EMISSIONS 2009: NETHERLANDS CONTINENTAL SHELF, PORT AREAS AND OSPAR REGION II

Final Report

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GLOSSARY OF DEFINITIONS AND ABBREVIATIONS

Substances:

NMVOC	Non-methane volatile organic compounds. Substance number **1237**.
Sulphur dioxide (SO_2)	Gas formed from the combustion of fuels that contain sulphur. Substance number **4001**.
Nitrogen oxides (NOx)	The gases nitrogen monoxide (NO) and nitrogen dioxide (NO_2). NO is predominantly formed in high temperature combustion processes and can subsequently be converted to NO2 in the atmosphere. Substance number **4013**.
Carbon Monoxide (CO)	A highly toxic colourless gas, formed from the combustion of fuel. Particularly harmful to humans. Substance number **4031**.
Carbon Dioxide (CO_2)	Gas formed from the combustion of fuel. Substance number **4032**.
PM	Particulates from marine diesel engines irrespective of fuel type. Substance number **6598**.
PM-MDO	Particulates from marine diesel engines operated with distillate fuel oil. Substance number **6601**.
PM-HFO	Particulates from marine diesel engines operated with residual fuel oil. Substance number **6602**.

Abbreviations:

AIS	Automatic Identification System
CRS	Correction factor Reduce Speed
DCMR	Dienst Centraal Milieubeheer Rijnmond
EMS	Emissieregistratie en Monitoring Scheepvaart (Shipping Emission inventory and Monitoring)
IMO	International Maritime Organization
LLG	Lloyd's List Group (previous LMIU Lloyd's Marine Intelligence Unit)
LMIU	Lloyd's Marine Intelligence Unit
MMSI	Maritime Mobile Service Identity is a unique number to call a ship. The number is added to each AIS message.

MCR	Maximum Continuous Rating is defined as the maximum output (MW) that a generating station is capable of producing continuously under normal conditions over a year
NCS	Netherlands Continental Shelf
nm	nautical mile or sea mile is 1852m
SAMSON	Safety Assessment Model for Shipping and Offshore on the North Sea
TNO	Instituut voor Toegepast Natuurwetenschappelijk Onderzoek.

1 INTRODUCTION

Since 2005 all merchant vessels over 300 Gross Tonnage are equipped with an Automatic Identification System (AIS). These systems transmit information about the ship, its voyage and its current position, speed and course. Static information, such as name, IMO number, ship type, size, destination and draft, is transmitted every six minutes. Dynamic information such as position, speed and course is transmitted every 2 to 10 seconds.

Although meant for improving safety at sea, dynamic AIS information offers great opportunities to gain insight into the spatial use of sea and waterways. Local traffic intensities and densities can, for example, be calculated very precisely. By linking the AIS data with ship databases, additional characteristics about the ship can be used, allowing for calculations of emissions during movements.

In 2008 a pilot study [1] has been performed, commissioned by the Ministry of Transport, Public Works and Water Management, DCMR and the Netherlands Environmental Assessment Agency, (PBL), in which the ship emissions for 2007 were quantified for the port of Rotterdam area. The pilot study was successful. The knowledge about the level and spatial distribution of all emissions was improved, which is used for making policy with respect to emissions.

Subsequently a study, co-financed by the Ministry of Transport and the Netherlands Environmental Assessment Agency, has been performed in which the study area was extended to the Netherlands Continental Shelf (NCS) and the port areas of the Western Scheldt, Rotterdam, Amsterdam and the Ems. The emissions for 2008 in these areas were calculated based on the AIS data of 2008. The calculated emissions for 2008 on the NCS and the traffic database of 2008 of SAMSON were used for estimating the emissions in the OSPAR Region II, a region that covers a much larger sea area.

RIVM has asked MARIN to continue with this work. This report describes the emissions for 2009 for the four port areas, the NCS and the OSPAR Region II. This is the first time that the emissions of two subsequent years are calculated based on AIS for all these regions, so that these results can be compared with each other. This report gives the results of the emission calculations for 2009 and the changes in the emissions compared to those of 2008. Other deliveries of this study are the databases with all emissions on a grid size of 500 x 500 m for the port areas and 5000 x 5000 m for the NCS and the OSPAR Region II sea area.

Because fishing vessels are not obliged to have an AIS transponder, it was agreed not to take fishing vessels into account in this study. However, the AIS data of all vessels of which it was possible to make a connection with the ship characteristics database of LLG, has been used for the emission calculation, including fishing vessels. This will mainly be large fishing vessels, such as fish factories that are larger than 300 Gross Tonnage. The results for the Netherlands Continental Shelf based on AIS data therefore contain the EMS ship type Fishing. As the calculations for the OSPAR region II are only performed for vessel types that are defined as route bound in the SAMSON model, and fishing vessels are normally categorized as non route bound vessels, these large fishing vessels are reported as a part of EMS vessel type 9, miscellaneous.

This report contains the following chapters:

Chapter 2 describes the objectives of the study.
Chapter 3 describes the base elements required for the calculations and the methodology developed for the calculation of the emissions.
Chapter 4 contains the emissions for the port areas and the NCS.
Chapter 5 contains the emission for OSPAR Region II.
Chapter 6 contains an explanation of the coverage of AIS.
Chapter 7 contains the conclusions and the recommendations.

Notations
In all numbers the point is used as decimal separator and the comma as thousands separator. Some values are given with a large number of digits, because they are copied from the calculation results without rounding off.

2 OBJECTIVE

This study aims to determine the emissions for 2009, totals and spatial distribution, over the Netherlands Continental Shelf and the port areas Western Scheldt, Rotterdam, Amsterdam and the Ems from AIS data. In addition, the information contained in the AIS data for the NCS and the SAMSON model are used to determine the emissions for 2009 in the OSPAR Region II area.

The emissions for 2009 are determined for NMVOC, SO_2, NO_x, CO, CO_2 and particulate matter (PM). A distinction will be made for ships sailing under EU-flag and non-EU flag and sailing within or outside the 12 miles zone.

3 BASE ELEMENTS

3.1 Definition of the port areas and the NCS

In this study, AIS data of 2009 from the NCS and the port areas Western Scheldt, Rotterdam, Amsterdam and the Ems will be used to calculate the emissions in these areas.
Because AIS data of outside the NCS is not available by MARIN, the emissions in the OSPAR Region II area are estimated based on the traffic database of 2008 of the SAMSON model. The traffic database of 2008 is based on all voyages crossing the North Sea in 2008 collected by Lloyd’s Marine Intelligence Unit. The traffic database in SAMSON, based on this expensive data source, is updated until now once in 4 to 5 years. The traffic database of 2008 of SAMSON is used for the spread of the traffic within the OSPAR Region II area. The changes in traffic volume and behaviour extracted from the AIS data of 2008 and 2009 on the NCS are superimposed on the traffic in the OSPAR region, assuming that these changes on the NCS are also representative for the whole OSPAR Region II.

The emissions are calculated on a grid of 5000 x 5000 m in the sea areas NCS and OSPAR Region II and on a grid of 500 x 500 m in the port areas. The grids are chosen in such a way that they do not overlap each other. The areas are presented in Figure 3-1 on an electronic sea chart. The purple lines are the traffic separations schemes and the squares are offshore platforms. The different areas are indicated by plotting the centre points of the grid cells with different colours with the following meaning:

- The black points at sea are the cells outside the 12 miles zone;
- The orange points at sea are the cells at sea within the 12 miles zone;
- The black points in the port area are cells belonging to the study area of the port, but are cells without ships and thus without emissions;
- The red points within the port areas are the cells that are included in the database when there is any emission;

The four port areas are illustrated with more detail in Figure 3-2 to Figure 3-5. In the outer west part of the port of Rotterdam in Figure 3-3, there are some red points on land. This is caused by the extension of this area for Maasvlakte II, which is not yet implemented in the available version of the electronic chart. Also on other places there are some red points on land. In some cases this is caused by the detail of the chart, thus waterways and or quays really exist, Also it has been observed that the determination of the GPS position is disturbed by container cranes, so that the AIS message is not fed with the correct position.

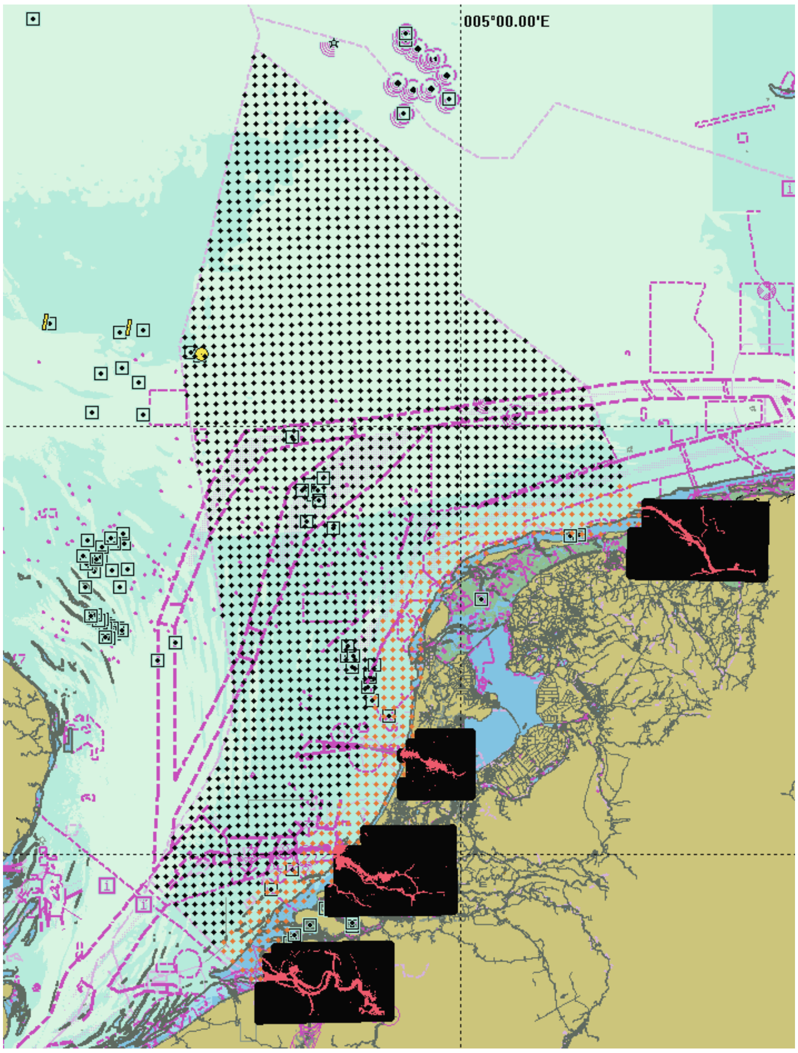

Figure 3-1 The Netherlands Continental Shelf with four port areas

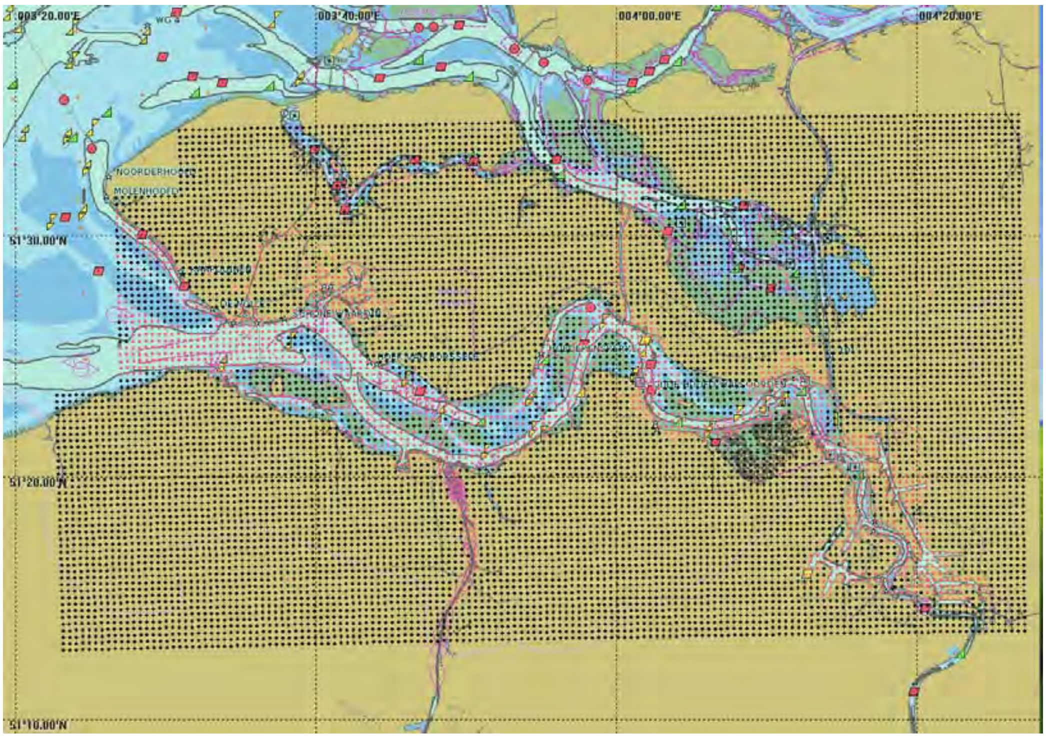

Figure 3-2 Western Scheldt

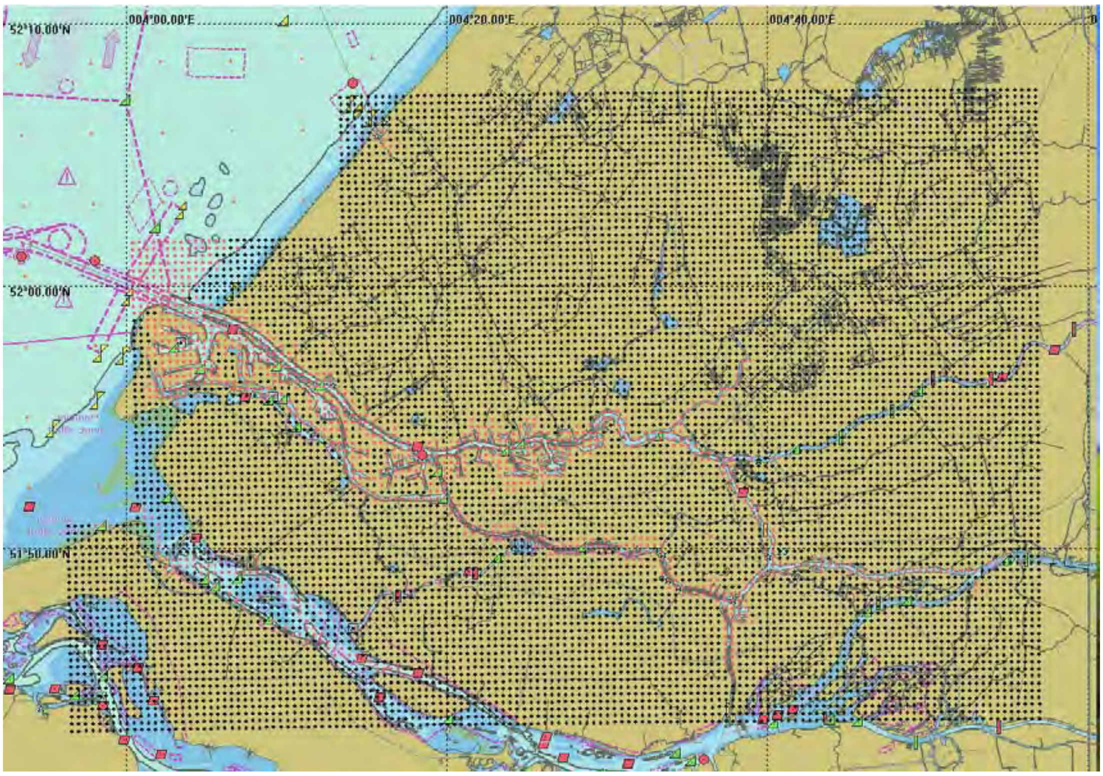

Figure 3-3 Rotterdam

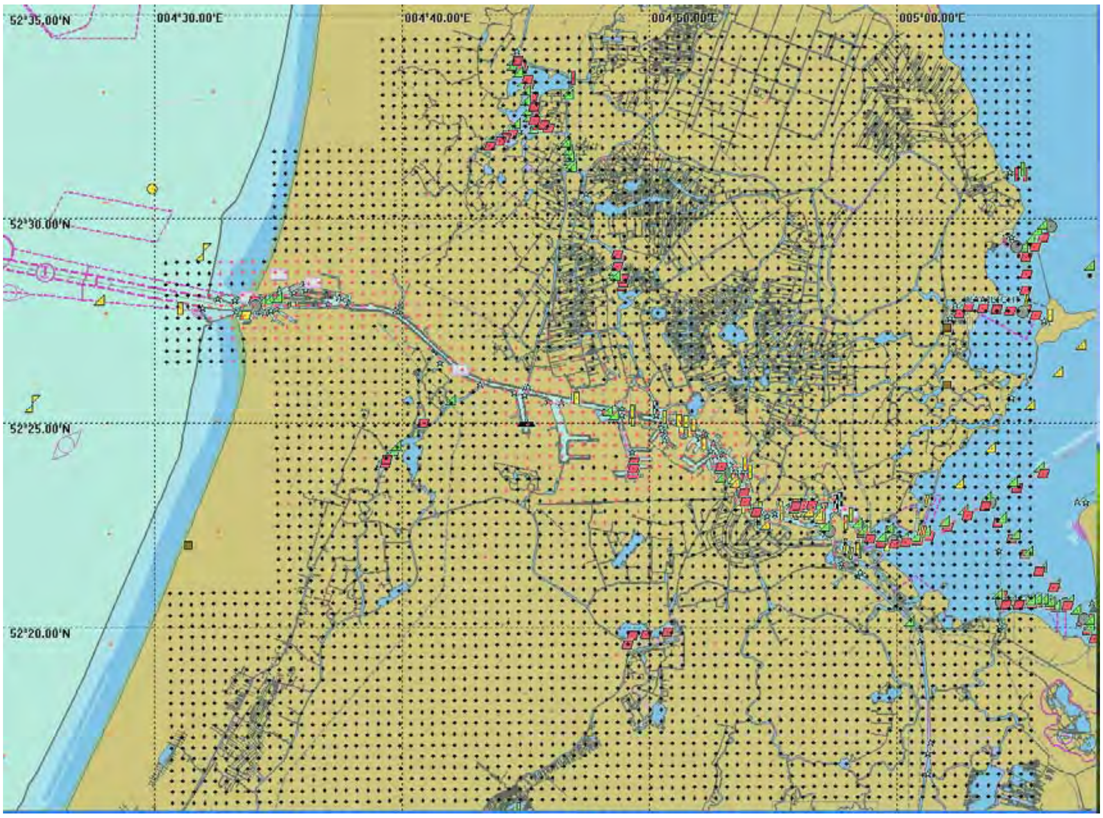

Figure 3-4 Amsterdam

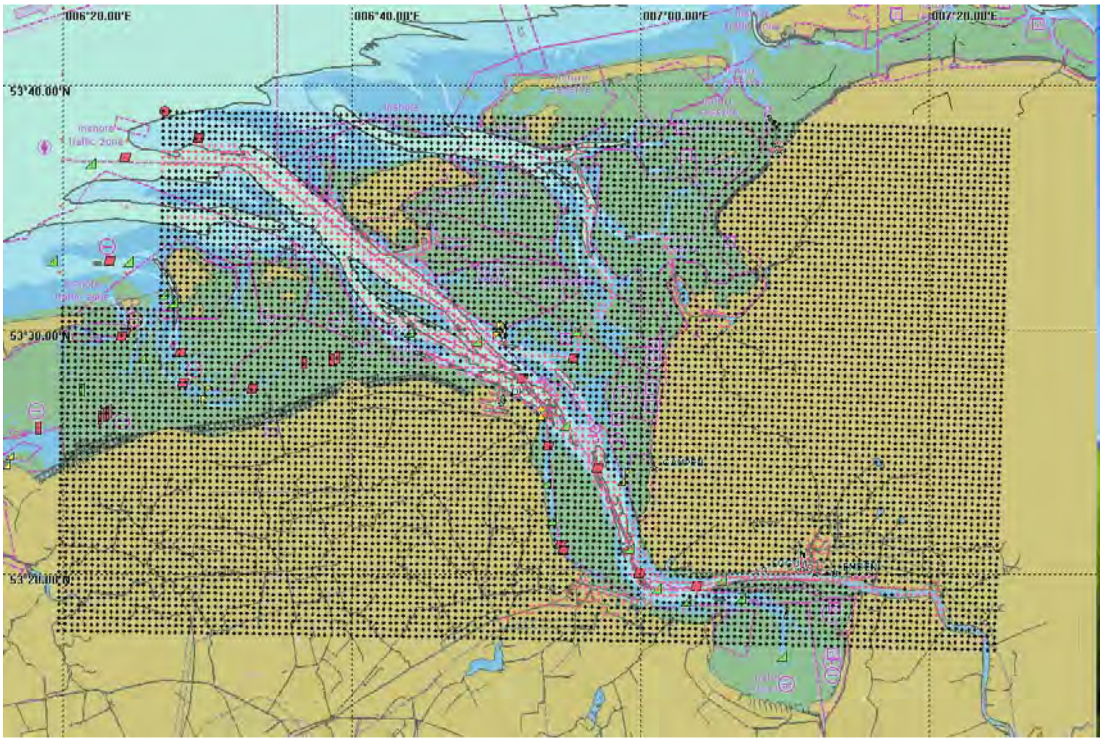

Figure 3-5 Ems

3.2 AIS data

A number of AIS messages are sent out at certain time intervals and these contain various data. Each AIS message contains an MMSI number, which is (in most cases) a unique number for an individual ship. However, there are cases where different ships may use the same MMSI number, which can cause problems with identification. Further, there is the default MMSI number, 1193046, which a number of ships may adopt, again making it impossible to couple the ship to the ship characteristics database.

