Methodologies for estimating shipping emissions in the Netherlands

This is a publication of the Netherlands Research Program on Particulate Matter

Netherlands Environmental Assessment Agency

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BOP report

Methodologies for estimating shipping emissions in the Netherlands

A documentation of currently used emission factors and related activity data

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ECN Energy research Centre of the Netherlands
PBL Netherlands Environmental Assessment Agency
TNO Built Environment and Geosciences
RIVM National Institute for Public Health and the Environment

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Rapport in het kort

Een juiste schatting van scheepvaart emissies is essentieel bij het in kaart brengen van de effecten door scheepvaart op luchtkwaliteit en gezondheid in havensteden en kustgebieden. In Nederland is scheepvaart een belangrijke emissiebron voor fijn stof. Sinds 2000 zijn specifieke schattingsmethodieken ontwikkeld voor de emissies op de Noordzee, in havens en voor de binnenvaart. Dit rapport geeft een samenvatting en beschrijving van de methoden om fijn stof emissies van scheepvaart te schatten zoals momenteel in gebruik bij de Nederlandse Emissie Registratie, inclusief recente aanpassingen. Extra aandacht wordt gegeven aan de huidige emissiefactoren en activiteitsdata benodigd om emissies van stilliggende schepen en de binnenvaart te schatten. De hieruit volgende aanbevelingen voor onderhoud van de basisgegevens en mogelijke verdere verbeteringen worden gepresenteerd.

Contents

Summary

Shipping is an important source of PM. Total emissions of sea shipping in and around Europe are estimated at ~300 kton annually. The Netherlands is a coastal country with major ports like Rotterdam and Amsterdam. Hence the share of shipping on Dutch territory in total Dutch emissions is significant especially for SO_2, NO_x and PM_{10}. For 2008 shipping contributed 53%, 31% en 19% to total Dutch SO_2, NO_x and PM_{10} emissions, respectively. The majority of this emission (> 80%) occurs on the Dutch part of the Continental shelf (NCP), CBS (2009).

Proper estimation and allocation of shipping emissions is crucial for understanding the impact of shipping on air quality and health in harbour cities and coastal regions. This report summarizes the emission factors and methodologies to estimate emissions from inland shipping and sea shipping by the Dutch Pollutant Release & Transfer Register (PRTR). Inland shipping is split in national and international inland shipping. Emissions from seagoing ships are split in emissions from seagoing ships on the Dutch continental shelf, seagoing ships, manoeuvring in and towards Dutch harbours and emissions from seagoing ships at berth. The core of the present report is a clear and concise documentation of the Dutch emission estimation methodology based on available (Dutch) reports and protocols developed since 2000. These methodologies rely heavily on the work done in the frame work of the project Emission registration and Monitoring Shipping (EMS) executed in 2000-2003. EMS was initiated by DG Goederenvervoer (Directorate-General freight transport[1]) of the Dutch Ministry of Transport, Public Works and Water Management .

It is important to stress that the objective of the current report is not to report shipping emissions. These can be obtained through the Dutch national statistics as a product of the Pollutant Release & Transfer Register (PRTR; see CBS, 2009). The objective is to document the methodologies used in the PRTR regarding PM emissions from shipping, including any implemented updates. Furthermore, it is also considered important, now and in the future, to provide internationally accessible and transparent descriptions of the Dutch methodology. Such a concise (English) documentation was not yet available. Sometimes the PRTR methodology was updated since the original report or protocol was published. In such cases, the change has been documented and if applicable explained by providing reference and/or inclusion of the underlying motivation. This implies that for some specific features e.g. the correction of SO_2 emission due to introduction of low sulphur fuels the current report can be seen as an update of the in-use methodology. As such the report will be presented to the PRTR for discussion and as an optional documentation of the in-use methodology. The report also contains e.g. as a result of a review of recent literature on the impact of fuel quality on emissions, suggestions how the PRTR could be improved. An original contribution in this report is the methodology to consistently estimate emissions from total European inland shipping. Although this methodology is less accurate than the current PRTR approach, it is less data demanding and can be applied to all European countries based on freight statistics. Total PM_{10} emission in Europe due to inland shipping is estimated at ~ 7kton/yr making it a minor source. However, locally it can be important. The Netherlands contributes about 15 % to this total. A review of the methodology and underlying data to estimate emissions from inland shipping in the Netherlands show that over time the vessels grow in size and an update of emission factors would be needed as it is currently based on the year 2003 survey. Especially PM_{10} emission factors for inland shipping are considered uncertain.

A major achievement under the EMS project was the development of a methodology for estimating emissions from seagoing ships at berth. Accurate estimates of emissions from ships at berth demand reliable knowledge of the fuel consumption while at berth and associated fuel characteristics. Since assured information about energy use and fuel consumption of seagoing ships at berth is scarce, a survey of energy consumption and fuel use on board of 89 seagoing ships was made in 2003 as part of the EMS close cooperation with the Port of Rotterdam. In this report the survey results as well as the emission estimations are compared to the (scarce) information that is available outside the Netherlands. The compiled survey data underlie the current Dutch emission estimation methodology for emissions of ships at berth. As a part of this BOP project this methodology is now also internationally presented and published (Hulskotte and Denier van der Gon 2008, 2009). A remarkable finding from the on-board survey was that in 2003 heavy fuel oil (HFO) was the dominant energy source for ships at berth. The fuel type used in marine engines and the quality of that fuel has a major impact on the amount of PM emitted. Especially the sulphur content and ash content of heavy fuel oil has a large impact on PM emission as well as

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[1] This is the predecessor of the current Directorate-General Civil Aviation and Maritime Affairs (DGLM)

the share of finer $PM_{2.5}$ in PM10 emissions. In theory the effect of the composition is covered by the overall emission factor. However, recent regulations e.g. SECA (sulphur emission control areas) zones, cause the fuel quality to change and hence emission factors need to be adjusted. A methodology to adjust the PM emission factors with changing sulphur content is presented in the report as well as a suggestion for adjustment of the current in-use $PM_{2.5}$ fraction of PM_{10}. Currently the PRTR uses a $PM_{2.5}$ fraction of 95% in PM_{10} whereas recent literature suggests this is an overestimation. Based on the present report the PRTR may consider an adjustment and/or some further study on this subject.

Finally, the report notes and discusses new developments such as field measurements of shipping emissions and the use of AIS (automatic identification system) to estimate shipping emissions. Recommendations for further research, based on new developments as well as weaknesses in the current methodologies are discussed in the final section of this report

Last but not least it should be stressed that the present report is not a complete documentation of shipping-related emissions in the Netherlands. The goal of BOP is to reduce uncertainties about particulate matter (PM) and hence a complete documentation of all methodologies to estimate all other (non-PM) pollutants from shipping is out of scope of the present report.

Guidance to the reader

Chapter 1 provides a description of the various shipping categories covered in the Dutch Pollutant Release & Transfer Register (PRTR), a listing of the available documentation for the in-use estimation methodologies and an overview of currently estimated emissions from shipping in the Netherlands. The methodology to estimate the emissions of seagoing ships on Dutch territory is discussed in chapter 2. This methodology estimates emissions from shipping on the Dutch part of the continental shelf of the North Sea separately from emissions on other Dutch territory (mainly encompassing manoeuvring towards and in Dutch harbours). A separate chapter (chapter 3) is dedicated to estimating emissions from seagoing ships at berth based on their actual fuel consumption, which is based on a on-board survey, and the fuel type used. Fuel quality has a major impact on the amount of PM emitted. A discussion on the impact of sulphur content and ash content of heavy fuel oil on PM emission and the fraction of $PM_{2.5}$ in PM_{10} is presented in chapter 4.

The methodology and underlying data to estimate emissions from inland shipping in the Netherlands are discussed in chapter 5. Next, an emission estimate for European inland shipping is made based on statistics of freight transport in Europe (chapter 6). This estimation approach is less accurate than the methodology presented in chapter 5, but it requires less detailed input data and therefore can be applied to all of Europe. Chapter 6 also presents the spatial distribution of the European emission by inland shipping to facilitate the use in air quality models. Finally, chapter 7 briefly discusses new developments such as field measurements of shipping emissions and the use of AIS (automatic identification system) to estimate shipping emissions. Recommendations for further research, based on new developments as well as weaknesses in the current methodologies are discussed in the final section of this report

1

Estimation of shipping emissions in the Netherlands

Emission factors for the various shipping activities in the Netherlands have been collected in the framework of the project Emission registration and Monitoring Shipping (EMS). EMS was initiated by DG Goederenvervoer (Directorate-General freight transport[1]) of the Dutch Ministry of Transport, Public Works and Water Management as outlined in “ Voortgangsnota Scheepvaart en Milieu” (DGG, 1998). In this chapter we summarize the currently used emission factors and provide reference to the underlying documentation. The primary sources for this summary are listed in Table 1.1. Most of this documentation is in Dutch. However, the methodology to calculate shipping emissions based on the reports in Table 1.1 is briefly described in English by Klein et al. (2007).

The Dutch National Emission Inventory has a separate task force “Traffic and Transport” which also covers the emissions of shipping. The shipping-related emission causes, istinguished in the Dutch Pollutant Release & Transfer Register (PRTR), are presented in Table 1.2. The calculation methods used by the task force to calculate emissions for the different shipping source categories listed in Table 1.2 are described by Klein et al. (2007). The emission factors used in the calculation methods are mostly based on the results of the EMS project and can be found in the reports listed in Table 1.1.

The Dutch emission registration calculates and reports several emission estimates for the same emission cause listed Table 1.2 depending on the requirements of reporting obligations. Different reporting requirements according to Klein et al. (2007) are:

Actual emissions; The aim of calculating the actual emissions is to determine all emissions from activities within the borders of the Netherlands, including the national portion of the continental shelf.

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[1] This is the predecessor of the current Directorate-General Civil Aviation and Maritime Affairs (DGLM)

Documentation underlying the calculations of Dutch shipping emissions

Table 1.1

Authors	Title	Year
Hulskotte, J., R. Koch	Emissiefactoren zeeschepen (In Dutch). TNO Built Environment and Geosciences, TNO report R 2000/221, Apeldoorn.	2000
Denier van der Gon, H.A.C., Hulskotte, J.H.J.,	Emissiefactoren voor methaan en lachgas uit de luchtvaart en de scheepvaart (In Dutch)., TNO-report R2003/294.	2002
Oonk, H., J. Hulskotte, R. Koch, G. Kuipers, J. van Ling	Methodiek voor afleiding van emissiefactoren van binnenvaartschepen (In Dutch), TNO report R2003/437, version 2.	2003a
Oonk, H., J. Hulskotte, R. Koch, G. Kuipers, J van Ling	Emissiefactoren van zeeschepen voor de toepassing in de jaarlijkse emissieberekeningen (In Dutch), TNO-report R2003/438, version 2.	2003b
Hulskotte, J., Bolt E., Broekhuizen, D	Emissies door verbrandingsmotoren van zeeschepen op het Nederlands Continentaal Plat, EMS protocol, november 2003. (in Dutch), Ministry of traffic and transport.	2003a
Hulskotte, J., E.W.B. Bolt, D. Broekhuizen, P. Paffen	Protocol voor de berekening van emissies door verbrandingsmotoren van binnenvaartschepen, Adviesdienst Verkeer en Vervoer (AVV), Rotterdam. (In Dutch).	2003b
Hulskotte, J.	Protocol voor de vaststelling van het brandstofgebruik en de broeikasgasemissies van de visserij in Nederland conform de IPCC-richtlijnen (In Dutch). TNO-report 3 2004/391.	2004
Klein, J., A. Hoen, J. Hulskotte, N. van Duynhoven, R. Smit, A. Hensema, D. Broekhuizen	Methods for calculating the emissions of transport in the Netherlands, task force Traffic and Transport of the National Emission Inventory, October 2007, CBS, Voorburg.	2007

Shipping emission sources, categorised by the Dutch Pollutant Release & Transfer Register (PRTR)

Table 1.2

Source category	Detailed emission cause
Inland shipping	Exhaust gas, inland shipping national Exhaust gas, inland shipping national, ferries Exhaust gas, inland shipping international Exhaust gas, pleasure craft Gasoline evaporation and other products, inland shipping, degassing[a)]
Seagoing ships	Exhaust gas, seagoing ships, manoeuvring in and towards Dutch harbours Exhaust gas, seagoing ships, Dutch continental shelf Exhaust gas, seagoing ships at berth
Fisheries[a)]	Exhaust gas, national inland and sea shore fisheries

[a)]Not covered in current report

Current emissions of PM$_{10}$, NO$_x$, SO$_2$ and NMVOC reported by the Dutch Pollutant Release & Transfer Register (PRTR) differentiated by shipping category (PRTR, 2009

Table 1.3

Emission cause	1990	1995	2000	2005	2006	2007	2008
	PM$_{10}$ (10^3 kg)						
Inland shipping national; push navigation	15	20	24	40	44	44	44
Inland shipping national	218	214	290	262	241	241	241
Inland shipping international; push navigation	85	108	105	130	133	133	133
inland shipping international	868	833	748	577	551	551	551
Inland shipping national, ferries	125	144	144	144	144	144	144
Pleasure craft	48	52	54	53	52	52	52
National inland and sea shore fisheries	390	433	378	265	264	253	243
Seagoing ships, Dutch continental shelf	5198	5335	6491	6499	6813	7109	7109
Seagoing ships at berth	193	199	283	319	334	351	351
Seagoing ships, manoeuvring in and towards Dutch harbours	744	769	949	792	842	892	892
	NO$_x$ (10^3 kg)						
Inland shipping national; push navigation	4505	4255	6461	6432	6021	6021	6021
Inland shipping national	1566	1800	1800	1800	1800	1800	1800
Inland shipping international; push navigation	370.7	393	524.7	986.5	1097	1097	1097
inland shipping international	2135	2151	2346	3190	3315	3315	3315
Inland shipping national, ferries	20210	16580	16690	14190	13770	13770	13770
Pleasure craft	1922	2080	2200	2203	2217	2232	2232
National inland and sea shore fisheries	16450	18240	15910	11150	11110	10680	10250
Seagoing ships, Dutch continental shelf	75680	77670	94400	105700	111500	117000	117000
Seagoing ships at berth	3813	3940	5313	5969	6259	6497	6497
Seagoing ships, manoeuvring in and towards Dutch harbours	8966	9265	11130	12080	12850	13610	13610
	SO$_2$ (10^3 kg)						
Inland shipping national; push navigation	132	159	174	236	245	245	245
Inland shipping national	304	315	478	476	446	446	446
Inland shipping international; push navigation	107	123	123	123	123	109	68
inland shipping international	23	29	39	73	81	81	81
Inland shipping national, ferries	1263	1225	1235	1050	1019	1019	1019
Pleasure craft	55	59	61	59	59	53	33
National inland and sea shore fisheries	954	1057	922	646	644	550	330
Seagoing ships, Dutch continental shelf	44330	45500	55400	53790	56270	58600	58600
Seagoing ships at berth	2431	2512	3751	4169	4372	4593	4593
Seagoing ships, manoeuvring in and towards Dutch harbours	4975	5142	6302	5860	6227	6583	6583
	NMVOC (10^3 kg)						
Inland shipping national; push navigation	122	146	139	165	166	166	166
Inland shipping national	362	288	383	332	302	302	302
Inland shipping international; push navigation	1311	1123	989	732	690	690	690
inland shipping international	22	27	31	51	55	55	55
Inland shipping national, ferries	180	207	207	207	207	207	207
Pleasure craft	3273	3656	3737	3288	3120	2947	2947
National inland and sea shore fisheries	723	801	699	490	488	469	450
Seagoing ships, Dutch continental shelf	2239	2298	2794	3031	3194	3347	3347
Seagoing ships at berth	175	181	235	266	279	291	291
Seagoing ships, manoeuvring in and towards Dutch harbours	319	329	395	406	432	452	452

IPCC emissions; The IPCC emissions are the Dutch emissions of greenhouse gases as reported to the United Nations and the European Union. Various aspects of this process take place due to the reporting obligations of the UN Framework Convention on Climate Change (UNFCCC) and the EU Greenhouse Gas Monitoring Mechanism. The emissions are calculated according to the IPCC regulations. The IPCC (Intergovernmental Panel on Climate Change) provides the scientific supervision of the implementation of the Kyoto Protocol.

NEC emissions; In 2001, the European Parliament and the Council of Europe approved a Directive concerning national emission ceilings for trans-border air pollution which contributes to acidification, soil eutrophication and tropospheric ozone formation. This Directive is referred to as the NEC Directive (National Emission Ceilings). When ascertaining the national emission ceilings according to this Directive, the contribution of seagoing shipping is not taken into account. Otherwise, the calculations are in accordance with the calculations of the actual emissions.

Actual emissions are needed to access air quality in the Netherlands; therefore this report focuses on the estimation methodologies for actual emissions of inland shipping and seagoing ships. This includes the international shipping emissions on all Dutch territory, which includes the Dutch part of the continental shelf of the North Sea (NCP). Emissions on NCP are reported as a separate category due to the location and magnitude of the emissions.

Emission registration is an on-going activity and new developments and insights are being incorporated as they become available. The current estimate of shipping-related emissions of PM_{10}, NO_x, SO_2 and NMVOC by the PRTR is presented in Table 1.3. The Netherlands is a coastal country with major ports like Rotterdam and Amsterdam. Hence the share of shipping on Dutch territory in total Dutch emissions is significant, especially for SO_2, NO_x and PM_{10}. For 2008 shipping contributed 53%, 31% en 19% to total Dutch SO_2, NO_x and PM_{10} emissions, respectively. The majority of this emission (> 80%) occurs on the NCP (CBS, 2009).

The data presented in Table 1.3 represent a “snapshot” of the current state of knowledge concerning shipping emissions in the Netherlands. The methodologies to estimate the separate shipping emission categories are discussed in the next chapters. The focus is on PM emissions, as this report is a part of the BOP programme, but where available emissions and emission factors for other pollutants are given for completeness.

Netherlands Research Program on Particulate Matter (BOP)

This study was conducted under the auspices of the Netherlands Research Program on Particulate Matter (BOP), a national programme on PM_{10} and $PM_{2.5}$ funded by the Netherlands Ministry of Housing, Spatial planning and the Environment (VROM). The programme is a framework of cooperation, involving four Dutch institutes: the Energy research Centre of the Netherlands (ECN), the Netherlands Environmental Assessment Agency (PBL), the Environment and Safety Division of the National Institute for Public Health and the Environment (RIVM), and TNO Built Environment and Geosciences.

The goal of the BOP programme is to reduce uncertainties about particulate matter (PM) and the number of policy dilemmas which complicate development and implementation of adequate policy measures. Uncertainties concerning health aspects of PM are not explicitly addressed.

The approach for dealing with these objectives is through integration of mass and composition measurements of PM_{10} and $PM_{2.5}$. emission studies and model development. In addition, dedicated measurement campaigns were conducted to research specific PM topics.

The results from the BOP research programme are published in a special series of reports. The subjects in this series, in general terms, are: sea salt, mineral dust, secondary inorganic aerosol, elemental and organic carbon (EC/OC), and mass closure and source apportionment. Some BOP reports concern specific PM topics: shipping emissions (this report), PM trend, urban background, EC and OC emissions from traffic, and attainability of $PM_{2.5}$ standards. Technical details of the research programme are condensed in two background documents; one on measurements and one on model developments. In addition, all results are combined in a special summary for policymakers.

2

Emissions from seagoing vessels in Dutch territorial waters

Maritime navigation is often referred to as international shipping, but, strictly speaking, international shipping can also involve international inland shipping. This chapter refers to emission estimation methodologies for seagoing vessels only. The Dutch methodology for determining the emission factors of seagoing vessels has been described in the EMS protocol for seagoing vessels (Hulskotte *et al*., 2003a; Hulskotte and Denier van der Gon, 2009) and partly based on Oonk *et al.* (2003b). The Dutch methodology was previously summarised in English by Klein *et al.* (2007), and treated in more detail in the current report. The Dutch PRTR divides emissions from seagoing vessels into the following categories:

- Seagoing vessels on the Dutch continental shelf;
- Seagoing vessels travelling and manoeuvring in Dutch territorial waters, except on the Dutch continental self;
- Seagoing vessels anchored in ports (in berths).

