STREAM International Freight 2011

Comparison of various transport modes on a EU scale with the STREAM database

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Preface

This report has been developed in the context of modal competition and co-modality in EU international freight transport. With the report, it is our aim to contribute to EU level discussions on the environmental performance of the different modes and the environmental consequences of modal shift and co-modality, in the context of the 2011 White Paper on transport.

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The content is the sole responsibility of the authors.

The authors

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Summary

Background
The discussion about an optimal use of the different freight transport modes is multi dimensional. Air pollution and in particular climate change remain important challenges of the modern society, but also the accessibility of port and industry areas contribute to the modal split discussion. EU air quality standards are not yet met at many locations and existing legislation may be strengthened in the coming years. Freight transport emissions show the highest growth in projections for the coming decades. Various GHG reduction options are considered, including a modal shift from road to alternative modes as illustrated in the recent Transport White Paper of the European Commission.

Objective
The objective of this study is to provide an easily accessible and ready-to-use overview of the current and future air emissions of different freight transport modes as related to their performance, in a European context. The report can contribute to a discussion on an EU level[1] on future emissions legislation and the potential impact of increased co-modality. In addition, the dataset of emission factors can also be used for carbon foot printing purposes.

Methodology
The report contains an overview of emissions factors per tonne-kilometre for the different freight modes in different market segments. For this comparison the emission data, vehicle utilisation data and data detouring compared to other modes are important. In many cases, the travel distance by rail and certainly by inland barge is longer than by road. When comparing the modes on relevant corridors, this factor has to be taken into account. In addition, pre- and end-haulage needs to be taken into account.

The emissions of the entire transport chain are taken into account; emissions from fuel production and transportation and electricity production and transportation. Wear and tear emissions[2] and vehicle production, maintenance, end-of-life and infrastructure related emissions are not included.

Emissions data per vehicle-kilometre have been taken from the most authoritative European sources available, preferably resulting from (real world) measurements. Logistical data (load factors and empty running) is one of the corner stones for calculating emissions per tonne-kilometre. Information on the average utilisation of the different modes has been gathered from relevant industry sectors, companies and experts per market segment.

[1] The approach differs from the 2008 STREAM study that was directed at the Dutch situation. It should be noted that the change in scope of the study influences the results.

[2] Wear and tear emissions are discussed in Section 5.7.

2009-2020 trend

In the period 2009-2020, the CO_2 emission factors for all modes are expected to decrease at a roughly similar rate, around 5%, with a little higher figure for maritime transport.

Between 2009 and 2020 the well-to-wheel PM_{10} and NO_x emission factors will decrease most for trucks (50-65%), compared to 30% for inland waterway and rail diesel. This trend is the result of the effective European emission standards that apply to truck engines. For the other modes the reduction is smaller because of a slower fleet renewal and in the case of inland barge and marine engines also less stringent emission standards.

In 2020 the SO_2 exhaust emissions of short sea transport will be much lower than they are now and by then the sum of the exhaust and upstream emissions are expected to be more comparable to road upstream SO_2 emissions.

Wear and tear emissions, from road and rail transport only, are already important in these days, and their importance will increase even further, since engine emissions are projected to decrease but wear and tear emission factors are more or less stable. The environmental impact of these particles is due to their size and composition, however, less harmful than the impact of exhaust emissions.

Comparison of transport modes

Generally, the following factors influence the emissions per tonne-kilometre when comparing various transport modes:

- Vehicle utilisation.
- Detouring and pre- and end-haulage.
- Scale of transport.
- Emission technology.
- Energy efficiency.

To compare the different transport modes, three representative cases were calculated, representing both favourable and less favourable circumstances for the different modes and using average emission technology and vehicle utilisation.

In general, electric trains have the lowest emissions over the entire transport chains studied. Detouring of rail transport can hardly undo the benefits electric rail has over the other modes. It should, however, be noted that electric train transport scores very well for the average EU electricity mix, but are less advantageous in cases where the fossil fuel content for electricity production is high.

In the presented cases, rail and inland waterways score generally better on CO_2 emissions than road both in 2009 and 2020. However, when detouring is significant for the two non-road modes and the scale of transport is small, emissions can get close to the level of the road emissions.
$PM_{2.5}$ emissions for rail diesel and inland waterways can be similar as for road, but also higher in case of significant detouring and small ships. NO_x emissions of rail diesel and inland waterways can be either lower or higher, depending on the characteristics mentioned.

SO_2, NO_x and $PM_{2.5}$ emissions for short sea shipping are high as compared to the other modes.

1 Introduction

1.1 Background

Freight transport has become a basic part of modern life. It is expected to continue to grow in the next decades. At the same time air pollution and in particular climate change remain important challenges of modern society. As freight transport is a significant contributor to both, the discussion about freight transport emissions will continue.

Last two decades, air pollutant emissions decreased for all transport modes. However, they are still on the political agenda, because the EU air quality standards are not yet met at many locations, let alone the tighter 2020 standards and the 2020 national emission ceilings (NEC). Also the differences between test cycle values and real life emissions, the long vehicle lifetimes of some transport modes and the increasing evidence on the severe health impacts of some emissions, in particular small particle emissions, play a role in this discussion.

Unlike for most other economic sectors, the greenhouse gas (GHG) emissions of transport rise. Within the transport sector, freight transport shows the highest growth, both in the past decades as in projections for the coming decades. Various GHG reduction options are considered, including a modal shift from road to alternative modes. For the latter, ambitious targets have been defined in the recently published Transport White Paper of the European Commission.

Also from a congestion and accessibility point of view, the optimal modal split is being discussed[3]. Thus, also from this point of view, data about the environmental performance is needed.

Up-to-date emission data are important for both policy makers, but also various stakeholders. In some cases very detailed data are required, but for many applications, more aggregated and easily accessible emission data are needed. This report aims to provide an overview of such ready-to-use aggregated air emissions per unit of performance of the different freight transport modes on an EU level. The data have been calculated with CE Delft's STREAM model using average logistic data.

This study has been developed for the Dutch Ministry of Infrastructure and Environment in the context of its emission policy for the different transport modes and the revision of EU Directive 97/68 on the emissions of inland barges. It is an update of the freight transport part of the 2008 study STREAM (CE, 2008; in Dutch).

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[3] In the Port of Rotterdam, an obligatory modal split has been agreed for the planned container terminals at Maasvlakte II, with the following targets:
- Inland shipping: 45% (currently approx. 30%).
- Rail: 20% (currently approx. 10%).
- Road: 35% (currently approx. 60%).

1.2 Objectives

The objective of this study is:

To provide an easily accessible and ready-to-use overview of the emissions of different freight transport modes as related to their performance, in a European context.

More specific, this study provides:
- Data on vehicle emission for the year 2009 and 2020.
- A translation of the emission per vehicle-kilometre to emissions per tonne-kilometre for different market segments.
- Insight in the influence of the infrastructure network density of the modes on their final emission performance.
- Insight in the effects of pre- and end-haulage on the their final emission performance.

As compared to sources such as TREMOVE, TNO data and Handbuch Emissionsfaktoren that provide emission factors per vehicle-kilometre, this study relates the emissions to the transport output per mode expressed in tonne-kilometre. Moreover, all emission related to vehicle use, including upstream emission of electricity generation and fuel production are included. Also the Internet based EcoTransIT tool[4] has been used as a data source in some cases. This tool also provides data per tonne-kilometre. It can be used for the calculation of specific cases, while this report provides a ready-to-use and interpret overview.

In this report data have been used from authoritative studies and databases mentioned.

Primarily, the results of the study (Chapter 5) can be used to calculate the effects of different modal shift scenario's. Furthermore, the study gives an overview of the effects to be expected from modal shifting in different situations (Chapter 6).

The results can also be used for footprint calculations, but users should be aware that average emission and logistic parameters have been used. For specific cases data should be adapted according to the specific case parameters.

1.3 Differences with STREAM 2008 (NL)

This STREAM study is a European update of STREAM 2008 (CE, 2008) which contains transport emission factors for the Netherlands. The most important differences between this study and CE, 2008 are:
- Emission factors for road are based on the European vehicle fleet. Differences with the Dutch vehicle fleet are limited.
- Rail and maritime transport emission factors are based on European sources. (For inland waterways Dutch data are representative for Europe).
- The reader should be aware that for some vehicle categories the definition, in terms of load capacity, has changed as compared to STREAM 2008. This change also affects the emission per tonne-kilometre.
- Emission factors for electricity production are based on the average European electricity mix. These emission factors are lower (CO_2),

4 www.ecotransit.org

respectively higher (air pollutants) than those for the Dutch electricity mix in STREAM 2008. Emission factors for electric train are therefore much lower.
- Upstream emissions for diesel production are based on European data. These emissions are higher than the Dutch average.

1.4 Report structure

- Chapter 2 describes the methodology used in this report and concerns the system boundaries and system definitions.
- Chapter 3 gives an overview of the emissions factor per vehicle-kilometre for every mode.
- In Chapter 4 the logistic data that have been used for the different market segments are presented.
- In Chapter 5 an overview is given from the emission factors per tonne-kilometre that result from the data in Chapter 3 and Chapter 4.
- Finally in Chapter 6, several cases are presented in which the emissions per mode are compared. In the cases the effects of detouring due to infrastructure limitations and the effect of pre-and end-haulage are illustrated.

2 Methodology

2.1 Introduction

In this chapter, the main methodological issues are discussed.
First, the emission factors are defined by the impacts included and the processes taken into account. The report focuses on the use phase of transport vehicles; emissions from infrastructure development and vehicle construction or end-of-life processes are not taken into account.

2.2 Environmental impacts: vehicle emissions

The following air emissions from transport sources are covered in this study: CO_2 (climate change) and $PM_{2.5}$, PM_{10}, NO_x and SO_x (air pollution).
Table 1 gives an overview of the emission and their environmental impacts.

Table 1 Environmental impacts included

	Environmental impact
Carbon dioxide (CO_2)	Global warming
Particulates ($PM_{2.5}$ and PM_{10})	Human toxicity, summer smog
Nitrogen oxides (NO_x)	Human toxicity, acidification, eutrophication, eco-toxicity, summer smog
Sulphur oxides (SO_2)	Human toxicity, acidification, eco-toxicity

In reference to electricity driven rail transport the risks of nuclear power generation from radiation and waste disposal are not considered.

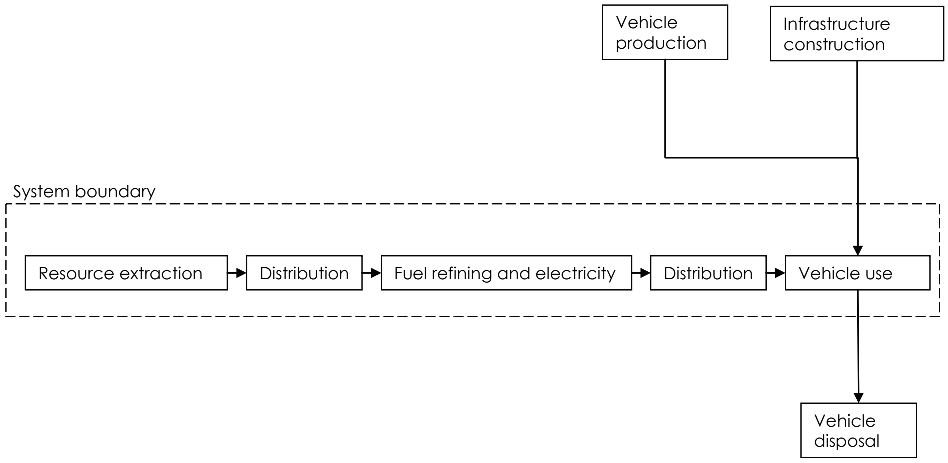
Particulate matter emissions are subdivided in emissions from combustion engines ($PM_{2.5}$), and the particulate matter emissions from abrasion and twirling (PM_{10}). The impacts of these two emission classes differ due to the difference in size and composition of the particulates.

The air pollutant emissions in this report are given in gram per tonne-kilometre. It should, however, be noted that the health effect of the emissions (human toxicity) strongly depend on the location of the emissions (urban road, motorway, sea, chimney). It is, however, very difficult to provide one single EU figure for human toxicity because this effect strongly depends on factors like population density, spatial mapping and other factors.

2.3 System boundaries

This study takes the whole transport chain into account, except vehicle and infrastructure construction. The indirect emissions of fuel and electricity production (upstream) are included. An overview of the processes included in the analysis is shown in Figure 1.

Figure 1 System boundaries and processes included



2.4 EU approach

This report is based on data representative for the EU. This implies that the study result cannot be used to draw firm conclusions on a national basis. Vehicle utilisation, emission factors (notably electricity production and fuel refining) are based on EU average figures.

2.5 Transport modes, vehicle types and market segments

This study focuses on the different modes for long distance freight transport within the EU. It includes:
- Road.
- Rail.
- Inland waterways.
- (Short) sea shipping.

Air transport is excluded as it is of minor importance for freight transport within the EU and hardly competes with other modes. For road transport also light commercial vehicles (vans) are included in Chapter 4 to allow for modelling the complete chain from origin to destiny.

The transport modes are defined for two types of cargo:
1. Bulk and general cargo.
2. Containerised cargo.

For the two types of cargo three different market segments are distinguished according to the weight of the cargo as defined in Table 2.

Table 2 **Definition of weight classes of cargo**

Weight class	Bulk and general cargo Density of load	Containerised cargo Maximum load per container*
Volume	< 0.4 kg/litre	6 ton/TEU [5]
Average	0.5-1.2 kg/litre	10.5 ton/TEU
Heavy	> 1.3 kg/litre	14.5 ton/TEU

* based on IFEU, 2010.

Table 3 and Table 4 give an overview of the transport modes and vehicle types discussed in this study. The vehicle types are characterised by their average load capacity in tonne and TEU[5]. For rail transport, electric and diesel traction are distinguished.

Table 3 **Definition of transport modes and vehicle types for bulk and general cargo**

Mode and vehicle type	Load capacity (tonne)		
	Volume goods	Average goods	Heavy goods
Road[a]			
Small van < 2 tonne	0.7		X
Large van > 2 tonne	1.2		X
Truck < 10 tonne (average GVW 6.9 tonne)	2.6		X
Truck 10-20 tonne (average GVW 16.2 tonne) [b]	8.0		X
Truck > 20 tonne (average GVW 28.6 tonne)[b]	16.1		X
Truck trailer (average GVW 36.1 tonne)	26.2		
Long and heavy vehicle (LHV) (average GVW 55 tonne)	39.5		
Rail (electric and diesel)			
Short train (22 wagons length 14 à 15 m)	594	935	1,276
Medium train (33 wagons length 14 à 15 m)	891	1,403	1,914
Long train (44 wagons length 14 à 15 m)	1,188	1,870	2,668
IWW			
Spits-Peniche	350		
Campine Barge	550		
Rhine Herne Canal Ship	1,350		
Large Rhine Ship			
Convoy Europe II-C3b	5,500		
Pushed Convoy 2x2	12,000		
Pushed Convoy 3x2	18,000		
(Short) sea			
Crude oil tanker 0-9,999 dwt[c]	3,668		
Crude oil tanker 10,000-59,999 dwt	38,361		
Crude oil tanker 80,000-119,999 dwt	103,403		
Products tanker 0-4,999 dwt	1,800		
Products tanker 5,000-10,000 dwt	7,000		

5 TEU: Twenty feet Equivalent Unit; Container volume capacity expressed in the volume of a twenty feet container.

Mode and vehicle type	Load capacity (tonne)		
	Volume goods	Average goods	Heavy goods
General Cargo 0-4,999 dwt		2,545	
General Cargo 5,000-10,000 dwt		6,957	
Bulk carrier (feeder) 0-9,999 dwt		2,400	
Bulk carrier (handysize) 10,000-35,000 dwt		26,000	
Bulk carrier (handymax) 35,000-59,999 dwt		45,000	

[a] Tonne ranges in the vehicle name denote the gross vehicle weight (GVW) range. The Gross vehicle weight is the maximum permitted weight of vehicle and load.

[b] Truck GVW 10-20 tonne and truck GVW > 20 tonne are a mix of 75% single truck and 25% rigid truck an trailer (CE, 2008).

[c] Dwt: dead weight tonne; maximum permissible weight of the total of cargo, fuel, fresh water, ballast water and provisions.

Source: Road: CBS, 2011b; TNO 2011. Rail: DB Schenker, 2011; SBB Cargo, 2011; Railcargo, 2011. IWW: TNO, 2003; EICB, 2011. Short sea: IMO, 2009; elaborated by CE Delft.

Table 4 Definition of transport modes and vehicle types for container transport

Mode and vehicle type	Capacity (TEU)
Road	
Truck GVW > 20 tonne	1.2
Truck trailer	2
Long and heavy vehicle (LHV)	3
Rail	
Short train	45
Medium train	70
Long train	90
Inland waterways	
Neo Kemp	48
Rhine Herne Canal Ship	96
Pushed convoy	160
Container Ship Rhine	200
Long large Rhine ship	272
Rhinemax Ship	470
Maritime shipping	
Container Ship (feeder) 0-999 TEU	500
Container Ship (like handysize) 1,000-1,999 TEU	1,414
Container Ship (like handymax) 2,000-2,999 TEU	2,400
Container Ship (like panamax) 3-4,999 TEU	4,112
Container Ship (like aframax) 5-7,999 TEU	5,765
Container Ship (like suezmax) > 8,000 TEU	9,800

Source: Road: TNO, 2011. Rail: DB Schenker, 2011; SBB Cargo, 2011; Railcargo, 2011. IWW: TNO, 2003; A&S, 2003. Short sea: IMO, 2009; elaborated by CE Delft.

2.6 Emission legislation for 2020

Table 5 gives an overview of the legislations that have been taken into account for the emission factor calculations for 2020.

Table 5 **Policies relevant for 2020**

Transport mode/ pollutant	Legislation
Vans	
CO_2	175 g/vkm in2014/2017, COM/2009/0593
NO_x, PM_{10}	Euro 6 will be introduced in 2014/15 (Reg. 715/2007)
Trucks	
CO_2	--
NO_x, PM_{10}	Euro 6 will be introduced in 2013/14 (Reg. 595/2009)
Inland shipping	
CO_2	--
NO_x, PM_{10}	Phase 4 will be introduced in 2016 by assumption; proposals are being discussed
Sulphur	Maximum 10 ppm sulphur in 2011 (Reg. 2009/30/EG)
Rail	
CO_2	--
NO_x, $PM_{2.5}$	Tightening of emission standards in 2012/13 (Directive 2004/26)
Sulphur	Maximum 10 ppm sulphur in 2011 (Reg. 2009/30/EG)
Maritime shipping	
CO_2	--
NO_x	2008 tightening of IMO Annex-VI (Tier II from 2011)
PM_{10}	Reduction trough lower sulphur contents
Sulphur	2008 tightening of IMO Annex-VI (0.1% in ECA from 2015)

All transport sectors, except maritime shipping, use 10 ppm Sulphur fuel in 2020. For rail and inland waterways 10 ppm S fuel is mandatory from 2011 on. So far the European Commission has proposed CO_2 legislation for vans only. We take account of differences between real life and test cycle emissions (about 20% difference). CO_2 reduction for the other vehicle types is the result of autonomous development. The European Commission is currently investigating the options for regulation of the fuel efficiency of trucks, but it is not clear whether this will result in a legislative proposal.

Note that for all modes in case of new vehicle standards, a simple fleet model was used to calculate the fleet average emission factors in 2020.

2.7 Emission calculation method

For all modes the emission are expressed per tonne-kilometre. The **tonne-kilometre** is the unit of measure representing the transport of one tonne over one kilometre. The distance to be taken into consideration is the distance actually run to deliver the goods.

By expressing the emissions per tonne-kilometre they are expressed in relation to the achievement both in distance and delivered weight.

For all modes the well-to-wheel[6] emissions per tonne-kilometre (E_{tkm}) are defined as follows:

$$EF_{tkm,\mathrm{mode}}(WTW) = \frac{EF_{vkm}(TTW) + EF_{vkm}(WTT)}{LC \times UF} \quad (1)$$

With:
EF_{vkm}(TTW): Exhaust (tank-to-wheel) emissions per vehicle-kilometre.
EF_{vkm}(WTT): Emission of refining or electricity production (well-to-tank) per vehicle-kilometre.
LC: Load capacity.
UF: Utilisation Factor = LF × LKF.
LF: Load factor of loaded trips (=load/load capacity).
LKF: Loaded kilometre factor; the share of loaded kilometres in the total of kilometres (= 1-empty kilometre factor).

The utilisation factor (UF) in the denominator takes into account the empty trips (with the factor LKF). When the loaded kilometres equal 50% (LKF = 0.5), the emission factor per vehicle-kilometre is multiplied by 2 (=divided by 50%), accounting for the empty return trip.

For container transport the calculation method is adapted as follows:

$$EF_{tkm}(WTW) = \frac{EF_{vkm}(TTW) + EF_{vkm}(WTT)}{CC \times UC \times CL} \quad (2)$$

With :
CC: Container unit Capacity of vehicle (TEU capacity).
UC: Utilisation TEU capacity; (loaded TEU/TEU apacity).
CL: Load per TEU (tonne/TEU) = LLC × SLC.
LLC: Load per loaded container unit.
SLC: Share of loaded container units.

The actual calculation method of the emissions per vehicle-kilometre vary per mode and depend on the available data (see Chapter 3). The resulting emissions per tonne-kilometre, based on the logistic data in Chapter 4 are given in Chapter 5.

2.8 Logistic characteristics

A comparison of the environmental performance of the different transport modes can only be made if the logistical characteristics are taken into account properly. Basically, information is needed about:
- Payload capacity.
- Load factor loaded trip.
- Empty running.

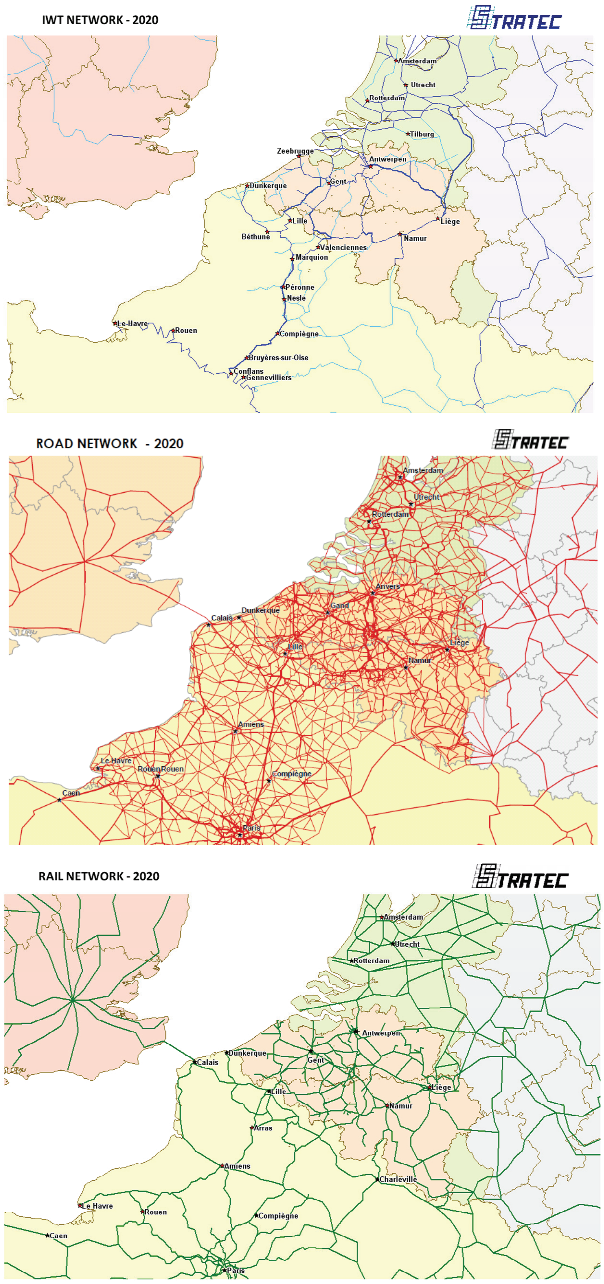
These factors are taken into account in expressing the emissions per tonne-kilometre as described in the previous section.

[6] Well-to-wheel emissions are the sum of exhaust emissions and upstream emission (emissions of refining and electricity production).

However, in the case of comparing the use of different modes in real cases, the following factors also need to be taken into account:
– Detouring.
– Pre- and end-haulage.
– Loading and unloading.

Figure 2 illustrates the impact of the availability of infrastructure. Especially the inland waterway network for big size ships is limitedly ramified, compared to the road network (Figure 2). For example, the route from Rotterdam to Cologne is 15% longer by inland barge than by truck.

Figure 2 Comparison of density of inland waterway (top) road (middle) and rail network in North-Western Europe



Source: AEA, 2010.

Detouring, the influence of pre- and post-haulage, and the influence of loading and unloading can vary strongly per case. In Chapter 6 different cases are presented.

3 Emissions data

3.1 Introduction

In this chapter the methods to calculate the emission data per vehicle-kilometre are presented. The emission data per vehicle-kilometre together with the logistic data in Chapter 4 form the basis to calculate the emission data per tonne-kilometre (Chapter 5).

3.2 Road transport

3.2.1 Energy consumption and exhaust emission factors for 2009

Emissions factors for trucks and delivery vans can be divided in two sets:

1. Emissions that are related to fuel type and fuel consumption (CO_2, SO_2 and upstream emission). And,
2. Emissions that are related to vehicle technology and driving pattern ($PM_{2.5}$ and NO_x).

1. Fuel type and fuel consumption related emissions.
   Truck energy consumption and CO_2 and SO_2 emission factors are based on TNO CO_2 emission factors per road type (Annex A, Table 60). LHV emission factors have been modelled relative to the truck trailer on base of TML, 2008 and TRL, 2008 (see Table 66, Annex A).
   CO_2 emission factors for vans are based on several sources (WLO, 2008; TNO, 2008 and TREMOVE, 2010) to be able to construct a complete set of CO_2 emission factors differentiated both to weight class and to road type (Annex A, Table 60),
   From the CO_2 emission factors energy consumption and SO_2 emission factors have been derived by the carbon content of diesel (73.3 g CO_2/MJ) and by the sulphur content of diesel (10 ppm sulphur). The upstream emissions are discussed in Section 3.7.

2. Vehicle technology related emission.
   The $PM_{2.5}$ and NO_x emission factors are based on the TNO emission factors per Euro class and road type (Annex A, Table 62, Table 63). Emission factors for average trucks and vans in 2010 have been constituted using the European vehicle-kilometre distribution of vehicle technologies according to TREMOVE for the year 2009 (Annex A, Table 64). The resulting emission factors for 2009 per road type are given in Table 61. LHV emission factors have been modelled relative to the truck trailer on base of TML, 2008 and TRL, 2008 (see Table 66, Annex A).

Empty and full load emission factors

The emission factors are valid for average load factors (in terms of mass) as depicted in Table 6. According to data from the model Artemis on three different size classes of trucks (Madre, 2010) the energy consumption per kilometre is on average the same for different size classes and typically depends on the payload as depicted in Table 7.[7] It was assumed that the same

[7] The load only effects the tire rolling resistance and therefore does not depend on the size class.

dependency is valid for vans. The Artemis data are in good accordance with several other data sources (Nylund, 2005; Coyle, 2007; CE, 2003; IFEU, 2010).

Table 6 **Load factor and load capacity per vehicle class**

Vehcile type	Load factor
Small van < 2 tonne	35%
Large van > 2 tonne	35%
Truck < 10 tonne	35%
Truck 10-20 tonne	40%
Heavy truck > 20 tonne	44%
Truck trailer	49%

Source: CE, 2008.

Table 7 **Change in MJ/km per additional tonne payload for different road types**

Urban	Non-urban	Motorway
0.33	0.20	0.14

Source: Madre, 2010; elaborated to values in MJ/km by CE Delft.

Using the data from Table 6 and Table 7, emission factors for empty and full trucks have been constructed, assuming that the emission factors (EF) scale linearly with the energy consumption (EC), according to:

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

For CO_2, SO_2, NO_x the factor ε equals 1, for $PM_{2.5}$ it is assumed to equal 0.5, based on HBEFA, 2010. The resulting energy consumption and emission factors for empty and full trucks are depicted in Table 8.

Table 8 **Energy consumption and emission factors road vehicles in 2009 (range from empty to fully loaded)**

	Vehicle type	Urban	Non-urban	Motorway
Energy consumption (MJ/km)	Small van < 2 tonne	3.8-4.1	2.5-2.6	3.4-3.5
	Large van > 2 tonne	4.4-4.8	2.9-3.1	4.0-4.2
	Truck < 10 tonne	6.7-7.5	5.1-5.6	5.3-5.7
	Truck 10-20 tonne	12.0-14.6	8.3-9.9	7.3-8.4
	Truck > 20 tonne	16.0-21.4	11.4-14.7	9.9-12.1
	Truck trailer	14.0-22.7	9.5-14.8	7.6-11.2
	LHV	18.8-30.6	12.8-19.9	10.3-15.1
CO_2 (gram/km)	Small van < 2 tonne	280-297	182-192	251-258
	Large van > 2 tonne	325-355	211-229	293-305
	Truck < 10 tonne	488-552	373-412	391-417
	Truck 10-20 tonne	876-1,071	608-726	539-618
	Truck > 20 tonne	1,174-1,566	839-1,078	724-885
	Truck trailer	1,023-1,661	694-1,082	558-819
	LHV	1,381-2,243	937-1,461	754-1,106

	Vehicle type	Urban	Non-urban	Motorway
SO_2 (mg/km)	Small van < 2 tonne	2.1-2.3	1.4-1.5	1.9-2.0
	Large van > 2 tonne	2.5-2.7	1.6-1.7	2.2-2.3
	Truck < 10 tonne	3.7-4.2	2.8-3.1	3.0-3.2
	Truck 10-20 tonne	6.7-8.2	4.6-5.5	4.1-4.7
	Truck > 20 tonne	8.9-11.9	6.4-8.2	5.5-6.7
	Truck trailer	7.8-12.6	5.3-8.2	4.3-6.2
	LHV	10.5-17.1	7.1-11.1	5.7-8.4
$PM_{2.5}$ (mg/km)	Small van < 2 tonne	126-130	66-68	92-93
	Large van > 2 tonne	142-148	76-79	109-111
	Truck < 10 tonne	134-143	80-84	64-66
	Truck 10-20 tonne	199-220	114-125	88-94
	Truck > 20 tonne	261-301	151-172	116-128
	Truck trailer	256-325	140-174	101-122
	LHV	309-392	168-210	121-147
No_x (gram/km)	Small van < 2 tonne	1.0-1.1	0.6-0.6	0.7-0.8
	Large van > 2 tonne	1.2-1.3	0.7-0.8	0.8-0.9
	Truck < 10 tonne	3.9-4.4	3.1-3.4	3.1-3.3
	Truck 10-20 tonne	7.4-9.0	5.3-6.3	4.4-5.0
	Truck > 20 tonne	10.0-13.4	7.3-9.4	5.9-7.2
	Truck trailer	8.6-14.0	5.9-9.3	4.8-7.0
	LHV	10.3-16.8	7.1-11.1	5.7-8.4

3.2.2 Energy consumption and exhaust emission factors for 2020

It is assumed that between 2009 and 2020, the fuel efficiency of vans and trucks will improve. The fuel efficiency improvements have been modelled according to data from AEA, 2010. For vans the given improvement ratio takes into account the mandatory new vehicle CO_2 standards of 175 g CO_2/km by 2014/2017 (where these test cycle values are corrected to real life emission values).

Table 9 Fuel efficiency improvement 2010-2020

Vehicle type	Ratio fuel consumption 2020/2009
Small van < 2 tonne	88%
Large van > 2 tonne	88%
Truck < 10 tonne	96%
Truck 10-20 tonne	96%
Truck > 20 tonne	96%
Truck trailer (and LHV)	96%

The emission factors for $PM_{2.5}$ and NO_x in 2020 have been calculated by using the vehicle-kilometre distribution of Euro classes in 2020 according to TREMOVE (Annex A, Table 64). The resulting energy consumptions and emission factors for 2020 are depicted in Table 10.