MARIN receives AIS messages of the type 1, 2, 3 and 5 from the Netherlands Coastguard. Messages. Type 1, 2 and 3 contain information about the position of the ship and message 5 contains ship static and voyage related data. Information is not always complete and is occasionally entered incorrectly. Table 3-1 shows an example of the kind of information contained in these messages.

Table 3-1 Example of AIS data collected from various message types.

Data fields	Contents (example)	AIS message type
MMSI	235007237	1, 2, 3, 5
Call Sign	GFVM	1, 2, 3
IMO-number	377438	5
ship name	HITT-STENA TRANSFER	5
ship type	60	5
Latitude	51.987485	1, 2, 3
Longitude	4.060318	1, 2, 3
Heading	110	1, 2, 3
course over ground	112	1, 2, 3
rate of turn	0	1, 2, 3
speed over ground	14.3	1, 2, 3
navigational status	0	1, 2, 3
actual draught	6.2	5
Altitude	0	
a (distance of antenna to bow)	140	5
b (distance of antenna to stern)	43	5
c (distance of antenna to portside)	8	5
d (distance of antenna to starboard)	16	5
Destination	HUMBER\HOOKOFHOLLAND	5
navSensorType	0	5
navName		5
parseTime (in seconds from 01/10/1970)	1178004614	1, 2, 3
ETA	01/05/07 07:00:00	5
posAccuracy	0	1, 2, 3
ownShip	0	
lastSysTimeOfReport	00/00/00 00:00:00	Added
Valid	0	Added
lastUtcTimeFromTarget	01/05/07 07:30:14	Added
utcTimeStamp	19	1, 2, 3

The information on a ship's position is the most reliable as this is automatically given out via the navigation equipment installed onboard. The navigational status, which specifies whether a ship is sailing, at anchor or moored, is often incorrect. This is visible, for example, when a ship has an anchoring status, but yet still has a considerable speed. The speed thus, in most cases, gives a better indication of the ship's real navigational status than the navigational status field which needs to be manually filled in by crew.

3.3 Emission factors

During sailing and manoeuvring, the main engine(s) are used to propel/manoeuvre the ship. In the emission factor calculation, the nominal engine power and the speed are used. For this study these parameters were taken from the October 2010 shipping database. It is assumed that a vessel uses 85% of its maximum continuous rating power (MCR) to attain the design speed, the service speed mentioned in the ship characteristics database.

Because the speed of a ship is an important parameter and this is part of the AIS message, the emissions for each observed ship can be calculated with the observed speed of the AIS message and the emission factors for that ship. The relations and emission factors are determined by TNO according to the EMS protocols and described in the Appendix.

3.4 Methodology

The AIS messages contain detailed information about the location and speed of the ships. This is the most important information for calculating the emissions they produce at that time. The main problem is how to organize the tremendous amount of data flows and keep the computing time manageable. Therefore, the work is divided into a number of separate activities, delivering intermediate results. The final emission calculation uses these intermediate databases. Figure 3-6 visualizes the databases that are mentioned in the description of the methodology.

The basic files are the ones indicated in blue in Figure 3-6:

- All AIS data files collected in 2009
- Shipping database of October 2010 from Lloyd's List Group (the ship characteristics database).

From "AIS-data 2009" to "observed ships"
Each AIS data file contains the AIS messages of all ships received in exactly one minute. The total collection of the AIS data of 2009 contains 525,578 files, which is 99.996% of the maximum number of 525,600 (365 days times 24 hours times 60 minutes) files. Thus only a few files are missing due to failures in the process. In case the failure is less than 20 minutes, this has no effect on the results because each ship is kept in the system until no AIS message is received during 20 minutes. This approach is followed to prevent incompleteness for larger distances from the coast where the reception of AIS messages by the base station decreases. For 2009 it was not necessary to apply a completion factor. (In 2008 a correction factor of 1.025 has been applied to correct for missing data). It remains possible that certain areas are not covered during some time, but it is impossible to check that. Some checks have been performed and analyzed. One of the checks executed is analysing a plot of the number of ships counted on each whole hour on a large grid of 5 geographical minutes in direction north (thus 5 nautical miles) and 10 minutes in direction east (just more than 6 nautical miles). The lines show a drop for an hour in which a certain base station has failed and will show a peak in case of very intensive shipping activities. Based on these plots, a further in depth analysis has been carried out for the Eems. A distinction in ship type classes was made to find the ships that caused the tops. No suspicious elements that had to be corrected were found.

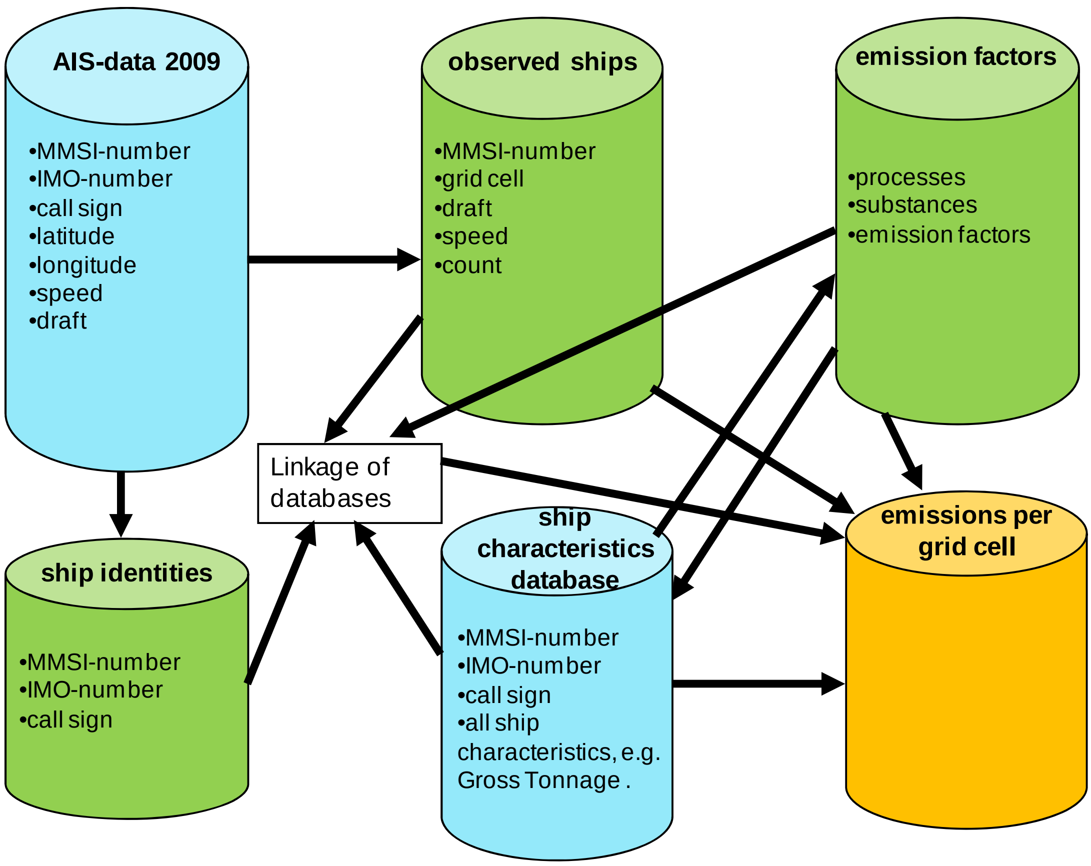

Figure 3-6 Databases with relations (blue = input, green = intermediate, orange = output)

Each AIS data file contains the data of the ships in standard AIS format. That means that the file cannot be read with a text editor but only by a program that converts the data into readable values. It is impossible to deal with all full text data. Therefore an approach is chosen in which every two minutes an observation is done to determine for the whole area which ships are in which grid cell. The essential parameters that are collected during processing the AIS data files are:

- The ships are indicated by the unique MMSI number.
- The position of each ship gives the grid cell in which the ship is observed.
- The speed is converted to a speed class by cutting off to whole values. Thus speed class 10 means a speed between 10 and 11 knots.
- The navigational status and the draught of the ship in classes of 1 meter are added for future use.

A certain combination of these parameters forms an unique observation. For all ships in the area, it is checked whether the observation has already be done. If so, the counter for this specific observation is increased by 1, otherwise a new observation is added with an initial count of 1. At the end of the observation period, all observations with corresponding counts are written to the “observed ships“ log file that is used in the next steps. The determination of the total “observed ships” file for the North Sea is carried out in steps of one month as observation period due to memory limitations. For the NCS this process, 12 runs of one month, delivers nearly 18 million records for the whole year 2009. These records are stored in “observed ships”.
Within the subsequent calculations it is **assumed that the emission for each ship in the next two minutes takes place in the observed grid cell and can be based on the observed speed.**

From “ship characteristics database” to “emission factors”

A separate step is to assess the emission factors for all 115,000 ships, operating worldwide. For this purpose the shipping database of LLG of October 2010 is purchased that contains all characteristics, such as year of built, type, size, main and auxiliary engine. TNO has determined the emission factors per nautical mile for each ship based on these characteristics.

Connect MMSI number from “ship identities” to “ship characteristics database”

Another activity is to find the corresponding ship in the shipping database for each MMSI number. This is not as easy as one would expect, because only 60% of the ships in the shipping database contain an MMSI-number and this number does not always correspond with the MMSI number in the AIS data. For this task all ships that are present in the AIS data of 2009 are extracted from the database and stored in “ship identities”. The combination of MMSI number, IMO-number and call sign is stored. These three items, unique for each ship, were used to find a linkage between the observed ships and the ship characteristics database. When at least two of the three linkages delivered the same ship, there was no doubt. In the remaining cases a manual view was necessary to decide which linkage was most likely. Often a digit was wrong or zeros were added before or after the correct number in the AIS message. This is a time consuming task but is necessary in order to link as much MMSI numbers as possible to the correct ship. By following this approach, nearly all MMSI numbers could be coupled with a ship in the shipping database, thus with the emission factors. Different from previous year, the success of coupling is only given for the MMSI-AIS_type combinations that belong to route bound ships, because these ships give the highest contribution to the emissions. Of all 11249 ships that according to AIS were route bound ships (thus AIS type 40 and 60-99), only 228 ships could not be coupled (Appendix B contains a table with AIS ship type numbers). These ships are not included in the emissions, because it is expected that they do not really belong to the route bound ships but belong to inland ships or recreation ships. All ships of which is was possible to connect the AIS data with a ship in the ship characteristic database were used for the emission calculations, including fishing vessels.

4 THE EMISSIONS OF 2009 IN THE PORT AREAS AND ON THE NCS

4.1 Introduction

The results of the emission calculations for 2009 are presented in this chapter. The emissions for the port area are given in section 4.2 and for the NCS in section 4.3. Section 4.4 contains an overview of the number of ships in the areas. In section 4.5, the changes in shipping in the Ems port area between 2008 and 2009 are investigated, because these changes were opposite to changes in other areas. As example the emissions of CO_2 are presented spatially over the areas in section 4.6.

4.2 Emissions in port areas

The results of the emission calculations and the most important shipping characteristics are presented in tables in this chapter. Because it is important to know how the emissions evolve over the years, all values for 2009 are also presented as percentages of the values of year 2008. It is not possible to go further back in time because the present calculation of emissions started for 2008, described in [2]. All values are copied from the calculated results and not rounded off.

Table 4-1 contains the emissions for all port areas, calculated for ships berthed, and for the main and auxiliary engines during the journeys within the port area. Table 4-2 contains the emissions for 2009 expressed as a percentage of corresponding emissions in 2008.

In the calculation for 2009 a distinction is made between the aerosols from marine diesel engines operated with distillate fuel oil (substance 6601) and aerosols from marine diesel engines operated with residual fuel oil (substance 6602). This has been done because it is expected that the fractions PM2.5 and PM10 in the total aerosol emission differs between these fuel types. The fractions PM2.5 and PM10 are applied to the total aerosol emission when the data are loaded in the database of the Dutch emission inventory. The sum of the emission of both numbers can be compared with the substance number 6598 of 2008. For this reason the values of 6601 and 6602 are summarized, so that they can be compared with the emissions of 6598 of 2008.

Table 4-2 shows the changes, or trend. The emissions in Rotterdam are decreased with a few percent and in Amsterdam and the Western Scheldt they decreased with more than 10%. The emissions in the Ems area increased with 20 to 40%. Especially the growth of the ships berthed has increased extremely. This has been investigated in more detail later in section 4.5.

The trends presented in Table 4-2 are the results of the calculations. It is difficult to explain each trend, because the trend is the summarized result of differences in:

- the number and location of the visits in that port;
- variations in ship type, ship size, main and auxiliary engine;
- variations in the speed used.

However, the results can be made more plausible when other independent sources will show the same trends.

Table 4-1 Total emissions in ton in each area for 2009 based on the AIS data

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Totaal
1237 NMVOC	Berthed	39	256	62	22	379
	Sailing: Main engine	208	141	27	22	398
	Sailing: Auxiliary engines	32	28	6	4	71
	Total	***279***	***425***	***95***	***48***	***848***
4001 SO_2	Berthed	409	2,810	617	233	4,068
	Sailing: Main engine	2,274	1,300	199	208	3,981
	Sailing: Auxiliary engines	419	392	70	37	919
	Total	***3,103***	***4,502***	***886***	***477***	***8,968***
4013 NO_x	Berthed	918	5,768	1,389	528	8,603
	Sailing: Main engine	6,552	3,618	592	580	11,342
	Sailing: Auxiliary engines	956	850	171	112	2,088
	Total	***8,426***	***10,236***	***2,152***	***1,220***	***22,033***
4031 CO	Berthed	178	1,161	278	104	1,721
	Sailing: Main engine	1,336	993	184	127	2,639
	Sailing: Auxiliary engines	180	163	32	22	397
	Total	***1,693***	***2,317***	***494***	***253***	***4,757***
4032 CO_2	Berthed	77,280	595,729	138,730	41,953	853,691
	Sailing: Main engine	247,670	146,034	22,818	24,869	441,391
	Sailing: Auxiliary engines	50,109	46,287	8,859	5,705	110,960
	Total	***375,058***	***788,050***	***170,407***	***72,527***	***1,406,042***
6601 Aerosols MDO	Berthed	44	333	74	22	472
	Sailing: Main engine	10	12	3	4	30
	Sailing: Auxiliary engines	54	50	9	5	117
	Total	***108***	***395***	***86***	***31***	***619***
6602 Aerosols HFO	Berthed	0	0	0	0	0
	Sailing: Main engine	357	196	31	26	611
	Sailing: Auxiliary engines	0	0	0	0	0
	Total	***357***	***196***	***31***	***26***	***611***
6598 Aerosols MDO+HFO	Berthed	44	333	74	22	472
	Sailing: Main engine	367	209	34	31	640
	Sailing: Auxiliary engines	54	50	9	5	117
	Total	***465***	***591***	***117***	***58***	***1,230***

Table 4-2 Emissions in each area for 2009 as percentage of the emissions in 2008

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Totaal
1237 NMVOC	Berthed	86.2%	99.4%	90.9%	173.6%	98.8%
	Sailing: Main engine	86.5%	93.3%	77.8%	100.8%	88.8%
	Sailing: Auxiliary engines	85.8%	95.2%	78.4%	99.9%	89.3%
	Total	***86.4%***	***97.0%***	***85.9%***	***124.7%***	***93.1%***
4001 SO_2	Berthed	83.2%	97.8%	91.0%	213.1%	98.0%
	Sailing: Main engine	89.9%	96.4%	82.7%	101.2%	92.1%
	Sailing: Auxiliary engines	89.3%	100.2%	82.1%	101.0%	93.4%
	Total	***88.9%***	***97.6%***	***88.3%***	***136.0%***	***94.8%***
4013 NO_x	Berthed	87.2%	102.6%	89.5%	174.3%	100.9%
	Sailing: Main engine	88.7%	95.4%	81.8%	97.6%	90.8%
	Sailing: Auxiliary engines	87.5%	97.1%	79.3%	100.8%	91.0%
	Total	***88.4%***	***99.5%***	***86.4%***	***121.0%***	***94.5%***
4031 CO	Berthed	86.6%	100.8%	91.5%	170.4%	99.9%
	Sailing: Main engine	88.1%	96.0%	78.7%	104.5%	90.8%
	Sailing: Auxiliary engines	88.0%	98.1%	79.7%	101.3%	91.8%
	Total	***87.9%***	***98.5%***	***85.5%***	***124.0%***	***94.0%***
4032 CO_2	Berthed	86.5%	97.7%	94.7%	185.3%	98.3%
	Sailing: Main engine	90.0%	96.5%	82.4%	102.4%	92.2%
	Sailing: Auxiliary engines	89.1%	98.6%	80.4%	102.6%	92.6%
	Total	***89.1%***	***97.5%***	***92.0%***	***138.2%***	***95.9%***
6601 Aerosols MDO	Berthed					
	Sailing: Main engine					
	Sailing: Auxiliary engines					
	Total					
6602 Aerosols HFO	Berthed					
	Sailing: Main engine					
	Sailing: Auxiliary engines					
	Total					
6598 Aerosols MDO+HFO	Berthed	85.8%	101.1%	92.2%	187.9%	100.1%
	Sailing: Main engine	89.0%	95.8%	82.2%	98.3%	91.2%
	Sailing: Auxiliary engines	89.0%	100.2%	82.0%	99.9%	93.2%
	Total	***88.7%***	***99.1%***	***88.3%***	***120.3%***	***94.6%***

Therefore a comparison has been made with the statistics published by the National Ports Council (in Dutch: Nationale Havenraad, NHR). These numbers are presented in Table 4-3 in the same way as in the other tables, thus with the values of 2009 and the percentage with respect to the value in 2008. The table contains the number of visits and for Rotterdam and Antwerp only the summarized GT from the internet sites of those ports. The percentages in Table 4-3 show trends as in Table 4-2, namely a decrease of more than 10% in the number of calls in the Western Scheldt and in Amsterdam, a slight decrease in Rotterdam and an increase of 17.4% in the Ems area. For Antwerp and Rotterdam only, also the statistics in GT were available. The percentages for the GT, with 95.6% for Rotterdam and 89.9% for Antwerp, are larger than for the number of visits, with 89.3% for Rotterdam and 84.9% for Antwerp. This means that the average size of the vessel is larger in 2009. Because the emissions are more related to the size, thus GT of the ship, the emissions are closer related to the growth in GT than the growth in number of calls. For this reason the percentages in Table 4-2 are a little bit higher than those for the number of calls in Table 4-3. Thus the observed growth in the Ems corresponds with these sources.