The methodology for seagoing vessels anchored in ports is described in Chapter 3.

The method for determining emissions from sailing and manoeuvring with seagoing vessels in Dutch territorial waters was mainly derived from the method for seagoing vessels sailing the Dutch continental shelf. Therefore, this emission calculation method is presented first.

2.1 Seagoing vessels on the Dutch continental shelf

The calculation method used has been described in general terms in the EMEP/CORINAIR Emission Inventory Guidebook (EEA, 2000), under the heading 'ship movement methodology'. This means that ship movement data (i.e. ships travelling distances) are used as activity data, instead of for instance fuel consumption data. Additional emission factors per travelling distance are derived for individual ships from technical data from the Lloyd's register of shipping information. Most important input parameters are the design speed of the ship and the maximum continuous rating (MCR) of the main propulsion engine(s). Based on the assumption that the ship can maintain the design speed at 85% of the MCR, the energy consumption per distance sailed can be calculated. Emission factors per amount of energy on behalf of the EMS were derived by Oonk *et al.* (2003b).

In these emission factors distinction is made between two fuel types (distillate and residual fuel), the engine characteristics (two- or four-stroke, or steam or gas turbine) and the engine's year of manufacture. Therefore, to derive emission factors per individual ship, additional information is required about fuel type, engine type and year of manufacture. For the fuel type, a generic algorithm is used, based on engine power, engine type and engine speed. The installed engine type is in most cases available from the database or can be derived from the manufacturer's information. The year of manufacture can be either directly taken from the database or assumed to equal the age of the ship. Finally, emission factors are available for distances travelled, for each ship, from which emissions can be calculated by combining these factors with data on travelling distances for each ship, in a certain year, on the Dutch continental shelf.

For each of these categories, a distinction is made between main engines and auxiliary engines. Main engines are intended for propelling the vessel. Auxiliary engines are required for manoeuvring (bow propeller engines) and generating electricity for operations, such as loading and unloading, and housing workers or passengers (in the case of ferries).

For each year, Tables 2.1 and 2.2 show the average derived emission factors for seagoing vessels, expressed in grams per kWh. For completeness, the emission factors for ships propelled by gas turbines and steam engines are presented in Table 2.3. PM emissions are fuel type dependent and data is provided for Heavy Fuel Oil (HFO) and Marine Diesel Oil (MDO) in Tables 2.1 to 2.3.

2.1.1 NOx Emission factors from 2000 onwards

The NO_x emissions are regulated according to the IMO (International Maritime Organization) guidelines and NO_x technical code. The NO_x emission factor depends on the engine's revolutions per minute (rpm) and is presented for

Emission factors for low-speed engines (two-stroke engines) Table 2.1

Year of manufacture	HC	CO	NO_x	PM (HFO)[a)]	PM (MDO)	Fuel Cons.
	(g/kWh)					
< 1974	0.6	3.0	16	1.7	0.5	210
1975-1979	0.6	3.0	18	1.7	0.5	200
1980-1984	0.6	3.0	19	1.7	0.5	190
1985-1989	0.6	2.5	20	1.7	0.5	180
1990-1994	0.5	2.0	18	1.7	0.4	175
1995-1999	0.4	2.0	15	1.5	0.3	170
2000	0.3	2.0	Table 6	1.5	0.3	168

Source: Oonk *et al.* (2003b)

[a)] Note: the current in-use PM emission factor is ~ 25% lower based on Duyzer et al. (2007a), see section 2.4.

Emission factors for medium and high-speed engines (four-stroke engines) Table 2.2

Year of manufacture	HC	CO	NO_x	PM (HFO)	PM (MDO)	Fuel Cons.
	(g/kWh)					
< 1974	0.6	3.0	12	0.8	0.5	225
1975-1979	0.6	3.0	14	0.8	0.5	215
1980-1984	0.6	3.0	15	0.8	0.5	205
1985-1989	0.6	2.5	16	0.8	0.5	195
1990-1994	0.5	2.0	14	0.8	0.4	190
1995-1999	0.4	2.0	11	0.7	0.3	185
2000	0.3	2.0	Table 6	0.7	0.3	183

Source: Oonk *et al.* (2003b)

Emission factors for ships propelled by gas turbines and steam engines (kg/tonne fuel) Table 2.3

	HC	CO	NO_x (HFO)	NO_x (MDO)	PM (HFO)	PM (MDO)
ST	0.2	0.5	3.3	7	2.5	2.1
TB	0.1	0.5		16		1.1

Source: Hulskotte and Koch (2000)

IMO limit values and NOx emission factors for seagoing vessels Table 2.4

revolutions per minute (rpm)	IMO limit value (g/kWh)	NO_x emission [a)] (g/kWh)	NO_x emission [a)] (kg/tonne fuel)
< 130 rpm	17.0	14.5	79
130 - 2000 rpm	$45 \cdot n^{-0.2}$ [b)]	$38 \cdot n^{-0.2}$ [b)]	42-79
> 2000 rpm	9.8	8.3	42

[a)] Oonk *et al.*, 2003b (assuming 184 g fuel used per kWh)

[b)] n = value of rpm for the engine of a particular ship

various rpm categories in Table 2.4. It is assumed that the emission factors of NO_x are 85% of the IMO limit value for each individual ship.

2.2 Seagoing vessels sailing Dutch territorial waters (excluding the Dutch continental shelf)

In this report, the term Dutch territorial waters does not apply to the Dutch continental shelf although strictly speaking this is also Dutch territory. In the EMS, distinct methods were derived for seagoing vessels sailing Dutch territorial waters. This was necessary because the Lloyd's data on ship travels contains no exact information on port of origin or destination, and because in the calculation method the effect of travelling at reduced speeds had to be incorporated. The miles travelled at reduced speeds depend specifically on the route to port, the ship's volume and normal cruising speed on open sea. Furthermore, the manoeuvring time in ports depends on port layout and ship characteristics. This needed to be incorporated in the model to estimate emissions during manoeuvring.

2.2.1 Activity data

The activity data used to calculate emission in national territorial waters were number of berths per ship category (8 types; Table 2.5) for a selected number of ports responsible for more than 99 percent of freight from seagoing vessels in the Netherlands. The eight ship types were stratified in 8 or 9 ship volume ranges, expressed in Gross tonnage GT) (Table 2.6). The emission factors presented in Tables 2.1 to 2.3 were

Types of seagoing vessels discerned in EMS

Table 2.5

Ship type
Oil tankers
Other tankers
Bulk carriers
Container ships
Conventional Cargo ships
Ferries and RORO ships
Reefers
Other ships
Average ship on the Western Scheldt

Sizes of seagoing vessels discerned in EMS, (GT)

Table 2.6

Ship sizes
100 – 499
500 – 999
1000 – 1599
1600 – 9999
10000 – 29999
29999 – 59999
60000 – 99999
> 100000

transformed from g/kWh to kg/GT.km to match these activity data (Table 2.7).

2.2.2 Emission factors per distance travelled

Main engine emission factors that were applied in the calculation of emissions for ships in Dutch territorial waters, were derived from the emission factors of individual ships sailing the Dutch continental shelf in 2004. The emission factors, divided according to the specifications in Tables 7 and 8, are presented in Table 2.7. The emission factors per unit of GT differed widely (Table 2.7) and no linear relationship between GT and emission existed. Therefore, models that apply average ship volumes in order to calculate emissions may well end up with erroneous results.

The emission factors (Table 2.8) applied in the emission calculations for ships in Dutch territorial waters were derived from the emission factors for auxiliary engines of individual ships sailing the Dutch continental shelf in 2004.

Emission factors for auxiliary engines were taken as full engine loads from 'First Aux', which is the most important auxiliary engine aboard a particular ship, and which is always running. The assumption to base emission factors on full engine loads of the 'First Aux' is rather arbitrary, but a better documented alternative is presently not available.

The application of the emission factors of Tables 2.7 and 2.8 depended on the phase of the ships movements towards the port. The calculation of emissions for those different phases is described in the next sections.

2.2.3 Emission modelling of seagoing vessels at cruising speeds

The simplest cases are those in which ships are travelling at cruising speeds towards one of the ports. In such cases, the emission per ship type can be calculated, thus:

Emission = 2 x (Number of ships) x (ship's Volume) x (Distance on Cruising speed) x (Emission factor)

Because it was assumed that each seagoing vessel would take the same route going back, the emissions were multiplied by two. In the EMS, the 'Distance on cruising speed' depends on the specific port and the individual ship (separate table in the EMA protocol (Hulskotte *et al*., 2003b; Table B.3 not shown in this report).

2.2.4 Modelling of seagoing vessels at reduced speeds

Somewhat more complicated are calculations for seagoing vessels travelling at reduced speeds. In such calculations, two corrections are necessary. The first correction is that in energy consumption, because of the diminished engine power at lower speeds. The second correction is for the change in emission factors at diminished engine loads.

Emission = 2 x (Number of ships) x (ship's Volume) x (Distance on Cruising speed) x (Emission factor) x (correction factor energy consumption) x (correction factor emission factors)

For tables with correction factors for energy consumption and for emission factors used in the above equation, we refer to the EMS protocol (Hulskotte *et al*., 2003b).

2.2.5 Modelling of manoeuvring seagoing vessels

During manoeuvring a ship's travelling speed is almost zero while it is slowly moving ahead, backwards or sideways. In the modelling of emissions while manoeuvring, this phenomenon is solved by estimating the ship's power consumption as a fraction of the power consumption at sea. Because the ship's travelling speed at sea is known, multiplication of this speed with fractions of power consumption delivers conversion factors for the emission factors at sea, from the dimension kg/GT.km to kg/GT.hour. The emissions while manoeuvring can be calculated by estimating the duration (in hours) of

Basic emission factors for main engines, (kg/GT.km)

Table 2.7

Type of ship	from GT to GT	CO_2	NO_x	PM	SO_2	CO	VOC
Oil tankers	100 - 499	1.85E-02	4.83E-04	2.39E-05	1.96E-04	7.99E-05	1.75E-05
Oil tankers	500 - 999	2.30E-02	4.31E-04	2.53E-05	2.22E-04	9.70E-05	1.94E-05
Oil tankers	1000 - 1599	1.29E-02	2.82E-04	1.16E-05	9.63E-05	5.01E-05	1.05E-05
Oil tankers	1600 - 9999	1.30E-02	3.12E-04	2.54E-05	2.37E-04	5.86E-05	1.22E-05
Oil tankers	10000 - 29999	7.98E-03	2.49E-04	1.53E-05	1.28E-04	3.58E-05	7.83E-06
Oil tankers	29999 - 59999	3.96E-03	1.17E-04	6.85E-06	5.86E-05	1.51E-05	3.03E-06
Oil tankers	60000 - 99999	3.29E-03	9.36E-05	4.99E-06	4.36E-05	1.24E-05	2.27E-06
Oil tankers	100000 - 999999	2.55E-03	7.47E-05	3.84E-06	3.32E-05	9.73E-06	1.88E-06
Other tankers	100 - 499	2.51E-02	5.20E-04	2.22E-05	1.76E-04	1.06E-04	2.12E-05
Other tankers	500 - 999	2.11E-02	4.24E-04	1.56E-05	1.12E-04	8.98E-05	1.82E-05
Other tankers	1000 - 1599	1.63E-02	3.67E-04	2.03E-05	1.79E-04	6.10E-05	1.28E-05
Other tankers	1600 - 9999	1.22E-02	2.78E-04	1.59E-05	1.44E-04	4.54E-05	9.05E-06
Other tankers	10000 - 29999	7.23E-03	1.98E-04	1.04E-05	9.08E-05	2.76E-05	5.21E-06
Other tankers	29999 - 59999	4.36E-03	1.29E-04	7.59E-06	6.55E-05	1.73E-05	3.31E-06
Other tankers	60000 - 99999	4.64E-03	1.21E-04	3.98E-06	3.51E-05	1.67E-05	2.80E-06
Bulk carriers	100 - 499	2.19E-02	4.60E-04	2.82E-05	2.52E-04	9.67E-05	1.93E-05
Bulk carriers	500 - 999	1.54E-02	3.12E-04	1.06E-05	7.84E-05	5.84E-05	1.30E-05
Bulk carriers	1000 - 1599	1.48E-02	3.30E-04	2.07E-05	1.88E-04	6.25E-05	1.28E-05
Bulk carriers	1600 - 9999	1.03E-02	2.75E-04	1.93E-05	1.72E-04	4.42E-05	9.13E-06
Bulk carriers	10000 - 29999	7.21E-03	2.15E-04	1.33E-05	1.16E-04	3.18E-05	6.51E-06
Bulk carriers	29999 - 59999	4.58E-03	1.36E-04	7.78E-06	6.75E-05	1.89E-05	3.70E-06
Bulk carriers	60000 - 99999	3.23E-03	9.56E-05	5.95E-06	5.19E-05	1.30E-05	2.59E-06
Bulk carriers	100000 - 999999	2.16E-03	6.73E-05	4.37E-06	3.69E-05	8.84E-06	1.94E-06
Container ships	500 - 999	1.44E-02	3.75E-04	1.17E-05	7.32E-05	5.87E-05	1.41E-05
Container ships	1000 - 1599	1.72E-02	3.48E-04	1.59E-05	1.47E-04	6.01E-05	1.25E-05
Container ships	1600 - 9999	1.45E-02	2.91E-04	1.11E-05	1.04E-04	5.08E-05	8.97E-06
Container ships	10000 - 29999	9.39E-03	2.71E-04	1.37E-05	1.20E-04	3.72E-05	7.14E-06
Container ships	29999 - 59999	8.15E-03	2.42E-04	1.47E-05	1.28E-04	3.26E-05	6.54E-06
Container ships	60000 - 99999	7.54E-03	2.06E-04	9.03E-06	8.06E-05	2.83E-05	4.56E-06
Conventional Cargo ships	100 - 499	2.60E-02	5.96E-04	2.28E-05	1.69E-04	1.09E-04	2.36E-05
Conventional Cargo ships	500 - 999	1.51E-02	3.32E-04	1.13E-05	8.50E-05	6.03E-05	1.28E-05
Conventional Cargo ships	1000 - 1599	1.51E-02	3.19E-04	1.34E-05	1.16E-04	5.65E-05	1.16E-05
Conventional Cargo ships	1600 - 9999	1.32E-02	2.99E-04	1.84E-05	1.68E-04	5.03E-05	9.87E-06
Conventional Cargo ships	10000 - 29999	8.39E-03	2.41E-04	1.52E-05	1.33E-04	3.44E-05	6.92E-06
Conventional Cargo ships	29999 - 59999	5.64E-03	1.59E-04	1.12E-05	9.90E-05	2.25E-05	4.16E-06
Ferries and RORO ships	100 - 499	4.00E-02	8.58E-04	4.88E-05	3.58E-04	1.68E-04	3.41E-05
Ferries and RORO ships	500 - 999	6.25E-02	1.32E-03	1.19E-04	1.04E-03	2.78E-04	5.56E-05
Ferries and RORO ships	1000 - 1599	1.44E-02	3.29E-04	1.66E-05	1.38E-04	5.67E-05	1.25E-05
Ferries and RORO ships	1600 - 9999	1.11E-02	2.54E-04	1.68E-05	1.52E-04	4.29E-05	9.25E-06
Ferries and RORO ships	10000 - 29999	9.14E-03	1.79E-04	1.44E-05	1.45E-04	3.27E-05	6.40E-06
Ferries and RORO ships	29999 - 59999	4.71E-03	1.22E-04	6.82E-06	5.99E-05	1.87E-05	3.46E-06
Ferries and RORO ships	60000 - 99999	5.41E-03	1.05E-04	5.28E-06	5.60E-05	1.28E-05	2.25E-06
Ferries and RORO ships	100000 - 999999	6.88E-03	7.67E-05	1.72E-06	3.49E-05	7.81E-06	1.37E-06
Reefers	100 - 499	3.00E-02	6.11E-04	2.09E-05	1.52E-04	1.27E-04	2.55E-05
Reefers	500 - 999	2.52E-02	5.16E-04	3.14E-05	2.80E-04	1.12E-04	2.23E-05
Reefers	1000 - 1599	1.67E-02	4.44E-04	2.69E-05	2.30E-04	7.12E-05	1.55E-05
Reefers	1600 - 9999	1.43E-02	4.18E-04	2.64E-05	2.23E-04	5.96E-05	1.31E-05
Reefers	10000 - 29999	1.26E-02	3.84E-04	2.66E-05	2.30E-04	5.41E-05	1.16E-05
Other ships	100 - 499	1.16E-01	2.34E-03	9.19E-05	7.29E-04	4.81E-04	9.53E-05
Other ships	500 - 999	4.82E-02	1.11E-03	4.05E-05	2.79E-04	2.09E-04	4.35E-05
Other ships	1000 - 1599	2.26E-02	5.14E-04	1.86E-05	1.45E-04	8.89E-05	1.90E-05
Other ships	1600 - 9999	1.44E-02	3.00E-04	1.12E-05	9.33E-05	5.70E-05	1.13E-05
Other ships	10000 - 29999	1.07E-02	2.61E-04	1.42E-05	1.26E-04	4.51E-05	9.34E-06
Other ships	29999 - 59999	7.29E-03	2.08E-04	1.21E-05	1.08E-04	3.27E-05	6.89E-06
Other ships	60000 - 99999	2.12E-03	4.13E-05	3.09E-06	2.83E-05	8.08E-06	1.62E-06
Other ships	100000 - 999999	5.52E-03	9.35E-05	3.90E-06	2.80E-05	2.34E-05	4.67E-06
Average ship on Western Scheldt	100 - 999999	8.13E-03	2.10E-04	1.52E-05	1.07E-04	3.19E-05	6.24E-06