Table 10 **Energy consumption and emission factors road vehicles in 2020 in range from empty to fully loaded**

	Vehicle type	Urban	Non-urban	Motorway
Energy consumption (MJ/km)	Small van < 2 tonne	3.4-3.6	2.2-2.3	3.0-3.1
	Large van > 2 tonne	3.9-4.3	2.5-2.8	3.5-3.7
	Truck < 10 tonne	6.2-7.5	4.8-5.6	5.0-5.6
	Truck 10-20 tonne	11.2-14.5	7.8-9.8	6.9-8.3
	Truck > 20 tonne	15.3-20.7	11.0-14.2	9.5-11.7
	Truck trailer	13.1-22.1	8.9-14.4	7.2-10.9
		17.7-29.8	12.0-19.4	9.7-14.7
CO_2 (gram/km)	Small van < 2 tonne	246-263	159-170	221-228
	Large van > 2 tonne	285-314	185-203	258-269
	Truck < 10 tonne	455-553	350-409	370-410
	Truck 10-20 tonne	821-1,065	572-720	509-609
	Truck > 20 tonne	1,124-1,514	804-1,041	695-854
	Truck trailer	960-1,618	652-1,053	527-796
	LHV	1,296-2,184	881-1,422	711-1,074
SO_2 (mg/km)	Small van < 2 tonne	1.9-2.0	1.2-1.3	1.7-1.7
	Large van > 2 tonne	2.2-2.4	1.4-1.5	2.0-2.1
	Truck < 10 tonne	3.5-4.2	2.7-3.1	2.8-3.1
	Truck 10-20 tonne	6.3-8.1	4.4-5.5	3.9-4.6
	Truck > 20 tonne	8.6-11.5	6.1-7.9	5.3-6.5
	Truck trailer	7.3-12.3	5.0-8.0	4.0-6.1
	LHV	9.9-16.6	6.7-10.8	5.4-8.2
$PM_{2.5}$ (mg/km)	Small van < 2 tonne	39-40	20-21	26-27
	Large van > 2 tonne	41-43	22-23	29-30
	Truck < 10 tonne	35-37	20-21	15-15
	Truck 10-20 tonne	53-59	29-32	22-24
	Truck > 20 tonne	71-82	40-45	29-33
	Truck trailer	65-82	34-43	24-29
	LHV	78-99	42-52	29-35
NO_x (gram/km)	Small van < 2 tonne	0.5-0.5	0.3-0.3	0.3-0.3
	Large van > 2 tonne	0.5-0.6	0.3-0.3	0.3-0.4
	Truck < 10 tonne	1.5-1.8	1.6-1.8	1.5-1.7
	Truck 10-20 tonne	2.7-3.5	2.6-3.3	2.1-2.5
	Truck > 20 tonne	3.9-5.3	3.7-4.8	3.0-3.6
	Truck trailer	3.2-5.5	2.9-4.7	2.3-3.5
	LHV	3.9-6.6	3.5-5.6	2.8-4.2

As the emissions per vehicle-kilometre are assumed to vary linearly with the load, the emission per vehicle-kilometre (E_{vkm}) at W% utilisation of the load capacity are calculated as follows:

$$E_{vkm}\ (W\%) = E_{vkm}\ (empty) + W\% \times (E_{vkm}\ (full) - E_{vkm}\ (empty))$$

Upstream emission per vehicle-kilometre are discussed in Chapter 3.7.

3.2.3 Wear and tear emissions

Dust is also released as a result of wear and tear from tires, brakes and road surfaces. Dust particles from wear and tear of tires and road surfaces consist for about 5% of PM_{10} dust. Dust emissions from braking, consist for about 50% of PM_{10} (Taakgroep, 2009). It is assumed that the wear and tear PM_{10} emission as a function of loading vary linearly with the energy consumption of the vehicles. The wear and tear emissions per road vehicle type are based on TNO emission factors (Annex A, Table 65) and are elaborated by CE Delft to the emission factor ranges in Table 11, using the energy consumption data above.

Table 11 **Wear and tear PM_{10} emissions in mg/vkm (range from empty to fully loaded)**

Vehicle type	Urban	Non-urban	Motorway
Small van < 2 tonne	29-32	14-15	14-14
Large van > 2 tonne	29-32	14-15	14-14
Truck < 10 tonne	131-148	64-70	64-69
Truck 10-20 tonne	126-154	61-73	62-72
Truck > 20 tonne	120-159	59-75	60-73
Truck trailer	94-153	46-72	48-71
LHV	137-222	67-105	70-103

3.3 Rail transport

3.3.1 Energy consumption rail for 2009 and 2020

The emission factors per vehicle-kilometre for all pollutants are calculated from the Energy consumption per vehicle-kilometre, using emission factor per Mega Joule (see Section 3.3.2).
The best available set of energy consumption figures for rail transport from the EcoTransIT tool (IFEU, 2010). The data are amongst others based on a dataset with 200,000 rides of freight trains by Railion in different train types and weight classes. Furthermore, a comparison was made with the UIC energy and CO_2 database.

The data set used has a long history and has been primary developed by the EU TRENDS project. In later years, the defined formula was confirmed and further developed by the EX-TREMIS project and finally by EcoTransIT (IFEU, 2010). The formulas have been elaborated by CE Delft to express the energy consumption in Mega Joules per vehicle-kilometre.

The formula for the specific energy consumption (EC) for hilly countries (European average) is as follows:

Electric: GTW < 2,200 tonne: EC (MJ_E/vkm) = $4.32 \times GTW^{0,38}$.
GTW > 2,200 tonne: EC (MJ_E/vkm) = $0,036 \times GTW$.
Diesel: GTW < 2,200 tonne: EC (MJ_{diesel}/vkm)= $11.68 \times GTW^{0,38}$.
GTW> 2,200 tonne: EC (MJ_E/vkm) = $0,097 \times GTW$.

With:
GTW: The gross tonne weight of the train. The gross weight is the weight of the freight carried including empty wagons, but without locomotive.

For flat countries, the values of the function are multiplied by 0.9, for mountainous countries the factor is 1.1 (IFEU, 2010).

Given the load factors (LF) for rail trips (see Chapter 4) (Table 36-Table 39) For bulk and general goods the gross tonne weight of loaded (GTW_L) and unloaded (GTW_U) trains has been determined using the wagon parameters in Table 12 as follows:

$GTW_L = NW \times (LF \times LCW) + NW \times WW$.
$GTW_U = NW \times WW$.

With:
NW: Number of wagons (Table 3 and Table 4).
LF: Load factor (see Chapter 4).
LCW: Load capacity wagon (Table 12).
WW: Weight of wagon (Table 12).

For container transport it is assumed that the train never runs completely empty and GTW_L is determined using the wagon parameters in Table 13 as follows:

$$GTW_L = NW \times TCW \times UC \times (CL+WT) + NW \times WW$$

With:
TCW: TEU capacity per wagon (Table 13).
UC: Utilisation TEU capacity; (loaded TEU/TEU capacity) (see Chapter 4).
CL: Load per TEU; average of full and empty containers (tonne/TEU) (see Table 2 and Chapter 4).
WT: Weight of an empty container unit (see Chapter 4).

Table 12 Wagon specification for bulk and general cargo transport

	Volume transport	Medium transport (mix of wagons)	Heavy transport
Weight wagon (WW in tonne)	12.5	17.25	22
Load capacity wagon (LCW in tonne)	27	42.5	58
Length wagon (m)	15	14.5	14

Table 13 Wagon specification for container transport

	Volume transport	Average transport (mix of wagons)	Heavy transport
Weight wagon (WW in tonne)	12.5	16.3	20
TEU/wagon (TCW)	2	2.5	3
Length wagon (m)	14.0	16.9	19.7

Given the gross tonne weight of a (partly) loaded train (GTW_L) and of an unloaded train (GTW_U), the average energy consumption per vehicle-kilometre for a given loaded kilometre factor (LKF) was calculated as follows:

$$EC_{vkm} = C \times (LKF \times GTW_L^{0.38} + (1-LKF) \times GTW_U^{0.38})$$

With C equal to 4.32 for electric trains and 11.68 for diesel trains.
The difference between the two arises from the differences in energy carrier: for electric trains this formula yields the electric energy, while for diesel trains this yields the energy content of the diesel used. The efficiency of an electric engine is much higher, mainly because the main energy losses are higher in the chain with the electricity production, while for a diesel engine, the main losses are in the engine itself.

Table 14 and Table 15 give an overview of the energy consumption per vehicle-kilometre (MJ/vkm) for bulk and general cargo, and containers.
The energy consumption values are based on the logistic parameters described in Chapter 4.

For 2020, AEA, 2010 estimate in a business-as-usual scenario a 4% reduction in the energy consumption of freight trains, as compared to 2010. This value has been taken over for both electric and diesel trains.

Table 14 **Energy consumption of trains for bulk and general cargo (MJ/vkm)***

	Year 2009			Year 2020		
	Voluminous cargo	Average cargo	Heavy cargo	Voluminous cargo	Average cargo	Heavy cargo
Electric						
Short train (22 wagons length 14 à 15 m)	45	53	61	43	51	58
Medium train (33 wagons length 14 à 15 m)	52	62	75	50	59	72
Long train (44 wagons length 14 à 15 m)	58	69	99	56	66	95
Diesel						
Short train (22 wagons length 14 à 15 m)	121	143	164	116	137	158
Medium train (33 wagons length 14 à 15 m)	141	167	203	135	160	195
Long train (44 wagons length 14 à 15 m)	157	186	267	151	179	256

* See Chapter 4 for the logistic parameters on which the values are based. Note that these are no primary energy uses but for electric trains MJ-electric, for diesel MJ-diesel.

Table 15 **Energy consumption of trains for containerised cargo (MJ/vkm)***

	Year 2009			Year 2020		
	Voluminous cargo	Average cargo	Heavy cargo	Voluminous cargo	Average cargo	Heavy cargo
Electric						
Short train (45 TEU)	46	48	50	44	46	48
Medium train (70 TEU)	54	57	59	52	54	57
Long train (90 TEU)	60	62	65	57	60	62
Diesel						
Short train (45 TEU)	118	123	128	113	118	123
Medium train (70 TEU)	139	145	151	134	139	145
Long train (90 TEU)	153	160	166	147	153	160

* See Chapter 4 for the logistic parameters on which the values are based. Note that these are no primary energy uses but for electric trains MJ-electric, for diesel MJ-diesel.

3.3.2 Emission factors Diesel trains for 2009 and 2020

IFEU (2010) presents an overview of emission factors for diesel locomotives from different sources. The overview illustrates that there are large differences between the sources (See Table 16).

Table 16 **Emission factors for diesel trains (NO_x, PM) from different sources (g/kg diesel)**

	Unit	NO_x	PM
Different European Railway Companies	g/kg	40-70	0.6-5.0
UIC Rail Diesel, main locomotives	g/kg	64.7	1.15
DB 2008	g/kg	48.3	1.35
Canada 2003	g/kg	63.9	1.4
Default EcoTransIT World 2010	g/kg	48.3	1.3
	kg/TJ	1,126	31

It was assumed that the German emission factors (Deutsche Bahn) for $PM_{2.5}$ and NO_x are the most representative for the EU diesel locomotive fleet. SO_2 emission factors for 2009 were based on the Dutch average (CBS, 2011a).

For 2020, it was assumed that the diesel locomotive fleet will have the same age distribution as in 2009. Due to renewal of locomotives and engines and tightened emissions standards (stage IIIB), emission factors will be lower than in 2010. On the basis of a simplified fleet model, we assume that emission factors for NO_x and PM will be 28 and 27% lower than in 2009 respectively. The emission factors for Diesel trains in 2009 and 2020 are shown in Table 17.

Table 17 **Pollutant emission factors of rail diesel engines (g/MJ fuel)**

CO_2 g/MJ		NO_X g/MJ		$PM_{2.5}$ g/MJ		SO_2 g/MJ	
2009	2020	2009	2020	2009	2020	2009	2020
73.6	73.6	1.12	0.81	0.031	0.023	0.022	0.0005

The exhaust emission of electric trains are zero. The upstream emissions per vehicle-kilometre both for electric and diesel trains are discussed in Chapter 3.7.

3.3.3 Wear and tear PM_{10} emissions

PM_{10} emissions for trains are caused by wear and tear of brakes, rail track, wheels and overhead lines. Data sources on the these emission are limited. According to INFRAS, 2007 in Switzerland in 2004 the total PM_{10} emission from freight rail transport amounted to 478 tonne (Table 18).

Table 18 **Non-exhaust PM_{10} emissions rail transport in Switzerland in 2004**

Source	Non-exhaust PM_{10} emissions for rail in Switzerland 2004			
	Passenger transport	Freight transport	Sum	
	Tonne/annum	Tonne/annum	Tonne/annum	%
Brakes	345	264	618	60%
Rail track	90	49	139	14%
Wheels	82	160	242	24%
Overhead wire	20	5	25	2%
Total	546	478	1024	100%
Share	53%	47%	100%	

Taking into account the total vehicle-kilometres by freight trains in Switzerland (31 million km in 2008, source: UIC) the wear and tear PM_{10} emissions for an average electric freight train are estimated at 15.4 gram per vehicle-kilometre. For diesel trains the emissions for overhead lines (2%) are substracted to give an emission factor of 15.1 gram PM_{10} per vehicle-kilometre. As for road, it is assumed that the PM_{10} emission vary linearly with the energy consumption of the train. The resulting emission factors are depicted in Table 19.

Table 19 **PM_{10} emission factors (wear and tear) for trains**

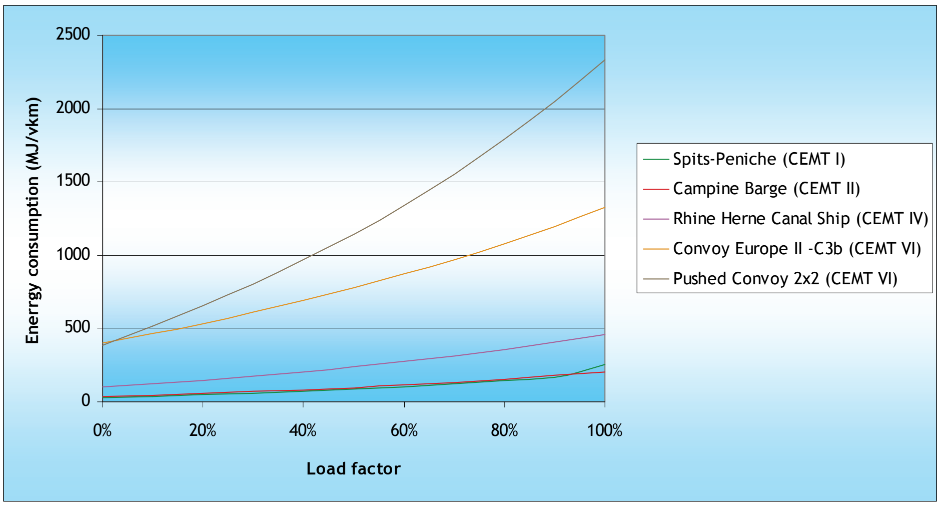
	PM_{10} emission factor
Electric train (g/MJ-electric)	0.29
Diesel train (g/MJ-diesel)	0.11

3.4 Inland waterways transport

3.4.1 Energy consumption

For all pollutants, the emission factors per vehicle-kilometre of inland waterway (IWW) vessels are calculated from the energy consumption per vehicle-kilometre, using emission factors per Mega Joule (see Section 3.4.2). The energy consumption data of the IWW vessels have been modelled using the inland waterway model developed by TNO and the Dutch Ministry of Infrastructure and Environment (see for model description AVV, 2003a). Inputs for the model are data on the IWW vessels (e.g. dimensions, speed, load) and data on the waterways (e.g. cross-section waterway and velocity of flow). The influence of the load on the energy consumption per vehicle-kilometre is illustrated in Figure 3 for several ship categories.

Figure 3 **Influence of the load on the energy consumption for several ship categories**



For every ship the energy consumption for (partly) loaded trips (EC_L) and empty trips (EC_U) have been determined according to the model. Similarly as for trains, the average energy consumption (EC_{vkm}) over loaded and unloaded trips is calculated by:

$$EC_{vkm} = LKF \times EC_L + (1-LKF) \times EC_U$$

With:
LFK: The loaded kilometre factor
Table 20 and Table 21 give an overview of energy consumption per vehicle-

kilometre (MJ/vkm) for bulk & general cargo and container transport respectively. The energy consumption values are based on the logistic parameters described in Chapter 4. The values include a 7% add-on for the energy consumption of the bow thruster on base of AVV, 2003b.

For 2020 an autonomous energy efficiency increase of engines is assumed, lowering energy use by 5% in 2020 (AEA, 2010).

Table 20 Energy consumption IWW vessels for bulk and general cargo on different waterways (MJ/vkm)*

Ship type	Canal type/ river	Year 2009			Year 2020		
		Voluminous cargo	Average cargo	Heavy cargo	Voluminous cargo	Average cargo	Heavy cargo
Spits-Peniche	CEMT I	79	100	133	75	95	126
	CEMT V	68	79	93	64	75	88
	CEMT VI	63	72	82	59	68	78
	River Waal	58	66	76	55	63	72
Campine Barge	CEMT II	92	112	147	87	107	139
	CEMT V	103	120	141	98	114	134
	CEMT VI	99	113	129	94	107	122
	River Waal	102	115	130	97	110	123
Rhine Herne Canal Ship	CEMT IV	224	271	344	213	257	327
	CEMT V	228	270	327	217	256	311
	CEMT VI	249	283	322	236	269	306
	River Waal	215	242	274	204	230	261
Large Rhine Ship	CEMT V	383	469	615	364	445	585
	CEMT VI	406	465	541	386	442	514
	River Waal	412	458	514	391	435	489
Convoy Europe II-C3b	CEMT VI	719	832	986	683	791	936
	River Waal	597	672	783	567	638	744
Pushed Convoy 2x2	CEMT VI	1,027	1,372	1,667	976	1,303	1,584
	River Waal	969	1,220	1,430	921	1,159	1,359
Pushed Convoy 3x2	CEMT VI	1,205	1,570	1,929	1,145	1,492	1,832
	River Waal	1,042	1,274	1,482	990	1,210	1,408

* See Chapter 4 for the logistic parameters on which the values are based.

Table 21 Energy consumption IWW vessels for containerised cargo on different waterways (MJ/vkm)*

Ship type	Canal type/river	Year 2009			Year 2020		
		Voluminous cargo	Average cargo	Heavy cargo	Voluminous cargo	Average cargo	Heavy cargo
Neo Kemp (48 TEU)	CEMT III	116	145	176	110	138	167
	CEMT V	127	153	178	120	145	169
	CEMT VI	150	177	201	143	168	191
	River Waal	127	147	166	121	140	158
Rhine Herne Canal Ship (96 TEU)	CEMT IV	251	314	380	238	298	361
	CEMT V	260	317	374	247	301	356
	CEMT VI	283	331	375	269	314	357
	River Waal	238	272	304	226	259	289
Pushed convoy (160 TEU)	CEMT V	266	338	409	253	321	389
	CEMT VI	363	447	525	345	424	498
	River Waal	314	381	440	298	362	418

Ship type	Canal type/river	Year 2009			Year 2020		
		Voluminous cargo	Average cargo	Heavy cargo	Voluminous cargo	Average cargo	Heavy cargo
Container Ship Rhine (200 TEU)	CEMT V	303	382	464	288	363	441
	CEMT VI	362	428	492	344	407	467
	River Waal	293	336	374	279	319	355
Long large Rhine ship (272 TEU)	CEMT V	382	476	574	363	452	546
	CEMT VI	441	515	586	419	489	557
	River Waal	351	397	438	333	377	416
Rhinemax Ship (470 TEU)	CEMT VI	786	945	1,105	746	898	1,050
	River Waal	560	636	707	532	604	671

* See Chapter 4 for the logistic parameters on which the values are based.

3.4.2 Emission factors Inland Waterway

Emission factors for 2009 for inland waterways are based on Dutch statistics (CBS, 2011a).
For 2020 emission factors of SO_2, $PM_{2.5}$ and NO_x are expected to drop.
SO_2 emissions will drop due to the 10 ppm sulphur standard for IWW diesel as from 2011. On base of the introduction of Phase IV legislation and on base of a IWW park model NO_x and $PM_{2.5}$ emissions are expected to drop 20 and 28%, respectively (Table 22). The emission factors for 2009 and 2020 are depicted in Table 23.

Table 22 Changes in energy consumption and emission factor between 2009 and 2020

	Ratio emissions/ consumption 2010/2020	Source
MJ/km	95%	AEA, 2010
CO_2	100%	
SO_2	1,1%	EU legislation
$PM_{2.5}$	72%	CE, 2008
NO_x	80%	CE, 2008

Table 23 Emission factors IWW 2009 and 2020

CO_2 g/MJ		NO_x g/MJ		$PM_{2.5}$ g/MJ		SO_2 g/MJ	
2009	2020	2009	2020	2009	2020	2009	2020
73,6	73,6	1,039	0,863	0,039	0,028	0,041	0,0005

Source: CBS, 2011a, Table 18.

3.5 Maritime transport

3.5.1 Energy consumption for 2009 and 2020

Maritime transport emission factors have been developed on the basis of the second IMO GHG study (IMO, 2009). This study provides a database with information on the fuel consumption of different categories and sizes of ships.

The fuel consumption of ships has been calculated by taking the following factors into account:
- Main engine power (P, in kW).
- Average engine load (El, in %).
- Specific fuel consumption (Fc, in kg/kWh).
- Average operating speed (V in km/h).
- Energy density of heavy fuel oil (ED, 40.5 MJ/Kg).

The fuel consumption was calculated (in MJ/vkm) by the following formula:

$$fuel\ consumption = \frac{P \times El \times Fc \times ED}{V}$$

In addition, a correction was made for the energy consumption of boilers and auxiliary engines by increasing the energy consumption using the correction factors in Table 24.

Table 24 **Correction factors giving the share of Maritime Diesel oil (MDO) consumption as percentage of heavy fuel oil consumption for different ships**

Ship type	Correction factor
Crude oil tanker 0-9,999 dwt	73%
Crude oil tanker 10,000-59,999 dwt	40%
Crude oil tanker 80,000-119,999 dwt	34%
Products tanker 0-4,999 dwt	80%
Products tanker 5,000-10,000 dwt	73%
General Cargo 0-4,999 dwt	36%
General Cargo 5,000-10,000 dwt	21%
Bulk carrier (feeder) 0-9,999 dwt	38%
Bulk carrier (handysize) 10,000-35,000 dwt	14%
Bulk carrier (handymax) 35,000-59,999 dwt	11%
Container (feeder) 0-999 TEU	27%
Container (like handysize) 1,000-1,999 TEU	15%
Container(like handymax) 2,000-2,999 TEU	15%
Container (like panamax) 3-4,999 TEU	12%
Container (like aframax) 5-7,999 TEU	13%
Container (like suezmax) > 8,000 TEU	13%

Source: Elaboration of IMO (2009).

Table 25 and Table 26 give an overview of the energy consumption per vehicle-kilometre. It is assumed that the energy consumption is not affected by the load as empty ships carry extra ballast water.
On the basis of IMO (2009), we assume a 2% lower fuel consumption improvement for the 2009-2020 period as a result of technical improvement and a speed reduction of 10% for container ships and 5% for all other ships.

Table 25 **Energy consumption per vehicle-kilometre of sea going ships for bulk and average cargo (MJ/vkm)**

	2009	2020
Crude oil tanker 0-9,999 dwt	779	726
Crude oil tanker 10,000-59,999 dwt	2,266	2,119
Crude oil tanker 80,000-119,999 dwt	3,969	3,714
Products tanker 0-4,999 dwt	491	458
Products tanker 5,000-10,000 dwt	1,230	1,147
General Cargo 0-4,999 dwt	323	302
General Cargo 5,000-10,000 dwt	950	891
Bulk carrier (feeder) 0-9,999 dwt	558	522
Bulk carrier (handysize) 10,000-35,000 dwt	1,528	1,435
Bulk carrier (handymax) 35,000-59999 dwt	1,893	1,778

Source: Elaboration of IMO (2009).

Table 26 **Energy consumption per vehicle-kilometre of sea going ships for containerised cargo (MJ/vkm)**

	2009	2020
Container (feeder) 0-999 TEU	1,180	1,105
Container (like handysize) 1,000-1,999 TEU	2,078	1,950
Container(like handymax) 2,000-2,999 TEU	3,404	3,195
Container (like panamax) 3-4,999 TEU	4,410	4,140
Container (like aframax) 5-7,999 TEU	6,188	5,809
Container (like suezmax) > 8,000 TEU	7,925	7,440

Source: Elaboration of IMO (2009).

3.5.2 Emission factors Maritime transport for 2009

The NO_x emissions have been estimated on the basis of the share of ships built before and after 2000 and the corresponding emission factors. The average age significantly differs over ship types. The average age of big size container ships is two years, while the average age of small tankers is 22 years on average. (IMO, 2009) Assuming that all ships are equally distributed over a lifetime of zero and two times the average lifetime, it was assessed which part of the ships were built before and after 2000. By using the emission factors from Table 27, the average NO_x emission factor per ship type and size was calculated.

Generally slow speed engines are used for the propulsion of ships. Auxiliary engines have a higher rated speed. Therefore, for main engines emission factors for slow speed engines (SS) were used, while for auxiliary engines emission factors for middle speed engines (MS) were used. The emission factors are given in Table 27.

Table 27 **NO_x emission factors of ship engines (g/kg fuel)**

	Tier 0 (<2000)	Tier I (2000-2010)	Tier II (>2010)
SS (slow speed)	90	78	63
MS (middle speed)	60	51	41

Source: IMO, 2009.

The SO_x emissions depend on the sulphur content of the fuel used. Therefore, PM emissions were calculated on the basis of the fuel sulphur content that applies to the sulphur ECA. In 2009, the average sulphur content in the ECA was 1,5% S. In addition, we assume that MDO (0,5% S) was used by auxiliary engines and in boilers.

The $PM_{2.5}$ emissions have been estimated by TNO (2006) as function of the sulphur content of the fuel. The data, shown in Table 28, are the result from field measurements in the port of Rotterdam area by TNO.

Table 28 $PM_{2.5}$ emissions as function of the fuel and engine type (g/kg fuel)

	S content 0.1%	S content 1.5%	MDO
2-stroke	3.5	5	
4-stroke	1	5	2

Source: TNO, 2006.

3.5.3 Emission factors maritime transport for 2020

For 2020 several developments were taken into account:
- Autonomous fleet renewal.
- Fleet growth due to economic growth.
- Slow steaming.
- Energy efficiency improvements.
- IMO and EU regulations on air pollutants.

With autonomous fleet renewal, shipping emissions will decrease due to tightened IMO Annex VI limit values for NO_x and lower fuel sulphur levels. For this study we took the regulations that will apply to the North Sea as a starting point for the analysis. This means a Tier II limit value for new ship engines and a fuel sulphur content of 0,1% S.

Maritime transport is expected to grow significantly in the next decades. A significant number of new ships will be put on the market, reducing the average pollutant emission level of ships. A moderate growth scenario (scenario 1AB from IMO, 2009) was used.

To calculate the air pollutant emission levels in 2020, it was assumed that 33% of the ships will be replaced by new ships if minimal 33% of the ships was built before 2000. In case a smaller share of the ships was built before 2000, we assumed a lower rate of renewal. For big size container ships, the average age of the fleet is low at the moment, as indicated above. Therefore we assumed that only ships built before 2000 will be replaced by 2020. In addition, for new ships an emission level of Tier II was assumed.

Table 29 gives an overview of the emission factors for 2009 and 2020.

Table 29 **Emission factors (g/MJ) for different ship types in 2009 and 2020 considering a mix of HFO and MDO**

	CO_2		SO_2		$PM_{2.5}$		NO_x	
	2009	2020	2009	2020	2009	2020	2009	2020
Bulk and general cargo								
Crude oil tanker 0-9,999 dwt	76.0	76.8	0.26	0.02	0.09	0.06	1.81	1.59
Crude oil tanker 10,000-59,999 dwt	76.3	76.8	0.30	0.02	0.10	0.07	1.91	1.72
Crude oil tanker 80,000-119,999 dwt	76.3	76.8	0.31	0.02	0.10	0.07	1.88	1.62
Products tanker 0-4,999 dwt	76.0	76.8	0.26	0.02	0.09	0.06	1.80	1.59
Products tanker 5,000-10,000 dwt	76.0	76.8	0.26	0.02	0.09	0.06	1.81	1.49
General cargo 0-4,999 dwt	76.3	76.8	0.30	0.02	0.10	0.07	1.95	1.71
General cargo 5,000-10,000 dwt	76.5	76.8	0.33	0.02	0.11	0.08	2.02	1.56
Bulk carrier (feeder) 0-9,999 dwt	76.3	76.8	0.30	0.02	0.10	0.07	1.94	1.69
Bulk carrier (handysize) 10,000-35,000 dwt	76.6	76.8	0.34	0.02	0.11	0.08	2.06	1.83
Bulk carrier (handymax) 35,000-59,999 dwt	76.6	76.8	0.34	0.02	0.12	0.08	2.04	1.75
Containerised cargo								
Container (feeder) 0-999 TEU	76.4	76.8	0.32	0.02	0.11	0.07	1.95	1.73
Container (like handysize) 1,000-1,999 TEU	76.6	76.8	0.34	0.02	0.11	0.08	2.00	1.70
Container(like handymax) 2,000-2,999 TEU	76.6	76.8	0.34	0.02	0.11	0.08	2.00	1.74
Container (like panamax) 3-4,999 TEU	76.6	76.8	0.34	0.02	0.12	0.08	1.99	1.66
Container (like aframax) 5-7,999 TEU	76.6	76.8	0.34	0.02	0.11	0.08	1.89	1.60
Container (like suezmax) > 8,000 TEU	76.6	76.8	0.34	0.02	0.11	0.08	1.85	1.50

3.6 Electricity production

The transport chain not only comprises vehicle movements, but also mining and transport of energy sources and refining of fuels and the production of electricity.

The emission factors of electricity production depend on the mix of energy source used an differs significantly over Europe. Eurelectric (2009) provides an overview of power production and emission figures for different EU countries. On the basis of emissions and production figures, emission factors for different countries were calculated, see Table 30.

Table 30 **Emission factors of different countries and pollutants (g/kWh)**

	CO_2		NO_X		SO_2	
	2009	2020	2009	2020	2009	2020
NL	557	427	0.51	0.36	0.17	0.14
UK	575	481	1.23	0.85	1.02	0.39
IT	425	392	0.38	0.30	0.39	0.30
DE	482	495	0.34		0.26	
FR	53	43				
ES	297	225	0.65	0.16	1.03	0.28
PO	846	755	1.23	0.74	2.02	1.16
SE	12	9	0.03	0.03	0.02	0.02
RO	445	366	1.02	0.57	3.66	0.71
BG	626	361	0.99	0.57	11.57	6.66
CZ	465	461	0.61	0.60	0.63	0.60
HU	467	433	0.51	0.46	0.26	0.21

Source: Eurelectric, 2009.

As can be seen from Table 30, the differences between individual countries are significant. This is the result of both a difference in the energy sources and emission reduction technologies applied.

For this study values for the annual European Community LRTAP[8] convention emissions report were used (EEA, 2009). The emission factors include upstream emissions. The power plant emissions were increased by 5 g CO_2/kWh for the emissions of mining and transportation. The pollutant emissions of mining and transportation are negligible, compared to the emission caused by the burning of the fuel (CE, 2008).

The emission factors correspond with the mandatory limit values (BAT (Best Available Techniques values) from the EU large combustion plant Directive (2001/80).

In some countries, electricity is produced in power plants producing both electricity and heat. On the basis of IFEU, 2010 and own expertise we estimate that 5% of the emissions can be allocated to heat production.

Table 31 Electricity production emission factors used for this study

G/kwh	CO_2	$PM_{2.5}$	NO_x	SO_2
2009	421	0.03	0.52	0.91
2020	329	0.02	0.39	0.62

Source: Eurelectric, 2009; EEA, 2008; EC, 2010: values for 2009 are based on data for 2008 and assumed to be the same.

Upstream emission per vehicle-kilometre of electric trains are calculated as the product of the emission factors in Table 31 and the energy consumption of electric trains (in MJ/vkm, Table 14, Table 15) divided by 3.6 (kWh-MJ conversion).

3.7 Fuel refining

The air pollutant emissions from fuel refining are extracted from the Ecoinvent database. The data apply to the year 2000. However, in the period between 2000 and 2009, the IPCC Directive came into play, that enforcers pollution control from major industrial installations, such as oil refineries. The Directive states that to achieve the required level of protection of the environment, Best Available Techniques (BAT) are to be used. Therefore, a correction factor has been applied that takes into account the reduction of emissions in the 2000-2009 period, per unit of fuel produced. This correction factor has been based on statistics from IEA (2011) production figures and refining emission statistics as produced by the European Community LRTAP convention emissions report (EEA, 2009). To define at 2009 figures, the 2000 emission figures have been down-scaled by the scale factors shown in Table 32.

[8] LRTAP stands for Convention on Long-range Transboundary Air Pollution.
It is an Intergovernmental programme aimed at reducing transboundary air pollution.
Monitoring is one of the activities under the programme.
See http://www.unece.org/env/lrtap/lrtap_h1.htm

Table 32 **Scale factor for 2009 per pollutant**

Pollutant	Scale factor for year 2009 (2000 = 100%)
NO_x	95%
SO_x	77%
PM	60%

Source: IEA, 2011; EEA, 2009.

The CO_2 emissions of the upstream oil processes depend strongly on the type of oil used. Flaring of natural gas, fugitive emissions and API (American Petroleum Institute) gravities, dictate the CO_2 emissions of oil extraction. GHG emissions for tar sands are substantially higher than for conventional fuels. ICCT (2010) recognises three types of heavy fuel oil: tar sands, conventional with flaring and without flaring. Their average extraction-to-refining GHG emissions are 30, 20 and 8 g CO_2 eq./MJ fuel respectively. For this study we calculate with the weighted average figure of 12 g/MJ fuel.