Table 4-3 Number of calls from Nationale Havenraad and GT from www.PortOfRotterdam.nl and www.PortOfAntwerp.com

Port area	Ports	Number of calls		GT (in 1000 ton)	
		2009	2009/2008	2009	2009/2008
Western Scheldt	Antwerp	13923	84.9%	266,262	89.9%
	Vlissingen + Terneuzen	4946	78.2%		
Rotterdam	Maasmond	31565	89.3%	572,674	95.6%
Amsterdam	Noordzeekanaal	7656	84.9%		
Ems	Delfzijl + Eemshaven	1853	117.4%		

Because the emissions are related to ship types and ship sizes, it is useful to present the ships and emissions in these types of categories. This helps in explaining the emission values and getting insight in where in the port area the highest emissions are produced. The emission explaining variables are:

- hours: number of hours that ships are in the area;
- GT.hours: sum of (GT of the ship times the number of hours);
- GT.nm: sum of (GT of the ship times the nautical miles travelled in the area).

The emission explaining variables are presented in a table per ship type and a table per ship size class. The results are presented for each port area in Table 4-4 through Table 4-11. Because fishing vessels are not obliged to have an AIS transponder, it was agreed not to take fishing vessels into account in this study. However, the AIS data of all vessels of which it was possible to make a connection with the ship characteristics database of LLG has been used for the emission calculation, including fishing vessels. This will mainly be large fishing vessels, such as fish factories that are larger than 300 Gross Tonnage.

The other delivery of this study, the databases with emissions per grid cell for each substance, EMS ship type class and ship size class, moving / not moving and EU / non-EU flag can be used in studies for which a detailed spatial distribution of the emissions is necessary.

Table 4-4 Ship characteristics per EMS type for the Western Scheldt area

Ship type	Totals for Western Scheldt in 2009					2009 as percentage of 2008				
	Berthed		Moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	5,079	166,088,696	4,316	1,131,706,618	10.23	92.2%	106.4%	97.3%	98.6%	99.5%
Chem.+Gas tanker	30,327	313,710,937	29,656	2,440,738,236	10.92	87.7%	94.6%	94.3%	92.8%	101.4%
Bulk carrier	17,527	500,225,703	6,354	1,517,078,665	9.08	65.2%	69.5%	69.0%	66.1%	98.5%
Container ship	20,358	855,812,095	28,972	11,569,426,461	12.06	72.6%	76.8%	86.8%	92.1%	100.9%
General Dry Cargo	74,049	483,144,944	34,577	1,872,059,678	10.35	76.4%	76.2%	74.7%	81.3%	102.7%
RoRo Cargo / Vehicle	19,717	413,721,783	12,017	4,765,520,903	11.87	77.2%	71.4%	84.9%	89.5%	102.7%
Reefer	9,799	70,530,084	2,651	378,313,416	12.66	81.7%	70.2%	89.2%	93.2%	103.0%
Passenger	11,973	19,346,309	5,176	74,973,912	11.71	104.9%	112.2%	103.7%	113.7%	102.9%
Miscellaneous	92,246	266,117,167	24,627	664,279,858	8.21	105.2%	128.2%	102.5%	127.2%	106.0%
Tug/Supply	52,050	25,876,572	6,860	18,351,062	6.70	155.3%	220.6%	96.3%	127.6%	108.0%
Fishing	5,615	27,126,159	82	3,543,990	8.91	114.7%	203.8%	249.9%	180.3%	95.0%
Non Merchant	987	621,978	107	771,217	9.32	62.2%	46.5%	15.1%	16.7%	128.7%
Total	**339,727**	**3,142,322,427**	**155,396**	**24,436,764,016**	**11.30**	**92.2%**	**80.9%**	**86.9%**	**89.6%**	**101.6%**

Table 4-5 Ship characteristics per ships size classes for Western Scheldt port area

Ship size in GT	Totals for Western Scheldt in 2009					2009 as percentage of 2008				
	Berthed		moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	118,474	80,014,052	25,637	192,374,903	8.99	102.8%	87.7%	85.3%	80.7%	106.3%
1,600-3,000	74,576	172,128,499	33,699	718,752,942	9.17	99.0%	98.3%	87.2%	87.1%	100.4%
3,000-5,000	31,743	123,414,351	19,270	770,908,473	10.28	92.6%	91.9%	83.4%	84.1%	100.5%
5,000-10,000	30,275	206,422,766	20,745	1,679,152,393	11.45	84.3%	83.5%	90.9%	95.3%	102.8%
10,000-30,000	52,712	951,194,853	32,790	7,206,904,032	11.57	76.0%	74.4%	90.0%	93.6%	101.9%
30,000-60,000	24,741	1,028,311,754	17,545	8,594,128,375	11.36	82.7%	82.0%	79.1%	80.6%	101.6%
60,000-100,000	6,156	457,327,898	4,732	4,010,583,796	11.51	92.6%	90.1%	105.6%	105.0%	101.6%
>100,000	1,050	123,508,253	978	1,263,959,101	11.11	57.9%	62.4%	89.6%	93.1%	97.7%
Total	**339,727**	**3,142,322,427**	**155,396**	**24,436,764,016**	**11.30**	**92.2%**	**80.9%**	**86.9%**	**89.6%**	**101.6%**

Table 4-6 Ship characteristics per EMS type for the Rotterdam port area

Ship type	Totals for Rotterdam in 2009					2009 as percentage of 2008				
	berthed		moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	73,597	4,467,708,127	5,912	1,831,307,166	5.93	105.0%	119.0%	98.4%	109.4%	98.4%
Chem.+Gas tanker	156,795	1,891,933,383	22,838	1,617,799,912	7.87	63.1%	66.7%	85.8%	92.4%	102.0%
Bulk carrier	62,708	3,294,436,734	3,221	806,893,967	5.89	60.4%	57.1%	63.5%	71.6%	107.0%
Container ship	185,448	5,331,234,904	30,207	4,754,246,810	7.09	88.4%	93.6%	98.1%	102.6%	102.4%
General Dry Cargo	178,371	818,624,601	28,725	844,431,679	8.52	80.2%	83.9%	78.4%	88.5%	101.9%
RoRo Cargo / Vehicle	41,914	830,793,838	8,549	1,466,098,627	9.33	92.3%	82.1%	100.0%	90.2%	98.3%
Reefer	6,616	58,115,055	926	79,116,700	9.45	64.3%	59.1%	74.4%	72.1%	102.2%
Passenger	19,567	769,119,127	2,097	946,155,267	10.77	85.5%	94.9%	74.1%	91.1%	104.6%
Miscellaneous	105,003	1,316,992,365	17,540	584,970,897	7.00	174.1%	173.9%	106.8%	124.7%	95.8%
Tug/Supply	190,658	123,299,229	43,538	97,158,174	6.08	104.9%	123.0%	107.0%	114.3%	101.0%
Fishing	15,910	11,621,987	144	957,041	6.38	383.0%	319.8%	265.0%	169.1%	82.8%
Non Merchant	1,337	848,263	160	1,482,092	8.27	82.7%	72.2%	78.4%	118.5%	104.5%
Total	**1,037,925**	**18,914,727,613**	**163,858**	**13,030,618,331**	**7.34**	**87.9%**	**86.7%**	**93.6%**	**96.7%**	**101.2%**

Table 4-7 Ship characteristics per ships size class for the Rotterdam port area

Ship size in GT	Totals for Rotterdam in 2009					2009 as percentage of 2008				
	berthed		moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	248,080	121,380,583	56,506	186,712,052	6.97	105.1%	94.4%	95.8%	86.4%	97.5%
1,600-3,000	132,681	317,385,343	23,407	500,005,533	8.85	80.9%	82.9%	83.2%	86.5%	101.6%
3,000-5,000	103,148	415,030,115	18,523	634,204,929	8.40	72.9%	74.4%	84.5%	87.0%	101.1%
5,000-10,000	164,586	1,226,955,022	26,278	1,644,678,049	8.49	94.1%	95.5%	103.6%	103.3%	100.1%
10,000-30,000	206,526	4,089,295,362	25,161	4,024,051,414	8.45	80.1%	81.9%	98.0%	97.9%	99.4%
30,000-60,000	87,270	3,917,775,211	7,406	2,571,417,021	7.55	87.0%	87.2%	91.0%	94.4%	104.0%
60,000-100,000	69,727	5,398,628,255	5,071	2,408,781,141	6.00	87.8%	84.6%	93.2%	95.0%	100.9%
>100,000	25,906	3,428,277,723	1,506	1,060,768,191	5.21	96.3%	95.2%	101.0%	107.8%	105.4%
Total	**1,037,925**	**18,914,727,613**	**163,858**	**13,030,618,331**	**7.34**	**87.9%**	**86.7%**	**93.6%**	**96.7%**	**101.2%**

Table 4-8 Ship characteristics per EMS type for the Amsterdam port area

Ship type	Totals for Anmsterdam in 2009					2009 as percentage of 2008				
	berthed		moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	19,020	594,396,652	1,763	248,590,233	5.10	80.1%	94.2%	87.3%	108.8%	101.1%
Chem.+Gas tanker	55,459	921,466,352	6,658	528,442,323	5.54	102.1%	109.5%	105.6%	121.1%	104.7%
Bulk carrier	49,019	2,152,227,707	3,006	653,131,288	5.26	89.8%	89.4%	84.6%	92.1%	105.0%
Container ship	4,236	155,315,763	724	147,766,160	5.48	40.5%	43.2%	44.3%	48.6%	100.0%
General Dry Cargo	97,512	297,614,601	8,334	156,570,609	6.66	92.9%	96.8%	84.5%	88.6%	102.1%
RoRo Cargo / Vehicle	21,952	458,040,195	1,958	270,144,639	5.79	115.6%	100.5%	81.9%	81.4%	103.8%
Reefer	17,774	78,865,937	598	14,857,856	4.92	86.8%	90.0%	111.3%	124.5%	102.2%
Passenger	3,390	129,920,265	1,015	255,610,449	6.04	56.5%	57.4%	88.9%	91.9%	102.5%
Miscellaneous	34,104	156,422,170	3,002	75,229,827	5.08	71.6%	78.7%	51.0%	44.2%	107.5%
Tug/Supply	105,914	55,211,689	17,057	33,935,143	5.40	105.6%	76.1%	84.2%	81.7%	101.7%
Fishing	19,396	76,409,469	447	7,444,397	4.21	86.9%	93.6%	133.1%	122.6%	94.7%
Non Merchant	10,645	5,731,120	181	665,766	6.89	78.3%	95.5%	47.4%	52.7%	121.0%
Total	**438,423**	**5,081,621,922**	**44,743**	**2,392,388,691**	**5.52**	**91.8%**	**89.5%**	**82.4%**	**88.7%**	**103.6%**

Table 4-9 Ship characteristics per ships size classes for the Amsterdam port area

Ship size in GT	Totals for Amsterdam in 2009					2009 as percentage of 2008				
	berthed		moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	149,342	88,205,180	19,991	54,975,532	5.84	105.6%	105.7%	84.5%	93.3%	104.2%
1,600-3,000	78,719	183,105,235	6,172	99,242,137	6.73	77.1%	76.6%	78.5%	80.5%	101.7%
3,000-5,000	34,442	135,712,261	2,839	69,884,802	6.17	77.4%	76.3%	85.0%	89.0%	104.4%
5,000-10,000	44,199	321,524,949	4,747	216,252,859	6.03	77.9%	74.3%	64.0%	66.6%	110.1%
10,000-30,000	76,227	1,495,026,484	6,332	678,717,793	5.47	113.1%	109.2%	94.9%	104.5%	103.5%
30,000-60,000	40,641	1,635,092,503	3,396	733,148,254	5.37	86.4%	86.6%	88.4%	90.0%	102.9%
60,000-100,000	14,841	1,221,830,476	1,261	536,557,817	5.31	82.6%	82.5%	83.9%	85.6%	103.8%
>100,000	11	1,124,833	6	3,609,498	6.04	19.2%	17.6%	20.5%	18.7%	99.5%
Total	**438,423**	**5,081,621,922**	**44,743**	**2,392,388,691**	**5.52**	**91.8%**	**89.5%**	**82.4%**	**88.7%**	**103.6%**

Table 4-10 Ship characteristics per EMS type for the Ems area

Ship type	Totals for Ems in 2009					2009 as percentage of 2008				
	berthed		moving			Berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	639	1,498,394	342	5,921,685	9.41	135.3%	61.5%	121.2%	132.9%	108.8%
Chem.+Gas tanker	4,432	23,044,111	1,776	90,852,721	10.47	84.5%	75.5%	88.2%	111.7%	109.3%
Bulk carrier	6,146	93,343,452	743	78,103,616	9.12	129.8%	165.8%	92.8%	105.7%	95.5%
Container ship	69,739	675,895,431	811	43,319,608	4.88	704.5%	578.9%	239.0%	149.1%	57.6%
General Dry Cargo	129,364	451,264,595	9,386	297,242,285	9.55	144.5%	150.6%	91.4%	102.2%	100.2%
RoRo Cargo / Vehicle	50,670	612,370,270	8,451	1,094,745,273	12.33	151.6%	133.2%	93.9%	91.8%	100.7%
Reefer	3,759	12,923,883	202	6,239,668	10.25	150.7%	219.2%	101.6%	122.1%	100.9%
Passenger	24,839	104,155,907	3,864	62,218,842	10.81	76.8%	145.5%	106.1%	91.0%	97.5%
Miscellaneous	43,715	56,632,096	11,719	279,500,378	7.10	133.5%	167.7%	99.3%	104.7%	99.8%
Tug/Supply	83,548	32,096,174	6,073	15,513,748	6.88	176.9%	235.6%	147.9%	191.7%	103.5%
Fishing	5,828	2,584,993	477	1,377,285	8.18	509.7%	216.3%	469.0%	367.4%	102.7%
Non Merchant	533	230,713	105	217,810	5.41	55157.2%	13867.7%	3661.0%	898.8%	52.9%
Total	**423,213**	**2,066,040,019**	**43,948**	**1,975,252,918**	**10.14**	**163.3%**	**189.3%**	**103.3%**	**97.7%**	**97.1%**

Table 4-11 Ship characteristics per ships size classes for the Ems area

Ship size in GT	Totals for Ems in 2009					2009 as percentage of 2008				
	berthed		moving			Berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	161,534	85,274,623	15,948	74,336,430	8.60	132.8%	139.5%	106.1%	88.6%	96.8%
1,600-3,000	89,485	210,477,548	11,835	240,621,770	9.59	142.0%	152.0%	103.2%	101.4%	97.2%
3,000-5,000	61,724	241,134,893	5,757	197,798,901	8.22	244.3%	242.0%	80.9%	79.2%	101.0%
5,000-10,000	65,193	505,338,433	7,474	462,964,326	9.39	213.1%	223.8%	121.6%	103.7%	91.0%
10,000-30,000	32,093	585,000,980	1,896	371,762,684	10.70	273.3%	257.9%	107.6%	94.1%	94.5%
30,000-60,000	12,012	334,295,666	914	533,394,469	12.05	189.7%	118.1%	96.8%	99.0%	99.0%
60,000-100,000	682	44,947,972	108	79,165,980	11.57	167.4%	168.1%	146.9%	159.1%	107.8%
>100,000	489	59,569,904	16	15,208,357	7.91	200.2%	200.2%	81.5%	75.3%	92.3%
Total	**423,213**	**2,066,040,019**	**43,948**	**1,975,252,918**	**10.14**	**163.3%**	**189.3%**	**103.3%**	**97.7%**	**97.1%**

4.3 Emissions in the NCS

The emissions of the ships in the NCS are calculated for moving ships and non-moving ships. Ships are counted as non-moving when the speed is less than 1 knot. Most of the ships having this speed are at anchor in one of the anchorage areas. But there will be some ships having such a low speed for a while when waiting for something (for a pilot, for permission to enter a port or for another reason). Based on the observed speed in AIS, the emission is calculated for the main engine and auxiliary engines.
The calculated emissions for 2009 are summarized in Table 4-12. The emissions are again compared with the emissions determined for 2008. Table 4-13 and Table 4-14 contain the distributions of the main emission explaining variables divided over the ship type and ship size classes.

The increased effect of the economic crisis is visible at sea by the large number of ships at anchor. The average number of 96.8 “not moving ships”, of which most of them at anchor, is 37.9% higher than in 2008. The emissions are about 50% higher, which means that relatively larger ships with higher emissions were at anchor. Many ships use the anchorage areas to wait for orders. However, the not moving ships being 37% of all ships contribute only 4% to the total emissions.
A second consequence of the crisis is that the average speed of 13.45 knots at sea in 2009 (see Table 4-13), is 5.1% less than in 2008.