Basic emission factors for auxiliary engines, (kg/GT.km) **Table 2.8**

Type of ship	from GT to GT	CO_2	NO_x	PM	SO_2	CO	VOS
Oil tankers	100 - 499	1.59E-03	3.60E-05	1.21E-06	8.08E-06	6.78E-06	1.46E-06
Oil tankers	500 - 999	1.67E-03	3.21E-05	1.15E-06	8.48E-06	7.01E-06	1.40E-06
Oil tankers	1000 - 1599	1.05E-03	2.35E-05	7.23E-07	5.35E-06	4.12E-06	8.70E-07
Oil tankers	1600 - 9999	9.67E-04	2.32E-05	7.60E-07	4.91E-06	4.32E-06	9.12E-07
Oil tankers	10000 - 29999	5.19E-04	1.25E-05	4.00E-07	2.64E-06	2.17E-06	4.80E-07
Oil tankers	29999 - 59999	2.05E-04	4.28E-06	1.21E-07	1.04E-06	7.20E-07	1.41E-07
Oil tankers	60000 - 99999	2.74E-04	5.66E-06	1.60E-07	1.39E-06	9.78E-07	1.91E-07
Oil tankers	100000 - 999999	1.02E-04	2.06E-06	5.78E-08	5.16E-07	3.57E-07	6.63E-08
Other tankers	100 - 499	1.70E-03	3.49E-05	1.22E-06	8.66E-06	7.20E-06	1.45E-06
Other tankers	500 - 999	1.61E-03	3.25E-05	1.16E-06	8.19E-06	6.87E-06	1.39E-06
Other tankers	1000 - 1599	1.74E-03	3.79E-05	1.11E-06	8.85E-06	6.34E-06	1.34E-06
Other tankers	1600 - 9999	1.16E-03	2.42E-05	7.01E-07	5.87E-06	4.24E-06	8.42E-07
Other tankers	10000 - 29999	5.27E-04	1.09E-05	3.10E-07	2.67E-06	1.90E-06	3.57E-07
Other tankers	29999 - 59999	2.81E-04	5.94E-06	1.72E-07	1.43E-06	1.02E-06	1.93E-07
Other tankers	60000 - 99999	3.79E-04	7.34E-06	2.01E-07	1.92E-06	1.31E-06	2.05E-07
Bulk carriers	100 - 499	4.03E-03	6.87E-05	2.85E-06	2.04E-05	1.71E-05	3.41E-06
Bulk carriers	500 - 999	1.36E-03	2.83E-05	9.29E-07	6.91E-06	5.02E-06	1.14E-06
Bulk carriers	1000 - 1599	1.03E-03	2.19E-05	7.09E-07	5.21E-06	4.19E-06	8.66E-07
Bulk carriers	1600 - 9999	6.80E-04	1.52E-05	4.74E-07	3.45E-06	2.66E-06	5.76E-07
Bulk carriers	10000 - 29999	4.04E-04	8.79E-06	2.71E-07	2.05E-06	1.60E-06	3.24E-07
Bulk carriers	29999 - 59999	2.56E-04	5.39E-06	1.58E-07	1.30E-06	9.51E-07	1.84E-07
Bulk carriers	60000 - 99999	1.29E-04	2.69E-06	7.84E-08	6.54E-07	4.77E-07	9.21E-08
Bulk carriers	100000 - 999999	8.50E-05	1.95E-06	5.92E-08	4.32E-07	3.31E-07	7.31E-08
Container ships	500 - 999	1.14E-03	2.97E-05	9.27E-07	5.78E-06	4.63E-06	1.11E-06
Container ships	1000 - 1599	1.75E-03	3.51E-05	9.87E-07	8.87E-06	6.09E-06	1.27E-06
Container ships	1600 - 9999	7.79E-04	1.53E-05	4.26E-07	3.95E-06	2.71E-06	4.96E-07
Container ships	10000 - 29999	4.38E-04	9.11E-06	2.64E-07	2.22E-06	1.60E-06	3.10E-07
Container ships	29999 - 59999	3.26E-04	6.91E-06	2.04E-07	1.65E-06	1.22E-06	2.42E-07
Container ships	60000 - 99999	3.67E-04	6.99E-06	1.91E-07	1.86E-06	1.27E-06	1.99E-07
Conventional Cargo ships	100 - 499	1.03E-03	2.39E-05	7.78E-07	5.25E-06	4.27E-06	9.41E-07
Conventional Cargo ships	500 - 999	1.18E-03	2.67E-05	8.42E-07	6.00E-06	4.74E-06	1.02E-06
Conventional Cargo ships	1000 - 1599	1.27E-03	2.68E-05	7.96E-07	6.47E-06	4.73E-06	9.65E-07
Conventional Cargo ships	1600 - 9999	7.35E-04	1.51E-05	4.45E-07	3.74E-06	2.72E-06	5.32E-07
Conventional Cargo ships	10000 - 29999	4.43E-04	9.74E-06	2.97E-07	2.25E-06	1.71E-06	3.53E-07
Conventional Cargo ships	29999 - 59999	3.35E-04	6.66E-06	1.96E-07	1.70E-06	1.23E-06	2.30E-07
Ferries and RORO ships	100 - 499	1.49E-03	2.93E-05	1.08E-06	7.59E-06	6.29E-06	1.29E-06
Ferries and RORO ships	500 - 999	2.41E-03	5.19E-05	1.81E-06	1.22E-05	1.09E-05	2.17E-06
Ferries and RORO ships	1000 - 1599	1.07E-03	2.40E-05	7.42E-07	5.46E-06	4.23E-06	9.15E-07
Ferries and RORO ships	1600 - 9999	8.15E-04	1.80E-05	5.51E-07	4.14E-06	3.13E-06	6.78E-07
Ferries and RORO ships	10000 - 29999	5.41E-04	1.08E-05	3.39E-07	2.75E-06	2.07E-06	4.10E-07
Ferries and RORO ships	29999 - 59999	2.97E-04	6.32E-06	1.88E-07	1.51E-06	1.14E-06	2.15E-07
Ferries and RORO ships	60000 - 99999	3.89E-04	7.96E-06	2.27E-07	1.98E-06	1.41E-06	2.55E-07
Ferries and RORO ships	100000 - 999999	4.51E-04	8.59E-06	2.34E-07	2.29E-06	1.56E-06	2.47E-07
Reefers	100 - 499	2.90E-03	5.87E-05	1.97E-06	1.47E-05	1.21E-05	2.42E-06
Reefers	500 - 999	2.64E-03	5.10E-05	1.92E-06	1.34E-05	1.15E-05	2.31E-06
Reefers	1000 - 1599	1.66E-03	3.84E-05	1.22E-06	8.45E-06	6.83E-06	1.49E-06
Reefers	1600 - 9999	9.84E-04	2.28E-05	6.98E-07	5.00E-06	3.83E-06	8.55E-07
Reefers	10000 - 29999	7.21E-04	1.60E-05	5.03E-07	3.66E-06	2.84E-06	6.10E-07
Other ships	100 - 499	9.15E-03	1.81E-04	6.15E-06	4.65E-05	3.73E-05	7.27E-06
Other ships	500 - 999	4.54E-03	1.01E-04	3.19E-06	2.30E-05	1.85E-05	3.91E-06
Other ships	1000 - 1599	3.89E-03	8.79E-05	2.65E-06	1.98E-05	1.46E-05	3.20E-06
Other ships	1600 - 9999	2.36E-03	4.77E-05	1.42E-06	1.20E-05	8.82E-06	1.74E-06
Other ships	10000 - 29999	1.10E-03	2.41E-05	7.38E-07	5.58E-06	4.31E-06	8.57E-07
Other ships	29999 - 59999	2.40E-04	5.22E-06	1.73E-07	1.22E-06	9.96E-07	2.07E-07
Other ships	60000 - 99999	2.08E-04	4.24E-06	1.45E-07	1.06E-06	8.85E-07	1.77E-07
Other ships	100000 - 999999	1.44E-03	2.44E-05	1.02E-06	7.33E-06	6.11E-06	1.22E-06
Average ship on Western Scheldt	100 - 999999	5.17E-04	1.09E-05	3.24E-07	2.63E-06	1.94E-06	3.84E-07

Strengths and weaknesses of European activity based emission approaches for seagoing vessels **Table 2.9**

Methodology	Strengths	Weaknesses
MEET	European accepted methodology for emission inventory (PRTR) distinction in different navigational stages fishing boats taken into account good results for long journeys (amount of days)	for short journeys, like Belgian territory too rough no technological evolution taken into account
ENTEC	used in Europe as input for policy distinction in different navigational stages emission factors available fishing boats taken into account	not transparent in input and assumptions, complicating third party-use (outside an European project) ships under 500 GT are not taken into account very detailed division by which the uncertainty on the input parameters increases no technological evolution taken into account
EMS	distinction in different navigational stages clear handbook available, so reproducible geometry of the harbour taken into account technological evolution taken into account emission factors available in detail	Dutch approach (not European)
TREMOVE	analogous ENTEC	analogous ENTEC
TRENDS/ ARTEMIS	used in a European project	common approach by EC no distinction in different navigational stages

Source: Gommers *et al.*, 2007

the ships manoeuvring, depending on the type of ship and volume, in combination with the specific port layout.

Emission = 2 x (Number of ships) x (ship's Volume) x (Time for manoeuvring) x (Emission factor) x (conversion factor to kg/GT.hour) x (correction factor emission factors)

The conversion factor to kg/GT.hour and correction factor mentioned above are provided in the EMS protocol (Hulskotte *et al.,* 2003b). In the EMS, the 'Time for manoeuvring' depends on the specific port and the specific ship (Hulskotte *et al*., 2003b; Table B.3 which is not shown in this report).

2.3 The Dutch EMS approach for seagoing vessels from a European perspective

The following different European methodologies for estimating emissions from seagoing vessels have been evaluated by Gommers *et al.* (2007):

- MEET

The European project 'Methodologies for estimating air pollutant emissions from transport (MEET)' describes a methodology for calculating the emissions from seagoing vessels, among the methodologies for the other transport modes (MEET, 1999).

- ENTEC

ENTEC UK Limited conducted a study on behalf of the European Commission, to quantify among other things ship emissions of SO_2, NO , CO_2 and hydrocarbons, for the year 2000, in the North Sea, the Irish Sea, the English Channel, the Baltic Sea and the Mediterranean. For the pollutant PM, they have only quantified the in-port emissions (manoeuvring, loading/unloading and hotelling) (ENTEC, 2002).

- EMS

The project 'Emission registration and monitoring for shipping (EMS) (*Emissieregistratie en Monitoring Scheepvaart*) was carried out by the Dutch advisory service for traffic and transport (DVS) (formerly known as *Adviesdienst Verkeer en Vervoer (AVV)* (head performer), by order of the Directorate-General for freight transport (*Directoraat-Generaal Goederenvervoer (DGG)*). The aim of the project was to (better) map the different emissions from seagoing vessels en inland shipping for the Netherlands (AVV *et al*., 2003).

- TREMOVE

Transport & Mobility Leuven has included maritime shipping in their transport model TREMOVE'. The model calculates the emissions from seagoing vessels with the methodology that was set up by ENTEC.

- TRENDS

TRENDS stands for TRansport and ENvironment Database System (EC, 2003). The authors of TRENDS set up a methodology for determining the emissions from the four most important transport modes (road transport, railways, shipping, aviation). The module in the study 'Energy Consumption and Air Pollutant Emissions from Rail and Maritime Transport' (ARTEMIS; Georgakaki, 2003) was based on TRENDS. Within ARTEMIS the calculation of emissions from seagoing vessels was based on the TRENDS methodology.

Gommers *et al.* (2007) analysed the strengths and weaknesses of the various approaches (Table 2.9) and concluded that the methodologies do not pay any attention to the technological evolution of seagoing vessels, with the exception of the EMS approach. Moreover, the EMS approach is considered transparent, and provides a handbook with emission factors. Gommers *et al.,* therefore, selected the EMS approach as a starting point for their MOPSEA project, which estimated Belgian emissions from shipping.

2.4 Comparison of EMS emission factors with measurements and adjustment of the PM_{10} emission factor used in the Emission Registration

Current estimates on emission factors of seagoing vessels have been based on a limited number of laboratory experiments and on information on fuel usage and engine power. Especially emission of nitrogen oxides (NOx)[1] have been reported in literature, measurements of particulate

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[1] NO_x is the sum of concentrations of NO (nitric oxide) and NO_2(nitrogen dioxide).

Emission factors of PM and NO_x derived from field measurements and EMS

Table 2.10

	Duyzer *et al.* **(2007)**					**EMS**		
Four-stroke engines	**PM_1**	**$PM_{2.5}$**	**PM_{10}**	**$PM_{2.5}/PM_{10}$**	**NOx**		**PM_{10}**	**NO_x**
Fuel-S		(g/kg)		(%)		Fuel	(g/kg)	
S<1%	0.8	1.3	2.5	52	39	MDO	1.6	50
S>1%	1.7	2.9	6.0	48	63	HFO	3.9	
Two-stroke engines								
S<1%	1.1	1.7	3.3	52	39	MDO	1.8	75
S>1%	3.0	3.9	6.5	60	70	HFO	8.8	

Source: Duyzer *et al.* (2007)

matter (PM[2]) are scarcer. It is important to realise that there were large variations, especially in emissions of particulate matter, within the results from engines using HFO (Heavy Fuel Oil). These are therefore rather uncertain. In the process of developing scenarios to improve local air quality and decrease atmospheric deposition, accurate data on emissions are essential. In the Netherlands, Duyzer et al. (2007a) developed a method for measuring shipping emissions, which could be a base for validating and (if needed) adjusting emission factors. Our report only presents a summary table (Table 2.10) from their report, which compares emission factors derived from their field measurements with earlier estimates as presented in EMS (Klein *et al.,* 2007).

The field measurements by Duyzer *et al.* (2007a) did not cover all categories and situations as covered by EMS. The comparison is therefore indicative. The important conclusion from Table 2.10 would be that, overall, the emission factors from both methodologies agree quite well and do not show large deviations. This builds confidence. Uncertainties of the order of 20 to 30% exist, but it is unlikely that the emission estimates are off by more than a factor of 2. However, the lower PM_{10} emission factor reported by Duyzer et al. (2007a) for HFO was deemed significantly lower. The in-use PM_{10} emission factor in the Emission Registration is reduced by ~ 25% based on the results by Duyzer et al. (2007a).

2.5 Recommendations concerning emissions from seagoing ships

The weakest aspect of the emission calculations for seagoing vessels in Dutch territorial waters other than the Dutch continental shelf, is that these calculations strongly depend on emission factors derived from seagoing vessels travelling on that continental shelf. These emission factors were derived on a ship-by-ship basis and can be assumed to have been relatively accurate at the time of measurement. However, the periodic actualisation remains a weak point; the emission factors were updated only once in 2004. This implies that, in 2009, the set of emission factors which plays a pivotal role in the whole emission estimation methodology is already five years old. Recently (June 2009), a project to update these factors has been commissioned to MARIN and TNO, results are expected by the end of 2009.

Another shortcoming is the lack of data on energy consumption and fuel use in auxiliary engines of seagoing vessels while they are moving towards or in ports. It is generally known that energy consumption of auxiliary engines is much higher in such situations. This phenomenon, thus far, has been neglected in the EMS protocols and is not accounted for in current emission estimation methodologies. Furthermore the fractionation of PM into different size classes (TSP, PM_{10} and $PM_{2.5}$) is uncertain because 1) in the past PM, TSP and PM10 have sometimes been used without exact definition of the size class included and, 2) simultaneous measurements of PM_{10} and $PM_{2.5}$ emission from shipping are scarce. This aspect is further addressed in chapter 4.

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[2] PM is particulate matter. PM_{10} is the mass of particles with a diameter smaller than 10 µm. Similarly, $PM_{2.5}$ and PM_1 indicate particles smaller than 2.5 and 1 µm.

3

Fuel consumption and associated emissions from seagoing vessels in berth, derived from an on-board survey [1]

3.1 Introduction

Exhaust emissions from the growing marine transport sector are a significant source of air pollution. As EU land-based emission sources are abating, while shipping emissions remain largely unabated, the relative importance of shipping emissions is rapidly growing. Since many major ports are also major cities, port and near-port emissions from seagoing vessels that influence local air quality may directly affect a large population (Corbett *et al.*, 2007). Emissions from seagoing vessels can be separated in emissions 1) on international waters, 2) on national waters and while manoeuvring in port and, 3) while in berth. Ships in berth are the main source of shipping emissions in ports because the ships typically spend one or more days there, while manoeuvring only takes about two hours. Accurate estimates of emissions from ships in berth demand reliable knowledge of the fuel consumption while in berth and associated fuel characteristics. Fuel quality (e.g. the sulphur content) is an important factor because it largely controls the emission of pollutants, such as SO_2 and particulate matter (PM_{10}) (e.g., Kasper *et al.*, 2007). A common assumption is that ships are using distillates or fuels with low sulphur content in port areas. This would potentially limit the contribution from shipping to local air pollution, but a sound basis for this important assumption is lacking.

To fill this information gap, we executed a survey of energy consumption and fuel type used, for 89 seagoing vessels, in close cooperation with the Port of Rotterdam. The survey was performed in 2003, and a methodology for calculating the emissions from ships in berth was described in a protocol that is part of the so-called EMS modelling system (Emission registration and Monitoring of Shipping; Hulskotte *et al.*, 2003a). The EMS modelling system has been used in the Netherlands for calculating annual shipping emissions since 2003. Our report presents the assumptions made in the EMS modelling system concerning the calculation of emissions from ships in berth. Furthermore, we carried out a concise re-evaluation of the basic data that was collected in the survey on the energy consumption by ships in berth, and have provided recommendations for improving the emission inventory methodology of ships in berth.

3.2 Methodology

3.2.1 Questionnaire

We conducted a survey on shipping emissions in the Port of Rotterdam. Two former ship engineers together with the port's ship safety inspectors went on board of 89 ships to present them with a questionnaire. Explanation for the questionnaire was given in a letter to the captain, together with a written assurance that no identifiable ships data would be published or supplied to third parties. This ensured full cooperation and a 100 per cent response rate. The questionnaire contained questions about general ship characteristics, such as the ship's name, type, volume, year of manufacture, and IMO number (to access more detailed ship data later). Furthermore, the questionnaire asked for fuel consumption during different ship activities: cruising at open sea, manoeuvring towards port and while in berth (with most emphasis), together with duration of stay in berth. In addition, there were questions on fuel quality and on the type of engine and/or machinery. We aimed to cover the full spectrum of ship types, as well as ship volumes, and succeeded rather well at this (Figure 3.1). However, only

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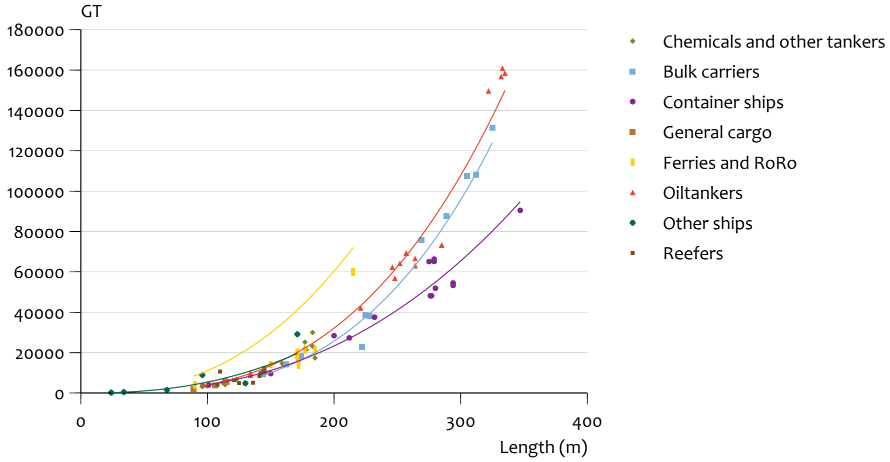
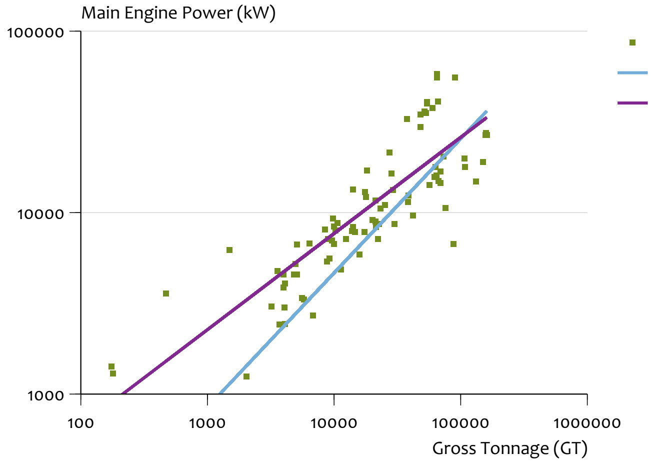
[1] Published as: Hulskotte J.H.J, H.A.C. Denier van der Gon, Emissions From Seagoing Ships At Berth Derived From An On-Board Survey, Atmospheric Environment, Doi: 10.1016/j.atmosenv.2009.10.018, 2009.

