). For all emissions, consideration is given to both the exhaust gas emissions (tank-to-wheel emissions) and the emissions associated with fuel extraction, production and transport and electric power generation (well-to-tank emissions).
The particulate emissions due to the wear and tear of vehicles and infrastructure are also covered in this report. Emissions associated with infrastructure construction and vehicle manufacture are beyond the scope of this study. Table 1 provides a summary of the emissions covered in this report.

1 In the remainder of this report "CO_2" always refers to CO_2-equivalents.

Table 1 Synopsis of emissions reported in STREAM

	Combustion (Tank-to-wheel)	Wear & tear (tyres, overhead wires, etc.)	Fuel production, power generation & upstream transport (Well-to-tank)
CO_2-eq.	X		X
NO_x	X		X
PM_{10}	X	X	X
SO_2	X		X

The logistical parameters for various types of transport can vary widely and, with them, the emission factors. This report therefore distinguishes emission factors for two main categories of transport:

- bulk/packaged cargo;
- containers.

For these two types of transport, STREAM then distinguishes three weight categories: light, medium and heavy.

Besides average emission factors for the year 2014, the study also provides figures on emission factors for alternative fuels and vehicle technologies.

Finally, a number of case studies are used to show how the reported emission factors can be used to compare transport modes in specific situations.

1.3 Use

The data in this report can be used for various kinds of study, the principal being policy analysis, intermodal comparison and (carbon) footprinting. *STREAM Freight Transport 2016* provides a very extensive selection of emission factors for a wide range of vehicle types, freight categories, fuel types and road and waterway classes. At the same time, in Chapter 2 it is indicated which factors are most representative for each transport mode.

When making use of these factors it is important to be aware of the following:

- While the emission factors provided in this report are characteristic of the respective vehicle types, they should be regarded as default figures for analyses where more detailed data are 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-kilometres and emission factors per tonne-kilometre.

- While the emission factors in this report can be used for comparing the emissions of various modes, the factors do not in themselves embody any such comparison. In making a comparison, due allowance must always be made for the distance travelled and the upstream and downstream transport involved in getting from origin to final destination. This is illustrated In Chapter 6.

– In this report, tonne-kilometres are based on the actual distance travelled by each transport mode and not on the distance ‘as the crow flies’[2] or shortest distance, for example.

– If STREAM emission factors are used for calculations on operations involving consolidated or distribution transport, it is important to realise that tonne-kilometres based on the shortest distance between origin and final destination will underestimate actual tonne-kilometres.

1.4 Differences from *STREAM Freight 2011*

While *STREAM Freight 2011* had a European perspective, *STREAM Freight 2016* adopts a purely Dutch perspective. This impacts specifically on the assumed composition of vehicle and vessel fleets and the sources used in that connection. Overall, though, the same methodology has been followed as in 2011. The main changes relative to 2011 are summarized below for each transport mode.

Road transport

Following publication of more extensive data on vehicles used by the Dutch Task Force on Transportation (2016), the road transport categories considered have been extended. Table 2 compares the categories considered in 2011 and now.

Table 2 Road vehicle categories

Category, 2011	Load capacity	Category, 2016	Load capacity
Small van < 2 tonne	0.7	Small van < 2 tonne	0.7
Large van > 2 tonne	1.2	Large van > 2 tonne	1.2
Truck < 10 tonne	3	Truck < 10 tonne, without trailer	3
Truck 10-20 tonne	8	Truck 10-20 tonne, without trailer	7.5
		Truck 10-20 tonne, with trailer	18
Truck > 20 tonne	16	Truck > 20 tonne, without trailer	13
		Truck > 20 tonne, with trailer	28
Truck-trailer		Tractor-semitrailer, light	16
	26	Tractor-semitrailer, heavy	29
LHV	39.5	LHV	41

Several categories have been divided in two, with consumption per tonne-kilometre for the lighter category slightly higher and for the heavier category slightly lower than the 2011 category. The tractor-semitrailer for container transport is now a heavier category, with a higher emission factor, than assumed in 2011.

Finally, in recent reports by the Task Force on Transportation and TNO vans and the lightest category of truck (< 10 t) have been estimated to be far more fuel-efficient per kilometre than in 2011.

[2] Tonne-kilometres based on this kind of ‘straight-line’ distance are used specifically in methodologies for allocating a carrier’s emissions to delivery addresses; see, for example (Connekt, TNO, Cap Gemini, 2014).

Inland shipping

- Emissions for inland shipping have been basically modelled in the same way as in 2011. Certain aspects of the input parameters have been modified, though. Sailing speeds have generally been adjusted downwards, based on new data from the Prelude study (Rijkswaterstaat, 2013) and practical data supplied by branch organization BLN-Schuttevaer. As a result, the energy consumption of inland waterway vessels is now generally lower.
- In 2011 the same emission factor (in g/kWh) for NO_x en PM_c was assumed for all vessel categories. In the present study we have differentiated according to tonnage class. For smaller vessels a higher emission factor has now been taken than for larger vessels, making the factors for smaller vessels now relatively higher and those for larger vessels relatively lower.
- In 2011 we calculated with a higher sulphur percentage in diesel for both inland shipping and rail for the year 2009. Since 2011 the diesel sulphur content has been equal to that in road diesel (10 ppm).

Rail

- Compared with 2011, a minor improvement in energy consumption and emission factors has been taken on board.
- In 2011 we calculated with a higher sulphur percentage in diesel for both inland shipping and rail for the year 2009. Since 2011 the diesel sulphur content has been equal to that in road diesel (10 ppm).

Maritime shipping (short-sea)

The calculated emissions of seagoing vessels (short-sea) are based on the third IMO GHG study (IMO, 2014). In STREAM 2011 the second IMO GHG study was used for as a basis for these calculations. In the new study the definition of several vessel categories has been modified. Product tankers and oil tankers are now combined, for example, and there are more tonnage categories.

There are also changes with respect to fleet characteristics, of which the following are the most important:

- On average, vessels now sail slower (by 15% up to as much as 35%, depending on the class of vessel).
- Despite the reduction in average speed, installed engine capacity has risen slightly. This is particularly true of General Cargo vessels (10-20% increase).

Besides the changes in fleet composition, there have also been substantial changes in relevant legislation. As of January 1st, 2015 vessels sailing in the North Sea and Baltic Sea must use low-sulphur fuels. Because of the major impact on sulphur and particulate emissions, this legislation has been taken on board in the calculations, thus deviating from our general adoption of 2014 as reference year.

Besides this, though, the same methodology has largely been employed for calculating maritime shipping emissions. One important difference is that in the present study fuel consumption has been taken as a function of vessel load, while in *STREAM 2011* this was assumed constant.

Upstream emissions

Upstream emissions are the emissions occurring during extraction, transport/transmission and production of fossil fuels and electricity.
The well-to-tank CO_2 emissions of diesel use have been estimated higher than in 2011. Recent research indicates that the CO_2 emissions associated with oil production are substantially higher than previously thought (JRC, 2014b).

1.5 Report outline

This study presents emission factors per tonne-kilometre for various modes of transport. These data form the core of the report and are therefore presented in an extensive middle section. The aim of the study is to provide an up-to-date and readily accessible review of freight transport emissions.

Chapter 2 presents a synopsis of the most representative data on each mode of transport. These are a selection of the detailed data presented in Chapter 3. In Chapter 3 data are provided on more vehicle and vessel categories and types of load (light, medium-weight, heavy), with various road and waterway classes being distinguished. The chapter ends with emission factors for alternative fuels and technologies. Derivation of the data in Chapter 3 is discussed in Chapter 4. In Chapter 5 we consider the logistical parameters relevant for comparing the emissions of various transport variants. Chapter 6 shows how the data can be used in specific cases. In Chapter 7 the emission factor calculated in the present report are briefly compared with those given in the previous report. The report closes in Chapter 8 with several recommendations.

2 Synopsis of results

2.1 Introduction

This chapter provides a compact synopsis of the results of the STREAM study. To that end, Section 2.2 gives representative emission factors per transport mode, while Section 2.3 reviews the ranges within which the factors lie for each mode. Section 2.4 then shows how the average emission factors relate to the newest vehicles and vessels in the respective fleets. The chapter is a condensed presentation of the results in the rest of the report. For the definitions used in this chapter and further on, the reader is referred to the list of Terms and Abbreviations at the beginning of the report and the extensive descriptions in Chapters 3 and 4.

2.2 Representative emission factors per transport mode

Table 3 and Table 4 present the emission factors for representative vehicles and vessels per mode and for the most representative type of freight (light, medium-weight, heavy) [3] carried. These are the vehicles and vessels with the greatest share in tonne-kilometres and/or kilometres.

- On the roads, the average type of freight carried is medium-weight. Here, heavy tractor-semitrailer combinations account for almost 60% of truck-kilometres and over 75% of tonne-kilometres. In transport with lighter trucks (load capacity < 20 t) medium-weight trucks play an important and, in terms of emission factors, representative role (CBS, 2015a). Larger vans (> 2 t GVW) account for almost 80% of van-kilometres (CBS, 2015b).
- Rail freight transport is dominated by electric trains (70-90%)[4]. It is predominantly heavy goods that are transported by rail. With respect to weight carried, the medium-length train (2,600 GTW full, average around 1,750 t) is representative of the average weight transported by rail (ProRail, 2016). For container transport this is the long train (90 TEU[5]).
- In inland shipping almost 50% of freight is carried by two categories 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).
- Short-sea transport involves a range of vessels. In terms of emissions per tonne-kilometre the General Cargo ship (10-20 dwkt) is representative of the average of these vessels[6]. For container transport this is the Panamax-like container vessel (4,060 TEU).

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[3] Based on analyses and sources from (CE Delft, 2016) and (TNO, 2015b) for road, rail and inland shipping.

[4] The range derives from two estimates: an approx. 70% share in km and tkm, based on (Ricardo Rail, 2015), and 90% in number of trains, based on an estimate by ProRail.

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

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

The tables below report the most policy-relevant emission factors, viz. well-to-wheel greenhouse gas emissions (CO_2, CH_4 and N_2O expressed as CO_2-equivalents) and exhaust emissions (tank-to-wheel) for particulates (PM_c) and NO_x.

Table 3 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	Large van	Med.-weight	1,153	0.148	5.03
	Truck, medium-size	Med.-weight	259	0.017	1.75
	Tractor-semitrailer	Med.-weight	82	0.003	0.29
Rail	Electric, medium-length*	Heavy	10	0	0
	Diesel, medium-length*	Heavy	18	0.005	0.19
Inland shipping	Rhine-Herne canal (RHC) vessel	Heavy	38	0.017	0.46
	Large Rhine vessel	Heavy	21	0.008	0.23
Short-sea	General Cargo 10-20 dwkt	Heavy	15	0.005	0.25

* Share of electric: 70-90%; share of diesel: 10-30%.

Table 4 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	102	0.004	0.36
Rail	Electric, long (90 TEU)*	Med.-weight	16		
	Diesel, long (90 TEU)*	Med.-weight	30	0.009	0.309
Inland shipping	RHC vessel (96 TEU)	Med.-weight	44	0.019	0.53
	Large Rhine vessel (208 TEU)	Med.-weight	24	0.009	0.26
Short-sea	Container (Panamax-like, 4,060 TEU)	Med.-weight	21	0.008	0.35

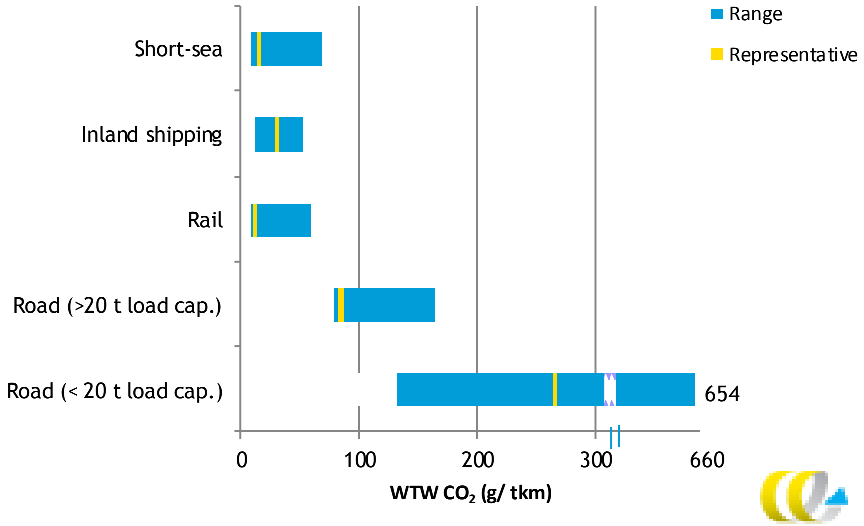
* Share of electric: 70-90%; share of diesel: 10-30%.

2.3 Emission factor ranges

The emission factors per mode are highly 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.[7] In each of the figures the representative values from Table 3 and 4 are shown in yellow. The blue bands indicate the extent to which the emission factors can vary, depending on the type of vehicle and goods (light, medium-weight, heavy) for the vehicles considered in Chapter 3.

Each of the figures shows 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 each mode and the up- and downstream transport involved in getting from A to B. To illustrate this, in Chapter 6 three concrete cases are elaborated in which allowance is made for varying distances per mode and up-and downstream transport or multimodal transport.

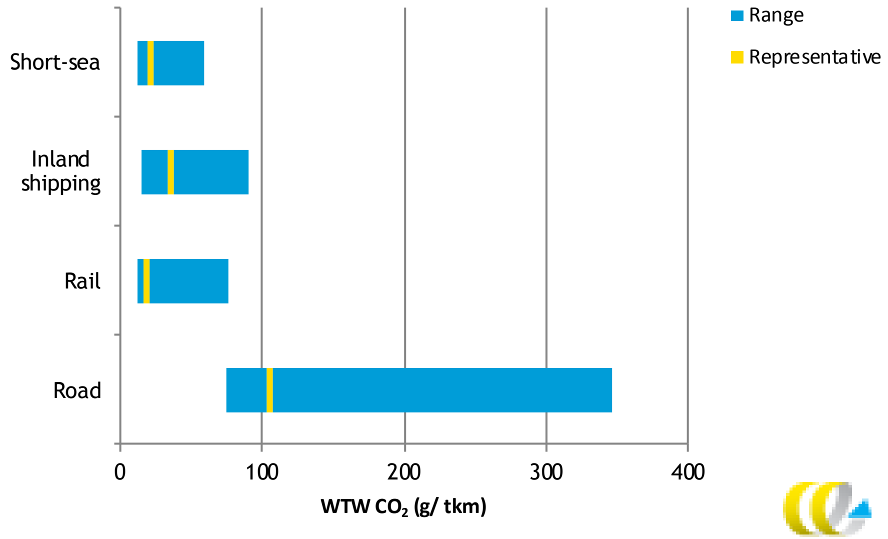
Figure 1 Ranges of CO_2 emission factors, bulk/packaged goods transport (well-to-wheel) (g/tkm)



Note: The representative values are taken from Table 3 and 4. For rail 80% electric and 20% diesel have been taken as representative, for inland shipping the average of the Rhine-Herne canal vessel and the Large Rhine vessel.

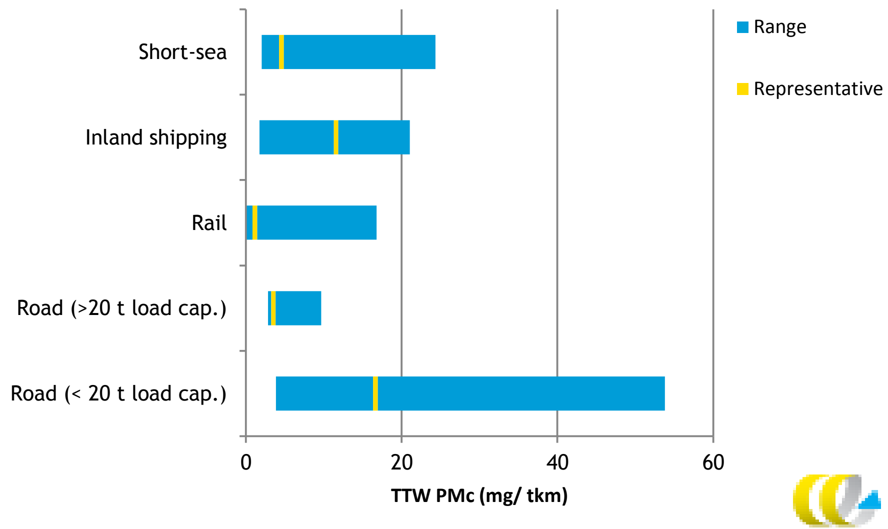
7 Vans are not shown because their emissions per tkm are exceptionally high. This is because these vehicles can transport only small loads at a time and are generally used for local distribution.

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



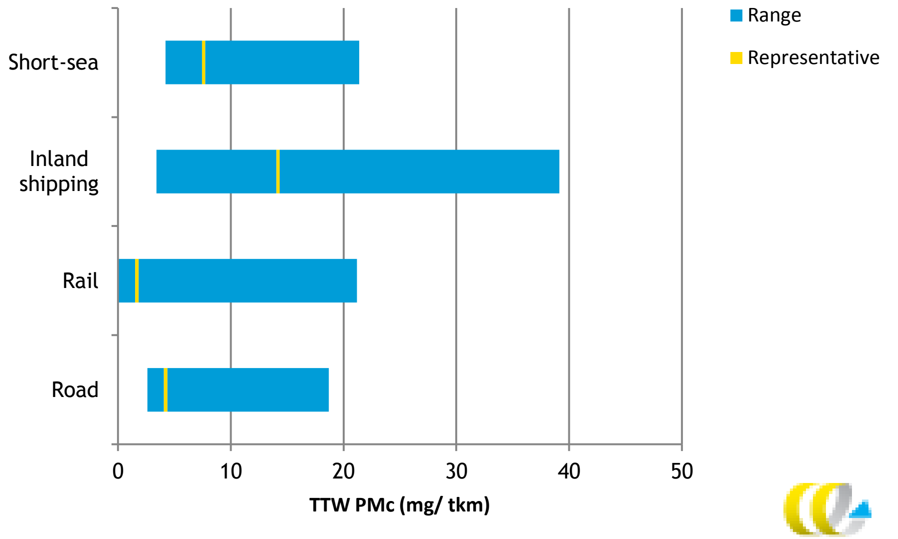
Note: The representative values are taken from Table 3 and 4. For rail 80% electric and 20% diesel have been taken as representative, for inland shipping the average of the Rhine-Herne canal vessel and the Large Rhine vessel.

Figure 3 Ranges of particulate (PM_c) emission factors, bulk/packaged goods transport (tank-to-wheel) (g/tkm)



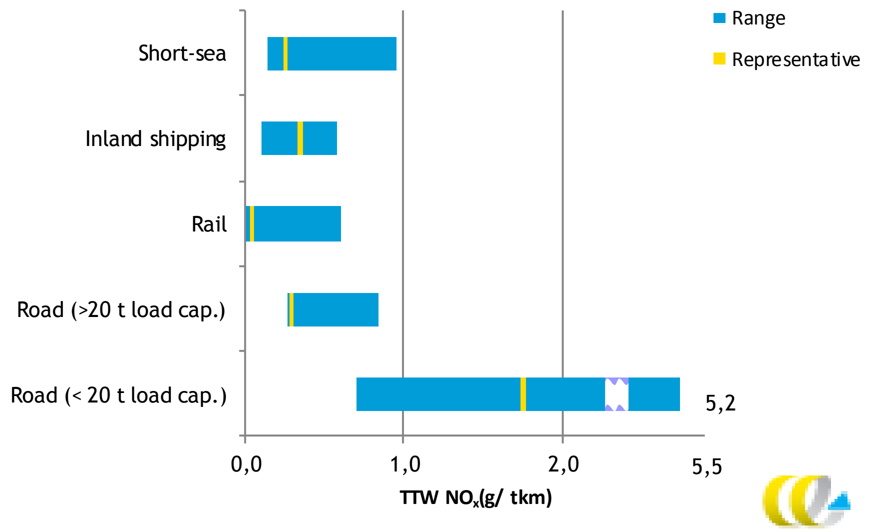
Note: The representative values are taken from Table 3 and 4. For rail 80% electric and 20% diesel have been taken as representative, for inland shipping the average of the Rhine-Herne canal vessel and the Large Rhine vessel.

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



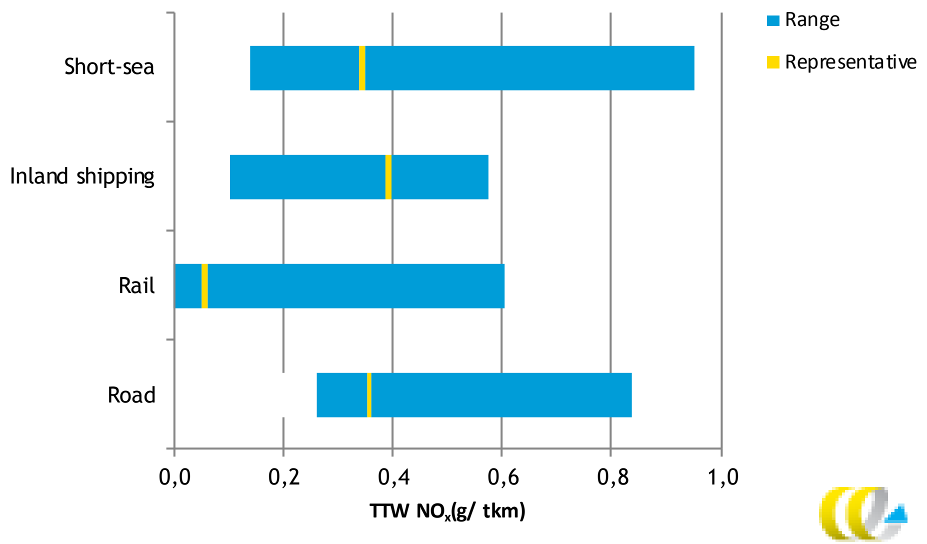
Note: The representative values are taken from Table 3 and 4. For rail 80% electric and 20% diesel have been taken as representative, for inland shipping the average of the Rhine-Herne canal vessel and the Large Rhine vessel.

Figure 5 Ranges of NO_x emission factors, bulk/packaged goods transport (tank-to-wheel) (g/tkm)



Note: The representative values are taken from Table 3 and 4. For rail 80% electric and 20% diesel have been taken as representative, for inland shipping the average of the Rhine-Herne canal vessel and the Large Rhine vessel.

Figure 6 Ranges of NO_x emission factors, container transport (tank-to-wheel) (g/tkm)



Note: The representative values are taken from Table 3 and 4. For rail 80% electric and 20% diesel have been taken as representative, for inland shipping the average of the Rhine-Herne canal vessel and the Large Rhine vessel.

2.4 Average fleet and new emission standards

The emission factors reported in Chapter 3 are average values for the various modes for the year 2014. Vehicle and vessel fleets are constantly being renewed, though, because of increasingly stringent environmental regulations on air-pollutant emissions, such as the Euro VI standard for HGVs and the Phase V standard for rail and inland shipping. In addition (and partly as a result of such regulation) a growing number of alternative fuels and drives are coming onto the market, such as CNG, LNG, biofuels and electric drives. In Section 3.6 the impact of these fuels and technologies on emissions is assessed using indices.