Table 4-12 Emissions of ships in ton in NCS for 2009

Nr	Substance	Emission in ton in 2009				Emission in 2009 as percentage of 2008			
		not moving	Moving		Total	not moving	moving		Total
			Auxiliary Engine	Main Engine			Auxiliary Engine	Main Engine	
1237	NMVOC	93	233	2,078	2,404	142.5%	100.4%	95.8%	97.5%
4001	SO_2	1,245	3,028	26,980	31,254	152.6%	104.7%	96.7%	98.9%
4013	NO_x	2,800	6,887	74,748	84,435	146.1%	102.2%	95.5%	97.2%
4031	CO	536	1,305	12,529	14,370	147.2%	102.6%	98.7%	100.3%
4032	CO_2	151,625	365,712	2,907,709	3,425,046	149.1%	103.8%	96.5%	98.8%
6601	Aerosols MDO	158	385	79	622				
6602	Aerosols HFO	0	0	4,111	4,111				
6598	Aerosols MDO+HFO	158	385	4,190	4,733	152.5%	104.3%	96.4%	98.2%
Ships		96.81	168.54		265.35	137.9%	97.2%		109.0%

Table 4-13 Ship characteristics per EMS type for the Netherlands Continental Shelf

Ship type	Totals for NCS in 2009					2009 as percentage of 2008				
	not moving (at anchor)		moving			not moving (at anchor)		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	165,576	8,270,940,763	85,144	42,991,299,620	10.87	177.3%	253.2%	109.3%	109.1%	88.5%
Chem.+Gas tanker	328,152	4,144,521,452	256,468	30,305,377,279	11.68	130.8%	150.3%	102.6%	104.8%	96.4%
Bulk carrier	31,230	1,104,691,652	78,238	26,382,939,309	11.68	52.8%	33.1%	80.4%	82.0%	106.3%
Container ship	77,977	1,764,224,930	174,365	95,366,299,430	16.49	164.5%	146.3%	102.5%	99.6%	93.7%
General Dry Cargo	88,451	322,680,028	431,006	17,406,918,478	11.13	185.4%	181.3%	87.0%	94.1%	101.0%
RoRo Cargo / Vehicle	6,512	188,039,933	110,857	44,472,365,783	15.93	203.5%	201.9%	93.3%	91.7%	97.4%
Reefer	4,088	26,096,427	25,531	3,249,956,285	15.89	86.9%	80.7%	85.0%	86.6%	100.1%
Passenger	55	2,035,889	21,201	14,239,278,673	17.84	11.7%	14.2%	87.9%	95.2%	99.5%
Miscellaneous	68,234	499,232,131	130,308	4,628,771,783	6.56	172.6%	302.6%	136.7%	187.9%	84.9%
Tug/Supply	70,372	109,332,131	132,330	1,234,327,711	7.17	119.1%	132.2%	105.0%	115.9%	98.7%
Fishing	5,659	3,355,767	25,038	231,934,711	8.91	68.6%	97.2%	100.0%	121.4%	104.9%
Non Merchant	1,768	591,564	5,912	26,784,345	8.47	157.0%	246.9%	67.7%	120.8%	97.8%
Total	**848,072**	**16,435,742,668**	**1,476,398**	**280,536,253,406**	**13.45**	**137.9%**	**147.5%**	**97.2%**	**98.2%**	**94.9%**

Table 4-14 Ship characteristics per ship size class for the Netherlands Continental Shelf

Ship size in GT	Totals for NCS in 2009					2009 as percentage of 2008				
	berthed		moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	74,039	53,031,734	235,970	1,436,432,536	7.17	107.6%	108.2%	91.6%	90.9%	101.5%
1,600-3,000	114,896	270,572,584	342,765	7,595,995,743	9.45	120.6%	120.4%	88.2%	88.5%	100.2%
3,000-5,000	96,314	378,615,225	190,258	8,093,641,109	10.77	122.7%	120.3%	96.8%	95.6%	98.1%
5,000-10,000	143,547	1,066,598,453	206,550	18,444,046,161	12.29	140.6%	139.4%	105.0%	99.3%	95.1%
10,000-30,000	271,282	5,215,930,308	302,890	75,875,049,791	13.04	159.4%	161.6%	106.8%	101.5%	93.8%
30,000-60,000	94,389	4,468,038,666	123,682	77,527,405,069	14.14	173.6%	186.1%	99.5%	93.5%	93.2%
60,000-100,000	39,222	2,750,106,793	63,083	70,572,452,531	14.70	111.1%	98.1%	102.3%	96.6%	95.3%
>100,000	14,383	2,232,848,907	11,200	20,991,230,465	14.02	140.4%	164.8%	117.3%	118.4%	98.4%
Total	**848,072**	**16,435,742,668**	**1,476,398**	**280,536,253,406**	**13.45**	**137.9%**	**147.5%**	**97.2%**	**98.2%**	**94.9%**

4.4 Overview of ships in the port areas and the NCS

The average number of ships in the port areas and at sea are given in Table 4-15 and graphically in Figure 4-1. The average GT of the ships is given in Table 4-16. The tables show large differences between ports in the average size of the ships and the ratio of not moving ships over moving ships. The ratio between not moving and moving ships is large in Amsterdam and the Ems, which means that relatively many ships are not moving, thus berthed in these areas. This ratio of not moving ships over moving ships decreases by an increased length of the route from sea to the berth. This route is for example long in the area of the Western Scheldt. Also the average speed is quite different among the port areas with an average of 5.52 knots for Amsterdam and 11.30 knots in the Western Scheldt. The speed in most port areas is slightly increased in 2009, compared to 2008. However, at sea the average speed in 2009 is with 13.45 knots, 5.1% less than in 2008, presumably still for fuel saving.
The percentages for the average number of ships in 2009 compared to 2008 are the same as found earlier in the tables Table 4-4 through Table 4-11 under the column ”Hours”.

The table with the average GT shows the difference in the average size of the ships in the different port areas. The average GT of a ship in Rotterdam is more than 3.5 times higher than of a ship in the Ems. Further the average GT of not moving (thus mostly berthed) ships is larger than for moving ships, which is caused by a relatively larger time on the berth for cargo handling. An exception is the Western Scheldt, because the larger ships are calling for Antwerp, thus a longer sailing route in the area and the port area of Antwerp is presumably not covered for 100% by AIS. However, this bad coverage in Antwerp has no influence on the emissions in the Western Scheldt, delivered on a grid size of 500 by 500 meter.

From these figures it can be concluded that due to the large differences in ship types, sizes, and speeds between the different areas, it is absolutely necessary to describe the shipping movements with large detail, in order to determine the emissions in these areas. The AIS data offers the opportunity to incorporate all these characteristics in the calculations.

Table 4-15 Average number of ships in distinguished areas

Area	in 2009				in 2009 as % percentage of 2008			
	average ships			speed	average ships			speed
	not moving	moving	total		not moving	moving	Total	knots
Western Scheldt	38.78	17.74	56.52	11.30	92.2%	86.9%	90.5%	101.6%
Rotterdam	118.48	18.71	137.19	7.34	87.9%	93.6%	88.6%	101.2%
Amsterdam	50.05	5.11	55.16	5.52	91.8%	82.4%	90.9%	103.6%
Ems	48.31	5.02	53.33	10.14	163.3%	103.3%	154.8%	97.1%
NCS	96.81	168.54	265.35	13.45	137.9%	97.2%	109.0%	94.9%

Table 4-16 Average GT of ships in distinguished areas

Area	in 2009			In 2009 as percentage of 2008		
	average GT of ships			average GT of ships		
	not moving	moving	total	not moving	moving	total
Western Scheldt	9,250	13,921	10,716	87.7%	101.4%	92.5%
Rotterdam	18,224	10,831	17,216	98.6%	102.2%	98.6%
Amsterdam	11,591	9,691	11,415	97.5%	103.9%	98.1%
Ems	4,882	4,434	4,840	115.9%	97.5%	113.6%
NCS	19,380	14,127	16,044	106.9%	106.4%	109.3%

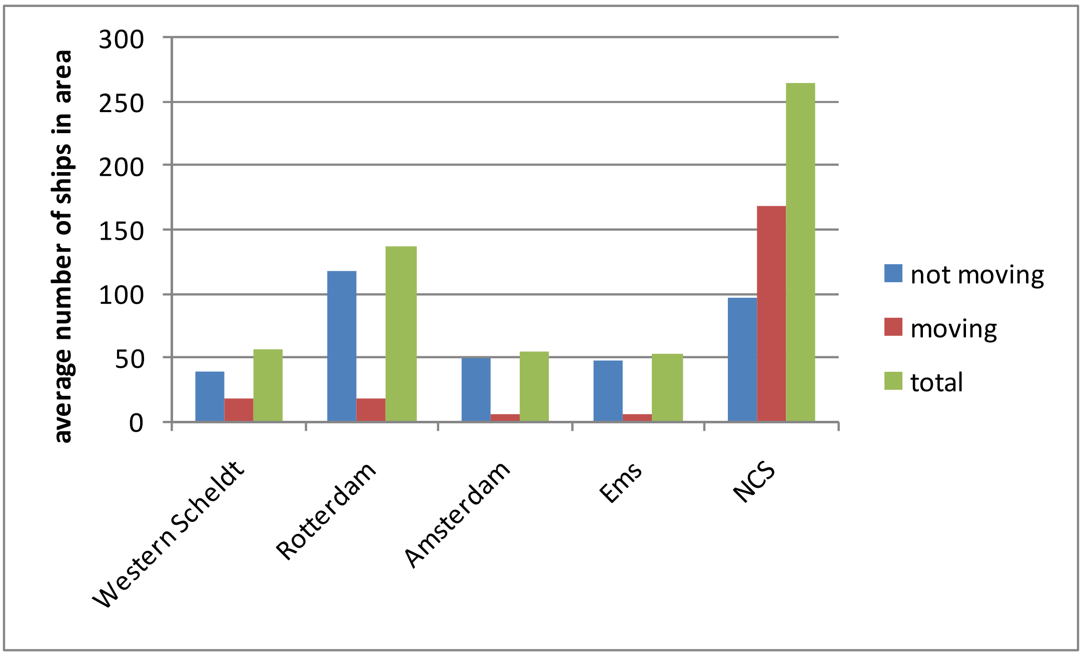

Figure 4-1 Average number of ships in distinguished areas

4.5 Investigation of changes in the Ems area

The largest changes have been observed for ships at anchor in the NCS and the number of berthed ships in the Ems.
The number of ships at anchor in the NCS is something that was expected. In various other projects this was already mentioned by the port authorities of Rotterdam and Amsterdam, because they want to extend their anchorage areas.
The change in the Ems port area has been further investigated. Table 4-3 has shown that the number of visits in Delfzijl + Eemshaven has grown, opposite to the other port areas. However, also German ports contribute to the traffic and emissions in the Ems. Therefore the movements in the Ems area have been investigated in more detail by counting the number of ships on each of the 24*365 whole hour moments of a year, to be able to discover strange effects, if any, in the numbers or spatial distribution of the observed ships. No strange effects were observed in both years 2008 and 2009. However, it was observed that some ships stayed a very long time, sometimes several months, in a port, during which the AIS transponder was not switched off (AIS transponder never switched off is the correct use of AIS). It seems that these ships were laid up temporarily, waiting for better times. These ships, just as ships at anchor in North Sea, have increased the number of not moving ships, and therewith the emissions in the port areas. In the past, TNO has already mentioned, that it would be better to decrease the emission factor for ships that are berthed during a longer period, because they will have less emissions by less activities (unloading and loading).

The traffic in the Ems is shown in Figure 4-2 for 2008 and in Figure 4-3 for 2009. The positions of all ships are plotted on each whole hour, thus, with a much larger time step than the 2 minutes for the emission calculations, but sufficiently to show the differences. The colour depends on the speed over ground (sog) of the ship. The numbers of ships are summarized in the table in the left upper corner of the figure. Because these numbers are not visible with this scale, the totals ("AIS type 0" + "AIS Type Other" of Figure 4-2 and Figure 4-3 are given in Table 4-17. The group not moving ships containing the red, purple, yellow and blue points did increase with 49.6% in 2009 compared to 2008.

Table 4-17 Number of AIS observations (1 hour intervals, 1.025 is the correction factor for incompleteness of AIS in 2008, for 2009 a factor was not required)

Speed over ground in knots	2008	2009	2009/(2008*1.025)
<0.01 (red points)	192,951	389,600	197.0%
<0.21 (purple points	94,215	109,952	113.9%
<0.41 (yellow points)	49,473	32,587	64.3%
<1 (blue points)	20,452	15,569	74.3%
Total not moving speed 0-1 knots	357,091	547,708	149.6%
Eastwards (black points)	26,395	28,464	105.2%
Westwards (brown points	25,788	28,677	108.5%
Total moving	52,183	57,141	106.8%

Because Emden takes care of more than 50% of the not moving ships, the same procedure has been followed for Emden only. In Emden a slightly higher growth of 53.7% for not moving ships was observed. Figure 4-4 and Figure 4-5 contain the hourly plots of the ships for Emden. When comparing these two figures a number of new berths (new red spots in black contours) can be located on Figure 4-5.