Ships length versus ships volume and ships power versus ships volume **Figure 3.1**

Ships length versus ships volume



Ships power versus ships volume



Ship's volume (GT) versus ship length and ship power versus ship's volume (GT)

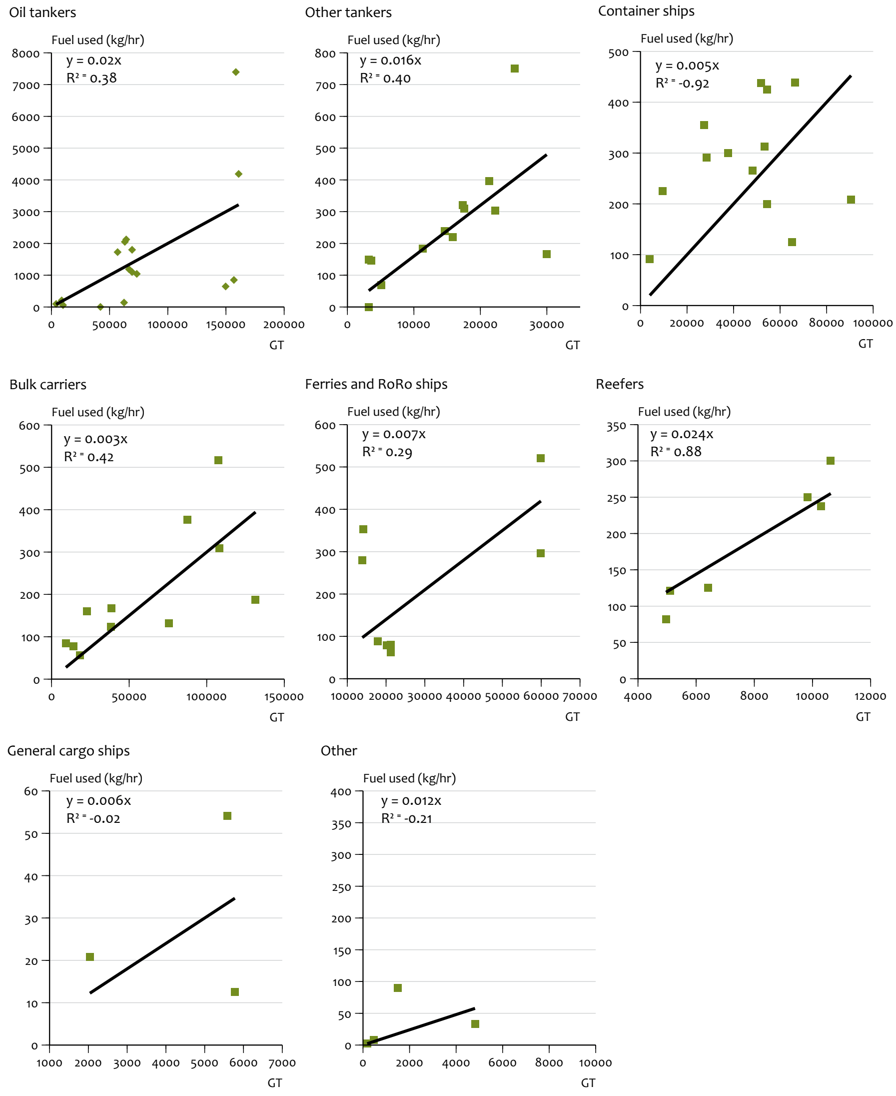
89 ships could be visited, which still implies that some ship types were under-represented. The key variable in describing the variety in ships is Gross Tonnage (GT). A ship volume measured in GT is the function of the ships length to the power of 2.6, which is slightly lower than an expected cubic relationship.

Ship's available propulsion power is almost proportional to the square root of ship's volume (see Figure 3.1). In Figure 1b, we also depicted the relationship found by Flodström (1997), which is slightly different because the regression line through our survey data was influenced by the presence of a limited number of small vessels. Bearing this in mind, there is good agreement between the two studies.

3.2.2 Fuel consumption

The basic activity data recorded in the PRTR are the number of berths of different ship types which are collected on a regular basis by Statistics Netherlands (2007). The number of berths is specified by ship type and by ship's volumes measured in GT. These robust activity data were selected to make the emission calculation methodology applicable for historical years as well as future years. For Figure 3.2, the total fuel use per berth per ship type, based on the ships questionnaire, was plotted as a function of an individual ship's GT. To have a simple descriptive function, the regression was forced through zero (a ship of 0 GT using 0 kg fuel). Correlation coefficients were rather low, because the number of ships per ship type was sometimes small and the variability in the outcome rather large. Nevertheless, the fuel use rate showed overall the best correlation with GT. It showed much better correlation than, for instance, the amount of auxiliary power available on a ship, which is often applied in other studies (e.g. Whal *et al.*, 2007). For three ship types, the correlation was poor (Figure 3.2; Container ships, General Cargo and "Other"). The weak correlation found for container ships is a serious concern as these ships contribute significantly to the total in emissions, and transport volumes of container ships are rising steeply in Rotterdam with about 6 million TEU in 2000 to 11 million TEU in 2008 (Figure 3.3). The increase in Figure 3 is expressed in the twenty-foot equivalent unit (TEU), representing the cargo capacity of a standard intermodal container.Fortunately, we were able to validate fuel consumption of container ships with an independent

Analysis of fuel rate by ship type as a function of ships volume **Figure 3.2**



Analysis of fuel use rate per ship type, as a function of ship's volume (GT)

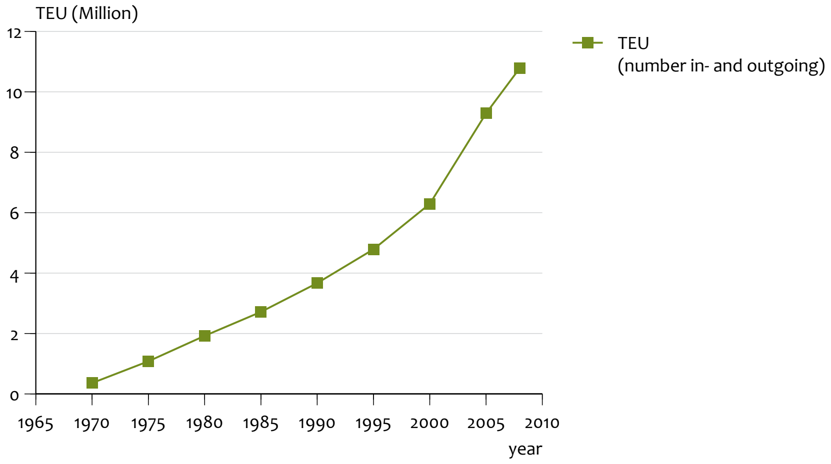
data set. The results of the validation of energy consumption of container ships are presented in the next section. Next to container ships, two other ship categories (General Cargo and 'Other', see Figure 3.2) show a poor relation between fuel use in berth and GT. However, these ship categories are of less concern as they represent a very small fraction of the total fleet and therefore have a minor influence on estimated emissions.

The derived fuel consumption rates while in berth, per ship type, are presented in Table 3.1 (Note; some small rounding errors may be seen between comparing regression coefficients in Figure 3.2 and the data in Table 3.1). The high fuel consumption rate of tankers is explained by the use of considerable amounts of installed power for the purpose of heating crude oil and for unloading operations.

Container ships and General cargo ships often carry a certain percentage of reefer containers that are refrigerated by means of on-board generated electricity. Reefer ships need to refrigerate all of their cargo, explaining the high fuel consumption rate of this ship type. Other ships differ greatly in purpose and shape, but sometimes have specialised equipment which may require extra power generation onboard. The data in Table 3.1 represent the ship category-specific fuel rates used within the EMS framework (Hulskotte *et al.*, 2003a).

Growth of container shipping in the Port of Rotterdam

Figure 3.3



Increase in container shipping in the Port of Rotterdam (Port of Rotterdam, 2009)

Fuel consumption by seagoing vessels in berth, as derived from the questionnaire

Table 3.1

Type of ship	Fuel consumption rate (kg fuel/1000 GT.hour)	Average hotelling time in berth (hours)
Oil tankers	19.3	28
Chemical and other tankers	17.5	24
Bulk carriers	2.4	52
Container ships	5.0	21
General cargo ships	5.4	25
Ferries and RoRo ships	6.9	24
Reefers	24.6	31
Other	9.2	46

3.2.3 Verification of energy consumption

Verification of energy consumption for container ships in Rotterdam

The data obtained for container ships showed a considerable range in fuel consumption. Since this ship category is relevant to the final emission estimation, we searched for additional data to verify our results. Doves (2006) presented data from 53 container ships, based on individual ships questionnaires divided over 34 large container ships and 19 small so-called container feeder ships. The individual data of observed fuel consumption from container ships were plotted against calculated fuel consumption rates based on container ship GT (5 kg fuel per 1000 GT.hour; Table 3.1 and Figure 3.4). The result indicated that the GT can indeed largely explain the variation in fuel consumption in berth.

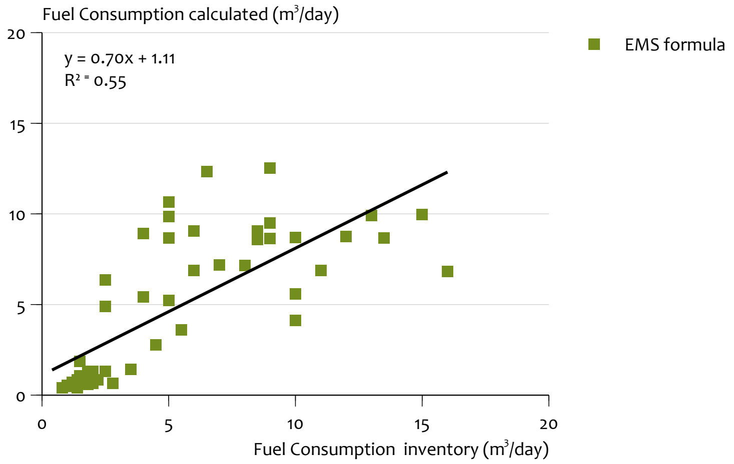
In addition, main engine power was tentatively tested as a possible explanatory parameter for the fuel consumption in berth. As an approximation of the best match, fuel consumption was assumed to be 4.5 % of individual container ships' main engine power, with thermal engine efficiency of 200 gram/kWh. This calculated fuel consumption was plotted as a function of observed fuel consumption (Figure 3.5). The correlation coefficient of the fitted curve in Figure 3.5 is close to the correlation coefficient observed in Figure 3.4, confirming that container ships' main engine power may also be used as an alternative explanatory parameter for fuel consumption in berth. However, GT is a parameter that is generally available while main engine power is less often available. Therefore, we chose GT as our explanatory parameter.

Collected independent fuel consumption data on container ships in berth was plotted against GT in Figure 3.6, and calculated fuel consumption based on the EMS fuel rate is presented by category (Table 3.1). From the slope of the fitted regression line in Figure 3.4 could be concluded that the EMS formula could lead to about a 16% underestimation of fuel consumption by container ships, depending on the actual spectrum of the port's visiting ships.

The calculated fuel consumption by small container ships was somewhat underestimated, while fuel consumption by bigger container ships was overestimated (Figure 3.6). Therefore, we tried to fit the data with a power function. This tended to compensate the deviation of the linear EMS formula. Such non-linear power functions have been published for ships cruising at sea (Georgakaki et al., 2005), but not yet for ships in berth. The increased correlation coefficient of 0.78 for the power function in Figure 3.6 (compared to the correlation coefficient of 0.55 in Figure 3.4) suggested that a non-linear power function would be more suitable for estimating fuel consumption by container ships in berth.

Fuel consumption — Figure 3.4

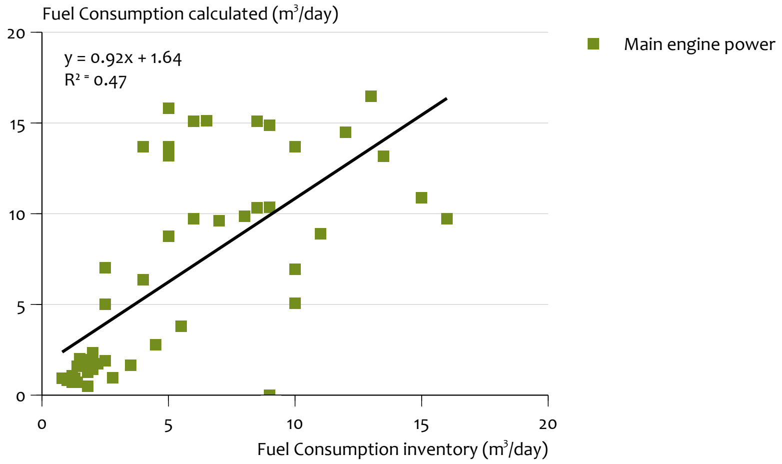
EMS formula compared to observations



Fuel consumption calculated using Gross Tonnage (EMS formula), compared with fuel consumption observed in an independent survey of 54 container ships in Rotterdam.

Fuel consumption compared — Figure 3.5

Fuel consumption with 4.5 percent of ships main engine power compared to fuel consumption observed



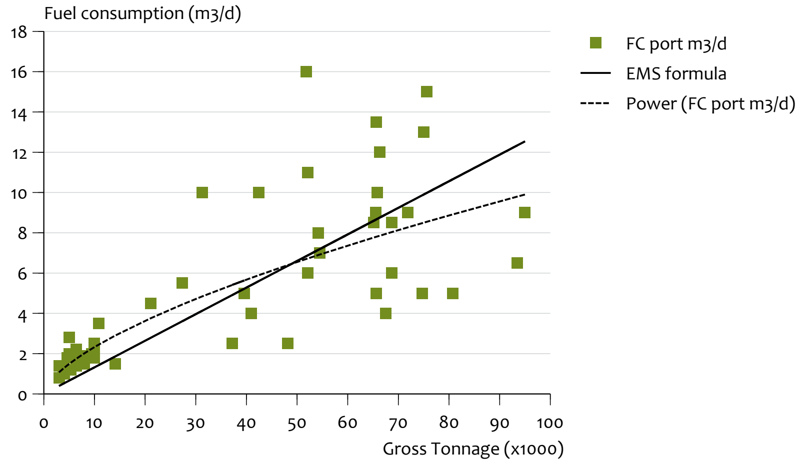
Fuel consumption calculated using 4.5 per cent of the ships main engine power, compared with fuel consumption observed in an independent survey of 54 container ships in Rotterdam.

Verification of energy consumption for other ships

Next to independent verification of fuel consumption for container ships in Rotterdam, we compared fuel rates derived from our questionnaire with the (few) published fuel consumption rates. Only four references were suitable for comparison with the data in Table 3.1. The data from Cooper (2003), Mar *et al.* (2007), Saxe and Larsen (2004), and Trozzi *et al.* (1995) were converted to fuel rates in a comparable dimension, as applied in this study and summarised in Table 3.2.

The data by Cooper (2003) and Marr *et al.* (2007) were based on measurements for individual ships, while fuel rates given by Saxe and Larsen (2004) and Trozzi *et al.* (1995) were estimations, based on expert judgement. The fuel rates in Rotterdam, based on the questionnaire, tended to be somewhat lower than in other studies (Table 3.2). One plausible explanation for such a deviation is that actual fuel consumption is not linear and can be better described with a power function in which the power number is below 1. This implies that bigger ships have relatively lower fuel rates. A similar conclusion could be deduced from the data on average GT for Rotterdam (Figure 3.6). In Rotterdam, one of the world's biggest ports, many calls are those of the world's biggest ships, which probably leads to somewhat lower fuel rates when expressed per GT. However, the lower fuel rate of ferries in our study could not be explained by this phenomenon. Another exception are bulk carriers, for which much higher fuel consumption was reported in Copenhagen than in Rotterdam. The validity of the Copenhagen figures, however, could be questionable as they were based on expert judgement and not on actual observations. The relatively

Measured fuel consumption against calculated fuel consumption and model **Figure 3.6**



Measured fuel consumption for container ships in berth (individual dots), against calculated fuel consumption (black line), and modelled best fit with power function (dashed line).

Overview of ship data and calculated fuel consumption rates for various ships in berth in Göteborg, Copenhagen, Aberdeen, Venice and in Rotterdam (this study) **Table 3.2**

Ship type	**Volume (GT)**	**Fuel use per ship (kg)**	**Time (hours)**	**Fuel rate calculated (kg/1000GT.hour)**	
	Göteborg (Cooper, 2003)				Rotterdam
Ferries	28727	1642	7.25	7.9	6.9
Ferries	39178	3754	10.50	9.1	6.9
Ferries	22528	4150	14.50	12.7	6.9
Gen. Cargo ships	52288	3890	13.00	5.7	5.4
Container/RoRo ships	58438	9925	54.00	3.1	5.0 or 6.9[e]
Chem. tankers unloading	5698	1660	11.00	26.5	17.5
Chem. tankers loading	5698	756	12.00	11.1	17.5
	Copenhagen (Saxe and Larsen, 2004)				Rotterdam
Tankers (oil and chemical)	5400[b]	1324[a]	8.80[b]	27.9	19.3 or 17.5[e]
Bulk carriers	5400[b]	428	8.80[b]	9.0	2.4
Container/gen. cargo	5400[b]	462	8.80[b]	9.7	5.0 or 5.4[e]
Ferries	21000[b]	2400	10.00[b]	11.4	6.9
Cruise ships	30000[b]	8908	18.00[b]	16.5	n.a.[d]
	Aberdeen (Marr et al., 2007)				Rotterdam
Ferries	12000[b]	157[c]		13.1	6.9
Ferries	12000[b]	146[c]		12.2	6.9
Supply ship	3100[b]	27.2[c]		8.8	9.2
Supply ship	3100[b]	27.2[c]		8.8	9.2
	Venice/Piombino (Trozzi et al., 1995)				Rotterdam
Ferry	1500	300	1.00	200.0	6.9
Cargo ships	15000	150	1.00	10.0	5.4
Lighters (=fuel tankers)	3600	100	1.00	27.8	19.3

[a] Fuel consumption was based on estimated energy consumption data (200 kg fuel/ MWh)

[b] number of ships and estimated average values from Saxe and Larsen (2004).

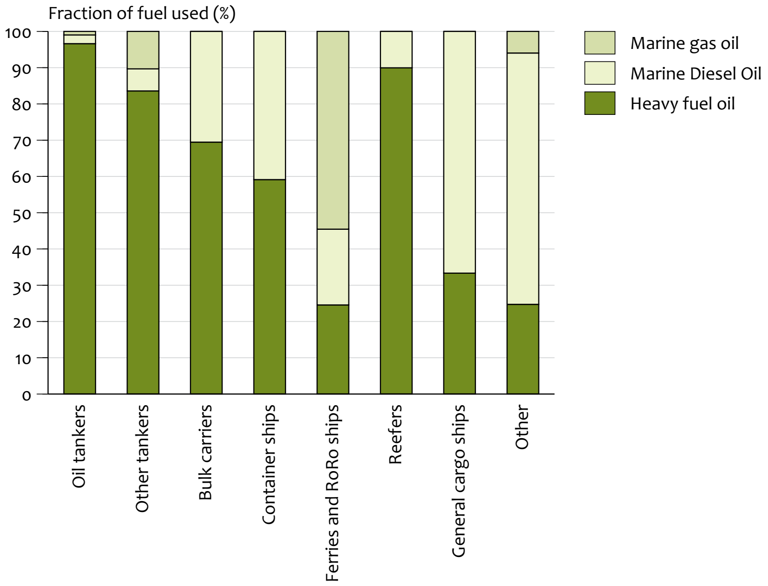
[c] Fuel consumption per hour reported by Marr et al. (2007)

[d] Data on cruise ships were not available for this study

[e] For the Rotterdam data, this ship category was not merged, but two separate ship category values were available, see also Table 13

small size of the Venice ferries may be a possible explanation for their deviating fuel consumption. The extreme fuel consumption of ferries in Venice may be an outlier related to their relatively small sizes but another possible explanation is that there is confusion of the definition of “in port” emissions. Possibly the fuel consumption of the Venice ferries in Trozzi et al. (1995) also includes the actual traffic emissions for crossings within the port. With the exception of the Venice ferry data, the differences between the reported fuel rates elsewhere and the estimates based on data collected in

Share of fuel type used dependant on ship type **Figure 3.7**



Share of fuel type used dependent on ship type.

this study are less than a factor of two which is considered a remarkable result.

Unfortunately, the number of ships surveyed was too limited to develop power functions for other ship types. To improve the fuel consumption estimation for the near future, we propose the development of power functions based on a larger number of questionnaires from more ship types (e.g. more ferries and cruise ships) with diversion over a wider spectrum of ship volumes, in a wider spectrum of ports.

