MARIN

SEA SHIPPING EMISSIONS 2013: NETHERLANDS CONTINENTAL SHELF, 12-MILE ZONE, PORT AREAS AND OSPAR REGION II

Final Report

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GLOSSARY OF DEFINITIONS AND ABBREVIATIONS

Definitions:

Voyage database	Database consisting of all voyages crossing the North Sea in 2012 collected by Lloyd's List Intelligence
SAMSON Traffic database	Database that contains the number of ship movements per year for each traffic link divided over ship type and size classes. It is based on the Lloyd's List Intelligence voyage database
Ship characteristics database	This database contains vessel characteristics of over 120,000 seagoing merchant vessels larger than 100 GT operating worldwide. The information includes year of built, vessel type, vessel size, service speed, installed power of main and auxiliary engine.
Netherlands sea area	NCS and 12-mile zone

Abbreviations/Substances:

Methane (CH_4)	Gas formed from the combustion of LNG. Substance number **1011**
VOC	*V*olatile Organic Compounds. Substance number **1237**
Sulphur dioxide (SO_2)	Gas formed from the combustion of fuels that contain sulphur. Substance number **4001**
Nitrogen oxides (NO_x)	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 NO_2 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/Other:

AIS	Automatic Identification System
EMS	Emissieregistratie en Monitoring Scheepvaart (Emission inventory and Monitoring for the shipping sector)
GT	Gross Tonnage
IMO	International Maritime Organization
LLI	Lloyd's List Intelligence (previously LLG and LMIU)
m	meter
MMSI	Maritime Mobile Service Identity is a unique number to call a ship. The number is added to each AIS message.
NCS	Netherlands Continental Shelf
nm	nautical mile or sea mile is 1852m
SAMSON	Safety Assessment Model for Shipping and Offshore on the North Sea

1 INTRODUCTION

1.1 Objective

This study aims to determine the emissions to air of seagoing vessels above 100 GT for 2013. The totals and the spatial distribution for the Netherlands Continental Shelf, the 12-mile zone and the port areas Rotterdam, Amsterdam, the Ems, Den Helder and Harlingen are based on AIS data. In addition, the information contained in the AIS data for the Netherlands sea area and in the SAMSON traffic database for the whole of the North Sea is used to determine the emissions for 2013 in the OSPAR region II area and the Western Scheldt.
The emissions for 2013 are determined for CH_4, VOC, SO_2, NO_x, CO, CO_2 and Particulate Matter (PM). A distinction is made between ships sailing under EU-flag and non-EU flag and between ships sailing in the NCS or in the Dutch 12-mile zone.

The grid size for the port area emissions and the 12-mile zone is 500 x 500 m, for the other areas a grid size of 5000 x 5000 m has been used.

1.2 Report structure

Chapter 2 describes the emission databases that were compiled for 2013.
Chapter 3 describes the procedure used for the emission calculation based on AIS data.
Chapter 4 describes the procedure used for the emission calculations based on the SAMSON database.
Chapter 5 describes the completeness of the AIS data, both with respect to missing files and with respect to spots that are not fully covered by base stations.
Chapter 6 contains the level of shipping activity in the Dutch port areas and the Netherlands sea area.
Chapter 7 summarises the emissions for 2013 for the Dutch port areas and the Netherlands sea area and makes a comparison with 2012.
Chapter 8 summarises the 2013 emissions for OSPAR region II. It also contains a comparison with 2012.
Chapter 9 presents conclusions and recommendations.

2 2013 EMISSION DATABASES

2.1 General information

Different Access databases with the calculated emissions to air from sea shipping have been delivered for:

- the Netherlands sea area (NCS and 12-mile zone);
- the five Dutch port areas Rotterdam, Amsterdam, the Ems, Den Helder and Harlingen;
- the Dutch port area Western Scheldt;
- the OSPAR region II at sea.

For the information on what can be found in the different databases, refer to [1]. Here the changes with respect to [1] are described. This year a new procedure is followed for LNG tankers, which are now assumed to be fuelled by LNG as long as more than 20% of the maximum engine power is used (see Appendix A for more information). When using LNG these ships produce methane instead of VOC. The substance number for methane is 1011. The sum of methane and VOC can be compared to the 2012 data for VOC. The contribution of methane was very low in 2013. Furthermore, it was noticed that in earlier years, the incorrect assumption was made that the auxiliary engines only use distillate fuel oil, which would mean that auxiliary engines only produce PM-MDO and no PM-HFO. This is corrected in this year, which means that there will be more emission of PM-HFO and less of PM-MDO compared to earlier years. Also, for anchored ships at sea (which only use their auxiliary engines), PM-HFO can occur, which was not the case before. In port areas, not-moving ships are assumed to be berthed, and it is still assumed that these ships only use distillate fuel oil. It is thus not possible to compare the emissions of these substances separately to that of last year. However, the sum of PM-HFO and PM-MDO can be compared.

2.2 Netherlands sea area and Dutch port areas

The emissions in the Netherlands sea area and the five Dutch port areas based on AIS data have been stored in:

- Emissions_2013_MARIN_12Miles.mdb (26-1-2015)
- Emissions_2013_MARIN_NCP.accdb (26-1-2015)
- Emissions_2013_MARIN_Dutch_port_areas.mdb (2-3-2015)

The databases contain the fishing vessels that are observed in the AIS data and that could be connected with the ship characteristics database. However, all figures and tables in the report are based on the data excluding fishing vessels.

Furthermore, the emissions in the port area Western Scheldt based on the SAMSON traffic database have been stored in:

- Emissions_2013_MARIN_Westerschelde.mdb (3-3-2015)

The emissions have been calculated on a 5000 x 5000 m grid for the NCS and on a 500 x 500 m grid in the 12-mile zone and in the port areas.

The Netherlands sea area and the port areas are presented in Figure 2-1. The dark grey lines represent the traffic separations schemes and the squares represent offshore platforms. The different areas are indicated by plotting the centre points of the grid cells with different colours:

- The green points at sea are the cells outside the 12-mile zone;
- The yellow points at sea are the cells within the 12-mile zone;
- The orange points within the port areas are the cells that are included in the database if there is any emission.