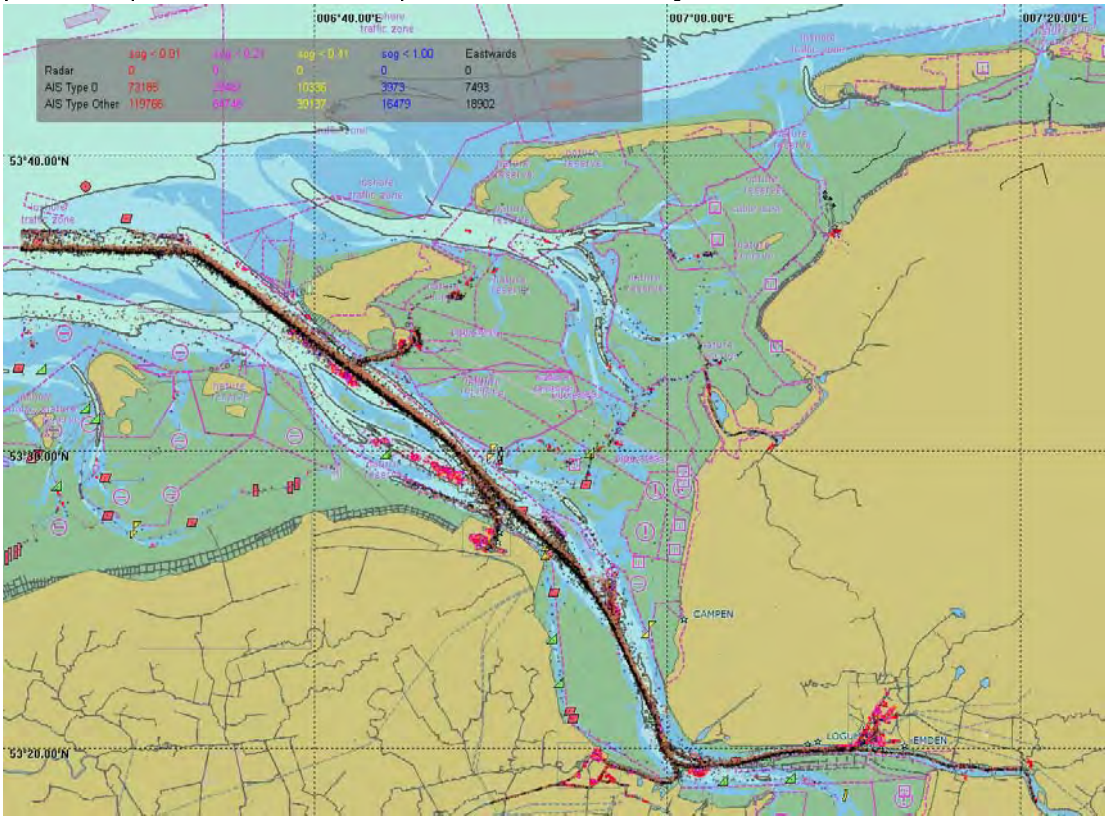

Figure 4-2 Traffic in the Ems in 2008

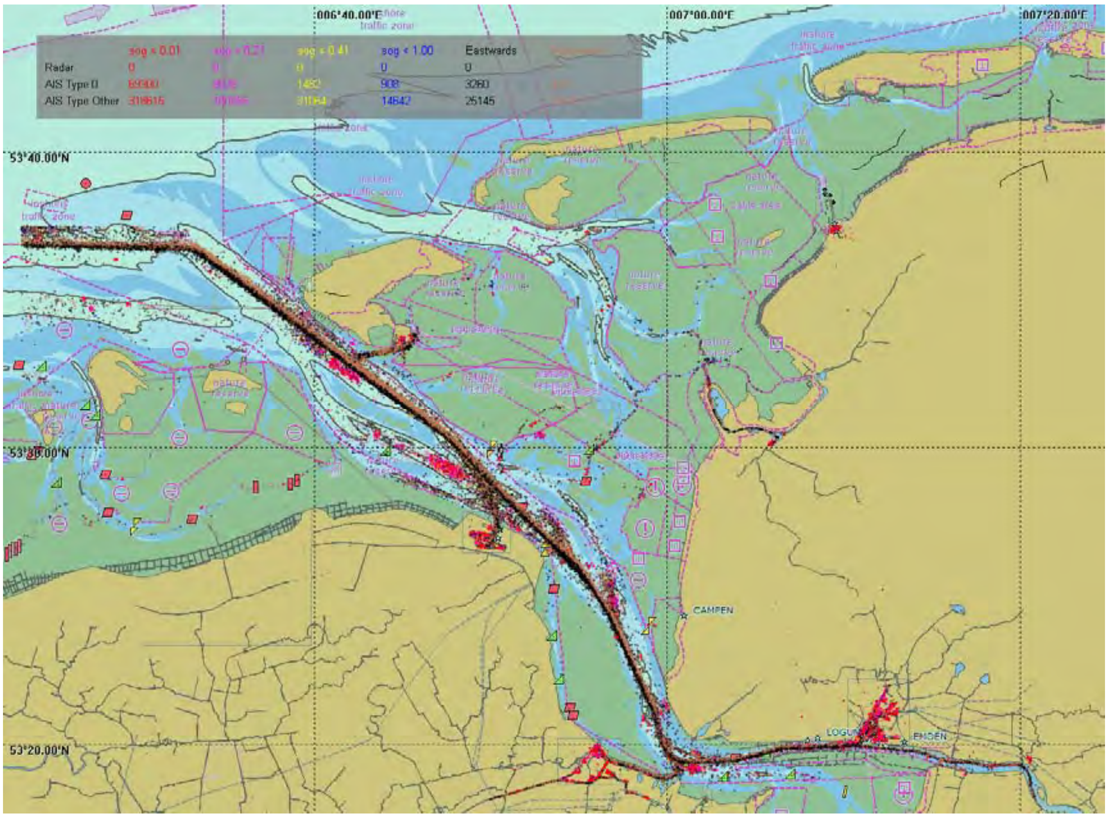

Figure 4-3   Traffic in the Ems in 2009

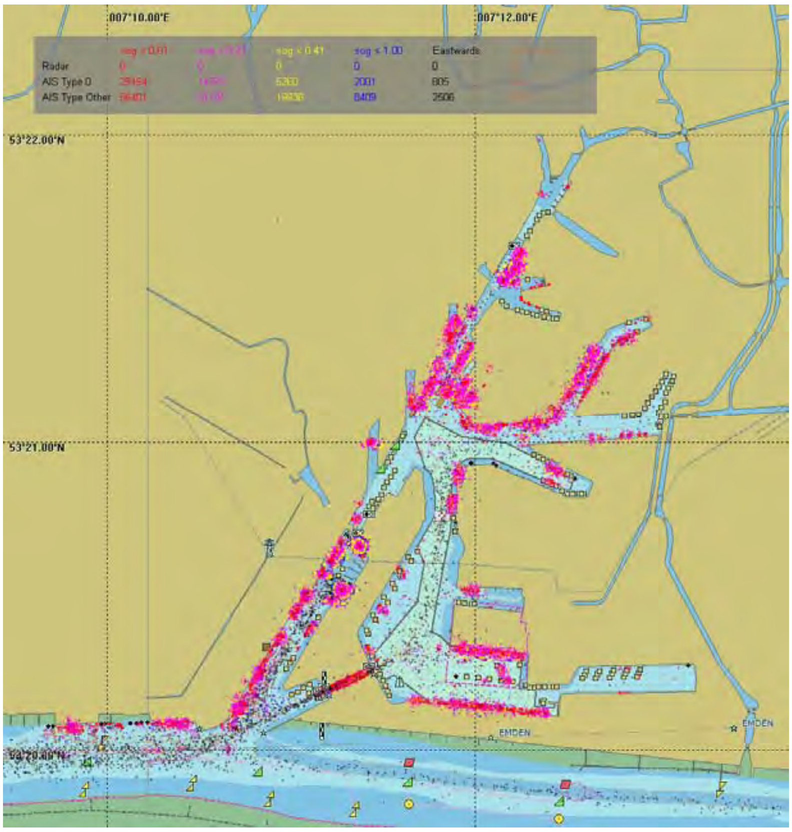

Figure 4-4   Traffic in the Emden in 2008

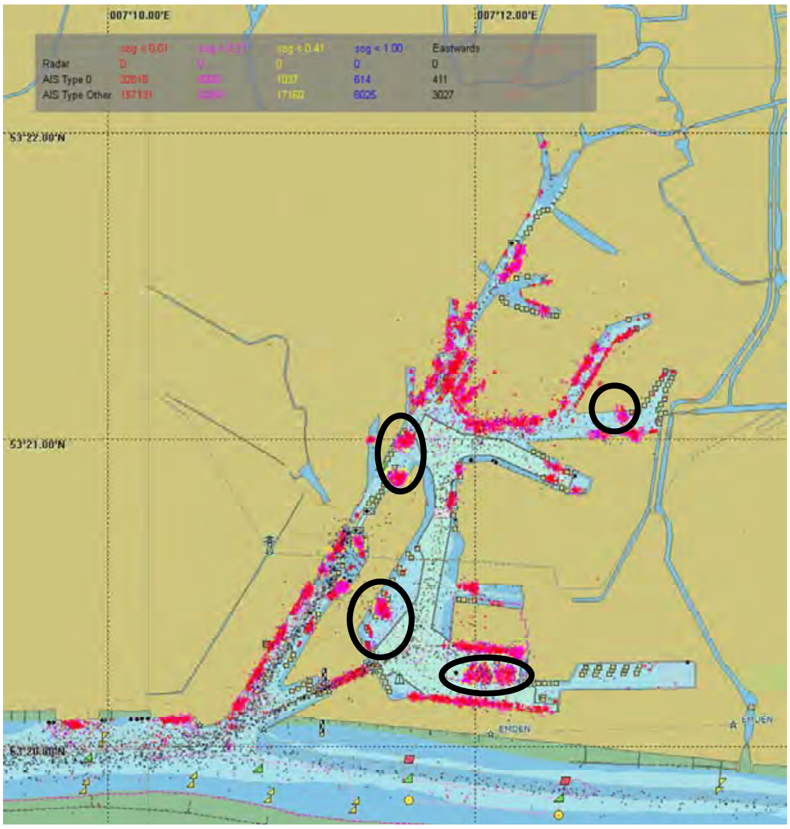

Figure 4-5 Traffic in the Emden in 2009

4.6 The spatial distribution of the emissions

All substances show more or less the same spatial distribution because there is a strong relation between the emissions and the shipping routes. Therefore only the emission spatial distribution of CO_2 is presented for the four port areas and for the NCS in the next figures. Two figures are composed for each area. The first figure contains the emission density of CO2 in kton/km^2. The second figure shows the increase of the emission in 2009 compared to the emission in 2008. To make it easier to compare the emissions of different areas, the same colour table has been used for all emission densities in 2009. Also the same colour table has been used for the “increase” figures in all port areas. Only for the NCS, a different scale has been used for illustrating the difference between 2009 and 2008. The reason is that the differences on the NCS are smaller, because the differences are more smoothed by the larger grid cells of 25km^2 compared to the 0.25 km^2 grid cells in the port areas.

In all figures of the port areas with the emissions in 2009 – the emissions of 2008 a decrease of the emissions show a decrease of emissions in the fairways and an increase in the areas with the berths. Figure 4-9 for Rotterdam shows further a little move of the activities from the more inland berths to the berths in Europort and Maasvlakte.
Figure 4-15 for the NCS shows fewer emissions in the shipping routes and more emissions in the anchorage areas.

Figure 4-6 CO_2 emission in the Western Scheldt by ships with AIS in 2009

Figure 4-7 CO_2 emission in the Western Scheldt by ships with AIS; emissions in 2009 – emissions in 2008

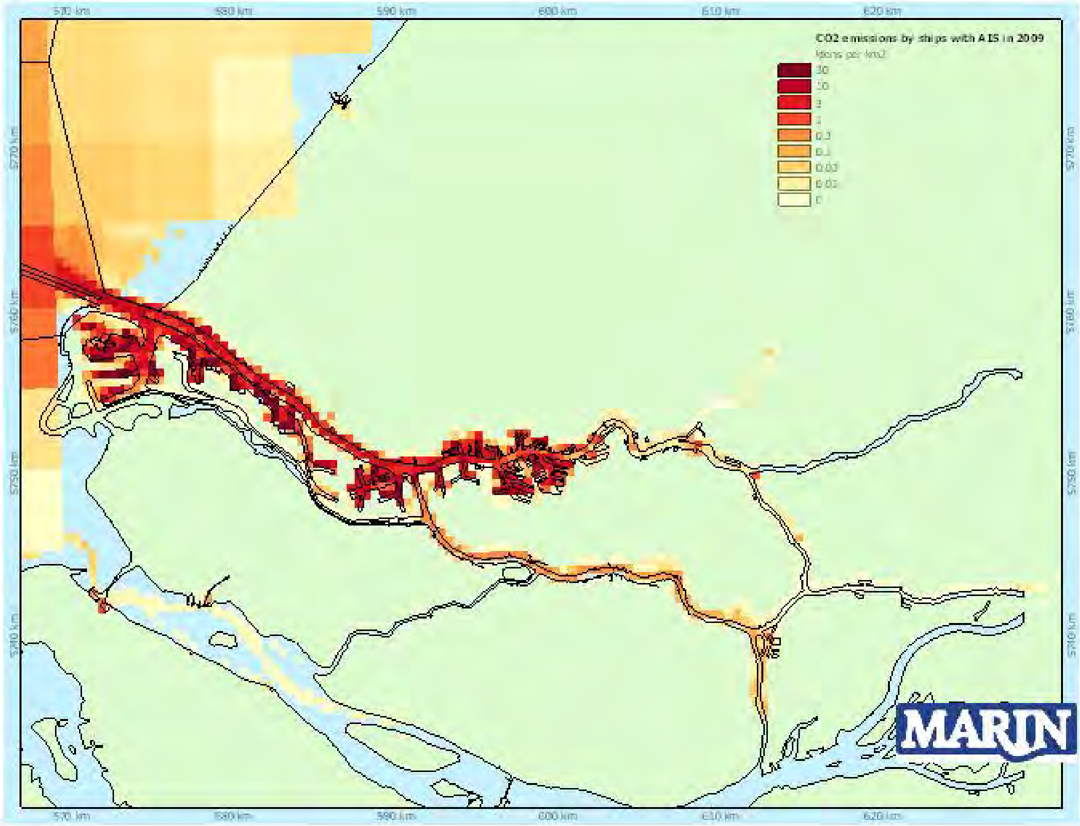

Figure 4-8 CO_2 emissions in the port area of Rotterdam by ships with AIS in 2009

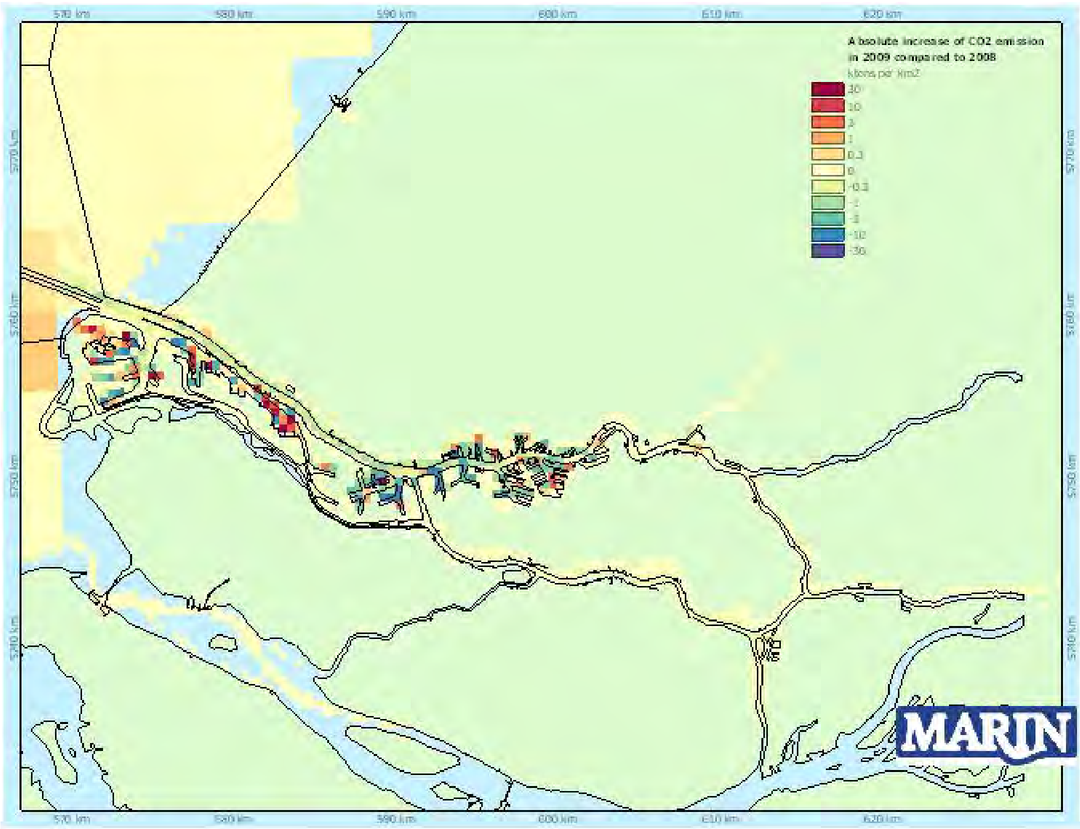

Figure 4-9 CO_2 emissions in the port area of Rotterdam by ships with AIS: emissions in 2009 – emissions in 2008

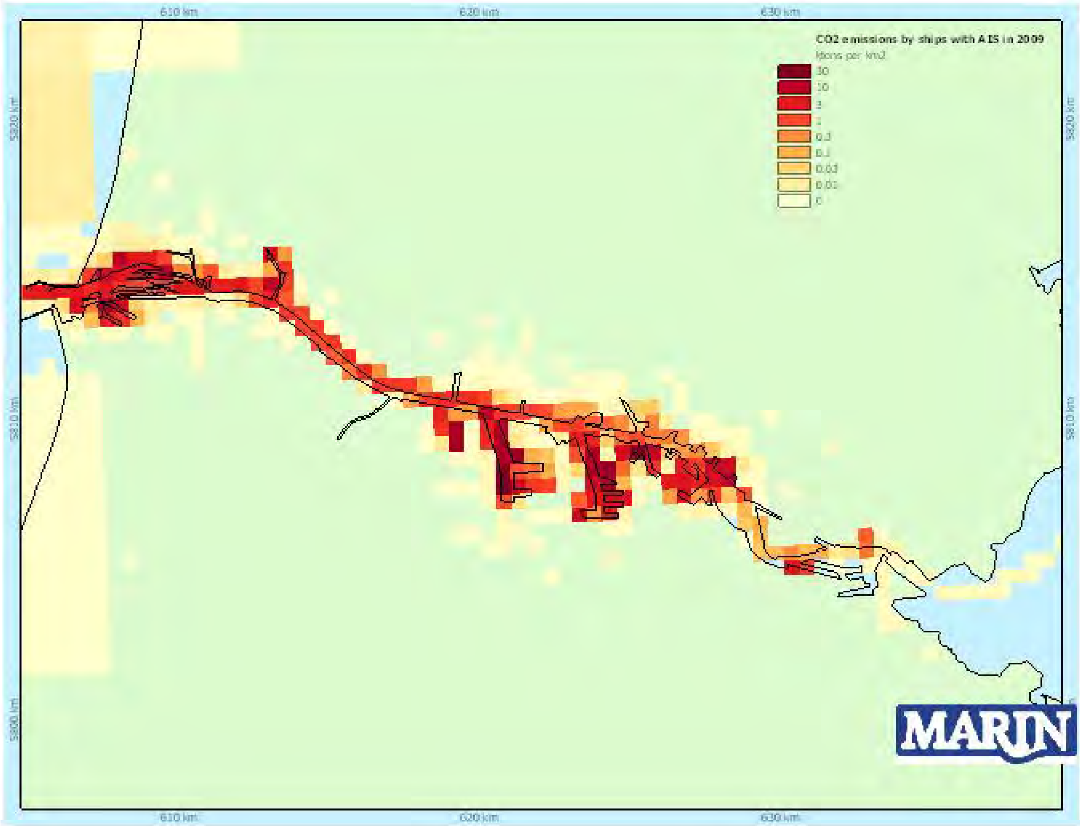

Figure 4-10 CO_2 emissions in the port area of Amsterdam by ships with AIS in 2009

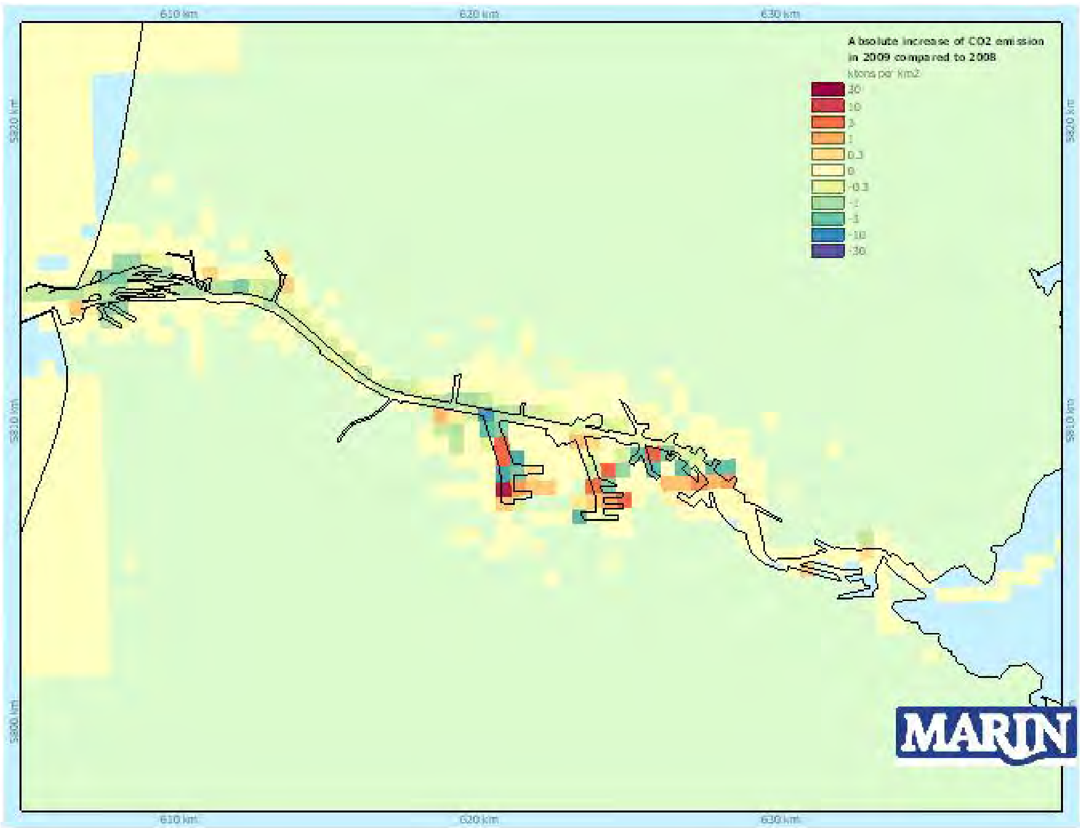

Figure 4-11 CO_2 emissions in the port area of Amsterdam by ships with AIS: emissions in 2009 – emissions in 2008

Figure 4-12 CO_2 emissions in the Ems area by ships with AIS in 2009

Figure 4-13 CO_2 emissions in the Ems area by ships with AIS: emissions in 2009 – emissions in 2008

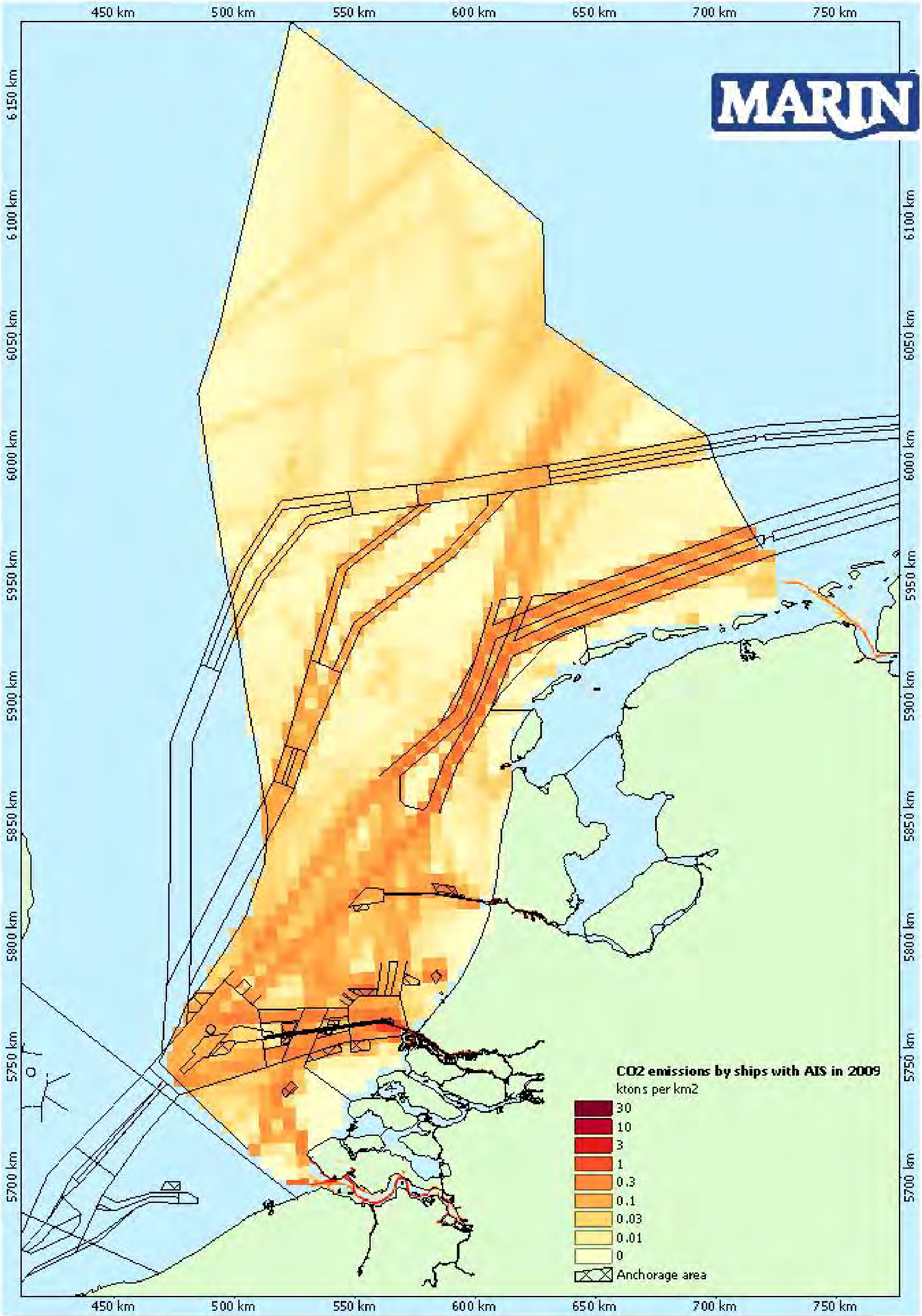

Figure 4-14 CO_2 emissions in the NCS (plus port areas) by ships with AIS in 2009