In Table 33, an overview of the refining emission factors used is shown.

Table 33 **Overview of refining emissions factors (2009)**

	Diesel	Heavy fuel oil (HFO)	Unit
CO_2	0.51	0.45	kg/kg
SO_2	3.3	3.1	g/kg
$PM_{2.5}$	134	124	mg/kg
NO_x	1.7	1.6	g/kg

Source: Ecoinvent/ICCT, 2010.

The air pollutant emission factors for 2020 are assumed to be 25% lower, compared to 2009. The updated IPCC Directive and the to be decided emission ceilings under the Gothenburg Protocol and the NEC Directive might contribute to this.

Regarding GHG emissions, a reduction of the GHG emissions of 6% at minimum is foreseen for 2020 by Directive 2009/30. We assume this figure to be representative for fuel efficiency improvements during the 2009-2020 period in the extraction-to-refining process.

Table 34 **Overview of refining emissions factors (2020)**

	Diesel	Heavy fuel oil (HFO)	Unit
CO_2	0.48	0.42	kg/kg
SO_2	2.49	2.29	g/kg
$PM_{2.5}$	100	93	mg/kg
NO_x	1.26	1.19	g/kg

Source: Ecoinvent; IEA, 2011; EEA, 2009.

Table 35 gives an overview of the emission factors in gram per mega Joules. Having the average energy consumption per vehicle-kilometre of the different modes the upstream emission can be calculated by the product of the energy consumption and the emission factors in Table 35.

Table 35 Upstream (WTT) emission factors of Diesel and HFO

Upstream Diesel				
g/MJ	CO_2	SO_2	$PM_{2.5}$	NO_x
2009	11.833	0.077	0.003	0.039
2020	11.137	0.058	0.002	0.029
Upstream HFO				
g/MJ	CO_2	SO_2	$PM_{2.5}$	NO_x
2009	10.441	0.072	0.003	0.037
2010	9.745	0.053	0.002	0.028

3.8 Energy consumption of loading and unloading (transhipping)

Emissions of Loading and unloading play a role in multimodal transport. These emissions should be considered when transport options are considered that require additional transhipping as compared to other options. The energy consumption values below are taken from IFEU, 2010. For container transfer the higher value from IFEU, 2010 has been taken as container terminal ECT suggested higher values for container transfer (ECT, 2011) than reported by IFEU, 2010.

- Container: 8.8 kWh per transfer process; assuming an average of 1.7 TEU per container this corresponds to 4.6 kWh/TEU (16.8 MJ_{el}/TEU).
- Liquid cargo: 0.4 kWh/tonne (1.4 MJ_{el}/tonne).
- Bulk cargo: 1.3 kWh/tonne (4.7 MJ_{el}/tonne).
- Other cargo: 0.6 kWh/tonne (2.2 MJ_{el}/tonne).

Emission factors for transhipping are obtained by applying the emission factors for electricity (Section 3.6).

4 Logistics data

4.1 Introduction

As explained in Section 2.7 the load capacity and utilisation factor determine the emissions per tonne-kilometre. The utilisation factor is defined as the product of the load factor of loaded trips and the share of loaded vehicle-kilometres (loaded kilometre factor).

On the one hand the load factor of a vehicle has a limited influence on the emission per vehicle-kilometre as explained in Chapter 3. Much stronger is the influence of the load on the performance in terms of tonne-kilometres. As the emission per vehicle-kilometre increases by ca. 20% going from a half-loaded to full-loaded truck, the tonne-kilometres are doubled. As a consequence the emissions per tonne-kilometre are reduced by 40% percent for this case. Empty kilometres do not add any performance in terms of tonne-kilometre, but do contribute to the emissions and therefore increase the emission per tonne-kilometre.

Data on loading factors, loaded trip factors (or empty trip factors) and/or utilisation factors are reported by Eurostat and national statistics. The data quality and completeness, however, varies between the various modes and mostly only average logistic data are given. A comparison between modes on base of average loading data does not take into account the fact that the different modes operate in different markets. Utilisation factors in the different market segments differ; bulk cargo is much more transported by rail than by road.

As the load factor and the share in loaded kilometres strongly influence the outcome of the emissions per tonne-kilometre a consultation round amongst different Dutch transport associations, hauliers and consultants has been made. Load factors, loaded kilometre factors and utilisation factors were proposed for the defined vehicle categories and markets (volume, average, heavy) based on CE, 2008; IFEU, 2010; IMO, 2009 and Eurostat and presented to the stakeholders. The stakeholders' comments have been processed, resulting into a consistent set of logistic data. In the following two paragraphs the resulting logistic data are presented for bulk and general cargo, and containerised cargo.

4.2 Bulk and general cargo

Table 36-Table 38 give an overview of the load parameters used in this study for voluminous, average and heavy cargo. The product of the utilisation factor and the load capacity gives the average load on a return trip (last column). For maritime shipping only utilisation factors are given as these data were not split up into load factors and loaded kilometre factors. As the energy consumption per vehicle-kilometre of maritime shipping is assumed to be in independent of the load factor, these data are not needed to determine the energy consumption per tonne-kilometre.

Table 36 Load parameters voluminous cargo (< 0.4 kg/litre; devices, furniture, mail, textiles, automobiles, designed products)

Vehicle type	Load capacity (tonne)	Load factor loaded trips (LF)	Loaded kilometre factor (LKF)	Utilisation factor (UF)	Average load (incl. full and empty trips) (tonne)
Road					
Small van < 2 tonne	0.7	30%	60%	**18%**	0.13
Large van > 2 tonne	1.2	30%	60%	**18%**	0.22
Truck < 10 tonne	3	30%	75%	**23%**	0.6
Truck 10-20 tonne	8	40%	80%	**32%**	3
Truck > 20 tonne	16	40%	80%	**32%**	5
Truck trailer	26	40%	80%	**32%**	8
LHV	39.5	40%	80%	**32%**	13
Rail					
Short train (22 wagons length 14 à 15 m)	594	40%	83%	**33%**	197
Medium train (33 wagons length 14 à 15 m)	891	40%	83%	**33%**	296
Long train (44 wagons length 14 à 15 m)	1,188	40%	83%	**33%**	394
Inland shipping					
Spits-Peniche	350	43%	80%	**34%**	120
Campine Barge	550	43%	80%	**34%**	189
Rhine Herne Canal Ship	1,350	43%	80%	**34%**	464
Large Rhine Ship	3,013	43%	80%	**34%**	1,036
Convoy Europe II-C3b	5,500	43%	80%	**34%**	1,892
Pushed Convoy 2x2	12,000	43%	85%	**37%**	4,386
Pushed Convoy 3x2	18,000	43%	82%	**35%**	6,347
Maritime shipping					
Crude oil tanker 0-9,999 dwt	3,668	-	-	**NA**	NA
Crude oil tanker 10,000-59,999 dwt	38,361	-	-	**NA**	NA
Crude oil tanker 80,000-119,999 dwt	103,403	-	-	**NA**	NA
Products tanker 0-4,999 dwt	1,800	-	-	**NA**	NA
Products tanker 5,000-10,000 dwt	7,000	-	-	**NA**	NA
General Cargo 0-4,999 dwt	2,545	-	-	**29%**	738
General Cargo 5,000-10,000 dwt	6,957	-	-	**29%**	2,018
Bulk carrier (feeder) 0-9,999 dwt	2,400	-	-	**NA**	NA
Bulk carrier (handysize) 10,000-35,000 dwt	26,000	-	-	**NA**	NA
Bulk carrier (handymax) 35,000-59,999 dwt	45,000	-	-	**NA**	NA

NA: Not applicable.
-: Not available.

Table 37 Load parameters average cargo (0.5-1.2 kg/litre; i.e. food products, wood, paper, plastics, chemicals, metal products, waste, oil, coals, cokes)

Vehicle type	Load capacity (tonne)	Load factor loaded trips (LF)	Loaded kilometre factor (LKF)	Utilisation factor (UF)	Average load (incl. full and empty trips) (tonne)
Road					
Small van < 2 tonne	0.7	35%	60%	**21%**	0.15
Large van > 2 tonne	1.2	35%	60%	**21%**	0.25
Truck < 10 tonne	3	35%	70%	**25%**	0.6
Truck 10-20 tonne	8	60%	75%	**45%**	4
Truck > 20 tonne	16	60%	75%	**45%**	7
Truck trailer	26	60%	75%	**45%**	12
LHV	39.5	60%	75%	**45%**	18
Rail					
Short train (22 wagons length 14 à 15 m)	935	80%	55%	**44%**	411
Medium train (33 wagons length 14 à 15 m)	1,403	80%	55%	**44%**	617
Long train (44 wagons length 14 à 15 m)	1,870	80%	55%	**44%**	823
Inland shipping					
Spits-Peniche	350	60%	75%	**45%**	158
Campine Barge	550	60%	75%	**45%**	248
Rhine Herne Canal Ship	1,350	60%	75%	**45%**	608
Large Rhine Ship	3,013	60%	75%	**45%**	1,356
Convoy Europe II-C3b	5,500	60%	75%	**45%**	2,475
Pushed Convoy 2x2	12,000	65%	80%	**52%**	6,240
Pushed Convoy 3x2	18,000	65%	77%	**50%**	9,009
Maritime shipping					
Crude oil tanker 0-9,999 dwt	3,668	-	-	**48%**	1,761
Crude oil tanker 10,000-59,999 dwt	38,361	-	-	**48%**	18,413
Crude oil tanker 80,000-119,999 dwt	103,403	-	-	**48%**	49,633
Products tanker 0-4,999 dwt	1,800	-	-	**45%**	810
Products tanker 5,000-10,000 dwt	7,000	-	-	**45%**	3,150
General Cargo 0-4,999 dwt	2,545	-	-	**60%**	1,527
General Cargo 5,000-10,000 dwt	6,957	-	-	**60%**	4,174
Bulk carrier (feeder) 0-9,999 dwt	2,400	-	-	**60%**	1,440
Bulk carrier (handysize) 10,000-35,000 dwt	26,000	-	-	**55%**	14,300
Bulk carrier (handymax) 35,000-59,999 dwt	45,000	-	-	**55%**	24,750

-: Not available.

Table 38 Load parameters heavy cargo (> 1.3 kg/litre; ores, minerals, metals, sand, stones)

Vehicle type	Load capacity (tonne)	Load factor loaded trips (LF)	Loaded kilometre factor (LKF)	Utilisation factor (UF)	Average load (incl. full and empty trips) (tonne)
Road					
Small van < 2 tonne	0.7	NA	NA	**NA**	NA
Large van > 2 tonne	1.2	NA	NA	**NA**	NA
Truck < 10 tonne	3	NA	NA	**NA**	NA
Truck 10-20 tonne	8	98%	55%	**54%**	4
Truck > 20 tonne	16	98%	55%	**54%**	9
Truck trailer	26	98%	55%	**54%**	14
LHV	39.5	98%	55%	**54%**	21
Rail					
Short train (22 wagons length 14 à 15 m)	1,276	98%	55%	**54%**	688
Medium train (33 wagons length 14 à 15 m)	1,914	98%	55%	**54%**	1032
Long train (44 wagons length 14 à 15 m)	2,668	98%	55%	**54%**	1438
Inland shipping					
Spits-Peniche	350	90%	60%	**54%**	189
Campine Barge	550	90%	60%	**54%**	297
Rhine Herne Canal Ship	1,350	90%	60%	**54%**	729
Large Rhine Ship	3,013	90%	60%	**54%**	1,627
Convoy Europe II-C3b	5,500	90%	60%	**54%**	2,970
Pushed Convoy 2x2	12,000	90%	65%	**59%**	7,020
Pushed Convoy 3x2	18,000	90%	65%	**59%**	10,530
Maritime shipping					
Crude oil tanker 0-9,999 dwt	3,668	-	-	**NA**	NA
Crude oil tanker 10,000-59,999 dwt	38,361	-	-	**NA**	NA
Crude oil tanker 80,000-119,999 dwt	103,403	-	-	**NA**	NA
Products tanker 0-4,999 dwt	1,800	-	-	**NA**	NA
Products tanker 5,000-10,000 dwt	7,000	-	-	**NA**	NA
General Cargo 0-4,999 dwt	2,545	-	-	**NA**	NA
General Cargo 5,000-10,000 dwt	6,957	-	-	**70%**	4,870
Bulk carrier (feeder) 0-9,999 dwt	2,400	-	-	**70%**	1,680
Bulk carrier (handysize) 10,000-35,000 dwt	26,000	-	-	**65%**	16,900
Bulk carrier (handymax) 35,000-59,999 dwt	45,000	-	-	**65%**	29,250

NA: Not applicable.
-: Not available

4.3 Containers

For container transport the utilisation of the TEU capacity and the share of loaded container units is assumed to be the same for the different market segment (volume average and heavy), as light and heavy containers are mostly shipped simultaneously. The load parameters for the containers are presented in Table 39.

Table 39 **Load parameters for container transport**

Mode and vehicle type	Container unit Capacity (TEU/vehicle) (CC)	Utilisation TEU capacity (Loaded TEU/TEU capacity) (UC)	Share of loaded containers units (SLC)
Road			
Truck > 20 ton	1.2	85%	75%
Truck trailer	2	85%	75%
LHV	3	85%	75%
Rail			
Short train	45	85%	65%
Medium train	70	85%	65%
Long train	90	85%	65%
Inland waterways			
Neo Kemp	48	85%	55%
Rhine Herne Canal Ship	96	85%	55%
Pushed convoy	160	85%	55%
Container Ship Rhine	200	85%	55%
Long large Rhine ship	272	85%	55%
Rhinemax Ship	470	85%	55%
Maritime shipping			
Container Ship (feeder) 0-999 TEU	500	70%	60%
Container Ship (like handysize) 1,000-1,999 TEU	1,414	70%	60%
Container Ship (like handymax) 2,000-2,999 TEU	2,400	70%	60%
Container Ship (like panamax) 3-4,999 TEU	4,112	70%	60%
Container Ship (like aframax) 5-7,999 TEU	5,765	70%	60%
Container Ship (like suezmax) > 8,000 TEU	9,800	70%	60%

The market segmentation is based on the different load per container. Table 40 gives an overview of the assumed loads and empty weights of the containers per market segments.

Table 40 Load and empty weight for volume, average and heavy containers

Weight class	Load per container*	Container weight*
Volume	6 tonne/TEU[9]	1.9 tonne/TEU
Average	10.5 ton/TEU	1.95 tonne/TEU
Heavy	14.5 ton/TEU	2.0 tonne/TEU

* Based on IFEU, 2010.

[9] TEU: Twenty feet Equivalent Unit; Container volume capacity expressed in the volume of a twenty feet container.

5 Emission factors for the different modes

5.1 Introduction

In this chapter, we report the emission factors for the different individual modes, by dividing the emissions estimated per vehicle-kilometre and the weight of the goods shipped, The resulting emission factors can be used for e.g. carbon foot printing and *NOT* for a comparison between modes.

The presented data in this chapter is without pre- and end-haulage and without detouring that plays a role when comparing the different modes.

For comparison of emission factors, total transport chains need to be taken into account, including pre- and end-haulage and detouring. This is discussed in Chapter 6.

For road the average emission factors are based on the road type shares presented in Table 41.

Table 41 Share of road types for different vehicles types

	Urban	Non-Urban	Motorway
Vans	40%	30%	30%
Trucks	12%	31%	57%
Truck-trailer	10%	15%	75%

Source: Taakgroep 2009/CE Delft.

The emission factors for container transport are expressed per loaded tonne-kilometre. As a consequence, empty containers are not included.

Rail and particularly inland waterways are used to a greater extent than road to reposition empty containers. The average container (full and empty) in rail and inland waterway transport therefore contains less cargo. The difference in the average container load comes to expression in the emission factors per tone-kilometre.
Another option is to express the emission factors per TEU-km to give container transport efficiency regardless of the load in the containers. The difference between this approach and the emissions per tonne-kilometre is further elaborated in Annex B.

5.2 Emission factors bulk and general cargo 2009

Table 42 Emission factors tank-to-wheel and well-to-wheel for voluminous bulk and general cargo transport for 2009

		Capacity	TTW	TTW emissions (g/tkm)				WTW emission (g/tkm)			
Vehicle type	Infrastructure	Load capacity (tonne)	MJ/tkm	CO_2	SO_2	$PM_{2.5}$	NO_x	CO_2	SO_2	$PM_{2.5}$	NO_x
Road											
Small van < 2 tonne	Average	0.7	26	1,938	0.015	0.78	6.4	2,251	2.0	0.86	7.5
	Urban	0.7	31	2,250	0.017	1.00	8.0	2,613	2.4	1.10	9.3
	Non-urban	0.7	20	1,457	0.011	0.53	4.8	1,692	1.5	0.59	5.6
	Motorway	0.7	27	2,005	0.015	0.73	5.9	2,328	2.1	0.82	7.0
Large van > 2 tonne	Average	1.2	18	1,320	0.0100	0.52	4.3	1,533	1.4	0.58	5.0
	Urban	1.2	21	1,531	0.012	0.66	5.4	1,778	1.6	0.73	6.2
	Non-urban	1.2	14	991	0.0075	0.35	3.3	1,151	1.0	0.40	3.8
	Motorway	1.2	19	1,367	0.0104	0.50	3.9	1,588	1.4	0.56	4.6
Truck < 10 tonne	Average	3	9.5	693	0.0053	0.13	5.5	805	0.7	0.16	5.9
	Urban	3	12	859	0.0065	0.23	6.8	998	0.9	0.27	7.3
	Non-urban	3	8.9	652	0.0050	0.14	5.4	758	0.7	0.17	5.8
	Motorway	3	9.3	679	0.0052	0.11	5.3	789	0.7	0.14	5.7
Truck 10-20 tonne	Average	8	3.4	248	0.0019	0.044	2.1	288	0.26	0.055	2.2
	Urban	8	5.0	367	0.0028	0.080	3.1	426	0.39	0.096	3.3
	Non-urban	8	3.4	252	0.0019	0.046	2.2	293	0.27	0.057	2.3
	Motorway	8	3.0	220	0.0017	0.035	1.8	256	0.23	0.044	1.9
Truck > 20 tonne	Average	16	2.3	171	0.0013	0.029	1.4	199	0.18	0.037	1.5
	Urban	16	3.4	252	0.0019	0.053	2.2	293	0.27	0.064	2.3
	Non-urban	16	2.4	178	0.0014	0.031	1.5	206	0.19	0.038	1.6
	Motorway	16	2.1	151	0.00115	0.023	1.22	175	0.158	0.030	1.31
Truck trailer	Average	26	1.2	87	0.00066	0.016	0.74	101	0.091	0.019	0.79
	Urban	26	2.0	146	0.00111	0.033	1.23	170	0.15	0.039	1.31
	Non-urban	26	1.3	98	0.00074	0.018	0.84	113	0.103	0.022	0.89
	Motorway	26	1.0	77	0.00058	0.0128	0.65	89	0.081	0.016	0.70
LZV	Average	39.5	1.1	78	0.00059	0.0125	0.59	90	0.082	0.016	0.63
	Urban	39.5	1.8	131	0.00100	0.0265	0.98	152	0.138	0.032	1.05
	Non-urban	39.5	1.2	87	0.00067	0.0144	0.66	101	0.092	0.018	0.71
	Motorway	39.5	0.9	69	0.00052	0.0103	0.52	80	0.072	0.013	0.56
Train, electric											
Short train		594	0.23	0	0	0	0	25	0.054	0.002	0.031
Medium train		891	0.18	0	0	0	0	19.5	0.042	0.001	0.024
Long train		1,188	0.15	0	0	0	0	16.4	0.035	0.001	0.020
Train, diesel											
Short train		594	0.61	45	0.0135	0.019	0.68	52	0.060	0.0208	0.71
Medium train		891	0.48	35	0.0105	0.015	0.53	41	0.047	0.0162	0.55
Long train		1,188	0.40	29	0.0088	0.012	0.45	34	0.039	0.0136	0.46

Vehicle type	Infrastructure	Capacity Load capacity (tonne)	TTW MJ/tkm	TTW emissions (g/tkm) CO_2	SO_2	$PM_{2.5}$	NO_x	WTW emission (g/tkm) CO_2	SO_2	$PM_{2.5}$	NO_x
Inland waterways											
Spits-Peniche	CEMT I	350	0.66	48	0.027	0.026	0.68	56	0.077	0.028	0.71
	CEMT V	350	0.56	41	0.023	0.022	0.58	48	0.066	0.024	0.61
	CEMT VI	350	0.52	38	0.021	0.020	0.54	44	0.061	0.022	0.56
	River Waal	350	0.48	35	0.020	0.019	0.50	41	0.056	0.020	0.52
Campine Barge	CEMT II	550	0.48	36	0.020	0.019	0.50	41	0.057	0.021	0.52
	CEMT V	550	0.55	40	0.022	0.021	0.57	47	0.064	0.023	0.59
	CEMT VI	550	0.53	39	0.021	0.021	0.55	45	0.062	0.022	0.57
	River Waal	550	0.54	40	0.022	0.021	0.56	46	0.064	0.023	0.58
Rhine Herne Canal Ship	CEMT IV	1,350	0.48	35	0.020	0.019	0.50	41	0.057	0.021	0.52
	CEMT V	1,350	0.49	36	0.020	0.019	0.51	42	0.058	0.021	0.53
	CEMT VI	1,350	0.54	39	0.022	0.021	0.56	46	0.063	0.023	0.58
	River Waal	1,350	0.46	34	0.019	0.018	0.48	40	0.054	0.020	0.50
Large Rhine Ship	CEMT V	3,013	0.37	27	0.015	0.015	0.38	32	0.043	0.016	0.40
	CEMT VI	3,013	0.39	29	0.016	0.015	0.41	33	0.046	0.017	0.42
	River Waal	3,013	0.40	29	0.016	0.016	0.41	34	0.047	0.017	0.43
Convoy Europe II-C3b	CEMT VI	5,500	0.38	28	0.016	0.015	0.39	32	0.045	0.016	0.41
	River Waal	5,500	0.32	23	0.013	0.012	0.33	27	0.037	0.013	0.34
Pushed Convoy 2x2	CEMT VI	12,000	0.23	17	0.0096	0.0092	0.24	20	0.027	0.010	0.25
	River Waal	12,000	0.22	16	0.0090	0.0087	0.23	19	0.026	0.0094	0.24
Pushed Convoy 3x2	CEMT VI	18,000	0.19	14	0.0078	0.0075	0.20	16	0.022	0.0081	0.20
	River Waal	18,000	0.16	12	0.0067	0.0065	0.17	14	0.019	0.0070	0.18
Maritime shipping											
Crude oil tanker 0-10 dwkt		3,668	-	-	-	-	-	-	-	-	-
Crude oil tanker 10-60 dwkt		38,361	-	-	-	-	-	-	-	-	-
Crude oil tanker 80-120 dwKt		103,403	-	-	-	-	-	-	-	-	-
Products tanker 0-5 dwkt		1,800	-	-	-	-	-	-	-	-	-
Products tanker 5-10 dwkt		7,000	-	-	-	-	-	-	-	-	-
General Cargo 0-5 dwkt		2,545	0.44	33	0.133	0.045	0.85	38	0.165	0.046	0.87
General Cargo 5-10 dwkt		6,957	0.47	36	0.154	0.052	0.95	41	0.188	0.053	0.97
Bulk carrier (feeder)		2,400	-	-	-	-	-	-	-	-	-
Bulk carrier (handysize)		26,000	-	-	-	-	-	-	-	-	-
Bulk carrier (handymax)		45,000	-	-	-	-	-	-	-	-	-

Table 43 Emission factors tank-to-wheel and well-to-wheel for average bulk and general cargo transport for 2009

		Capacity	TTW	TTW emissions (g/tkm)				WTW emission (g/tkm)			
Vehicle type	**Infrastructure**	**Load capacity (tonne)**	**MJ/tkm**	CO_2	SO_2	$PM_{2.5}$	NO_x	CO_2	SO_2	$PM_{2.5}$	NO_x
Road											
Small van < 2 tonne	Average	0.7	23	1,664	0.013	0.67	5.5	1,932	1.8	0.74	6.4
	Urban	0.7	26	1,932	0.015	0.86	6.9	2,244	2.0	0.94	7.9
	Non-urban	0.7	17	1,251	0.010	0.45	4.1	1,453	1.3	0.50	4.8
	Motorway	0.7	23	1,720	0.013	0.63	5.1	1,997	1.8	0.70	6.0
Large van > 2 tonne	Average	1.2	15	1,134	0.0086	0.45	3.7	1,317	1.2	0.50	4.3
	Urban	1.2	18	1,315	0.010	0.57	4.7	1,528	1.4	0.62	5.4
	Non-urban	1.2	12	852	0.0065	0.30	2.8	989	0.9	0.34	3.3
	Motorway	1.2	16	1,173	0.0089	0.43	3.4	1,363	1.2	0.48	4.0
Truck < 10 tonne	Average	3	8.7	638	0.0049	0.12	5.1	741	0.7	0.15	5.4
	Urban	3	11	791	0.0060	0.21	6.3	919	0.8	0.25	6.7
	Non-urban	3	8.2	600	0.0046	0.13	5.0	697	0.6	0.15	5.3
	Motorway	3	8.5	625	0.0048	0.10	4.9	725	0.7	0.13	5.2
Truck 10-20 tonne	Average	8	2.5	180	0.0014	0.032	1.5	209	0.19	0.039	1.6
	Urban	8	3.7	268	0.0020	0.058	2.3	311	0.28	0.069	2.4
	Non-urban	8	2.5	184	0.0014	0.033	1.6	213	0.19	0.041	1.7
	Motorway	8	2.2	160	0.0012	0.025	1.3	185	0.17	0.032	1.4
Truck >20 tonne	Average	16	1.7	126	0.0010	0.021	1.1	146	0.13	0.026	1.1
	Urban	16	2.5	186	0.0014	0.039	1.6	217	0.20	0.046	1.7
	Non-urban	16	1.8	131	0.0010	0.022	1.1	152	0.14	0.028	1.2
	Motorway	16	1.5	110	0.00084	0.017	0.89	128	0.116	0.021	0.95
Truck trailer	Average	26	0.9	65	0.00050	0.011	0.56	76	0.069	0.014	0.59
	Urban	26	1.5	111	0.00085	0.024	0.94	129	0.12	0.029	1.00
	Non-urban	26	1.0	74	0.00056	0.013	0.63	86	0.078	0.016	0.67
	Motorway	26	0.8	57	0.00044	0.0094	0.49	67	0.060	0.012	0.52
LHV	Average	39.5	0.8	58	0.00044	0.0091	0.44	68	0.061	0.012	0.47
	Urban	39.5	1.4	100	0.00076	0.0195	0.75	116	0.105	0.024	0.80
	Non-urban	39.5	0.9	66	0.00050	0.0105	0.50	77	0.069	0.013	0.54
	Motorway	39.5	0.7	51	0.00039	0.0075	0.39	60	0.054	0.010	0.42
Train, electric											
Short train		935	0.13	0	0	0	0	14	0.031	0.001	0.018
Medium train		1,403	0.10	0	0	0	0	11.1	0.024	0.001	0.014
Long train		1,870	0.08	0	0	0	0	9.3	0.020	0.001	0.012
Train, diesel											
Short train		935	0.35	26	0.0077	0.011	0.39	30	0.034	0.0119	0.40
Medium train		1,403	0.27	20	0.0060	0.008	0.30	23	0.027	0.0092	0.31
Long train		1,870	0.23	17	0.0050	0.007	0.25	19	0.022	0.0077	0.26
Inland waterways											
Spits-Peniche	CEMT I	350	0.63	47	0.026	0.025	0.66	54	0.074	0.027	0.68
	CEMT V	350	0.50	37	0.020	0.020	0.52	43	0.059	0.021	0.54
	CEMT VI	350	0.46	34	0.019	0.018	0.47	39	0.054	0.019	0.49
	River Waal	350	0.42	31	0.017	0.017	0.44	36	0.049	0.018	0.45
Campine Barge	CEMT II	550	0.45	33	0.019	0.018	0.47	39	0.053	0.019	0.49
	CEMT V	550	0.48	36	0.020	0.019	0.50	41	0.057	0.021	0.52
	CEMT VI	550	0.46	34	0.019	0.018	0.47	39	0.054	0.019	0.49
	River Waal	550	0.47	34	0.019	0.018	0.48	40	0.055	0.020	0.50
Rhine Herne Canal Ship	CEMT IV	1,350	0.45	33	0.018	0.018	0.46	38	0.052	0.019	0.48
	CEMT V	1,350	0.44	33	0.018	0.017	0.46	38	0.052	0.019	0.48
	CEMT VI	1,350	0.47	34	0.019	0.018	0.48	40	0.055	0.020	0.50
	River Waal	1,350	0.40	29	0.016	0.016	0.41	34	0.047	0.017	0.43

		Capacity	TTW	TTW emissions (g/tkm)				WTW emission (g/tkm)			
Vehicle type	**Infrastructure**	**Load capacity (tonne)**	**MJ/tkm**	**CO_2**	**SO_2**	**$PM_{2.5}$**	**NO_x**	**CO_2**	**SO_2**	**$PM_{2.5}$**	**NO_x**
Large Rhine Ship	CEMT V	3,013	0.35	25	0.014	0.014	0.36	30	0.041	0.015	0.37
	CEMT VI	3,013	0.34	25	0.014	0.014	0.36	29	0.040	0.015	0.37
	River Waal	3,013	0.34	25	0.014	0.013	0.35	29	0.040	0.014	0.36
Convoy Europe II-C3b	CEMT VI	5,500	0.34	25	0.014	0.013	0.35	29	0.039	0.014	0.36
	River Waal	5,500	0.27	20	0.011	0.011	0.28	23	0.032	0.012	0.29
Pushed Convoy 2x2	CEMT VI	12,000	0.22	16	0.0090	0.0087	0.23	19	0.026	0.009	0.24
	River Waal	12,000	0.20	14	0.0080	0.0077	0.20	17	0.023	0.0083	0.21
Pushed Convoy 3x2	CEMT VI	18,000	0.17	13	0.0071	0.0069	0.18	15	0.020	0.0074	0.19
	River Waal	18,000	0.14	10	0.0058	0.0056	0.15	12	0.017	0.0060	0.15
Maritime shipping											
Crude oil tanker 0-10 dwkt		3,668	0.44	34	0.12	0.040	0.80	38	0.15	0.042	0.82
Crude oil tanker 10-60 dwkt		38,361	0.12	9.4	0.037	0.013	0.23	11	0.046	0.013	0.24
Crude oil tanker 80-120 dwKt		103,403	0.08	6.1	0.024	0.0083	0.15	7.0	0.030	0.0085	0.15
Products tanker 0-5 dwkt		1,800	0.61	46	0.16	0.054	1.09	53	0.20	0.056	1.12
Products tanker 5-10 dwkt		7,000	0.39	30	0.10	0.036	0.71	34	0.13	0.037	0.72
General Cargo 0-5 dwkt		2,545	0.21	16	0.064	0.022	0.41	18	0.080	0.022	0.42
General Cargo 5-10 dwkt		6,957	0.23	17	0.074	0.025	0.46	20	0.091	0.026	0.47
Bulk carrier (feeder)		2,400	0.39	30	0.12	0.040	0.75	34	0.145	0.041	0.77
Bulk carrier (handysize)		26,000	0.11	8.2	0.036	0.012	0.22	9.3	0.044	0.013	0.22
Bulk carrier (handymax)		45,000	0.08	5.9	0.026	0.0089	0.16	6.7	0.032	0.0091	0.16

Table 44 Emission factors tank-to-wheel and well-to-wheel for heavy bulk and general cargo transport for 2009