3.2.4 Types of fuels

Emission factors of especially particulate matter (PM) and SO_2 are highly dependent on the type and quality of the fuel. Therefore, information on the fuel used by ships' auxiliary engines while in berth, was gathered from the questionnaire. The results indicated that Heavy Fuel Oil was the dominant energy source for ships in berth, in 2003, in Rotterdam (Figure 3.7). There was no reason to assume that this situation had changed dramatically since then. The use of Heavy Fuel Oil in berth was a surprising result, as it is often thought that ships use distilled fuels while in berth. The type of fuel used while in berth varied considerably per type of ship. Most notably, ferries and Roll-on/Roll-off (RoRo) ships showed only limited use of Heavy Fuel Oil while in berth. Why Ferries and RoRo ships use less HFO is not known, but a possible explanation could be that more people (incl. passengers) may be exposed to exhaust fumes on these ships form an incentive for using more environmentally friendly, low sulphur fuels.

3.2.5 Types of engines and machinery

Next to the types of fuels used, the emission of substances, such as NO_x and PM_{10}, are dependent on the type of machinery and/or the engines in which the fuels are used. For example, emission factors of NO_x from boilers are essentially different from reciprocating engines. Therefore, the fraction of total fuel used in berth per type of machinery (main engine, auxiliary engine or boiler) was requested from the ships engineer in the questionnaire. The results are summarised in Figure 3.8 and indicated that especially for seagoing oil tankers, other tankers and container ships the greater part of the fuels consumed while in berth are consumed by the boilers. These boilers are used to produce steam, electricity and inert (low-oxygen) gases that are used in tanker unloading operations. Remarkably, even the boilers of other categories of seagoing vessels were consuming 20 to 36% of the fuels in berth, only the mixed category of 'other ships' did not report energy consumption by boilers when in berth. Energy use by boilers appears to be ignored in most other studies, but is essential to properly estimate emissions from ships in berth.

3.2.6 Emission calculation scheme

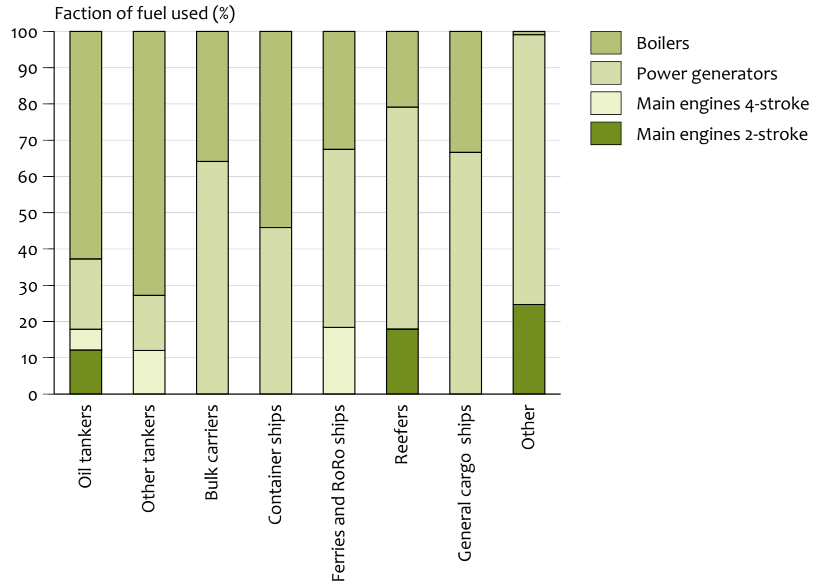
Emissions were calculated according to a scheme which directly applies rates of fuel use per ship type depending on the ship volume [Equation 2.1].

Emissioni = Number of berths x Ship Volume x Ship Fuel rate x Hotelling time x Emission factori [2.1]

Where *i* = the pollutant of study

Equation [2.1] formed the basis and was further specified using available information. For example, the fuel rate is dependent on ship type and ship volume, and hotelling times in berth are also different for each ship type. Furthermore, every ship type has a typical fuel-use profile. Some ship types use various fuels which requires the application of different emission factors. Moreover, each ship type when in berth uses fuel in different types of engines and machinery, each having its own specific emission factor.

Distribution of fuels by engine type/machinery **Figure 3.8**



Distribution of fuels per engine type/machinery.

Emission factors

Emission factors are related to the base year of the Pollutant Release & Transfer Register (PRTR), as technologies may change over time. The emission factors used in this study are those of the base year 2000 (Table 3.3). For any given year, emission factors are dependent on which types of fuels and engines or machinery were used. However, the impact differs by pollutant. PM_{10} emission factors depend both on fuel and engine type, NOx emission factors mostly depend on engine type, with only a small direct effect of fuel quality while SO_2 emission factors are only dependent on fuel sulphur content.

Most of the boilers in oil tankers and chemical tankers operate on Heavy Fuel Oil. These boilers are likely to have wet scrubbers in order to avoid major corrosion problems with ships machinery. Therefore, we applied (rather arbitrarily) reduction factors of 90% for SO_2 and 50% for PM_{10} on the boiler emission factors shown in Table 3.3.

3.3 Results

Within the framework of the Dutch Pollutant Release & Transfer Register, annual calculations are performed for all relevant Dutch ports. This section presents and discusses the results from the calculations for 2000 and 2005 for the municipality of Rotterdam (which, for shipping, comprises the port of Rotterdam).

3.3.1 Activity data

The activity data needed for emission calculations are delivered on a regular basis by Statistics Netherlands (Table 3.4). The overall activity in the port of Rotterdam increased between 2000 and 2005. The number of port calls increased by 4%, total ship volumes increased by 12.5%, and the average ship volume increased by 8.1% (Table 3.4).

3.3.2 Emissions from ships in berth in the Port of Rotterdam

The calculated emissions for the year 2005, including totals for the year 2000, are presented in Table 3.5. The overall outcome of the emission calculations were in line with the increment in total of ship volumes of 12.5%. Minor differences between the increment in pollutants in Table 2.3 were caused by shifts in relative shares in total volumes of different ship types.

Emissions within the municipality of Rotterdam were dominated by those from oil tankers (about 30%), container ships (about 25%) and ferries and RoRo-ships (about 20%) (Figure 3.9). As transport volumes rise, most emissions are expected to rise, as well. However, because of future regulation of the sulphur content of Heavy Fuel Oil (IMO, 2008), emissions of SO_2 and PM_{10} are expected to decline, compared to the current situation. Laboratory measurements on a large marine diesel engine demonstrated a substantial reduction in PM emission when changing from high sulphur Heavy Fuel Oil to low sulphur marine diesel oil (Kasper *et al.*, 2007). The linear relationship between PM emission factors and sulphur content of fuels was recently confirmed through direct measurements of exhaust plumes from seagoing vessels (Duyzer *et al.*, 2007), and further supported by data from Agrawal *et al.* (2008), showing that PM emissions from large container ships fuelled by Heavy Fuel Oil contain a large fraction of hydrated sulphate.

3.4 Conclusions

From the on-board questionnaire, distributed in Rotterdam in 2003 and covering a broad range of 89 seagoing vessels, the following conclusions were drawn:

Table 3.3

Emission factors of Heavy Fuel Oil (HFO), Marine Diesel Oil and Marine Gas oil depending on engine type or machinery (g/kg fuel) (data derived from Oonk et al., 2003)

	Heavy fuel oil			Marine diesel oil/Marine gas oil		
Substance	**Boiler**	**MS[a)]**	**SP[b)]**	**Boiler**	**MS[a)]**	**SP[b)]**
HC	0.8	2.6	2.9	0.8	2.6	2.9
SO_2	54	54	54	20[c)]/10[d)]	20[c)]/10[d)]	20[c)]/10[d)]
NOx	4.1	68.1	89.9	3.5	68.1	89.9
CO	1.6	12.2	13.3	1.6	12.2	13.3
CO_2	3173	3173	3173	3173	3173	3173
PM_{10}	2.0	3.1	6.5	0.7	2.1	2.2

[a)] Medium speed engines; [b)] Slow speed engines; [c)] Marine diesel oil; [d)] Marine gas oil

Table 3.4

Shipping activity data within the municipality of Rotterdam, for 2000 and 2005

Type of ship	**No. of calls**		**Total GTx1000**		**Average GT**	
Year	**2000**	**2005**	**2000**	**2005**	**2000**	**2005**
Oil tankers	1918	1800	75518	83043	39373	46135
Chemical and other tankers	4169	4934	28595	39174	6859	7940
Bulk carriers	1337	1095	58687	57411	43895	52430
Container ships	5376	6309	160475	182045	29850	28855
General cargo ships	7283	7778	24754	26898	3399	3458
Ferries and RoRo ships	5587	4825	109834	126273	19659	26171
Reefers	509	386	4318	3485	8484	9030
Other	587	718	4184	6281	7127	8748
Total	26766	27845	466365	524611	17424	18840
Increase 2000 to 2005		4.0%		12.5%		8.1%

Source: Statistics Netherlands (2007)

Table 3.5

Emissions from ships in berth within the municipality of Rotterdam, for 2005 (tonnes/year)

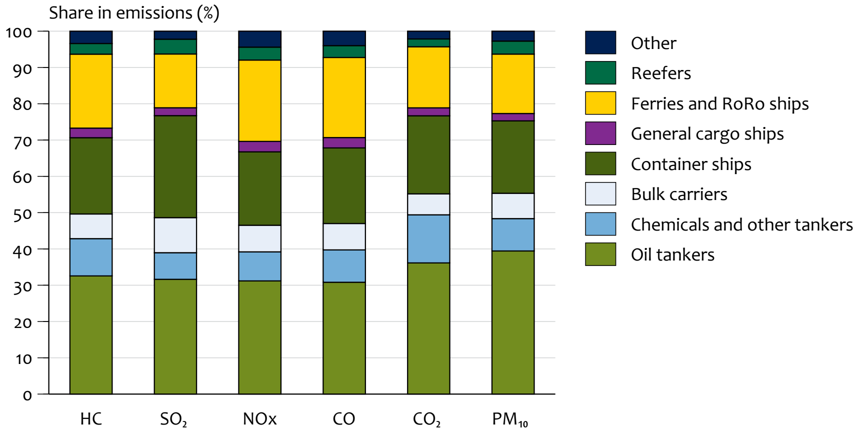
Type of ship	**HC**	**SO_2**	**NO_x**	**CO**	**CO_2**	**PM_{10}**
Oil tankers	67	1023	1372	255	142410	97
Chemical and other tankers	21	237	352	74	52208	22
Bulk carriers	14	312	323	60	22735	17
Container ships	44	909	890	172	84795	49
General cargo ships	5	70	127	24	8644	5
Ferries and RoRo ships	42	479	986	182	66346	40
Reefers	6	132	156	27	8435	9
Other	7	71	194	33	8434	7
Totals 2005	207	3233	4400	826	394007	245
Totals 2000	184	2903	3917	734	347434	218
Increase 2005 to 2000	12.8%	11.4%	12.3%	12.5%	13.4%	12.2%

- Oil tankers (30%), container ships (25%) and ferries and RoRo ships (20%) together covered around 75% of emissions from ships in berth.
- Seagoing vessels in berth consume considerable amounts of Heavy Fuel Oil, contrary to the expectation that fuel consumed in berth would be mainly distillate. This resulted in higher emissions than was expected based on the assumed use of low sulphur fuels.
- A substantial part of the fuel used by ships in berth was consumed by boilers. This phenomenon appears to have been neglected in most previous studies. Boilers generally have lower emission factors than internal combustion engines, partly because many boilers have scrubbers installed to reduce corrosion from acid exhaust gases, such as SO_2.

The higher emissions from the use of HFO, therefore, are partly compensated by the use of boilers. We derived linear relationships between fuel consumption and ship volume (expressed in GT), for eight different ship types. Ships' main engine power showed a similar correlation with fuel use in berth as with ship volume expressed in GT. However, GT is more often available and therefore we choose to work with GT.. Container ships are an important category and responsible for a substantial amount of emission in ports. For container ships (and general cargo ships and others) the linear relationship is poor, which may result in unreliable estimates. However, validation of the fuel consumption by container ships using an independent data set confirmed that fuel consumption by container ships as derived from the questionnaire was close to the average situation. The estimation of fuel use for container ships improved substantially when using a non-linear power function. As

Share of different ship types to total emissions by ships at berth **Figure 3.9**

in 2005



Share of different ship types in total emissions from ships in berth, for the year 2005.

average ship volumes continue to increase, it is desirable to develop such non-linear functions for ships in berth, in order to avoid overestimation of future emissions. However, fitting a non-linear relationship requires more data than fitting a linear relationship . Since underlying data are only available for container ships, collection of similar data for other ship types is recommended.

4

Fuel quality, S-content and PM emissions

In the previous chapters, emission factors for various fuel types have been presented. These emission factors are expected to approach the emission for a certain fuel type, based on average fuel type composition. However, especially the composition of Heavy Fuel Oil is variable, which has a distinct influence on PM emissions. In this chapter, the most important varying properties of HFO, sulphur content and ash content are discussed in relation to PM emissions. High S content and high ash content are synonymous with poor fuel quality, as these properties do not improve the energy content of the fuel and can lead to substantial damage of the engines through corrosion, wear and fouling.

4.1 Sulphur content

One of the most influential parameters for PM emissions from combustion of Heavy fuel Oil is the sulphur content of the fuel. Many other studies also found a linear relationship between PM emissions and the sulphur content of fuel, in all kinds of combustion processes (e.g., CONCAWE, 1999).

4.1.1 Observations on individual engines

When fuelling a low-speed marine diesel engine (which is the dominant engine type for marine emissions) with HFO, PM emissions were three times higher than when fuelled with MDO (Kasper *et al.*, 2007) (Table 4.1). PM emissions depend on the load percentage of CMCR (Power setting of the engine), this can be explained by the less efficient fuel combustion at low power settings, which increase the emission of incomplete combusted fuel particles. However, independent of the percentage of CMCR, the PM emissions were highly correlated with the S content; a three times higher S content resulted in close to three times higher PM emissions (Table 4.1).

The recalculated data, presented in Table 4.2, confirmed that fuel S had a profound impact on PM emissions. Emission factors measured from engines operated at high-S fuels were about double those of low-S fuels. However, although the relationship between S content and PM emissions pointed consistently in the same direction, the exact relationship varied; for example, from three times more S resulting in three times more PM (Table 4.3) to six times more S resulting in two times more PM (Table 4.2). This is not surprising as these are individual measurements. A much wider coverage of engine types and S ranges would be necessary to generate a more exact general relationship.

Another important observation from the data by Fridell *et al.* (2008) was the relationship between fuel S content and the fraction of PM_{10} in total PM (Table 19). It seemed that high-S fuels cause the emission of more particles in the coarse fraction of PM_{10}. Samples were taken halfway the exhaust funnel at temperatures between 220 and 375 °C, with an average of 300 °C. Main exhaust gas temperatures at the end of the funnel of ships may be lower. This probably will cause condensation of sulphur and organic compounds on particulate matter, causing higher emission factors. This phenomenon was recently investigated by Moldanová *et al.* (2009). In this study, it was shown that the increase in sulphate PM during cooling of the exhaust agreed well with the SO_3 concentration measured in the hot exhaust, indicating that sulphate is formed by SO_2 oxidation, followed by formation and condensation of H_2SO_4.

PM emissions from a low-speed marine diesel engine, operated on two types of fuels **Table 4.1**

Loading\Fuel	HFO (0.6% S)	MDO (0.155% S)
	gram/kWh	
1% CMCR[a)]	1.2	0.4
100% CMCR[a)]	0.7	0.2

[a)] Contracted Maximum Continuous Rating (Power setting of the engine)

Bron: Kasper *et al.*, 2007

Average PM emissions from engines operated at different fuel types **Table 4.2**

Engine type	Fuel	N	Average Fuel S	TSP g/kWh	PM_{10}	$PM_{2.5}$ g/kWh	PM_1 g/kWh	PM_{10}/PM
			(%)	g/kWh				%
Main Engine	HFO	10	2.34	1.54	0.39	0.26	0.21	28%
Auxiliary engine +Main engine	MDO	6	0.41	0.87	0.24	0.18	0.15	43%

4.1.2 Observational data that confirm the relationship between S content and PM emissions

Observational data that confirm the quantitative relationships between sulphur content of bunker fuels and PM in ambient air originating from seagoing vessels, are scarce. Recently, the Netherlands Organisation for Applied Scientific Research (TNO) and the Energy research Centre of the Netherlands (ECN) performed a field measurement campaign, analysing 180 plumes from seagoing vessels near the port of Rotterdam (Duyzer *et al.*, 2007). In this study, a linear relationship was found between PM_1 and $PM_{2.5}$ and the sulphur content of fuels used by the ships. The sulphur content of the fuel was measured by measuring the ratio between sulphur dioxide and carbon dioxide in the ships plumes. Duyzer *et al.* (2007) derived a provisional formula based on their data

$$\text{Emission factor of PM} = 4 + 1.0 \times S\% \text{ (gram PM/kg bunker fuel used).} \qquad [4.1]$$

According to Equation 4.1, the average emission factor for HFO with an average content of 2.7 % S would be 6.7 gram PM per kg HFO. Such a relationship between the fuel sulphur content and PM emissions is quite comparable to the formula for boilers and furnaces in refineries, as proposed by CONCAWE[1].

4.1.3 Implementation of emission factors dependent on fuel S content.

To reduce the environmental impact of shipping, certain areas have been declared 'Sulphur Emission Control Areas', or SECA zones. Examples are the Baltic Sea (since May 2006) and the North Sea (including the English Channel) (since August 2007). No vessels sailing in such a SECA zone can use fuel with a sulphur content of more than 1.5%. The lowering of the S content of HFO from an average 2.7% to less than 1.5%, outlined in the previous sections, must be reflected in the emission factors used to estimate emissions from shipping within a SECA zone. This concept also applies to any other zone or ship category confronted with a regulation concerning the S content of the fuel used.

To come to a more general description of the relation between S content and PM emissions, we assumed an efficiency of 170 gram fuel/kWh. The PM emission factor for HFO with an average S content of 2.7% would then be 1.1 gram PM/kWh. Currently the Dutch PRTR applies a linear interpolation on emission factors of PM, using the S-content of fuels as parameter (Equation 4.2). The formula was first proposed by Van der Tak and Hulskotte (2008). The starting point was the emission factor for MDO, with an assumed average S content of 1%. This emission factor was than modified for the S content, using a linear relationship between PM and S content, as an explanatory variable for the difference in PM emissions from the use of HFO or MDO.

$$PM_{SECA} = PM_{MDO} + (PM_{HFO}\text{-}PM_{MDO}) \text{ X } S\%_{SECA}/\ S\%_{HFO} \qquad [4.2]$$

Where:

PM_{HFO} = 1.2 g/kWh (Original emission factor of PM for HFO)
PM_{MDO} = 0.5 g/kWh (Emission factor of PM for MDO)
$S\%_{SECA}$ = 1.5% (maximum allowed S percentage in fuel used in SECA zone)
$S\%_{HFO}$ = 2.7% S percentage of HFO used outside SECA zone

Application of Equation 4.2. to calculate the PM emission factor for HFO in SECA zones, using the standard values presented above, resulted in EF_PM_{SECA}= 0.5 + [(1.2– 0.5) x (1.5%/2.7%)] = 0.8 g/kWh

Note that if the emission factor of MDO would change, or if the average S content in the SECA zone were to be lower than the maximum allowed value (1.5%), the result from Equation 4.2 would also change.

4.2 Ash content of the fuel

The ash content of fuel oils is not a fixed parameter and can vary considerably. An ash analysis indicated the presence of impurities, such as sand and rust, as well as various elements, such as vanadium, sodium, nickel, aluminium, silicon, and iron. Some elements, such as vanadium and nickel, are bound to the oil hydrocarbons and cannot be removed through normal centrifugal separation. The exhaust gas particulate emissions are a direct function of the ash content in the fuel. The allowed fuel ash content may be limited by engine requirements, or by regulations driven by environmental concerns. An extreme ash content will damage the engine through extreme wear and fouling.

4.2.1 Effect of ash content on PM emissions

According to the ISO 8217 standard for marine fuels, the maximum ash content of HFO is 0.1 or 0.15 per cent by weight (depending on the grade). The average ash content of HFO is estimated at half the allowed maximum in the range of about 0.02 to 0.08% by weight (Haga and Käll, 2005). Most of the fuel ash is thought to be emitted in the form of $PM_{10,}$ as otherwise engines would be fouled (Lyyränen, 2006) causing serious engine damage. Therefore, ash contribution to total PM is expected to amount to 0.3 to 0.9 grams PM per kg HFO used.