Figure 7 and 8 show, for the representative vehicles and vessels from Section 2.2, how fleet-average tank-to-wheel-emissions (TTW) of PM_c and NO_x per tonne-kilometre compare with those of vehicles and vessels with new engines and those satisfying future emission standards. For the emission factors associated with future standards it has been assumed that engines will meet the standard. In reality, future emissions may in practice be higher or lower and alternative fuels and drives may also play a major role, which means emissions may turn out to be lower.

Since 2013 new road-vehicle engines must satisfy the Euro VI standard (the current standard). The data show that Euro VI vehicles have 80-90% lower PM_c and NO_x emissions than the 2014 fleet-average. At the time of writing, no future road-vehicle standards have yet been set.

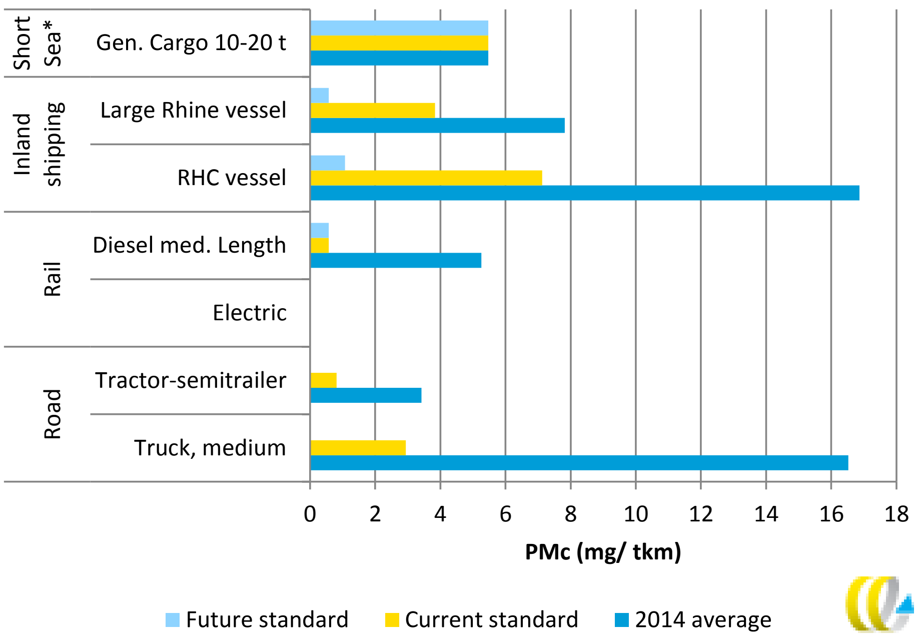
Since 2012 new rail locomotives must satisfy the Phase IIIb standard (the current standard). The emissions of these engines are around 90% lower for PM_c and 55% lower for NO_x than the 2014 fleet-average. The Phase V standard scheduled for introduction in 2021 (the future standard) leaves limits for PM_c

and NO_x emissions unchanged.[8] An increase in the number of Phase IIIb and Phase V engines in the locomotive fleet will mean a significant decrease in the fleet-average emissions of diesel locomotives. As electric trains have no combustion emissions, the respective values are zero.

In inland shipping, it is above all smaller vessel categories that have relatively older engines. The current CCNR2 standard[9] (in force since 2007) is substantially lower than the 2014 fleet-average, particularly for these smaller vessels. Engines satisfying the Phase V standard (the future standard, 2019-2021) will have 70-90% lower emissions.

For sea-going vessels, since 2011 engines must meet the IMO Tier II standard (the current standard in 2014). This year (2016) the IMO Tier III standard came into force in so-called NECAs (NO_x Emission Control Areas). In the North Sea there is as yet no NECA. The IMO standards cover only NO_x emissions.
In 2014 average emissions were slightly in excess of the Tier II standard.
The NO_x emissions of engines meeting the Tier III standard (in 2014 the future standard) are around 80% lower. For maritime shipping particulate emissions, the SECA standard in force since 2015 for the North Sea and Baltic Sea[10] has been taken as the point of departure. Based on this standard, no further decrease in emissions is foreseen.

Figure 7 TTW particulate (PM_c) emissions, bulk transport: comparison of 2014 average, current standard 2014 and future standard



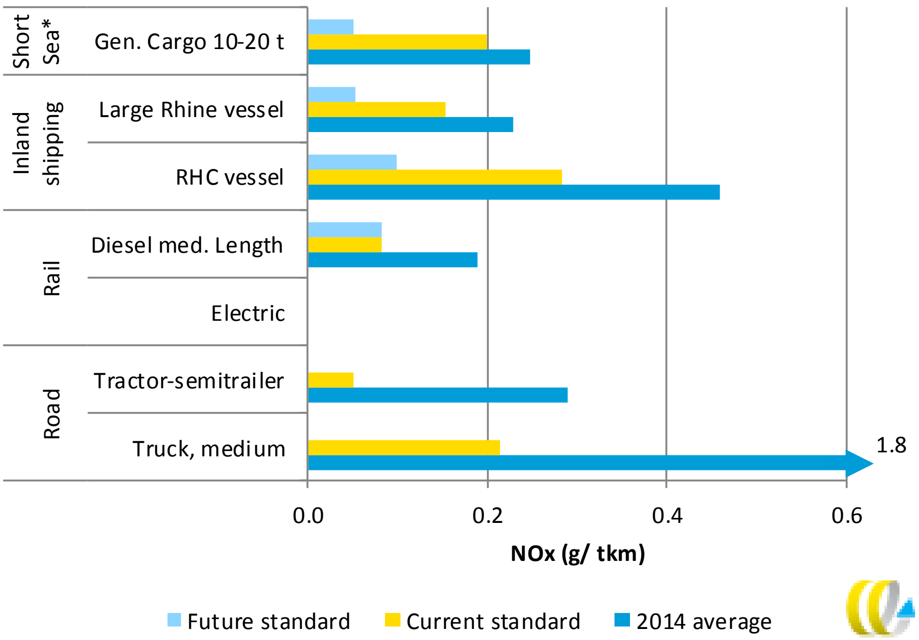
* For short sea, the tightened SECA standards as of 2015 have been taken.

8 As of 2021 there will be an additional criterion with respect to the number of particles, however.

9 Or the Phase IIIA standard, which is approximately the same.

10 For the North Sea and the Baltic Sea the SECA standard came into force on January 1st, 2015.

Figure 8 TTW NO_x emissions, bulk transport: comparison of 2014 average, current standard 2014 and future standard



3 Detailed data per transport mode

3.1 Introduction

This chapter goes into more detail on the freight-transport emission factors per tonne-kilometre presented in outline in Section 2.1. With the data in this chapter a distinction can be made between various road classes, while insight is also provided into all well-to-tank emissions.

A separate section is devoted to the emission factors of each transport mode, divided into two sub-sections. 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 (approx. < 0.4 kg/litre in loading area);
- medium-weight transport: food products, timber, paper, plastics, chemicals, metal products, cars, waste (approx. 0.5-1.2 kg/litre in loading area);
- heavy transport: ores, minerals, coal, coke, oil (typically for liquids and cargo > 1.3 kg/litre.

The second sub-section gives the emission factors for container transport, again distinguishing three weight categories:
- light containers: 6 t/TEU[11];
- medium-weight containers: 10.5 t/TEU;
- heavy containers: 14 t/TEU.

Besides the emission factors, the tables also report the capacity utilization and average load per vehicle/vessel, representative for the category of transport.

For alternative fuels and technologies, indices for energy consumption and CO_2, PM_c and NO_x emissions are given in Section 3.6, indicating how the emission factors for alternative (or specific) technologies and fuels compare with the relevant baseline. In each case an index is also given for the fleet-average, allowing the emission factor for the alternative to be calculated from:

$$EF_{tkm-\ alternative} = \frac{index_{alternative}}{index_{2014\ average}} \times EF_{tkm-2014\ average}$$

where EF_{tkm} stands for the emission factor per tonne-kilometre.

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

11 Unit of container size: Twenty-foot Equivalent Unit.

3.2 Road transport

3.2.1 Fleet-average data for road transport of bulk and general cargo

Table 5 Emission factors, tank-to-wheel and well-to-wheel, light-bulk road transport, 2014

Vehicle type	Load capacity (tonne)	2014									
			TTW emissions (g/tkm)					WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_{sl}	CO_2-eq	SO_2	PM_c	NO_x
Small van, GVW < 2 t											
Average	0.7	17.1	1,230	0.008	0.413	5.9	0.13	1,585	1.6	0.473	6.5
Urban	0.7	21.4	1,537	0.010	0.673	6.6	0.22	1,980	2.0	0.749	7.3
Rural	0.7	12.7	909	0.006	0.363	5.0	0.11	1,171	1.2	0.407	5.4
Motorway	0.7	18.6	1,334	0.008	0.364	6.3	0.12	1,718	1.8	0.429	6.9
Large van, GVW > 2 t											
Average	1.2	14.5	1,042	0.006	0.173	5.9	0.08	1,342	1.4	0.224	6.3
Urban	1.2	17.5	1,256	0.008	0.247	6.8	0.13	1,617	1.7	0.308	7.4
Rural	1.2	10.7	772	0.005	0.135	4.8	0.07	995	1.0	0.172	5.1
Motorway	1.2	15.9	1,141	0.007	0.174	6.2	0.07	1,470	1.5	0.230	6.8
Truck < 10 t											
Average	3	6.8	493	0.003	0.054	5.2	0.11	634	0.7	0.078	5.5
Urban	3	9.2	666	0.004	0.078	7.5	0.16	856	0.9	0.111	7.8
Rural	3	6.2	446	0.003	0.049	4.7	0.09	574	0.6	0.071	4.9
Motorway	3	5.6	403	0.002	0.039	4.0	0.09	518	0.5	0.059	4.2
Truck 10-20 t											
Average	7.5	4.1	301	0.002	0.025	2.7	0.04	387	0.4	0.040	2.8
Urban	7.5	6.3	457	0.003	0.042	4.5	0.06	588	0.6	0.065	4.8
Rural	7.5	4.1	296	0.002	0.025	2.7	0.03	381	0.4	0.039	2.8
Motorway	7.5	3.5	251	0.002	0.019	2.0	0.03	323	0.3	0.032	2.2
Truck 10-20 t + trailer											
Average	18	2.1	155	0.001	0.013	1.1	0.02	200	0.2	0.021	1.2
Urban	18	3.3	237	0.001	0.021	1.9	0.02	305	0.3	0.032	2.0
Rural	18	2.1	153	0.001	0.013	1.1	0.01	196	0.2	0.020	1.1
Motorway	18	1.8	130	0.001	0.011	0.9	0.01	167	0.2	0.017	1.0
Truck > 20 t											
Average	13	3.3	236	0.001	0.017	1.9	0.02	304	0.3	0.028	2.0
Urban	13	5.3	381	0.002	0.030	3.4	0.04	490	0.5	0.048	3.6
Rural	13	3.4	246	0.002	0.018	2.0	0.02	317	0.3	0.030	2.1
Motorway	13	2.8	202	0.001	0.014	1.5	0.02	260	0.3	0.024	1.6
Truck > 20 t + trailer											
Average	28	1.7	124	0.001	0.010	0.8	0.01	160	0.2	0.016	0.9
Urban	28	2.8	201	0.001	0.017	1.5	0.02	259	0.3	0.027	1.6
Rural	28	1.8	128	0.001	0.010	0.8	0.01	164	0.2	0.016	0.9
Motorway	28	1.5	107	0.001	0.008	0.7	0.01	137	0.1	0.013	0.7
Tractor-semitrailer, light											
Average	15.7	2.7	195	0.001	0.006	1.5	0.02	250	0.3	0.015	1.5
Urban	15.7	4.9	352	0.002	0.011	2.9	0.03	452	0.5	0.028	3.1
Rural	15.7	3.1	227	0.001	0.007	1.7	0.01	292	0.3	0.018	1.8
Motorway	15.7	2.5	183	0.001	0.006	1.3	0.02	235	0.2	0.014	1.4
Tractor-semitrailer, heavy											
Average	29.2	1.3	91	0.001	0.005	0.4	0.01	117	0.1	0.009	0.5
Urban	29.2	2.6	190	0.001	0.011	1.1	0.01	245	0.3	0.020	1.2
Rural	29.2	1.6	119	0.001	0.007	0.6	0.01	153	0.2	0.012	0.6
Motorway	29.2	1.1	83	0.001	0.005	0.4	0.01	106	0.1	0.009	0.4
LHV											
Average	40.8	1.2	88	0.001	0.004	0.4	0.01	113	0.1	0.009	0.5
Urban	40.8	2.5	184	0.001	0.009	1.0	0.01	237	0.2	0.018	1.1
Rural	40.8	1.6	115	0.001	0.006	0.5	0.01	147	0.2	0.011	0.6
Motorway	40.8	1.1	80	0.0005	0.004	0.4	0.01	103	0.1	0.008	0.4

Table 6 Emission factors, tank-to-wheel and well-to-wheel, medium-weight-bulk road transport, 2014

Vehicle type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Small van, GVW < 2 t											
Average	0.7	14.7	1,057	0.007	0.354	5.1	0.11	1,362	1.4	0.406	5.6
Urban	0.7	18.4	1,321	0.008	0.578	5.7	0.19	1,701	1.8	0.643	6.3
Rural	0.7	10.9	781	0.005	0.311	4.3	0.10	1,006	1.0	0.349	4.6
Motorway	0.7	15.9	1,146	0.007	0.312	5.4	0.10	1,476	1.5	0.368	5.9
Large van, GVW > 2 t											
Average	1.2	12.5	895	0.006	0.148	5.0	0.07	1,153	1.2	0.192	5.4
Urban	1.2	15.0	1,079	0.007	0.212	5.9	0.11	1,390	1.4	0.265	6.4
Rural	1.2	9.2	664	0.004	0.116	4.1	0.06	855	0.9	0.148	4.4
Motorway	1.2	13.6	981	0.006	0.149	5.3	0.06	1,264	1.3	0.197	5.8
Truck < 10 t											
Average	3	4.6	336	0.002	0.036	3.5	0.08	432	0.4	0.053	3.7
Urban	3	6.3	454	0.003	0.053	5.1	0.11	583	0.6	0.075	5.3
Rural	3	4.2	304	0.002	0.033	3.2	0.06	391	0.4	0.048	3.3
Motorway	3	3.8	275	0.002	0.027	2.7	0.06	353	0.4	0.040	2.8
Truck 10-20 t											
Average	7.5	2.8	201	0.001	0.017	1.8	0.02	259	0.3	0.026	1.8
Urban	7.5	4.2	306	0.002	0.028	3.0	0.04	393	0.4	0.043	3.1
Rural	7.5	2.7	198	0.001	0.016	1.8	0.02	255	0.3	0.026	1.8
Motorway	7.5	2.3	168	0.001	0.013	1.3	0.02	216	0.2	0.021	1.4
Truck 10-20 t + trailer											
Average	18	1.5	106	0.001	0.009	0.8	0.01	136	0.1	0.014	0.8
Urban	18	2.2	162	0.001	0.014	1.3	0.02	208	0.2	0.022	1.4
Rural	18	1.4	104	0.001	0.009	0.7	0.01	134	0.1	0.014	0.7
Motorway	18	1.2	88	0.001	0.007	0.6	0.01	114	0.1	0.011	0.6
Truck > 20 t											
Average	13	2.2	159	0.001	0.011	1.3	0.02	204	0.2	0.019	1.3
Urban	13	3.5	256	0.002	0.020	2.3	0.02	329	0.3	0.032	2.4
Rural	13	2.3	166	0.001	0.012	1.3	0.01	213	0.2	0.020	1.4
Motorway	13	1.9	136	0.001	0.009	1.0	0.01	175	0.2	0.016	1.1
Truck > 20 t + trailer											
Average	28	1.2	86	0.001	0.006	0.6	0.01	110	0.1	0.011	0.6
Urban	28	1.9	139	0.001	0.011	1.0	0.01	179	0.2	0.018	1.1
Rural	28	1.2	88	0.001	0.007	0.5	0.01	113	0.1	0.011	0.6
Motorway	28	1.0	74	0.0005	0.005	0.5	0.01	95	0.1	0.009	0.5
Tractor-semitrailer, light											
Average	15.7	1.8	134	0.001	0.004	1.0	0.01	172	0.2	0.010	1.0
Urban	15.7	3.3	242	0.001	0.007	2.0	0.02	311	0.3	0.019	2.1
Rural	15.7	2.2	156	0.001	0.005	1.2	0.01	201	0.2	0.012	1.2
Motorway	15.7	1.7	126	0.001	0.004	0.9	0.01	162	0.2	0.010	1.0
Tractor-semitrailer, heavy											
Average	29.2	0.9	64	0.0004	0.003	0.3	0.004	82	0.1	0.007	0.3
Urban	29.2	1.8	133	0.001	0.007	0.7	0.01	171	0.2	0.014	0.8
Rural	29.2	1.1	83	0.0005	0.004	0.4	0.004	107	0.1	0.008	0.4
Motorway	29.2	0.8	58	0.0004	0.003	0.3	0.004	74	0.1	0.006	0.3
LHV											
Average	40.8	0.8	61	0.0004	0.003	0.3	0.005	79	0.1	0.006	0.3
Urban	40.8	1.8	129	0.001	0.006	0.7	0.01	166	0.2	0.012	0.7
Rural	40.8	1.1	80	0.0005	0.004	0.3	0.004	103	0.1	0.008	0.4
Motorway	40.8	0.8	56	0.0003	0.003	0.2	0.004	72	0.1	0.005	0.3

Table 7 Emission factors, tank-to-wheel and well-to-wheel, heavy-bulk road transport, 2014

Vehicle type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Truck 10-20 t											
Average	7.5	2.6	189	0.001	0.016	1.6	0.02	243	0.2	0.025	1.7
Urban	7.5	4.0	288	0.002	0.026	2.8	0.04	370	0.4	0.040	2.9
Rural	7.5	2.6	186	0.001	0.015	1.6	0.02	240	0.2	0.024	1.7
Motorway	7.5	2.2	158	0.001	0.012	1.3	0.02	203	0.2	0.020	1.3
Truck 10-20 t + trailer											
Average	18	1.4	100	0.001	0.008	0.7	0.01	129	0.1	0.013	0.8
Urban	18	2.1	153	0.001	0.013	1.2	0.02	197	0.2	0.021	1.3
Rural	18	1.4	98	0.001	0.008	0.7	0.01	127	0.1	0.013	0.7
Motorway	18	1.2	84	0.001	0.007	0.6	0.01	107	0.1	0.011	0.6
Truck > 20 t											
Average	13	2.1	150	0.001	0.011	1.2	0.01	193	0.2	0.018	1.2
Urban	13	3.3	242	0.001	0.019	2.1	0.02	311	0.3	0.030	2.2
Rural	13	2.2	156	0.001	0.011	1.2	0.01	201	0.2	0.019	1.3
Motorway	13	1.8	128	0.001	0.009	1.0	0.01	165	0.2	0.015	1.0
Truck > 20 t + trailer											
Average	28	1.1	81	0.0005	0.006	0.5	0.01	104	0.1	0.010	0.6
Urban	28	1.8	132	0.001	0.011	1.0	0.01	169	0.2	0.017	1.0
Rural	28	1.2	84	0.001	0.006	0.5	0.01	107	0.1	0.010	0.6
Motorway	28	1.0	70	0.0004	0.005	0.4	0.01	90	0.1	0.008	0.5
Tractor-semitrailer, light											
Average	15.7	1.8	129	0.001	0.004	0.9	0.01	166	0.2	0.010	1.0
Urban	15.7	3.2	233	0.001	0.007	1.9	0.02	300	0.3	0.018	2.0
Rural	15.7	2.1	151	0.001	0.004	1.1	0.01	194	0.2	0.012	1.2
Motorway	15.7	1.7	121	0.001	0.004	0.9	0.01	156	0.2	0.009	0.9
Tractor-semitrailer, heavy											
Average	29.2	0.8	61	0.0004	0.003	0.3	0.004	78	0.1	0.006	0.3
Urban	29.2	1.8	128	0.001	0.007	0.7	0.01	164	0.2	0.013	0.7
Rural	29.2	1.1	80	0.0005	0.004	0.3	0.004	102	0.1	0.008	0.4
Motorway	29.2	0.8	56	0.0003	0.003	0.2	0.004	71	0.1	0.006	0.3
LHV											
Average	40.8	0.8	59	0.0004	0.003	0.3	0.004	76	0.1	0.006	0.3
Urban	40.8	1.7	124	0.001	0.006	0.6	0.01	159	0.2	0.012	0.7
Rural	40.8	1.1	77	0.0005	0.004	0.3	0.004	99	0.1	0.007	0.4
Motorway	40.8	0.7	54	0.0003	0.003	0.2	0.004	69	0.1	0.005	0.3

3.2.2 Fleet-average data for road container transport

Table 8 Emission factors, tank-to-wheel and well-to-wheel, light-container road transport, 2014

Vehicle type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Truck > 20 t											
Average	1	3.6	262	0.002	0.019	2.1	0.025	337	0.35	0.031	2.2
Urban	1	5.8	423	0.003	0.033	3.8	0.039	543	0.56	0.053	4.0
Rural	1	3.8	273	0.002	0.020	2.2	0.021	352	0.36	0.033	2.3
Motorway	1	3.1	224	0.001	0.015	1.7	0.024	288	0.30	0.026	1.8
Truck > 20 t + trailer											
Average	2	2.1	149	0.001	0.011	1.0	0.013	192	0.20	0.019	1.1
Urban	2	3.3	242	0.001	0.020	1.8	0.019	311	0.32	0.032	1.9
Rural	2	2.1	154	0.001	0.012	1.0	0.011	198	0.20	0.019	1.0
Motorway	2	1.8	128	0.001	0.010	0.8	0.012	165	0.17	0.016	0.9
Tractor-semitrailer, heavy											
Average	2	1.8	129	0.001	0.007	0.6	0.009	166	0.17	0.013	0.7
Urban	2	3.7	271	0.002	0.015	1.5	0.014	349	0.36	0.028	1.7
Rural	2	2.3	169	0.001	0.009	0.8	0.008	217	0.22	0.017	0.9
Motorway	2	1.6	118	0.001	0.007	0.6	0.009	151	0.16	0.012	0.6
LHV											
Average	3	1.6	118	0.001	0.006	0.6	0.009	151	0.16	0.012	0.6
Urban	3	3.4	247	0.002	0.012	1.4	0.014	317	0.33	0.024	1.5
Rural	3	2.1	154	0.001	0.008	0.7	0.008	198	0.20	0.015	0.8
Motorway	3	1.5	107	0.001	0.005	0.5	0.009	138	0.14	0.010	0.5

Table 9 Emission factors, tank-to-wheel and well-to-wheel, medium-weight-container road transport, 2014