		Capacity	TTW	TTW emissions (g/tkm)				WTW emission (g/tkm)			
Vehicle type	**Infrastructure**	**Load capacity (tonne)**	**MJ/tkm**	**CO_2**	**SO_2**	**$PM_{2.5}$**	**NO_x**	**CO_2**	**SO_2**	**$PM_{2.5}$**	**NO_x**
Road											
Small van < 2 ton	Average	0.7	-	-	-	-	-	-	-	-	-
	Urban	0.7	-	-	-	-	-	-	-	-	-
	Non-urban	0.7	-	-	-	-	-	-	-	-	-
	Motorway	0.7	-	-	-	-	-	-	-	-	-
Large van > 2 ton	Average	1.2	-	-	-	-	-	-	-	-	-
	Urban	1.2	-	-	-	-	-	-	-	-	-
	Non-urban	1.2	-	-	-	-	-	-	-	-	-
	Motorway	1.2	-	-	-	-	-	-	-	-	-
Truck < 10 ton	Average	3	-	-	-	-	-	-	-	-	-
	Urban	3	-	-	-	-	-	-	-	-	-
	Non-urban	3	-	-	-	-	-	-	-	-	-
	Motorway	3	-	-	-	-	-	-	-	-	-
Truck 10-20 ton	Average	8	2.1	153	0.0012	0.027	1.3	177	0.16	0.033	1.4
	Urban	8	3.1	228	0.0017	0.049	1.9	264	0.24	0.058	2.0
	Non-urban	8	2.1	156	0.0012	0.028	1.4	181	0.16	0.034	1.4
	Motorway	8	1.8	135	0.0010	0.021	1.1	157	0.14	0.027	1.2
Truck > 20 ton	Average	16	1.5	107	0.0008	0.018	0.9	124	0.11	0.022	1.0
	Urban	16	2.2	160	0.0012	0.033	1.4	185	0.17	0.039	1.4
	Non-urban	16	1.5	111	0.0008	0.019	1.0	129	0.12	0.023	1.0
	Motorway	16	1.3	93	0.00071	0.014	0.76	109	0.098	0.018	0.81
Truck trailer	Average	26	0.8	56	0.00043	0.010	0.48	65	0.059	0.012	0.51
	Urban	26	1.3	97	0.00074	0.021	0.82	112	0.10	0.025	0.87
	Non-urban	26	0.9	64	0.00049	0.011	0.55	74	0.067	0.014	0.58
	Motorway	26	0.7	49	0.00038	0.0079	0.42	57	0.052	0.010	0.45

Vehicle type	Infrastructure	Capacity Load capacity (tonne)	TTW MJ/tkm	TTW emissions (g/tkm) CO_2	SO_2	$PM_{2.5}$	NO_x	WTW emission (g/tkm) CO_2	SO_2	$PM_{2.5}$	NO_x
LHV	Average	39.5	0.7	50	0.00038	0.0078	0.38	59	0.053	0.010	0.41
	Urban	39.5	1.2	87	0.00066	0.0166	0.65	101	0.091	0.020	0.70
	Non-urban	39.5	0.8	57	0.00044	0.0090	0.44	67	0.060	0.011	0.47
	Motorway	39.5	0.6	44	0.00034	0.0064	0.34	51	0.047	0.008	0.36
Train, electric											
Short train		1,276	0.09	0	0	0	0	10	0.021	0.001	0.012
Medium train		1,914	0.07	0	0	0	0	8.1	0.018	0.001	0.010
Long train		2,668	0.07	0	0	0	0	7.6	0.017	0.000	0.009
Train, diesel											
Short train		1,276	0.24	18	0.0053	0.007	0.27	20	0.024	0.0081	0.28
Medium train		1,914	0.20	15	0.0043	0.006	0.22	17	0.019	0.0067	0.23
Long train		2,668	0.19	14	0.0041	0.006	0.21	16	0.018	0.0063	0.22
Inland waterways											
Spits-Peniche	CEMT I	350	0.70	52	0.029	0.028	0.73	60	0.082	0.030	0.76
	CEMT V	350	0.49	36	0.020	0.019	0.51	42	0.058	0.021	0.53
	CEMT VI	350	0.43	32	0.018	0.017	0.45	37	0.051	0.019	0.47
	River Waal	350	0.40	30	0.016	0.016	0.42	34	0.047	0.017	0.43
Campine Barge	CEMT II	550	0.49	36	0.020	0.019	0.51	42	0.058	0.021	0.53
	CEMT V	550	0.48	35	0.019	0.019	0.50	41	0.056	0.020	0.51
	CEMT VI	550	0.43	32	0.018	0.017	0.45	37	0.051	0.018	0.47
	River Waal	550	0.44	32	0.018	0.017	0.45	37	0.051	0.019	0.47
Rhine Herne Canal Ship	CEMT IV	1,350	0.47	35	0.019	0.019	0.49	40	0.055	0.020	0.51
	CEMT V	1,350	0.45	33	0.018	0.018	0.47	38	0.053	0.019	0.48
	CEMT VI	1,350	0.44	33	0.018	0.017	0.46	38	0.052	0.019	0.48
	River Waal	1,350	0.38	28	0.015	0.015	0.39	32	0.044	0.016	0.41
Large Rhine Ship	CEMT V	3,013	0.38	28	0.015	0.015	0.39	32	0.044	0.016	0.41
	CEMT VI	3,013	0.33	24	0.014	0.013	0.35	28	0.039	0.014	0.36
	River Waal	3,013	0.32	23	0.013	0.012	0.33	27	0.037	0.013	0.34
Convoy Europe II-C3b	CEMT VI	5,500	0.33	24	0.014	0.013	0.34	28	0.039	0.014	0.36
	River Waal	5,500	0.26	19	0.011	0.010	0.27	23	0.031	0.011	0.28
Pushed Convoy 2x2	CEMT VI	12,000	0.24	17	0.0097	0.0094	0.25	20	0.028	0.010	0.26
	River Waal	12,000	0.20	15	0.0083	0.0080	0.21	17	0.024	0.0087	0.22
Pushed Convoy 3x2	CEMT VI	18,000	0.18	13	0.0075	0.0072	0.19	16	0.022	0.0078	0.20
	River Waal	18,000	0.14	10	0.0057	0.0056	0.15	12	0.017	0.0060	0.15
Maritime shipping											
Crude oil tanker 0-10 dwkt		3,668	-	-	-	-	-	-	-	-	-
Crude oil tanker 10-60 dwkt		38,361	-	-	-	-	-	-	-	-	-
Crude oil tanker 80-120 dwKt		103,403	-	-	-	-	-	-	-	-	-
Products tanker 0-5 dwkt		1,800	-	-	-	-	-	-	-	-	-
Products tanker 5-10 dwkt		7,000	-	-	-	-	-	-	-	-	-
General Cargo 0-5 dwkt		2,545	0.18	14	0.055	0.019	0.35	16	0.068	0.019	0.36
General Cargo 5-10 dwkt		6,957	0.20	15	0.064	0.022	0.39	17	0.078	0.022	0.40
Bulk carrier (feeder)		2,400	0.33	25	0.10	0.034	0.64	29	0.124	0.035	0.66
Bulk carrier (handysize)		26,000	0.09	6.9	0.031	0.010	0.19	7.9	0.037	0.011	0.19
Bulk carrier (handymax)		45,000	0.06	5.0	0.022	0.0075	0.13	5.6	0.027	0.0077	0.13

5.3 Emission factors container transport for 2009

Table 45 Emission factors tank-to-wheel and well-to-wheel for volume container transport 2009

Vehicle type	Infra-structure	Capacity Load Cap. (TEU)	TTW MJ/tkm	TTW emissions (g/tkm) CO_2	TTW emissions (g/tkm) SO_2	TTW emissions (g/tkm) $PM_{2.5}$	TTW emissions (g/tkm) NO_x	WTW emission (g/tkm) CO_2	WTW emission (g/tkm) SO_2	WTW emission (g/tkm) $PM_{2.5}$	WTW emission (g/tkm) NO_x
Road											
Truck > 20 ton	Average	1.2	2.68	196	0.0015	0.033	1.65	228	0.21	0.041	1.75
	Urban	1.2	3.96	290	0.0022	0.060	2.48	337	0.31	0.073	2.63
	Non-urban	1.2	2.78	204	0.0016	0.035	1.78	237	0.21	0.043	1.89
	Motorway	1,2	2.35	172	0.0013	0.026	1.40	200	0.18	0.034	1.49
Truck trailer	Average	2	1.35	99	0.00075	0.017	0.84	115	0.10	0.022	0.90
	Urban	2	2.30	168	0.0013	0.037	1.42	196	0.18	0.044	1.51
	Non-urban	2	1.52	112	0.00085	0.020	0.96	130	0.12	0.025	1.02
	Motorway	2	1.19	87	0.00066	0.014	0.74	101	0.09	0.018	0.79
LHV	Average	3	1.21	89	0.00068	0.014	0.67	103	0.09	0.018	0.72
	Urban	3	2.07	151	0.00115	0.030	1.13	176	0.16	0.036	1.22
	Non-urban	3	1.37	101	0.00077	0.016	0.76	117	0.11	0.020	0.82
	Motorway	3	1.07	78	0.00060	0.012	0.60	91	0.08	0.015	0.64
Train, electric											
Short train		45	0.31	0	0	0	0	34	0.074	0.0022	0.04
Medium train		70	0.23	0	0	0	0	26	0.056	0.0017	0.03
Long train		90	0.20	0	0	0	0	22	0.048	0.0014	0.03
Train, diesel											
Short train		45	0.83	61	0.018	0.026	0.93	71	0.082	0.028	0.96
Medium train		70	0.63	47	0.014	0.020	0.71	54	0.062	0.022	0.73
Long train		90	0.54	40	0.012	0.017	0.61	46	0.053	0.018	0.63
Inland waterways											
Neo Kemp	CEMT III	48	0.86	63	0.035	0.034	0.89	74	0.10	0.037	0.93
	CEMT V	48	0.94	69	0.038	0.037	0.98	80	0.11	0.040	1.01
	CEMT VI	48	1.12	82	0.046	0.044	1.16	95	0.13	0.047	1.20
	River Waal	48	0.94	69	0.038	0.037	0.98	81	0.11	0.040	1.02
Rhine Herne Canal Ship	CEMT IV	96	0.93	68	0.038	0.037	0.97	79	0.11	0.040	1.00
	CEMT V	96	0.97	71	0.039	0.038	1.00	82	0.11	0.041	1.04
	CEMT VI	96	1.05	77	0.043	0.041	1.09	90	0.12	0.045	1.13
	River Waal	96	0.88	65	0.036	0.035	0.92	75	0.10	0.038	0.95
Pushed convoy	CEMT V	160	0.59	44	0.024	0.023	0.62	51	0.070	0.025	0.64
	CEMT VI	160	0.81	59	0.033	0.032	0.84	69	0.095	0.034	0.87
	River Waal	160	0.70	52	0.029	0.028	0.73	60	0.082	0.030	0.76
Container Ship Rhine	CEMT V	200	0.54	40	0.022	0.021	0.56	46	0.064	0.023	0.58
	CEMT VI	200	0.65	48	0.026	0.025	0.67	55	0.076	0.027	0.70
	River Waal	200	0.52	38	0.021	0.021	0.54	45	0.061	0.022	0.56
Long large Rhine ship	CEMT V	272	0.50	37	0.020	0.020	0.52	43	0.059	0.021	0.54
	CEMT VI	272	0.58	43	0.024	0.023	0.60	49	0.068	0.025	0.62
	River Waal	272	0.46	34	0.019	0.018	0.48	39	0.054	0.020	0.50
Rhinemax Ship	CEMT VI	470	0.60	44	0.024	0.024	0.62	51	0.070	0.025	0.64
	River Waal	470	0.42	31	0.017	0.017	0.44	36	0.050	0.018	0.46
Maritime shipping											
C. Ship (feeder)		500	0.94	72	0.30	0.10	1.83	82	0.36	0.10	1.86
C. Ship (lhandysize)		1414	0.58	45	0.20	0.066	1.17	51	0.24	0.07	1.19
C. Ship (lhandymax)		2400	0.56	43	0.19	0.064	1.12	49	0.23	0.07	1.15
C. Ship (lpanamax)		4112	0.43	33	0.15	0.049	0.85	37	0.18	0.05	0.86
C. Ship (aframax)		5765	0.43	33	0.15	0.049	0.81	37	0.18	0.05	0.82
C. Ship (suezmax)		9800	0.32	25	0.11	0.037	0.59	28	0.13	0.04	0.60

Table 46 Emission factors tank-to-wheel and well-to-wheel for average container transport 2009

		Capacity	TTW	TTW emissions (g/tkm)				WTW emission (g/tkm)			
Vehicle type	Infra-structure	Load capacity (TEU)	MJ/ tkm	CO_2	SO_2	$PM_{2.5}$	NO_x	CO_2	SO_2	$PM_{2.5}$	NO_x
Road											
Truck > 20 ton	Average	1.2	1.61	118	0.0009	0.019	0.99	137	0.12	0.024	1.05
	Urban	1.2	2.41	177	0.0013	0.036	1.51	205	0.19	0.043	1.60
	Non-urban	1.2	1.68	123	0.00094	0.020	1.07	143	0.13	0.026	1.14
	Motorway	1.2	1.40	103	0.00078	0.015	0.83	119	0.11	0.020	0.89
Truck trailer	Average	2	0.84	62	0.00047	0.010	0.53	72	0.07	0.013	0.56
	Urban	2	1.46	107	0.00081	0.022	0.90	124	0.11	0.027	0.96
	Non-urban	2	0.96	70	0.00054	0.012	0.60	82	0.074	0.015	0.64
	Motorway	2	0.74	54	0.00041	0.009	0.46	63	0.057	0.011	0.49
LHV	Average	3	0.76	56	0.00042	0.008	0.42	65	0.058	0.011	0.45
	Urban	3	1.31	96	0.00073	0.018	0.72	112	0.101	0.022	0.77
	Non-urban	3	0.86	63	0.00048	0.010	0.48	73	0.067	0.012	0.52
	Motorway	3	0.66	49	0.00037	0.007	0.37	57	0.051	0.009	0.40
Train, electric											
Short train		45	0.18	0	0	0	0	20	0.044	0.0013	0.03
Medium train		70	0.14	0	0	0	0	15	0.034	0.0010	0.02
Long train		90	0.12	0	0	0	0	13	0.029	0.0008	0.02
Train, diesel											
Short train		45	0.50	36	0.011	0.015	0.55	42	0.049	0.017	0.57
Medium train		70	0.38	28	0.0083	0.012	0.42	32	0.037	0.013	0.44
Long train		90	0.32	24	0.0071	0.010	0.36	28	0.032	0.011	0.37
Inland waterways											
Neo Kemp	CEMT III	48	0.62	45	0.025	0.024	0.64	53	0.072	0.026	0.67
	CEMT V	48	0.65	48	0.026	0.026	0.67	55	0.076	0.028	0.70
	CEMT VI	48	0.75	55	0.031	0.030	0.78	64	0.088	0.032	0.81
	River Waal	48	0.63	46	0.026	0.025	0.65	53	0.073	0.027	0.67
Rhine Herne Canal Ship	CEMT IV	96	0.67	49	0.027	0.026	0.69	57	0.078	0.028	0.72
	CEMT V	96	0.67	50	0.027	0.027	0.70	57	0.079	0.029	0.73
	CEMT VI	96	0.70	52	0.029	0.028	0.73	60	0.082	0.030	0.76
	River Waal	96	0.58	43	0.024	0.023	0.60	49	0.068	0.025	0.62
Pushed convoy	CEMT V	160	0.43	32	0.018	0.017	0.45	37	0.051	0.018	0.46
	CEMT VI	160	0.57	42	0.023	0.022	0.59	49	0.067	0.024	0.61
	River Waal	160	0.48	36	0.020	0.019	0.50	41	0.057	0.021	0.52
Container Ship Rhine	CEMT V	200	0.39	29	0.016	0.015	0.40	33	0.046	0.017	0.42
	CEMT VI	200	0.44	32	0.018	0.017	0.45	37	0.051	0.019	0.47
	River Waal	200	0.34	25	0.014	0.013	0.36	29	0.040	0.015	0.37
Long large Rhine ship	CEMT V	272	0.36	26	0.015	0.014	0.37	30	0.042	0.015	0.38
	CEMT VI	272	0.39	28	0.016	0.015	0.40	33	0.045	0.016	0.42
	River Waal	272	0.30	22	0.012	0.012	0.31	25	0.035	0.013	0.32
Rhinemax Ship	CEMT VI	470	0.41	30	0.017	0.016	0.43	35	0.048	0.017	0.44
	River Waal	470	0.28	20	0.011	0.011	0.29	24	0.032	0.012	0.30
Maritime shipping											
C. Ship (feeder)		500	0.54	41	0.17	0.06	1.04	47	0.21	0.059	1.1
C. Ship (lhandysize)		1414	0.33	26	0.11	0.038	0.67	29	0.14	0.039	0.68
C. Ship (lhandymax)		2400	0.32	25	0.11	0.037	0.64	28	0.13	0.037	0.65
C. Ship (lpanamax)		4112	0.24	19	0.084	0.028	0.48	21	0.10	0.029	0.49
C. Ship (aframax)		5765	0.24	19	0.083	0.028	0.46	21	0.10	0.029	0.47
C. Ship (suezmax)		9800	0.18	14	0.062	0.021	0.34	16	0.076	0.022	0.35

Table 47 Emission factors tank-to-wheel and well-to-wheel for heavy container transport 2009

		Capacity	TTW	TTW emissions (g/tkm)				WTW emission (g/tkm)			
Vehicle type	Infra-structure	Load capacity (TEU)	MJ/ tkm	CO_2	SO_2	$PM_{2.5}$	NO_x	CO_2	SO_2	$PM_{2.5}$	NO_x
Road											
Truck >20 ton	Average	1.2	1.22	89	0.00068	0.014	0.75	104	0.09	0.018	0.80
	Urban	1.2	1.84	135	0.0010	0.027	1.15	156	0.14	0.032	1.22
	Non-urban	1.2	1.27	93	0.00071	0.015	0.81	108	0.10	0.019	0.86
	Motorway	1.2	1.05	77	0.00059	0.011	0.63	90	0.081	0.015	0.67
Truck trailer	Average	2	0.66	48	0.00037	0.008	0.41	56	0.051	0.010	0.44
	Urban	2	1.15	84	0.00064	0.017	0.71	98	0.089	0.021	0.75
	Non-urban	2	0.75	55	0.00042	0.009	0.47	64	0.058	0.011	0.50
	Motorway	2	0.57	42	0.00032	0.006	0.36	49	0.044	0.008	0.38
LHV	Average	3	0.59	43	0.00033	0.006	0.33	50	0.046	0.008	0.35
	Urban	3	1.03	76	0.00058	0.014	0.57	88	0.080	0.017	0.61
	Non-urban	3	0.68	49	0.00038	0.007	0.38	57	0.052	0.009	0.40
	Motorway	3	0.51	38	0.00029	0.005	0.29	44	0.040	0.007	0.31
Train, electric											
Short train		45	0.14	0	0	0	0	15	0.033	0.0010	0.02
Medium train		70	0.11	0	0	0	0	12	0.025	0.0007	0.01
Long train		90	0.09	0	0	0	0	10	0.022	0.0006	0.01
Train, diesel											
Short train		45	0.37	28	0.0082	0.012	0.42	32	0.037	0.013	0.43
Medium train		70	0.28	21	0.0063	0.009	0.32	24	0.028	0.010	0.33
Long train		90	0.24	18	0.0054	0.008	0.27	21	0.024	0.008	0.28
Inland waterways											
Neo Kemp	CEMT III	48	0.54	40	0.022	0.021	0.56	46	0.063	0.023	0.58
	CEMT V	48	0.55	40	0.022	0.022	0.57	47	0.064	0.023	0.59
	CEMT VI	48	0.62	46	0.025	0.024	0.64	53	0.073	0.026	0.67
	River Waal	48	0.51	38	0.021	0.020	0.53	44	0.060	0.022	0.55
Rhine Herne Canal Ship	CEMT IV	96	0.58	43	0.024	0.023	0.61	50	0.069	0.025	0.63
	CEMT V	96	0.58	42	0.023	0.023	0.60	49	0.068	0.024	0.62
	CEMT VI	96	0.58	42	0.024	0.023	0.60	49	0.068	0.025	0.62
	River Waal	96	0.47	34	0.019	0.018	0.49	40	0.055	0.020	0.50
Pushed convoy	CEMT V	160	0.38	28	0.015	0.015	0.39	32	0.044	0.016	0.41
	CEMT VI	160	0.48	36	0.020	0.019	0.50	41	0.057	0.021	0.52
	River Waal	160	0.41	30	0.017	0.016	0.42	35	0.048	0.017	0.44
Container Ship Rhine	CEMT V	200	0.34	25	0.014	0.013	0.36	29	0.040	0.015	0.37
	CEMT VI	200	0.36	27	0.015	0.014	0.38	31	0.043	0.015	0.39
	River Waal	200	0.28	20	0.011	0.011	0.29	24	0.032	0.012	0.30
Long large Rhine ship	CEMT V	272	0.31	23	0.013	0.012	0.32	27	0.037	0.013	0.34
	CEMT VI	272	0.32	23	0.013	0.013	0.33	27	0.037	0.014	0.34
	River Waal	272	0.24	17	0.010	0.009	0.25	20	0.028	0.010	0.26
Rhinemax Ship	CEMT VI	470	0.35	26	0.014	0.014	0.36	30	0.041	0.015	0.37
	River Waal	470	0.22	16	0.0091	0.009	0.23	19	0.026	0.009	0.24
Maritime shipping											
C. Ship (feeder)		500	0.39	30	0.12	0.04	0.76	34	0.15	0.043	0.77
C. Ship (lhandysize)		1414	0.24	18	0.081	0.027	0.48	21	0.10	0.028	0.49
C. Ship (lhandymax)		2400	0.23	18	0.079	0.026	0.47	20	0.10	0.027	0.47
C. Ship (lpanamax)		4112	0.18	13	0.060	0.020	0.35	15	0.073	0.021	0.36
C. Ship (aframax)		5765	0.18	13	0.060	0.020	0.33	15	0.073	0.021	0.34
C. Ship (suezmax)		9800	0.13	10	0.045	0.015	0.25	12	0.055	0.016	0.25

5.4 Emission factors bulk and general cargo 2020

Table 48 Emission factors tank-to-wheel and well-to-wheel for voluminous bulk and general cargo transport for 2020

		Capacity	TTW	TTW emissions (g/tkm)				WTW emission (g/tkm)			
Vehicle type	Infrastructure	Load capacity (tonne)	MJ/ tkm	CO_2	SO_2	$PM_{2.5}$	NO_x	CO_2	SO_2	$PM_{2.5}$	NO_x
Road											
Small van < 2 ton	Average	0.7	23	1,704	0.013	0.23	3.1	1,963	1.4	0.29	3.8
	Urban	0.7	27	1,977	0.015	0.31	4.0	2,277	1.6	0.37	4.8
	Non-urban	0.7	17	1,280	0.010	0.16	2.4	1,475	1.0	0.20	2.9
	Motorway	0.7	24	1,763	0.013	0.21	2.6	2,031	1.4	0.27	3.3
Large van > 2 ton	Average	1.2	16	1,160	0.0088	0.15	1.9	1,336	0.9	0.18	2.4
	Urban	1.2	18	1,344	0.010	0.19	2.5	1,548	1.1	0.23	3.0
	Non-urban	1.2	12	871	0.0066	0.10	1.5	1,003	0.7	0.13	1.8
	Motorway	1.2	16	1,202	0.0092	0.14	1.6	1,385	1.0	0.17	2.1
Truck < 10 ton	Average	3	9.0	660	0.0050	0.033	2.7	760	0.5	0.05	3.0
	Urban	3	11	816	0.0062	0.060	2.6	940	0.6	0.09	2.9
	Non-urban	3	8.5	620	0.0047	0.034	2.8	715	0.5	0.05	3.0
	Motorway	3	8.8	648	0.0049	0.026	2.7	746	0.5	0.05	2.9
Truck 10-20 ton	Average	8	3.2	238	0.0018	0.011	0.98	274	0.19	0.019	1.08
	Urban	8	4.8	351	0.0027	0.021	1.17	405	0.28	0.033	1.31
	Non-urban	8	3.3	242	0.0018	0.012	1.09	279	0.19	0.019	1.19
	Motorway	8	2.9	211	0.0016	0.0088	0.88	244	0.17	0.015	0.96
Truck > 20 ton	Average	16	2.2	165	0.0013	0.0076	0.70	190	0.13	0.013	0.77
	Urban	16	3.3	242	0.0018	0.014	0.85	279	0.19	0.022	0.95
	Non-urban	16	2.3	171	0.0013	0.0080	0.79	197	0.14	0.0134	0.86
	Motorway	16	2.0	145	0.0011	0.0059	0.62	167	0.12	0.01	0.68
Truck trailer	Average	26	1.1	83	0.00063	0.0038	0.35	95	0.066	0.0064	0.38
	Urban	26	1.9	140	0.0011	0.0084	0.47	161	0.11	0.013	0.53
	Non-urban	26	1.3	93	0.00071	0.0044	0.41	107	0.074	0.0074	0.45
	Motorway	26	1.0	73	0.00056	0.0031	0.32	84	0.058	0.0054	0.35
LHV	Average	39.5	1.0	74	0.00056	0.0030	0.28	85	0.059	0.0054	0.31
	Urban	39.5	1.7	125	0.00095	0.0067	0.37	144	0.099	0.0107	0.42
	Non-urban	39.5	1.1	83	0.00063	0.0035	0.33	96	0.066	0.0062	0.36
	Motorway	39.5	0.9	65	0.00050	0.0025	0.26	75	0.052	0.0045	0.28
Train, electric											
Short train		594	0.22	0	0	0	0	19	0.036	0.0010	0.022
Medium train		891	0.17	0	0	0	0	14.7	0.028	0.00077	0.017
Long train		1,188	0.14	0	0	0	0	12.3	0.023	0.00065	0.014
Train, diesel											
Short train		594	0.59	43	0.00027	0.013	0.47	50	0.034	0.015	0.49
Medium train		891	0.46	34	0.00021	0.010	0.37	39	0.027	0.011	0.38
Long train		1,188	0.38	28	0.00018	0.0086	0.31	32	0.022	0.0095	0.32
Inland waterways											
Spits-Peniche	CEMT I	350	0.63	46	0.00029	0.018	0.54	53	0.036	0.019	0.56
	CEMT V	350	0.53	39	0.00025	0.015	0.46	45	0.031	0.016	0.48
	CEMT VI	350	0.49	36	0.00023	0.014	0.43	42	0.029	0.015	0.44
	River Waal	350	0.46	34	0.00021	0.013	0.39	39	0.027	0.014	0.41

Vehicle type	Infrastructure	Capacity Load capacity (tonne)	TTW MJ/ tkm	TTW emissions (g/tkm) CO_2	SO_2	$PM_{2.5}$	NO_x	WTW emission (g/tkm) CO_2	SO_2	$PM_{2.5}$	NO_x
Campine Barge	CEMT II	550	0.46	34	0.00021	0.013	0.40	39	0.027	0.014	0.41
	CEMT V	550	0.52	38	0.00024	0.014	0.45	44	0.030	0.016	0.46
	CEMT VI	550	0.50	37	0.00023	0.014	0.43	42	0.029	0.015	0.45
	River Waal	550	0.51	38	0.00024	0.014	0.44	44	0.030	0.016	0.46
Rhine Herne Canal Ship	CEMT IV	1,350	0.46	34	0.00021	0.013	0.39	39	0.027	0.014	0.41
	CEMT V	1,350	0.47	34	0.00022	0.013	0.40	40	0.027	0.014	0.42
	CEMT VI	1,350	0.51	37	0.00024	0.014	0.44	43	0.030	0.015	0.45
	River Waal	1,350	0.44	32	0.00020	0.012	0.38	37	0.026	0.013	0.39
Large Rhine Ship	CEMT V	3,013	0.35	26	0.00016	0.010	0.30	30	0.020	0.011	0.31
	CEMT VI	3,013	0.37	27	0.00017	0.010	0.32	32	0.022	0.011	0.33
	River Waal	3,013	0.38	28	0.00018	0.011	0.33	32	0.022	0.011	0.34
Convoy Europe II-C3b	CEMT VI	5,500	0.36	27	0.00017	0.010	0.31	31	0.021	0.011	0.32
	River Waal	5,500	0.30	22	0.00014	0.0084	0.26	25	0.017	0.0091	0.27
Pushed Convoy 2x2	CEMT VI	12,000	0.22	16	0.00010	0.0062	0.19	19	0.013	0.0067	0.20
	River Waal	12,000	0.21	15	0.000097	0.0059	0.18	18	0.012	0.0064	0.19
Pushed Convoy 3x2	CEMT VI	18,000	0.18	13	0.000084	0.0051	0.16	15	0.011	0.0055	0.16
	River Waal	18,000	0.16	11	0.000072	0.0044	0.13	13	0.009	0.0047	0.14
Maritime shipping											
Crude oil tanker 0-10 dwkt		3,668	-	-	-	-	-	-	-	-	-
Crude oil tanker 10-60 dwkt		38,361	-	-	-	-	-	-	-	-	-
Crude oil tanker 80-120 dwKt		103,403	-	-	-	-	-	-	-	-	-
Products tanker 0-5 dwkt		1,800	-	-	-	-	-	-	-	-	-
Products tanker 5-10 dwkt		7,000	-	-	-	-	-	-	-	-	-
General Cargo 0-5 dwkt		2,545	0.41	31	0.010	0.029	0.70	36	0.032	0.030	0.71
General Cargo 5-10 dwkt		6,957	0.44	34	0.011	0.033	0.69	38	0.035	0.034	0.70
Bulk carrier (feeder)		2,400	-	-	-	-	-	-	-	-	-
Bulk carrier (handysize)		26,000	-	-	-	-	-	-	-	-	-
Bulk carrier (handymax)		45,000	-	-	-	-	-	-	-	-	-

Table 49 Emission factors tank-to-wheel and well-to-wheel for average bulk and general cargo transport for 2020

Vehicle type	Infrastructure	Capacity Load capacity (tonne)	TTW MJ/ tkm	TTW emissions (g/tkm) CO_2	SO_2	$PM_{2.5}$	NO_x	WTW emission (g/tkm) CO_2	SO_2	$PM_{2.5}$	NO_x
Road											
Small van < 2 ton	Average	0.7	20	1,463	0.011	0.20	2.7	1,685	1.2	0.25	3.2
	Urban	0.7	23	1,698	0.013	0.26	3.5	1,956	1.4	0.32	4.1
	Non-urban	0.7	15	1,099	0.008	0.14	2.0	1,266	0.87	0.17	2.5
	Motorway	0.7	21	1,512	0.012	0.18	2.2	1,742	1.2	0.23	2.8
Large van > 2 ton	Average	1.2	14	996	0.0076	0.13	1.6	1,148	0.79	0.16	2.0
	Urban	1.2	16	1,156	0.009	0.16	2.1	1,331	0.92	0.20	2.6
	Non-urban	1.2	10	748	0.0057	0.087	1.3	862	0.60	0.11	1.6
	Motorway	1.2	14	1,032	0.0079	0.12	1.4	1,189	0.82	0.15	1.8
Truck < 10 ton	Average	3	8.3	608	0.0046	0.03	2.5	700	0.48	0.05	2.7
	Urban	3	10	752	0.0057	0.06	2.4	866	0.60	0.08	2.7
	Non-urban	3	7.8	572	0.0044	0.03	2.5	659	0.45	0.05	2.8
	Motorway	3	8.1	596	0.0045	0.02	2.5	687	0.47	0.04	2.7