The six port areas are illustrated in more detail in Figure 2-2 to Figure 2-7. At some places, there are orange points on land. There are several reasons for this. In general, the detail of the charts presented here is such that not all existing waterways and/or quays are visible, though they do 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. When, for whatever reason, AIS signals are disturbed or lost, positions are extrapolated and this is done before MARIN receives the data.

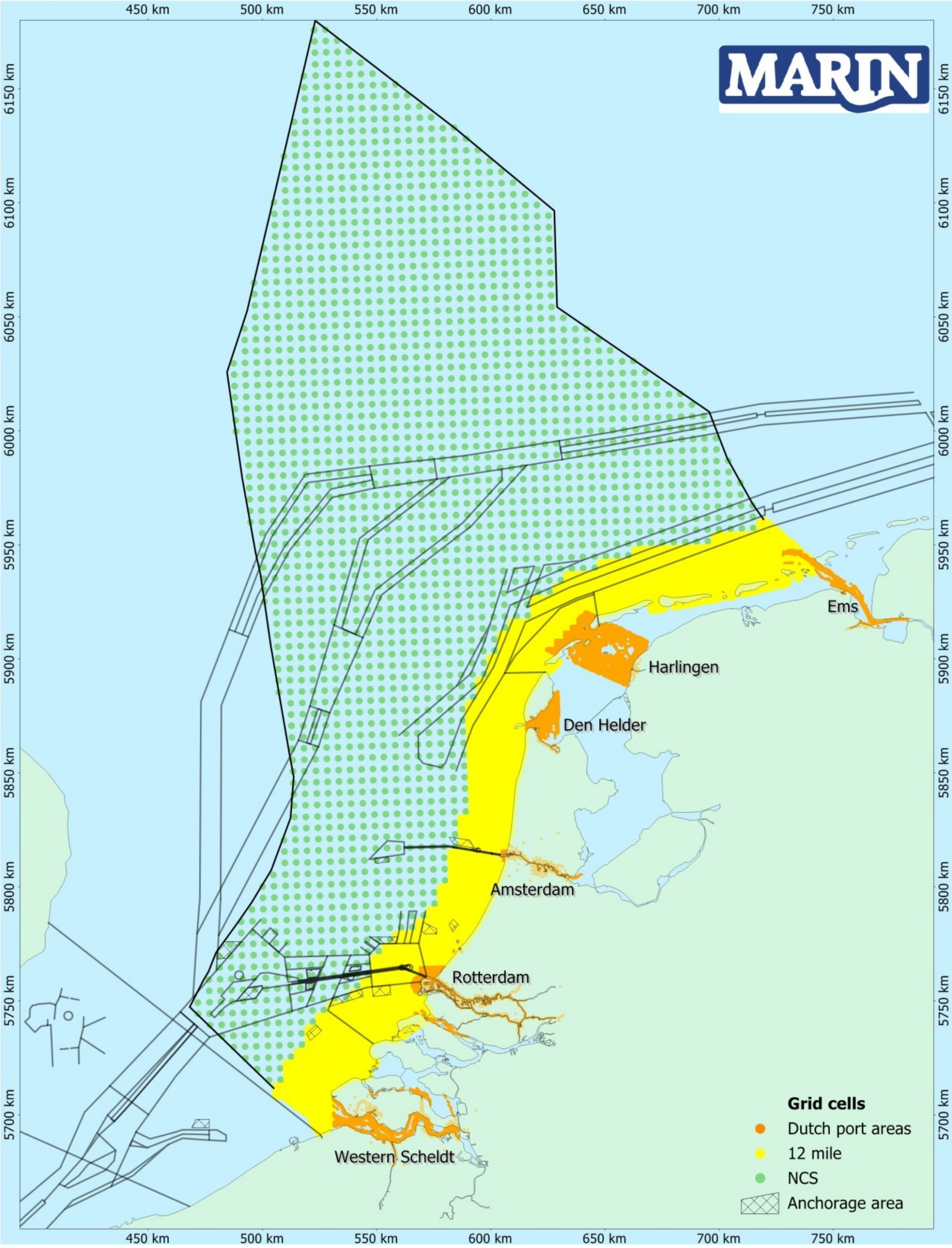

Figure 2-1 **The Netherlands Continental Shelf, 12-mile zone and six port areas**