Vehicle type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Truck > 20 t											
Average	1	2.1	155	0.001	0.011	1.2	0.015	200	0.20	0.018	1.3
Urban	1	3.5	251	0.002	0.019	2.2	0.023	322	0.33	0.031	2.3
Rural	1	2.2	162	0.001	0.011	1.3	0.013	208	0.21	0.019	1.3
Motorway	1	1.8	133	0.001	0.009	1.0	0.014	171	0.18	0.015	1.0
Truck > 20 t + trailer											
Average	2	1.3	91	0.001	0.007	0.6	0.008	117	0.12	0.011	0.6
Urban	2	2.0	147	0.001	0.012	1.1	0.012	190	0.19	0.019	1.1
Rural	2	1.3	94	0.001	0.007	0.6	0.007	120	0.12	0.012	0.6
Motorway	2	1.1	78	0.0005	0.006	0.5	0.007	100	0.10	0.009	0.5
Tractor-semitrailer, heavy											
Average	2	1.1	80	0.0005	0.004	0.4	0.006	102	0.10	0.008	0.4
Urban	2	2.3	167	0.001	0.009	0.9	0.009	214	0.22	0.017	1.0
Rural	2	1.4	104	0.001	0.006	0.5	0.005	134	0.14	0.011	0.5
Motorway	2	1.0	72	0.0004	0.004	0.3	0.005	93	0.10	0.007	0.4
LHV											
Average	3	1.0	73	0.0004	0.003	0.3	0.005	93	0.10	0.007	0.4
Urban	3	2.1	152	0.001	0.007	0.8	0.009	196	0.20	0.015	0.9
Rural	3	1.3	95	0.001	0.004	0.4	0.005	122	0.13	0.009	0.4
Motorway	3	0.9	66	0.0004	0.003	0.3	0.005	85	0.09	0.006	0.3

Table 10 Emission factors, tank-to-wheel and well-to-wheel, heavy-container road transport, 2014

Vehicle type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Truck > 20 t											
Average	1	1.6	116	0.001	0.008	0.9	0.011	149	0.15	0.014	0.9
Urban	1	2.6	187	0.001	0.014	1.6	0.017	241	0.25	0.023	1.7
Rural	1	1.7	121	0.001	0.008	0.9	0.009	156	0.16	0.014	1.0
Motorway	1	1.4	99	0.001	0.007	0.7	0.010	128	0.13	0.011	0.8
Truck > 20 t + trailer											
Average	2	1.0	70	0.0004	0.005	0.4	0.006	89	0.09	0.008	0.5
Urban	2	1.6	113	0.001	0.009	0.8	0.009	145	0.15	0.014	0.8
Rural	2	1.0	71	0.0004	0.005	0.4	0.005	92	0.09	0.009	0.5
Motorway	2	0.8	60	0.0004	0.004	0.4	0.006	77	0.08	0.007	0.4
Tractor-semitrailer, heavy											
Average	2	0.8	61	0.0004	0.003	0.3	0.004	79	0.08	0.006	0.3
Urban	2	1.8	128	0.001	0.007	0.7	0.007	165	0.17	0.013	0.7
Rural	2	1.1	80	0.0005	0.004	0.3	0.004	103	0.11	0.008	0.4
Motorway	2	0.8	56	0.0003	0.003	0.2	0.004	72	0.07	0.006	0.3
LHV											
Average	3	0.8	56	0.0003	0.003	0.2	0.004	72	0.07	0.005	0.3
Urban	3	1.6	118	0.001	0.005	0.6	0.007	151	0.16	0.011	0.6
Rural	3	1.0	73	0.0004	0.003	0.3	0.004	94	0.10	0.007	0.3
Motorway	3	0.7	51	0.0003	0.002	0.2	0.004	66	0.07	0.005	0.2

3.3 Rail

3.3.1 Fleet-average data for rail transport of bulk and packaged cargo

Table 11 Emission factors, tank-to-wheel and well-to-wheel, light-bulk rail transport, 2014

Vehicle type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Electric train											
Short	594	0.23	-	-	-	-	0.01	31	0.017	0.001	0.029
Medium-length	891	0.18	-	-	-	-	0.01	24	0.013	0.001	0.023
Long	1,188	0.15	-	-	-	-	0.01	20	0.011	0.001	0.019
Diesel train											
Short	594	0.62	44	0.0003	0.017	0.60	0.01	57	0.059	0.019	0.624
Medium-length	891	0.48	34	0.0002	0.013	0.47	0.01	44	0.046	0.015	0.485
Long	1,188	0.40	29	0.0002	0.011	0.39	0.01	37	0.038	0.012	0.406

Table 12 Emission factors, tank-to-wheel and well-to-wheel, medium-weight-bulk rail transport, 2014

Vehicle type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Electric train											
Short	935	0.12	-	-	-	-	0.01	16	0.009	0.001	0.015
Medium-length	1,403	0.09	-	-	-	-	0.01	12	0.007	0.001	0.012
Long	1,870	0.08	-	-	-	-	0.00	10	0.006	0.000	0.010
Diesel train											
Short	935	0.32	23	0.0001	0.009	0.31	0.01	29	0.030	0.010	0.322
Medium-length	1,403	0.25	18	0.0001	0.007	0.24	0.01	23	0.024	0.008	0.250
Long	1,870	0.21	15	0.0001	0.006	0.20	0.00	19	0.020	0.006	0.209

Table 13 Emission factors, tank-to-wheel and well-to-wheel, heavy-bulk rail transport, 2014

	Load capacity	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
Voertuigtype	ton	MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Electric train											
Short	1,276	0.09	-	-	-	-	0.01	12	0.006	0.001	0.011
Medium-length	1,914	0.07	-	-	-	-	0.00	10	0.005	0.000	0.009
Long	2,668	0.07	-	-	-	-	0.00	9	0.005	0.000	0.009
Diesel train											
Short	1,276	0.23	17	0.0001	0.006	0.23	0.01	22	0.022	0.007	0.237
Medium-length	1,914	0.19	14	0.0001	0.005	0.19	0.00	18	0.018	0.006	0.195
Long	2,668	0.18	13	0.0001	0.005	0.18	0.00	17	0.017	0.006	0.184

3.3.2 Fleet-average data for rail container transport

Table 14 Emission factors, tank-to-wheel and well-to-wheel, light-container rail transport, 2014

	Load capacity	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
Vehicle type	(tonne)	MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Electric train											
Short	45	0.29	-	-	-	-	0.019	39	0.021	0.002	0.037
Medium-length	70	0.22	-	-	-	-	0.014	30	0.016	0.001	0.028
Long	90	0.19	-	-	-	-	0.012	26	0.014	0.001	0.024
Diesel train											
Short	45	0.78	57	0.0004	0.021	0.76	0.018	73	0.075	0.024	0.787
Medium-length	70	0.59	44	0.0003	0.016	0.58	0.014	56	0.057	0.018	0.599
Long	90	0.51	37	0.0002	0.014	0.50	0.012	48	0.048	0.016	0.512

Table 15 Emission factors, tank-to-wheel and well-to-wheel, medium-weight-container rail transport, 2014

	Load capacity	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
Vehicle type	(tonne)	MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Electric train											
Short	45	0.18	-	-	-	-	0.012	24	0.013	0.001	0.023
Medium-length	70	0.14	-	-	-	-	0.009	19	0.010	0.001	0.017
Long	90	0.12	-	-	-	-	0.008	16	0.009	0.001	0.015
Diesel train											
Short	45	0.49	36	0.0002	0.013	0.47	0.011	46	0.046	0.015	0.491
Medium-length	70	0.37	27	0.0002	0.010	0.36	0.009	35	0.035	0.011	0.373
Long	90	0.32	23	0.0001	0.009	0.31	0.007	30	0.030	0.010	0.319

Table 16 Emission factors, tank-to-wheel and well-to-wheel, heavy-container rail transport, 2014

	Load capacity	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
Vehicle type	(tonne)	MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Electric train											
Short	45	0.14	-	-	-	-	0.009	19	0.010	0.001	0.018
Medium-length	70	0.11	-	-	-	-	0.007	14	0.008	0.001	0.013
Long	90	0.09	-	-	-	-	0.006	12	0.007	0.001	0.011
Diesel train											
Short	45	0.37	28	0.0002	0.010	0.37	0.009	35	0.036	0.011	0.378
Medium-length	70	0.28	21	0.0001	0.008	0.28	0.007	27	0.027	0.009	0.288
Long	90	0.24	18	0.0001	0.007	0.24	0.006	23	0.023	0.007	0.246

3.4 Inland shipping

3.4.1 Fleet-average data for inland-waterway transport of bulk and packaged cargo

Table 17 Emission factors, tank-to-wheel and well-to-wheel, light-bulk inland-waterway transport, 2014

Vessel type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Spits											
CEMT-I	365	0.55	40	0.0002	0.025	0.6	-	51	0.053	0.027	0.67
CEMT-Va	365	0.55	39	0.0002	0.024	0.6	-	51	0.053	0.026	0.67
CEMT-VIb	365	0.48	34	0.0002	0.022	0.6	-	44	0.046	0.024	0.58
Waal	365	0.50	35	0.0002	0.022	0.6	-	45	0.047	0.024	0.59
Campine vessel											
CEMT-II	617	0.49	35	0.0002	0.022	0.6	-	45	0.047	0.023	0.58
CEMT-Va	617	0.56	40	0.0002	0.024	0.6	-	51	0.053	0.026	0.67
CEMT-VIb	617	0.51	37	0.0002	0.023	0.6	-	47	0.049	0.024	0.61
Waal	617	0.55	39	0.0002	0.024	0.6	-	51	0.052	0.026	0.65
Rhine-Herne canal vessel											
CEMT-IV	1,537	0.35	25	0.0002	0.014	0.4	-	32	0.033	0.015	0.40
CEMT-Va	1,537	0.51	36	0.0002	0.021	0.6	-	47	0.049	0.022	0.58
CEMT-VIb	1,537	0.52	37	0.0002	0.021	0.6	-	48	0.050	0.023	0.60
Waal	1,537	0.51	37	0.0002	0.021	0.6	-	47	0.049	0.023	0.59
Large Rhine vessel											
CEMT-Va	3,013	0.24	17	0.0001	0.008	0.2	-	22	0.023	0.009	0.25
CEMT-VIb	3,013	0.32	23	0.0001	0.011	0.3	-	29	0.031	0.012	0.34
Waal	3,013	0.28	20	0.0001	0.010	0.3	-	26	0.027	0.011	0.30
Coupled: Class Va + 1 Europe II barge, wide											
CEMT-VIb	5,046	0.21	15	0.0001	0.007	0.2	-	19	0.020	0.008	0.22
Waal	5,046	0.29	20	0.0001	0.010	0.3	-	26	0.027	0.011	0.30
4-barge push convoy											
CEMT-VIb	11,181	0.20	14	0.0001	0.004	0.2	-	19	0.019	0.005	0.16
Waal	11,181	0.24	17	0.0001	0.005	0.2	-	22	0.023	0.006	0.19
6-barge push convoy (long)											
CEMT-VIb	16,444	0.14	10	0.0001	0.003	0.1	-	13	0.014	0.003	0.11
Waal	16,444	0.17	12	0.0001	0.003	0.1	-	15	0.016	0.004	0.13

Table 18 Emission factors, tank-to-wheel and well-to-wheel, medium-weight-bulk inland-waterway transport, 2014

Vessel type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Spits											
CEMT-I	365	0.49	35	0.0002	0.022	0.6	-	45	0.046	0.024	0.59
CEMT-Va	365	0.45	32	0.0002	0.020	0.5	-	41	0.043	0.022	0.55
CEMT-VIb	365	0.39	27	0.0002	0.017	0.5	-	35	0.037	0.019	0.47
Waal	365	0.40	28	0.0002	0.018	0.5	-	36	0.038	0.019	0.48
Campine vessel											
CEMT-II	617	0.43	31	0.0002	0.019	0.5	-	40	0.041	0.020	0.51
CEMT-Va	617	0.46	33	0.0002	0.020	0.5	-	42	0.044	0.021	0.54
CEMT-VIb	617	0.41	29	0.0002	0.018	0.5	-	37	0.039	0.019	0.48
Waal	617	0.43	31	0.0002	0.019	0.5	-	40	0.041	0.020	0.51
Rhine-Herne canal vessel											
CEMT-IV	1,537	0.29	21	0.0001	0.012	0.3	-	27	0.028	0.013	0.33
CEMT-Va	1,537	0.42	30	0.0002	0.017	0.5	-	39	0.040	0.019	0.48
CEMT-VIb	1,537	0.41	29	0.0002	0.017	0.5	-	38	0.039	0.018	0.47
Waal	1,537	0.40	29	0.0002	0.016	0.4	-	37	0.038	0.018	0.46
Large Rhine vessel											
CEMT-Va	3,013	0.20	14	0.0001	0.007	0.2	-	18	0.019	0.008	0.21
CEMT-VIb	3,013	0.24	17	0.0001	0.009	0.2	-	22	0.023	0.009	0.26
Waal	3,013	0.21	15	0.0001	0.007	0.2	-	19	0.020	0.008	0.22
Coupled: Class Va + 1 Europe II barge, wide											
CEMT-VIb	5,046	0.17	12	0.0001	0.006	0.2	-	16	0.016	0.007	0.18
Waal	5,046	0.22	16	0.0001	0.008	0.2	-	20	0.021	0.009	0.23
4-barge push convoy											
CEMT-VIb	11,181	0.17	12	0.0001	0.003	0.1	-	16	0.016	0.004	0.14
Waal	11,181	0.19	14	0.0001	0.004	0.1	-	18	0.019	0.005	0.16
6-barge push convoy (long)											
CEMT-VIb	16,444	0.12	8	0.0001	0.002	0.1	-	11	0.011	0.003	0.09
Waal	16,444	0.13	9	0.0001	0.003	0.1	-	12	0.013	0.003	0.11

Table 19 Emission factors, tank-to-wheel and well-to-wheel, heavy-bulk inland-waterway transport, 2014

Vessel type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Spits											
CEM- I	365	0.56	40	0.0003	0.025	0.7	-	52	0.054	0.027	0.68
CEMT-Va	365	0.47	34	0.0002	0.021	0.6	-	43	0.045	0.023	0.57
CEMT-VIb	365	0.40	28	0.0002	0.018	0.5	-	37	0.038	0.019	0.48
Waal	365	0.41	29	0.0002	0.018	0.5	-	38	0.039	0.020	0.50
Campine vessel											
CEMT-II	617	0.48	34	0.0002	0.021	0.6	-	44	0.046	0.022	0.57
CEMT-Va	617	0.48	34	0.0002	0.021	0.6	-	44	0.046	0.023	0.57
CEMT-VIb	617	0.42	30	0.0002	0.018	0.5	-	38	0.040	0.020	0.50
Waal	617	0.44	32	0.0002	0.019	0.5	-	41	0.042	0.021	0.52
Rhine-Herne canal vessel											
CEMT-IV	1,537	0.32	23	0.0001	0.013	0.4	-	29	0.030	0.014	0.36
CEMT-Va	1,537	0.45	32	0.0002	0.018	0.5	-	42	0.043	0.020	0.52
CEMT-VIb	1,537	0.42	30	0.0002	0.017	0.5	-	39	0.040	0.019	0.48
Waal	1,537	0.41	30	0.0002	0.017	0.5	-	38	0.040	0.018	0.47
Large Rhine vessel											
CEMT-Va	3,013	0.23	16	0.0001	0.008	0.2	-	21	0.022	0.009	0.24
CEMT-VIb	3,013	0.26	19	0.0001	0.009	0.3	-	24	0.025	0.010	0.28
Waal	3,013	0.22	16	0.0001	0.008	0.2	-	21	0.021	0.009	0.24
Coupled: Class Va + 1 Europe II barge, wide											
CEMT-VIb	5,046	0.20	14	0.0001	0.007	0.2	-	18	0.019	0.008	0.21
Waal	5,046	0.24	17	0.0001	0.008	0.2	-	22	0.023	0.009	0.25
4-barge push convoy											
CEMT-VIb	11,181	0.19	14	0.0001	0.004	0.1	-	17	0.018	0.004	0.15
Waal	11,181	0.21	15	0.0001	0.004	0.2	-	20	0.020	0.005	0.17
6-barge push convoy (long)											
CEMT-VIb	16,444	0.13	9	0.0001	0.003	0.1	-	12	0.013	0.003	0.11
Waal	16,444	0.14	10	0.0001	0.003	0.1	-	13	0.013	0.003	0.11

3.4.2 Fleet-average data for inland-waterway container transport

Table 20 Emission factors, tank-to-wheel and well-to-wheel, light-container inland-waterway transport, 2014

Vessel type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Neo Kemp											
CEMT-III	40	0.56	40	0.0002	0.023	0.63	-	51	0.054	0.025	0.65
CEMT-Va	40	0.87	62	0.0004	0.036	0.97	-	80	0.083	0.039	1.00
CEMT-VIb	40	1.01	72	0.0005	0.042	1.14	-	93	0.097	0.046	1.17
Waal	40	0.94	67	0.0004	0.039	1.06	-	87	0.090	0.042	1.09
Rhine-Herne canal vessel (96 TEU)											
CEMT-IV	96	0.41	29	0.0002	0.017	0.45	-	37	0.039	0.018	0.46
CEMT-Va	96	0.64	46	0.0003	0.026	0.71	-	59	0.061	0.028	0.73
CEMT-VIb	96	0.73	52	0.0003	0.030	0.81	-	67	0.070	0.032	0.84
Waal	96	0.73	52	0.0003	0.029	0.81	-	67	0.069	0.032	0.83
Europe IIa push convoy (160 TEU)											
CEMT-Va	160	0.55	39	0.0002	0.019	0.56	-	51	0.053	0.021	0.58
CEMT-VIb	160	0.66	47	0.0003	0.023	0.68	-	61	0.063	0.026	0.70

Vessel type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Waal	160	0.64	46	0.0003	0.022	0.65	-	59	0.061	0.025	0.68
Large Rhine vessel (208 TEU)											
CEMT-Va	208	0.30	22	0.0001	0.011	0.31	-	28	0.029	0.012	0.32
CEMT-VIb	208	0.44	31	0.0002	0.015	0.45	-	41	0.042	0.017	0.46
Waal	208	0.40	28	0.0002	0.014	0.40	-	37	0.038	0.015	0.42
Extended large Rhine vessel (272 TEU)											
CEMT-Va	272	0.31	22	0.0001	0.006	0.24	-	28	0.030	0.007	0.25
CEMT-VIb	272	0.40	29	0.0002	0.008	0.31	-	37	0.038	0.009	0.32
Waal	272	0.32	23	0.0001	0.006	0.25	-	30	0.031	0.008	0.26
Coupled: Europe II-C3l (348 TEU)											
CEMT-Va	348	0.27	20	0.0001	0.010	0.28	-	25	0.026	0.011	0.29
CEMT-VIb	348	0.31	22	0.0001	0.011	0.31	-	28	0.029	0.012	0.32
Waal	348	0.28	20	0.0001	0.010	0.29	-	26	0.027	0.011	0.30
Rhinemax vessel											
CEMT-VIb	434	0.41	29	0.0002	0.008	0.32	-	38	0.040	0.010	0.33
Waal	434	0.43	31	0.0002	0.009	0.33	-	40	0.041	0.010	0.35

Table 21 Emission factors, tank-to-wheel and well-to-wheel, medium-weight-container inland-waterway transport, 2014

Vessel type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Neo Kemp											
CEMT-III	40	0.37	27	0.0002	0.016	0.42	-	34	0.036	0.017	0.43
CEMT-Va	40	0.57	41	0.0003	0.024	0.64	-	52	0.055	0.026	0.66
CEMT-VIb	40	0.65	47	0.0003	0.027	0.73	-	60	0.062	0.029	0.75
Waal	40	0.61	43	0.0003	0.025	0.68	-	56	0.058	0.027	0.70
Rhine-Herne canal vessel (96 TEU)											
CEMT-IV	96	0.29	21	0.0001	0.012	0.32	-	27	0.028	0.013	0.33
CEMT-Va	96	0.45	32	0.0002	0.018	0.50	-	41	0.043	0.020	0.51
CEMT-VIb	96	0.49	35	0.0002	0.020	0.55	-	45	0.047	0.022	0.56
Waal	96	0.48	34	0.0002	0.019	0.53	-	44	0.046	0.021	0.55
Europe IIa push convoy (160 TEU)											
CEMT-Va	160	0.41	30	0.0002	0.014	0.42	-	38	0.040	0.016	0.43
CEMT-VIb	160	0.47	34	0.0002	0.017	0.48	-	44	0.045	0.018	0.50
Waal	160	0.45	32	0.0002	0.016	0.46	-	42	0.043	0.017	0.47
Large Rhine vessel (208 TEU)											
CEMT-Va	208	0.22	15	0.0001	0.008	0.22	-	20	0.021	0.008	0.23
CEMT-VIb	208	0.30	21	0.0001	0.010	0.30	-	27	0.028	0.011	0.31
Waal	208	0.26	18	0.0001	0.009	0.26	-	24	0.025	0.010	0.27
Extended large Rhine vessel (272 TEU)											
CEMT-Va	272	0.22	16	0.0001	0.004	0.17	-	21	0.021	0.005	0.18
CEMT-VIb	272	0.27	19	0.0001	0.005	0.21	-	25	0.026	0.006	0.22
Waal	272	0.21	15	0.0001	0.004	0.16	-	19	0.020	0.005	0.17
Coupled: Europe II-C3l (348 TEU)											
CEMT-Va	348	0.20	15	0.0001	0.007	0.21	-	19	0.019	0.008	0.21
CEMT-VIb	348	0.21	15	0.0001	0.007	0.22	-	19	0.020	0.008	0.22
Waal	348	0.19	13	0.0001	0.007	0.19	-	17	0.018	0.007	0.20
Rhinemax vessel											
CEMT-VIb	434	0.29	21	0.0001	0.006	0.22	-	27	0.028	0.007	0.23
Waal	434	0.29	21	0.0001	0.006	0.22	-	27	0.028	0.007	0.23

Table 22 Emission factors, tank-to-wheel and well-to-wheel, heavy-container inland-waterway transport, 2014

Vessel type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Neo Kemp											
CEMT-III	40	0.31	22	0.0001	0.013	0.35	-	29	0.030	0.014	0.36
CEMT-Va	40	0.46	33	0.0002	0.019	0.52	-	43	0.044	0.021	0.54
CEMT-VIb	40	0.52	37	0.0002	0.022	0.59	-	48	0.050	0.023	0.60
Waal	40	0.48	34	0.0002	0.020	0.54	-	44	0.046	0.022	0.56
Rhine-Herne canal vessel (96 TEU)											
CEMT-IV	96	0.25	18	0.0001	0.010	0.28	-	23	0.024	0.011	0.29
CEMT-Va	96	0.38	27	0.0002	0.015	0.42	-	35	0.037	0.017	0.44
CEMT-VIb	96	0.41	29	0.0002	0.017	0.45	-	37	0.039	0.018	0.46
Waal	96	0.39	28	0.0002	0.016	0.43	-	36	0.037	0.017	0.44
Europe IIa push convoy (160 TEU)											
CEMT-Va	160	0.37	27	0.0002	0.013	0.38	-	34	0.036	0.014	0.39
CEMT-VIb	160	0.41	29	0.0002	0.014	0.42	-	38	0.039	0.016	0.43
Waal	160	0.38	27	0.0002	0.013	0.39	-	35	0.037	0.015	0.40
Large Rhine vessel (208 TEU)											
CEMT-Va	208	0.19	14	0.0001	0.007	0.19	-	17	0.018	0.007	0.20
CEMT-VIb	208	0.25	18	0.0001	0.009	0.25	-	23	0.024	0.009	0.26
Waal	208	0.21	15	0.0001	0.007	0.21	-	19	0.020	0.008	0.22
Extended large Rhine vessel (272 TEU)											
CEMT-Va	272	0.20	14	0.0001	0.004	0.15	-	18	0.019	0.005	0.16
CEMT-VIb	272	0.23	16	0.0001	0.005	0.17	-	21	0.022	0.005	0.18
Waal	272	0.17	12	0.0001	0.003	0.13	-	16	0.016	0.004	0.14
Coupled: Europe II-C3l (348 TEU)											
CEMT-Va	348	0.18	13	0.0001	0.006	0.19	-	17	0.018	0.007	0.19
CEMT-VIb	348	0.18	13	0.0001	0.006	0.18	-	16	0.017	0.007	0.19
Waal	348	0.15	11	0.0001	0.005	0.16	-	14	0.015	0.006	0.16
Rhinemax vessel											
CEMT-VIb	434	0.25	18	0.0001	0.005	0.19	-	23	0.024	0.006	0.20
Waal	434	0.24	17	0.0001	0.005	0.18	-	22	0.023	0.006	0.19