Vehicle type	Infrastructure	Capacity Load capacity (tonne)	TTW MJ/ tkm	TTW emissions (g/tkm) CO_2	SO_2	$PM_{2.5}$	NO_x	WTW emission (g/tkm) CO_2	SO_2	$PM_{2.5}$	NO_x
Truck 10-20 ton	Average	8	2.4	174	0.0013	0.008	0.72	201	0.14	0.014	0.79
	Urban	8	3.5	259	0.0020	0.015	0.86	298	0.21	0.024	0.96
	Non-urban	8	2.4	177	0.0013	0.009	0.80	204	0.14	0.014	0.87
	Motorway	8	2.1	154	0.0012	0.006	0.64	177	0.12	0.011	0.70
Truck >20 ton	Average	16	1.7	121	0.0009	0.006	0.51	139	0.10	0.009	0.56
	Urban	16	2.4	179	0.0014	0.011	0.63	207	0.14	0.016	0.70
	Non-urban	16	1.7	126	0.00096	0.0058	0.58	145	0.10	0.0098	0.63
	Motorway	16	1.4	106	0.00081	0.0043	0.45	122	0.084	0.0076	0.49
Truck trailer	Average	26	0.9	62	0.00048	0.0028	0.27	72	0.050	0.0048	0.29
	Urban	26	1.5	107	0.00081	0.0062	0.36	123	0.08	0.0095	0.40
	Non-urban	26	1.0	71	0.00054	0.0032	0.31	81	0.056	0.0055	0.34
	Motorway	26	0.7	55	0.00042	0.0022	0.24	63	0.044	0.0040	0.27
LHV	Average	39.5	0.8	56	0.00043	0.0022	0.21	64	0.045	0.0040	0.23
	Urban	39.5	1.3	95	0.00073	0.0049	0.29	110	0.076	0.0080	0.32
	Non-urban	39.5	0.9	63	0.00048	0.0026	0.25	73	0.050	0.0046	0.28
	Motorway	39.5	0.7	49	0.00037	0.0018	0.19	57	0.039	0.0033	0.21
Train, electric											
Short train		935	0.12	0	0	0	0	11	0.020	0.00057	0.013
Medium train		1,403	0.10	0	0	0	0	8.3	0.016	0.00044	0.010
Long train		1,870	0.08	0	0	0	0	7.0	0.013	0.00037	0.008
Train, diesel											
Short train		935	0.33	25	0.00015	0.0075	0.27	28	0.019	0.0083	0.28
Medium train		1,403	0.26	19	0.00012	0.0059	0.21	22	0.015	0.0065	0.22
Long train		1,870	0.22	16	0.00010	0.0049	0.17	18	0.013	0.0054	0.18
Inland waterways											
Spits-Peniche	CEMT I	350	0.60	44	0.00028	0.017	0.52	51	0.035	0.018	0.54
	CEMT V	350	0.48	35	0.00022	0.013	0.41	40	0.028	0.014	0.43
	CEMT VI	350	0.43	32	0.00020	0.012	0.37	37	0.025	0.013	0.39
	River Waal	350	0.40	29	0.00019	0.011	0.34	34	0.023	0.012	0.36
Campine Barge	CEMT II	550	0.43	32	0.00020	0.012	0.37	36	0.025	0.013	0.38
	CEMT V	550	0.46	34	0.00021	0.013	0.40	39	0.027	0.014	0.41
	CEMT VI	550	0.43	32	0.00020	0.012	0.37	37	0.025	0.013	0.39
	River Waal	550	0.44	33	0.00021	0.012	0.38	38	0.026	0.013	0.40
Rhine Herne Canal Ship	CEMT IV	1,350	0.42	31	0.00020	0.012	0.37	36	0.025	0.013	0.38
	CEMT V	1,350	0.42	31	0.00020	0.012	0.36	36	0.025	0.013	0.38
	CEMT VI	1,350	0.44	33	0.00021	0.012	0.38	37	0.026	0.013	0.39
	River Waal	1,350	0.38	28	0.00018	0.011	0.33	32	0.022	0.011	0.34
Large Rhine Ship	CEMT V	3,013	0.33	24	0.00015	0.009	0.28	28	0.019	0.010	0.29
	CEMT VI	3,013	0.33	24	0.00015	0.009	0.28	28	0.019	0.010	0.29
	River Waal	3,013	0.32	24	0.00015	0.009	0.28	27	0.019	0.010	0.29
Convoy Europe II - C3b	CEMT VI	5,500	0.32	24	0.00015	0.0089	0.28	27	0.019	0.010	0.28
	River Waal	5,500	0.26	19	0.00012	0.0072	0.22	22	0.015	0.0078	0.23
Pushed Convoy 2x2	CEMT VI	12,000	0.21	15	0.00010	0.0058	0.18	18	0.012	0.0063	0.19
	River Waal	12,000	0.19	14	0.000086	0.0052	0.16	16	0.011	0.0056	0.17
Pushed Convoy 3x2	CEMT VI	18,000	0.17	12	0.000077	0.0046	0.14	14	0.010	0.0050	0.15
	River Waal	18,000	0.13	10	0.000062	0.0038	0.12	11	0.0078	0.0041	0.12

		Capacity	TTW	TTW emissions (g/tkm)				WTW emission (g/tkm)			
Vehicle type	**Infrastructure**	**Load capacity (tonne)**	**MJ/ tkm**	**CO_2**	**SO_2**	**$PM_{2.5}$**	**NO_x**	**CO_2**	**SO_2**	**$PM_{2.5}$**	**NO_x**
Maritime shipping											
Crude oil tanker 0-10 dwkt		3,668	0.41	32	0.010	0.025	0.65	36	0.033	0.026	0.67
Crude oil tanker 10-60 dwkt		38,361	0.12	8.8	0.0028	0.0079	0.20	10	0.0091	0.0082	0.20
Crude oil tanker 80-120 dwKt		103,403	0.07	5.7	0.0018	0.0053	0.12	6.5	0.0059	0.0055	0.12
Products tanker 0-5 dwkt		1,800	0.57	43	0.014	0.033	0.90	49	0.045	0.035	0.91
Products tanker 5-10 dwkt		7,000	0.36	28	0.0089	0.022	0.54	32	0.029	0.023	0.55
General Cargo 0-5 dwkt		2,545	0.20	15	0.0048	0.014	0.34	17	0.016	0.014	0.34
General Cargo 5-10 dwkt		6,957	0.21	16	0.0052	0.016	0.33	19	0.017	0.017	0.34
Bulk carrier (feeder)		2,400	0.36	28	0.0089	0.025	0.61	32	0.029	0.026	0.62
Bulk carrier (handysize)		26,000	0.10	7.7	0.0025	0.0079	0.18	8.7	0.0079	0.0081	0.19
Bulk carrier (handymax)		45,000	0.07	5.5	0.0018	0.0058	0.13	6.2	0.0056	0.0059	0.13

Table 50 Emission factors tank-to-wheel and well-to-wheel for heavy bulk and general cargo transport for 2020

		Capacity	TTW	TTW emissions (g/tkm)				WTW emission (g/tkm)			
Vehicle type	**Infrastructure**	**Load capacity (tonne)**	**MJ/ tkm**	**CO_2**	**SO_2**	**$PM_{2.5}$**	**NO_x**	**CO_2**	**SO_2**	**$PM_{2.5}$**	**NO_x**
Road											
Small van < 2 ton	Average	0.7	-	-	-	-	-	-	-	-	-
	Urban	0.7	-	-	-	-	-	-	-	-	-
	Non-urban	0.7	-	-	-	-	-	-	-	-	-
	Motorway	0.7	-	-	-	-	-	-	-	-	-
Large van > 2 ton	Average	1.2	-	-	-	-	-	-	-	-	-
	Urban	1.2	-	-	-	-	-	-	-	-	-
	Non-urban	1.2	-	-	-	-	-	-	-	-	-
	Motorway	1.2	-	-	-	-	-	-	-	-	-
Truck < 10 ton	Average	3	-	-	-	-	-	-	-	-	-
	Urban	3	-	-	-	-	-	-	-	-	-
	Non-urban	3	-	-	-	-	-	-	-	-	-
	Motorway	3	-	-	-	-	-	-	-	-	-
Truck 10-20 ton	Average	8	2.0	148	0.0011	0.0068	0.61	175	0.14	0.012	0.68
	Urban	8	3.0	221	0.0017	0.013	0.74	261	0.21	0.021	0.84
	Non-urban	8	2.1	151	0.0012	0.0072	0.68	179	0.14	0.013	0.76
	Motorway	8	1.8	131	0.0010	0.0053	0.54	154	0.12	0.010	0.61
Truck > 20 ton	Average	16	1.4	103	0.0008	0.0047	0.44	122	0.10	0.0086	0.49
	Urban	16	2.1	154	0.0012	0.0089	0.54	182	0.15	0.015	0.61
	Non-urban	16	1.5	107	0.00082	0.0049	0.50	127	0.10	0.0090	0.55
	Motorway	16	1.2	90	0.00068	0.0036	0.38	106	0.086	0.0070	0.43
Truck trailer	Average	26	0.7	54	0.00041	0.0024	0.23	64	0.052	0.0044	0.26
	Urban	26	1.3	93	0.00071	0.0053	0.31	110	0.09	0.0088	0.36
	Non-urban	26	0.8	61	0.00047	0.0028	0.27	73	0.059	0.0051	0.30
	Motorway	26	0.6	48	0.00036	0.0019	0.21	56	0.045	0.0037	0.23
LHV	Average	39.5	0.7	49	0.00037	0.0019	0.18	57	0.046	0.0037	0.21
	Urban	39.5	1.1	83	0.00063	0.0042	0.25	99	0.079	0.0074	0.29
	Non-urban	39.5	0.8	55	0.00042	0.0022	0.22	65	0.052	0.0043	0.24
	Motorway	39.5	0.6	43	0.00032	0.0015	0.17	50	0.041	0.0031	0.19

		Capacity	TTW	TTW emissions (g/tkm)				WTW emission (g/tkm)			
Vehicle type	**Infrastructure**	**Load capacity (tonne)**	**MJ/ tkm**	**CO_2**	**SO_2**	**$PM_{2.5}$**	**NO_x**	**CO_2**	**SO_2**	**$PM_{2.5}$**	**NO_x**
Train, electric											
Short train		1,276	0.08	0	0	0	0	12	0.023	0.00065	0.015
Medium train		1,914	0.07	0	0	0	0	10.2	0.019	0.00054	0.012
Long train		2,668	0.07	0	0	0	0	10.0	0.019	0.00053	0.012
Train, diesel											
Short train		1,276	0.23	17	0.00011	0.0052	0.18	21	0.022	0.0061	0.20
Medium train		1,914	0.19	14	0.000088	0.0043	0.15	17	0.018	0.0050	0.16
Long train		2,668	0.18	13	0.000083	0.0040	0.14	17	0.018	0.0048	0.15
Inland waterways											
Spits-Peniche	CEMT I	350	0.67	49	0.00031	0.019	0.58	58	0.047	0.021	0.60
	CEMT V	350	0.47	34	0.00022	0.013	0.40	41	0.033	0.014	0.42
	CEMT VI	350	0.41	30	0.00019	0.012	0.36	36	0.029	0.013	0.37
	River Waal	350	0.38	28	0.00018	0.011	0.33	33	0.027	0.012	0.34
Campine Barge	CEMT II	550	0.47	35	0.00022	0.013	0.41	41	0.033	0.014	0.42
	CEMT V	550	0.45	33	0.00021	0.013	0.39	39	0.032	0.014	0.41
	CEMT VI	550	0.41	30	0.00019	0.012	0.36	36	0.029	0.013	0.37
	River Waal	550	0.42	31	0.00019	0.012	0.36	36	0.029	0.013	0.37
Rhine Herne Canal Ship	CEMT IV	1,350	0.45	33	0.00021	0.013	0.39	39	0.031	0.014	0.40
	CEMT V	1,350	0.43	31	0.00020	0.012	0.37	37	0.030	0.013	0.38
	CEMT VI	1,350	0.42	31	0.00019	0.012	0.36	37	0.029	0.013	0.38
	River Waal	1,350	0.36	26	0.00017	0.010	0.31	31	0.025	0.011	0.32
Large Rhine Ship	CEMT V	3,013	0.36	26	0.00017	0.010	0.31	31	0.025	0.011	0.32
	CEMT VI	3,013	0.32	23	0.00015	0.009	0.27	27	0.022	0.010	0.28
	River Waal	3,013	0.30	22	0.00014	0.008	0.26	26	0.021	0.009	0.27
Convoy Europe II - C3b	CEMT VI	5,500	0.32	23	0.00015	0.009	0.27	27	0.022	0.010	0.28
	River Waal	5,500	0.25	18	0.00012	0.007	0.22	22	0.017	0.0077	0.22
Pushed Convoy 2x2	CEMT VI	12,000	0.23	17	0.00010	0.0063	0.19	19	0.015	0.0069	0.20
	River Waal	12,000	0.19	14	0.000090	0.0054	0.17	17	0.013	0.0059	0.17
Pushed Convoy 3x2	CEMT VI	18,000	0.17	13	0.000081	0.0049	0.15	15	0.012	0.0053	0.16
	River Waal	18,000	0.13	10	0.000062	0.0037	0.12	12	0.009	0.0041	0.12
Maritime shipping											
Crude oil tanker 0-10 dwkt		3,668	-	-	-	-	-	-	-	-	-
Crude oil tanker 10-60 dwkt		38,361	-	-	-	-	-	-	-	-	-
Crude oil tanker 80-120 dwKt		103,403	-	-	-	-	-	-	-	-	-
Products tanker 0-5 dwkt		1,800	-	-	-	-	-	-	-	-	-
Products tanker 5-10 dwkt		7,000	-	-	-	-	-	-	-	-	-
General Cargo 0-5 dwkt		2,545	0.17	13	0.0042	0.012	0.29	15	0.015	0.012	0.29
General Cargo 5-10 dwkt		6,957	0.18	14	0.0045	0.014	0.29	16	0.016	0.014	0.29
Bulk carrier (feeder)		2,400	0.31	24	0.0076	0.022	0.52	28	0.027	0.022	0.53
Bulk carrier (handysize)		26,000	0.08	6.5	0.0021	0.0067	0.16	7.5	0.0075	0.0069	0.16
Bulk carrier (handymax)		45,000	0.06	4.7	0.0015	0.0049	0.11	5.4	0.0053	0.0050	0.11

5.5 Emission factors container transport for 2020

Table 51 Emission factors tank-to-wheel and well-to-wheel for volume container transport 2020

Vehicle type	Infra-structure	Capacity Load Cap. (TEU)	TTW MJ/tkm	TTW emissions (g/tkm) CO_2	SO_2	$PM_{2.5}$	NO_x	WTW emission (g/tkm) CO_2	SO_2	$PM_{2.5}$	NO_x
Road											
Truck > 20 ton	Average	1.2	2.58	189	0.00144	0.0087	0.80	218	0.15	0.0146	0.88
	Urban	1.2	3.81	279	0.0021	0.016	0.98	322	0.22	0.025	1.09
	Non-urban	1.2	2.67	196	0.0015	0.0091	0.91	226	0.16	0.0153	0.99
	Motorway	1,2	2.26	165	0.0013	0.0067	0.71	191	0.13	0.0119	0.77
Truck trailer	Average	2	1.29	95	0.00072	0.0043	0.40	109	0.08	0.0073	0.44
	Urban	2	2.20	161	0.0012	0.0094	0.54	186	0.13	0.0145	0.61
	Non-urban	2	1.46	107	0.00081	0.0050	0.48	123	0.09	0.0084	0.52
	Motorway	2	1.14	83	0.00064	0.0034	0.37	96	0.07	0.0061	0.40
LHV	Average	3	1.16	85	0.00065	0.0034	0.32	98	0.07	0.0061	0.36
	Urban	3	1.98	145	0.00110	0.0076	0.43	167	0.12	0.0122	0.49
	Non-urban	3	1.31	96	0.00073	0.0040	0.38	111	0.08	0.0070	0.42
	Motorway	3	1.02	75	0.00057	0.0027	0.30	86	0.06	0.0051	0.33
Train, electric											
Short train		45	0.30	0	0	0	0	26	0.049	0.0014	0.030
Medium train		70	0.22	0	0	0	0	20	0.037	0.0010	0.023
Long train		90	0.19	0	0	0	0	17	0.032	0.00088	0.020
Train, diesel											
Short train		45	0.76	59	0.00037	0.018	0.64	68	0.047	0.020	0.67
Medium train		70	0.58	45	0.00028	0.014	0.49	51	0.035	0.015	0.51
Long train		90	0.49	38	0.00024	0.012	0.42	44	0.030	0.013	0.43
Inland waterways											
Neo Kemp	CEMT III	48	0.82	60	0.00038	0.023	0.71	69	0.048	0.025	0.73
	CEMT V	48	0.89	66	0.00041	0.025	0.77	76	0.052	0.027	0.80
	CEMT VI	48	1.06	78	0.00049	0.030	0.91	90	0.062	0.032	0.95
	River Waal	48	0.90	66	0.00042	0.025	0.77	76	0.052	0.027	0.80
Rhine Herne Canal Ship	CEMT IV	96	0.88	65	0.00041	0.025	0.76	75	0.051	0.027	0.79
	CEMT V	96	0.92	67	0.00043	0.026	0.79	78	0.053	0.028	0.82
	CEMT VI	96	1.00	73	0.00046	0.028	0.86	85	0.058	0.030	0.89
	River Waal	96	0.84	62	0.00039	0.023	0.72	71	0.049	0.025	0.75
Pushed convoy	CEMT V	160	0.56	41	0.00026	0.016	0.49	48	0.033	0.017	0.50
	CEMT VI	160	0.77	57	0.00036	0.022	0.66	65	0.045	0.023	0.68
	River Waal	160	0.66	49	0.00031	0.019	0.57	56	0.039	0.020	0.59
Container Ship Rhine	CEMT V	200	0.51	38	0.00024	0.014	0.44	44	0.030	0.016	0.46
	CEMT VI	200	0.61	45	0.00028	0.017	0.53	52	0.036	0.019	0.55
	River Waal	200	0.50	37	0.00023	0.014	0.43	42	0.029	0.015	0.44
Long large Rhine ship	CEMT V	272	0.48	35	0.00022	0.013	0.41	40	0.028	0.014	0.42
	CEMT VI	272	0.55	40	0.00025	0.015	0.47	47	0.032	0.017	0.49
	River Waal	272	0.44	32	0.00020	0.012	0.38	37	0.025	0.013	0.39
Rhinemax Ship	CEMT VI	470	0.57	42	0.00026	0.016	0.49	48	0.033	0.017	0.51
	River Waal	470	0.40	30	0.00019	0.011	0.35	34	0.023	0.012	0.36
Maritime shipping											
C. Ship (feeder)		500	0.88	67	0.022	0.064	1.52	76	0.069	0.066	1.55
C. Ship (lhandysize)		1414	0.55	42	0.013	0.043	0.93	47	0.043	0.044	0.95
C. Ship (lhandymax)		2400	0.53	41	0.013	0.042	0.92	46	0.041	0.043	0.93
C. Ship (lpanamax)		4112	0.40	31	0.0098	0.032	0.66	35	0.031	0.033	0.67
C. Ship (aframax)		5765	0.40	31	0.0098	0.032	0.64	35	0.031	0.033	0.65
C. Ship (suezmax)		9800	0.30	23	0.0074	0.024	0.45	26	0.024	0.025	0.46

Table 52 Emission factors tank-to-wheel and well-to-wheel for average container transport 2020

		Capacity	TTW	TTW emissions (g/tkm)				WTW emission (g/tkm)			
Vehicle type	**Load capacity (TEU)**	**Load capacity (TEU)**	**MJ/ tkm**	**CO_2**	**SO_2**	**$PM_{2.5}$**	**NO_x**	**CO_2**	**SO_2**	**$PM_{2.5}$**	**NO_x**
Road											
Truck > 20 ton	Average	1.2	1.55	114	0.00087	0.0051	0.48	131	0.090	0.0087	0.53
	Urban	1.2	2.32	170	0.0013	0.010	0.60	196	0.14	0.015	0.66
	Non-urban	1.2	1.62	118	0.00090	0.0054	0.55	136	0.094	0.0091	0.60
	Motorway	1.2	1.35	99	0.00075	0.0039	0.42	114	0.079	0.0070	0.46
Truck trailer	Average	2	0.81	60	0.00045	0.0025	0.25	69	0.047	0.0044	0.28
	Urban	2	1.41	103	0.00078	0.0057	0.35	119	0.082	0.0089	0.39
	Non-urban	2	0.93	68	0.00052	0.0030	0.30	78	0.054	0.0051	0.33
	Motorway	2	0.71	52	0.00040	0.0020	0.23	60	0.042	0.0037	0.25
LHV	Average	3	0.73	54	0.00041	0.0020	0.20	62	0.043	0.0037	0.22
	Urban	3	1.26	93	0.00071	0.0046	0.28	107	0.074	0.0075	0.31
	Non-urban	3	0.83	61	0.00046	0.0024	0.24	70	0.048	0.0043	0.27
	Motorway	3	0.64	47	0.00036	0.0016	0.18	54	0.037	0.0031	0.20
Train, electric											
Short train		45	0.18	0	0	0	0	15	0.029	0.00081	0.018
Medium train		70	0.13	0	0	0	0	12	0.022	0.00061	0.014
Long train		90	0.11	0	0	0	0	10	0.019	0.00052	0.012
Train, diesel											
Short train		45	0.45	35	0.00022	0.011	0.38	40	0.028	0.0119	0.40
Medium train		70	0.34	27	0.00017	0.0082	0.29	31	0.021	0.0090	0.30
Long train		90	0.29	23	0.00014	0.0070	0.25	26	0.018	0.0077	0.26
Inland waterways											
Neo Kemp	CEMT III	48	0.59	43	0.00027	0.016	0.51	50	0.034	0.018	0.52
	CEMT V	48	0.62	45	0.00029	0.017	0.53	52	0.036	0.019	0.55
	CEMT VI	48	0.71	52	0.00033	0.020	0.61	60	0.042	0.022	0.64
	River Waal	48	0.59	44	0.00028	0.017	0.51	50	0.035	0.018	0.53
Rhine Herne Canal Ship	CEMT IV	96	0.63	47	0.00029	0.018	0.55	54	0.037	0.019	0.56
	CEMT V	96	0.64	47	0.00030	0.018	0.55	54	0.037	0.019	0.57
	CEMT VI	96	0.67	49	0.00031	0.019	0.58	56	0.039	0.020	0.59
	River Waal	96	0.55	40	0.00025	0.015	0.47	47	0.032	0.017	0.49
Pushed convoy	CEMT V	160	0.41	30	0.00019	0.011	0.35	35	0.024	0.012	0.37
	CEMT VI	160	0.54	40	0.00025	0.015	0.47	46	0.031	0.016	0.48
	River Waal	160	0.46	34	0.00021	0.013	0.40	39	0.027	0.014	0.41
Container Ship Rhine	CEMT V	200	0.37	27	0.00017	0.010	0.32	31	0.022	0.011	0.33
	CEMT VI	200	0.41	31	0.00019	0.012	0.36	35	0.024	0.013	0.37
	River Waal	200	0.32	24	0.00015	0.009	0.28	28	0.019	0.010	0.29
Long large Rhine ship	CEMT V	272	0.34	25	0.00016	0.009	0.29	29	0.020	0.010	0.30
	CEMT VI	272	0.37	27	0.00017	0.010	0.32	31	0.021	0.011	0.33
	River Waal	272	0.28	21	0.00013	0.008	0.24	24	0.016	0.0086	0.25
Rhinemax Ship	CEMT VI	470	0.39	29	0.00018	0.011	0.34	33	0.023	0.012	0.35
	River Waal	470	0.26	19	0.00012	0.007	0.23	22	0.015	0.0079	0.23
Maritime shipping											
C. Ship (feeder)		500	0.50	38	0.012	0.037	0.87	44	0.039	0.038	0.88
C. Ship (handysize)		1414	0.31	24	0.0077	0.024	0.53	27	0.024	0.025	0.54
C. Ship (handymax)		2400	0.30	23	0.0074	0.024	0.53	26	0.024	0.024	0.53
C. Ship (panamax)		4112	0.23	18	0.0056	0.018	0.38	20	0.018	0.019	0.39
C. Ship (aframax)		5765	0.23	18	0.0056	0.018	0.37	20	0.018	0.019	0.37
C. Ship (suezmax)		9800	0.17	13	0.0042	0.014	0.26	15	0.013	0.014	0.26

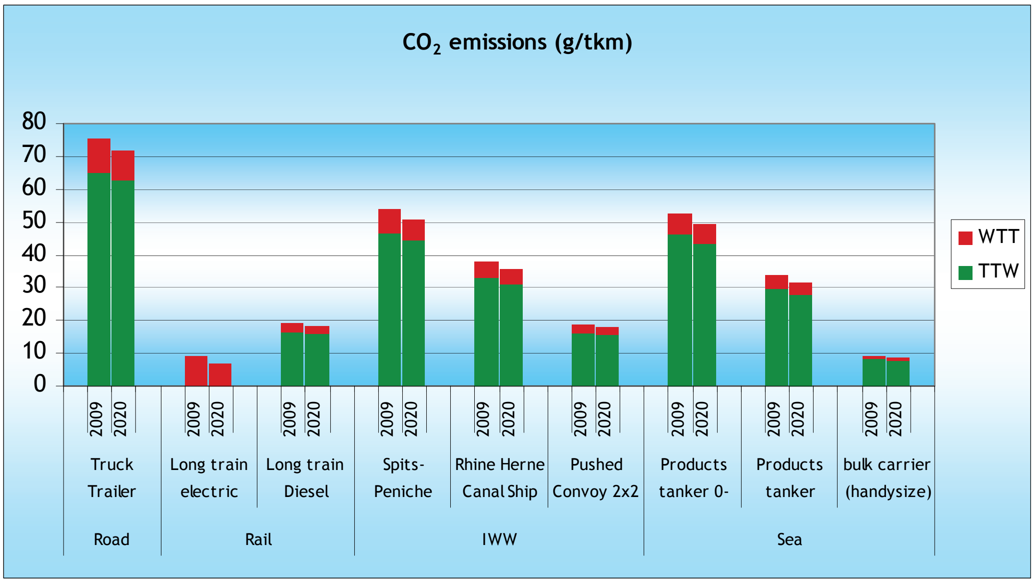
Table 53 Emission factors tank-to-wheel and well-to-wheel for heavy container transport 2020

		Capacity	TTW	TTW emissions (g/tkm)				WTW emission (g/tkm)			
Vehicle type	Load capacity (TEU)	Load capacity (TEU)	MJ/ tkm	CO_2	SO_2	$PM_{2.5}$	NO_x	CO_2	SO_2	$PM_{2.5}$	NO_x
Road											
Truck > 20 ton	Average	1.2	1.17	86	0.00065	0.004	0.37	99	0.068	0.006	0.40
	Urban	1.2	1.77	130	0.0010	0.007	0.46	150	0.10	0.011	0.51
	Non-urban	1.2	1.23	90	0.00068	0.004	0.42	104	0.072	0.007	0.45
	Motorway	1.2	1.01	74	0.00057	0.003	0.32	86	0.059	0.005	0.35
Truck trailer	Average	2	0.64	47	0.00036	0.002	0.20	54	0.037	0.003	0.22
	Urban	2	1.11	82	0.00062	0.004	0.28	94	0.065	0.007	0.31
	Non-urban	2	0.73	53	0.00041	0.002	0.24	61	0.042	0.004	0.26
	Motorway	2	0.55	41	0.00031	0.002	0.18	47	0.032	0.003	0.20
LHV	Average	3	0.57	42	0.00032	0.002	0.16	48	0.033	0.003	0.17
	Urban	3	1.00	73	0.00056	0.003	0.22	85	0.058	0.006	0.25
	Non-urban	3	0.65	48	0.00037	0.002	0.19	55	0.038	0.003	0.21
	Motorway	3	0.50	37	0.00028	0.001	0.14	42	0.029	0.002	0.16
Train, electric											
Short train		45	0.13	0	0	0	0	12	0.022	0.00061	0.014
Medium train		70	0.10	0	0	0	0	9	0.017	0.00046	0.010
Long train		90	0.09	0	0	0	0	8	0.014	0.00040	0.009
Train, diesel											
Short train		45	0.34	26	0.00017	0.0081	0.29	30	0.021	0.0090	0.30
Medium train		70	0.26	20	0.00013	0.0062	0.22	23	0.016	0.0068	0.23
Long train		90	0.22	17	0.00011	0.0053	0.19	20	0.014	0.0058	0.20
Inland waterways											
Neo Kemp	CEMT III	48	0.51	38	0.00024	0.014	0.44	43	0.030	0.016	0.46
	CEMT V	48	0.52	38	0.00024	0.015	0.45	44	0.030	0.016	0.46
	CEMT VI	48	0.59	43	0.00027	0.016	0.51	50	0.034	0.018	0.52
	River Waal	48	0.48	36	0.00022	0.014	0.42	41	0.028	0.015	0.43
Rhine Herne Canal Ship	CEMT IV	96	0.55	41	0.00026	0.016	0.48	47	0.032	0.017	0.50
	CEMT V	96	0.55	40	0.00025	0.015	0.47	46	0.032	0.017	0.49
	CEMT VI	96	0.55	40	0.00025	0.015	0.47	46	0.032	0.017	0.49
	River Waal	96	0.44	33	0.00021	0.012	0.38	38	0.026	0.013	0.40
Pushed convoy	CEMT V	160	0.36	26	0.00017	0.010	0.31	30	0.021	0.011	0.32
	CEMT VI	160	0.46	34	0.00021	0.013	0.40	39	0.027	0.014	0.41
	River Waal	160	0.39	28	0.00018	0.011	0.33	33	0.022	0.012	0.34
Container Ship Rhine	CEMT V	200	0.33	24	0.00015	0.009	0.28	28	0.019	0.010	0.29
	CEMT VI	200	0.34	25	0.00016	0.010	0.30	29	0.020	0.010	0.31
	River Waal	200	0.26	19	0.00012	0.007	0.23	22	0.015	0.008	0.23
Long large Rhine ship	CEMT V	272	0.30	22	0.00014	0.008	0.26	25	0.017	0.009	0.26
	CEMT VI	272	0.30	22	0.00014	0.008	0.26	26	0.018	0.009	0.27
	River Waal	272	0.23	17	0.00010	0.006	0.19	19	0.013	0.007	0.20
Rhinemax Ship	CEMT VI	470	0.33	24	0.00015	0.009	0.28	28	0.019	0.010	0.29
	River Waal	470	0.21	16	0.00010	0.006	0.18	18	0.012	0.006	0.19
Maritime shipping											
C. Ship (feeder)		500	0.36	28	0.01	0.03	0.63	32	0.029	0.027	0.64
C. Ship (handysize)		1414	0.23	17	0.006	0.018	0.39	20	0.018	0.018	0.39
C. Ship (handymax)		2400	0.22	17	0.005	0.017	0.38	19	0.017	0.018	0.39
C. Ship (panamax)		4112	0.17	13	0.004	0.013	0.27	14	0.013	0.014	0.28
C. Ship (aframax)		5765	0.17	13	0.004	0.013	0.26	14	0.013	0.013	0.27
C. Ship (suezmax)		9800	0.12	10	0.003	0.010	0.19	11	0.010	0.010	0.19

5.6 Development emission factors 2009-2020 time-frame

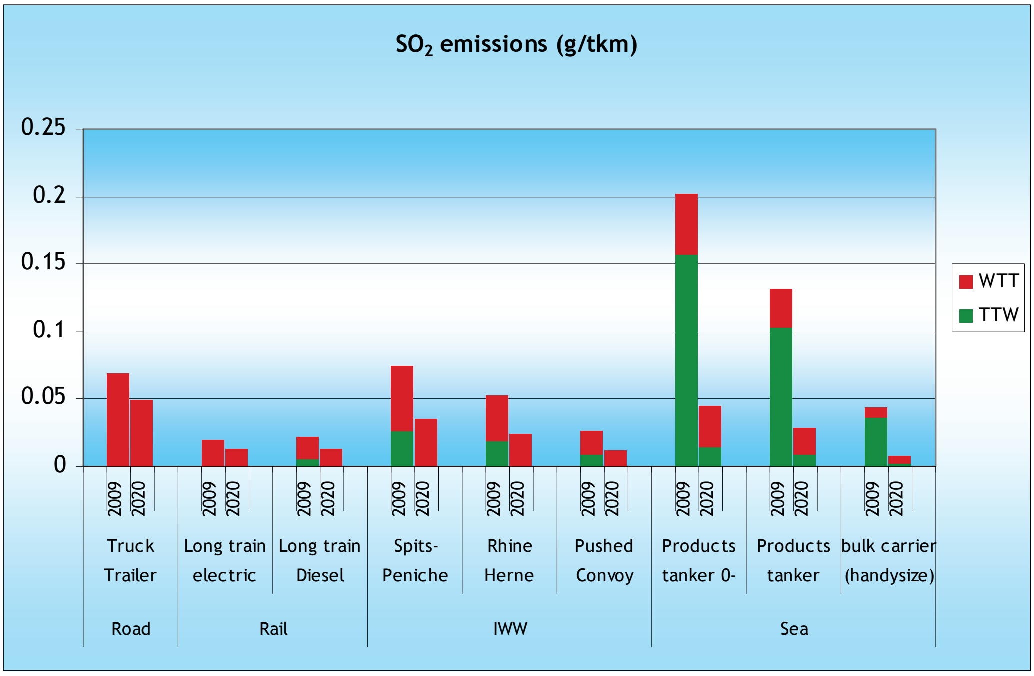
In Figure 4-Figure 7 the development of the emission from 2009 to 2020 are illustrated by the emission factors (g/tkm) of several selected vehicle types for average bulk & general cargo transport. As can be seen in the figures, the decrease of emission factors for CO_2 are quite similar for the different modes. The reduction is between 4 and 5%, and little higher for maritime transport.

Figure 4 Comparison of CO_2 emissions 2009 and 2020 for selected vehicle types



The high SO_2 exhaust emissions in 2009 for diesel trains, inland waterway vessels, and in particular maritime shipping are significantly reduced in 2020 due to the introduction of 10 ppm S fuels. In 2020 only for maritime shipping SO_2 exhaust emissions have a significant share in the total well-to-wheel emissions, but the reduction is significant, compared to 2009. For the other modes upstream SO_2 emissions are dominant in 2020.

Figure 5 Comparison of SO_2 emissions 2009 and 2020 for selected vehicle types



For $PM_{2.5}$ and NO_x emissions the reduction of emissions from 2009 to 2020 are the strongest for road (66 and 51% respectively for $PM_{2.5}$ and NO_x), which can be explained by the European emissions standards for trucks and the shorter lifetime of vehicles. For rail diesel (30% both) and inland shipping (32 and 21% respectively for $PM_{2.5}$ and NO_x), emissions reductions are lower. The figures reflect WTW emissions.