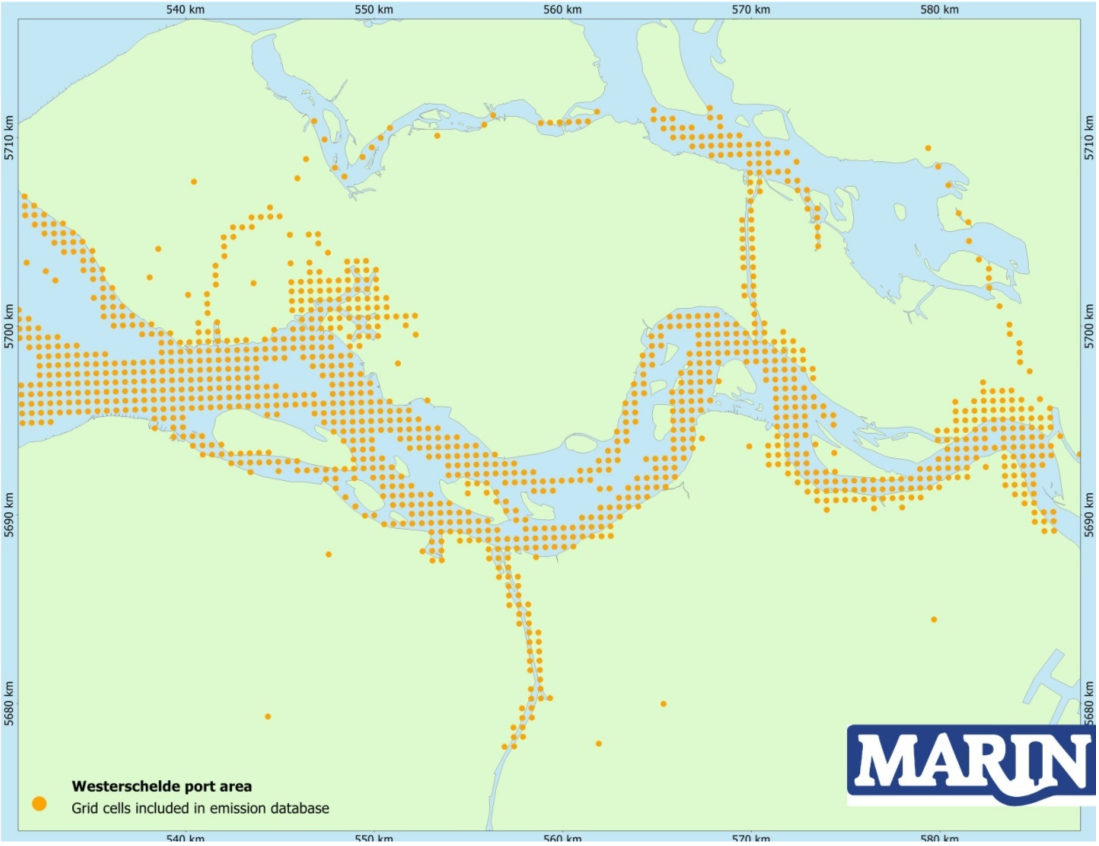

Figure 2-2 Western Scheldt: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database

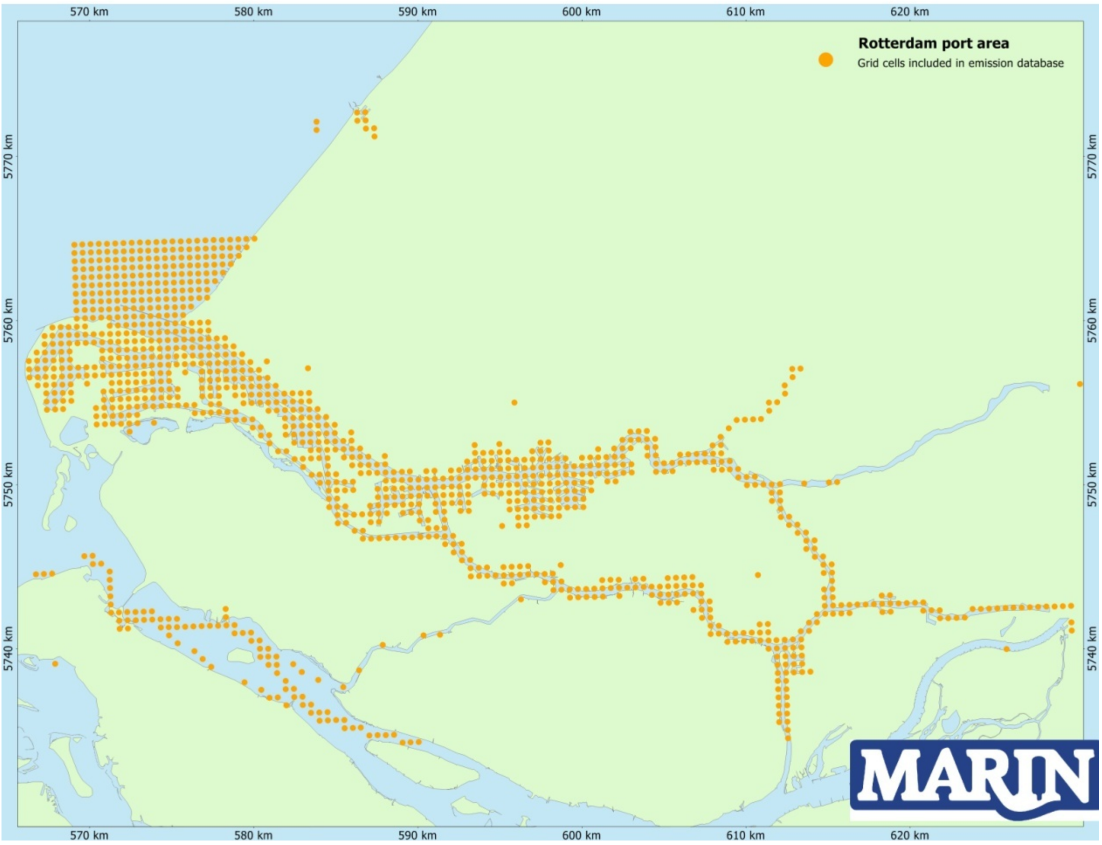

Figure 2-3 Rotterdam: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database