3.5 Maritime shipping (short-sea)

3.5.1 Fleet-average data for short-sea transport of bulk and packaged cargo

Table 23 Emission factors, tank-to-wheel and well-to-wheel, light-bulk short-sea transport, 2014

Vessel type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
General cargo											
General Cargo, 0-5 dwkt	1,925	0.53	40	0.025	0.018	0.83	0	50	0.075	0.020	0.85
General Cargo, 5-10 dwkt	7,339	0.38	29	0.018	0.013	0.60	0	36	0.054	0.015	0.61
General Cargo, 10-20 dwkt	22,472	0.25	19	0.012	0.009	0.39	0	24	0.036	0.010	0.40

Table 24 Emission factors, tank-to-wheel and well-to-wheel, medium-weight-bulk short-sea transport, 2014

Vessel type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
General cargo											
General Cargo, 0-5 dwkt	1,925	0.29	22	0.013	0.010	0.46	0	27	0.041	0.011	0.47
General Cargo, 5-10 dwkt	7,339	0.22	17	0.010	0.008	0.36	0	21	0.032	0.009	0.36
General Cargo, 10-20 dwkt	22,472	0.16	12	0.007	0.006	0.25	0	15	0.023	0.006	0.26
Bulk carrier											
Bulk carrier (feeder)	3,341	0.39	29	0.018	0.014	0.60	0	37	0.055	0.015	0.61
Bulk carrier (Handysize)	27,669	0.12	9	0.006	0.004	0.19	0	11	0.017	0.005	0.20
Bulk carrier (Handymax)	52,222	0.09	7	0.004	0.003	0.14	0	8	0.013	0.003	0.15

Table 25 Emission factors, tank-to-wheel and well-to-wheel, heavy-bulk short-sea transport, 2014

Vessel type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Oil tanker											
Oil tanker, 0-5 dwkt	1,985	0.72	55	0.034	0.025	0.95	0	69	0.103	0.028	0.97
Oil tanker, 5-10 dwkt	6,777	0.33	25	0.016	0.012	0.45	0	32	0.048	0.013	0.46
Oil tanker, 10-20 dwkt	15,129	0.25	19	0.012	0.009	0.33	0	24	0.036	0.010	0.34
Oil tanker, 20-60 dwkt	43,763	0.19	15	0.009	0.007	0.28	0	19	0.028	0.007	0.28
Oil tanker, 60-80 dwkt	72,901	0.13	10	0.006	0.005	0.20	0	13	0.019	0.005	0.21
Oil tanker, 80-120 dwkt	109,259	0.11	8	0.005	0.004	0.16	0	10	0.015	0.004	0.16
General cargo											
General Cargo, 0-5 dwkt	1,925	0.28	21	0.013	0.010	0.45	0	27	0.040	0.011	0.46
General Cargo, 5-10 dwkt	7,339	0.22	17	0.010	0.008	0.35	0	21	0.031	0.008	0.36
General Cargo, 10-20 dwkt	22,472	0.16	12	0.007	0.005	0.25	0	15	0.022	0.006	0.25
Bulk carrier											
Bulk carrier (feeder)	3,341	0.38	28	0.018	0.013	0.58	0	36	0.054	0.014	0.59
Bulk carrier (Handysize)	27,669	0.11	9	0.005	0.004	0.19	0	11	0.016	0.004	0.19
Bulk carrier (Handymax)	52,222	0.09	7	0.004	0.003	0.14	0	8	0.012	0.003	0.14

3.5.2 Fleet-average data for short-sea container transport

Table 26 Emission factors, tank-to-wheel and well-to-wheel, light-container short-sea transport, 2014

Vessel type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Container ship											
Container (feeder)	635	0.61	46	0.029	0.021	0.97	0	58	0.087	0.023	0.99
Container (Handysize-like)	1,500	0.47	36	0.022	0.016	0.73	0	45	0.067	0.018	0.75
Container (Handymax-like)	2,750	0.40	31	0.019	0.014	0.63	0	39	0.058	0.016	0.65
Container (Panamax-like)	4,060	0.37	28	0.017	0.013	0.59	0	35	0.053	0.014	0.60
Container (Aframax-like)	5,600	0.32	24	0.015	0.011	0.52	0	31	0.046	0.012	0.53
Container (Suezmax-like)	8,170	0.27	21	0.013	0.010	0.45	0	26	0.039	0.010	0.45

Table 27 Emission factors, tank-to-wheel and well-to-wheel, medium-weight-container short-sea transport, 2014

Vessel type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Container ship											
Container (feeder)	635	0.36	27	0.017	0.013	0.58	0	35	0.052	0.014	0.59
Container (Handysize-like)	1,500	0.28	21	0.013	0.010	0.43	0	26	0.040	0.011	0.44
Container (Handymax-like)	2,750	0.24	18	0.011	0.008	0.37	0	23	0.034	0.009	0.38
Container (Panamax-like)	4,060	0.22	16	0.010	0.008	0.35	0	21	0.031	0.008	0.36
Container (Aframax-like)	5,600	0.19	14	0.009	0.007	0.31	0	18	0.027	0.007	0.31
Container (Suezmax-like)	8,170	0.16	12	0.008	0.006	0.26	0	15	0.023	0.006	0.27

Table 28 Emission factors, tank-to-wheel and well-to-wheel, heavy-container short-sea transport, 2014

Vessel type	Load capacity (tonne)	2014									
		TTW emissions (g/tkm)						WTW emissions (g/tkm)			
		MJ/tkm	CO_2-eq	SO_2	PM_c	NO_x	PM_w	CO_2-eq	SO_2	PM_c	NO_x
Container ship											
Container (feeder)	635	0.27	20	0.013	0.009	0.43	0	26	0.039	0.010	0.44
Container (Handysize-like)	1,500	0.21	16	0.010	0.007	0.32	0	20	0.029	0.008	0.33
Container (Handymax-like)	2,750	0.18	13	0.008	0.006	0.28	0	17	0.025	0.007	0.28
Container (Panamax-like)	4,060	0.16	12	0.008	0.006	0.26	0	15	0.023	0.006	0.26
Container (Aframax-like)	5,600	0.14	11	0.007	0.005	0.23	0	13	0.020	0.005	0.23
Container (Suezmax-like)	8,170	0.12	9	0.006	0.004	0.20	0	11	0.017	0.005	0.20

3.6 Alternative technologies and fuels

The following tables give indices for alternative technologies and fuels. These are discussed in Section 4.8.

3.6.1 Road transport

Table 29 Indices for alternative fuels and technologies, vans (indexed to Euro V = 100)

Fuel/technology	TTW	TTW emissions (g/km)			WTW emissions (g/km)		
	MJ/km	CO_2-eq	PM_c	NO_x	CO_2-eq	PM_c	NO_x
Diesel, Euro 5	3.1	231.1	0.001	1.5	295	0.010	0.1
Index of average diesel 2014 relative to Euro 5							
Diesel, average 2014	100	100	3681	87	100	423	88
Index (Euro 5 = 100)							
Diesel, Euro 5	100	100	100	100	100	100	100
Diesel, Euro 6	100	100	100	72	100	100	74
Diesel, Plug-in hybrid, Euro 6	88	88	75	75	88	87	76
GTL, Euro 5	100	96	80	85	100	110	87
Biodiesel, Euro 5 (B100)	100	0	40	125	22	228	127
CNG, Euro 6	110	84	100	20	80	12	20
Bio-CNG, Euro 6	110	0	100	20	30	43	22
Electric	52	0	0	0	74	89	13
Hydrogen	67	0	0	0	74	348	18

Table 30 Indices for alternative fuels and technologies, medium-weight trucks (10-20 t GVW) (indexed to Euro V = 100)

Fuel/technology	TTW	TTW emissions (g/km)			WTW emissions (g/km)		
	MJ/km	CO_2-eq	PM_c	NO_x	CO_2-eq	PM_c	NO_x
Diesel, Euro V	8.1	612.9	0.012	4.6	781	0.039	4.9
Index of average diesel 2014 relative to Euro V							
Diesel, average 2014	100	100	394	112	100	192	111
Index (Euro V = 100)							
Diesel, Euro V	100	100	100	100	100	100	100
Diesel, Euro VI	100	100	70	9	100	91	14
Diesel, hybrid, Euro VI	90	90	100	100	90	93	99
GTL, Euro V	96	92	80	85	96	100	86
Biodiesel, Euro V (B30)	100	70	80	110	77	124	110
Biodiesel, Euro V (B100)	100	0	40	125	22	182	127
CNG (Euro VI)	110	84	70	9	81	24	9
Bio-CNG, Euro VI	110	0	70	9	30	48	11
LNG, Euro VI)	110	84	70	9	87	47	13
Bio-LNG, Euro VI	110	0	70	9	30	48	11
Electric	56	0	0	0	79	72	12
Hydrogen	72	0	0	0	79	283	16

Table 31 Indices for alternative fuels and technologies, heavy tractor-semitrailers (indexed to Euro V = 100)

Fuel/technology	TTW	TTW emissions (g/km)			WTW emissions (g/km)		
	MJ/km	CO_2-eq	PM_c	NO_x	CO_2-eq	PM_c	NO_x
Diesel, Euro V	13.9	1,050	0.040	3.1	1.339	0.086	3.5
Index of average diesel 2014 relative to Euro V							
Diesel, average 2014	100	100	126	131	100	112	127
Index (Euro V = 100)							
Diesel, Euro V	100	100	100	100	100	100	100
Diesel, Euro VI	100	100	30	23	100	68	33
GTL, Euro V	96	92	80	85	96	95	88
Biodiesel, Euro V (B30)	100	70	80	110	77	114	111
Biodiesel, Euro V (B100)	100	0	40	125	22	151	129
LNG, Euro VI	110	84	30	23	87	33	32
Bio-LNG, Euro VI	110	0	30	23	30	34	27
Hydrogen	81	0	0	0	89	248	43

3.6.2 Rail

Table 32 Indices for green-powered electric rail (indexed to average electricity = 100)

Fuel/technology	TTW emissions			WTW emissions		
	CO_2-eq	PM_c	NO_x	CO_2-eq	PM_c	NO_x
Electricity, average (g/kWh-electric)	0	0	0	490	0.02	0.46
Index relative to electricity, average						
Electricity, average	100	100	100	100	100	100
Green electricity/wind power	0	0	0	0	0	0
Overhead wires 3 kV (instead of 1.5 kV)	0	0	0	80	80	80

Table 33 Indices for alternatives and average 2014 for diesel rail (indexed to Stage IIIa = 100)

Fuel/technology	Energy consumption	TTW emissions			WTW emissions		
	MJ_{fuel}/ kWh*	CO_2-eq	PM_c	NO_x	CO_2-eq	PM_c	NO_x
Stage IIIa (g/kWh)*	8.7	625	0.2	6.7	829	0.23	6.98
Index relative to Stage IIIa							
Stage IIIa (2007/2009)	100	100	100	100	100	100	100
Average, 2014	100	100	115	124	100	113	123
Stage IIIb (2012)	100	100	13	54	100	24	56
Stage V (2019/2020)	100	100	13	54	100	24	56

* Refers to kWh effective engine output (as in emission standards).

3.6.3 Inland shipping

Table 34 Indexcijfers for alternatives and average 2014 for inland shipping (indexed to CCNR2 =100)

Fuel/technology	Energy consumption	TTW emissions			WTW emissions		
	MJ_{fuel}/ kWh*	CO_2-eq	PM_c	NO_x	CO_2-eq	PM_c	NO_x
Diesel, CCNR2 (g/kWh*)	8.7	625	0.15	6.0	830	0.18	6.28
Index van average for 2014 relative to CCNR2							
Spits, 2014	100	100	262	172	100	235	169
Rhine-Herne canal vessel	100	100	237	162	100	213	159
Large Rhine vessel, 2014	100	100	204	149	100	187	146
Rhinemax vessel, 2014	100	100	116	112	100	114	111
Index of alternatives relative to CCNR2							
Diesel, CCNR2	100	100	100	100	100	100	100
Stage V (2019/2020)	100	100	15	35	100	29	38
Diesel hybrid, CCNR2	95	95	95	95	95	95	95
LNG, pilot 2%D	100	100	25	25	98	27	28
LNG, dual-fuel, 20%D	100	100	50	50	98	49	52
LNG, single-fuel, SI	100	100	10	25	98	14	28
CCNR2 with GTL **	100	96	80	90	100	86	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

* Refers to kWh effective engine output (as in emission standards).

** The reduction percentages also hold if the alternative is used in a CCNR0 or CCNR1 engine relative to the engine without the measure. There are limited measurements for GTL; particulates reduction varies from 15% to 60%.

3.6.4 Maritime shipping (short-sea)

Table 35 Emission factors for alternative fuels and technologies, short-sea shipping (indexed to MGO = 100)

Fuel/technology	TTW MJ/kWh	TTW emissions (g/kWh) CO_2-eq	PM_c	NO_x	SO_x	WTW emissions (g/kWh) CO_2-eq	PM_c	NO_x	SO_x
MGO, Tier II	7.9	599	0.10	10.2	0.37	757	0.12	10.4	1.13
Index of diesel, average MGO relative to MGO, Tier II									
MGO	100	100	100	124	100	100	100	100	100
Index of alternatives relative to MGO, Tier II									
MGO, Tier III	100	100	100	100	100	100	100	100	100
MGO, Tier III	100	100	100	25	100	100	100	27	100
HFO + Scrubber	103	104	120 (50-190)	120	5-100*	96	118	119	5-100
LNG	103	97	11	13	1	97	13	15	0.6

* Monitoring reports (COWI, 2012) (Holland America Line and Hamworthy- Krystallon, 2010) (Wärtisilä, 2010) show a range in sulphur emission reduction by scrubbers from 95% below the SECA standard to slightly below that standard.
Based on recent measurements (monitoring report obtained via personal communication KVNR) a high reduction in sulphur emissions appears feasible. Further study on this issue is required, but it is clear the SECA standard will be achieved.

4 Emission data: description and assumptions

4.1 Introduction

This chapter goes into the assumptions and computational methods used to obtain the emission factors reported in Chapter 3. In Section 4.2 we first discuss the general assumptions and methods used in calculating emissions per tonne-kilometre. In Sections 4.3 (road), 4.4 (rail) 4.5 (inland shipping) and 4.6 (maritime shipping) for each mode the specific assumptions and method employed for calculating per-kilometre vehicle/vessel emissions (tank-to-wheel[12] (TTW) emissions) are discussed. Section 4.7 deals with upstream emissions (WTT) per kilometre. The chapter concludes with a section on the assumptions and method used in calculating the correction factors (indices) for alternative fuels and technologies (Section 4.8) and a section on indices for transhipment (Section 4.9). The logistical data on which the indices per tonne-kilometre are based are described in Chapter 5.

4.2 General methodology

The emission factors in Chapter 3 are expressed as emissions per tonne-kilometre (EF_{tkm}). The **tonne-kilometre** is a unit of transport performance, indicating transport of one tonne over a distance of one kilometre.
The distance considered in our context is the actual distance travelled in delivering the goods.[13] The tonne-kilometre thus indicates the transport performance expressed in terms of both distance and delivered weight.

For all emissions, we report on both exhaust emissions (tank-to-wheel-emissions) and total use-dependent emissions down the supply chain (well-to-wheel emissions), which also factor in the emissions occurring during fuel extraction, production and transport and electric power generation (well-to-tank-emissions).

"CO_2 emissions" refer to aggregate CO_2-equivalent (CO_2-eq.) emissions, whereby emissions of methane (CH_4) and nitrous oxide (N_2O) are expressed in CO_2-equivalents using the GWP factors shown in Table 36.

Table 36 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)	28
Nitrous oxide (N_2O)	265

Source: IPCC, 2014: Fifth Assessment Report (exclusive of climate-carbon feedbacks, ARS method)

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[12] For inland and maritime shipping this can be read as 'tank-to-propeller'.

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

Emissions per tonne-kilometre are calculated from the average emissions per vehicle-kilometre[14] (EF_{vkm}) and the vehicle load averaged over full and empty trips($Tonne_{average}$), as follows:

$$EF_{tkm} = \frac{EF_{vkm}}{Tonne_{average}} \quad (1)$$

EF_{vkm}

For all transport modes, the emission factor per vehicle-kilometre is the average of the emission factors for loaded ($EF_{vkm\text{-}loaded}$) and empty kilometres ($EF_{vkm\text{-}empty}$), weighted according to the ratio of loaded ($\%vkm_{loaded}$) to empty kilometres ($\%vkm_{empty}$), using:

$$EF_{vkm} = EF_{vkm-loaded} \times \%vkm_{loaded} + EF_{vkm-empty} \times \%vkm_{empty} \quad (2)$$

The emission factor for loaded kilometres obviously depends on the vehicle load. In the case of container transport the weight of the empty container also affects the emission factor. The method used to compute the emission factor for loaded kilometres differs for each mode and is explained separately in Sections 4.3 (road), 4.4 (rail), 4.5 (inland shipping) and 4.6 (maritime shipping).

$Tonne_{average}$ - bulk and piece good transport

The average tonnage over loaded and empty kilometres ($Tonne_{average}$) is calculated from vehicle capacity (Cap), average load factor on loaded trips (%tonne) and share of loaded kilometres, according to:

$$Tonne_{average} = Cap \times \%tonne \times \%vkm_{loaded} \quad (3)$$

For each transport mode the vehicle capacity, average load factor and average number of loaded kilometres are given in Chapter 5, thereby distinguishing between light, medium-weight and heavy transport.

$Tonne_{average}$ - container transport

For container transport the average tonnage over loaded and empty kilometres is calculated from container capacity (CapTEU), average container slot utilization (%TEU) and average container load (tonne/TEU), using:

$$Tonne_{average} = CapTEU \times \%TEU \times tonne/TEU \quad (4)$$

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

Upstream emissions per kilometre ($EF_{g/km}(WTT)$) are related directly to energy consumption per kilometre ($EC_{MJ/km}$) and are calculated from emission factors for fuel and electricity ($EF_{g/MJ}$) according to:

$$EF_{g/km}(WTT) = EC_{MJ/km} * EF_{g/MJ} \quad (5)$$

[14] Where relevant, “vehicle” also stands for (inland or short-sea) “shipping vessel”.

For each mode, energy consumption per kilometre (MJ/km) is reported in Sections 4.3 to 4.6. Upstream emissions per fuel type are given In Section 4.7.

4.3 Road transport

4.3.1 Introduction

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

$$\boldsymbol{EF_{vkm-loaded} = EF_{empty} + \%load \times (EF_{max\ full} - EF_{empty})} \quad (6)$$

Using the load factors for light, medium-weight and heavy transport from Section 5, the energy consumption and emission factors for each of these categories were calculated. The sources and methods used to calculate the per-kilometre energy consumption and CO_2 emission factors of full and empty vehicles are described In Section 4.3.2. Section 4.3.3 reports the data used for air-pollutant emission factors.

The road vehicles covered by this study are listed in Table 37. The vehicle definitions have been taken in accordance with the emission factors used in (Task Force on Transportation, 2016). The load capacities and empty weights for trucks have been taken from (TNO, 2015b). The empty weights of light and heavy tractor-semitrailers were estimated using CBS fleet data. As those figures indicate, the tractor weighs around 7 tonnes while the empty weight of the semi-trailer is 7-9 tonnes.

Table 37 Definitions of road vehicle categories

Vehicle category	Load capacity (tonne)	Empty vehicle weight (tonne)	GVW (tonne)
Small van < 2 t	0.7	1.3	2
Large van > 2 t	1.2	2.3	3.5
Truck < 10 t	3	4.5	7.5
Truck 10-20 t	7.5	8.5	16
Truck 10-20 t + trailer	18	15	33
Truck > 20 t	13	15	28
Truck, rigid > 20 t + 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 and CO_2 emissions

The energy consumption of vans, trucks and tractor-semitrailers is based on the CO_2 factors reported in (TNO, 2016a) per road class. This source gives emission factors for light and heavy vans and for the seven standard classes of truck (small, medium-size and large trucks, with and without a trailer, and light and heavy tractor-semitrailers). The emission factors for long heavy vehicles (LHVs) were modelled relative to the tractor-semitrailer, based on TML, 2008 en TRL, 2008 (see Table 73, Annex A).

The emission factors in (TNO, 2016a) 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 full vehicles (EF_{full}) were calculated from the average emission factors according to expressions 7 and 8.

$$E_{empty} = EF_{average-load} - difCO_2 \times Load_{average} \quad (7)$$

$$EF_{full} = EF_{average-load} + difCO_2 \times (Capacity - Load_{average}) \quad (8)$$

This calculation was performed using the $difCO_2$ factors in Table 38, which express the relationship between vehicle weight and CO_2 emission per kilometre.

Table 38 Difference in CO_2 emissions (g/km) per tonne load ($DifCO_2$)

Vehicle	Increase or decrease of CO_2/km with load increase or decrease (Δ (g CO_2/ km)/Δ ton)
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. Energy consumption was then calculated by dividing the CO_2 emission factors (g/km) by the CO_2 content of diesel (74.3 g CO_2/MJ).

The energy consumption and CO_2 emission factors for empty and (100%) full vehicles are reported in Table 39.

Table 39 **Energy consumption and CO_2 emission factors for road transport per road class and vehicle category, 2014 (range: empty to 100% full)**

	Vehicle category	Urban	Rural	Motorway
Energy consumption (MJ/km)	Small van < 2 t	2.7-2.9	1.6-1.7	2.3-2.5
	Large van > 2 t	3.7-4.1	2.3-2.5	3.4-3.7
	Truck < 10 t	5.6-6.4	3.8-4.3	3.4-3.8
	Truck 10-20 t	11.5-13.6	7.5-8.8	6.3-7.5
	Truck 10-20 t + trailer	13.8-18.7	8.9-12.0	7.5-10.2
	Truck > 20 t	16.5-20.2	10.7-13.1	8.7-10.7
	Truck > 20 t + trailer	17.8-25.9	11.3-16.4	9.4-13.7
	Tractor-semitrailer, light	16.0-21.1	10.3-13.6	8.3-11.0
	Tractor-semitrailer, heavy	19.5-30.4	12.1-18.9	8.5-13.2
	LHV	26.3-41.0	16.4-25.6	11.4-17.8
CO_2 (gram/km)	Small van < 2 t	197-213	117-126	171-185
	Large van > 2 t	276-302	170-186	250-275
	Truck < 10 t	419-472	281-316	253-286
	Truck 10-20 t	858-1,009	555-653	471-554
	Truck 10-20 t + trailer	1,023-1,387	658-892	559-757
	Truck > 20 t	1,223-1,501	791-971	649-796
	Truck > 20 t + trailer	1,321-1,922	838-1,220	700-1,019
	Tractor-semitrailer, light	1,189-1,565	768-1,011	619-814
	Tractor-semitrailer, heavy	1,447-2,258	901-1,407	628-981
	LHV	1,954-3,048	1,217-1,899	848-1,324

4.3.3 Emission data

Emission factors for PM_c (combustion particulates) and NO_x (nitrogen oxides) are based on data compiled by the Dutch Task Force on Transportation per Euro emission class and road class (Task Force on Transportation, 2016). The shares of the Euro classes per vehicle category were calculated on the basis of Task Force data and are reported in Table 72 in Annex A. It was assumed that road class distribution is the same for every Euro class.