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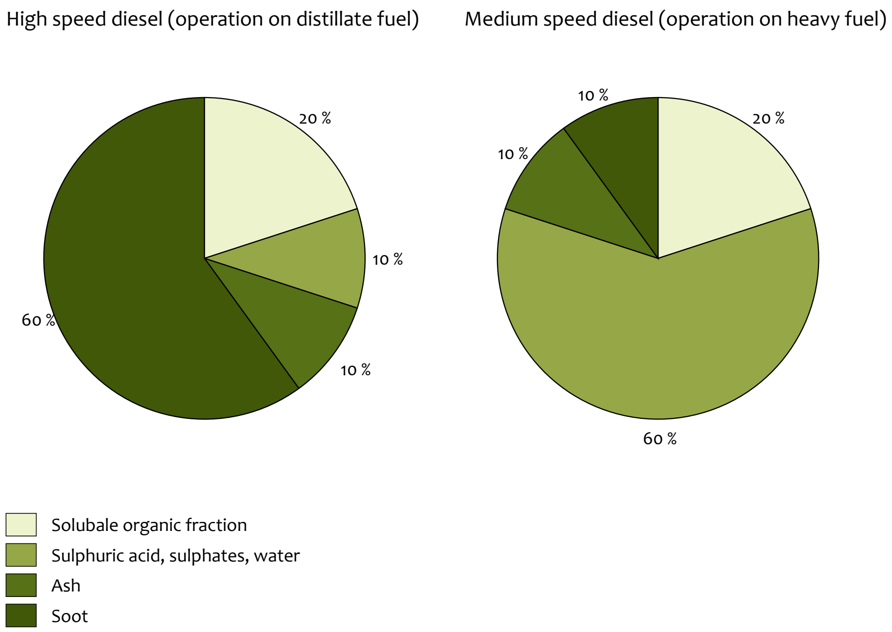
[1] For boilers and furnaces between 10 and 100 MW, CONCAWE has proposed: Emission factor of PM = 24.229 x S% + 8.004 (gram/GJ residual oil used); assuming 41 MJ/kg fuel, this can be translated as: emission factor of PM = 0.33 + 0.99 x S% (gram/GJ residual oil used); the offset of 0.33 is probably representing the ash fraction of PM emissions

Particulate composition of shipping emissions using distillate fuel or HFO **Figure 4.1**



Composition of particulate shipping emissions using distilled fuel or HFO (Hellén, 2006).

4.3 The effect of fuel quality on PM composition and emissions

Assuming emission factors of total PM of between 5 and 10 gram per kilogram fuel, it can be calculated that about 10 per cent of PM emissions from ships fuelled with HFO originate from the ash content of the HFO. The same percentage was estimated as a typical value by Hellén, (2006) in a recent presentation of Wärtsila (Figure 4.1). The typical ash content of MDO is about 0.01 per cent and has relatively the same effect on the total emission of PM (Figure 4.1). However, since PM emission factors of MDO-fuelled engines are about three times lower than for HFO, the absolute effect of ash in MDO is small, compared to HFO.

An indicative understanding of the influence of ash content and S content on PM emissions is presented in Figure 4.2. This somewhat idealised picture shows that S content and ash content influence PM emission independently. At a fixed S content, an increase in ash content causes an increase in PM emissions and vice versa.

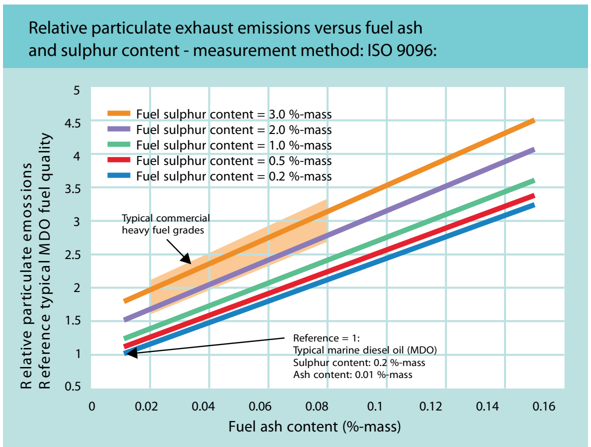
4.4 Effect of Lube oil consumption on PM emissions

Irrespective of the sulphur content of marine fuels, the fuels used in low speed marine engines are usually low quality heavy residual fuels. Most cylinder oils have full lubricating capacity, with respect to detergency and dispersion, irrespective of their BN (Base Number: acid neutralising capacity) which is dictated by the sulphur content of the fuel. In the mid-1950s, cylinder lubricants of high alkalinity became available to neutralise the acids generated by the combustion of high sulphur residual fuels, and engine wear rates became comparable with those of engines fuelled by low sulphur distillate (Spreutels &Vermeire, 2001). Cylinder oil feed rate has an important impact on the emission of particulate matter. When this rate is reduced, PM emissions are also reduced. From data by Aabo (2002) can be concluded that about 10 per cent of lube oil is emitted in the form of PM_{10}. At a typical oil feed rate of about 1 g/kWh (Aabo, 2002), PM emissions caused by lube oil are calculated to be about 0.1 g/kWh. Assuming equal amounts of lube oil consumed in HFO and distillate fuel-powered engines, the emissions from lube oil in HFO-fuelled ships will make up about 10% of the PM. Because PM emissions from distillate fuel-powered ships are about three times lower, the share of lube oil in PM from distillate fuel-powered ships may be as high as 30 per cent of total PM.

4.5 Size fractionation of PM emissions

At the time of the initiation and development of the EMS protocols (2000-2003) the particulate matter metric of interest was PM_{10}. Later, especially driven by the European Commission Clean Air for Europe (CAFE) Programme and the subsequent Communication from the Commission to the Council and the European Parliament of 21 September 2005 - Thematic Strategy on air pollution [COM(2005) 446- Not published in the Official Journal], the interest shifted to include $PM_{2.5}$ next to PM_{10}. However, detailed and measurement-based emission factors for $PM_{2.5}$ for many sources are lacking. Therefore, the Dutch PRTR has taken a pragmatic approach by using expert judgment, documented in Visschedijk et al. (2007) to provide the $PM_{2.5}$ fraction of PM10 emissions by source and fuel type based on the CEPMEIP Programme (Visschedijk et al., 2004). The $PM_{2.5}$ fraction of PM_{10} emission due to HFO and MDO consumption

Influence of fuel sulphur content and ash content on particulate emissions **Figure 4.2**



Influence of fuel sulphur content and ash content on emissions of particulate matter. Bron: Hellén, 2003.

in shipping engines proposed by Visschedijk et al. (2007) is 95%. This implies that 95% of the PM10 emission is expected to be in the $PM_{2.5}$ size range.

Recently published studies suggest that this fraction is an overestimation of the fraction $PM_{2.5}$ in PM_{10} from shipping. The study by Duyzer et al (2007) suggests a fraction as low as 50% (Table 2.10). However, the measuring methodology applied by Duyzer et al. is less accurate for the coarser size fractions of PM (as it is based on counting particle numbers). So, in this study the PM10 are less reliable than the PM_1 or PM2.5 data, and PM10 may be underestimated. The data recently published by Fridell et al. 2008 can also be used to investigate the fraction of $PM_{2.5}$ in PM_{10}. The fraction $PM_{2.5}$ in PM10 for combustion of HFO and MDO is 66% and 75%, respectively (Table 4.2). This is, again, substantially smaller than the current in-use $PM_{2.5}$ fraction of 95%. Another important finding in Table 4.2 is that only a small part of TSP is PM_{10} (23% and 43% for HFO and MDO, respectively). It is highly critical that measurement data of PM from shipping are size fractionated, as we would be comparing apples and oranges. If we are not aware of the exact size of the PM emissions reported, this could lead to large errors. The data by Fridell et al. (2008) are in line with our understanding of the processes: the cleaner the fuel the smaller the PM emission but the larger the fraction of fine particulates. In the case of e.g. a modern diesel or gasoline car, this development is already much further where all exhaust PM is PM10 and >> 95% of this is $PM_{2.5}$.

4.6 Conclusions and Recommendations for further research

The sulphur content of marine fuels has a dominant effect on marine PM emissions. However, S content is not the only fuel property causing additional PM emissions; ash content is also an important parameter. Furthermore, although not strictly a fuel quality parameter, the lube oils needed in marine engines can cause substantial PM emissions. The following issues would need additional investigation:

- PM emissions from shipping are often reported as PM, but not further specified as PM_{10} or $PM_{2.5}$. This may cause some confusion in data interpretation. As is shown in Table 4.2, the fraction PM_{10} of total PM emissions may be less than 50%. Improvement of fuel quality will cause total PM emissions to decline, but the fraction of small particles will increase. Hence, it is not guaranteed and in fact unlikely that all emission reduction improvement will be in the PM_{10} range.
- If the S content of fuels changes any further, adjusted emission factors will be necessary. It is foreseen that the S content of MDO also will decrease, asking for adjustments in the PM emission factor. Moreover, since S content is such a sensitive parameter, the S content of fuels used in SECA areas should also be closely monitored, to see if it approaches the maximum (1.5%) or is substantially lower.
- Potential for further reduction of PM emissions by limiting ash content and/or reducing the need for lube oils, should be investigated.
- Chemical speciation of the emitted PM will become important as it relates not only to the impact on human health, but also to the potential measures for reducing PM emissions. For example, the fraction carbonaceous aerosol requires a different treatment than the ash content related PM emissions, as the latter cannot be burned.
- Size fractionation of PM emissions and related emission factors is important. The review of literature suggests that the Dutch Pollutant Release & Transfer Register (PRTR) currently overestimates the fraction of PM2.5 in shipping PM10 emissions. We suggest that the Dutch PRTR reconsiders the current in-use PM2.5 fraction of PM10. A revision should not be based on one study only but a dedicated action would most likely result in further evidence that the PM2.5 fraction of current shipping PM10 emissions is more likely in the range of 70-80%.

5

Emissions from inland shipping in the Netherlands

Inland shipping (or inland navigation) is a category that may cause confusion in international emission reporting. This is mostly caused by the distinction between national inland shipping and international inland shipping. However, both are a source of emissions within the country. National inland shipping takes place within one country, and the related emissions need to be reported by that country. International inland shipping, however, only takes place within several countries. This makes the energy statistics unsuitable as a basis for activity data – part of the fuel bought in one country can/will be used within another. Therefore, countries need to develop their own estimates on the emissions from inland shipping, based on actual vessel kilometres or the transportation of goods (tonne kilometres). This can be done in various ways, depending on the type of nationally collected data.

Moreover, international inland shipping is by definition an international activity (although part of the emissions take place within specific country borders), and according to, for instance, IPCC and EMEP, countries are not required to report related emissions. The result is that data on inland shipping emissions are less comparable between countries than data on various other emission sources, and it is often not transparent which categories have been included and on what basis.

A separate investigation into the framework of the EMS project (Emission registration and Monitoring of Shipping) was dedicated to establishing emission factors for inland shipping, the results of which were reported by Oonk *et al.* (2003a): For various engine types, average emission factors were derived, related to specific energy use. This information was then used in a protocol developed within the EMS project and described in detail by Hulskotte *et al.* (2003b) (in Dutch) and summarised by Klein *et al.* (2007) (in English). This chapter presents the methodology used in the Netherlands for calculating emissions from inland shipping. In the next chapter, a bottom-up estimation is given of emissions from inland shipping within Europe. The two methodologies do not exactly match, because the methodology used for Europe is more generic as the detailed fleet data recorded for the Netherlands are not available for Europe.

5.1 Calculation of actual emissions from inland shipping in the Netherlands

Inland shipping is transport with vessels over inland waters (canals, rivers) between inland ports, quays and wharfs. The methodology for calculating emissions from inland shipping in the Netherlands has been described by Klein *et al.* (2007). However, they describe the methodology only; specific emission factors and activity data can be found in separate Dutch reports (Hulskotte *et al.*, 2003c; Oonk *et al.*, 2003a), and, for recent years, can be obtained from Statistics Netherlands. Therefore, this report provides a summary of the methodology and key figures, based on the aforementioned data. Klein *et al.* (2007) made a distinction between actual emissions, NEC emissions and IPCC emissions. For our report, we have focused on actual emissions only. For the differences between the emission categories we refer to Klein *et al.* (2007).

The emission calculation method was developed as part of the EMS project, and implemented on behalf of the Ministry of Transport, Public Works and Water Management. The developed protocol has been described by Hulskotte *et al.* (2003c, in Dutch). The emissions are calculated by multiplying the explanatory variables with the emission factors. The calculation was conducted for each base year, in two steps, for each vessel class. In total, 28 vessel classes were distinguished. The calculation of the emissions was based on the energy consumption per vessel class. For all 28 vessel classes, the power demand (kW) was calculated for the various types of inland waterway. During this process, a distinction was made between loaded and unloaded vessels. In addition, the average speed with which the various vessel classes travel on the various waterways was ascertained, per vessel class and depending on the maximum speed allowed on a particular waterway.

Emission factors for diesel engines used in inland shipping (Oonk et al., 2003a) **Table 5.1**

	NO_x	PM	CO	VOC	Fuel use
Engine year of manufacture	**(g/kWh)**				
< 1974	10	0.6	4.5	1.2	235
1975-1979	13	0.6	3.7	0.8	230
1980-1984	15	0.6	3.1	0.7	225
1985-1989	16	0.5	2.6	0.6	220
1990-1994	14	0.4	2.2	0.5	210
1995-2001	11	0.3	1.8	0.4	205
2002 -	8	0.3	1.5	0.3	200

Current emission factors for diesel engines used for inland shipping in the Dutch Pollutant Release & Transfer Register **Table 5.2**

	NO_x	PM_{10}	CO	VOC	Fuel use
Engine construction year	**(g/kWh)**				
1900-1974	10.8	0.6	4.5	1.2	235
1975-1979	10.6	0.6	3.7	0.8	230
1980-1984	10.4	0.6	3.1	0.7	225
1985-1989	10.1	0.5	2.6	0.6	220
1990-1994	10.1	0.4	2.2	0.5	220
1995-2001	9.4	0.3	1.8	0.4	205
2002-2008	9.2	0.3	1.5	0.3	200
2009-2011	6	0.2	1.3	0.2	200

The general, the formula for calculating emissions from inland shipping is:

$$Emissions = Number \times Power \times Time \times Emission\ factor \qquad [5.1]$$

Equation [5.1] was used for calculating the emission of substance (s) in one direction (d) specifically for a certain vessel class (v,c), with or without cargo (b), for a distinct route (r) on Dutch inland waterways. This resulted in a calculation scheme as presented in Textbox 5.1.

5.1.1 Emission factors

The construction year of an engine is an important parameter determining actual emissions due to technology development over time. Oonk et al. (2003a) derived emissions factors depending on the engine construction year and fuel use for shipping engines (Table 5.1). Recently, Duyzer et al. (2007b) made a survey among 146 inland ships and reported higher emission factors for NO_x than reported by Oonk et al. (2003a). Therefore, the NO_x emission factors from diesel engines used in inland shipping have been adjusted. The currently used emission factors in the Dutch Pollutant Release & Transfer Register (PRTR) are presented in Table 5.3. The emission

Textbox 5.1 Scheme to calculate emissions from inland shipping in the Netherlands (source: Klein et al., 2007; Hulskotte et al., 2003c)

Emissions from propulsion engines =
the sum of vessel classes, cargo situations, routes and directions for:
{number of sailings *times*
average power use *times*
average emission factor *times*
length of route *divided by* speed}

or

$$E_{v,c,b,r,s,d} = N_{v,c,b,r,d} \cdot P_{bv,b,r} \cdot L_r/(V_{v,r,d} + V_r) \cdot EF_{v,s} \quad (1)$$

Where:

E v,c,b,r,s,d = Emission per vessel class, (kg) for substance s, this route, this direction, this cargo situation

Nv,c,b,r,d = Number of vessels of this class on this route and in this cargo situation sailing in this direction

Pbv,b,r = Average power of this vessel class on this route (kW) in this cargo situation

EFv,s = Average emission factor for the engines of this vessel class (kg/kWh) for substance s

Lr = Length of the route (km)

Vv,r = Average speed of the vessel of this class on this route (km/h)

Vr = Rate of flow of the water on this route (km/h), (can also be a negative value)

v,c,b,r,s,d = indices for vessel class, aggregated cargo capacity class, cargo situation, route, substance, and direction of travel, respectively

Emission factors for CO_2 and SO_2 **Table 5.3**

	Emission (g/kg fuel)	Reference
CO_2	3173	Vreuls, 2006
SO_2 *(before 2008)*	3.4	Hulskotte *et al*., 2003c
SO_2 *(after 2008)*	2.0	Assuming[a] 1000 ppm S
SO_2 *(after 2011)*	0.02	Assuming[a] 10 ppm S

[a] The limit value is assumed to be the actual content. In reality the S-content (of part) of the fuels may also be below the limit value. Thus it is not excluded that an actual monitoring programme would reveal that the average S-content is half the limit value but such data are currently not available.

Average emission factors for diesel engines used in inland shipping (g/kWh) **Table 5.4**

Substance\year	1990	1995	2000	2005	2010
NO_x	10.5	10.3	10.1	9.8	9.4
PM	0.6	0.5	0.5	0.4	0.4
CO	3.5	3.1	2.7	2.3	2.0
VOC	0.8	0.7	0.6	0.5	0.4
SO_2	0.8	0.8	0.7	0.7	0.004
CO_2	722	714	695	677	662

factors for NO_x and PM_{10} are reduced for engines built from 2009 onwards. This is to accommodate the new emission guideline (CCR II) which results in ~ 30% lower emissions of NO_x and PM10. However, it is possible that in practice CCR-II was implemented earlier (e.g. from 2007 or 2008 onwards). Dutch PRTR should verify this entrance date and if needed adjust the values in Table 5.2.

Originally, in the EMS model, the ages of engines of inland vessels, per vessel class, were derived from the IVS register of inland vessel. However, later it appeared that the years of manufacture of the engines in this IVS register were not accurate, because this register was not consistently updated (Duyzer *et al.*, 2007b). Therefore, replacement of vessel engines by newer versions was simulated by a separate module, which was developed in 2007, within the framework of the EMMOSS modelling tool for Flanders (Vanherle *et al.*, 2007). In 2008, this module was also introduced in the EMS modelling system. This module is used for calculating average annual emission factors, as a linear combination of emission factors per group, for year of manufacture. From the survey held among 146 inland vessels (Duyzer *et al.*, 2007b), it appeared that the average engine age was 9 years. This quantitative result was inserted in the newly added module that simulates engine replacement. Table 5.4 shows the results from the module which calculates fleet average emission factors for a number of past and future years.

5.2 Auxiliary engines

Based on a survey among 109 vessels Hulskotte *et al.* (2003c) reported that the fuel use of auxiliary engines in inland shipping is ~ 13% of the fuel used by the main engine. Since the emission of the main engine is known and reported, the (missing) emission from the use of auxiliary engines can be approximated by assuming them equal to 13% of the main engine emissions. Although, emissions from auxiliary engines were reported separately to maintain transparency about emission sources, it should be realized that they are directly linked to emissions from main engines through this estimation methodology.

5.3 Activity data

The combination of the number of vessels, their power and their speed is the explanatory variable for emissions. The unit of the explanatory variable for emissions is ‘kWh’, it expresses the energy use per vessel class.