Figure 6 Comparison of $PM_{2.5}$ emissions 2009 and 2020 for selected vehicle types

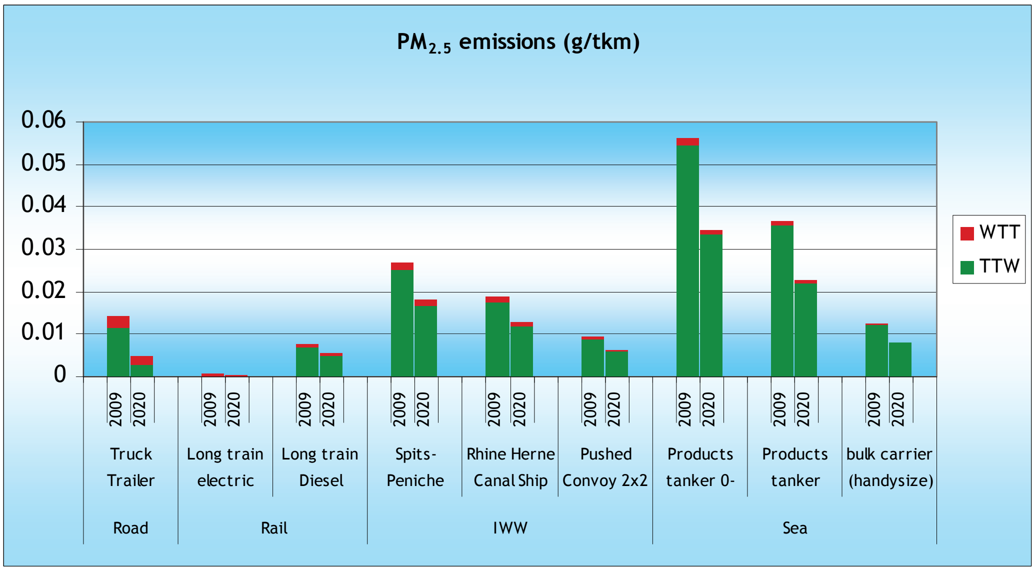
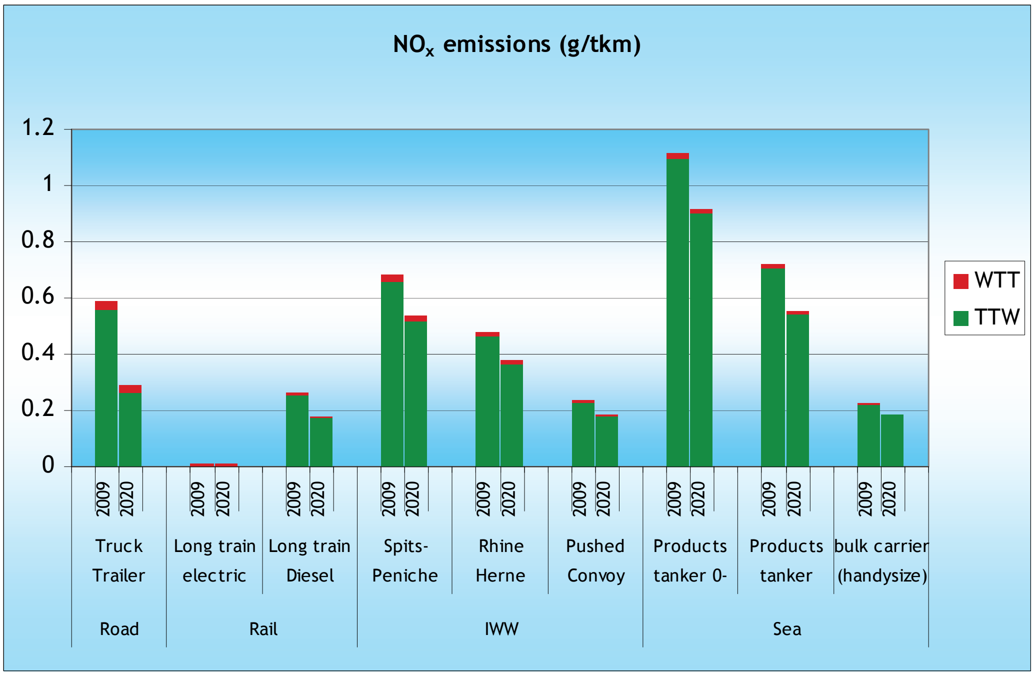


Figure 7 Comparison of NO_x emissions 2009 and 2020 for selected vehicle types



5.7 Wear and tear emissions road an rail 2009 and 2020

In Table 54-Table 55 the wear and tear PM_{10} emissions for road and rail are shown for both general & bulk cargo and containerised cargo, respectively. For comparison the $PM_{2.5}$ exhaust emission are also shown. It is assumed that the wear and tear emissions remain the same in 2020. The comparison with the exhaust emission shows that PM_{10} emissions will have a large share in the total of particulate matter emissions ($PM_{2.5}$ and PM_{10}).

Table 54 Wear and tear PM_{10} emissions for road and rail: general & bulk cargo (g/tkm): for comparison exhaust (TTW) $PM_{2.5}$ emissions for2009 and 2020 are shown between brackets

		Voluminous cargo		Average cargo		Heavy vargo	
		PM_{10} wear & tear	TTW $PM_{2.5}$ (2009/2020)	PM_{10} wear & tear	TTW $PM_{2.5}$ (2009/2020)	PM_{10} wear & tear	TTW $PM_{2.5}$ (2009/2020)
Road							
Small van < 2 tonne	Total	0.16	(0.78/0.23)	0.14	(0.67/0.20)	-	-
	Urban	0.23	(1.00/0.31)	0.20	(0.86/0.26)	-	-
	Non-urban	0.11	(0.53/0.16)	0.10	(0.45/0.14)	-	-
	Motorway	0.11	(0.73/0.21)	0.10	(0.63/0.18)	-	-
Large van > 2 tonne	Total	0.09	(0.52/0.15)	0.08	(0.45/0.13)	-	-
	Urban	0.14	(0.66/0.19)	0.12	(0.57/0.16)	-	-
	Non-urban	0.06	(0.35/0.10)	0.06	(0.30/0.09)	-	-
	Motorway	0.06	(0.50/0.14)	0.06	(0.43/0.12)	-	-
Truck < 10 tonne	Total	0.13	(0.13/0.03)	0.12	(0.12/0.03)	-	-
	Urban	0.23	(0.23/0.06)	0.21	(0.21/0.06)	-	-
	Non-urban	0.11	(0.14/0.03)	0.10	(0.13/0.03)	-	-
	Motorway	0.11	(0.11/0.03)	0.10	(0.10/0.02)	-	-
Truck 10-20 tonne	Total	0.029	(0.04/0.011)	0.021	(0.03/0.008)	0.018	(0.027/0.007)
	Urban	0.053	(0.08/0.021)	0.038	(0.06/0.015)	0.033	(0.049/0.013)
	Non-urban	0.025	(0.05/0.012)	0.018	(0.03/0.009)	0.016	(0.028/0.007)
	Motorway	0.025	(0.04/0.009)	0.018	(0.03/0.006)	0.016	(0.021/0.005)
Truck > 20 tonne	Total	0.014	(0.03/0.008)	0.010	(0.02/0.006)	0.009	(0.018/0.005)
	Urban	0.026	(0.05/0.014)	0.019	(0.04/0.011)	0.016	(0.033/0.009)
	Non-urban	0.012	(0.03/0.008)	0.009	(0.02/0.006)	0.008	(0.019/0.005)
	Motorway	0.012	(0.02/0.006)	0.009	(0.02/0.004)	0.008	(0.014/0.004)
Truck trailer	Total	0.007	(0.02/0.004)	0.005	(0.011/0.003)	0.005	(0.010/0.002)
	Urban	0.013	(0.03/0.008)	0.010	(0.024/0.006)	0.009	(0.021/0.005)
	Non-urban	0.007	(0.02/0.004)	0.005	(0.013/0.003)	0.004	(0.011/0.003)
	Motorway	0.007	(0.01/0.003)	0.005	(0.009/0.002)	0.004	(0.008/0.002)
LHV	Total	0.007	(0.01/0.003)	0.005	(0.009/0.002)	0.005	(0.008/0.002)
	Urban	0.013	(0.03/0.007)	0.010	(0.019/0.005)	0.009	(0.017/0.004)
	Non-urban	0.006	(0.01/0.004)	0.005	(0.011/0.003)	0.004	(0.009/0.002)
	Motorway	0.006	(0.01/0.002)	0.005	(0.007/0.002)	0.004	(0.006/0.002)
Train, electric							
Short train		0.07	-	0.04	-	0.03	-
Medium train		0.05	-	0.03	-	0.02	-
Long train		0.04	-	0.02	-	0.02	-
Train, diesel							
Short train		0.06	(0.02/0.01)	0.04	(0.011/0.008)	0.03	(0.007/0.005)
Medium train		0.05	(0.01/0.01)	0.03	(0.008/0.006)	0.02	(0.006/0.004)
Long train		0.04	(0.01/0.01)	0.02	(0.007/0.005)	0.02	(0.006/0.004)

Table 55 Wear and tear PM_{10} emissions for road and rail: Containerised cargo (g/tkm): for comparison exhaust (TTW) $PM_{2.5}$ emissions for 2009 and 2020 are shown between brackets

		Voluminous cargo		Average cargo		Heavy vargo	
		PM_{10} wear & tear	TTW $PM_{2.5}$ (2009/2020)	PM10 wear & tear	TTW $PM_{2.5}$ (2009/2020)	PM_{10} wear & tear	TTW $PM_{2.5}$ (2009/2020)
Road							
Truck > 20 tonne	Total	0.016	(0.03/0.009)	0.010	(0.02/0.005)	0.0073	(0.014/0.004)
	Urban	0.030	(0.06/0.016)	0.018	(0.04/0.010)	0.014	(0.027/0.007)
	Non-urban	0.014	(0.03/0.009)	0.009	(0.02/0.005)	0.0065	(0.015/0.004)
	Motorway	0.014	(0.03/0.007)	0.009	(0.02/0.004)	0.0064	(0.011/0.003)
Truck trailer	Total	0.008	(0.02/0.004)	0.005	(0.010/0.003)	0.0040	(0.008/0.002)
	Urban	0.015	(0.04/0.009)	0.010	(0.022/0.006)	0.0077	(0.017/0.004)
	Non-urban	0.007	(0.02/0.005)	0.005	(0.012/0.003)	0.0037	(0.009/0.002)
	Motorway	0.008	(0.01/0.003)	0.005	(0.009/0.002)	0.0036	(0.006/0.002)
LHV	Total	0.008	(0.01/0.003)	0.005	(0.008/0.002)	0.0039	(0.006/0.002)
	Urban	0.015	(0.03/0.008)	0.010	(0.018/0.005)	0.0075	(0.014/0.003)
	Non-urban	0.007	(0.02/0.004)	0.005	(0.010/0.002)	0.0036	(0.007/0.002)
	Motorway	0.007	(0.01/0.003)	0.005	(0.007/0.002)	0.0035	(0.005/0.001)
Train, electric							
Short train		0.090	-	0.053	-	0.040	-
Medium train		0.068	-	0.041	-	0.031	-
Long train		0.058	-	0.035	-	0.026	-
Train, diesel							
Short train		0.088	(0.03/0.018)	0.052	(0.015/0.011)	0.040	(0.012/0.008)
Medium train		0.067	(0.02/0.014)	0.040	(0.012/0.008)	0.030	(0.009/0.006)
Long train		0.057	(0.02/0.012)	0.034	(0.010/0.007)	0.026	(0.008/0.005)

6 Comparison of transport modes

6.1 Introduction

In this chapter, we discuss the environmental impacts of modal shift. Modal shift is under discussion from both an air quality and climate point of view. The Transport 2050 roadmap of the recently published White Paper describes a large role for rail and inland transport on longer distances; 30% of road freight over 300 km should shift to other modes such as rail or waterborne transport, and more than 50% by 2050.

In the previous chapters, we discussed the emissions of the different transport modes separately. In this chapter, we will make a comparison between the different modes for situations where different modes are available and competition between the different modes exists. In addition to the emissions of the different modes, the logistical characteristics need to be taken into account. These can have a major influence, as detour factors can be as high as 150% and infrastructure might dictate the maximum vehicle size.

Since modal shift has the biggest potential on the long distance, we will concentrate on transport distances over 200 km.

When comparing the emissions of different transport modes, several important factors need to be taken into account, as indicated in Chapter 2:
- Detouring.
- Pre- and end-haulage.
- Logistical characteristics.
- Loading and unloading.

Section 6.2 illustrates the differences between modes in detouring. From the examples in this section a selection is made and elaborated in Section 6.3. Cases with different levels of detouring and pre- and end-haulage are compared.

6.2 Selection of cases

Since the emissions of transport modes strongly depend on the logistical characteristics and the logistical characteristics vary significantly per case, we will calculate the emission factors for specific cases.

The impact of detouring is illustrated in Table 56. A detour factor of 1.5 implies that the distance for the particular mode is 50% higher than the distance needed over the shortest link.

Table 56 Detour factors for selected transport chains

Origin	Destination	Distance (km)				Distance shotest link (km)	Detour factor			
		Road	Rail	IWW	SSS	(km)	Road	Rail	IWW	SSS
Port of Rotterdam	Milan	1,018	1,082	--	--	**1,018**	1.00	1.06	--	--
Port of Rotterdam	Köln	268	245	303	--	**245**	1.09	1.00	1.24	--
Hamburg	Duisburg	631	629	--	--	**629**	1.00	1.00	--	--
Rotterdam	Thionville	388	397	668	--	**388**	1.00	1.02	1.72	--
Rotterdam	Vienna	1,104	1,180	1,580	--	**1,104**	1.00	1.07	1.43	--
Rotterdam	Duisburg	240	241	253	--	**240**	1.00	1.00	1.05	--
Groningen seaport	Vienna	1,068	1,321	1,601	--	**1,068**	1.00	1.24	1.50	--
Bilbao	Rotterdam	1,368	1,428	--	1,418	**1,368**	1.00	1.04	--	1.04
Antwerp	Barcelona	1,390	1,435	--	3,508	**1,390**	1.00	1.03	--	2.52
Amsterdam	Regensburg	759	788	1,047	--	**759**	1.00	1.04	1.38	--

Source: www.ecotransit.org.

Table 56 reveals that for some links detour factors can be significant. Furthermore, in particular detour factors for inland waterways and short sea shipping can be high. The significant variation in detour factors is one of the reasons that impede drawing conclusions in a general way.

On the basis of an exploration of market cases, the following links have been selected for which a modal shift may be relevant within the next ten years. The cases are a mix of hardly any detouring and significant detouring and include end-haulage to other cities.

Cases:
- Rotterdam–Duisburg Container transport: see Table 57 for details per mode.
- Rotterdam-Bilbao Container transport: see Table 58 for details per mode.
- Amsterdam- Regensburg bulk (steel) transport: see Table 59 for details per mode.

6.3 Comparison of modes for various cases

To be able to make a good comparison between the different modes in the cases, all emissions are expressed per tonne-kilometre over the shortest link. In this way the effect of detouring and pre- and end-haulage are included in the emissions per tonne-kilometre. The shortest link kilometres are determined by the mode with the shortest connection between origin and destination. Detouring of a certain mode results in higher emissions per tonne-kilometre over the shortest link, as compared to the emission per tonne-kilometre over the real distance covered by the mode.

The emission per tonne-kilometre (EF) are based on the emission factors of Chapter 5 and the corresponding logistic parameters of Chapter 4. It should be noted that for electric trains the emission are highly depended on the electricity mix. Here an average European electricity mix is applied. Applying a country specific electricity mix might increase emissions easily by 50% percent.

Emission per tonne-kilometre over the shortest link (EF_{sl}) including detouring and pre- and end-haulage are calculated for a certain mode as follows:

$$EF_{sl} = \frac{EF_{tkm,mode} \times Dist_{mode} + EF_{trans} + EF_{EH} \times Dist_{EH}}{Dist_{sl}}$$

With:

EF_{mode}: Emission factor (g/tkm) of transport mode (Chapter 5)
$Dist_{mode}$: Distance covered by the transport mode
E_{trans}: Emissions of transshipment
EF_{EH}: Emission factor (g/tkm) of End-Haulage per truck (Chapter 5)
$Dist_{EH}$: Distance of end-haulage per truck
$Dist_{sl}$: Distance to destination over the shortest link

6.3.1 Case Rotterdam-Duisburg

In this case average container transport from Rotterdam to Duisburg is evaluated. Detouring of the modes is limited in this case. The effect on the emission per tonne-kilometre for end-haulage to Essen and Dortmund are included in the comparison. The transport distances for the different modes are summarised in Table 57.

Table 57 Distances Case Rotterdam Duisburg

	Rotterdam-Duisburg		Rottterdam-Essen		Rotterdam-Dortmund	
	Distance of mode	Distance truck end-haulage	Distance of mode	Distance truck end-haulage	Distance of mode	Distance truck end-haulage
Truck-trailer	240 (0:12:88)*	0	266 (0:11:89)*	0	290 (1:11:88)*	0
Train 70 TEU Diesel	241	0	241	26 (8:0:92)*	241	63 (6:6:87)*
Train 70 TEU Electric	241	0	241	26 (8:0:92)*	241	63 (6:6:87)*
Inland Waterway ship 272 TEU	253	0	253	26 (8:0:92)*	253	63 (6:6:87)*
Inland waterway ship 470 TEU	253	0	253	26 (8:0:92)*	253	63 (6:6:87)*

* % urban : nonurban: motorway.

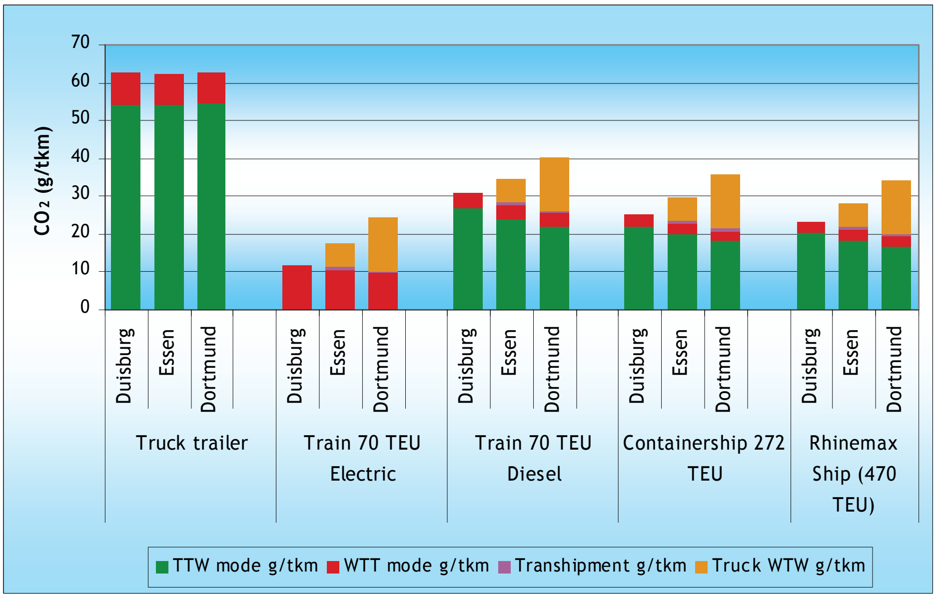
In the Figures below the cases are defined as follows:
- Duisburg: Transport from Rotterdam to Duisburg.
- Essen: Transport from Rotterdam to Essen; for rail and inland waterways containers are transhipped in Duisburg.
- Dortmund: Transport from Rotterdam to Dortmund; for rail and inland waterways containers are transhipped in Duisburg.

As the comparison between modes give a quite similar picture for the year 2009 and 2020 only the results for the year 2020 are shown in this chapter. The results for 2009 can be found in Annex C.

CO_2 emissions

Figure 24 (Annex C) and Figure 8 compare the results for the CO_2 emissions per tonne-kilometre for container transport (average weight) with different modes in 2009 and 2020.The lowest emissions per tonne-kilometre are found for the electric train, the highest for road. Detouring for the different modes on the track Rotterdam-Duisburg is limited and the emissions per tonne-kilometres over the shortest link are hardly increased by detouring. Introduction of end-haulage to Essen or Dortmund does not change the outcome of the comparison although for the non-road modes, the end-haulage to Dortmund has a rather large impact on the total CO_2 emission per tonne-kilometre. The emissions of transhipment are negligible at the distance Rotterdam-Duisburg.

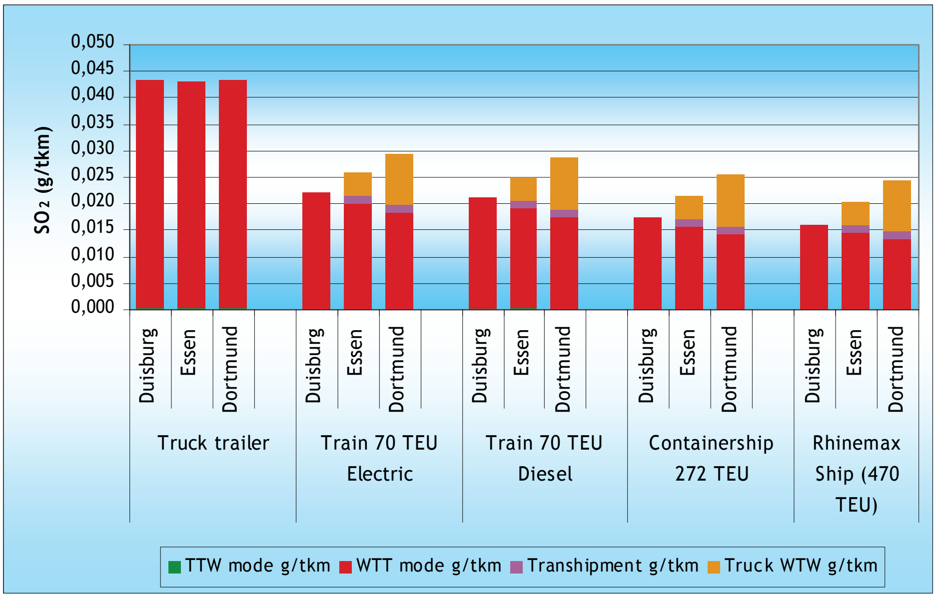
Figure 8 **CO_2 emission per tonne-km for average container transport; case: Rotterdam-Duisburg 2020**



SO_2 emissions

Figure 25 (Annex C)) and Figure 9 compare the results for the SO_2 emissions per tonne-kilometre for container transport (average weight) with different modes in 2009 and 2020. In 2009 the exhaust emission (TTW) for diesel trains and inland waterways are by far higher than for road transport and electric trains. For all modes, however, the upstream (WTT) emissions are dominant. In 2020 the sulphur content of diesel for all modes is the same due to more stringent legislation for rail and IWW diesel. In 2020 SO_2 exhaust emission for all modes are negligible as compared to the upstream emissions. The non-road modes, with the higher load capacity, score optimal.

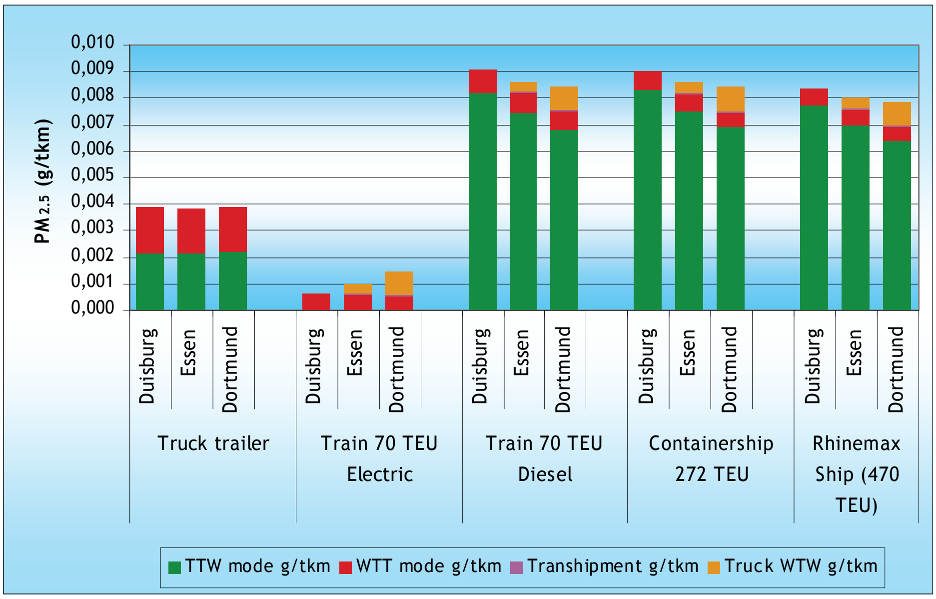
Figure 9 SO_2 emission per tonne-km for average container transport; case: Rotterdam-Duisburg 2020



$PM_{2.5}$ emissions

Figure 26 (Annex C) and Figure 10 compare the results for the $PM_{2.5}$ emissions per tonne-kilometre for container transport (average weight) with different modes in 2009 and 2020. $PM_{2.5}$ emissions for electric trains are by far the lowest. The other modes score quite similar. For electric trains, the effect of end-haulage is significant due its low own emissions. For the other non-road modes detouring and end-haulage to Essen and Dortmund make them score worse than road. In 2020 emissions for road are strongly reduced due to the introduction of newer Euro classes.

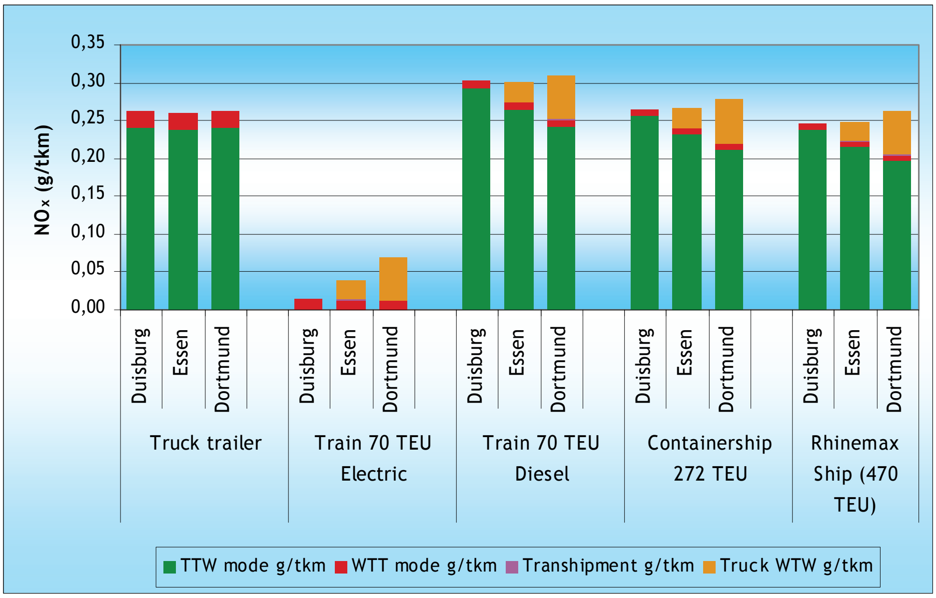
Figure 10 $PM_{2.5}$ emission per tonne-km for average container transport; case: Rotterdam-Duisburg 2020



NO_x emissions

Figure 27 (Annex C) and Figure 11 compare the results for the NO_x emissions per tonne-kilometre for container transport (average weight) with different modes in 2009 and 2020. Again NO_x emissions for electric trains are lowest and the effect of end-haulage is relatively significant. The emissions for road transport in 2009 are somewhat higher than for the other non-road diesel modes, whereas in 2020 they are somewhat lower.

Figure 11 NO_x emission per tonne-km for average container transport; case: Rotterdam-Duisburg 2020



6.3.2 Case Rotterdam-Bilbao

In this case average container transport from Rotterdam to Bilbao is evaluated. The effect on the emissions per tonne-kilometre for end-haulage to Madrid is included in the comparison. The transport distances per mode are summarised in Table 60.

Table 58 Distances Case Rotterdam-Bilbao

	Rotterdam-Bilbao		Rotterdam-Madrid	
	Distance of mode	Distance truck end-haulage	Distance of mode	Distance truck end-haulage
Truck-trailer	1368 (0:2:98)*	0	1708 (0:2:98)*	0
Train 70 TEU Diesel	1428	0	1879	0
Train 70 TEU Electric	1428	0	1879	0
Container seaship (feeder) 0-999 TEU	1418	0	1418	398 (2:1:97)*

* % urban : nonurban: motorway.

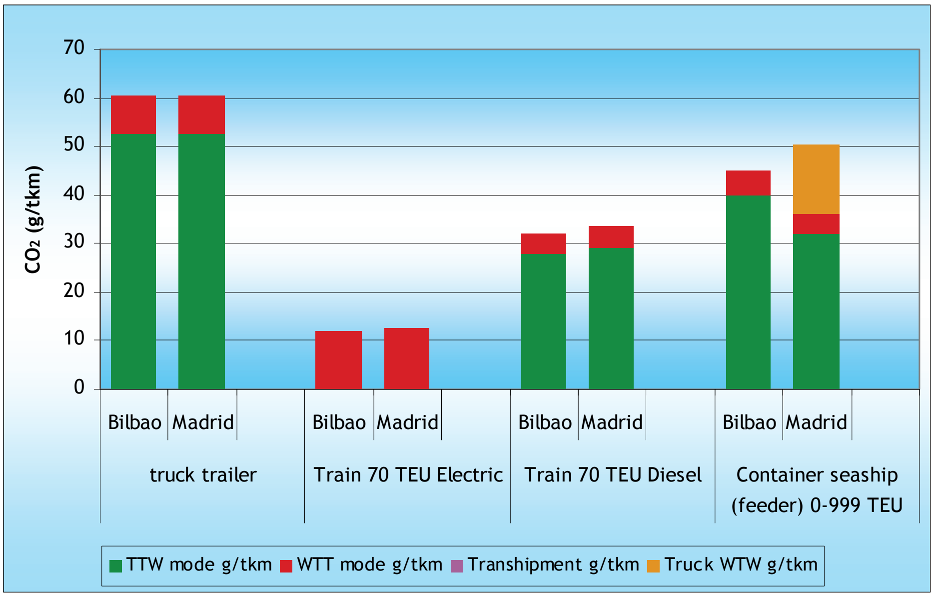
In the Figures below the cases are defined as follows:
- Bilbao: Transport from Rotterdam to Bilbao harbour.
- Madrid: Transport from Rotterdam to Bilbao; for short sea shipping containers are transhipped in Bilbao.

The results for the year 2020 are shown below. The results for 2009 can be found in Annex C

CO_2 emissions

Figure 28 (Annex C) and Figure 12 compare the results for the CO_2 emissions per tonne-kilometre for container transport (average weight) with different modes in 2009 and 2020.The lowest emissions per tonne-kilometre are found for the electric train, the highest for road. Due to detouring, emissions per tonne-kilometre for short sea shipping come close to those of road, in particular for end-haulage to Madrid. The emissions of transhipment are negligible at the distance Rotterdam-Bilbao.

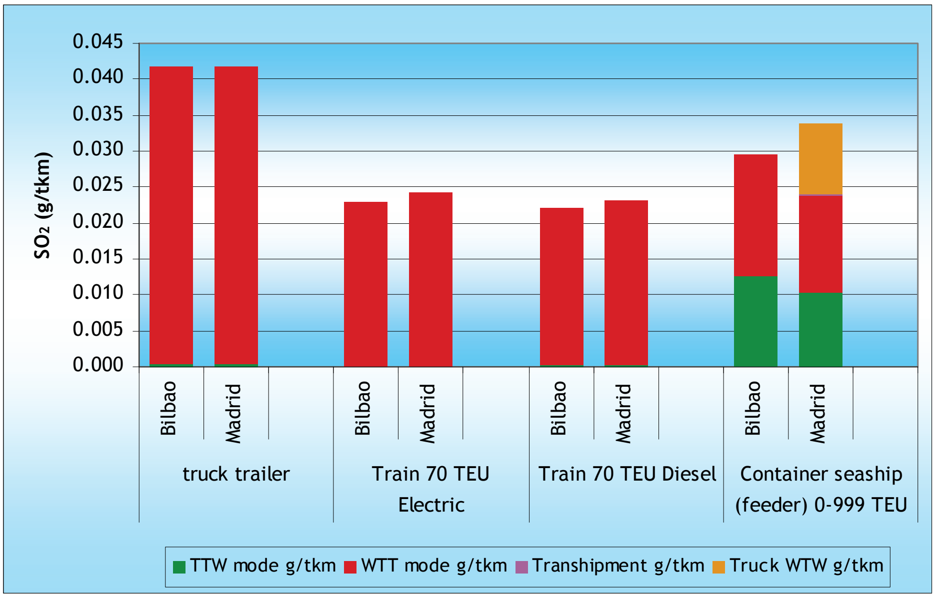
Figure 12 CO_2 emission per tonne-km for average container transport; case: Rotterdam-Bilbao 2020



SO_2 emission

Figure 29 (Annex C) and Figure 13 compare the results for the SO_2 emissions per tonne-kilometre for container transport (average weight) with different modes in 2009 and 2020. In 2009 the exhaust emission (TTW) for diesel trains and in particular short sea shipping are by far higher than for road transport and electric trains. For all modes, except short sea shipping, the upstream (WTT) emissions are dominant. In 2020 the sulphur content of rail diesel is the same as for road and the sulphur content of heavy fuel oil for short sea shipping has decreased significantly. In 2020 short sea shipping will have lower well-to-tank emission on this track than road, despite the higher tank-to-wheel emissions and the detouring.