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 indices reported in (Task Force on Transportation, 2016). In the case of tyre abrasion, allowance was made for the number of tyres per vehicle type. Around 5% of the particle matter from wear and tear of tyres and road surfaces consists of PM_{10}. For abrasion of brakes this is about 50%.

Emission 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, 2016).

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

$$EC_{full} / EC_{empty} = EF_{full} / EF_{empty} * \varepsilon$$

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 increase in air-pollutant emissions. It was assumed that the NO_x emission factor for Euro IV-VI is independent of the load carried, as is the PM_c emission factor for Euro VI. The factors are shown in Table 40.

Table 40 **Factor for relative change in air-pollutant emissions relative to energy consumption (ε)**

Euro emission class	NO_x	PM_c	PM_w	SO_2
Euro 0-III	0.75	0.5	1	1
Euro IV-V	0	0.5	1	1
Euro VI	0	0	1	1

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

On this basis a 1% increase in energy consumption also leads to a 1% increase in abrasion emissions, while particulate emissions due to combustion (PM_c) rise by 0.5% for Euro 0-V vehicles. For Euro-VI vehicles, particulate emissions due to combustion are independent of load (ε=0).

Emission factors for LHVs were modelled relative to the heavy tractor-semitrailer in the same way as in (CE Delft, 2011) (see Table 73, Annex A). The resultant emission factors are reported in Table 41. Road class-average emissions per tonne-kilometre in Chapter 3 were calculated using the road-class distribution in Table 74 (Annex A).

Table 41 **Emission factors for SO_2, PM_c, NO_x and PM_w (range: empty to 100% full) per road class and vehicle category, 2014**

Emission factor	Vehicle category	Urban	Rural	Motorway
SO_2 (mg/km)	Small van < 2 t	1.2-1.3	0.7-0.8	1.0-1.1
	Large van > 2 t	1.7-1.8	1.0-1.1	1.5-1.6
	Truck < 10 t	2.5-2.8	1.7-1.9	1.5-1.7
	Truck 10-20 t	5.1-6.0	3.3-3.9	2.8-3.3
	Truck 10-20 t + trailer	6.1-8.3	3.9-5.3	3.3-4.5
	Truck > 20 t	7.3-9.0	4.7-5.8	3.9-4.8
	Truck > 20 t + trailer	7.9-11.5	5.0-7.3	4.2-6.1
	Tractor-semitrailer, light	7.1-9.4	4.6-6.1	3.7-4.9
	Tractor-semitrailer, heavy	8.7-13.5	5.4-8.4	3.8-5.9
	LHV	11.7-18.3	7.3-11.4	5.1-7.9
PM_c (mg/km)	Small van < 2 t	84-88	45-47	45-47
	Large van > 2 t	53-55	29-30	37-39
	Truck < 10 t	49-52	30-32	25-26
	Truck 10-20 t	79-86	46-50	36-39
	Truck 10-20 t + trailer	92-108	57-67	47-55
	Truck > 20 t	96-107	57-64	45-50
	Truck > 20 t + trailer	113-139	68-83	54-66
	Tractor-semitrailer, light	37-42	23-27	19-22
	Tractor-semitrailer, heavy	84-107	52-66	37-47
	LHV	101-128	63-80	44-56
NO_x (g/km)	Small van < 2 t	0.8-0.9	0.6-0.6	0.8-0.8
	Large van > 2 t	1.5-1.5	1.0-1.0	1.3-1.4
	Truck < 10 t	4.7-4.8	3.0-3.1	2.5-2.6
	Truck 10-20 t	8.6-8.9	5.1-5.3	3.9-4.1
	Truck 10-20 t + trailer	8.6-9.5	4.7-5.3	4.0-4.5
	Truck > 20 t	11.3-11.9	6.5-6.9	5.0-5.4
	Truck > 20 t + trailer	10.6-12.0	5.7-6.5	4.8-5.5
	Tractor-semitrailer, light	10.2-10.7	6.1-6.4	4.7-5.0
	Tractor-semitrailer, heavy	9.2-9.9	4.7-5.1	3.3-3.6
	LHV	12.3-13.2	6.2-6.8	4.4-4.8

Emission factor	Vehicle category	Urban	Rural	Motorway
$PM_{slijtage}$ (mg/km)	Small van < 2 t	27-30	14-15	15-16
	Large van > 2 t	27-30	14-15	15-16
	Truck < 10 t	100-113	53-60	58-65
	Truck 10-20 t	103-121	55-65	61-72
	Truck 10-20 t + trailer	102-138	56-75	62-84
	Truck > 20 t	110-135	60-73	67-82
	Truck > 20 t + trailer	104-151	58-84	65-95
	Tractor-semitrailer, light	86-113	46-60	50-66
	Tractor-semitrailer, heavy	74-116	41-64	46-71
	LHV	108-168	59-93	66-104

4.4 Rail

4.4.1 Introduction

For rail, average emissions per kilometre were calculated from average energy consumption per km and emission factors per megajoule energy consumption, reported below in Sections 4.4.2 and 4.4.3, respectively.

The train categories adopted in this study are defined in Table 42, with a distinction made between transport of bulk/packaged cargo and containers. Besides the load capacity, the table also shows the Gross Tonne Weight (GTW) of the loaded train, a standard unit of train size. The GTW is the sum of the empty weight of the train and its load. For comparison: trains on the Dutch Betuwe route had an average GTW of 1,900 t (average of loaded and unloaded). On the border crossings at Eijsden (South Limburg) and Oldenzaal (Twente) the average GTW of the trains was 1,300 and 1,100 t, respectively. For the Netherlands as a whole, the average weight is around 1,570 t (ProRail, 2016); see Annex B.

Table 42 Train categories distinguished in STREAM

Name	Number of wagons *(length of average wagon, metres)*	Load capacity (tonne or TEU) *(GTW, loaded trip, tonnes)*		
Bulk and packaged goods				
		Light transport	Mid-weight transport	Heavy transport
Short trains	22 *(15 m)*	594 *(513)*	935 *(1,128)*	1,276 *(1,734)*
Med.-length trains	33 *(14.5 m)*	891 *(769)*	1.403 *(1,691)*	1,914 *(2,602)*
Long trains	44/46* *(14 m)*	1.188 *(1,025)*	1.870 *(2,255)*	1,668 *(3,627)*
Containers				
		Light transport	Mid-weight transport	Heavy transport
Short trains	15 *(14.0 m)*	45 *(505)*	45 *(635)*	45 *(748)*
Med.-length trains	23 *(16.9 m)*	70 *(786)*	70 *(988)*	70 *(1,163)*
Long trains	30 *(19.9 m)*	90 *(1,010)*	90 *(1,270)*	90 *(1,496)*

* The maximum number of wagons for international transport is maximized by a train length of 650 metres. Because of the slightly shorter wagons generally used for heavy goods, for heavy transport we have assumed 46 rather than 44 wagons.

4.4.2 Energy consumption

The energy consumption of trains was calculated in the same way as in *STREAM Freight 2011* (CE Delft, 2011) and is based on the methodology described in (IFEU, Infras, IVE, 2014), which has been verified with practical data.

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

$$EC\ (MJ_E/vkm) = 4.23 \times GTW^{0.38} \text{ - for GTW < 2,200 tonnes}$$
$$EC\ (MJ_E/vkm) = 0.035 \times GTW \text{ - for GTW > 2,200 tonnes}$$

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

$$EC\ (MJ_{diesel}/vkm) = 11.4 \times GTW^{0.38} \text{ - for GTW < 2,200 tonnes}$$
$$EC\ (MJ_{diesel}/vkm) = 0.095 \times GTW \text{ - for GTW > 2,200 tonnes}$$

In the formulae it has been assumed, based on (CE Delft, 2011), that the energy consumption per kilometre declined by 2% between 2009 (reference year in *STREAM 2011*) and 2014. Taking the GTW for empty and loaded trains, the formulae can be used to calculate energy consumption.

GTW calculation

To calculate energy consumption, for the various categories of train the gross tonnage of the loaded wagons (GTW) was calculated. For bulk/packaged cargo the weight of loaded (GTW_l) and empty (GTW_e) trains was determined based on the wagon specifications in Table 43 and the load factors in Chapter 5, according to:

$$GTW_l = NW \times (LF \times CapW) + NW \times WW$$
$$GTW_e = NW \times WW$$

where:

NW:	number of wagons (see Table 42).
LF:	load factor (see logistical data in Chapter 5).
CapW:	wagon load capacity (see Table 42).
WW:	wagon weight (Table 43 and Table 44).

For container transport it has been assumed that the train is never unloaded and GTW_l is calculated using the wagon specifications in
Table 44 from:

$$GTW_l = NW \times TEUcap \times TCU \times (LPT+WEC) + NW \times WW$$

where:

TEUcap:	TEU capacity per wagon (see Tabel 44).
TCU:	TEU capacity utilization (see Chapter 5).
LPT:	load per TEU: average of full and empty containers (tonne/TEU) (see Chapter 5).
WEC:	weight of empty container (see Chapter 5).

Table 43 Wagon specifications for bulk and packaged goods transport

	Light goods	Medium-weight goods	Heavy goods
Wagon weight (WW in tonnes)	12.5	17.3	22.0
Wagon load capacity (CapW in tonnes)	27	42.5	58
Wagon length (m)	15	14.5	14

Table 44 Wagon specifications for container transport

	Light goods	Medium-weight goods	Heavy goods
Wagon weight (WW in tonnes)	12.5	16.3	20.0
TEU/wagon (TEUcap)	2	2.5	3
Wagon length (m)	14.0	16.9	19.7

Calculation of energy consumption

Using the GTW indices for full and empty trains, the respective energy consumption figures were calculated, which were then weighted according to the share of loaded and unloaded kilometres indicated in Section 4.2. The resultant energy consumption figures are reported in Table 45 and Table 46.

Table 45 Energy consumption of trains carrying bulk and packaged goods (MJ/vkm)*

	Light goods	Medium-weight goods	Heavy goods
Electric train			
Short	43	53	60
Medium-length	51	62	74
Long	57	69	97
Diesel train			
Short	117	143	161
Medium-length	137	167	199
Long	153	186	262

* For electric MJ_e, for diesel MJ_{diesel}.

Table 46 Energy consumption of trains carrying containers (MJ/vkm)*

	Light containers	Medium-weight containers	Heavy containers
Electric train			
Short	45	49	52
Medium-length	53	58	62
Long	59	64	68
Diesel train			
Short	122	133	141
Medium-length	144	167	167
Long	159	173	184

* For electric MJ_e, for diesel MJ_{diesel}.

4.4.3 Emission data

Emission factors per kilometre for rail transport were calculated from energy consumption per kilometre using the emission factors per megajoule electricity or diesel in Table 47. The emission factors in (CE Delft, 2011) were updated using the cited sources.

Table 47 Emission factors per megajoule for trains

	Diesel (g/MJ_{diesel})	Electric (g/MJ_e)	Source
CO_2	71.47	-	Based on (Task Force on Transportation, 2014)
SO_2	0.0004	-	
PM_c	0.027	-	2014 factors calculated by linear interpolation of emission factors for 2009 and 2020 in (CE Delft, 2011)
NO_x	0.978	-	
PM_w	0.0235	0.065	(CE Delft, 2014)
CH_4	0.0050	-	Based on (Task Force on Transportation, 2014)
N_2O	0.0006	-	

4.5 Inland shipping

4.5.1 Introduction

For inland shipping, average emissions per kilometre were calculated from average energy consumption per kilometre and an emission factor per kilowatt-hour engine energy consumption, as reported in Sections 4.5.2 and Section 4.5.3, respectively.

The inland waterway vessels distinguished in this study are defined in Table 48.

Table 48 Inland waterway vessel categories distinguished in STREAM

	Vessel category	AVV class	Load capacity (t)
Bulk and packaged cargo			
Spits	Motorized	M1	365
Campine vessel	Motorized	M2	617
Rhine-Herne canal (RHC) vessel	Motorized	M6	1,537
Large Rhine vessel	Motorized	M8	3,013
Class Va + 1 Europe II barge, wide	Coupled	C3b	5,046
4-barge push convoy	Push convoy	BII-4	11,181
6-barge push convoy (long)	Push convoy	BII-6l	16,444
Container ships			
Neo Kemp (32-48 TEU)*	Motorized	M3	850
Rhine-Herne canal (RHC) vessel (96 TEU)	Motorized	M6	1,537
Europe IIa push convoy (160 TEU)	Push convoy	BIIa	2,708
Large Rhine vessel (208 TEU)	Motorized	M8	3,013
Extended large Rhine vessel (272 TEU)	Motorized	M9	3,736
Coupled: Europe-II C3l (348 TEU)	Coupled	C3l	4,518
Rhinemax vessel (398-470 TEU)*	Motorized	M12	6,082

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

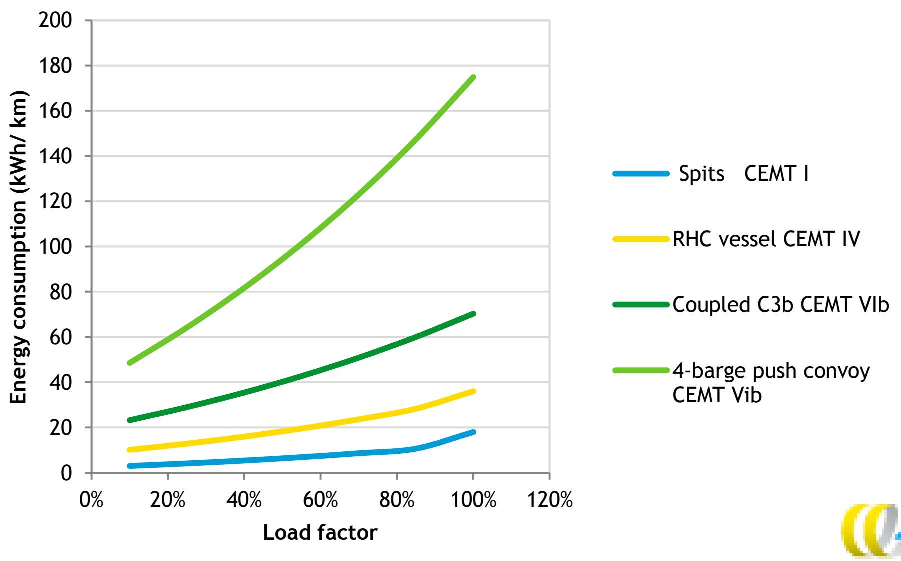
4.5.2 Energy consumption

Method

For inland shipping, emission factors per vessel-kilometre were calculated from energy consumption per kilometre, using emission factors per kilowatt-hour (see Section 4.5.3). Energy consumption per kilometre was modelled using the model used by the Dutch Pollutant Release and Transfer Register (referred to further as the "Dutch Emissions Register"). For a description of the model the reader is referred to (AVV, 2003).

The model estimates energy consumption using 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 9 for a combination of several types of vessel and waterway (CEMT class).

Figure 9 **Influence of load factor on energy consumption of inland waterway vessels**



The vessel parameters used for modelling the categories of ship distinguished in this study are reported in Annex C. Sailing speeds were differentiated according to waterway class and load status (loaded vs. empty) and were taken from (Rijkswaterstaat, 2013).

Using the model, energy consumption can thus be calculated for the various types of vessel on classes of waterways, distinguishing between energy consumption on full and empty trips. For rivers an additional distinction is made between energy consumption on trips up- and downstream.

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

$$\boldsymbol{EC_{av} = \%km_{loaded} \times EC_{full} + (1 - \%km_{loaded}) \times EC_{empty}}$$

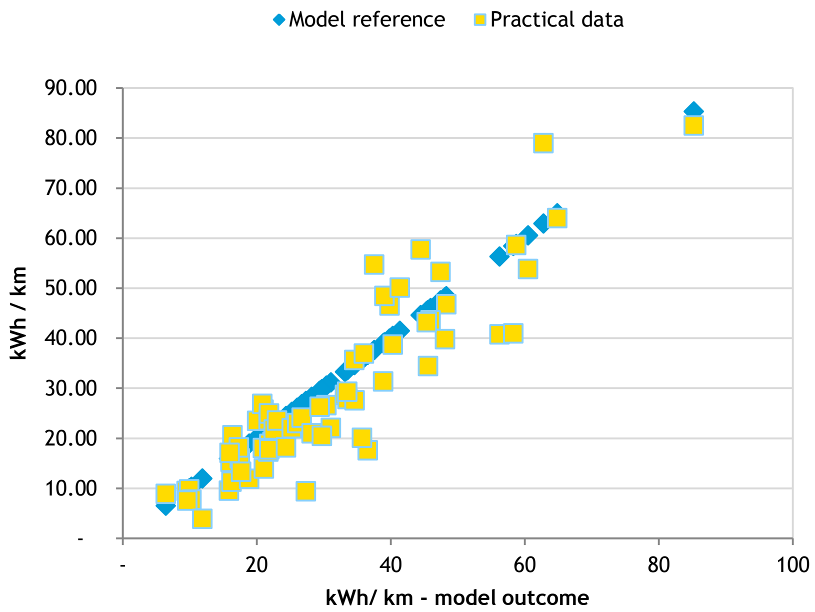
The share of loaded kilometres for inland shipping used in the calculation is reported in Chapter 5. For rivers, the relative share of loaded versus empty kilometres was additionally broken down into upstream and downstream, thereby assuming that loaded kilometres are evenly divided between 50% upstream and 50% downstream.

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

Verification

The modelling results were validated using practical data on 100 inland waterway vessels compiled by BLN Schuttevaer. In Figure 10 these annual average real-world data are plotted against the modelled data for the same vessels (for further description, see Annex D). As can be seen from this figure, the model predicts energy consumption fairly accurately on average. At the same time, in individual cases consumption may deviate substantially.

Figure 10 Inland shipping energy consumption: real-world data versus model 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 49 and for container transport in Table 50.

Table 49 Motor power consumption (kWh/km) and engine diesel consumption (MJ/km), bulk/packaged goods

Vessel category (designated class)	Waterway class	Motor power consumption (kWh/km)			Engine diesel consumption (MJ/km)*		
		Light	Med.-weight	Heavy	Light	Med.-weight	Heavy
Spits (M1)	CEMT-I	7	10	12	68	93	111
	CEMT-Va	7	9	10	68	86	93
	CEMT-VIb	6	8	8	59	74	78
	Waal	7	8	9	61	76	81
Campine vessel (M2)	CEMT-II	11	15	17	102	140	159
	CEMT-Va	13	16	17	116	148	160
	CEMT-VIb	12	14	15	107	132	139
	Waal	12	15	16	114	140	147
Rhine-Herne canal (RHC) vessel (M6)	CEMT-IV	19	25	28	180	236	264
	CEMT-Va	28	37	40	264	341	375
	CEMT-VIb	29	36	38	272	332	351
	Waal	29	35	37	267	323	344
Large Rhine vessel (M8)	CEMT-Va	27	35	42	254	329	388
	CEMT-VIb	36	44	48	335	407	447
	Waal	32	37	41	295	347	378
Class Va + 1 Europe II barge, wide (C3b)	CEMT-VIb	39	51	60	366	471	554
	Waal	54	66	73	504	617	676
4-barge push convoy (BII-4)	CEMT-VIb	84	113	128	783	1,053	1,187
	Waal	101	130	144	941	1,203	1,339
6-barge push convoy (long) (BII-6l)	CEMT-VIb	88	116	132	817	1,075	1,224
	Waal	103	129	138	960	1,195	1,282

* Diesel consumption calculated using a specific fuel consumption of 204 g diesel/kWh (see 4.5.3) and a figure of 42.7 MJ/kg for the energy density of diesel (100% fossil).

Table 50 Motor power consumption (kWh/km) and engine diesel consumption (MJ/km), container transport

Vessel category (TEU capacity) (designated class)	Waterway class	Motor power consumption (kWh/km)			Engine diesel consumption (MJ/km)*		
		Light	Med.-weight	Heavy	Light	Med.-weight	Heavy
Neo Kemp (32-48 TEU) (M3)	CEMT-III	8	9	11	73	85	98
	CEMT-Va	12	14	16	113	130	146
	CEMT-VIb	14	16	18	132	149	165
	Waal	13	15	16	123	138	152
Rhine-Herne canal (RHC) vessel (96 TEU) (M6)	CEMT-IV	14	17	20	127	158	189
	CEMT-Va	21	26	31	199	244	289
	CEMT-VIb	25	29	33	229	270	307
	Waal	24	28	32	227	262	294
Europe IIa push convoy (160 TEU) (BII-1)	CEMT-Va	31	41	50	287	377	468
	CEMT-VIb	37	47	56	346	433	516
	Waal	36	44	52	335	411	481
Large Rhine vessel (208 TEU) (M8)	CEMT-Va	22	28	33	206	257	310
	CEMT-VIb	32	38	43	298	352	403
	Waal	29	33	37	269	307	342
Extended large Rhine vessel (272 TEU) (M9)	CEMT-Va	30	37	46	274	348	426
	CEMT-VIb	38	46	52	356	422	486
	Waal	31	35	39	285	326	364
Coupled: Europe II-C3l (348 TEU) (C3l)	CEMT-Va	34	44	54	311	404	504
	CEMT-VIb	37	45	53	347	419	488
	Waal	34	40	45	319	372	420
Rhinemax vessel (398-470 TEU) (M12)	CEMT-VIb	63	78	94	584	725	868
	Waal	66	77	88	610	716	814

* Diesel consumption calculated using a specific fuel consumption of 204 g diesel/kWh (see 4.5.3) and a figure of 42.7 MJ/kg for the energy density of diesel (100% fossil).

4.5.3 Emission data

Emission factors for CO_2 and SO_2 depend directly on engine diesel consumption. Emissions of the greenhouse gases N_2O and CH_4 are likewise linearly related to diesel consumption, for which Task Force data were taken (Task Force on Transportation, 2016). Based on a specific fuel consumption of 204 gram diesel per kilowatt-hour for inland-waterway vessels (based on (Rijkswaterstaat, 2013) and (Emissieregistratie, 2012)), emission factors per megajoule were converted to emission factors per kilowatt-hour (Table 51).