The energy use for 28 different vessel classes distinguished in the calculation scheme (Textbox 5.1) was as accurately estimated as feasible for the year 2003, by combining available reported data for canals with estimations for rivers, as the latter of which is rather poorly documented. The ship categories for 2003 are linked to inland shipping statistics, as available from Statistics Netherlands (www.cbs.nl) through a specific conversion model developed by Hulskotte *et al.* (2003c). The conversion model uses vessel kilometres, distinguishes eight groups of vessel load capacity (as discerned by Statistics Netherlands), and uses data on loaded and unloaded vessels as input for annual calculations. The emissions for the year 2003 were recalculated with average engine emission factors for the year of study, subsequently divided by the number of vessel kilometres in each load capacity group for the year 2003. This resulted in emission factors per distance, for the year of study, for each of the eight load capacity groups. In Tables 5.5 and 5.6, the derived emission factors are shown for 2005, which are to be used in combination with currently available activity data.

Subsequently, these emission factors were multiplied by the vessel kilometres in the calculation year and divided in vessel load capacity groups. The underlying assumption was that no important shifts in vessel kilometres over different water types had occurred and that there had been no important shifts in vessel classes within the load capacity groups. Since there is an increasing amount of larger ships on the main

Average emission factors per distance for fully loaded ships, for 2005,(kg/kilometre) Table 5.5

Substance	>=20 tonnage < 250	>= 250 tonnage < 400	>= 400 tonnage < 650	>= 650 tonnage < 1000	>=1000 tonnage < 1500	>=1500 tonnage < 2000	>=2000 tonnage < 3000	tonnage >=3000
PM	0.005	0.005	0.008	0.011	0.016	0.019	0.024	0.034
CO_2	8.912	7.684	13.464	18.168	27.039	32.445	40.112	57.052
CO	0.030	0.026	0.046	0.062	0.092	0.110	0.137	0.194
VOS	0.007	0.006	0.010	0.014	0.021	0.025	0.031	0.044
NO_2	0.129	0.111	0.195	0.263	0.392	0.470	0.581	0.826
SO_2	0.010	0.008	0.014	0.019	0.029	0.035	0.043	0.061

Average emission factors per distance for unloaded ships, for 2005 (kg/kilometre) Table 5.6

Substance	>=20 tonnage < 250	>= 250 tonnage < 400	>= 400 tonnage < 650	>= 650 tonnage < 1000	>=1000 tonnage < 1500	>=1500 tonnage < 2000	>=2000 tonnage < 3000	tonnage >=3000
PM	0.003	0.003	0.005	0.007	0.010	0.012	0.014	0.017
CO_2	5.635	5.253	8.500	11.683	16.899	20.838	23.987	28.747
CO	0.019	0.018	0.029	0.040	0.058	0.071	0.082	0.098
VOS	0.004	0.004	0.007	0.009	0.013	0.016	0.019	0.022
NO_2	0.082	0.076	0.123	0.169	0.245	0.302	0.347	0.416
SO_2	0.006	0.006	0.009	0.013	0.018	0.022	0.026	0.031

Emissions from inland shipping in the Netherlands, for the base years 1995, 2000, 2005 Table 5.7

Year	Transport	Vessel km	Engine	CO_2	PM_{10}	NO_x	CO	VOS	SO_2
	(10^9 ton.km)	(10^6 km)	(kton)						
1995	35.5	61.5	Main	1402	1.0	20.4	6.0	1.4	1.5
			Auxiliary	210	0.2	3.0	0.9	0.2	0.2
2000	41.3	61.9	Main	1563	1.0	22.6	6.0	1.4	1.7
			Auxiliary	234	0.2	3.4	0.9	0.2	0.3
2005	43.6	58.1	Main	1490	0.9	21.6	5.0	1.2	1.6
			Auxiliary	223	0.1	3.2	0.8	0.2	0.2

waterways, this assumption is most likely not valid. However, better data are not available.

5.4 Emissions from inland shipping, as calculated according to Dutch methodology

Table 5.7 presents the emissions for inland shipping in Dutch territorial waters over three years, calculated according to the Dutch methodology, as was outlined above.

Table 5.7 illustrates that transport expressed in tonne kilometre (tkm[1]) has increased by 20% since 1995, while vessel kilometres have stayed almost constant or even have decreased. This clearly points, on average, to growing vessel sizes. As larger vessels have a significantly better fuel economy, compared to smaller vessels, CO_2 emissions only increased by about 7% since 1995. The emissions of other substances, such as NO_x, increased even less (around 6%), indicating an impact from fleet engine renewal.

5.5 Discussion and recommendations

The EMS modelling system for inland shipping was developed to calculate emissions from figures about inland shipping traffic intensities (i.e. exact data on the combination of vessel class and a particular inland waterway). When the EMS system was designed in 2003, such data were not readily available, but was expected to be made available soon. However, up to today (2010), these data are still not available. The consequence has been that provisional indirect derived data, that were used to make a first approximation are still being used instead of (the intended) real traffic data. Therefore, the emission data produced by the EMS model, in a sense, are still to be considered provisional data. This situation is undesirable since important international reporting is performed using these data, such as the reporting of greenhouse gases under the Kyoto protocol.

One of the uncertain aspects mentioned in the EMS-protocol are the emission factors of PM10 of inland ships. A measuring campaign has been executed to verify the emission factors used in EMS (Duyzer et al., 2007b). As a result of this measuring campaign the emission factors of NO_x have been adjusted (see section 5.1.1). Unfortunately, the field method of measuring emission factors on the shore as employed by Duyzer et al. (2007b) was not sensitive enough

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[1] Tonne-kilometres (tkm) are the aggregate product of the quantity of goods multiplied by the distances over which they have been conveyed. Tkm is the primary physical measure of freight transport output

to draw firm conclusions about emission factors of PM_{10}. However, the data suggested emission factors that seemed to be 30 percent higher than emission factors derived for the EMS system. This clearly warrants further investigation. Consequently, uncertainty of emission factors of PM_{10} of inland ships is still a major point of concern. Representative on board measurements of emission factors of PM_{10} for a representative set of ships e.g. with a portable emission monitoring system (PEMS) is highly recommended.

The Dutch Pollutant Release & Transfer Register (PRTR) is a high quality emission register and new developments are absorbed as they become available. However, because of this constant adjustment, documentation may lack behind and transparency is not optimal. It is recommended to aim for updating methodology descriptions for major sources more regularly. This could of course be limited to documenting changes as compared to a publicly available previous report. This may also stimulate the input from other experts. In the case of the present report the suggestion was done that CCR-II emission regulation was implemented earlier than assumed. This should be verified and adjusted in the PRTR.

From 2010 onwards, the sulphur content of fuels used in inland shipping will be reduced. Furthermore, from 2012 onwards, engines of vessels navigating the Rhine will have to comply with new regulation proposed by the CNR (central commission for navigation on the Rhine). Potentially, these two developments will reduce PM emissions from inland shipping, considerably. A current on-board survey to document the starting situation, with a follow up in, for instance, 2014, would be very useful for assessing the impact of policies and to underpin the emission estimates used in reporting.

6

Emissions from inland shipping in Europe

Inland waterway transport plays an important role in the transportation of goods within Europe. In the EU27, navigable waterways stretching over 43,000 kilometres connect hundreds of cities and industrial regions. In 2007, 141 billion tonne-kilometres of freight were transported over inland waterways in the EU27 (EC, 2009). While 18 out of 25 EU Member States have inland waterways, 10 of which with an interconnected waterway network, the modal share of river transport accounts for only 3.3% of the total inland transport within the EU27

6.1 Emissions from inland shipping in Europe

Emissions from inland shipping are usually reported under the source sector non-road transport. The national reporting of emissions from inland shipping is rather obscured because a part of inland shipping can be international navigation, which does not have to be reported to, for example, EMEP or UNFCC. A (detailed) description of what part of the total emissions from inland shipping is included in the reporting is usually not required and not present. Hence, it is unclear what countries have exactly selected as their share of inland shipping emissions, and on what basis. This does not necessarily mean that the figures are incorrect; they are simply not transparent and prohibit a proper comparison between countries.

To address the above issues, we made an independent bottom-up calculation for inland shipping per country, following a general methodology. The methodology is by definition less sophisticated than that used by some countries, because it lacks the detailed data that may be available to country experts. However, it is comparable and transparent. This allows inter-country comparisons and gives an overview of total emissions from inland shipping. To more accurately distribute these emissions, spatially, a new map with inland waterways and coastal shipping was made.

6.2 Activity data

Energy statistics data for inland shipping cannot be used as activity data to accurately calculate emissions that occur within a country, because of the mixing of national and international inland shipping. Fuel bought in one country may be used in another. The best activity data for inland navigation are data on tonnes per kilometre (tkm) transported. Such data are reported by, for instance, the EU Market Observation for inland shipping 2006 (EC, 2007a, b) (Table 6.1). It is possible that for a particular country more detailed data than tkm alone are available (e.g. detailed fleet engine compositions), but this will not be the case for most countries. To keep a transparent and comparable approach, the activity data of choice are tonne kilometres (tkm). For Italy, the United Kingdom and Finland, the data in Table 6.1 have been completed using Eurostat/DGtren data for the year 2000. These data were confirmed to be consistent, based on the available data for the United Kingdom, from a report on UK waterborne freight (Table 6.2), which indicated 0.2 billion tkm for total inland waters, equalling the 200 million tkm for this country as presented in Table 6.1, based on Eurostat data. Data on the Russian Federation and the Ukraine were taken from the EFIN (2004).

Table 6.1 Transport services for inland waterway transport, in millions of tonne kms for 2005

6.3 Emission factors

Emission factors for fuel combustion in inland shipping, per unit of fuel consumed, have been collected from various sources (Table 6.3). The emission factors needed to be converted, because we chose to use tonne kilometres (tkm) as activity data. To recalculate emission factors from unit of fuel consumption to emission per tkm, a data set from the Netherlands was used. The Dutch total emissions from inland shipping (www.emissieregistratie.nl/) were divided by the national tonne kilometres (Table 6.1), resulting in emission factors per tkm (Table 6.4). Based on the CO_2 data (Table 6.4 and Rohács and Simongáti (2007)) we estimated the fuel use per tkm. This was done assuming 3.17 kg CO_2 was emitted per kg diesel, resulting in 10 to 12.5 tonne MD per million tkm (Table 6.5). Rohács and Simongáti (2007) reported an assumed fuel use per tkm, although the origin of their figure is not entirely clear. The amount of fuel used per tkm, based on a recalculation of Dutch data, is higher than for the average European fleet, as derived from Rohács and Simongáti (2007). However, those were

Transport services for inland waterway transport, in millions of tonne kms for 2005 **Table 6.1**

country	split	Inland transport [1] (10^6 tkm)
Austria	national	37
Austria	international	1715
Belgium	national	3067
Belgium	international	5651
Bulgaria	national	54
Bulgaria	international	701
Croatia	national	39
Croatia	international	79
Czech Rep.	national	60
Czech Rep.	international	33
Finland[2]		460
France	national	4640
France	international	3217
Germany	national	11695
Germany	international	52400
Hungary	national	5
Hungary	international	2105
Italy[2]		200
Luxembourg	national	0
Luxembourg	international	342
Netherlands	national	10519
Netherlands	international	32548
Poland	national	640
Poland	international	0
Romania	national	2641
Romania	international	2505
Serbia	national	454
Serbia	international	1033
Slovakia	national	3
Slovakia	international	737
Switzerland	national	1
Switzerland	international	45
UK[2]		200
Europe	Total	137828
Russia[3]		71000
Ukraine[3]		13000

[1] year 2005 based on EC (2007b), unless otherwise indicated.
[2] no data available from EC 2007b, data taken from Eurostat for the year 2000.
[3] data for the year 2000, source UNECE cited in EFIN (2004)

rather generic estimates and the estimates from these independent approximations are in line (Table 6.5). The most remarkable difference between the studies is the variation in PM_{10} emission factors (Table 6.3). CO emission factors also vary substantially, but are of less interest to us. Because of the considerable difference in PM_{10} emission factors, the difference between PM_{10} emissions calculated by using different emission factors is large; amounting for Europe to around 2200 tonnes PM_{10}/year. However, as Dutch experts confirmed, engines installed on barges and vessels transporting goods within the Netherlands are relatively new, and there was a clear agreement that emission factors of 40 to 50 kg PM_{10} per 10^6 tkm do not apply to the current Dutch situation. Therefore, we interpreted this as being the result from more recent new engine installations on barges and vessels transporting goods over the Rhine, compared to the results from the average European fleet. Hence, we made a rather arbitrary decision to apply the average European emission factors to all countries, except the Netherlands and Germany. The calculated emissions from shipping on inland waterways are presented in Table 6.6.

A remarkable feature from Table 6.5 is that the implied fuel use and CO_2 emission factor per tkm is higher for the Netherlands than for the average for the EU. The most likely cause is that the sum of tkm as activity value, led to an underestimation of emissions, because empty vessels are not accounted for. In the Dutch methodology, unloaded vessels were also included, and based on the Dutch data these are responsible for around 25% of the fuel use and emissions. This fits the discrepancy observed in Table 6.5 surprisingly well, which is very close to 25% for both fuel use and CO_2. For the other substances, this is not the case, as the assumed emission factors differ substantially, due to year of engine manufacture and the installed technologies. Fuel use and CO_2 emissions are rather independent of the technologies. The notion that emissions estimated in Table 6.6 may have been

Waterborne freight in the United Kingdom (DTLR, 1999)

Table 6.2

	Goods moved (billion tonne-kilometres)		Goods lifted (million tonnes)	
	1989	1999	1989	1999
Seagoing traffic				
At sea				
Coastwise	40.4	40.6	64	73
One-port	15.1	16.2	49	33
Total at sea	55.5	56.8		
Inland waters				
Coastwise	0.3	0.2	12	9
One-port	0.5	0.3	13	7
Foreign	1.3	1.3	36	34
Total inland waters	2.1	1.8		
Total seagoing	57.6	58.6	*149	*140
Internal on inland waters	0.3	0.2	7	4
Total on inland waters	2.4	1.9	68	54
Total waterborne	57.9	58.7	*156	*145

*Tonnages of coastwise traffic and one-port traffic on inland waters are counted both “at sea”and under “inland waters; these tonnages are therefore included once only in the total. Tonne-kilometres “at sea” and on “inland waters” are additive.

Emission factors for NO$_x$, VOC and PM$_{10}$ used for inland shipping

Table 6.3

Source/ representation	NO$_x$	VOC	PM$_{10}$
	g/kg marine diesel		
average EU situation (Rohács and Simongáti, 2007)	47.02	2.39	3.19
Netherlands (CBS/TNO)	45.90	2.47	1.87
Rains (IIASA)	61.78	8.32	4.89
Rains (IIASA) v2 [1)]	50.75	6.83	4.01

[1)] corrected for fuel estimate difference

Emission factors for inland shipping per million tonne kilometres

Table 6.4

Substance	Emission factor (kg/10^6 tkm)
PM$_{10}$	23
NH$_3$	0.13
N$_2$O	1.0
CO$_2$	39770
CO	135
VOC	31
NO$_x$	576
SO$_2$	43

recalculated from Dutch data by Hulskotte *et al.* (2003c)

Fuel consumption and emission factors per tkm for CO2, NOx, VOC, PM10 and CO

Table 6.5

emission factors	fuel	CO$_2$	No$_x$	VOC	PM$_{10}$	CO	reference
	kg/ 10^6 tkm						
Average EU	10200	30900	590	30	40	30	Rohács and Simongáti, 2007
NL, DLD, BEL	12550	39770	580	31	23	135	CBS/TNO 2007
RAINS			637	86	50		RAINS PM module (Klimont *et al.*, 2002)

underestimated by 25%, because empty vessels were not accounted for, warrants further study.

6.4 Spatial Distribution of emissions from inland shipping

For inland shipping, a map was produced, using the results from the EU TRANS-TOOLS project (TNO, 2008). The spatial representation of the inland waterways in the TRANS-TOOLS maps is not very accurate, as the project focuses on traffic flows, not on exact locations. Inland waterways are

Estimated emissions of VOC, NOx, PM10, CO and SO2 from inland shipping in 2005 **Table 6.6**

Country	**Emission**[1)] **(tonne/yr)**				
	VOC	**NO$_x$**	**PM$_{10}$**	**CO**	**SO$_2$**[2)]
Austria	52.6	1034.0	70.1	52.6	74.7
Belarus	152	880	89		94
Belgium	262	5144	349	262	372
Bulgaria	23	445	30	23	32
Croatia	3.6	70	4.7	3.6	5.1
Czech Rep.	2.8	55	3.7	2.8	4.0
Denmark					
Estonia					
Finland	14	271	18	14	
France	236	4636	314	236	335
Germany	1987	37175	1501	8653	2732
Greece					
Hungary	63	1245	84	63	90
Ireland					
Italy	6.0	118	8.0	6.0	
Latvia					
Lithuania	30	186	18		19
Luxembourg	10	202	14	10	
Netherlands	1335	24979	1009	5814	15
Norway					1836
Poland	19	377	26	19	27
Portugal					
Romania	154	3036	206	154	219
Russian Federation	2130	41890	2840	2130	3053
Serbia	45	877	59	45	63
Slovakia.	22	437	30	22	32
Spain					
Sweden					
Switzerland	1.4	27	1.9	1.4	2.0
Turkey					
Ukraine	399	7847	532	399	572
United Kingdom	6.0	118	8.0	6.0	
Total	6953	131050	7215	17916	9576

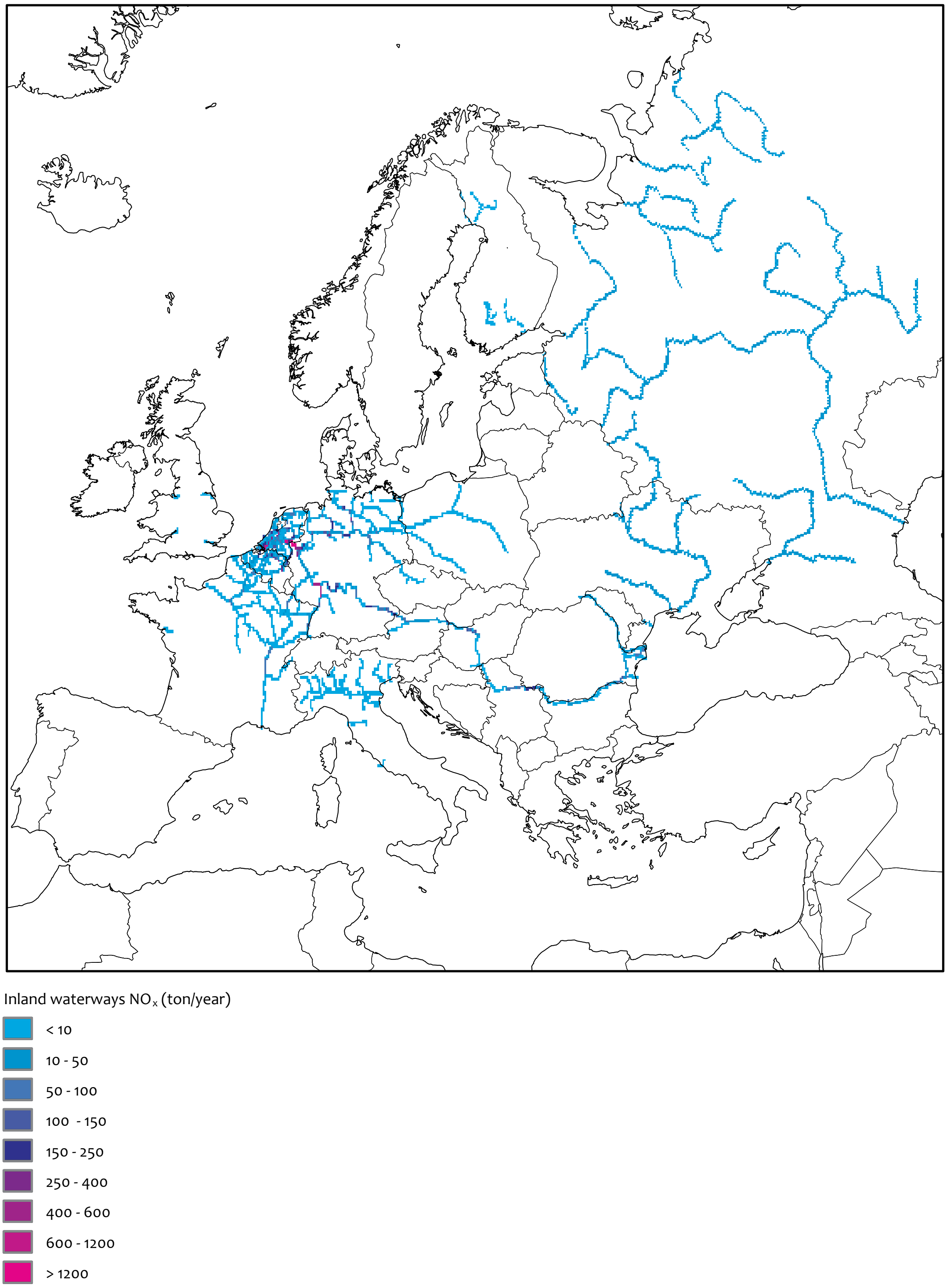
[1)] Calculated with an average emission factor except for NL, DLD where a Dutch EF was used (Table 6.3).
[2)] For SO$_2$, only a Dutch emission factor was available, as we had no fuel type specification. SO$_2$. therefore, may have been underestimated.

represented by lines that intersect at nodes. However, the value of the TRANS-TOOLS maps is that the line segments have a traffic intensity which allows a much better spatial allocation of emissions on a national scale. Not all countries of our domain were covered by the TRANS-TOOLS project. For the remaining countries, we used a simplified version of the ESRI major waterways map (http://www.esri.com/) or manually added a line segment to the map, depicting the location of the waterway, based on geographic maps. The map used for emission distribution from inland shipping is shown in Figure 6.1, with NO$_x$ emission grids as an example. Figure 6.2 is the zoom version of the same map, to show that intensity differences indeed occur on certain inland waterways. In the near future, a foreseeable improvement will be the transfer of the intensities from the TRANS-TOOLS map to a better geographical representation of the major rivers.