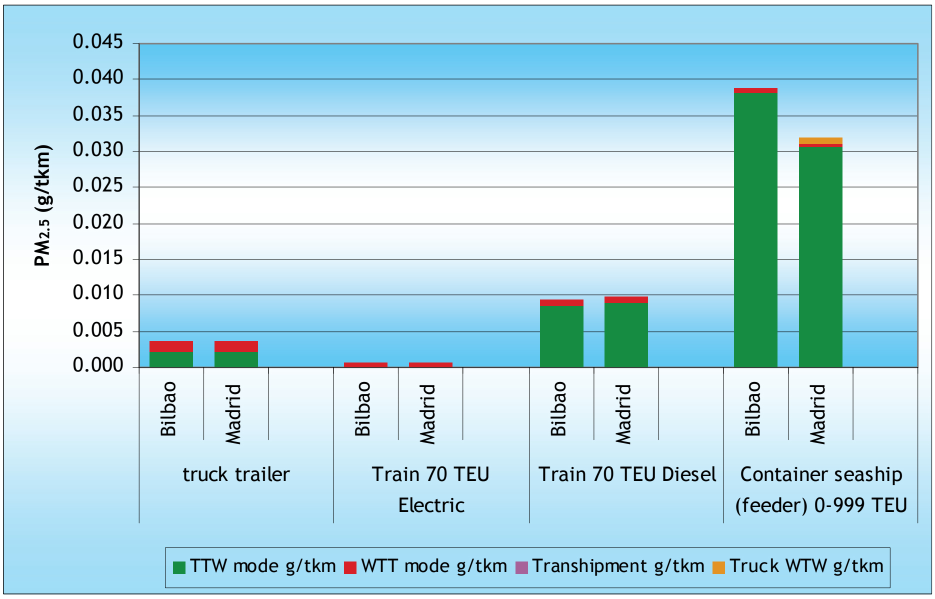
Figure 13 SO_2 emission per tonne-km for average container transport; case: Rotterdam-Bilbao 2020



$PM_{2.5}$ emission

Figure 30 (Annex C) and Figure 14 show the results for the $PM_{2.5}$ emissions per tonne-kilometre for container transport (average weight) with different modes in 2009 and 2020. $PM_{2.5}$ emissions for electric trains are by far the lowest on this track and the $PM_{2.5}$ emission for short sea shipping are by fart the highest. End-haulage to Madrid decreases the emission per tonne-kilometre (over the shortest link) because of the share of trucks in the transport chain. The latter effect is more pronounced than the effect of extra kilometres for end-haulage for short sea shipping as compared to direct transport by truck.

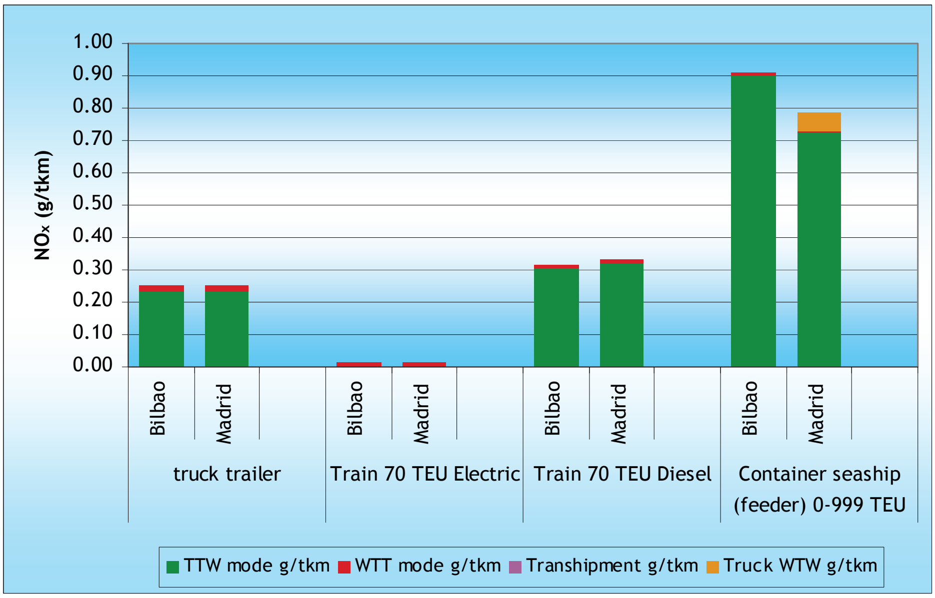
Figure 14 $PM_{2.5}$ emission per tonne-km for average container transport; case: Rotterdam-Bilbao 2020



NO_x emission

Figure 31 (Annex C) and Figure 15 show the results for the NO_x emissions per tonne-kilometre for container transport (average weight) with different modes in 2009 and 2020. Again NO_x emissions for electric trains are lowest, but also NO_x emission for short sea transport are low. Due to stronger legislation for trucks in 2020, diesel trains will have higher NO_x emissions than trucks in 2020 on this track.

Figure 15 **NO_x emission per tonne-km for average container transport; case: Rotterdam-Bilbao 2020**



6.3.3 Case Amsterdam-Regensburg (steel)[10]

In this case average transport of steel from Amsterdam to Regensburg is evaluated. The effect on the emission per tonne-kilometre for end-haulage to Munich is included in the comparison. The transport distances for the different modes are summarised in Table 59.

Table 59 **Distances Case Amsterdam-Regensburg**

	Amsterdam-Regensburg		Amsterdam-Munich	
	Distance of mode	Distance truck end-haulage	Distance of mode	Distance truck end-haulage
Truck-trailer	759 (0:0:100)*	0	832 (0:0:100)*	0
Long train electric	788	0	868	0
Short train Diesel	788	0	868	0
Long train Diesel	788	0	868	0
Rhine Herne Canal Ship	1,047	0	1,047	141 (0:1:99)*
Large Rhine vessel	1,047	0	1,047	141 (0:1:99)*

* % urban : nonurban: motorway.

10 A Tata steel plant is located in the Amsterdam port area.

In Figure 16-Figure 19 below the following cases are shown:

- Regensburg: Transport from Amsterdam to Regensburg harbour.
- Munich: Transport from Amsterdam to Munich; for inland waterway transport the steel is transhipped in Regensburg.

The results for the year 2020 are shown below. The results for 2009 can be found in Annex C.

As compared to the results of the previous cases, it can be seen that due to a higher detouring factor for inland waterways, emission for this mode are relatively higher.

Figure 16 CO_2 emission per tonne-km for heavy bulk transport; case: Amsterdam-Regensburg 2020

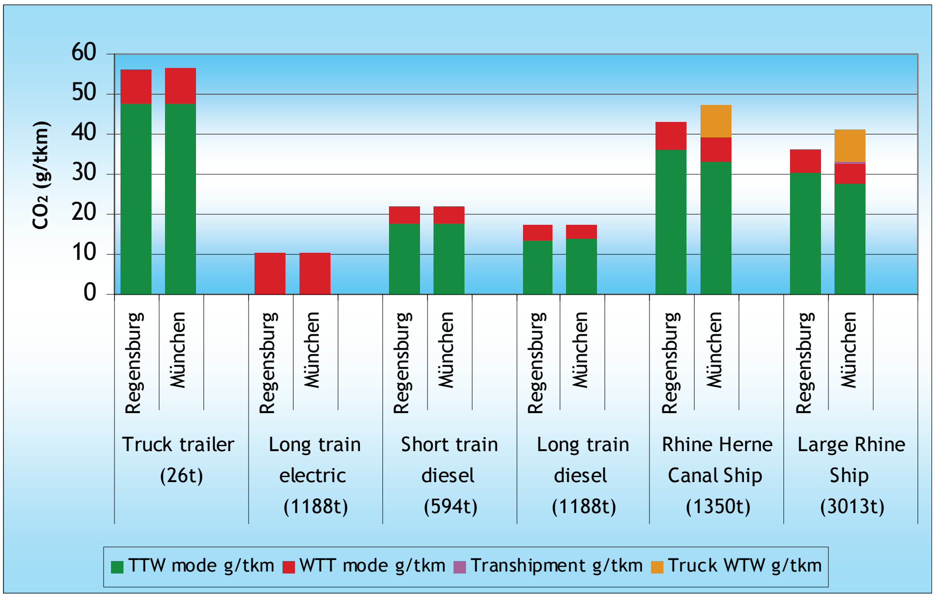


Figure 17 SO_2 emission per tonne-km for heavy bulk transport; case: Amsterdam-Regensburg 2020

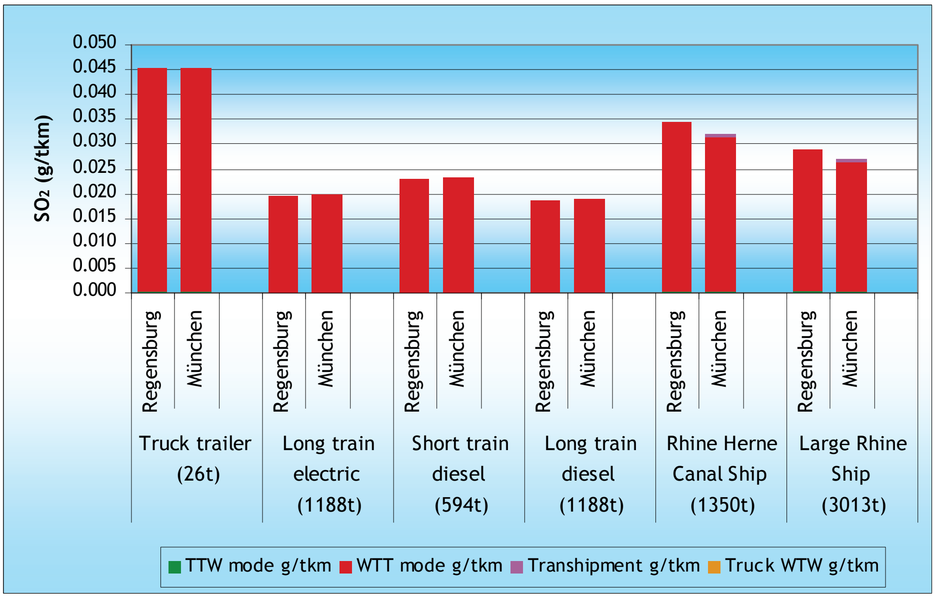


Figure 18 PM_{10} emission per tonne-km for heavy bulk transport; case: Amsterdam-Regensburg 2020

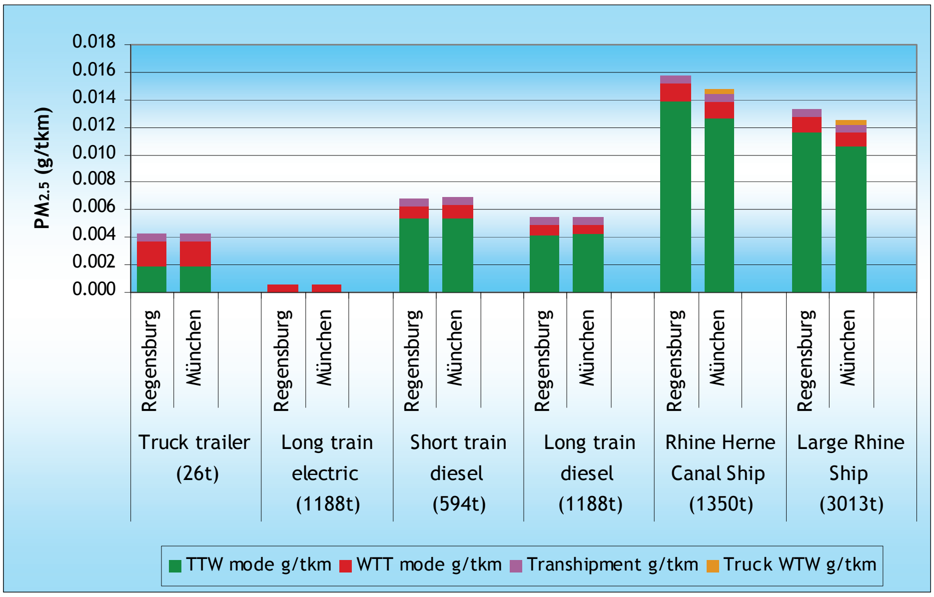
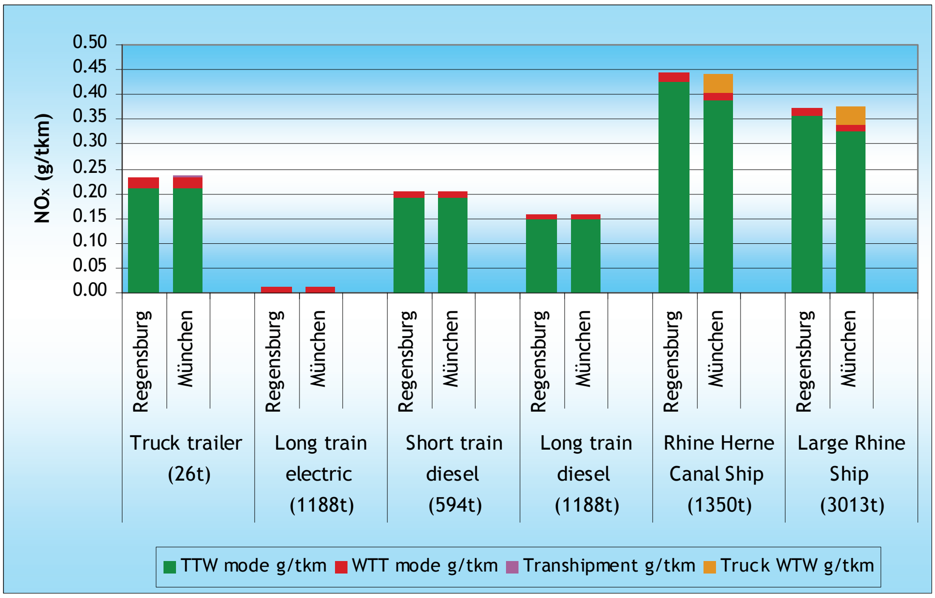


Figure 19 NO_x emission per tonne-km for heavy bulk transport; case: Amsterdam-Regensburg 2020



6.4 Conclusion

In general electric trains have the lowest emissions except for the upstream SO_2 emissions. Detouring of rail transport can hardly undo the benefits electric rail has over the other modes. It should, however, be noted that electric trains score very well for the average EU electricity mix. For another mix, in which the fossil fuel content for electricity production is high, emission can easily be 50% higher.

In the presented cases exhaust SO_2, NO_x and PM_{10} emission for short sea shipping in 2009 are extremely high as compared to the other modes. It should be noted, however, that the location of the emissions is at sea and that the

impact of the emissions is therefore different from the emissions of the other modes that are in more populated areas. In 2020 the SO_2 exhaust emissions of short sea transport will be much lower and the sum of the exhaust and upstream emission are more comparable to road upstream SO_2 emissions.
In the presented cases rail diesel and inland waterways score better on CO_2 and SO_2 emission than road transport. However, when detouring is significant for the two non-road modes, emissions might get closer to the level of the road emissions.

$PM_{2.5}$ emissions for rail diesel and inland waterways can be similar as for road, but also higher in case of significant detouring and small ships. NO_x emissions of rail diesel and inland waterways can be either lower or higher, depending on the characteristics mentioned.

The emissions of transhipping hardly play any role on distances over 200 km.

7 Conclusion

7.1 Approach and methodology

The approach of the study is to provide an overview of the average fleet performance of the different freight modes for policy makers, as to enhance the understanding of the competing transport modes. The report is to be used for a discussion on a EU level on future emissions legislation and the potential impact of increased co-modality.

This study contains a large amount of basic emission and logistical data, which can be used to calculate transport emissions. Given the approach, the data are mainly based on European datasets or data representative for average international transport movements in the EU. Both data on vehicle use and vehicle technology have been used. Emission data are presented per tonne-kilometre. The approach differs from the 2008 STREAM study that was directed at the Dutch situation. It should be noted that the change in scope of the study influences the results.

The emissions of the entire transport chain are taken into account; emissions from fuel production and transportation and electricity production and transportation. Wear and tear emissions and vehicle production, maintenance, end-of-life and infrastructure related emissions are not included.

The data can be used for two purposes. First, the emission factors for different modes and vehicle types presented in Chapter 4 can be used for footprint calculations. The comparison of modes should *only* be done on the basis of the cases presented in Chapter 5. In that chapter, the effect of detouring and end-haulage on the emissions is taken into account and illustrated by representative cases. The cases also illustrate how the tonne-kilometre data can be used to compare different modes for a certain track.

Data are given for the years 2009 and 2020.

7.2 Results: development until 2020

In the period 2009-2020, CO_2 emissions for all modes are expected to decrease at a roughly similar rate, around 5% with little higher figures for maritime transport.

In 2020 the PM_{10} and NO_x emission factors for truck transport are reduced most (50-65% versus over the WTW chain compared 30% on average for inland waterway and rail diesel) as compared to 2009, due to the effective European emission standards that apply for truck engines. For the other modes the reduction is smaller. This can be explained by less fleet renewal and less stringent emission standards in case of inland barge and marine engines.

In 2020 the SO_2 exhaust emissions of short sea transport will be much lower and the sum of the exhaust and upstream emissions are more comparable to road upstream SO_2 emissions.

Wear and tear emissions, from road and rail transport only, are already important in these days, and their importance will be increased in 2020, since engine emissions are projected to decrease. The environmental impact of these particles is due to their size and composition less harmful than exhaust emissions.

7.3 Results: comparison of transport modes

Generally, the following factors influence the emissions per tonne-kilometre:
- Vehicle utilisation.
- Detouring and pre- and end-haulage.
- Scale of transport.
- Emission technology.
- Energy efficiency.

To compare the different transport modes, three representative cases were calculated, representing both favourable and less favourable circumstances for the different modes, with using average emission technology and vehicle utilisation.

In general, electric trains have the lowest emissions over the entire chain studied. Detouring of rail transport can hardly undo the benefits electric rail has over the other modes. It should, however, be noted that electric train transport scores very well for the average EU electricity mix. For another mix, in which the fossil fuel content for electricity production is high, emission can easily be 50% higher.

GHG emissions
In the presented cases rail and inland waterways score generally better on CO_2 emissions than road both in 2009 and 2020. However, when detouring is significant for the two non-road modes and the scale of transport is small, emissions might get close to the level of the road emissions.

Pollutant emissions
$PM_{2.5}$ emissions for rail diesel and inland waterways can be similar as for road, but also higher in case of significant detouring and small ships. NO_x emissions of rail diesel and inland waterways can be either lower or higher, depending on the characteristics mentioned.

SO_2, NO_x and $PM_{2.5}$ emission for short sea shipping are high as compared to the other modes.

The emissions of transhipping hardly play any role on distances over 200 km.

The conclusions above apply to 2009. The projections for 2020 show that the gap between road transport and inland navigation and short sea shipping will grow.

7.4 Recommendations

The fuel consumption of inland vessels is based on a model that calculates the fuel consumption as function of e.g. vessel speed, water speed, water depth and ship shape. This model is widely used in different transport models like TREMOVE and the Dutch national emission inventory. However, energy consumption of road and rail transport is based on real world, inland shipping energy consumption is only based on modelling. Although fuel consumption of inland shipping is based on many variables, it would make sense to validate the model outcome with field measurements.

Infrastructure and vehicle construction are not included in the analyses, due to lack of data. However, recent preliminary research by AEA (2011) shows that especially for rail, the share of infrastructure construction in the overall energy consumption over the entire life cycle can be considerable. AEA (2011) cites figures of 30% and higher. Since the modes itself get more fuel efficient in the next decades, inclusion of infrastructure and vehicle construction will become more important.

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Annex A Emission factors Road (background data)

Table 60 CO_2 emission factors of trucks per road type (gram/km)

GVW	Truck/van type	Urban road	Non-urban road	Motorway
< 2 ton	Small van*	286	185	254
> 2 ton	Large van*	336	217	297
<10 ton	Light truck	511	386	401
10-20 ton	Medium weight truck with trailer	1,125	820	682
	Medium weight truck	897	600	533
> 20 ton	Truck trailer combination	1,336	884	686
	Heavy weight truck with trailer	1,516	1,115	918
	Heavy weight truck	1,290	887	754

Source: 1) Vans: TREMOVE, 2010; TNO, 2007 and WLO, 2008. 2) Trucks: TNO 2008.

* WLO 2008 and TREMOVE give very similar CO_2 emission factors for the average van, which has been used as starting point. The differentiation to road type is based on the TREMOVE data base. The data have been differentiated to small and large vans on base of (TNO, 2007) assuming 1:1 ratio between small and large vans.

Table 61 Emission factors $PM_{2.5}$ and NO_x of trucks and vans per road type (gram/km)

Pollutant	Truck type	GVW	Urban road	Non-urban road	Motorway
$PM_{2.5}$	Small van	GVW < 2 ton	0.13	0.07	0.09
	Large van	GVW > 2 ton	0.14	0.08	0.11
	Light truck	GVW < 10 ton	0.14	0.08	0.06
	Medium truck	GVW 10-20 ton	0.21	0.12	0.09
	Heavy truck	GVW > 20 ton	0.28	0.16	0.12
	Truck trailer	all	0.29	0.16	0.11
NO_x	Small van	GVW < 2 ton	1.02	0.61	0.75
	Large van	GVW > 2 ton	1.19	0.71	0.85
	Light truck	GVW < 10 ton	4.1	3.2	3.1
	Medium truck	GVW 10-20 ton	8.0	5.7	4.6
	Heavy truck	GVW > 20 ton	11.5	8.2	6.5
	Truck trailer	all	11.3	7.6	5.9

Source: Table 14-16.

Table 62 $PM_{2.5}$ emission factors per technology and road type

Vehcile type	Euro class	Urban road	Non urban road	Motorway
Delivery van < 2 tonne	PréEURO	0,899	0,470	0,415
	EURO1	0,211	0,102	0,151
	EURO2-DI 3)	0,140	0,054	0,121
	EURO2-IDI 3)	0,121	0,086	0,085
	EURO3	0,077	0,040	0,076
	EURO4	0,082	0,043	0,090
	EURO5	0,003	0,002	0,004
	EURO6	0,003	0,002	0,004
Delivery van > 2 ton	PréEURO	0,899	0,470	0,415
	EURO1	0,263	0,134	0,198
	EURO2-DI 3)	0,192	0,077	0,174
	EURO2-IDI 3)	0,164	0,121	0,120
	EURO3	0,107	0,058	0,109
	EURO4	0,052	0,027	0,056
	EURO5	0,003	0,002	0,004
	EURO6	0,003	0,002	0,004
Truck < 10 ton	PréEURO	1,000	0,546	0,473
	EURO0	0,693	0,419	0,322
	EURO1	0,268	0,161	0,132
	EURO2	0,114	0,080	0,071
	EURO3	0,141	0,082	0,061
	EURO4	0,025	0,014	0,010
	EURO5	0,026	0,014	0,010
	EURO6	0,013	0,007	0,005
Truck 10-20 ton	PréEURO	1,442	0,745	0,553
	EURO0	0,840	0,491	0,358
	EURO1	0,498	0,290	0,219
	EURO2	0,209	0,135	0,113
	EURO3	0,248	0,141	0,108
	EURO4	0,045	0,024	0,017
	EURO5	0,045	0,024	0,017
	EURO6	0,023	0,012	0,008
Truck > 20 ton	PréEURO	1,761	0,915	0,692
	EURO0	0,918	0,554	0,405
	EURO1	0,695	0,408	0,302
	EURO2	0,298	0,189	0,152
	EURO3	0,328	0,188	0,143
	EURO4	0,059	0,031	0,022
	EURO5	0,060	0,031	0,022
	EURO6	0,030	0,016	0,011
Truck and trailer	PréEURO	2,337	1,071	0,794
	EURO0	0,916	0,526	0,374
	EURO1	0,720	0,402	0,269
	EURO2	0,296	0,175	0,134
	EURO3	0,326	0,183	0,127
	EURO4	0,059	0,030	0,020
	EURO5	0,060	0,030	0,020
	EURO6	0,030	0,015	0,010

Source: Taakgroep, 2009; factors in red on base of TNO estimations.

Table 63 NO_x emission factors per technology and road type

Vehcile type	Euro class	Urban road	Non urban road	Motorway
Delivery van < 2 tonne	PréEURO	1,624	1,586	2,731
	EURO1	1,219	0,684	0,776
	EURO2-DI 3)	1,486	0,787	0,969
	EURO2-IDI 3)	1,211	0,551	0,844
	EURO3	1,128	0,659	0,764
	EURO4	0,654	0,361	0,334
	EURO5	0,589	0,325	0,301
	EURO6	0,236	0,130	0,120
Delivery van > 2 ton	PréEURO	2,023	1,982	2,731
	EURO1	1,491	0,831	0,942
	EURO2-DI 3)	1,814	0,968	1,193
	EURO2-IDI 3)	1,440	0,660	1,013
	EURO3	1,349	0,791	0,917
	EURO4	0,644	0,355	0,329
	EURO5	0,580	0,320	0,296
	EURO6	0,232	0,128	0,119
Truck < 10 ton	PréEURO	6,542	5,905	6,625
	EURO0	7,413	5,892	6,222
	EURO1	5,301	4,315	4,448
	EURO2	5,689	4,499	4,520
	EURO3	4,690	3,486	3,138
	EURO4	2,655	2,126	2,065
	EURO5	1,614	2,126	2,065
	EURO6	0,807	1,063	1,033
Truck 10-20 ton	PréEURO	16,450	13,175	12,523
	EURO0	17,084	12,314	10,824
	EURO1	10,446	7,437	6,395
	EURO2	11,025	7,775	6,599
	EURO3	9,147	6,147	4,676
	EURO4	5,219	3,699	2,982
	EURO5	3,154	3,699	2,982
	EURO6	1,577	1,849	1,491
Truck > 20 ton	PréEURO	21,240	17,401	15,668
	EURO0	20,989	15,401	12,974
	EURO1	15,213	10,881	8,972
	EURO2	15,875	11,169	9,179
	EURO3	12,824	8,781	6,514
	EURO4	7,556	5,382	4,197
	EURO5	4,534	5,382	4,197
	EURO6	2,267	2,691	2,098
Truck and trailer	PréEURO	24,606	19,319	16,922
	EURO0	21,231	14,434	11,334
	EURO1	15,138	10,174	8,004
	EURO2	15,574	10,340	8,134
	EURO3	12,594	8,030	5,992
	EURO4	7,382	4,893	3,791
	EURO5	4,420	4,893	3,791
	EURO6	2,210	2,447	1,896

Source: Taakgroep, 2009; factors in red on base of TNO estimations.

Table 64 Vehicle-kilometre distribution of vehicle technologies

Vehcile type	Euro class	2010	2020
Delivery van < 2 tonne	PréEURO	6%	2%
	EURO1	4%	1%
	EURO2-DI 3)	8%	1%
	EURO2-IDI 3)	8%	1%
	EURO3	41%	7%
	EURO4	15%	4%
	EURO5	18%	35%
	EURO6	0%	48%
Delivery van > 2 ton	PréEURO	6%	2%
	EURO1	4%	1%
	EURO2-DI 3)	8%	1%
	EURO2-IDI 3)	8%	1%
	EURO3	41%	7%
	EURO4	15%	4%
	EURO5	18%	35%
	EURO6	0%	48%
Truck < 10 ton	PréEURO	3%	0%
	EURO0	3%	0%
	EURO1	3%	0%
	EURO2	15%	2%
	EURO3	32%	7%
	EURO4	38%	9%
	EURO5	6%	18%
	EURO6	0%	63%
Truck 10-20 ton	PréEURO	3%	0%
	EURO0	3%	0%
	EURO1	3%	0%
	EURO2	15%	1%
	EURO3	35%	8%
	EURO4	37%	10%
	EURO5	6%	17%
	EURO6	0%	62%
Truck > 20 ton	PréEURO	3%	0%
	EURO0	3%	0%
	EURO1	3%	0%
	EURO2	15%	1%
	EURO3	35%	10%
	EURO4	36%	11%
	EURO5	5%	17%
	EURO6	0%	60%
Truck and trailer	PréEURO	3%	0%
	EURO0	3%	0%
	EURO1	3%	0%
	EURO2	14%	1%
	EURO3	35%	9%
	EURO4	36%	11%
	EURO5	6%	17%
	EURO6	0%	61%

Source: TREMOVE, 2010.

Table 65 PM_{10} emission factors for road (wear and tear) per technology and road type

Vehicle type	Urban road	Non urban road	Motorway
Delivery van < 2 tonne	0,030	0,014	0,014
Delivery van > 2 ton	0,030	0,014	0,014
Truck < 10 ton	0,137	0,066	0,066
Truck 10-20 ton	0,137	0,066	0,066
Truck > 20 ton	0,137	0,066	0,066
Truck and trailer	0,123	0,059	0,059

Source: Taakgroep, 2009.

Table 66 Ratio of LHV and truck trailer emission factors in g/km

Pollutant	Ratio of emission factors LHV and truck trailer (g/km-LHV/ g/km- truck trailer)	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)	1.45	Taakgroep, 2009

Annex B How to calculate emissions from container transport?

In the main report, the emissions are calculated per tonne-km of load. This approach is generally applied in studies calculating the emissions of transport (o.a. Ecotransit), since society benefits from the content of the containers, and not the containers itself.

However, the container market is not one single market. Actually, the market for full containers and empty containers are different markets. Inland shipping has a relatively important position in the relocation of empty containers, leading to a slighter bad performance since no benefits were allocated for bringing empty containers back to the sea ports. The unbalanced modal split in both markets, is an impeding factor when calculating emissions per unit of transport.

Basically, two approaches can be used:
1. Calculation of emissions per tonne-km of load.
2. Calculation of emissions per TEU (irrespective of actual load).

Calculation of emissions per tonne-km

Arguments for this approach are:
- The low load factor of inland navigation return trips is due to its limited flexibility. If inland shipping would be able to transport full containers on the return trip, it would do so.
- Only full containers are beneficial for society.
- Including empty containers leads to a reduction of the weight of an average container. Containers transported by road will then be lighter than they actual are. This implies that using the TEU approach (irrespective of load) also leads to difficulties, since road transport is disadvantaged against inland shipping.

Calculations of emissions per TEU-km (irrespective of load)

It could also be stated that an empty container is of the same importance as a full container, since all container needs to be relocated before they can actually be used again. Arguments for taking all containers into account are:
- Transporting empty containers is business.
- Relocation of empty containers needs to be done anyway.

The difference between the two approaches for the relative emission factors of the modes is illustrated in Figure 20-Figure 23. In the comparison it is assumed that in the “per TEU-km approach” all containers (full and empty) for the different modes have the same weight of 7.6 tonne per TEU. Especially inland waterway transport benefits form the “per TEU-km” approach, relatively to the other modes as the share of empty containers is the highest for this mode.