Table 51 Emission factors for CO_2, N_2O, CH_4 and SO_2 per kilowatt-hour

Emission factor	g/kWh	Source
CO_2	622	204 g diesel/kWh x 3.034 g CO_2/kg diesel
N_2O	0.0052	204 g diesel/kWh x 0.025 g N_2O/kg diesel (Task Force on Transportation, 2016)
CH_4	0.044	204 g diesel/kWh x 0.21 g N_2O/kg diesel (Task Force on Transportation, 2016)
SO_2	0.0041	204 g diesel/kWh x 0.02 g N_2O/kg diesel (10 ppm S)

The NO_x and PM_c emission factors for inland shipping depend on vessel construction year and the emission standards in force in that year. As of 2003 NO_x and PM_c emissions became regulated under standards set by the Central Commission for Navigation of the Rhine (CCNR, 2000) and (CCNR, 2001)) and later by EU Directive 2004/26 (PbEU L225/3). Based on these regulations, a distinction can be made between engines prior to 2003 (CCNR0), engines dating from 2003-2006 (CCNR1) and engines dating from 2007 or later (CCNR2). The average emission factors for the three CCNR classes are given in Table 52. The values are based on the construction-year-indexed emission factors reported in the EMS protocol in the Dutch Emissions Register for inland shipping (Emissieregistratie, 2012) and the results of a recent study by (CE Delft, 2015).

Table 52 Emission factors for NO_x and PM_c per construction-year class (CCNR class) and share of class per vessel category

	PM_c (g/kWh)[a]	NO_x (g/kWh)[a]	M1 [b]	M2 [b]	M3 [b]	M6 [b]	M8, C3l, C3b, BII-1 [b]	M9, M12, BII-4, BII-6l [b]
CCNR0 (cnst. year < 2003)	0.4	10.4	96%	91%	83%	79%	58%	2%
CCNR1 (cnst. year 2003-2006)	0.25	9.2	2%	4%	6%	7%	12%	20%
CCNR2 (cnst. year > 2007)	0.15	6	2%	5%	11%	14%	30%	78%

[a] Based on (Emissieregistratie, 2012) and (CE Delft, 2015).

[b] Based on (TNO, 2015c).

Besides the emission factors per CCNR class, (Table 52) also gives a percentage breakdown per vessel category. These shares are based on the age distribution per type of motor vessel reported in (TNO, 2015c). The percentage shares per CCNR class per vessel category and the emission factors per CCNR class were used to calculate emission factors (in g/kWh) for NO_x and PM_c, as reported in Table 53.

Table 53 Emission factors for NO_x and PM_c per vessel category

	M1	M2	M3	M6	M8, C3l, C3b, BII-1	M9, M12, BII-4, BII-6l
NO_x (g/kWh)	10.3	10.1	9.8	9.7	8.9	6.7
PM_c (g/kWh)	0.39	0.38	0.36	0.35	0.31	0.17

4.6 Maritime shipping (short-sea)

4.6.1 Introduction

For maritime (short-sea) shipping, emissions per tonne-km are based on emissions per vessel-kilometre and average load factor. The principal sources used in the calculations are the third IMO GHG study (IMO, 2014) and Task Force data (Task Force on Transportation, 2016).

For all vessel categories and all size classes the third IMO GHG study (IMO, 2014) provides data on:
– average vessel size (load capacity or deadweight, DWT);
– average design speed and average sailing speed;
– average installed capacity and average effective output of the main engine.

The reference data on the vessel categories used in short sea-shipping are shown in Table 54. The vessel parameters (load capacity, engine capacity, sailing speed) are representative for 2012. On the assumption that there has been little, if any, change in these parameters between 2012 and 2014, these were used for the calculations.

Table 54 Characteristics (IMO, 2014) of maritime vessel categories distinguished in STREAM

Maritime vessels (Short-sea)	Size class	Average dwt (tonne)	Average engine capacity (kW)	Average engine load (%MCR)	Average sailing speed (km/h)
Oil tanker	0-4,999 dwt	1,985	1,274	67%	16.2
Oil tanker	5,000-9,999 dwt	6,777	2,846	49%	17.0
Oil tanker	10,000-19,999 dwt	15,129	4,631	49%	17.9
Oil tanker	20,000 -59,999 dwt	43,763	8,625	55%	21.8
Oil tanker	60,000 -79,999 dwt	72,901	12,102	57%	22.6
Oil tanker	80,000 -119,999 dwt	109,259	13,813	51%	21.6
General Cargo	0-4,999 dwt	1,925	1,119	53%	16.3
General Cargo	5,000-9,999 dwt	7,339	3,320	51%	18.8
General Cargo	10,000 + dwt	22,472	7,418	53%	22.3
Bulk carrier (feeder)	0-9,999 dwt	3,341	1,640	70%	17.5
Bulk carrier (Handysize)	10,000-34,999 dwt	27,669	6,563	59%	21.2
Bulk carrier (Handymax)	35,000-59,999 dwt	52,222	9,022	58%	21.9
Container (feeder)	0-999 TEU	8,634	5,978	52%	23.0
Container (Handysize-like)	1,000-1,999 TEU	20,436	12,578	45%	25.9
Container (Handymax-like)	2,000-2,999 TEU	36,735	22,253	39%	27.9
Container (Panama-like)	3,000-4,999 TEU	54,160	36,549	36%	29.9
Container (Aframax-like)	5,000-7,999 TEU	75,036	54,838	32%	30.2
Container (Suezmax-like)	8,000-11,999 TEU	108,650	67,676	32%	30.2

Since publication of *STREAM Freight 2011* the IMO study has been updated. This means there are a number of changes relative to the previous STREAM study (see also Section 1.4). In particular, there are changes in average sailing speed (and consequently in average engine load), average engine capacity and also average vessel size within the designated vessel classes. Generally speaking, vessels now sail far slower on average (by 15-20%), but engine capacities have increased slightly. The average engine load has decreased.

4.6.2 Energy consumption

The calculations of energy consumption per kilometre are based on data on the average fleet compiled by IMO (IMO, 2014). The same methodology as in *STREAM Freight 2011*has largely been adopted, but in the present study a distinction has been made between ballast trips (no load) and loaded trips.[15] First the average energy consumption for both types of trip was calculated, from which specific figures for ballast trips and loaded trips were then derived.

The average energy consumption of vessels was calculated from the following parameters :

- installed capacity of the main engine (P, in kW);
- average effective output of the main engine (El, in %MCR);
- average fuel consumption of the main engine in the given vessel class (Fc, expressed in g/kWh);
- average sailing speed (V_{av}, in km/h);
- calorific value of MGO (CV, 42.7 MJ/kg).

These parameters were inserted into the following formula to determine the average energy consumption per kilometre of the various vessel categories:

$$\boldsymbol{Energy\ consumption\left(\frac{MJ}{km}\right)=\frac{P\cdot El\cdot Fc\cdot CV}{V_{av}}}$$

Ships consume less energy on ballast trips than when loaded. In (UCL, 2013) figures for vessel fuel consumption are reported based on AIS data, with an indication of whether vessels were on ballast or loaded trips. These data were used to estimate the difference in energy consumption between ballast and loaded trips; the results are shown in Table 55. These parameters and the share of loaded trips per vessel category were used to calculate the fuel consumption for ballast and loaded trips. These results are given in Table 56.

Table 55 Dependence of energy consumption on load for various vessel categories

Vessel category	Difference in energy consumption (ballast vs. loaded)
Oil tanker	-35%
General Cargo	-50%
Bulk carrier	-20%
Container ship	-20%

Source: Calculation by CE Delft based on (UCL, 2013).

15 Ships carrying little or no load use ballast water to stabilize the vessel.

The fuel consumption of the boilers and auxiliary engines was estimated by applying correction factors to main-engine fuel consumption based on IMO (2014). The correction factor represents the average annual ratio between the fuel consumption of the main engine and that of the auxiliary engines and boilers, under the assumption that the fuel consumption of the auxiliary engines and boilers is independent of the ship's load. Table 56 shows the energy consumption per vessel-kilometre for all vessel categories and the calculated correction factors.

Table 56 Range of energy consumption per vessel-kilometre, ballast to loaded trips (MJ/km)

Vessel category	Energy consumption of main engines, ballast to loaded (MJ/km)	Correction factor for auxiliary engines	Correction factor for boilers	Total energy consumption, ballast to loaded (MJ/km)
Oil tanker 0-5 dwkt	305-470	100%	22%	1,288-1,452
Oil tanker 5-10 dwkt	497-765	91%	20%	1,957-2,225
Oil tanker 10-20 dwkt	796-1,225	97%	21%	3,124-3,552
Oil tanker 20-60 dwkt	1,471-2,264	54%	12%	4,373-5,165
Oil tanker 60-80 dwkt	2,050-3,155	33%	5%	5,426-6,530
Oil tanker 80-120 dwkt	2,201-3,387	43%	9%	6,172-7,358
General Cargo 0-5 dwkt	169-338	28%	0%	558-727
General Cargo 5-10 dwkt	471-943	29%	0%	1,452-1,923
General Cargo 10-20 dwkt	912-1,825	35%	0%	2,806-3,718
Bulk carrier (feeder)	469-587	54%	0%	1,317-1,435
Bulk carrier (Handysize)	1,289-1,612	17%	0%	2,998-3,321
Bulk carrier (Handymax)	1,699-2,123	17%	0%	3,940-4,365
Container (feeder) < 999 TEU	935-1,169	31%	0%	2,350-2,584
Container (Handysize-like) 1-1.999 TEU	1,521-1,901	41%	0%	3,985-4,365
Container (Handymax-like) 2-2.999 TEU	2,094-2,618	39%	0%	5,378-5,902
Container (Panamax-like) 3-4.999 TEU	2,976-3,720	28%	0%	7,250-7,994
Container (Aframax-like) 5-7.999 TEU	3,715-4,644	21%	0%	8,765-9,693
Container (Suezmax-like) 8-11.999 TEU	4,595-5,743	18%	0%	10,675-11,824

4.6.3 Emission data

The emission factors for CO_2, SO_2, PM and NO_x depend directly on the amount of fuel consumed by the ship's engines. Emission of the greenhouse gases N_2O en CH_4 are likewise linearly dependent on fuel consumption and were set on the basis of Task Force data (Task Force on Transportation, 2016). In our calculations, emission factors have thus been related one-on-one to the ship's energy consumption, using the energy density of the fuel (42.7 MJ/kg).

An important development for sulphur emissions is the tightening of the SECA standards on the North Sea and the Baltic Sea. As of 2007 the North Sea and Baltic Sea have been designated a Sulphur Emissions Control Area (SECA). Since January 1st, 2015 the sulphur limit has been substantially tightened to a maximum of 0.1%. This means that the gasoil burned may have a sulphur content of no more than 0.1% (unless other technologies are used, such as LNG-powered vessels or those fitted with a scrubber). Because this legislation reduces sulphur dioxide emissions by around 90%, we have opted to calculate emission factors on the basis of these new figures. Also for particulates this means a reduction of about 80-90%.

The SO_2 emission factors are directly related to the sulphur content of the fuel burned. Ships have been assumed to sail on MGO (0.1% S), giving an SO_2 emission factor of 2 g/kg.

PM emission factors are related to the sulphur content of the fuel used. Given the SECA standards now in force, PM emission factors were calculated using data from (FMI, 2016) on MGO.

The NO_x emissions of these vessels depend on engine type (main engine, auxiliary engine and boilers) and respective rpm and Tier category to which the engines belong. Engines manufactured prior to 2000 are Tier 0, from 2000 to 2010 are Tier I and post-2010 are Tier II. On January 1st 2016 so-called NECAs (NO_x Emission Control Areas) were introduced in North American waters, where ships must satisfy Tier III (see also Section 4.8.4). The NO_x emission factors are based on (Task Force on Transportation, 2016). As a rule, ships use slow-speed engines for propulsion, while the auxiliary engines operate at a higher speed. For our calculations we have therefore used slow-speed-engine (SS) factors for the main engines and medium/ high-speed-engine (MS/HS) factors for the auxiliary engines.

The emission factors in gram/kg are given in Table 57. Owing to tighter emission standards (Tier I and Tier II; see Table 58) combined with fleet renewal, NO_x emissions (g/kg) are now 11-24% lower than in *STREAM 2011*.

Table 57 Emission factors used for ship's engines (g/kg diesel)

Engine type	CO_2	NO_x[16]	PM	SO_2	N_2O	CH_4
Main engine (ME, slow-speed)	3,173	73	1.5	2	0.085	0.299
Auxiliary engines (AE, medium-/high-speed)	3,173	52.6	1.5	2	0.085	0.299
Boiler (in tankers)	3,173	3.5	1.5	2	0.085	0.299

Table 58 NO_x Emission factors for various Tier levels per engine type (g/kg diesel)

Engine type	Tier 0	Tier I	Tier II
Main engine (ME, slow-speed)	90	71.4	60
Aux. engines (AE, medium-/high-speed)	60	49	39
Boiler (in tankers)		3.5	

Source: Tier I and Tier II based on Task Force average.

4.7 Upstream emissions

4.7.1 Fuel production

Upstream emissions, i.e. well-to-tank emissions, were calculated by multiplying WTT emission factors per MJ by energy consumption per kilometre. The WTT CO_2 emission factors per megajoule are reported in Table 59.

Based on a recent study (JRC, 2014b) the WTT emissions of diesel have been revised upwards. In that study it was found that the CO_2 emissions associated with oil recovery are substantially higher than previously assumed.

16 Average calculated using average distribution of energy consumption for all vessels.

Table 59 also shows the WTT emission factors for alternative fuels, for use in the analysis in Section 4.8. For biofuels and hydrogen a range is given, because the CO_2 emissions are highly dependent on production route (JRC, 2014b).

Most of the WTT CO_2 data derive from (JRC, 2014b), with the average for biodiesel and biogas based on the mix of production routes reported in (NEA, 2015). Based on (TNO & CE Delft, 2014) allowance has also been made for ILUC impacts in the biodiesel routes. Because the share of waste-derived biodiesel has increased considerably due to new legislation, the ILUC impacts of biodiesel in the Netherlands are very limited.

The emission factors for air-pollutant emissions are given in Table 60 and are based largely on (Ecoinvent, 2010).

Table 59 Well-to-tank CO_2 emission factors for fuels

Fuel type	CO_2 (g/MJ_{fuel})	Source
Diesel, total* (3.8% biodiesel)	24	(JRC, 2014b)
Diesel oil, fossil	21	(JRC, 2014b)
Biodiesel**	Range: 8.1-116 Average: 21	(JRC, 2014a); (EC, 2015); (NEA, 2015)
Marine gas oil (MGO)	20	Estimate based on (TNO & CE Delft, 2014); (JRC, 2014b) and (Ecoinvent, 2010)
CNG	13	(JRC, 2014a)
LNG	18.8	(JRC, 2014a)
Bio-CNG/Bio LNG	Range: -69.9-40.8 Average:15.4	(JRC, 2014a); (NEA, 2015)
GTL	23.4	(JRC, 2014a)
Hydrogen	4.2-494 Average 105	(JRC, 2014a); (TNO & CE Delft, 2014)

* Admixture percentage based on energy content (MJ). Besides the upstream emissions from JRC 2014, ILUC impacts have also been factored in (see following note).

** Based on (EC, 2015)) an correction factor for ILUC impacts was factored in.

Table 60 Well-to-tank air-pollutant emission factors for fuels

Fuel type	NO_x (g/MJ)	PM_c (g/MJ)	SO_2 (g/MJ)
Diesel, total* (3.8% biodiesel)	0.033	0.004	0.10
Diesel oil, fossil	0.032	0.003	0.074
Biodiesel**	0.050	0.008	0.063
Marine gas oil (MGO)	0.032	0.003	0.10
CNG	0.01	0.0001	0.0003
LNG	0.03	0.0011	0.0004
Bio-CNG/Bio LNG	0.02	0.0011	0.01
GTL	0.036	0.004	0.11
Hydrogen	0.134	0.02	0.13

Source: (Ecoinvent, 2010); for GTL: (CE Delft, TNO, ECN, 2013).

* Admixture percentage based on energy content (MJ).

4.7.2 Electricity generation

While electric transport modes have no direct emissions, they do give rise to emissions during electric power generation and during fuel extraction and transport.

For the emissions occurring during power generation the indices in (CE Delft, 2014) have been updated using the electricity mix reported in (CE Delft, 2014). Calculations proceed from the average mix of electricity produced in the Netherlands, including power generated from renewable sources. Renewable electricity is thus considered part and parcel of the average Dutch mix and is therefore not included as a separate item (see also Text Box 1).

Text Box 1. Two approaches for electricity

The emission factors calculated in this study are based on the mix of electricity *produced* in the Netherlands, supplemented by the imports required when demand exceeds supply. An alternative approach is to proceed from the Dutch *trade* mix. In that case the electricity 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 electricity 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 chosen 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 power subsidized under the Dutch SDE renewable energy incentive scheme.

The CO_2 emissions occurring during actual power production are based on energy-labelling data (CE Delft, 2014). The air-pollutant emissions and CO_2 emissions arising in the upstream chain are based on (Ecoinvent, 2010), taking the electricity mix and production efficiency figures from (CE Delft, 2014) as our point of departure. The NO_x, PM_c and SO_2 emissions from (Ecoinvent, 2010) have been adapted (lowered) based on the data supplied to the EU by Dutch generators in the framework of Directive 2001/80/EC over the year 2012 (EEA, 2015). The resultant emission factors for electricity are given in Table 61.

Table 61 Power generation emissions, 2013

	CO_2	NO_x	PM_c	SO_2
g/kWh_e	490	0.46	0.022	0.27
g/MJ_e	136	0.13	0.006	0.07

4.8 Alternative fuels and technologies

For each transport mode, this section provides a description of the indices for a range of alternative technologies and fuels. In each case the indices in Chapter 3 are reported relative to a recent standard. Besides the indices for these alternatives, indices for the fleet-average for 2014 are also given. This allows the average emission factors for 2014 from Chapter 3 to be translated to a specific technology or fuel.

This is done by means of the following formula:

$$EF_{tkm-\ alternative} = \frac{index_{alternative}}{index_{2014\ average}} \times EF_{tkm-2014\ average}$$

where EF_{tkm} stands for the emission factor per tonne-kilometre.

Below, we present and briefly discuss the TTW indices for each transport mode. The WTT indices are based on the figures in Section 4.7.

4.8.1 Road transport

In the case of road transport, the options for alternative fuels and technologies depend on the vehicle category concerned. In Chapter 3 the alternatives are reported for large vans (>2 t GVW), medium-size trucks (10-20 t GVW) and heavy tractor-semitrailers. In setting emission factors for alternative technologies, use was made of (TNO & CE Delft, 2014) and (CE Delft, TNO, ECN, 2013). In these reports a Euro 5/V diesel vehicle is taken as the reference and this approach has been adopted here.

We consider the following fuels and technologies:

- Diesel Euro 5/V and Euro 6/VI (diesel vehicles subject to EU emission standards from 2008 and 2013, respectively).
- Diesel hybrids and plug-in hybrids (both satisfying the Euro 6/VI emission standard).
- GTL (Gas-To-Liquid, a high-quality synthetic diesel oil made from natural gas; data are available up to and including Euro 5/V).
- Biodiesel (esterified diesel oil produced from vegetable oils and fats; data available up to and including Euro 5/V).
- CNG and LNG (compressed and liquefied natural gas; vehicles satisfy the Euro 6/VI emission standard).
- Electric and hydrogen (data only indicative, as the technologies are still at an early stage, particularly for heavy road vehicles).

For the various alternative fuels and technology options, the energy consumption relative to Euro 5/V vehicles is reported in Table 62 (where relevant for the vehicle in question). The assumptions and sources for the energy-consumption and emissions data are shown in Table 63.

Table 62 **Energy consumption for alternative fuels and technologies, road transport (indexed to diesel = 100)**

Fuel/Technology	LGV	HGV	Tractor-trailer
Diesel, Euro 5/V	100	100	100
Diesel, Euro 6/VI*	100	100	100
Diesel, hybrid Euro VI	-	90	-
Diesel, plug-in hybrid, Euro 6	88**	-	-
GTL Euro 5/V	100	96	96
Biodiesel, Euro 5/V (B30)	-	100	100
Biodiesel, Euro 5/V (B100)	100	100	100
CNG, Euro 6/VI	110	110	-
Bio-CNG, Euro 6/VI	110	110	-
LNG, Euro 6/VI	-	110	110
Bio-LNG, Euro 6/VI	-	110	110
Electric	52	56	-
Hydrogen	67	72	81

Source: *Natural Gas in Transport* (CE Delft, TNO, ECN, 2013).

* While engines are generally becoming steadily more efficient, this does not correlate directly with Euro emissions class.

** Based on 25% electric.

Table 63 **Assumptions and sources for energy consumption and air-pollutant emissions of alternative road-transport technologies**

Fuel/Technology	Assumptions on energy consumption	Assumptions on air-pollutant emissions
Diesel Euro 6/VI	Consumption same as Euro 5/V. Newer engines are generally slightly more efficient, but this does not correlate directly with Euro class.	Based on data from (Task Force on Transportation, 2016).
Diesel hybrid	Consumption based on (CE Delft, TNO, ECN, 2013).	Air-pollutant emission standards same as for non-hybrid vehicles; emissions therefore the same.
Plug-in hybrid	Vans based on (TNO & CE Delft, 2014), assumed 25% electric.	If the hybrid vehicle is running 100% electric, local emissions are zero.
GTL	Consumption slightly lower than for diesel, based on (CE Delft, TNO, ECN, 2013).	GTL generally has substantially lower air-pollutant emissions. For each emissions class from Euro III to Euro V, GTL gives the following emission reduction relative to standard diesel: NO_x: approx. 10 to 20% reduction, PM_c: approx. 20% reduction (TNO & CE Delft, 2014). For Euro VI the impact is as yet unclear, as there are no direct monitoring results available.
Biodiesel	For biodiesel, bio-CNG and bio-LNG, consumption taken the same as for conventional technology. Zero TTW CO_2 emissions.	With FAME NO_x emissions are generally a little higher, with B100 sometimes a lot higher (B30: +10%, B100: +25%), while with HVO and BTL they are lower (by up to 10%). Particulate emissions are lower for all biodiesels: for B30 by 20%, for B100 by 60%. All data based on FAME (TNO & CE Delft, 2014).

Fuel/Technology	Assumptions on energy consumption	Assumptions on air-pollutant emissions
CNG[17] and LNG	CNG vehicle consumption is around 10% higher than for a diesel vehicle. In combination with the lower CO_2 emissions per MJ calorific value (-25%), the technology has a well-to-wheel CO_2 benefit of 13% (CE Delft, TNO, ECN, 2013) (TNO, 2015d).	Natural gas fuels have lower air-pollutant emissions, but since introduction of Euro VI these no longer differ from those of diesel (TNO & CE Delft, 2014). For trucks and tractor-semitrailers it has therefore been assumed that NO_x and PM emissions are the same as for diesel Euro VI. For vans a significant reduction has been assumed relative to diesel, based on (CE Delft, TNO, ECN, 2013).
Electric/ Hydrogen	Consumption for these vehicles based on (TNO & CE Delft, 2014). Electric vans calculated relative to trucks and tractor-semitrailers.	Electric and hydrogen trucks and tractor-semitrailers have zero local air-pollutant emissions.

It is on this basis that the emission factors indices reported in Section 3.6 for vans, trucks and tractor-semitrailers have been calculated. The emission factors for the reference (diesel Euro 5) are given in g/km, those for the alternative fuels relative to Euro 5/V.