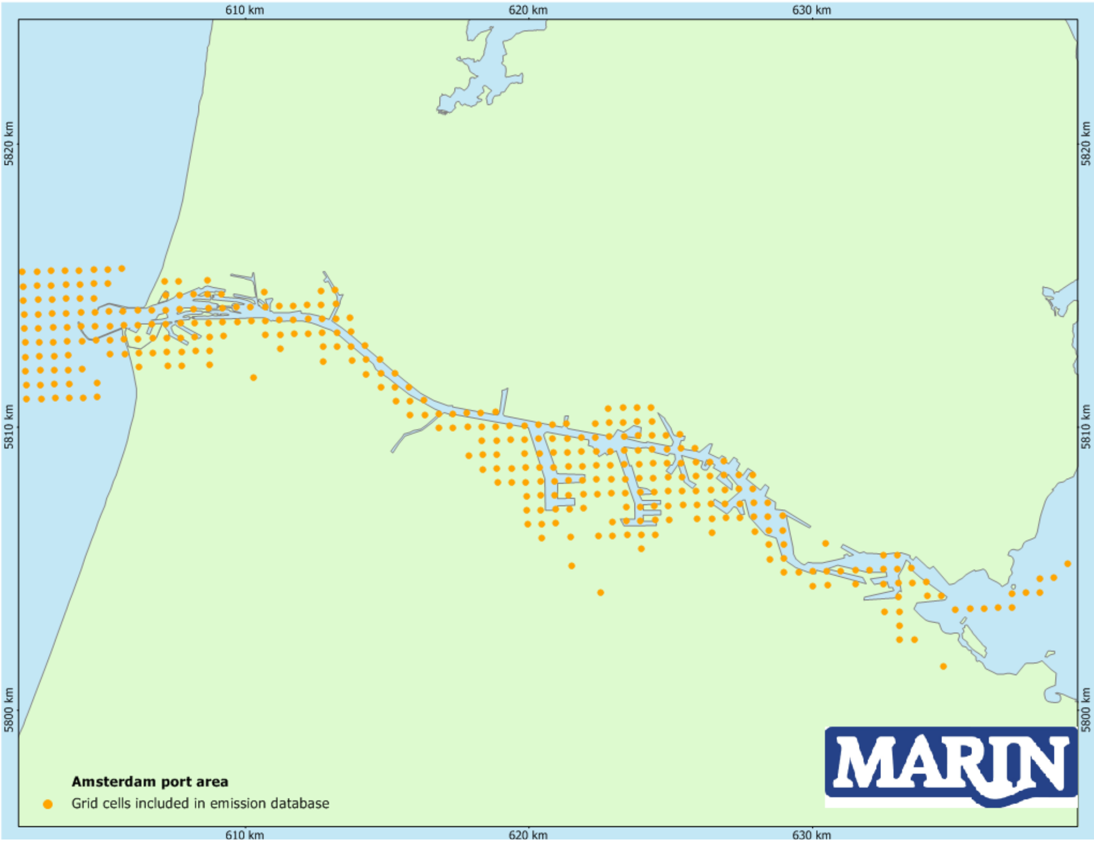

Figure 2-4 **Amsterdam: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

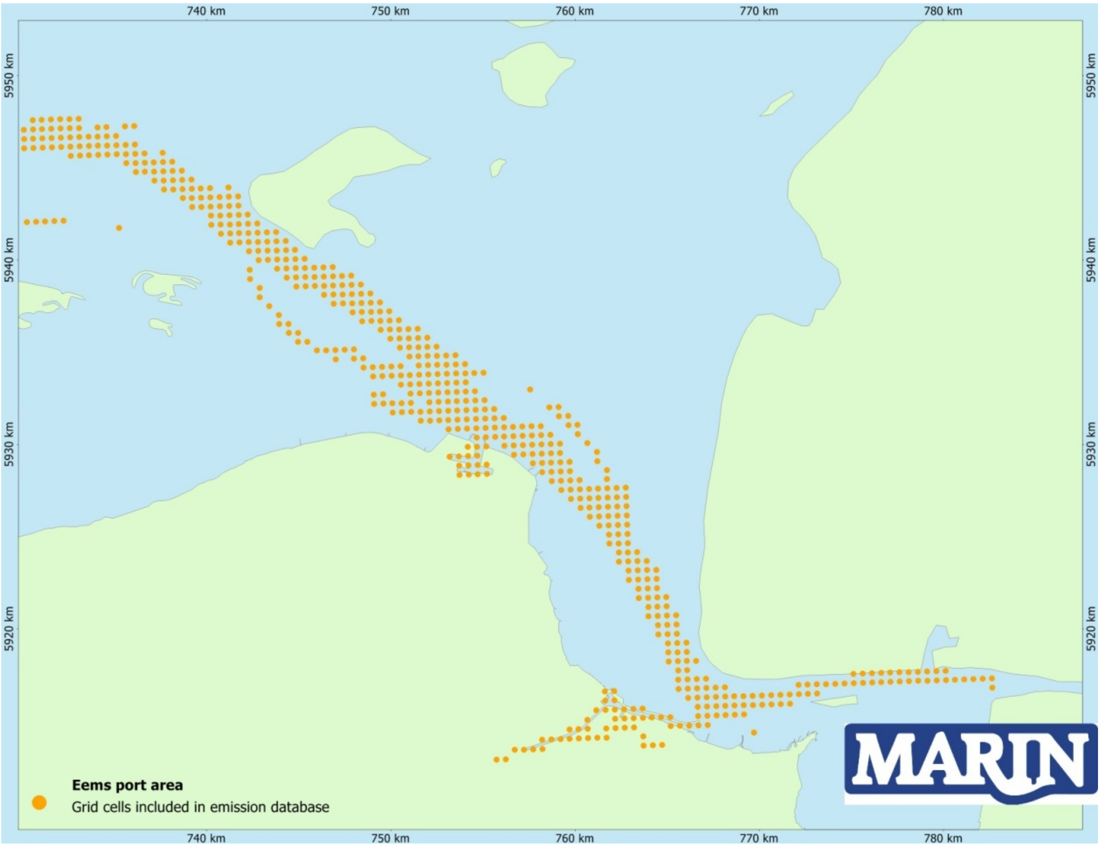

Figure 2-5 **Ems: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

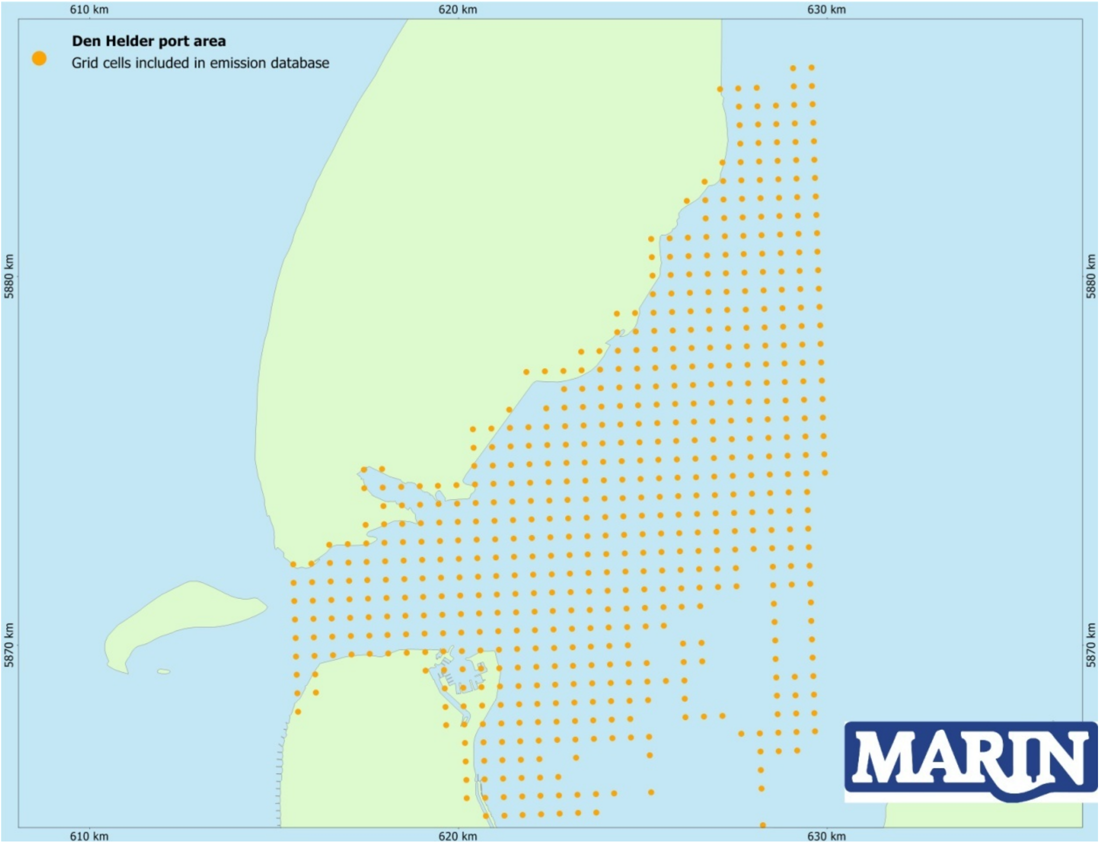

Figure 2-6 **Den Helder: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

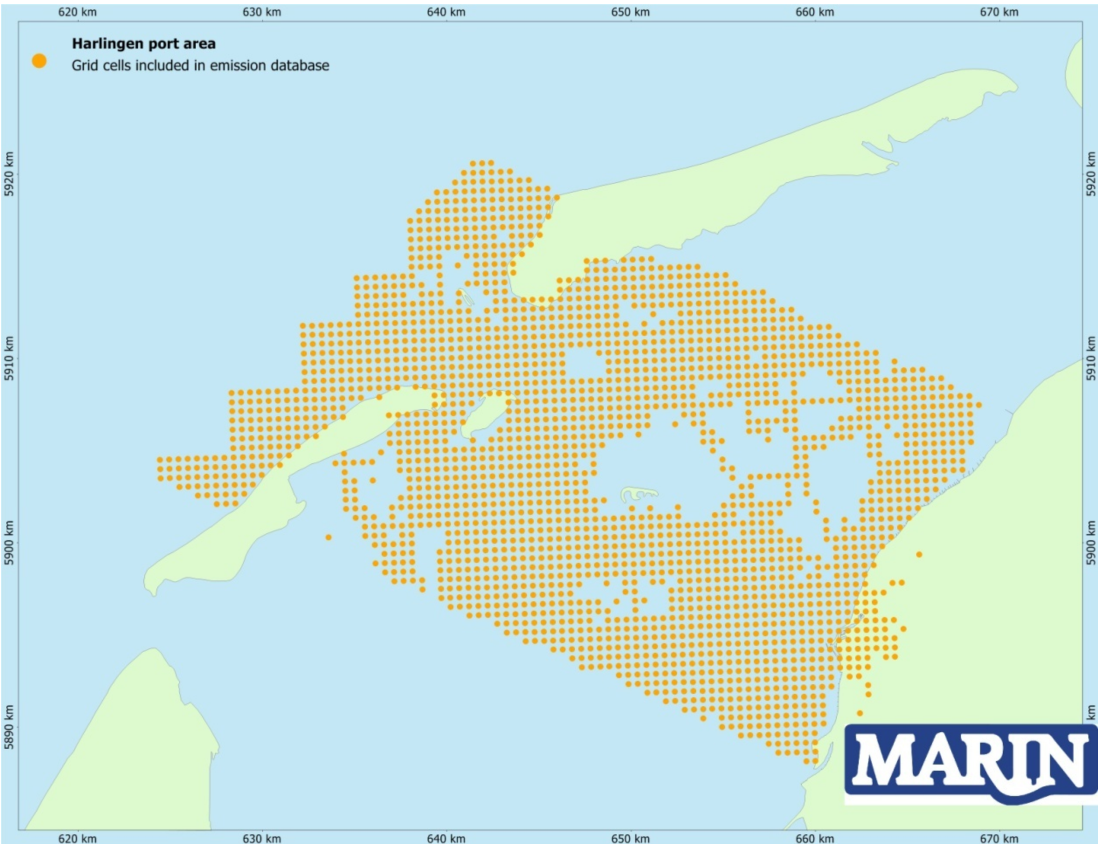

Figure 2-7 **Harlingen: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

2.3 OSPAR region II

The emissions in OSPAR region II are stored in:
"Emissions_OSPAR_region_II_2013_MARIN_sea.mdb.
The data is based on the SAMSON traffic database of 2012.

The calculated emissions have been corrected for the changes in the traffic volumes and composition between 2012 and 2013. For more information on the method for the calculations, refer to [1].

The database contains the fishing vessels that are part of the traffic database. However, all figures and tables in the report are based on the data excluding fishing vessels.

The emissions have been calculated on a 5000 x 5000 m grid. The area covered is shown in Figure 2-8.