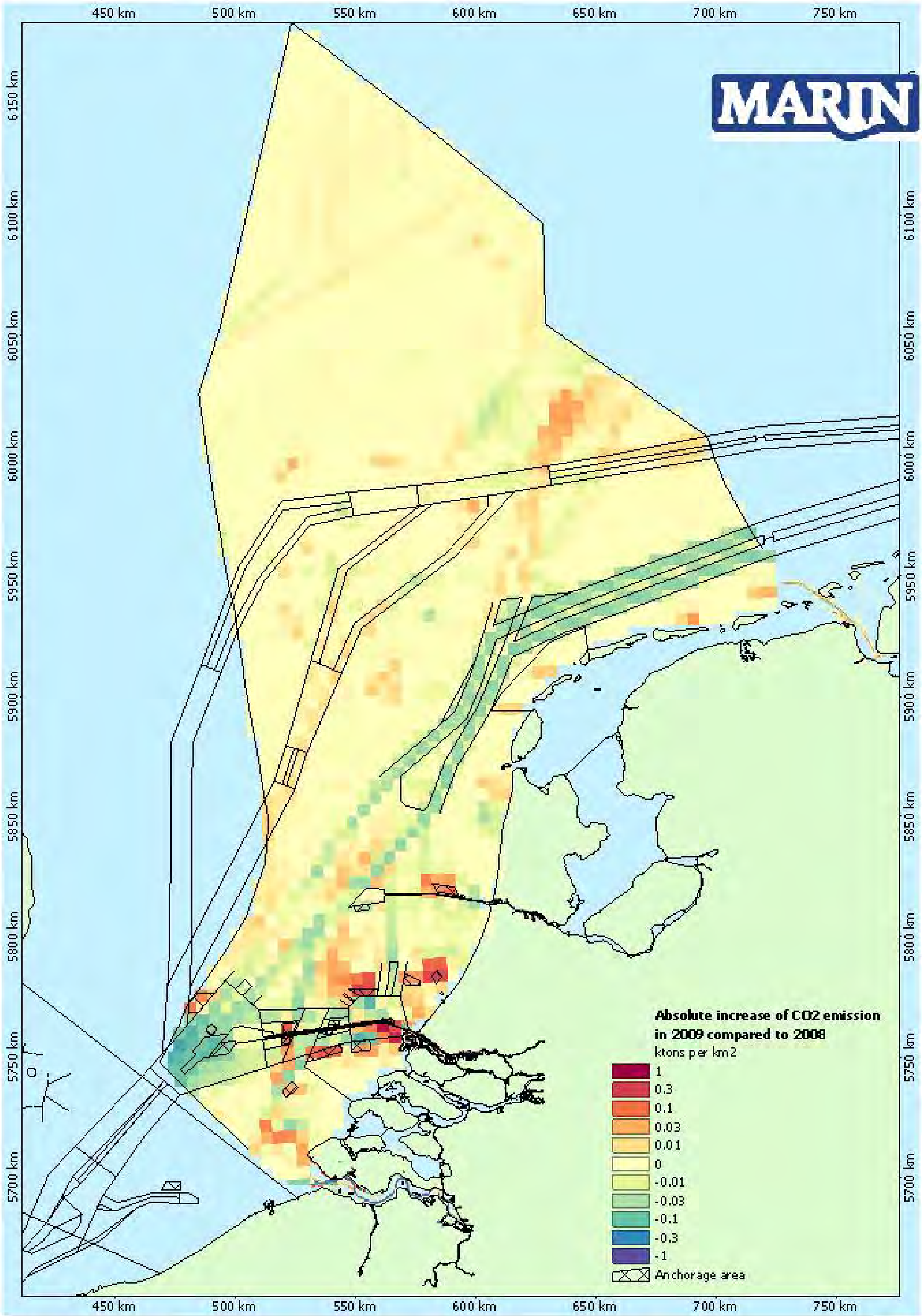

Figure 4-15 CO_2 emissions in the NCS (plus port areas) by ships with AIS: emissions in 2009 – emissions in 2008

5 EMISSIONS IN OSPAR REGION II, THE GREATER NORTH SEA

5.1 Approach

The OSPAR Region II, called the Greater North Sea, is the area between 48° and 62° N and 5°W and 13°E. MARIN has no access to AIS data for this whole area. For the estimation of the emissions in the Greater North Sea an extrapolation has been performed based on the traffic database of SAMSON. Figure 5-1 shows all traffic links defined within the traffic database of 2008.

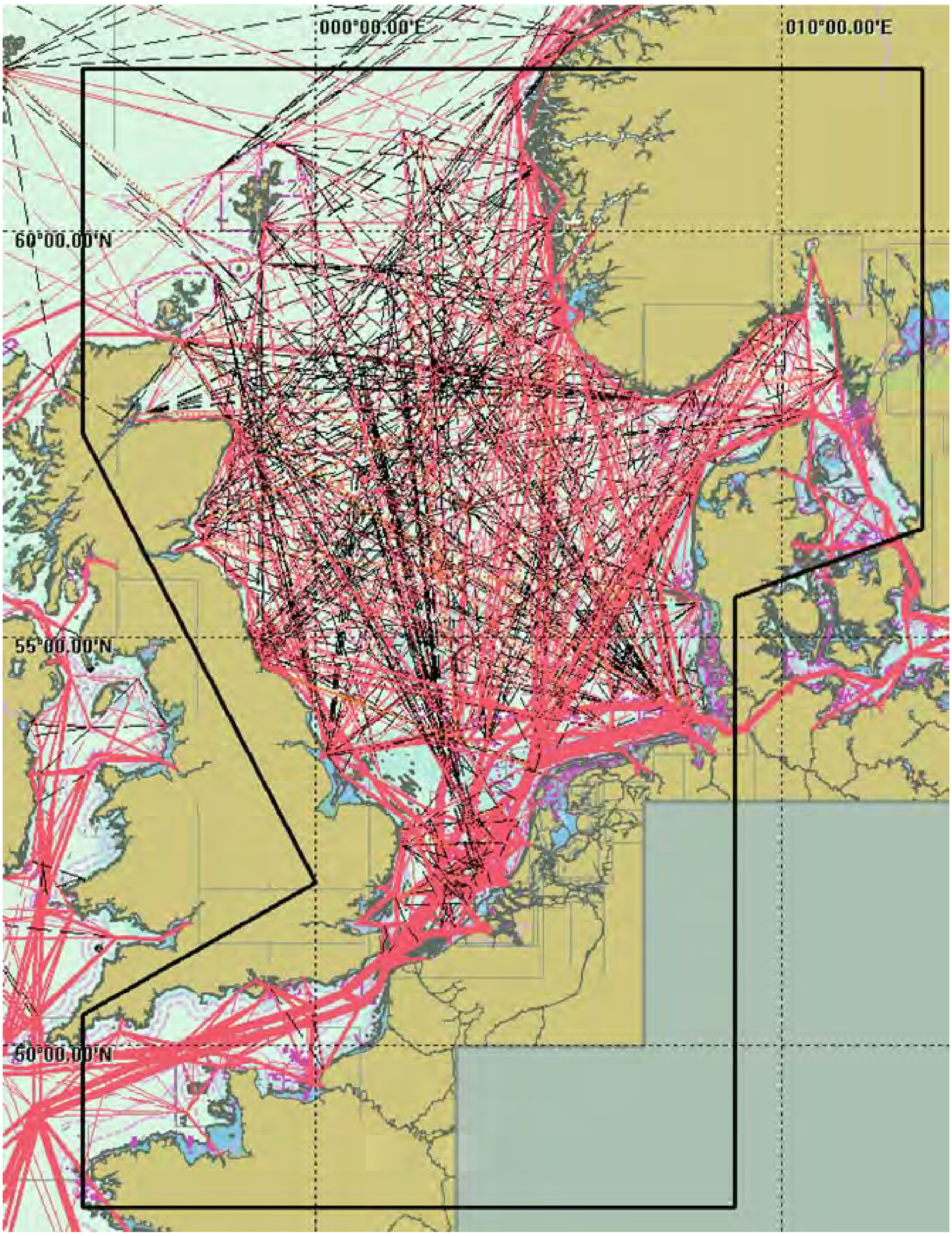

Figure 5-1 Traffic links in OSPAR Region II (thick black frame). The width indicates the intensity of ships on the link (red represents a higher intensity than black).

The black lines represent links with less than one movement per month. The red lines describe the traffic links with more movements. The width indicates, on a non linear base, the number of movements per years. The traffic links in Dover Strait represent about 40,000 movements in one direction per year.

The traffic database of SAMSON contains the number of ship movements per year for each traffic link spread over 36 ship types and 8 ship size classes. Further the database contains the lateral distribution of each traffic link, thus how the ship movements are divided over a crossing line. All safety calculations with SAMSON use the traffic database.
The most appropriate output that can be used from SAMSON is the output of the average number of ships in each grid cell. In this typical calculation the lateral distribution is not used. It is assumed that all ships sail over the centre line of the traffic link. The average number of ships of type i and class j in grid cell c is calculated in SAMSON with:

$$Ships_{cij} = n_{ijk} \frac{L_k}{v_{ij}}$$

Herein is:

- n_{ijk} the number of ship movements of type i and size j over link k per year in 2008 (here divided by the number of hours per year for the right unit);
- L_k the length of the link k within the grid cell in nautical miles;
- v_{ij} the average speed in knots of ship type i and size j.

Based on analyses in the past, SAMSON uses 90% of the service speed for v_{ij}. However, the AIS data of 2008 has learnt that the average speed in 2008 was significantly less. In [2] it was derived from the AIS that the speed was about 80% of the service speed instead of the 90% assumed in SAMSON. The main reason for this phenomenon was the crisis, that has led to a decrease in transport freight, thus indirectly to more idle time. This “idle time” is amongst others used to sail with reduced speed, which delivers a considerable saving of fuel costs.

Therefore, it is better to base the emissions in the OSPAR Region II on the number of ship miles sailed in each grid cell. This can be calculated from the average number of ships by assuming that the ships sail with 90% of the service speed, as assumed in SAMSON. Subsequently the number of shipping miles per ship type and size class is multiplied with the average emission per mile for the corresponding ship type and size class on the Netherlands Continental Shelf based on the AIS data of 2009. This includes the real speed distribution of 2009 at sea. The emission of ships type i and size j in each grid cell c of the OSPAR Region II can be calculated with:

$$Emission_{cij} = n_{ijk} \cdot L_k \cdot \frac{Emission_{NCS_{ij}}}{D_{NCS_{ij}}}$$

Herein is:

- $Emission\_NCS_{ij}$ total emission in the NCS for ship type i and size j
- D_NCS_{ij} total distance in nautical miles sailed by ships type i size j in the NCS.

The time the ship is in a grid cell is proportional to 1/speed and the produced emission per hour is proportional to the third power of the speed. Thus the emission in the grid cell and each other area is proportional to the second power of the speed.

The average emission per nautical mile for each ship type and ship size as determined from the AIS data of 2009 in the NCS, contains implicitly the behaviour of the ships in 2009, thus also the reduced speed.

With this approach it is assumed that the average emission per ship type and size per nautical mile in the NCS is representative for the whole OSPAR Region II, thus that the speed of a ship at sea is not dependent on the geographical location.

A correction has to be applied because the year 2009 for which the emissions in OSPAR Region II have been calculated differs from the year 2008 of the traffic database of SAMSON. This correction is essential, because it has been observed that the traffic volume in 2009 is decreased with respect to 2008 by the crisis that started for the transport over sea in the last months of 2008 and continued during the whole year 2009. The number of calls in most ports was lowered. For both 2008 and 2009, it was determined from the AIS data how many nautical miles were travelled in the NCS, spread over all ship type and ship size classes. For each individual ship type class i and ship size class j, the ratio between the number of miles travelled in 2008 and 2009 has been determined from the AIS data. This factor derived for the NCS is applied to the whole OSPAR Region II area and is:

$$F\_traffic_{ij} = \frac{AIS\_Nautical\_miles_{2009_{ij}}}{AIS\_Nautical\_miles_{2008_{ij}}}$$

This correction factor per individual ship type and size accounts for different impacts of the crisis on tankers, container ships etc. Also the impact can be different for larger ships than for smaller ships. It is assumed that the impact on the traffic volume in the NCS is representative for the whole OSPAR Region II.

5.2 Results for OSPAR Region II

The emissions for the total OSPAR Region II have been calculated for each substance separately and are summarized in Table 5-1. The average number of ships at sea in the OSPAR Region II amounts to 890.5. This is the number calculated with SAMSON after applying the corrections for the difference between the assumed speed in SAMSON and the real speed as found in the AIS data of 2009 and after applying the correction factor for the traffic volume in 2009.

Table 5-2 contains the emissions in 2009 for the NCS based on the SAMSON database. The emissions in the NCS amount to approximately 19% of the emissions in the OSPAR Region II, while the number of ships in the NCS is only 17.8% (=158.29/890.55). This is because an average ship in the NCS is larger than an average ship in the OSPAR Region II.

The calculations for OSPAR region II are performed for vessel types that are defined as route-bound in the SAMSON model. As fishing vessels are normally categorized as non route bound vessels, the large fishing vessels that were observed in the voyage database of Lloyd's have been reported as a part of EMS vessel type 9, miscellaneous.

Table 5-1 Emissions of ships in ton in OSPAR Region II for 2009, based on SAMSON

Nr	Substance	Emission in ton in 2009			Emission in 2009 as percentage of 2008		
		moving		Total	moving		Total
		Auxiliary Engine	Main Engine		Auxiliary Engine	Main Engine	
1237	NMVOC	1,235	11,006	12,240	99.7%	96.0%	96.4%
4001	SO_2	16,081	143,465	159,546	104.2%	97.6%	98.2%
4013	NO_x	36,490	397,289	433,779	101.5%	96.5%	96.9%
4031	CO	6,915	65,545	72,460	101.9%	98.8%	99.1%
4032	CO_2	1,938,676	15,494,294	17,432,970	103.2%	97.4%	98.0%
6601	Aerosols MDO	2,045	449	2,494			
6602	Aerosols HFO	0	21,755	21,755			
6598	Aerosols MDO+HFO	2,045	22,204	24,249	103.9%	97.3%	97.8%
Average number of ships in area		890.55			96.2%		

Table 5-2 Emissions of ships in ton in NCS for 2009, based on SAMSON

Nr	Substance	Emission in ton in 2009			Emission in 2009 as percentage of 2008		
		moving		Total	moving		Total
		Auxiliary Engine	Main Engine		Auxiliary Engine	Main Engine	
1237	NMVOC	229	2,100	2,329	99.3%	95.4%	95.7%
4001	SO_2	3,016	27,573	30,589	103.7%	96.6%	97.3%
4013	NO_x	6,781	76,633	83,413	101.1%	95.7%	96.1%
4031	CO	1,286	12,625	13,911	101.5%	98.2%	98.5%
4032	CO_2	361,374	2,970,723	3,332,097	102.8%	96.4%	97.1%
6601	Aerosols MDO	383	77	461			
6602	Aerosols HFO	0	4,208	4,208			
6598	Aerosols MDO+HFO	383	4,285	4,669	103.4%	96.5%	97.0%
Average number of ships in area		158.29			95.8%		

In Table 5-3 the calculated emission from SAMSON is compared with the emissions determined from the AIS data of Table 4-12. The results are very close to each other, which means that the method with SAMSON seems to be very useful. However, the two methods are not completely independent, because the average emission per nautical mile for each ship type and size calculated from the AIS data has been used within the calculation of the emissions from the database of SAMSON. Thus the nice fit of the results means that the SAMSON traffic database fits well with the reality described by the AIS data. The reason that the average number of ships from SAMSON is much less than the average number of AIS (93.9%) is caused by the considerable number of service vessels as pilot tenders, tugs, service vessels, dredgers that are included in the AIS data and not in the route bound traffic of SAMSON (described in more detail in [2]).

Table 5-3 Emissions of ships in ton in the NCS, based on SAMSON and AIS

Nr	Substance	Emission in ton in 2009			Emission in 2009 based on SAMSON as percentage of emission in 2009 based on AIS		
		Moving		Total	moving		Total
		Auxiliary Engine	Main Engine		Auxiliary Engine	Main Engine	
1237	NMVOC	229	2,100	2,329	98.0%	101.1%	100.8%
4001	SO_2	3,016	27,573	30,589	99.6%	102.2%	101.9%
4013	NO_x	6,781	76,633	83,413	98.5%	102.5%	102.2%
4031	CO	1,286	12,625	13,911	98.5%	100.8%	100.6%
4032	CO_2	361,374	2,970,723	3,332,097	98.8%	102.2%	101.8%
6601	Aerosols MDO	383	77	461	99.5%	98.3%	99.3%
6602	Aerosols HFO	0	4,208	4,208		102.3%	102.4%
6598	Aerosols MDO+HFO	383	4,285	4,669	99.5%	102.3%	102.1%
Average number of ships in area		158.29			93.9%		

Figure 5-2 contains the spatial distribution of the CO_2 emissions in the OSPAR Region II. When the emissions on the NCP of Figure 5-2 are compared with the emissions of CO2 on the NCS based on AIS of Figure 4-14, it shows that the emissions of Figure 5-2 are more concentrated on the traffic lines. This is because in the extrapolation it was assumed that all ships sail over the centre line of each shipping route. Furthermore, the emissions based on AIS contain more ships sailing outside the main routes, as supply vessels and other work vessels.