4.8.2 Rail

For rail transport, two alternatives were already distinguished in Chapter 3: electric and diesel. The emission factors for electric trains given there are based on the average electricity production mix in the Netherlands. In opting for this mix, no allowance has been made for any purchase of green electricity.[18] However, if it can be assumed that the electric power derives solely from wind turbines, the emissions associated with electric trains can be taken as zero (see Table 32). It is only abrasion emissions that then remain.

Besides alternative power generation, there is also scope for improving energy efficiency. One way of doing so is to increase the voltage on the overhead wires from 1.5 kilovolts (as on the existing grid, apart from the Betuwe route) to 3 kilovolts. Research shows that this can lead to savings of around 20% on energy consumption and thus 20% on WTT emissions (Arcadis, 2013).

Since 2007/2009 locomotive diesel engines must satisfy the Stage IIIa and since 2012 the Stage IIIb standard laid down in the Non-Road Mobile Machinery (NRMM) Directive (97/68/EC). Because many engines currently in use date from before 2012, fleet-average emissions are higher than for Stage IIIa. For diesel trains, Table 33 indicates how the Stage IIIB standard and the future Stage V perform compared with Stage IIIa. It has here been assumed that real-world emissions will be close to the emission standard.

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[17] Engine type: stoichiometric, spark-ignition. There are various kinds of engine available for burning natural gas. Because of the strict methane limits, lean-burn and dual-fuel gas engines using current Euro V technology do not satisfy Euro VI standards, for which purpose a stoichiometric gas engine is required.

[18] There is debate on the extent to which purchase of green electricity justifies using emission factors for such electricity; on this debate, see (CE Delft, 2014) and Textbox 1 (Section 4.7.2)

4.8.3 Inland shipping

For inland-waterway vessels there are a range of alternative fuels and technologies available for application in the current fleet. Since 2007 engines must satisfy the CCNR2 emission limits or the equivalent Phase IIIA limits of the Non-Road Mobile Machinery Directive (97/68/EC). For vessels with high annual fuel consumption, LNG is an interesting alternative. As LNG is cheaper, investment in an LNG engine can soon be recuperated. There are various options available:

- LNG, single-fuel SI: spark-ignition (SI) engines burning only LNG;
- LNG, pilot 2%D: dedicated dual-fuel engines that can burn either diesel or LNG, with a small amount of diesel ('pilot injection') required for ignition;
- 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 without further engine adaptation.

The following add-on technologies are often used:

- SCR (selective catalytic reduction) to reduce NO_x emissions;
- DPF (diesel particle filters) to reduce particulate emissions.

Table 34 provides a synopsis of the indices for the above fuels and technologies compared with CCNR2 engines. The top row of this table gives an absolute value for the emissions per kilowatt-hour engine capacity[19] of a vessel satisfying CCNR2. The data are based on (VIA Donau, 2015) and (CE Delft, 2015a). Besides alternative technologies, fleet-average values are also reported for four categories of vessel.

4.8.4 Maritime shipping (short-sea)

For short-sea shipping the following alternative fuels and technologies have been considered:

- Tier II and III: NO_x emission standards set by the IMO. Vessels built after 2011 must have an engine satisfying the Tier II standard. No date has yet been set for implementing the Tier III standard in European waters. There is currently a proposal for introducing NECAs (NO_x Emission Control Areas) in the North Sea and Baltic Sea in 2021, where new ship's engines must already meet this standard. In North American coastal waters such NECAs are already in force.
- HFO (2.7% sulphur content) with a scrubber, an add-on technology for removing sulphur from exhausts, allowing the vessel to continue using heavy fuel oil.
- LNG (gas engine, Otto cycle). LNG can be burned in three types of engine: gas engines (Otto-cycle, lean-burn, spark-ignition), dual-fuel engines (Otto-cycle) and gas-diesel engines (diesel-cycle). The third IMO GHG study assumes that the majority of LNG engines used in 2007-2012 were of the first type. In our analysis we have done the same.

The assumptions made for the energy consumption and emissions of the alternative fuels and technologies are shown in Table 64.

[19] This is the parameter used for air-pollutant emission standards.

Table 64 **Assumptions and sources for energy consumption and air-pollutant emissions for alternative fuels and technologies for maritime (short-sea) shipping**

Fuel/Technology	Assumptions on energy consumption	Assumptions on air-pollutant emissions
Tier II & III	Consumption taken equal to average. The specific fuel-oil consumption (SFOC, in grams fuel per kWh engine capacity) for MGO is 185 g/kWh (IMO, 2014).	Tier II (emission standard as of 2011) means approx. 20% lower NO_x emissions compared with the average (Task Force on Transportation, 2016). Tier III (emission standard as of 2016) means approx. 75% lower emissions than Tier II, based on the difference in the limits (Dieselnet, 2016). The Tier standard does not affect other air-pollutant emissions.
HFO + Scrubber	+2% due to energy used by pumps and caustic soda consumption (CE Delft, 2015a). The SFOC for HFO is 195 g/kWh (IMO, 2014).	Over 95% reduction of sulphur emissions, 60-90% reduction of PM emissions and up to 10% reduction of NO_x emissions (CE Delft, 2015b) relative to HFO with 2.7% sulphur. Emissions for HFO (g/kg) are from (DNV-GL, 2015). This means the PM emissions are higher than for MGO.
LNG	Higher primary energy consumption, based on (CE Delft, TNO, ECN, 2013). The SFOC for LNG is 166 g/kWh (IMO, 2014).	Average engine capacity (kW) and average engine load (%MCR) assumed the same as for LNG, which means 0.9 kg LNG is required for every kg MGO diesel. The emission factors in g/kg LNG are from (IMO, 2014). LNG leads to lower SO_X and PM emissions and significantly lower NO_X emissions. Methane emissions are far higher than with MGO. Given the lower CO_2 emissions of LNG compared with MGO, the CO_2 reduction should be around 25%, but due to methane slip the CO_2 reduction may be cancelled out, as methane is a strong greenhouse gas. (CE Delft, TNO, ECN, 2013) provides an extensive review of measured methane slip emissions. It can be concluded that the amount of methane slip is as yet uncertain and varies from vessel to vessel, with maximum values occurring in older ships. Based on the cited study, 0.53 g/MJ methane slip has been assumed.

These assumptions hold for the various categories of coastal-shipping vessels considered in this report and lead to the emission factors reported in Table 65, cited in g emission/kg fuel.

Table 65 **Emission factors for maritime (short-sea) vessels, diesel (g/kg fuel) and alternative technologies**

Fuel/Technology	CO_2	NO_x[20]	PM	SO_2	N_2O	CH_4
MGO (average Tier level, 2014)	3,206	68	1.5	2	0.085	0.299
HFO	3,114	68	6.7	54	0.085	0.299
HFO + scrubber	3,114	61	0.7-2.7	0,1-2	0.085	0.299
LNG*	2,750	8	0.18	0,02	0.110	26
Diesel MGO, Tier II	3,206	55	0.53	2	0.085	0.299
Diesel MGO, Tier III	3,206	14	0.53	2	0.085	0.299

* Vessels running on LNG burn approx. 0.9 kg LNG for one kg MGO diesel.

20 Average calculated based on average engine fuel consumption.

For proper comparison between the various fuels/technologies, emissions have been calculated per kWh engine capacity. To this end the following specific fuel consumption figures were taken: 185 g/kWh (MGO), 195 g/kWh (HFO) and 166 g/kWh (LNG). For short-sea vessels this leads to the emission factors per kWh shown in Table 35 (for average load, average transport).

4.9 Transhipment

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

Data on energy consumption during transhipment have been taken from (IFEU, Infras, IVE, 2014) and are the same figures as in (CE Delft, 2011), as follows:
- container transfer: 4.4 kWh/ TEU (15.8 MJ_e/TEU);
- transfer of liquid load: 0.4 kWh/tonne (1.4 MJ_e/t);
- transfer of bulk load: 1.3 kWh/tonne (4.7 MJ_e/t);
- transfer of other loads: 0.6 kWh/tonne (2.2 MJ_e/t).

Emission factors for transhipment involving use of electrically powered cranes and other equipment can be calculated by applying the emission factors for electricity to the above consumption figures per tonne. For diesel-powered cranes and other equipment the emission factors for CCNR2 engines reported under inland shipping can be used (Table 52).

5 Logistical data

5.1 Introduction

As indicated in Chapter 4, vehicle/vessel load capacity and capacity utilization go a long way to determining emissions per tonne-kilometre. Capacity utilization is defined as the load factor on loaded kilometres multiplied by the percentage share of loaded vehicle-/vessel-kilometres.

Although a vehicle's load factor has only limited influence on emissions per vehicle-kilometre, the load defines transport performance in tonne-kilometre terms. While the fuel consumption of a truck increases by around 20% if the load rises from half-full (50%) to full, tonne-kilometres are doubled. As a result, emissions per tonne-kilometre decrease by 40%. In principle, the same applies to all modes of transport. For empty kilometres it holds that these leave transport performance in terms of tonne-kilometres unchanged, but do contribute to emissions, thus adding to overall emissions per tonne-kilometre.

In this study we have opted to express transport performance in tonne-kilometres. In principle, a different measure could have bene adopted, such as volume-km (m^3- km), package-km or pallet-km. The unit of tonne-kilometres can be used in a broad range of contexts, however, and is widely recognized by numerous parties.

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 loaded to full volume with feathers will always have a lower load factor than a vehicle half-full of coal. In the case of inland shipping, the water level and waterway depth also play a significant role in determining the extent to which a vessel can be loaded to maximum capacity. If water levels are low, effective capacity is sometimes lower than maximum capacity at high levels (the capacity reported here). With container ships on waterways with low bridges, high water may in contrast mean that containers can be stacked less high.

The load factors reported in this study are therefore not intended to make any pronouncement on transport efficiency, but are designed purely for calculating the emission factors per tonne-kilometre for the various transport 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 utilized. For some types of transport (such as coal transport) it is simply unfeasible to make the return trip loaded. Generally speaking, freight with a high load factor (such as coal) is associated with fewer loaded kilometres, freight with a low load factor often with more.

The logistical data used for transport of bulk and packaged goods are given In Section 5.2, those for container transport in Section 5.3. The tonnage used for container transport refers 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 has been factored in. In calculations on container transport for all transport modes we have worked with an average container load (tonne/TEU) and an average share of empty containers. In reality there are differences between the various modes, but for comparison on equal footing average values for all transport modes have been used.

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

The parameters from these statistics are not always complete for all the types of transport distinguished and have therefore been supplemented using estimates of our own. The logistical parameters adopted were then put to branch organizations and carriers in a consultation round. Based on their response and the data subsequently obtained the parameters were then finalized, as reported in this chapter, below.

5.2 Bulk and packaged cargo

Table 66 Logistical parameters for light, mid-weight and heavy loads, all vehicle categories

Vehicle/vessel category	Load capacity tonne	Light			Mid-weight			Heavy		
		Load factor	Loaded km	Capacity utilization	Load factor	Loaded km	Capacity utilization	Load factor	Loaded km	Capacity utilization
Road										
Small van < 2 tonne	0.7	30%	60%	18%	35%	60%	21%	n.a.	n.a.	n.a.
Large van > 2 tonne	1.2	30%	60%	18%	35%	60%	21%	n.a.	n.a.	n.a.
Truck < 10 tonne	3	28%	75%	21%	48%	65%	31%	n.a.	n.a.	n.a.
Truck 10-20 tonne	7.5	30%	85%	26%	52%	75%	39%	64%	65%	42%
Truck 10-20 tonne + trailer	18	30%	85%	26%	52%	75%	39%	64%	65%	42%
Truck > 20 tonne	13	30%	85%	26%	52%	75%	39%	64%	65%	42%
Truck > 20 tonne + trailer	28	30%	85%	26%	52%	75%	39%	64%	65%	42%
Tractor-semitrailer, light	15.7	30%	75%	23%	52%	65%	34%	64%	55%	35%
Tractor-semitrailer, heavy	29.2	37%	80%	30%	65%	70%	46%	80%	60%	48%
LHV	40.8	37%	80%	30%	65%	70%	46%	80%	60%	48%
Rail										
Short train (1,128 Gtonne)	594/935/1.276	40%	80%	32%	80%	60%	48%	98%	55%	54%
Medium-length train (1,691 Gtonne)	891/1,403/1,914	40%	80%	32%	80%	60%	48%	98%	55%	54%
Long train (2,255 Gtonne)	1,188/1,870/2,668	40%	80%	32%	80%	60%	48%	98%	55%	54%
Inland shipping										
Spits	365	45%	75%	34%	75%	70%	53%	90%	60%	54%
Campine vessel	617	45%	75%	34%	75%	70%	53%	90%	60%	54%
Rhine-Herne canal (RHC) vessel	1,537	45%	75%	34%	75%	70%	53%	90%	60%	54%
Large Rhine vessel	3,013	40%	87%	35%	65%	85%	55%	80%	70%	56%
Coupled: Europe II-C3b	5,046	40%	87%	35%	65%	85%	55%	80%	70%	56%
4-barge push convoy	11,181	40%	87%	35%	65%	85%	55%	80%	70%	56%
6-barge push convoy	16,444	40%	87%	35%	65%	85%	55%	80%	70%	56%
Short-sea										
Oil tanker, 0-5 dwkt	1,985	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	89%	75%	67%
Oil tanker, 5-10 dwkt	6,777	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	85%	75%	64%
Oil tanker, 10-20 dwkt	15,129	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	82%	75%	62%
Oil tanker, 20-60 dwkt	43,763	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	80%	43%	34%
Oil tanker, 60-80 dwkt	72,901	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	78%	45%	35%
Oil tanker, 80-120 dwkt	109,259	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	79%	44%	34%

Vehicle/vessel category	Load capacity tonne	Light			Mid-weight			Heavy		
		Load factor	Loaded km	Capacity utilization	Load factor	Loaded km	Capacity utilization	Load factor	Loaded km	Capacity utilization
General Cargo, 0-5 dwkt	1,925	n.c.	n.c.	30%	n.c.	n.c.	67%	92%	75%	69%
General Cargo, 5-10 dwkt	7,339	n.c.	n.c.	30%	n.c.	n.c.	59%	89%	69%	61%
General Cargo, 10-20 dwkt	22,472	n.c.	n.c.	30%	n.c.	n.c.	52%	86%	63%	54%
Bulk carrier (feeder)	3,341	n.a.	n.a.	n.a.	n.c.	n.c.	65%	90%	75%	67%
Bulk carrier (Handysize)	27,669	n.a.	n.a.	n.a.	n.c.	n.c.	52%	92%	59%	54%
Bulk carrier (Handymax)	52,222	n.a.	n.a.	n.a.	n.c.	n.c.	48%	88%	57%	50%

n.a.: Not applicable: vehicle/vessel not used for this type of goods.

n.c.: Not calculated: only capacity utilization estimated for this vehicle or vessel.

5.3 Container transport

Table 67 **Load capacity and average container slot utilization per vehicle category**

Vehicle/vessel type	Load capacity in TEU	Average container slot utilization[21]
Road		
Heavy truck > 20 ton	1	70%
Heavy truck + trailer > 20 ton	2	70%
Tractor-semitrailer	2	70%
LHV	3	70%
Rail		
Short train (22 wagons)	45	80%
Medium-length train (33 wagons)	70	80%
Long train (44 wagons)	90	80%
Inland shipping		
Neo Kemp (32-48 TEU)	40	75%
Rhine-Herne canal vessel	96	75%
Push convoy	160	75%
Rhine container vessel	208	75%
Extended Large Rhine vessel	272	75%
Coupled: Europe II-C3l	348	75%
Rhinemax vessel (398-470 TEU)	434	75%
Short-sea		
Container (feeder) 0-999 TEU	635	81%
Container (Handysize-like) 1.000-1.999 TEU	1,500	78%
Container (Handymax-like) 2.000-2.999 TEU	2,750	66%
Container (Panamax-like) 3.000-4.999 TEU	4,060	64%
Container (Aframax-like) 5.000-7.999 TEU	5,600	63%
Container (Suezmax-like) 8.000-11.999 TEU	8,170	61%
Container 12.000-14.500 TEU	13,350	57%

Table 68 **Load factors, loaded kilometres and capacity utilization rates for light, medium-weight and heavy container loads, all vehicle categories**

Container transport	Light transport	Medium-weight transport	Heavy transport
Share of loaded containers	72%	72%	72%
Share of empty containers	28%	28%	28%
Tonnage/loaded TEU*	6 t/TEU[22]	10.5 t/TEU	14.5 t/TEU
Weight of empty container/TEU*	1.90 t/TEU	1.95 t/TEU	2.00 t/TEU

* Based on (IFEU, Infras, IVE, 2014).

[21] Including return transport and empty containers.

[22] TEU: Twenty-feet Equivalent Unit (standard size unit for containers).

6 Comparison of modes

6.1 Introduction

To illustrate how calculations can be carried out using the emission factors presented in this report, in this chapter we consider a number of practical cases for 2014, as was done in previous STREAM reports. The cases Rotterdam-Duisburg and Amsterdam-Regensburg are similar to the cases in (CE Delft, 2011), while the case Rotterdam-Lithuania is new and also includes multimodal transport.

When calculating the emissions associated with any particular transport the following aspects are pertinent:
- distance travelled;
- upstream and downstream transport;
- logistical data;
- transhipment.

In each of the cases, total emissions have been calculated per tonne of freight for the corridor in question.

6.2 Case 1: Rotterdam-Duisburg

This first case evaluates transport of a medium-weight container from Rotterdam to Duisburg, a case involving little upstream or downstream transport. The impact on emissions per tonne of further transport to Essen and Dortmund has been included in the comparison. The distances for the various modes are summarized in Table 69. The results for CO_2, SO_2, PM_c and NO_x are shown in Figure 11 to Figure 14.

Table 69 Distances, Rotterdam-Duisburg case

	Rotterdam-Duisburg		Rotterdam-Essen		Rotterdam-Dortmund	
	Distance (km)	Downstr. transport, tract.-semitr. (km)	Distance (km)	Distance downstr. transport, tract.-semitr.	Distance (km)	Downstr. transport, tract.-semitr. (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 11 CO_2 emissions per tonne for medium-weight container transport, Rotterdam-Duisburg case

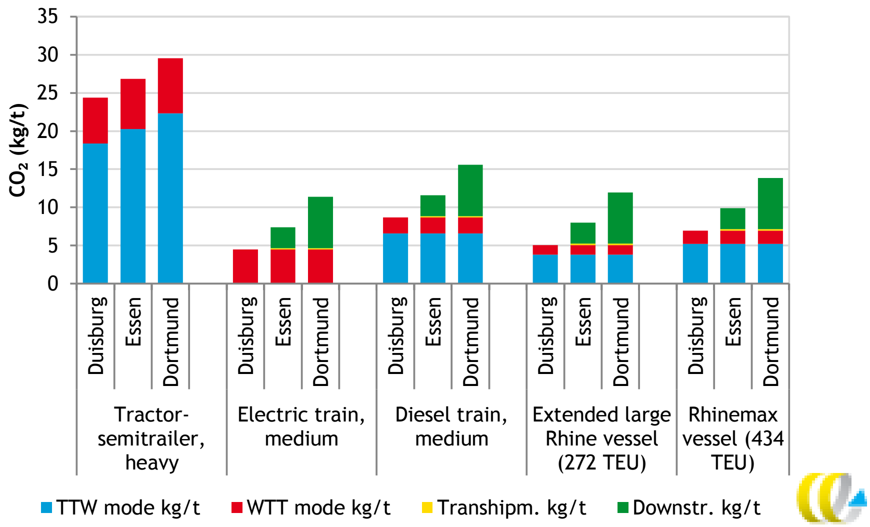


Figure 12 SO_2 emissions per tonne for medium-weight container transport, Rotterdam-Duisburg case

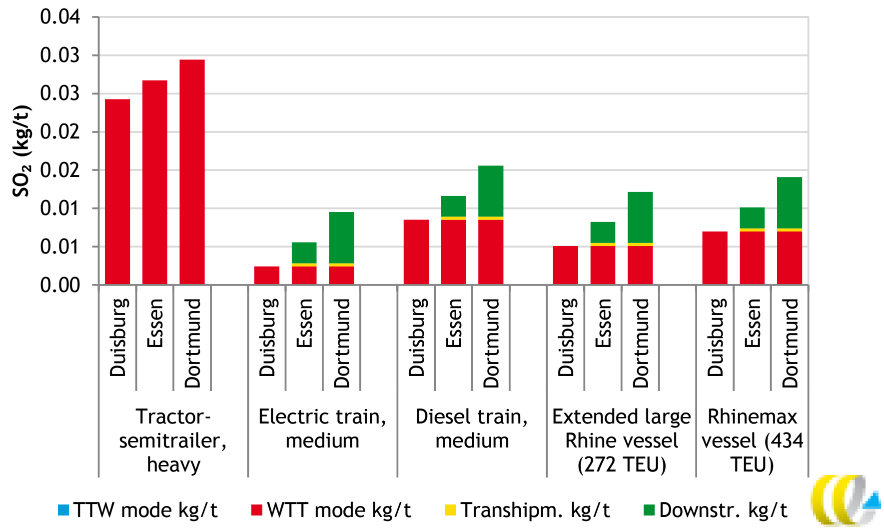


Figure 13 PM_c emissions per tonne for medium-weight container transport, Rotterdam-Duisburg case

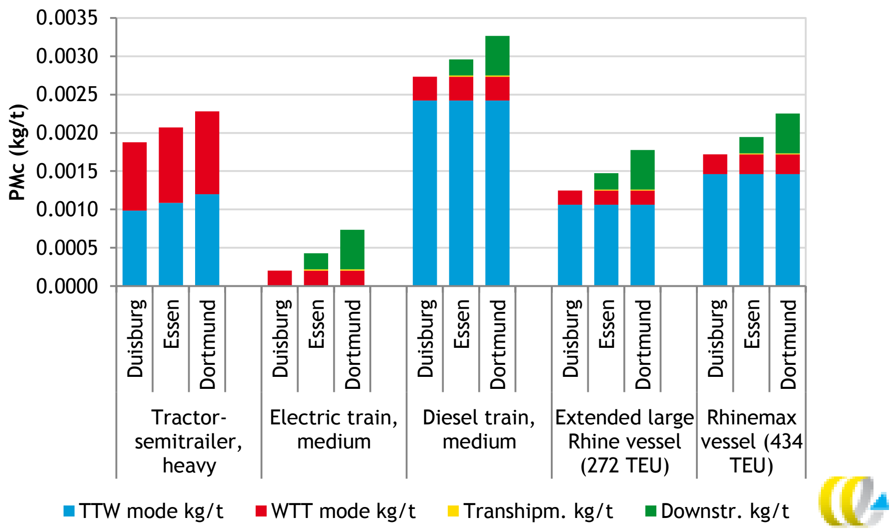
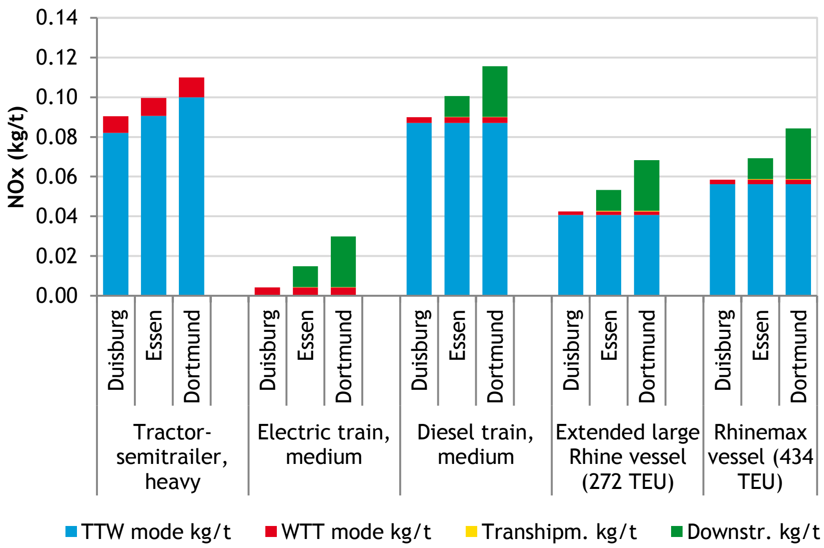


Figure 14 NO_x emissions per tonne for medium-weight container transport, Rotterdam-Duisburg case



6.3 Case 2: Amsterdam-Regensburg (steel)

The second case is transport of steel from Amsterdam to Regensburg.
The impact of downstream transport on emissions per ton has been taken on board by including the alternative destination of Munich. The distances for the various modes are summarized in Table 70. The results for CO_2, SO_2, PM_c and NO_x are shown in Figure 15 to Figure 18.