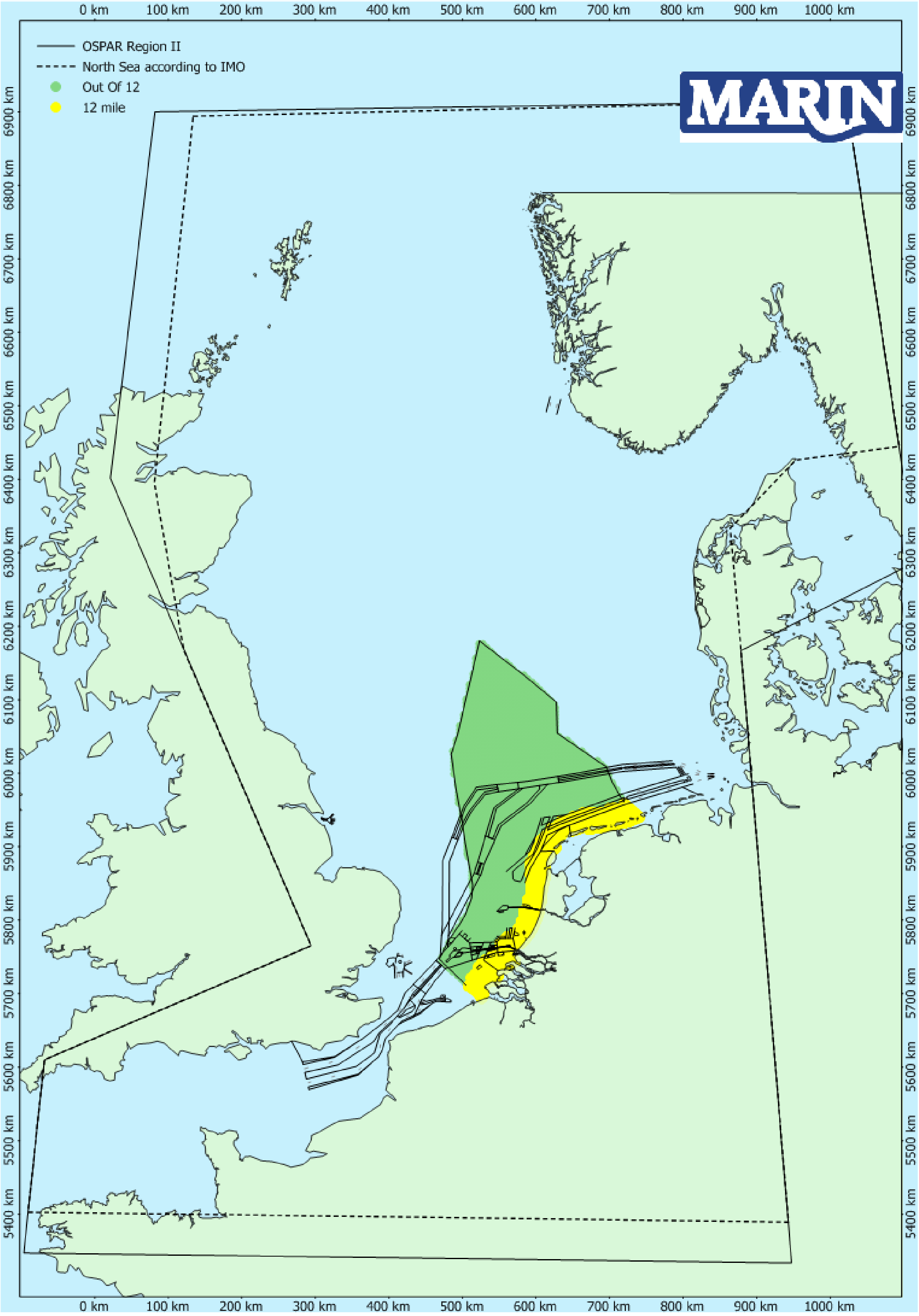

Figure 2-8 **Areas within OSPAR region II (solid black line) and the North Sea according to IMO (dotted black line)**

3 PROCEDURE FOR EMISSION CALCULATION BASED ON AIS DATA

This chapter describes the method for the emission calculation based on AIS data. This method has been used to calculate the emissions for both NCS, the 12-mile zone and five of the Dutch port areas. At first, the input used for the calculations will be explained. Then, the procedure for combining the input to obtain emissions will be described.

3.1 Input

AIS data for 2013
In this study, AIS data of 2013 received by the Netherlands Coastguard has been used to calculate the emissions. Refer to [1] for background information about the AIS data.

Ship characteristics database of November 2014
The LLI ship characteristics database of November 2014 has been purchased. This database, combined with earlier issues, contains vessel characteristics of over 120,000 seagoing merchant vessels larger than 100 GT operating worldwide.

3.2 Procedure for combining the input to obtain emissions

Refer to [1] and Appendix A for a description of how the input is combined to obtain emissions.

Results of coupling ships observed in AIS data with ship characteristics database
One of the steps is to find the corresponding ship in the ship characteristics database for each MMSI number in the AIS data of 2013.

For a description of the procedure, refer to [1].

Table 3-1 shows the final result of the process to link an MMSI number to a ship in the ship characteristics database. The ship characteristics database contains all vessels that have an IMO number, i.e. merchant seagoing vessels >100 GT, but is not complete for other types of ships. In the first step all 26,550 unique MMSI numbers in the AIS data of 2013 are divided into a group with 12,394 MMSI numbers with a corresponding IMO number that is not always equal to zero (so likely a relevant ship) and a group of 14,156 MMSI numbers with a corresponding IMO number equal to zero in all messages (suggesting the ship is not a seagoing vessel >100GT, thus not relevant in the calculations done here). There were 372 vessels with an IMO number not always equal to zero that could not be coupled, because they were not in the ship characteristics database for different reasons; this involved 14 inland ships, 7 pleasure crafts, 29 fishing vessels, 87 ships <100 GT and 235 for other unknown reasons.

Table 3-1 Number of ships in AIS database coupled with ships in LLI ship characteristics database

Different MMSI numbers in AIS data of 2013	IMO number in AIS message	Coupled		Not coupled
		Direct	After search	Ship is not a seagoing ship > 100GT
26,550	12,394 IMO≠0	12,019	3	87 <100GT 7 pleasure 29 fishing 14 inland 235 other reason
	14,156 IMO=0	0	892	13,264

From the second group, containing 14,156 ships with IMO always equal to zero, 892 could be coupled with a ship in the LLI database and 13,264 could not be coupled with a ship in the LLI database. Probably none or only a few of these ships are seagoing ships >100 GT. The 892 ships that could be coupled to the LLI database with seagoing vessels are considered as relevant vessels despite the fact that they have constantly sent AIS messages with IMO = 0. Generally these are small vessels (337 are in size class 1 < 1600GT) with a small contribution to the emissions, but even in size class 7 there are 42 ships.

Overall, it can be concluded that almost all MMSI numbers of the relevant ships could be coupled with the ship characteristics database of LLI. This link is essential, because the LLI database is the only database that contains data with respect to the engine of the ship, required for the determination of the emissions.

4 PROCEDURE FOR EMISSION CALCULATION BASED ON THE SAMSON TRAFFIC DATABASE

This chapter describes the method for the emission calculation based on the SAMSON traffic database. This method has been used to calculate the emissions for OSPAR region II.