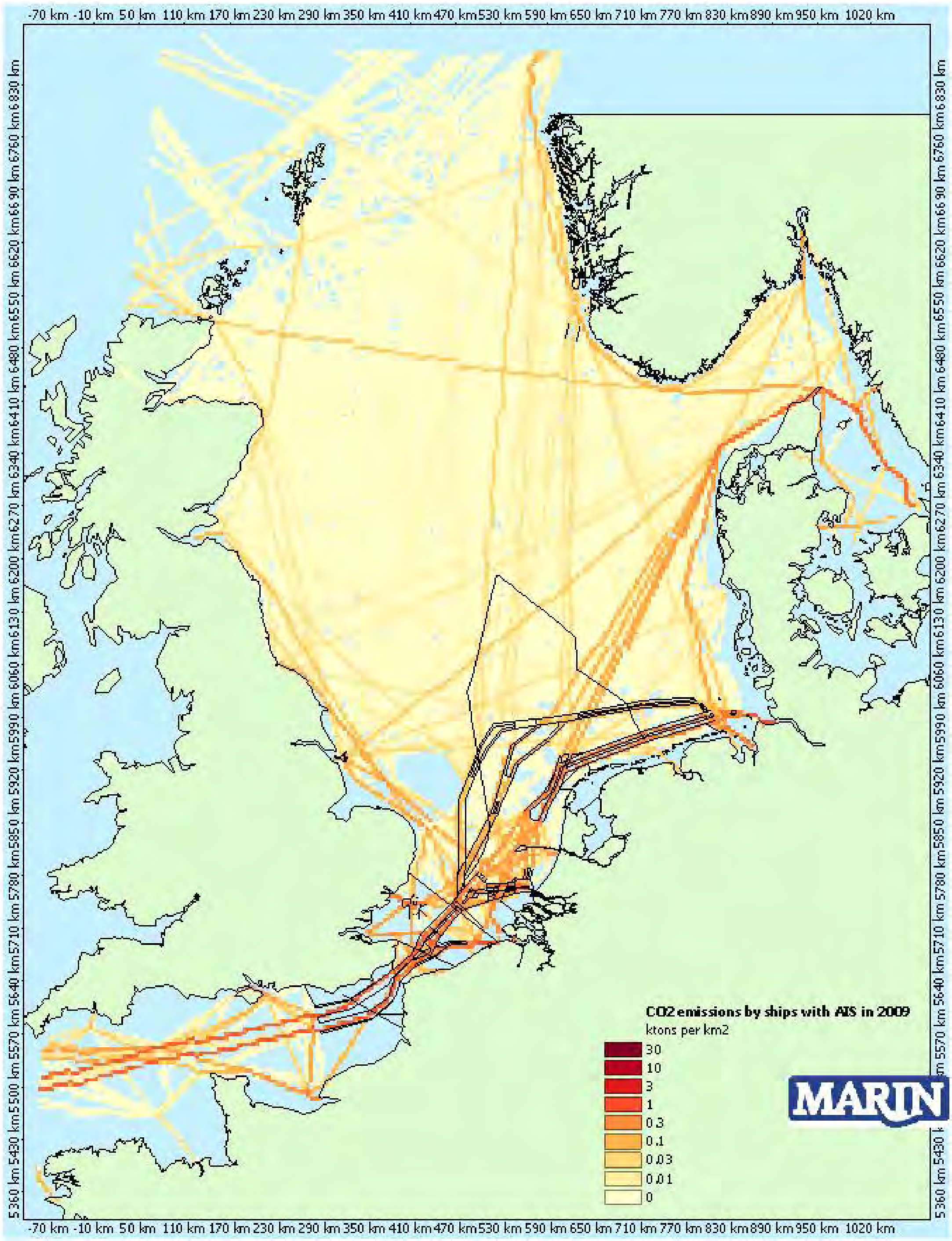

Figure 5-2 CO_2 emissions in OSPAR Region II by route bound ships

6 COVERAGE OF THE AIS DATA

In Chapter 3 the completeness of the data has been described by the number of files received from the Netherlands Coastguard. For 2009 a completeness of 99.996% was reached, which means that no correction factor was required this time. In 2008 a correction factor of 1.025 was used. But there is another type of completeness, namely, are all areas covered completely? This is illustrated in Figure 6-1, in which all base stations that deliver data to the Netherlands Coastguard are plotted. The circle with a radius of 20 nautical mile around each base station illustrates the area covered by that base station.

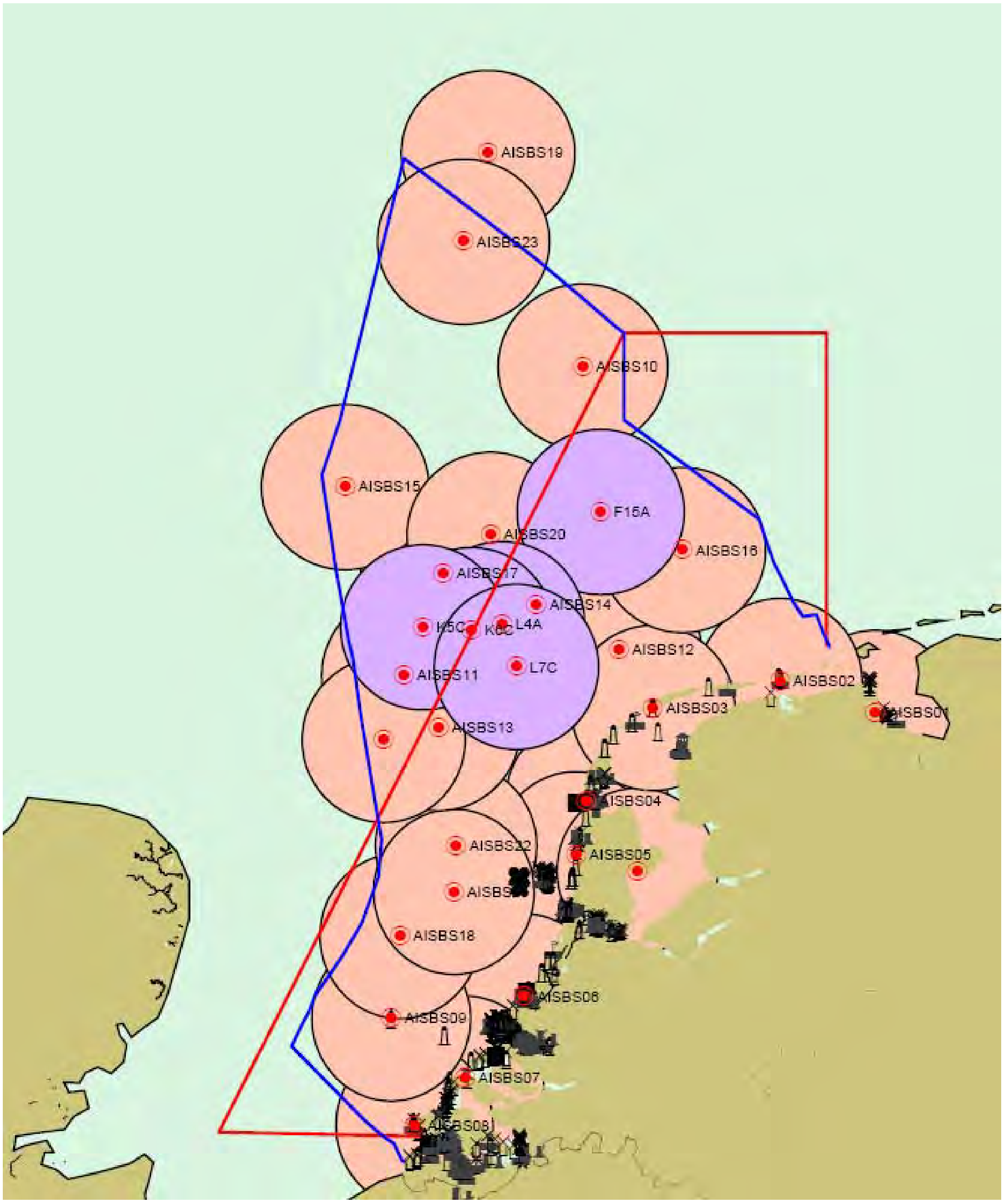

Figure 6-1 AIS base stations used delivering data to the Netherlands Coastguard, the blue lines are from the NCS

In reality the coverage varies with the atmospheric conditions. The figure shows that some areas are covered by several base stations, while other areas are covered by only one base station. So there are a few weak spots in the NCS. One weak spot is the area in the northern part of the NCS that is not covered at all. This is not a real shortcoming because the shipping density is very low in this area. Further, known weak spots are the spot above the Wadden on the border between the NCS and the German sector and the spot SW of Rotterdam. Especially this last location is a shortcoming because this is a very dense shipping traffic area. MARIN has signalled this also in other projects. In December 2010, the Coastguard has started up an investigation. Is this really a weak point, how is that possible and what can we do to improve that? In case such an improvement will be realized in 2011, it can be expected that the emissions based on AIS will increase there.

Furthermore, an increase of the emissions is expected by the stepwise mandatory introduction of AIS transponders on fishing vessels, also those under 300 Gross Tonnage. Finally, in 2014 all fishing vessels larger than 15 meter are obliged to be equipped with an AIS transponder.

Improvement of the coverage of AIS or the extension of the user group of AIS can cause a growth in the reported emissions that cannot be assigned to changes in emissions of ships. Therefore, this remains a point of attention in the future to prevent drawing wrong conclusions.

7 CONCLUSIONS AND RECOMMENDATIONS

The main delivery of this study is a set of databases containing the emissions per grid cell for each substance, EMS ship type class, ship size class, moving / not moving and EU / non-EU flag, inside/outside 12 miles zone. These databases can be used in studies for which a detailed spatial distribution of the emissions is required.

Because fishing vessels are not obliged to have an AIS transponder, it was agreed not to take fishing vessels into account in this study. However, the AIS data of all vessels of which it was possible to make a connection with the ship characteristics database of LLG, has been used for the emission calculation, including fishing vessels. This will mainly be large fishing vessels, such as fish factories that are larger than 300 Gross Tonnage. The results for the Netherlands Continental Shelf based on AIS data therefore contain the EMS ship type Fishing. As the calculations for the OSPAR region II are only performed for vessel types that are defined as route bound in the SAMSON model, and fishing vessels are normally categorized as non route bound vessels, these large fishing vessels are reported as a part of EMS vessel type 9, miscellaneous.

The conclusions and recommendations made here are based on the calculated totals for (1) the NCS, (2) the Dutch port areas and (3) OSPAR Region II where port areas have been excluded, and on the findings during the execution of the study.

7.1 Conclusions and findings

The conclusions of this study are:

- The AIS data is an excellent source for the determination of the spatial distribution of emissions by ships in the Netherlands Continental Shelf and the port areas;

- The calculation based on AIS delivers the effect of all changes by:
    - an economic crisis, leading to less traffic and lower speeds;
    - new transport flows;
    - changes in use of ship types and ship sizes;
    - new ships with other emission factors;
    - measures, adapting the emissions factors.

- The grid size of 5000 x 5000 m for the Netherlands Continental Shelf and 500 x 500 m for the other areas could be handled;

- The average number of ships on the NCS based on AIS corresponds very well with the number based on SAMSON. Only the number of pilot tenders, tugs, service vessels and dredgers is not included in the route-bound database of SAMSON;

- The emissions in the OSPAR Region II could be estimated from the SAMSON traffic database of 2008, corrected for the change in traffic volume between 2008 and 2009, and the emission per nautical mile in the NCS. The traffic correction factor and emission per nautical mile were derived from the AIS data of 2008 and 2009 for the NCS, assuming that they apply for the whole of the North Sea.

- Improvement of the coverage of AIS or the extension of the group of AIS-users (mandatory use of fishing vessels above 15 m and voluntary use of recreational vessels) can cause a growth in the reported emissions that cannot be assigned to changes in emissions of ships. Therefore, this remains a point of attention in the future to prevent drawing wrong conclusions.

Conclusions from the emissions of 2009 compared to the emissions of 2008:

- In general the emissions in 2009 are lower than in 2008. Only in the Ems, the shipping activities have increased in 2009, what is confirmed by the statistics of the Nationale Havenraad. The highest increase has been contributed by the not moving ships, especially in the port of Emden.

- The emissions of ships at anchor are very limited, less than 4% in the NCS while 37% of all ships in the NCS are at anchor.

7.2 Recommendations

It is recommended to continue with a yearly determination of the emissions. A longer sequence will give more insight in the trends.

In this study and also in other studies, it was observed that the most western part of the TSS to Rotterdam, just located in the NCS, is not covered so well. This weak spot has been discussed with the Netherlands Coastguard and they will investigate this further. Hopefully this will lead to an improvement in near future. Because such an improvement in the coverage can have some impact on the calculated emissions in this area, this will require special attention in future.

To perform the calculations, the latest ship characteristics database (costs about GBP 4,000) has to be purchased, because otherwise ships built in the last year are missing in the shipping characteristics database, thus they could not be dealt with correctly.
The emission factors have to be determined for the new database by TNO.

The SAMSON database has been composed from all voyages crossing the European waters. The voyage database collected by LLG, with port to port voyages, costs €30,000 for one year data. Next the SAMSON traffic database has to be composed from these voyages. Because this is rather expensive, a new traffic database in SAMSON is only created every fourth or fifth year. This traffic database in SAMSON is used during a number of years. Changes in the traffic patterns by for example, changes in the Traffic Separation Schemes and the offshore wind farms are implemented by rerouting the voyages of the last voyage database.
It is recommended to keep an update frequency of once every four years. A yearly update of the emission in the OSPAR Region II can be done based on an older traffic database of SAMSON.

It is recommended to investigate whether it is possible to derive from the AIS data the time at berth, so that for ships that are laid up, an adjusted emission factor can be used. However, this will have a considerable impact on the data collection from the AIS data, because at this moment the time berthed is not collected. An extra parameter can lead to memory problems. Thus in case this is required, this problem has to be solved.

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APPENDIX A: EMISSION FACTORS

Written by J. Hulskotte of TNO

1 EMISSION FACTORS

1.1 Sailing and Manoeuvring

1.1.1 Main Engines

During sailing and manoeuvring, the main engine(s) are used to propel/manoeuvre the ship. Their emission factors per ship, in g per kWh, were determined by TNO according to the EMS protocols [1, 2]. Recently an English language report [4] was published, which covered the emission calculations in accordance with the EMS protocols. In the emission factor calculation, the nominal engine power and the speed are used. For this study these parameters were taken from the April 2009 shipping database. It is assumed that a vessel requires 85% of its maximum continuous rating power (MCR) to attain the design speed (its service speed). The following formula is used to calculate the emission factor per nautical mile.

Formula 1:

$$EF^{'} = EF \cdot \frac{P \cdot \%MCR}{V}$$

where:
EF' the emission factor expressed as kg per nautical mile
EF the emission factor expressed as kg per KWh
P the engine power [Watts]
%MCR the percentage of the MCR
V is the vessel speed [knots]

However, ships do not always sail at their designed speed. As such, the actual power use has to be corrected for the actual speed. The power requirements are approximately proportional to the ship's speed to the power of three. For very low speeds this approximation would underestimate the required power, since manoeuvring in restricted waters increases the required power. Furthermore, engines are not capable of running below a certain load (minimal fuel consumption of 10% compared to full load). To account for this, the cubed relationship between speed and power is adjusted slightly to:

Formula 2:

$$CRS_{cor} = \frac{\left[\left(V_{actual} / V_{design}\right)^{3} + 0.2\right]}{1.2}$$

Note that the Correction Reduced Speed factor CRS_{cor} has to be capped at a maximum of 1.176, since this is the value for which 100% engine power is reached.

At speeds around the design speed, the emissions are directly proportional to the engine's energy consumption. However in light load conditions, the engine runs less efficiently. This phenomenon leads to a relative increase in emissions compared to the normal operating conditions. Depending on the engine load, correction factors specified per substance can be adopted according to the EMS protocols. The correction factors used are shown in Table A- 1. The correction factors for an MCR over 50% are equal to1.

Table A- 1 Correction factors

Power % of MCR	PM	CO	VOS	NOx
10	1.63	5.22	4.46	1.34
15	1.32	3.51	2.74	1.17
20	1.19	2.66	2.02	1.10
25	1.12	2.14	1.65	1.06
30	1.08	1.80	1.42	1.04
35	1.05	1.56	1.27	1.03
40	1.03	1.38	1.16	1.02
45	1.01	1.23	1.09	1.01
50	1.01	1.12	1.03	1.00

1.1.2 Auxiliary Engines and Equipment

Aside from the main engines, most vessels have auxiliary engines and equipment that provide (electrical) power to the ship's systems. There is very little information available on the use of auxiliary engines. Perhaps the best estimate to date has been made in the *Updated 2000 Study on Greenhouse Gas Emissions from Ships* report (Buhaug et al., 2008, [3]), to which many ship experts contributed. The percentage of the auxiliary power compared to the main engine power as presented in Table 14 of the Buhaug et al. report, was used in this study [3]. For those ships included in the *Register of Ships,* the auxiliary power of each individual ship was multiplied with the percentage given in Table 14. For the other ships, the percentage from Table 14 was multiplied with the main power of each individual ship.

1.2 Berthed

When a ship is berthed, the main engines are stopped. The auxiliary engines and equipment will be kept in service to provide (electrical) power to the ship's systems, onboard cargo handling systems and accommodations. The emission factors for this berthed condition are also based on the EMS protocol. However, instead of a fixed berth time per ship type, the AIS data is used to get an accurate value for the length of time that a vessel is berthed.

1.3 Connection between Emission Factors and Ship Data within the LMIU Database

In order to select the appropriate emission factors of an individual ship (or to calculate the emission factor per mile sailed), it is necessary to know the characteristics of the ship, as well as its engines and fuel use.
To select engine emission factors (EF) according to the EMS-protocol [1], the following engine and fuel characteristics are required:

- Engines year of build (grouped in classes)
- Engine type (slow speed or medium/high speed)
- Engines maximum revolutions per minute (RPM), from 2000 year of build
- Type of fuel used (Heavy Fuel Oil of Marine Diesel Oil)

In the next section the procedure, which has been used to complete the necessary data for the calculation of emission factors, will be described for each individual ship.

The main engine power and design speed of a ship are also needed to calculate the actual emission factor. These data were elaborated upon from an extract from the LMIU Database, containing data for 106,043 individual ships. In this way, emission factors can be derived for almost any seagoing ship, sailing the world's seas.

1.3.1 Engine Emission Factors

Table A- 1 to Table A- 8 show the engine emission factors per engine type and fuel type expressed in grams per unit of mechanical energy delivered by ships engines (g/kWh). Full implementation of the SECA according to the IMO in 2008 has been assumed. Therefore the sulphur percentage in heavy fuel oil is set on 1.5% and the sulphur percentage in marine diesel oil is assumed to be 0.8%.