Table 70 Distances, Amsterdam-Regensburg case

	Amsterdam-Regensburg		Amsterdam-Munich	
	Distance (km)	Downstr. transport, tract.-semitr. (km)	Distance (km)	Downstr. transport, tract.-semitr. (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 15 CO_2 emissions per tonne for heavy bulk transport, Amsterdam-Regensburg case

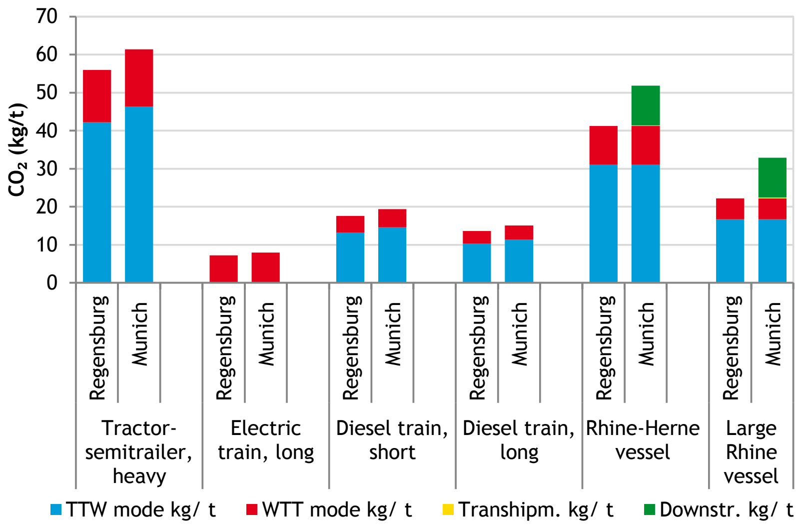


Figure 16 SO_2 emissions per tonne for heavy bulk transport, Amsterdam-Regensburg case

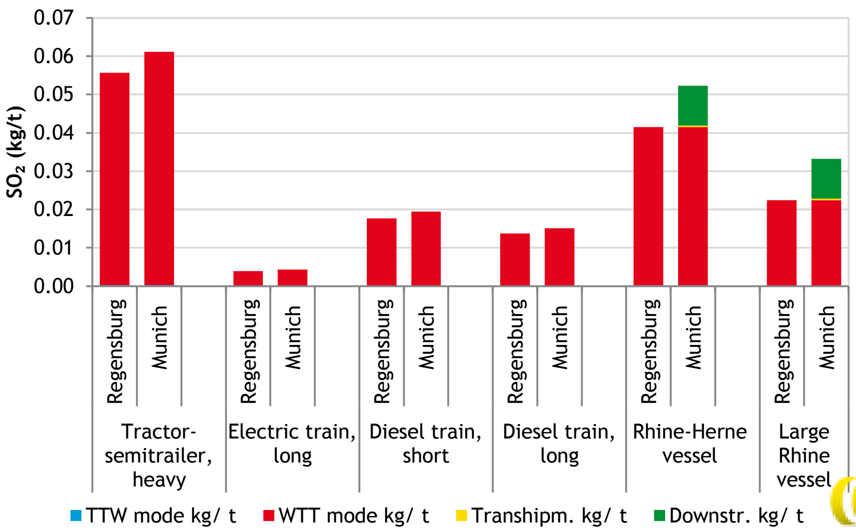


Figure 17 PM_c emissions per tonne for heavy bulk transport, Amsterdam-Regensburg case

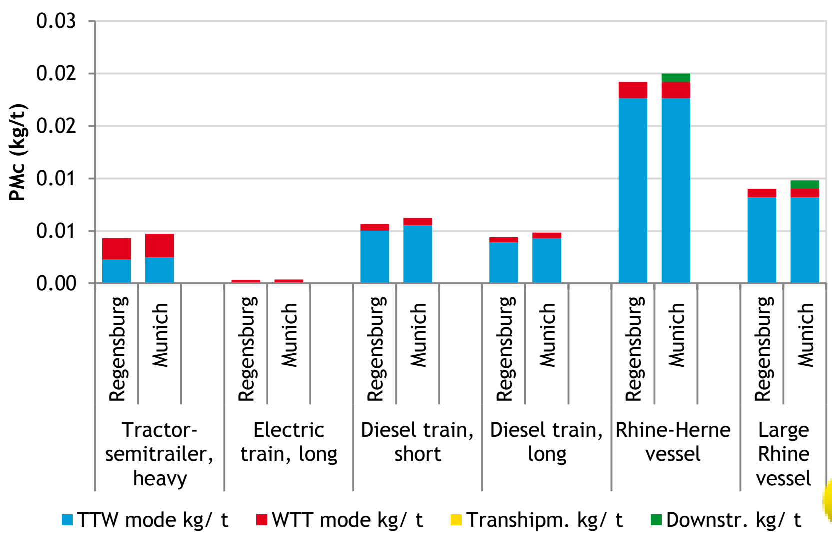
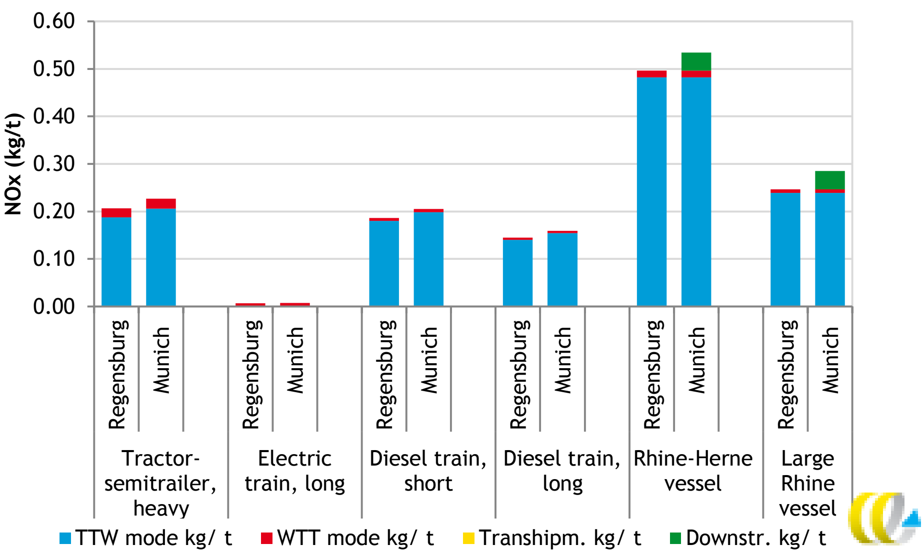


Figure 18 NO_x emissions per tonne for heavy bulk transport, Amsterdam-Regensburg case



6.4 Case 3: Rotterdam-Lithuania

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

This case not only illustrates differences between transport modes, but a multimodal option is also considered: transport from Rotterdam to Kiel by either road or rail, followed by a sea transport from Kiel to Klaipeda. For legibility, the difference between TTW and WTT has been omitted. The distances for the various options are summarized in Table 71. The results for CO_2, SO_2, PM_c and NO_x are shown in Figure 19 to Figure 22.

Table 71 Distances, Rotterdam-Lithuania case

	Rotterdam-Klaipeda			Rotterdam-Sestokai		
	Road distance	Rail distance	Sea distance	Road distance	Rail distance	Sea distance
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 19 CO_2 emissions per tonne for medium-weight container transport, Rotterdam-Lithuania case

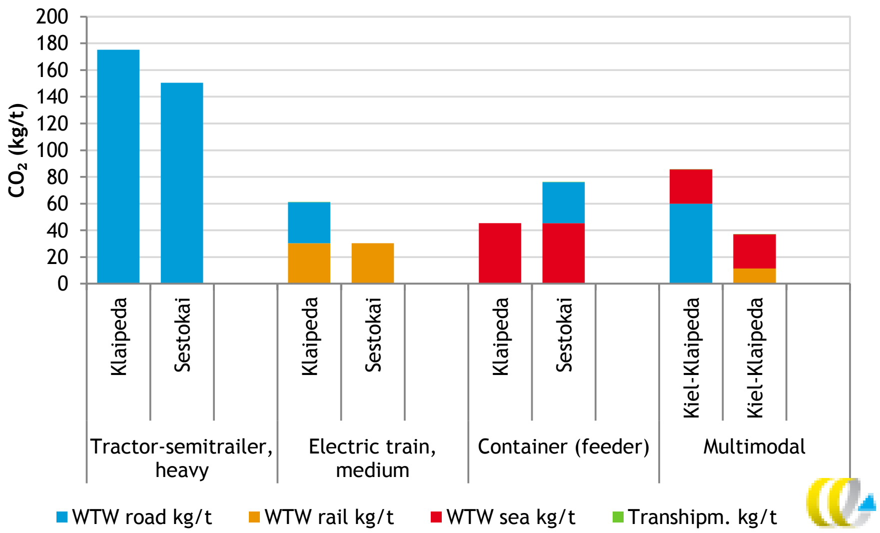


Figure 20 SO_2 emissions per tonne for medium-weight container transport, Rotterdam-Lithuania case

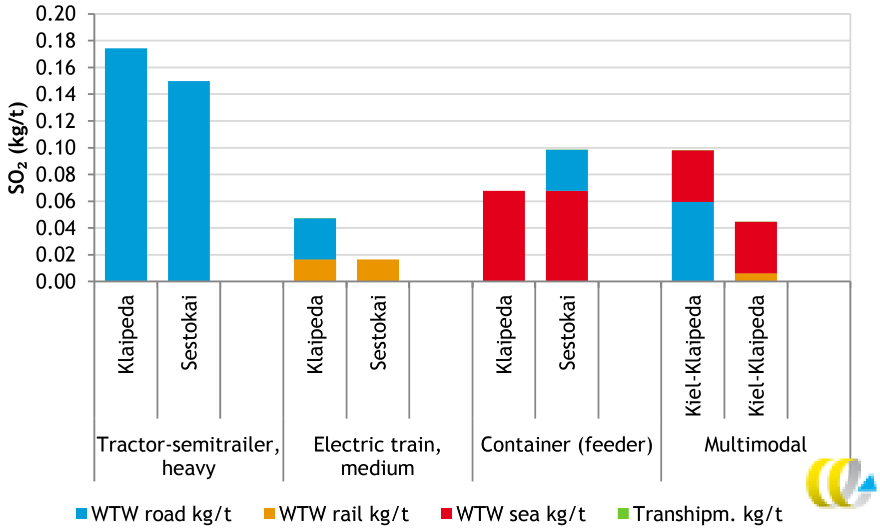


Figure 21 PM_c emissions per tonne for medium-weight container transport, Rotterdam-Lithuania case

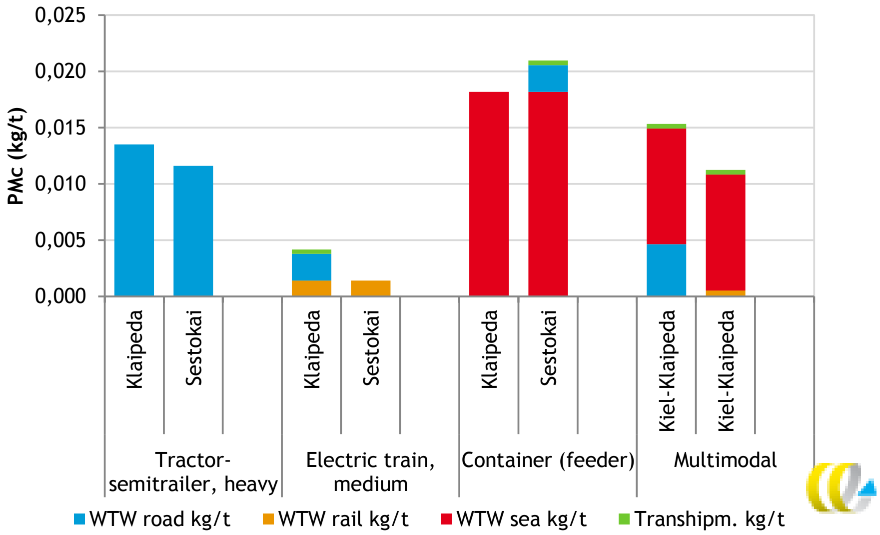
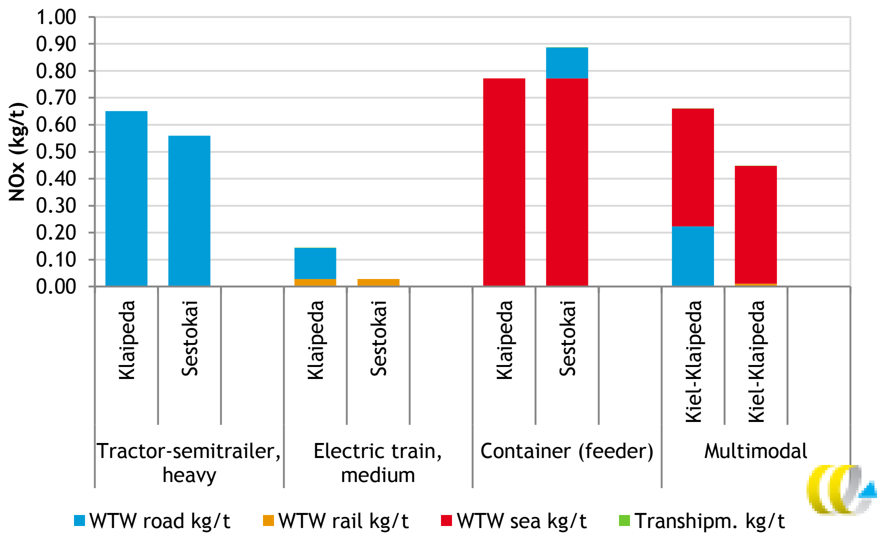


Figure 22 NO_x emissions per tonne for medium-weight container transport, Rotterdam-Lithuania case



6.5 Conclusion

The cases calculated using the 2014 data show that the comparative performance of the various transport modes (in kg/ t) depends not only on emission factors per tonne-kilometre but also, substantially, on the distances involved and the amount of upstream and downstream transport. In all the cases considered the CO_2 emissions associated with road transport are highest, but the Amsterdam-Munich case shows that if the distance accounted for by inland shipping is high and there is also downstream transport, the CO_2 emissions of inland shipping 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. The SO_2 emissions consequently exhibit the same pattern across transport modes as the 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 case, the highest emissions alternate between tractor-semitrailer, diesel train, inland-waterway or short-sea, depending on vehicle/vessel size, the distance and the amount of up- and downstream transport. In all cases electric rail scores lowest.

7 Comparison of results with *STREAM Freight 2011*

In the introduction a number of differences in methodology between the present and previous STREAM study were discussed. In this chapter we describe the main differences in results.

Compared with 2009,the reference year of *STREAM 2011*, the emission factors for road-transport particulates have decreased by 50-70%, thanks above all to uptake of Euro VI vehicles in the Dutch fleet in 2014. For heavier vehicles in particular, NO_x emission factors are now lower, by approximately 20-40%. The less marked decline compared with particulates derives in part from new insights into the real-world NO_x emissions of trucks. The CO_2 emission factors remain approximately the same, but some are higher or lower than in 2009 owing to adjustments to vehicle definitions.

In the case of rail, the emissions of electric trains are now slightly different because calculations for 2009 were based on the European electricity mix and those in the present study on the Dutch electricity mix. As a result, CO_2 emissions are now slightly higher, while NO_x and PM_{10} emissions are lower. Thanks to the uptake of newer trains, the NO_x and PM emissions of diesel trains have decreased a little since 2011. The SO_2 emissions of diesel trains are now very substantially lower (by 98-99%) as a result of mandatory use of diesel with a sulphur content below 10 ppm since 2011.

Compared with the previous study, the CO_2, NO_x and PM emissions of inland shipping have declined on average by 10-30%. This is due above all to slower sailing speeds, in turn due partly to new insights and partly to real-world changes. The change has been verified using practical energy consumption data. For inland waterway vessels, too, SO_2 emissions have declined very substantially (by 98-99%), thanks to mandatory use of diesel with a sulphur content below 10 ppm since 2011.

In short-sea shipping, too, sailing speeds have decreased since the previous study, leading to a slight decrease in fuel consumption and CO_2 emissions. As our calculations proceed from the SECA (Sulphur Emission Control area) in force on the North Sea and Baltic Sea as of 1st January, 2015, SO_2 and PM emissions are 80-90% lower. As a result of fleet renewal, NO_x emissions have declined by 5-30% since 2009.

Based on recent insights, the CO_2 emissions associated with diesel fuel production have been adjusted upwards substantially. While in 2011 a figure of 12 gram CO_2/MJ was assumed, a figure of almost 21 g/MJ is now deemed more accurate. This increase is based on recent insight gained from authoritative studies on the topic.

8 Recommendations for further study

- *STREAM Freight 2016* provides a comprehensive review of average transport emission factors based on the Dutch vehicle and vessel fleets as of 2014. It would be interesting to project into the future to 2020, 2025 and 2030, for instance, based on anticipated renewal of the respective fleets.

- The emission factors for the Dutch situation can be supplemented with factors for the EU as a whole, making due allowance for differences in fleet composition and other physical aspects (mountains, road types). Such emission factors would permit even better analysis of European corridors.

- The present study distinguishes three categories of freight: light, medium-weight and heavy. This could be further refined, by distinguishing more specific types of goods (using the NST2007 classification, for example) for which logistical data are available.

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Annex A Background data, road transport

Table 72 Distribution of Euro emission classes per vehicle category

Euro Class	Small van < 2 t	Large van > 2 t	Truck < 10 t	Truck 10-20 t	Truck > 20 t	Tractor-semitrailer
Euro 0	4%	2%	3%	2%	2%	1%
Euro 1/I	4%	2%	2%	2%	1%	1%
Euro 2/II	12%	6%	7%	7%	7%	4%
Euro 3/III	22%	10%	14%	14%	14%	8%
Euro 4/IV	35%	42%	11%	11%	11%	11%
Euro 5/V	21%	36%	55%	56%	57%	62%
Euro 6/VI	2%	3%	8%	8%	8%	14%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Calculations based on (Task Force on Transportation, 2016).

Table 73 Ratio between g/km emission factors of LHVs and tractor-semitrailers

Emission	Ratio, emission factors for LHVs and tractor-semitrailers (g/km-LHV / g/km tr.-semitr.)	Source
CO_2/SO_2	1.35	TML, 2008/McKinnon, 2008
NO_x	1.33	TML, 2008/McKinnon, 2008
$PM_{2.5}$	1.21	TML/McKinnon
PM_{10} (wear and tear)	See report	Own calculation, depending on number of tyres, using Task Force 2016 method

Table 74 Distribution of road classes per vehicle category

<table>
<tr><th>Vehicle category</th><th>Urban</th><th>Rural</th><th>Motorway</th></tr>
<tr><td>Small van < 2 t</td><td rowspan="2">16%</td><td rowspan="2">32%</td><td rowspan="2">52%</td></tr>
<tr><td>Large van > 2 t</td></tr>
<tr><td>Truck < 10 t</td><td>29%</td><td>33%</td><td>38%</td></tr>
<tr><td>Truck 10-20 t</td><td rowspan="2">19%</td><td rowspan="2">23%</td><td rowspan="2">58%</td></tr>
<tr><td>Truck 10-20 t + trailer</td></tr>
<tr><td>Truck > 20 t</td><td rowspan="2">14%</td><td rowspan="2">18%</td><td rowspan="2">67%</td></tr>
<tr><td>Truck > 20 t + trailer</td></tr>
<tr><td>Tractor-semitrailer, light</td><td rowspan="3">5%</td><td rowspan="3">8%</td><td rowspan="3">87%</td></tr>
<tr><td>Tractor-semitrailer, heavy</td></tr>
<tr><td>LHV</td></tr>
</table>

Calculations based on (Task Force on Transportation, 2016).

Annex B Gross tonnage, goods trains

Table 75 Average gross tonnage of trains in the Netherlands on Betuwe route and border crossings, 2015

Border crossing	Number of trains	Gross tonnage (mln tonne)	Average gross tonnage per train (GTW)
Oldenzaal- Bad Bentheim	4,950	5.6	1,131
Zevenaar-Emmerich	24,500	46.8	1,910
of which via dual network	1,650	2.5	1,515
of which via Betuwe route	22,850	44.3	1,939
Venlo-Kaldenkirchen	13,900	19.3	1,388
Eijsden-Visé	1,700	2.2	1,294
Rossendaal-Essen	6,950	7.7	1,108
Total/Average for border crossings	**52,000**	**81.6**	**1,569**

Source: (ProRail, 2016).

Annex C Modelling parameters, inland shipping

Table 76 Vessel parameters used to model energy consumption

	Load capacity (ton)	Width (m)	Length (m)	Draught, full (m)	Draught, empty (m)
Bulk and packaged cargo					
Spits	365	5.05	38.50	2.48	0.52
Campine vessel	617	6.60	55.00	2.60	0.60
Rhine-Herne canal (RHC) 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 Europe 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 (long)	16,444	22.80	268.00	3.75	0.60
Containers					
Neo Kemp	850	7.20	67.00	2.54	0.70
Rhine-Herne canal (RHC) 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: Europe 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).

Annex D Verification of inland shipping model with practical data

The following practical data on 100 inland waterway vessels were provided by BLN-Schuttevaer:
1. Vessel parameters (length, width, draught, capacity).
2. Annual tonnage transported.
3. Annual distance travelled, loaded and empty.
4. Description of sailing area.
5. Annual diesel consumption.

To validate the model, the data under items 1-3 were input to the model and an average energy consumption per kilometre was calculated for the various waterway categories, using the weighting methodology for loaded and empty trips described in Section 4.5.2. Using the data provided on waterways (item 4) a weighting procedure was then applied to the average emission factors per waterway class to determine an annual average energy consumption per kilometre.

The calculated energy consumption was then plotted against the energy consumption per kilometre reported in the practical data (see Figure 23). In doing so, the energy consumption (in litres/km) from the real-world data was converted back to engine consumption (in kWh/km) based on a specific fuel consumption of 204 g diesel/kWh and a diesel density of 0.83 kg/litre.

Figure 23 Inland shipping energy consumption: real-world data versus model outcome