Because AIS data outside the NCS is not available to MARIN, the emissions in OSPAR region II have been estimated based on all voyages crossing the North Sea in 2012 collected by Lloyd’s List Intelligence. This data has been processed into a SAMSON traffic database (Figure 4-1). In the 2012 Lloyd’s List Intelligence (LLI) voyage database, more voyages of ferries were covered than in the previous voyage database of 2008. However, on the busy ferry routes, voyages were still missing. An inventory of the missing ferry lines has been made and these have been added to the 2012 SAMSON traffic database. Therefore, in contrast to earlier studies the ferry movements didn’t have to be treated separately for the emission calculation.

The emission calculation in OSPAR region II followed the steps of the procedure described in [1].

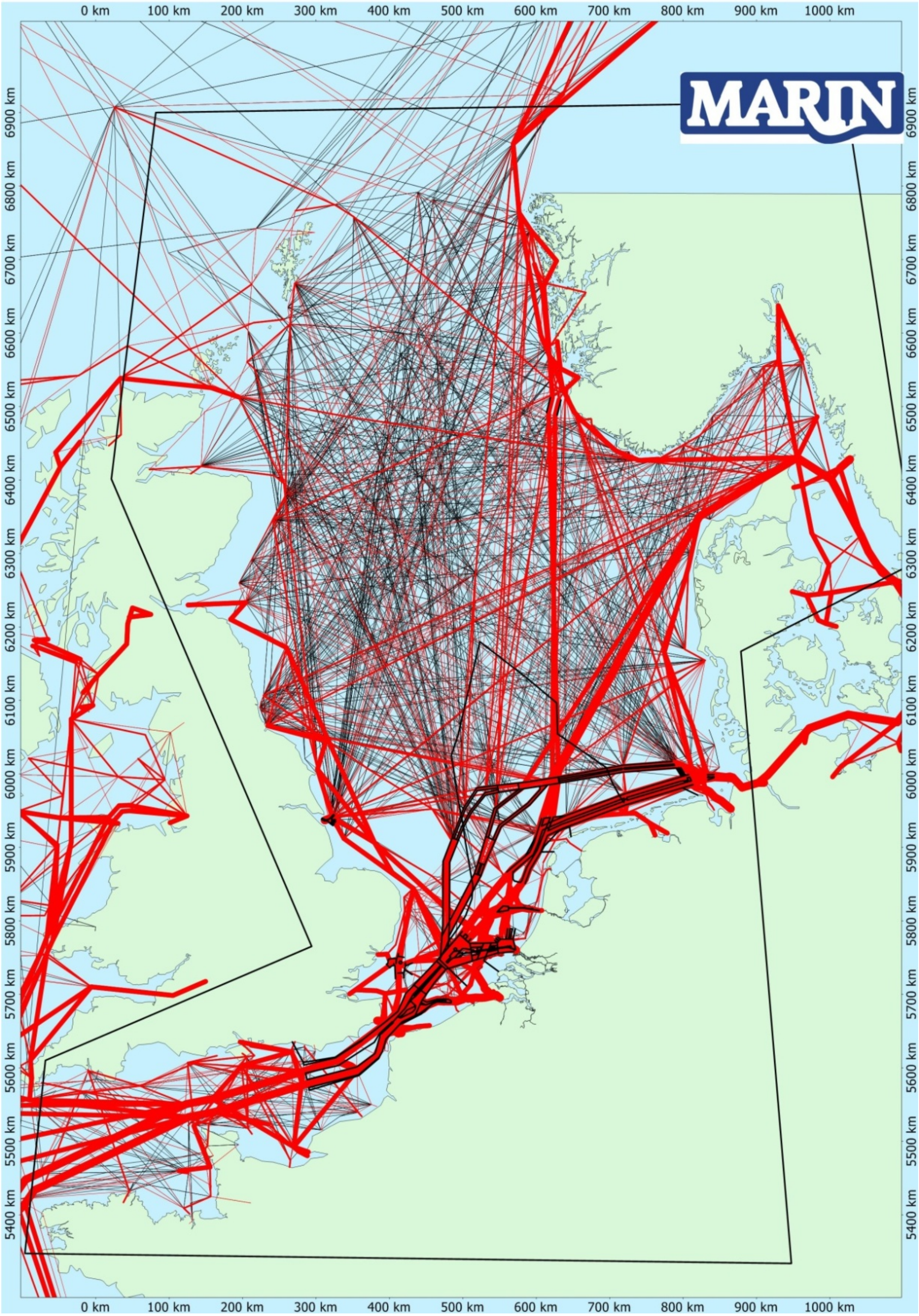

Figure 4-1 **Traffic links of the SAMSON traffic database of 2012 in OSPAR region II, the width of the links indicates the intensity of the ships on the links, red links represent a higher traffic intensity than black links**

5 COMPLETENESS OF AIS DATA

5.1 Missing AIS minute files

Each AIS data file contains the AIS messages of all ships received in exactly one minute. The total collection of the AIS data of 2013 contains 523,440 files, which is 99.59% of the expected number of 525,600 files (365 days times 24 hours times 60 minutes). Therefore, in total 1.5 days are missing due to failures in the process. In case the gap is less than 10 minutes, this has no effect on the results, because each ship is kept in the system until no AIS message has been received during 10 minutes. This approach has been followed to prevent incompleteness for larger distances from the coast for which the reception of AIS messages by the base station decreases. In 2013 the 2,160 missing files were consecutive, so a completion factor of 1.00413 (1/0.9959) has been used to correct for missing periods longer than 10 minutes. All emissions, in the NCS, the 12-mile zone and in the Dutch port areas have been multiplied with this factor.

5.2 Bad AIS coverage in certain areas

5.2.1 Base stations

In the previous section, the number of files received from the Netherlands Coastguard was used to describe the completeness of the data. This doesn't necessarily mean that the available minutes files cover the total area all the time. This is illustrated in Figure 5-1, in which all base stations that deliver data to the Netherlands Coastguard are plotted. The circle with a radius of 20 nautical miles around each base station illustrates the area covered by that base station.