Figure 20 Relative CO_2 emissions per unit-kilometre comparing the "per tkm" and per "TEU-km" approach

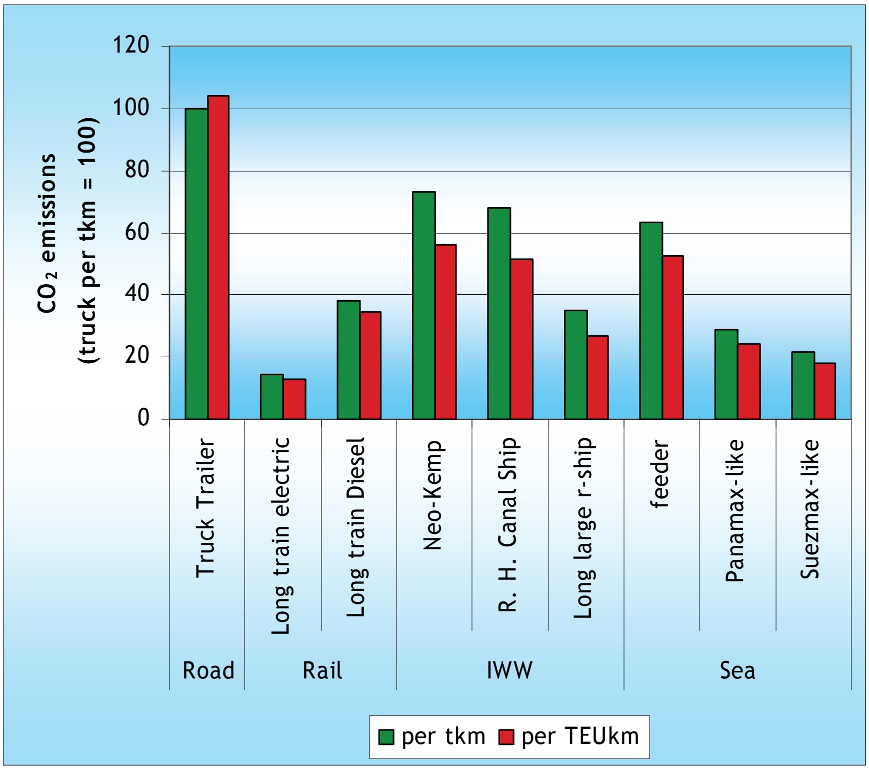


Figure 21 Relative SO_2 emissions per tonne-kilometre comparing the "per tkm"and per "TEU-km" approach

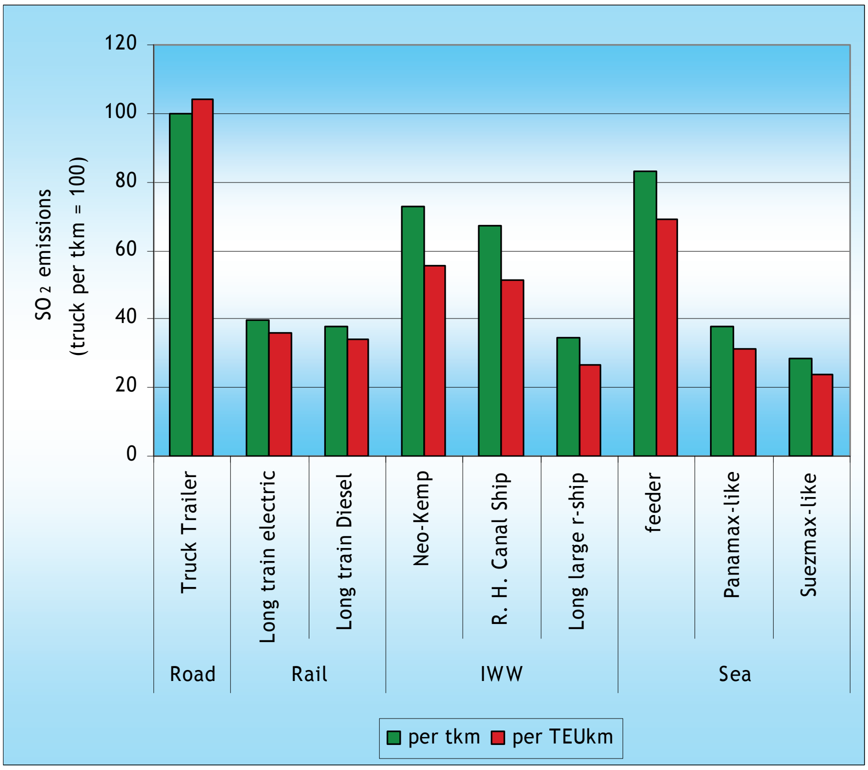


Figure 22 Relative NO_x emissions per tonne-kilometre comparing the "per tkm" and per "TEU-km" approach

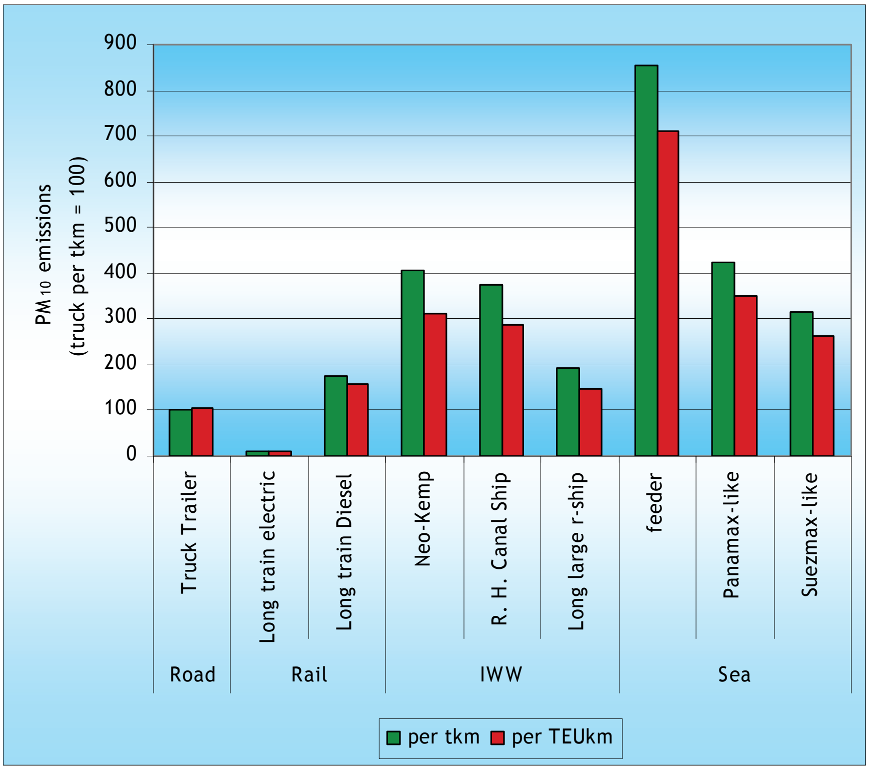
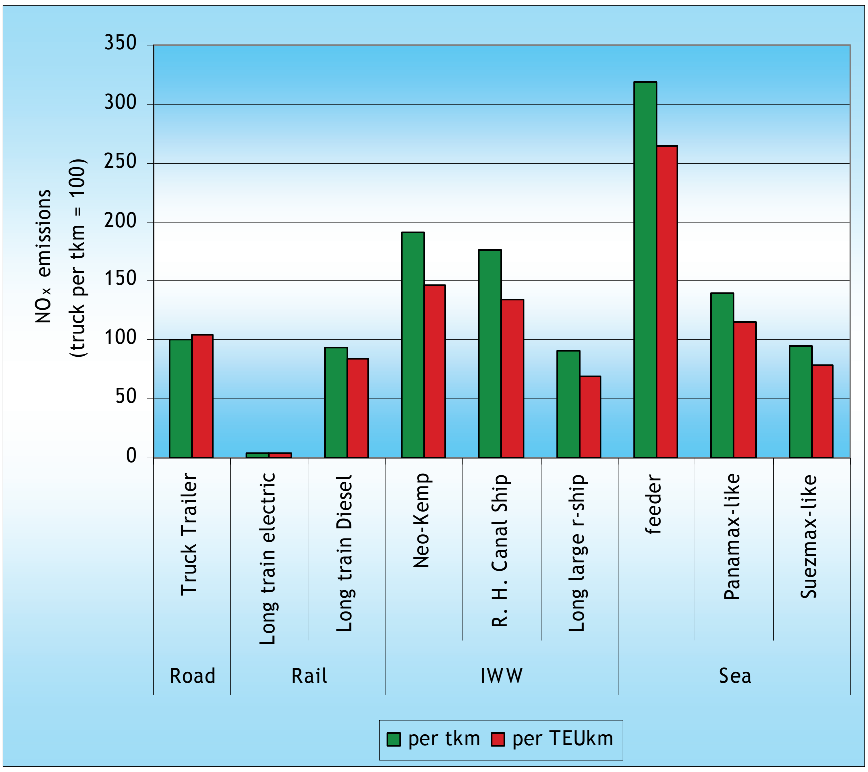


Figure 23 Relative PM_{10} emissions per tonne-kilometre comparing the "per tkm" and per "TEU-km" approach



Annex C Case result for 2009

C.1 Case Rotterdam-Duisburg

Figure 24 CO_2 emission per tonne-km for average container transport; case: Rotterdam-Duisburg 2009

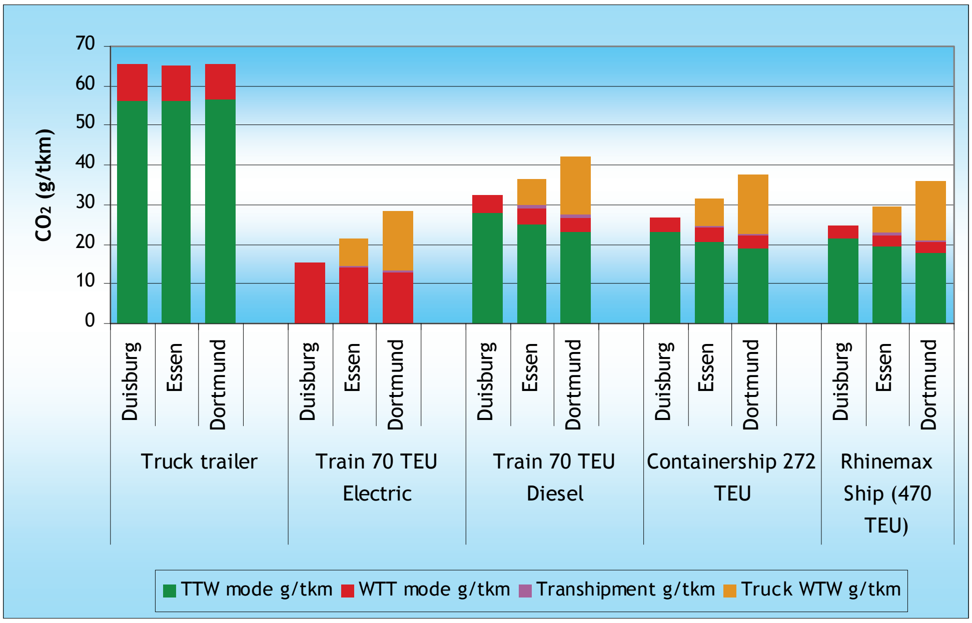


Figure 25 SO_2 emission per tonne-km for average container transport; case: Rotterdam-Duisburg 2009

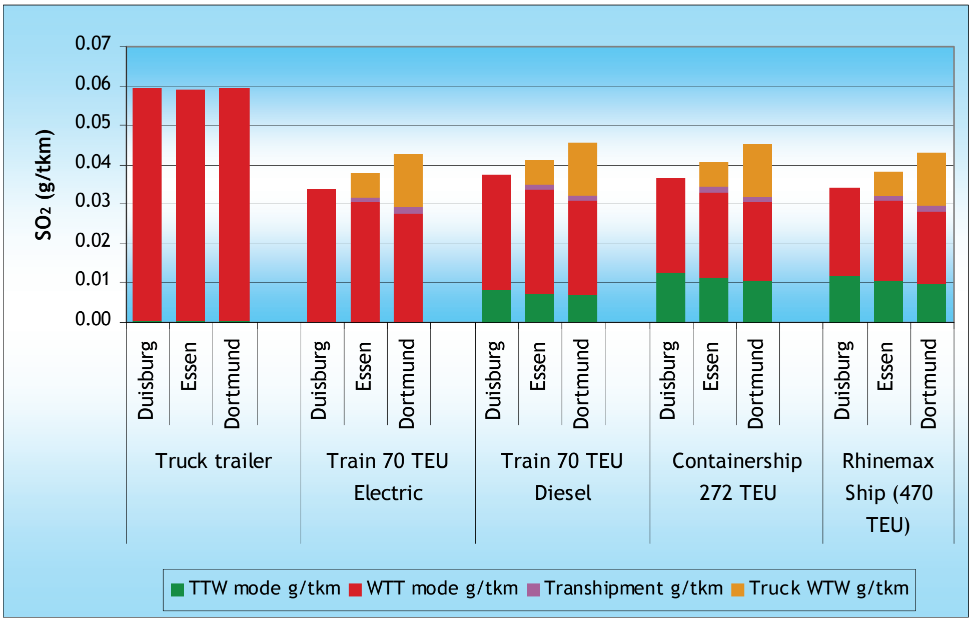


Figure 26 $PM_{2.5}$ emission per tonne-km for average container transport; case: Rotterdam-Duisburg 2009

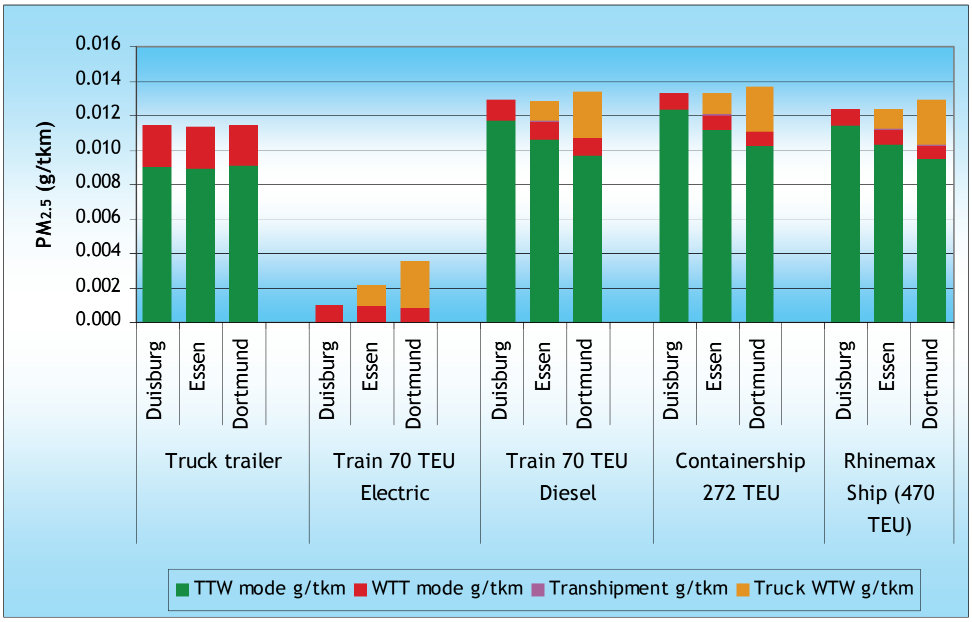
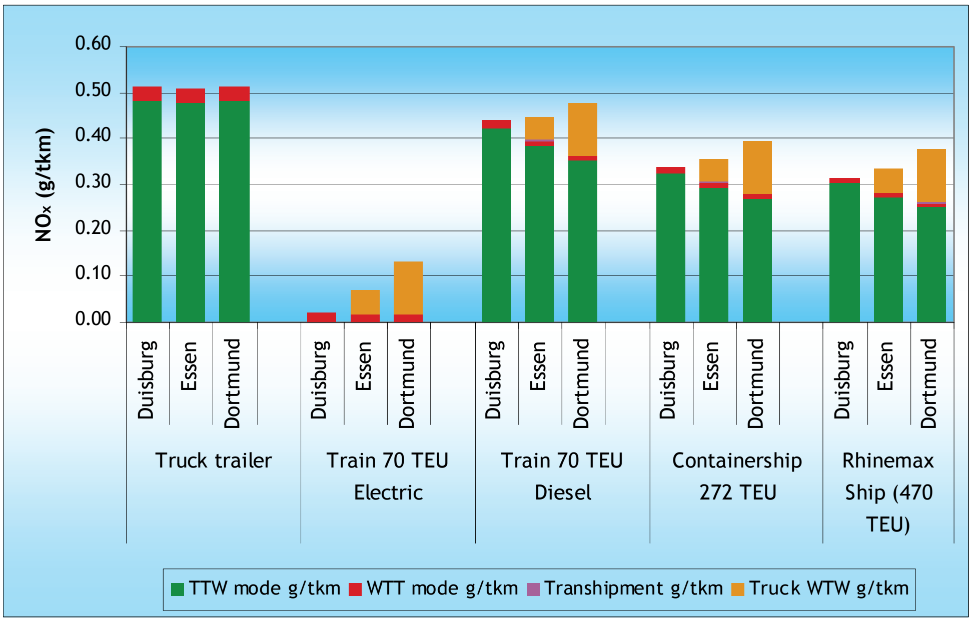


Figure 27 NO_x emission per tonne-km for average container transport; case: Rotterdam-Duisburg 2009



C.2 Case Rotterdam-Bilbao

Figure 28 CO_2 emission per tonne-km for average container transport; case: Rotterdam-Bilbao 2009

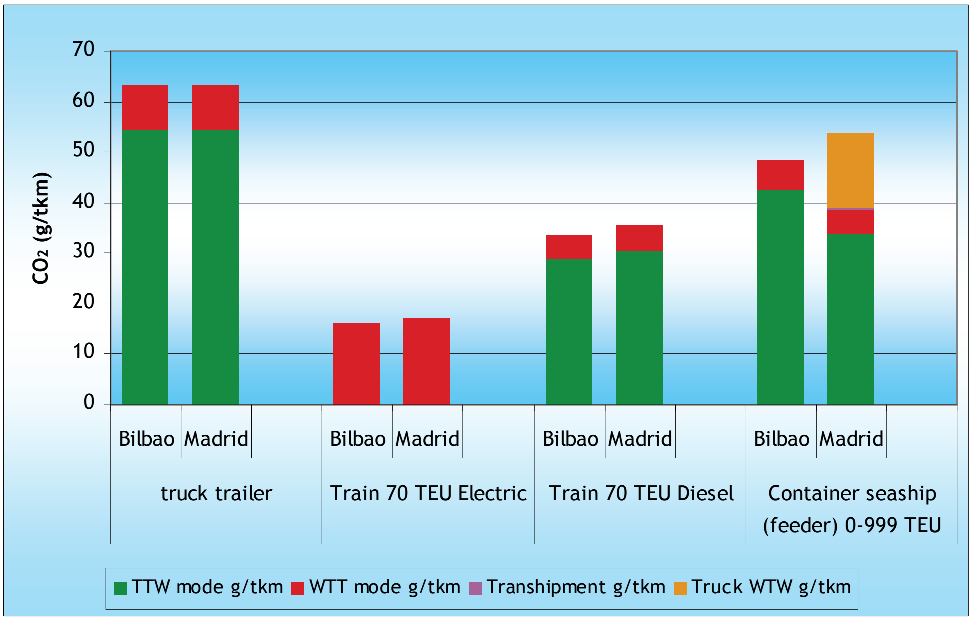


Figure 29 SO_2 emission per tonne-km for average container transport; case: Rotterdam-Bilbao 2009

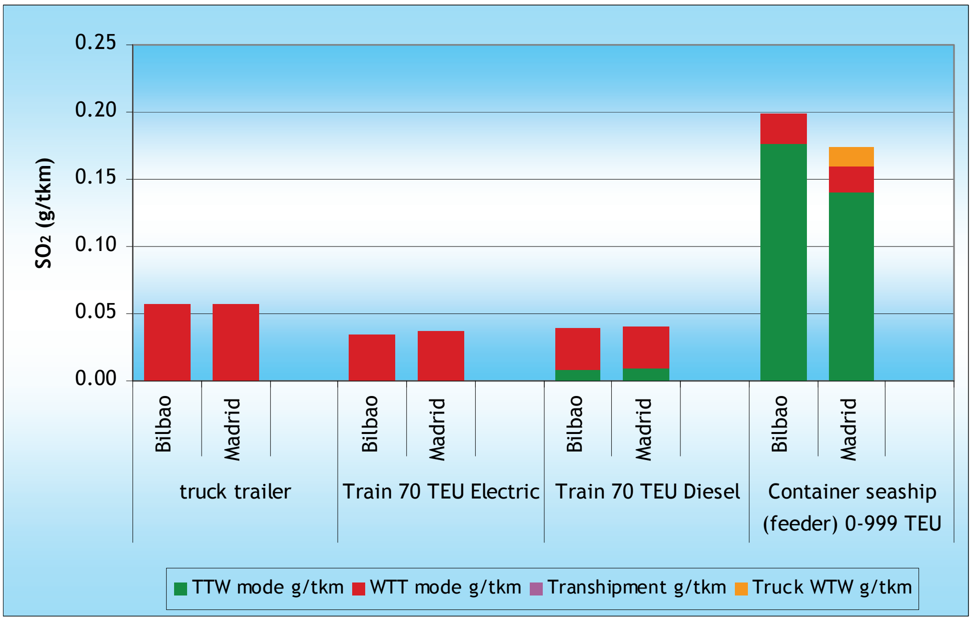


Figure 30 $PM_{2.5}$ emission per tonne-km for average container transport; case: Rotterdam-Bilbao 2009

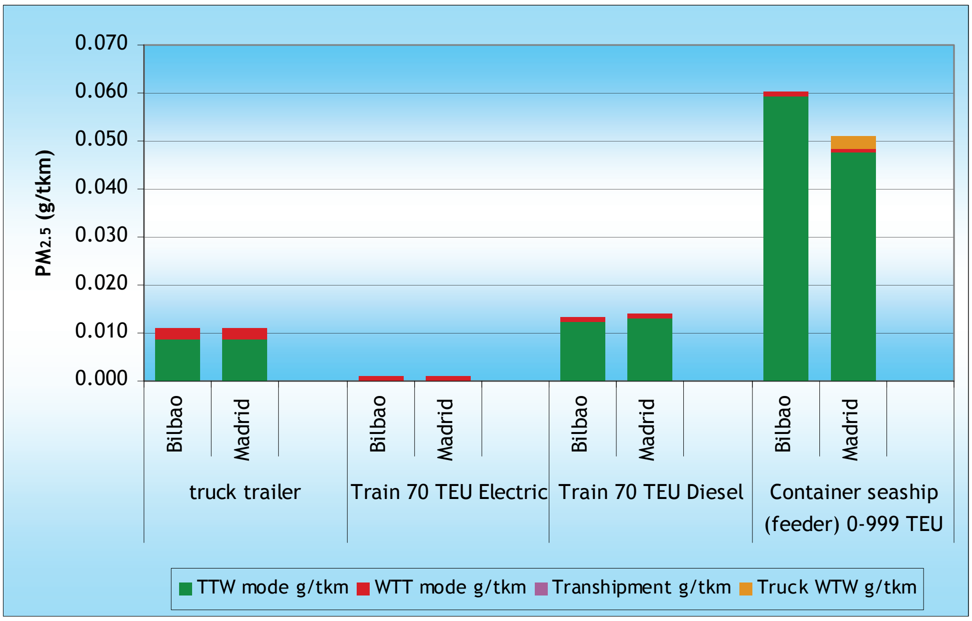
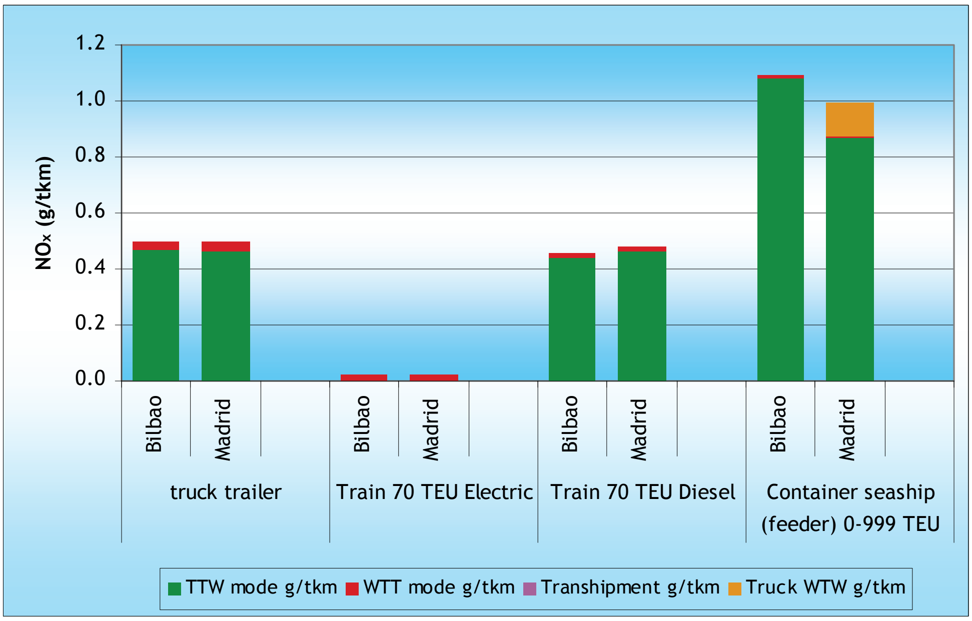


Figure 31 NO_x emission per tonne-km for average container transport; case: Rotterdam-Bilbao 2009



C.3 Case Amsterdam-Regensburg

Figure 32 CO_2 emission per tonne-km for heavy bulk transport; case: Amsterdam-Regensburg 2009

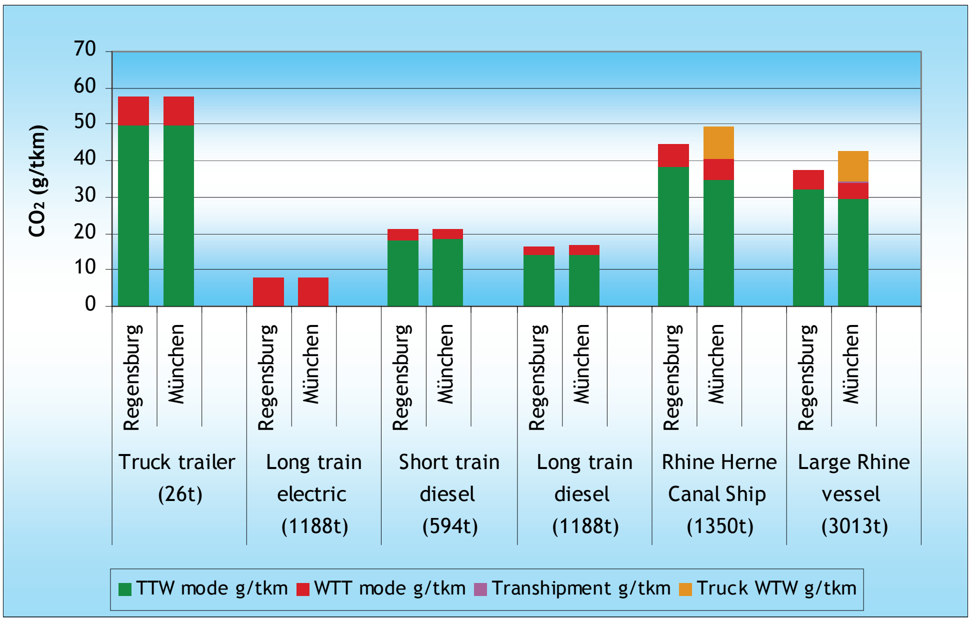


Figure 33 SO_2 emission per tonne-km for heavy bulk transport; case: Amsterdam-Regensburg 2009

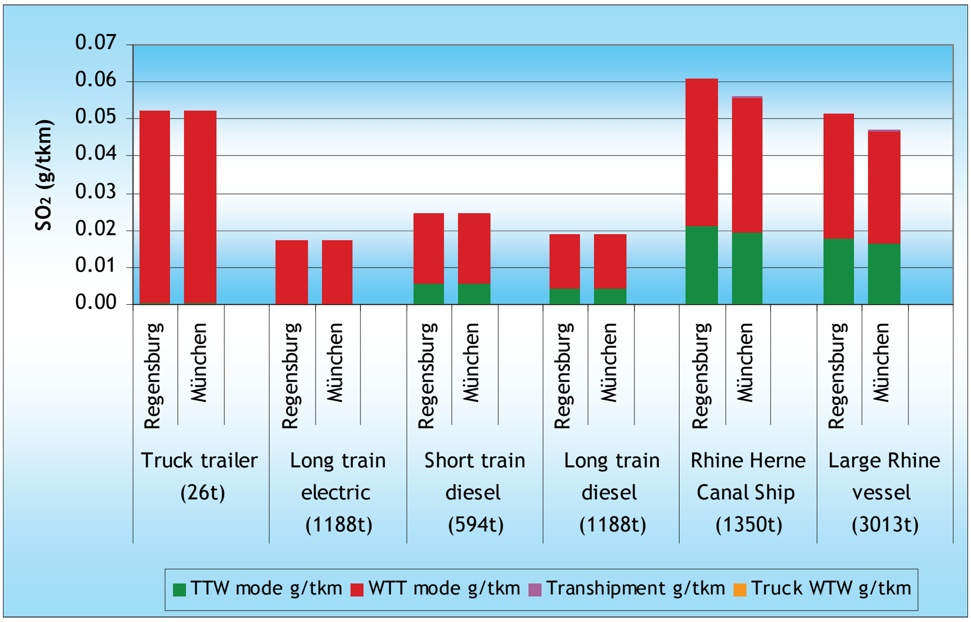


Figure 34 PM$_{2.5}$ emission per tonne-km for heavy bulk transport; case: Amsterdam-Regensburg 2009

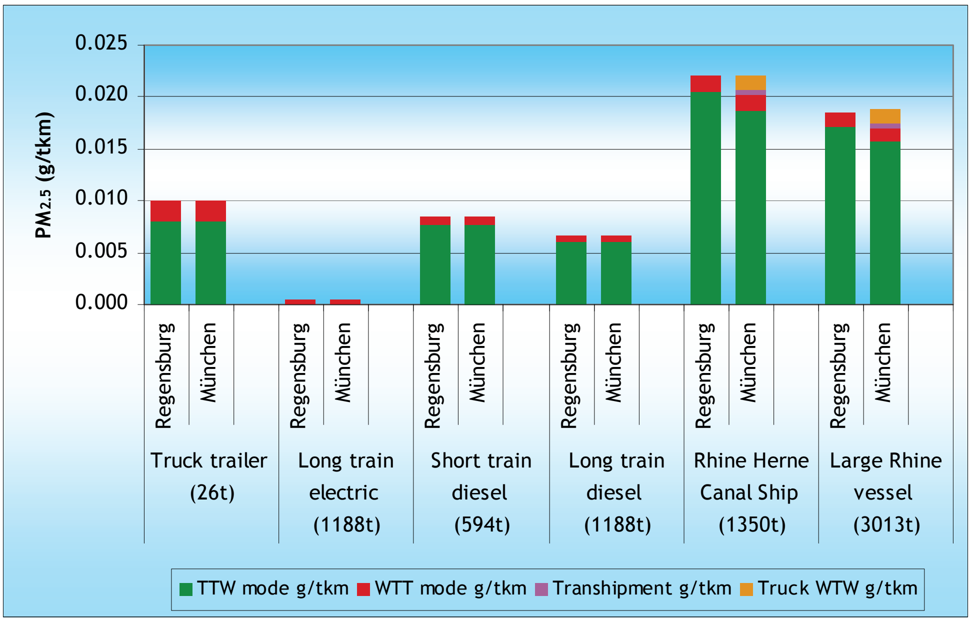
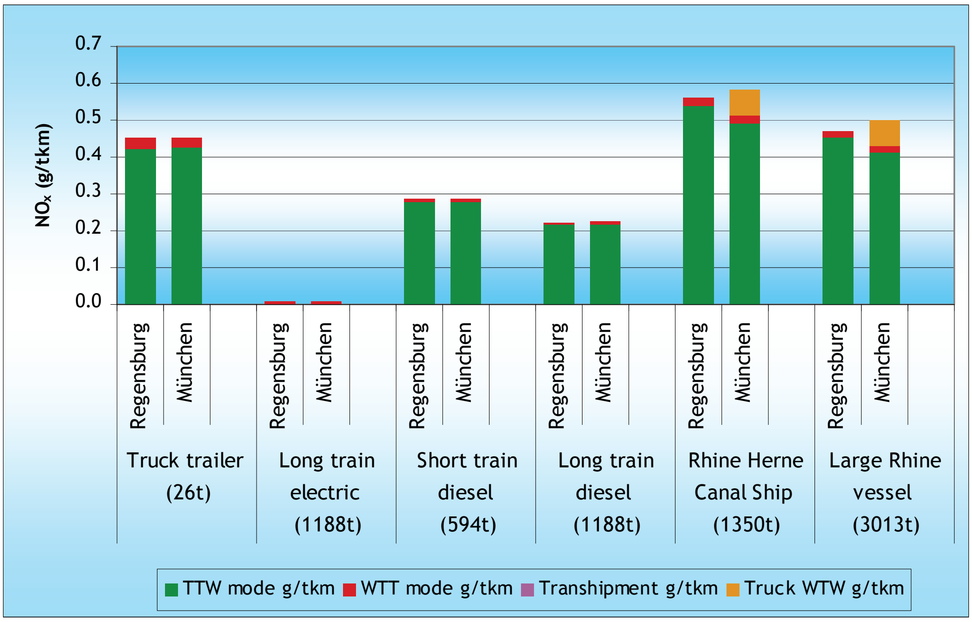


Figure 35 NO_x emission per tonne-km for heavy bulk transport; case: Amsterdam-Regensburg 2009



Annex D Expressions and abbreviations

CEMT	Conférence Européenne des Ministres de Transport
CO_2	Carbon dioxide
dw(k)t	Ddead weight (kilo) tonnage
EU	European Union
GHG	Greenhouse gases
GVW	Gross vehicle weight
HFO	Heavy fuel oil
IMO	International Maritime Organisation
IWW	Inland waterway
km	Kilometre
kWh	Kilo-watt-hour
LHV	Long and heavy vehicle
MDO	Marine diesel oil
mg	Milligram
MJ	Mege Joule
NEC	National emission ceiling
NO_x	Nitrogen oxides (expressed as NO_2)
$PM_{2,5}$	Particulate matter < 2,5 um
ppm	Parts per million
SO_2	Sulphur dioxide
TEU	Twenty feet equivalent unit (container)
tkm	Tonne-kilometre
TTW	Tank-to-wheel
vkm	Vehicle-kilometer
WTT	Well-to-tank

Note: Abbreviations used in formulas (mainly Chapter 3) are not included in this overview, but elaborated in the report.