6.5 Conclusions

Inland shipping is an emission category that may be highly relevant for air quality in the vicinity of busy navigation routes or ports. Therefore, a more in-depth assessment, transparent calculations and accurate allocation of emissions are important. The emissions estimated here, and their spatial allocation, will improve the accuracy of model-prediced air quality in the vicinity of busy navigation routes or ports . Moreover, the methodology can be used to further improve the emission estimates by using better national data when they become available. The activity data that are available for inland shipping are related to economic activity, in tonne kilometres (tkm). It is possible that the estimated emissions, based on these activity data, underestimate the total emissions from inland shipping, because empty ships are not accounted for. An indicative estimate to include the empty vessels, would increase the total emissions with 20 to 25%. Emissions from both national and international shipping on inland waterways are important, and should both be reported

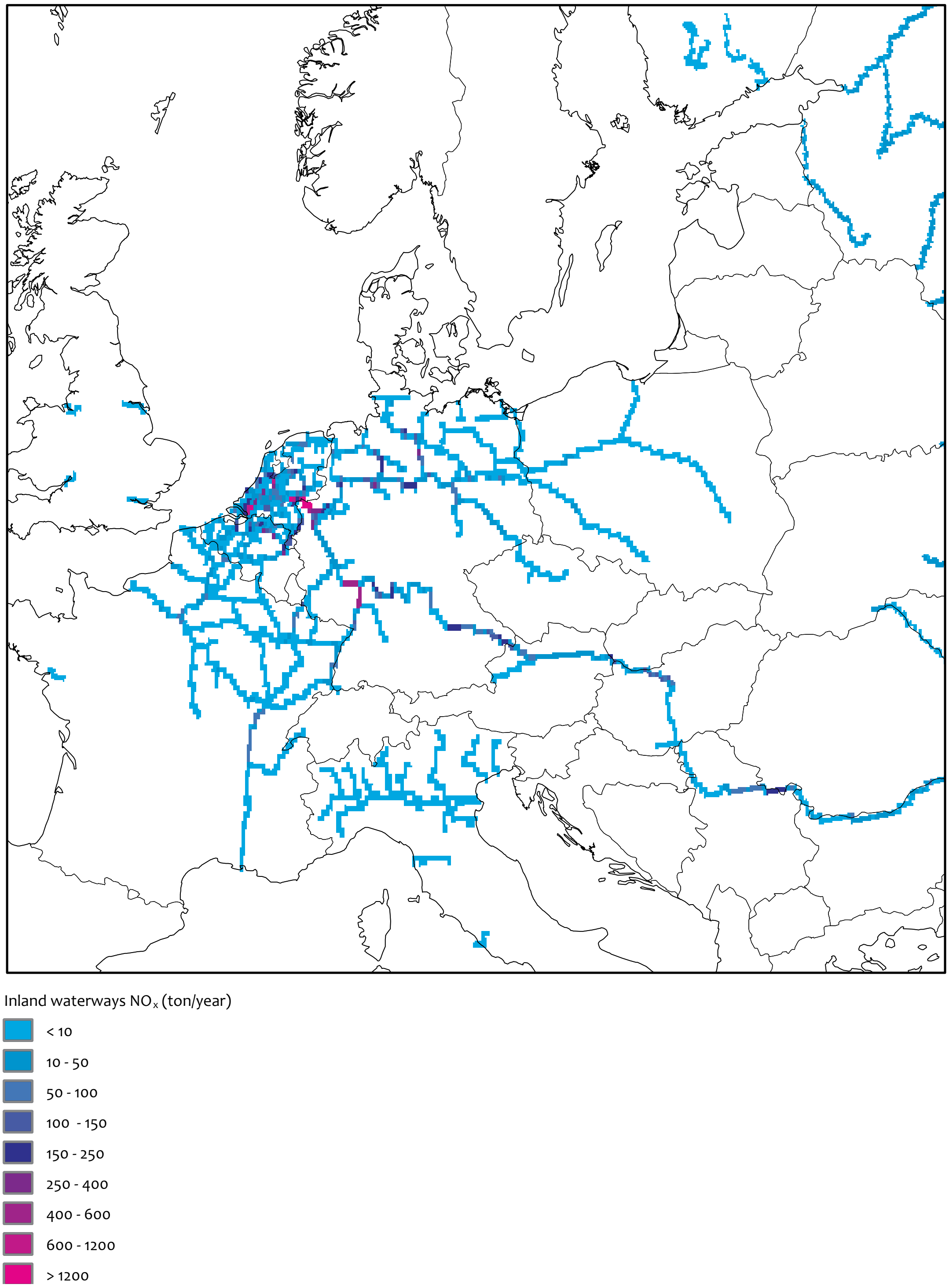
NO_x emissions from shipping on inland waterways based on-bottom-up estimate **Figure 6.1**



NO_x emissions from inland shipping, based on a bottom-up estimate (tkm approach; Table 6.6)

– even though for certain reporting obligations international traffic may be excluded.

NO_x emissions from shipping on inland waterways based on-bottom-up estimate **Figure 6.2**



NO_x emissions from inland shipping based on a bottom-up estimate (tkm approach; Table 6.6 zoom on north-western Europe.

7

New developments and research needs

7.1 Measurements and monitoring

This section presents two examples of new developments in estimating shipping emissions. These examples show that, in the near future, much more detailed data on shipping emissions will become available, at least for European waters. However, it mostly addresses the emission from sailing and/or manoeuvring ships. For ships in berth, additional information is required as described in Chapter 3. For example, a ship will not necessarily always have the same number of reefer containers on board. The cooling of these containers may dominate emissions while in berth and this information is not available from general information on particular ship types.

7.1.1 Direct measurements of emissions of PM and NO_x from seagoing vessels

Duyzer *et al.* (2007) applied a downwind plume method to quantify shipping emissions on Dutch waters. For this method, monitoring equipment is installed along the waterside, downwind from the passing ships. In the ideal case, the wind direction is almost perpendicular to the waterway. When a ship passes, its exhaust gas plume traverses the stationary monitoring equipment (equivalent to traversing the plume of a stationary source with mobile monitoring equipment) and the concentrations of the emitted air pollutants will temporary be increased above the background concentrations. This results in a concentration–time profile, equivalent to the plume profile. From the concentrations of, for example, NO_x, SO_2 and PM in the plume, rated against the simultaneously measured CO_2 concentration (CO_2 used as tracer of fuel consumption and power load of the ship), the emissions are calculated from the ratio between concentrations of pollutants and CO_2 concentrations. For a detailed description of the approach and validation we refer to Duyzer *et al.* (2007). From using a combination of different monitors, Duyzer *et al.* (2007) concluded that they were able to estimate emissions of $PM_{2.5}$ and PM_{10}, with a systematic error of between 20 and 50%. The systematic errors in measurements of NO_x emissions appeared quite low, as became clear from an intercomparison study carried out in the port of Rotterdam (Duyzer *et al.*, 2007). The generalised results from the study are presented in Table 7.1 and compared to the emission factors used in the Dutch EMS methodology.

Duyzer *et al.* (2007b) quantified the impact of the results of their study on emission estimates for PM and NO_x from shipping in the Netherlands. They concluded that estimated

Emission factors of PM and NO_x in g/kg fuel derived from Duyzer *et al.* (2007) and EMS **Table 7.1**

	Duyzer *et al.* (2007)				**EMS**		
	PM_1	**$PM_{2.5}$**	**PM_{10}**	**NOx 1)**		**PM_{10}**	**NO_x 2)**
Four strokeengines							
S<1%	0.8	1.3	2.5	39-63	MDO	1.6 (1.6-2.6)	59 (42-82)
S>1%	1.7	2.9	6.0		HFO	3.9 (3.6-4.2)	
Two-stroke engines							
S<1%	1.1	1.7	3.3	39-70	MDO	1.8 (1.8-2.8)	88 (76-111)
S>1%	3.0	3.9	6.5		HFO	8.8 (8.1-9.7)	

1) Averages observed in this study

2) Emission factor used in EMS, for the period between 1995 and 2000. Emission factors for different years between 1974 and 2000 and thereafter are given between brackets.

NO_x emissions remained unchanged. However, application of the derived PM emission factors to estimates on emissions from shipping for the Dutch continental shelf, ships in berth in Dutch territorial waters, and ships sailing on Dutch inland waters, resulted in 20 to 25% lower emissions for all categories. This was so, because emissions from two-stroke engines using HFO were dominant and for this particular category Duyzer et al. (2007b) reported a lower emission factor than the EMS methodology (Table 7.1). However, as indicated by Duyzer *et al.*, the range in estimated emission factors was quite large and additional measurements are needed to fine-tune the methodology.

7.1.2 Estimating shipping emissions using Automatic Identification System (AIS) messages

In order to minimise the probability of groundings and collisions of ships, the use of a system called AIS (Automatic Identification System) was made compulsory by the International Maritime Organization for all ships over 300 gross tonnage, from 1 January 2005, as stated in the SOLAS agreement (IMO Safety Of Life At Sea agreement). The AIS system automatically reports position and speed of a ship every few seconds. Jalkanen *et al.* (2009) recently presented an automated system for evaluation of exhaust emissions from marine traffic, that is based on the data contained in AIS messages. Potentially, this system can be applied to any sea region in the world, provided that AIS data from that region is available. The exhaust emissions from shipping are calculated in a new, ship-specific way, where the location and speed of each vessel is determined by the GPS coordinates sent in AIS messages. These signals allow very accurate positioning of vessels and their emissions. When combined with knowledge on each ship's engine and possible abatement techniques, a realistic estimation of fuel consumption and emissions can be made. Using this approach, Jalkanen *et al.* (2009) reported annual emission levels of NO_x, SO_x and CO_2 for the Baltic Sea area. During the year 2007, marine traffic on the Baltic Sea emitted roughly 400 kilotonnes of NO_x and 138 kilotonnes of SO_x. Carbon dioxide emissions from this traffic was calculated as 19.3 Mt. Since the AIS system identifies each individual ship, the emissions can be categorised by flag state and ship type. Another advantage of this methodology is that the processing of GPS coordinates in the AIS messages generates ship tracks which can be used for information on the spatial distribution of the estimated emissions. Recently, the MARIN and TNO institutes reported results from a pilot project to estimate shipping emissions in the port of Rotterdam, using the AIS (Tak and Hulskotte, 2008). Their main conclusion was that ship movements within the port of Rotterdam could be traced very accurately, allowing for calculation of emissions on a much finer geographical grid than could be done previously. Their pilot project confirmed that the use of AIS data was a significant improvement of emission estimates on shipping. Overall estimated emissions were quite similar to those from using the EMS methodology, but the emission location was quite different. Higher emission levels were calculated for the secluded areas of the port and lower emission levels for the near-city areas. Furthermore, including ship speed in the emission calculation, probably substantially improved the emission calculations for ships while cruising and manoeuvring. Emissions from main engines showed to be lower than in previous calculations. Emissions from auxiliary engines were estimated to be higher, however, the authors expressed serious concern about the weak knowledge on emissions from auxiliary engines concerning the type of fuel used, the power installed and the fraction of power actually used by auxiliary engines of ships approaching the quay. Times spent in berth were adapted by using AIS data, which delivered more accurate (higher) emissions for these circumstances.

7.2 Particle number emissions and climate relevance of shipping emissions

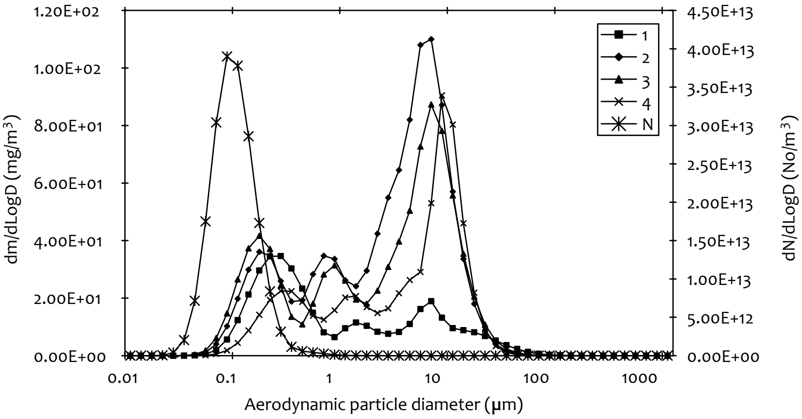
Currently, the emission inventories for the Netherlands focus on the priority pollutants for air quality, such as NO_x, SO_2 and PM. In the near future, both chemical speciation of PM and climate relevant properties of shipping emissions will become more important. The chemical speciation of PM (e.g., soot or elemental carbon (EC) content) may control the relative health relevance of shipping emissions compared to other PM sources. This is likely to gain more attention in the near future due to its impact on the population in coastal areas and harbour cities (Corbett et al., 2007). Furthermore, the climatic relevant properties of shipping aerosols have attracted more attention (e.g. Lack *et al.*, 2009; Fridell *et al.,* 2008). Next to particle mass (PM), particle number (PN) emissions are relevant, as they have the potential to act as cloud condensation nuclei (CCN). An example of how PM and PN are related is presented in Figure 7.1. Shown are the mass distributions from four measurements taken for a ship under different conditions, as well as one example of number distribution (data corresponding to curve 2). The peaks correspond to the well-known different modes in the size distribution of particles emitted from a diesel engine. The aerosol composition determines if the aerosol has a net cooling effect or net warming effect. All the above mentioned properties currently gain little attention in the Netherlands, but their importance is expected to grow.

7.3 Research needs and outlook

The review of the Dutch methodology for estimating shipping emissions, as discussed in Chapters 1 to 6, resulted in the identification of a number of research needs, which have been presented below. The points have not been presented in order of importance, as they tackle quite different aspects.

- A further specification in the PM emission factors for different engines and fuel type combinations, in terms of size distribution, particle numbers and chemical speciation is recommended to anticipate the further interest in shipping emission in relation to adverse effects on human health and climate change.
- The (further) development of shipping monitoring tools, such as the Automatic Identification System (AIS), and availability of data generated with these monitoring tools, will allow a better estimation of shipping emissions. A study to validate current estimates using detailed AIS data should be started., This has already been done by Jalkanen *et al.* (2009) for the Baltic Sea, but could also be done for the Dutch continental shelf, and for particular ports. A first tryout was done in Rotterdam (Tak and Hulskotte,

The size distribution from four measurements on ship B **Figure 7.1**



Particulate matter size distributions from four different measurements series on ship B. Curves 1 to 4 show the mass distribution, while curve N shows the number distribution. Source: Fridell et al., 2008.

2008), proving that also for the Netherlands this will result in increased accuracy. A project to use the AIS data for estimating emissions on the Dutch continental shelf has recently been commissioned, and results are expected in 2009/2010. In the near future, AIS data will also be available for inland shipping, allowing for similar progress in accuracy.

- The set of emission factors derived from seagoing vessels sailing the Dutch continental shelf should be updated, since the data set is over 5 years old (2004) and plays a key-role in estimating shipping emissions. Note: a project addressing this issue has recently been commissioned and results are expected in 2009/2010. Therefore, this recommendation is covered
- The energy consumption and fuel use by auxiliary engines of seagoing vessels while moving towards or in ports should be investigated, to enable a more accurate calculation of emissions from ships under these conditions. Thus far, this phenomenon has been neglected in the EMS protocols. The improvement in emission estimation, using AIS data as reported above, does not solve this issue, because the AIS data do not provide information on auxiliary engines.
- A detailed (EU-wide) assessment is needed of how much fuel is used in inland shipping. Since our current estimate was based on freight transport statistics (expressed in tonne kilometres), all travelled kilometres without cargo remain outside of the emission estimation. Our indicative estimate is that empty ships may add about 25% to the total emissions.
- An update of the energy use per vessel class for inland shipping should be made, as the data to calibrate current estimates are derived from a survey held in 2003. This information is over five years ago and may no longer be accurate. Moreover, the EMS modelling system for inland shipping was developed to calculate emissions from bottom-up figures about inland shipping traffic intensity (i.e. exact data on the combination of vessel class and type of waterway). When the EMS system was designed in 2003, such data were not yet readily available, although they were expected to become available in short time. Today (2009), they still are not. The consequence has been that provisional indirect derived data, used to make a first approximation, are still being used instead of (the intended) actual traffic data. Therefore, the emission data produced by the EMS model, in a sense, are still to be considered provisional. This situation is undesirable, since important international reporting is performed using these data, such as the reporting of greenhouse gases under the Kyoto protocol.
- One of the uncertain aspects mentioned in the EMS protocol are the emission factors of PM$_{10}$ for inland shipping. A measuring campaign has been executed to verify the emission factors used in EMS (Duyzer *et al.*, 2007b). As a result of this measuring campaign, the emission factors of NO$_x$ have been adjusted. However, the field method of measuring emission factors on land, as used by Duyzer *et al.* (2007b), was not sensitive enough to draw firm conclusions on emission factors of PM$_{10}$. Nevertheless, measured emission factors seemed to be 30 per cent higher than those derived for the EMS system. This clearly warrants further investigation. On-board measurements for emission factors of PM$_{10}$ to create a representative data set, for example, by using a portable emission monitoring system (PEMS), is highly recommended.
- Chapter 4 presents suggestions to further investigate the role of fuel quality on PM emissions from shipping. The suggestions include 1) investigation of the fraction PM$_{10}$ and PM$_{2.5}$ in total PM emissions from shipping, in relation to fuel type used, 2) the need to adjust average emission factors if the average S content of fuels is changing, 3) investigation of the potential to further reduce PM emission by limiting ash content and/or reducing the amount of lube oils used, and 4) provide chemical speciation of the PM emitted from shipping to better assess health relevance and potential measures.

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Related BOP presentations & publications

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Proper estimation of shipping emissions is essential for an impact assessment of shipping on air quality and health in port cities and coastal regions. In the Netherlands shipping is an important emission source for particulate matter. Therefore, detailed methodologies were developed, since 2000, for estimating emissions on the North Sea, in ports and from inland shipping. This report provides an internationally accessible and transparent summary and description of the methodologies used in the Netherlands Pollutant Release & Transfer Register regarding PM emissions from shipping, including any implemented updates. It describes in more detail the emission factors and activity data that are currently in use to estimate emissions from ships at anchor in ports, and from inland shipping. Subsequently, it presents recommendations for further research and improvement.

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