Table A- 2 Emission factors applied on slow speed engines (SP) operated on heavy fuel oil (HFO), (g/kWh)

Year of build	NOx	PM	SO2	HC	CO	CO2
1900 – 1973	16	1.0	6.3	0.6	3.0	666
1974 – 1979	18	1.0	6.0	0.6	3.0	634
1980 – 1984	19	1.0	5.7	0.6	3.0	602
1985 – 1989	20	1.0	5.4	0.6	2.5	571
1990 – 1994	18	1.0	5.3	0.5	2.0	555
1995 – 1999	15	0.8	5.1	0.4	2.0	539
2000 – 2010	~rpm[1]	0.8	5.0	0.3	2.0	533

Table A- 3 Emission factors applied on slow speed engines (SP) operated on marine diesel oil (MDO), (g/kWh)

Year of build	NOx	PM	SO2	HC	CO	CO2
1900 - 1973	16	0.5	3.4	0.6	3.0	661
1974 - 1979	18	0.5	3.2	0.6	3.0	630
1980 - 1984	19	0.5	3.0	0.6	3.0	598
1985 – 1989	20	0.5	2.9	0.6	2.5	567
1990 – 1994	18	0.4	2.8	0.5	2.0	551
1995 – 1999	15	0.3	2.7	0.4	2.0	535
2000 – 2010	~rpm	0.3	2.7	0.3	2.0	529

[1] Dependant on revolutions per minute

Table A- 4 Emission factors applied on medium/high speed engines (MS) operated on Heavy fuel oil (HFO), (g/kWh)

Year of build	NOx	PM	SO2	HC	CO	CO2
1900 – 1973	12	0.8	6.8	0.6	3.0	713
1974 – 1979	14	0.8	6.5	0.6	3.0	682
1980 – 1984	15	0.8	6.2	0.6	3.0	650
1985 – 1989	16	0.8	5.9	0.6	2.5	618
1990 – 1994	14	0.8	5.7	0.5	2.0	602
1995 – 1999	11	0.7	5.6	0.4	2.0	586
2000 – 2010	~rpm 10[1]	0.7	5.5	0.3	2.0	580

[1] applied on auxiliary engines only

Table A- 5 Emission factors applied on medium/high speed engines (MS) operated on marine diesel oil (MDO), (g/kWh)

Year of build	NOx	PM	SO2	HC	CO	CO2
1900 - 1973	12	0.5	3.6	0.6	3.0	709
1974 - 1979	14	0.5	3.4	0.6	3.0	677
1980 - 1984	15	0.5	3.3	0.6	3.0	646
1985 - 1989	16	0.5	3.1	0.6	2.5	614
1990 - 1994	14	0.4	3.0	0.5	2.0	598
1995 - 1999	11	0.3	3.0	0.4	2.0	583
2000 - 2010	~rpm 9[1]	0.3	2.9	0.3	2.0	576

[1] applied on auxiliary engines only

Table A- 6 Emission factors of gas turbines (TB) operated on marine diesel oil (MDO), (g/kWh)

Fuel	NOx	PM	SO2	HC	CO	CO2
MDO	4.96	0.155	4.96	0.031	0.341	976

Table A- 7 Emission factors of steam turbines (ST) operated on heavy fuel oil(HFO) and marine diesel oil (MDO), (g/kWh)

Fuel	NOx	PM	SO2	HC	CO	CO2
HFO	0.78	0.59	7.1	0.047	0.12	745
MDO	1.65	0.49	3.76	0.047	0.12	740

Table A- 8 Emission factors of NOx dependant on engines RPM

RPM range	IMO-norm (g/kWh)	Emission factor NOx (g/kWh)
< 130 RPM	17.0	0.85 x 17,0
Between 130 and 2000 RPM	$45 \times n^{-0,2}$	$0.85 \times 45 \times n^{-0,2}$
> 2000 RPM	9.8	0.85 x 9.8

1.3.2 Year of Build of Main Engines

For 72,554 ships, the ship engine year of build was directly taken from the field “ENGINE_DOB” from the LMIU Database. For 47,475 ships, this date is assumed to be very certain (value “A” in the field “DOB_QUALIFIER”). In 28,093 cases, the ship engine year of build was assumed to be equal to the ship year of build. For 5,395 cases, the ship engine year build was assumed to be the average of the ship type and/or a ship’s size.

Table A- 9 Method of assessment of engines year of build

Method of assessment	Number	Share
Directly taken from “ENGINE_DOB	74,376	65.2%
Directly taken from “BUILD”	33,582	29.4%
Average of ship type and/or Size	6,120	5.4%
Total	**114,078**	**100.0%**

The uncertainty in a ship engine year of build probably is not a major factor in all over uncertainty in ships emission factors.
Most ships are currently equipped with diesel engines. Engine speed or revolutions per minute (RPM) from diesel engines is an important property with respect to the emission characteristics as expressed by emission factors. Table A- 10 gives a complete overview of all engine types, which were observed in the LMIU Database. Diesel-electric propulsion is found increasingly in tugs, as this configuration is more efficient with a continuous fluctuation of power demand. Besides ships with diesel engines, there are a few hundreds of ships in service that are propelled by steam (engine or turbines). Also, gas turbines are still used in non-military ships. The number of ships with gas turbines may rise in the near future as the thermal efficiency of gas turbines has been enhanced considerably and because some of the engines’ flexibility may be attractive in some sectors (like cruise or passenger transport). In military battle ships, gas turbines are common practice. For all ships, for which the field “ENGINE_TYPE” was not filled in the database, it was assumed that these ships operate diesel engines. Considering the overwhelming number of diesel engines, the attributes of engine types will not introduce major errors in the assessment of emission factors.
Steam propulsion is rather common in LNG-ships because these engines are considered to be very safe and fluctuations in gas boil-off can more easily be absorbed by boilers independent of actual power demand. Recently, by-passes for these problems have been found and in the future, more diesel engines will be introduced in LNG ships mainly because of the improved thermal engine efficiency of diesel engines.

Table A- 10 Engine types in the LMIU-database

ENGINE_TYPE	ENGINE_TYPE_DECODE	Number	Engine type attributed
STM	Steam	518	ST
STT	Steam Turbine	3	ST
No data	No data	41,057	DSL
DSE	Diesel Electric	211	DSL
DSL	Diesel	72,185	DSL
ELC	Electric	19	DSL
GST	Gas Turbine	85	TB
		114,078	

1.3.3 RPM of Diesel Engines

Diesel engines were classified in two classes: slow speed engines (SP) and medium to high speed engines (MS). Diesel engines with a maximum RPM of less than 500 were classified as slow speed (SP) engines, while all other diesel engines were classified as MS.

For 41% of ships, the maximum RPM was provided by the LMIU Database. A good approximation of RPM was derived from most frequent occurring RPM in the "ENGINE_DESIGNATION" records.

A rougher approximation was derived from the average engine RPM per ship type and/or ships size. The fact that bigger ships mostly operate slow speed engines as their main engine, was taken into account. It is expected that an RPM value derived by this method may still result in a reasonable approximation.

Table A- 11 Assessment method of ships diesel engines RPM

Method of assessment	Number	Share
Directly taken from "RPM"	48,012	42%
Most frequent occurring RPM derived from "ENGINE_DESIGNATION"	23,332	20%
Average of ship type and/or size	42,734	37%
Total	**114,078**	**100%**

1.3.4 Power of Main Engines

Emission factors of ships are directly proportional to a ship's main engine power. Special attention was paid to the proper assessment of a ship's engine power. The LMIU Database contains the power data of the main engines in most cases. However, it was found that internal inconsistency can exist sometimes between the data field "brake horse power" (BHP) and the data field "POWER_KW". After considering the data, it was deduced that the field "BHP" most probably gives the correct value for the ship main engine power. However, when "BHP" was not available "POWER_KW" was taken as the second best choice. For most ships, for which power was not indicated in the LMIU Database, engine power was estimated by linear regression (power functions) per ship type against a ship's gross tonnage (GT). The remainder of ship engine power was estimated by averages per ship type and ship size class.

Table A- 12 Assessment method of main engine power

Method of assessment (kW)	Number	Share Number	Share Power
Directly via BHP * 0.746	85,097	75%	92%
Directly via POWER_KW	1,459	1%	1%
Via linear regression	24,577	22%	7%
Average of ship type and/or size	2,945	3%	0%
	114,078	**100%**	**100%**

Parameters for the applied regression functions are given Table A- 13. The resulting fitting functions which were created by means of the least squares approach, taking the mathematical from of:

Power = Coefficient x Gross ^{Power}
Wherein:
Power = Calculated ships main engine power (kW)
Coefficient= Function parameter assessed by linear regression
Gross = Volume of the ship measured in Gross ton (GT)
Power = Function parameter assessed by linear regression

Considering the R^2-coëfficiënts, it can be seen that relationship between power and ships GT is rather strong for most ship types. However, for very heterogeneous ship types such as “Tug/Supply” and “Other”, moderate R^2-coëfficiënts indicate rather weak relationships between ship power and ships GT.

Table A- 13 Parameters used for calculation of main engine power in case of lack of data

Ship type	Coefficient	Power	R^2	N
Bulk carrier	17,4	0,6	0,79	7709
Container ship	1,04	0,97	0,93	4962
General Cargo	4,52	0,75	0,74	14844
Passenger	38,3	0,5	0,61	4286
RoRo Cargo	7,01	0,7	0,86	2898
Oil Tanker	9,05	0,66	0,91	7368
Other Tanker	14,4	0,63	0,9	5734
Fishing	15,7	0,64	0,68	9600
Reefer	2,19	0,9	0,89	1394
Tug/Supply	44	0,47	0,48	7506
Other	71,4	0,46	0,43	14969

1.3.5 Power and Fuel of Auxiliary Engines

Only in a minority of records within the LMIU Database, details are provided for the power of installed auxiliary engines. Furthermore, this provided information is not always clear-cut. In some cases, the number of total auxiliary power is given together with the number of engines and in a few cases the number of engines is given together with individual power of one engine.

Table A- 14 Parameters used for calculation of auxiliary engine power in case of lack of data

Method of assessment	Number	Share %
Directly from LMIU-database	28,971	25%
Derived from main engine power based on ratios within IMO-report	85,039	75%
10% of main engine power	68	0%
	114,078	**100%**

For just 24% of ships, a value of ship auxiliary engine power could be derived from the LMIU Database. The completeness of this data is rather poor in this situation.
In order to cope with this situation, the best estimate available was taken as reported in the Buhaug et al., 2008 study [3]).

1.3.6 Type of Fuel Used in Main Engines

Obtaining a confirmation of the fuel type used by the main engines from the LMIU Database is rather complicated. Earlier versions of the database contained information about the type of fuel tanks (heated or not) that are present on a ship. This data was lacking in the current available database and in order to compensate a new algorithm was derived. Generally it is assumed that large ships are guided by economical considerations and as such they use heavy fuel oil. Following Lloyds [3] we assumed that all ships with an engine power greater than 3,000 kW use heavy fuel oil. Also, ships with engines with more than 1,000 kW may use heavy fuel oil, especially when the engine speed is less than 2,500 RPM. As such, a limitation that the engine power minus 0.8 x RPM must be greater than1000, was introduced. According to this formula a ship with 3,000 kW and 2,500 RPM will use MDO.

Table A- 15 Conditions for application of fuel types in dependence of Power and RPM at diesel engines

Power main engine and RPM	Fuel
Power <= 3000 kW : Power – 0.8 x RPM <= 1000	MDO
Power <= 3000 kW : Power – 0.8 x RPM > 1000	HFO
> 3000 kW all RPM	HFO

1.4 Emissions of Ships at Berth

The procedure for the calculation of emissions from ships at berth is derived from the EMS protocol with some minor modifications. The methodology was recently published in an article in the journal Atmospheric Environment [5]. In the EMS modelling system, a fixed value is assumed for the length of time at berth, for each ship type. In this study, the length of time at berth was derived for each individual event for each ship on the basis of AIS data. Ships with speeds below 1 knot have been considered as ships at berth. Since the year of build of each ship was known, emission factors per amount of fuel dependant on the classification of year of build were applied. The amount of fuel used was calculated from the length of time at berth, ship type and volume in gross tonnes. This amount of fuel was specified for different fuel types, and the engine or boiler in which this fuel is used in accordance to the specification given in the EMS-protocol.

Table A- 16 Fuel rate of ships at berth, (kg/1000 GT.hour)

Ship type	Fuel rate
Bulk carrier	2.4
Container ship	5
General Cargo	5.4
Passenger	6.9
RoRo Cargo	6.9
Oil Tanker	19.3
Other Tanker	17.5
Fishing	9.2
Reefer	24.6
Other	9.2
Tug/Supply	9.2

Table A- 17 specifies Total fuel use over fuel types in dependence of ship types.

Table A- 17 Specification of fuel types of ships at berth per ship type (%)

Ship type	HFO	MDO	MGO/ULMF
Bulk carrier	69	31	0
Container ship	59	41	0
General Cargo	33	67	0
Passenger	25	21	55
RoRo Cargo	25	21	55
Oil Tanker	97	2	1
Other Tanker	84	6	10
Fishing	25	69	6
Reefer	90	10	0
Other	25	69	6
Tug/Supply	25	69	6

Table A- 18 gives figures about allocation of fuel amount over engine types and apparatus during berth.

Table A- 18 Allocation of fuels in engine types and apparatus per ship type (%)

Ship type	Main Engine (SP)	Main Engine (MS)	Power (MS)	Boiler
Bulk carrier	0	0	64	36
Container ship	0	0	46	54
General Cargo	0	0	67	33
Passenger	0	18	49	32
RoRo Cargo	0	18	49	32
Oil Tanker	12	6	19	63
Other Tanker	0	12	15	73
Fishing	25	0	74	1
Reefer	18	0	61	21
Other	25	0	74	1
Tug/Supply	25	0	74	1

In following tables, Table A- 19 to Table A- 21, the emission factors used for emissions at berth are presented.

Table A- 19 Emission factors of medium/high speed engines (MS) at berth, (g/kg fuel)

Year of build	NOx	PM	PM	PM	HC	CO
Fuel	all	HFO	MDO	MGO/ULMF	all	all
1900 – 1973	53	2.8	2.2	1.4	2.7	13
1974 – 1979	65	2.9	2.3	1.5	2.8	14
1980 – 1984	73	3.1	2.4	1.6	2.9	15
1985 – 1989	82	3.3	2.6	1.8	3.1	13
1990 – 1994	74	3.0	2.1	1.3	2.6	11
1995 – 1999	59	2.6	1.6	0.8	2.2	11
2000 – 2010	54[1]/49[2]	2.5	1.6	0.8	1.6	11

[1] HFO; [2] MDO or MGO/ULMF

Table A- 20 Emission factors of slow speed engines (SP) at berth, (g/kg fuel)

Year of build	NOx	PM	PM	PM	HC	CO
Fuel	all	HFO	MDO	MGO/ULMF	all	all
1900 – 1973	76	4.9	2.4	1.6	2.9	14
1974 – 1979	90	5.2	2.5	1.7	3.0	15
1980 – 1984	100	5.4	2.6	1.8	3.2	16
1985 - 1989	111	5.7	2.8	2.0	3.3	14
1990 - 1994	103	5.6	2.3	1.5	2.9	11
1995 - 1999	88	4.9	1.8	1.0	2.4	12
2000 - 2010	75[1]/71.4[2]	5.0	1.8	1.0	1.8	12

[1] HFO; [2] MDO or MGO/ULMF

Table A- 21 Emission factors of boilers of boilers at berth, (g/kg fuel)

Fuel	NOx	PM	HC	CO
HFO	1.6	2	0.8	4.1
MDO	1.6	0.7	0.8	3.5
MGO/ULMF	1.6	0.7	0.8	3.5

Table A- 22 Emission factors of all engines and apparatus, (g/kg fuel)

Fuel	SO_2	CO_2
HFO	30	3170
MDO	16	3150
MGO/ULMF	4	3150

In tanker ships a reduction factor (50% for PM and 90% for SO_2) is applied to the emission factors for boilers, because gas scrubbers are often applied in order to protect ship internal spaces for corrosion by inert gases produced by boilers.

REFERENCES OF APPENDIX A

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[3] Buhaug, Ø., Corbett, J. J., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, D. S., Lee, D., Lindstad, H., Mjelde, A., Pålsson, C., Wanquing, W., Winebrake, J. J., Yoshida, K.
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[5] 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.

APPENDIX B: AIS SHIP TYPES

AIS Vessel Types

Type No.	Route bound(R) / Non Route Bound (N)	Omschrijving
0	N	undefined
1	N	reserved for future use
2	N	WIG[2]
20	N	WIG (All ships of this type)
21	N	WIG (Carrying DG, HS, or MP IMO hazard or pollutant category A)
22	N	WIG (Carrying DG, HS, or MP IMO hazard or pollutant category B)
23	N	WIG (Carrying DG, HS, or MP IMO hazard or pollutant category C)
24	N	WIG (Carrying DG, HS, or MP IMO hazard or pollutant category D)
25 - 28	N	WIG (reserved for future use)
29	N	WIG (No additional information)
30	N	Vessel (Fishing)
31	N	Vessel (Towing)
32	N	Vessel (Towing and length of the tow exceeds 200 m or breadth exceeds 25 m)
33	N	Vessel (Engaged in dredging or underwater operations)
34	N	Vessel (Engaged in diving operations)
35	N	Vessel (Engaged in military operations)
36	N	Vessel (Sailing)
37	N	Vessel (Pleasure Craft)
38	N	Vessel (reserved for future use)
39	N	Vessel (reserved for future use)
4	N	HSC[3]
40	R	HSC (All ships of this type)
41	R	HSC (Carrying DG, HS, or MP IMO hazard or pollutant category A)
42	R	HSC (Carrying DG, HS, or MP IMO hazard or pollutant category B)
43	R	HSC (Carrying DG, HS, or MP IMO hazard or pollutant category C)
44	R	HSC (Carrying DG, HS, or MP IMO hazard or pollutant category D)
45 - 48	R	HSC (reserved for future use)
49	R	HSC (No additional information)
50	N	Special craft (Pilot vessel)
51	N	Special craft (Search and rescue vessels)
52	N	Special craft (Tugs)
54	N	Special craft (Vessels with anti-pollution facilities or equipment)
55	N	Special craft (Law enforcement vessels)
56	N	Special craft (Spare for assignments to local vessels)
57	N	Special craft (Spare for assignments to local vessels)
58	N	Special craft (Medical transports)
59	N	Special craft (Ships according to RR Resolution No. 18)
6	R	Passenger ships

[2] Wing-In-Ground craft
[3] High Speed Craft

Type No.	Route bound(R) / Non Route Bound (N)	Omschrijving
60	R	Passenger ships (All ships of this type)
61	R	Passenger ships (Carrying DG, HS, or MP IMO hazard or pollutant category A)
62	R	Passenger ships (Carrying DG, HS, or MP IMO hazard or pollutant category B)
63	R	Passenger ships (Carrying DG, HS, or MP IMO hazard or pollutant category C)
64	R	Passenger ships (Carrying DG, HS, or MP IMO hazard or pollutant category D)
65 - 68	R	Passenger ships (reserved for future use)
69	R	Passenger ships (No additional information)
7	R	Cargo ships
70	R	Cargo ships (All ships of this type)
71	R	Cargo ships (Carrying DG, HS, or MP IMO hazard or pollutant category A)
72	R	Cargo ships (Carrying DG, HS, or MP IMO hazard or pollutant category B)
73	R	Cargo ships (Carrying DG, HS, or MP IMO hazard or pollutant category C)
74	R	Cargo ships (Carrying DG, HS, or MP IMO hazard or pollutant category D)
75 - 78	R	Cargo ships (reserved for future use)
79	R	Cargo ships (No additional information)
8	R	Tanker(s)
80	R	Tanker(s) (All ships of this type)
81	R	Tanker(s) (Carrying DG, HS, or MP IMO hazard or pollutant category A)
82	R	Tanker(s) (Carrying DG, HS, or MP IMO hazard or pollutant category B)
83	R	Tanker(s) (Carrying DG, HS, or MP IMO hazard or pollutant category C)
84	R	Tanker(s) (Carrying DG, HS, or MP IMO hazard or pollutant category D)
85 - 88	R	Tanker(s) (reserved for future use)
89	R	Tanker(s) (No additional information)
90	R	Other types of ship (All ships of this type)
91	R	Other types of ship (Carrying DG, HS, or MP IMO hazard or pollutant category A)
92	R	Other types of ship (Carrying DG, HS, or MP IMO hazard or pollutant category B)
93	R	Other types of ship (Carrying DG, HS, or MP IMO hazard or pollutant category C)
94	R	Other types of ship (Carrying DG, HS, or MP IMO hazard or pollutant category D)
95 - 98	R	Other types of ship (reserved for future use)
99	R	Other types of ship (No additional information)