5.2.2 Known weak spots

In reality, the covered area varies with the atmospheric conditions. Figure 5-1 shows that some areas are covered by several base stations, while other areas are covered by only one base station and some areas are only covered with favourable atmospheric conditions, when the base stations reach further than 20 nautical miles. This means that there are a few weak spots in the Netherlands sea area and in the Dutch port areas:

- the area in the northern part of the NCS, which is not covered at all. This is not a large shortcoming because the shipping density is very low in this area;
- the area North-West of Texel;
- the Western Scheldt closer to the border with Belgium, and
- the spot close to the border with the United Kingdom Continental Shelf, southwest of Rotterdam.

Especially the last location is a shortcoming, because it is a very dense shipping traffic area. MARIN has noticed this also in other projects. Also the Western Scheldt is a waterway with large traffic intensity. Therefore, 5.2.5 contains a description of the correction for this bad coverage on the Western Scheldt.

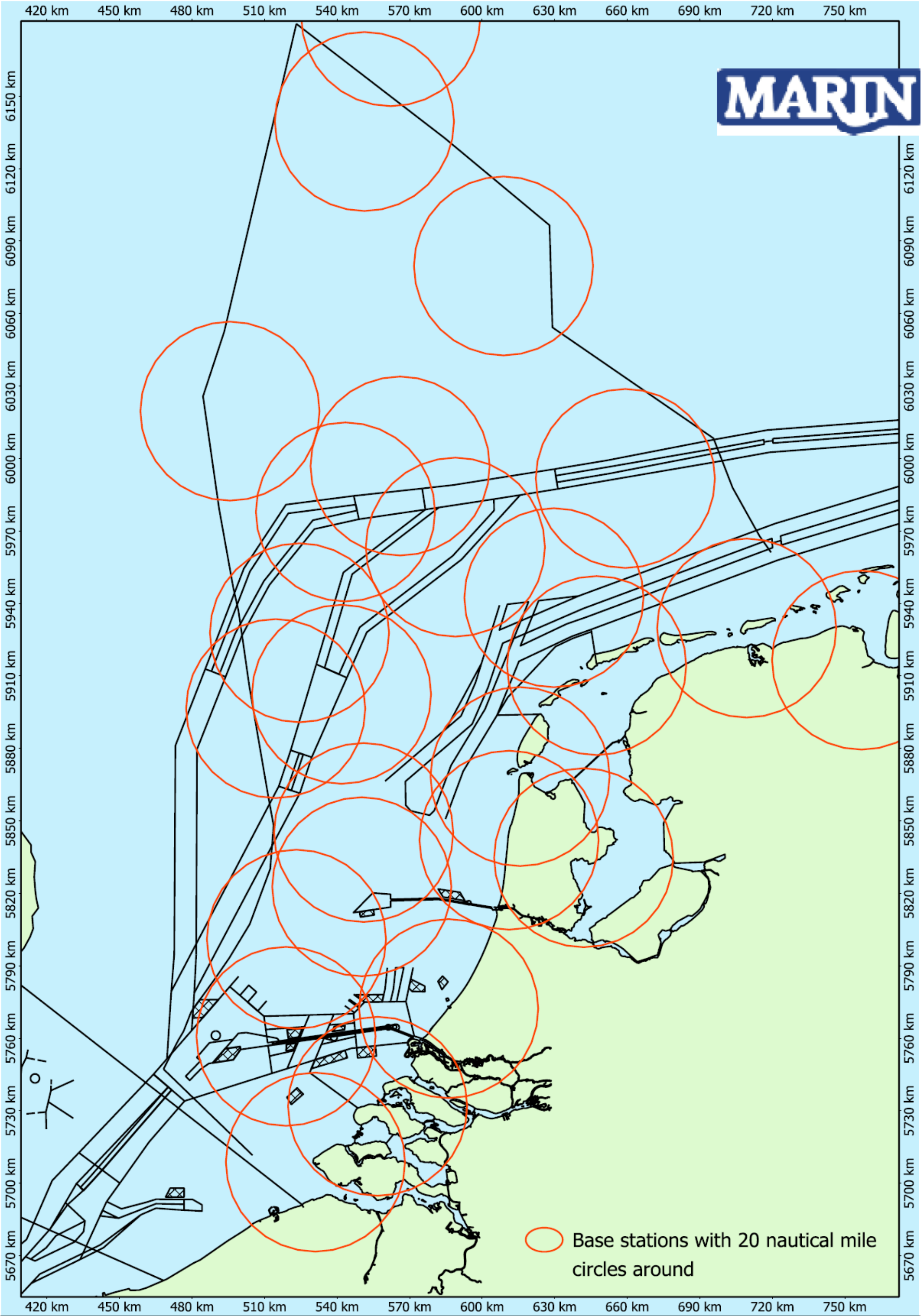

Figure 5-1 AIS base stations in 2013 delivering data to the Netherlands Coastguard

5.2.3 Coverage in the Netherlands sea area

For the Netherlands sea area, the weak spots in the collection of the AIS data are identified by the locations where ships lose contact. After 10 minutes without receiving a new AIS message of a ship, the ship is removed from the system. Figure 5-2 and Figure 5-3 show in each cell of 5x5km the number of ships that lose AIS contact with Dutch AIS base stations relative to the total number of observations. Sometimes the receipt of AIS messages is recovered after some time, which is the case in the center area of the Netherlands sea area. However, on most locations near the border of the Netherlands sea area it means that the ship has left the system until its next journey through the Netherlands sea area. Thus, the figure shows more or less the locations where ships are removed from the system. The ideal situation would be if the ships that leave the system are located outside the Netherlands sea area, which is the case on the west side of the NCS. The figures show that AIS messages are missing in the most southwestern point of the NCS and on the route to Skagerrak in the northeastern part of the NCS. Most ships in the dense traffic lanes above the Wadden leave the system when they are already in the German sector.

The figures are for April and July 2013. These months were chosen based on the size of the AIS logs. In April, the size of the AIS logs was small, which could mean that the coverage was bad. In July the size of the AIS logs was constantly around the average level, which implies the coverage was good. Figure 5-2 and Figure 5-3 confirm what is implied by the size of the AIS logs, in April the covered area was relatively small and in July the covered area reaches far.

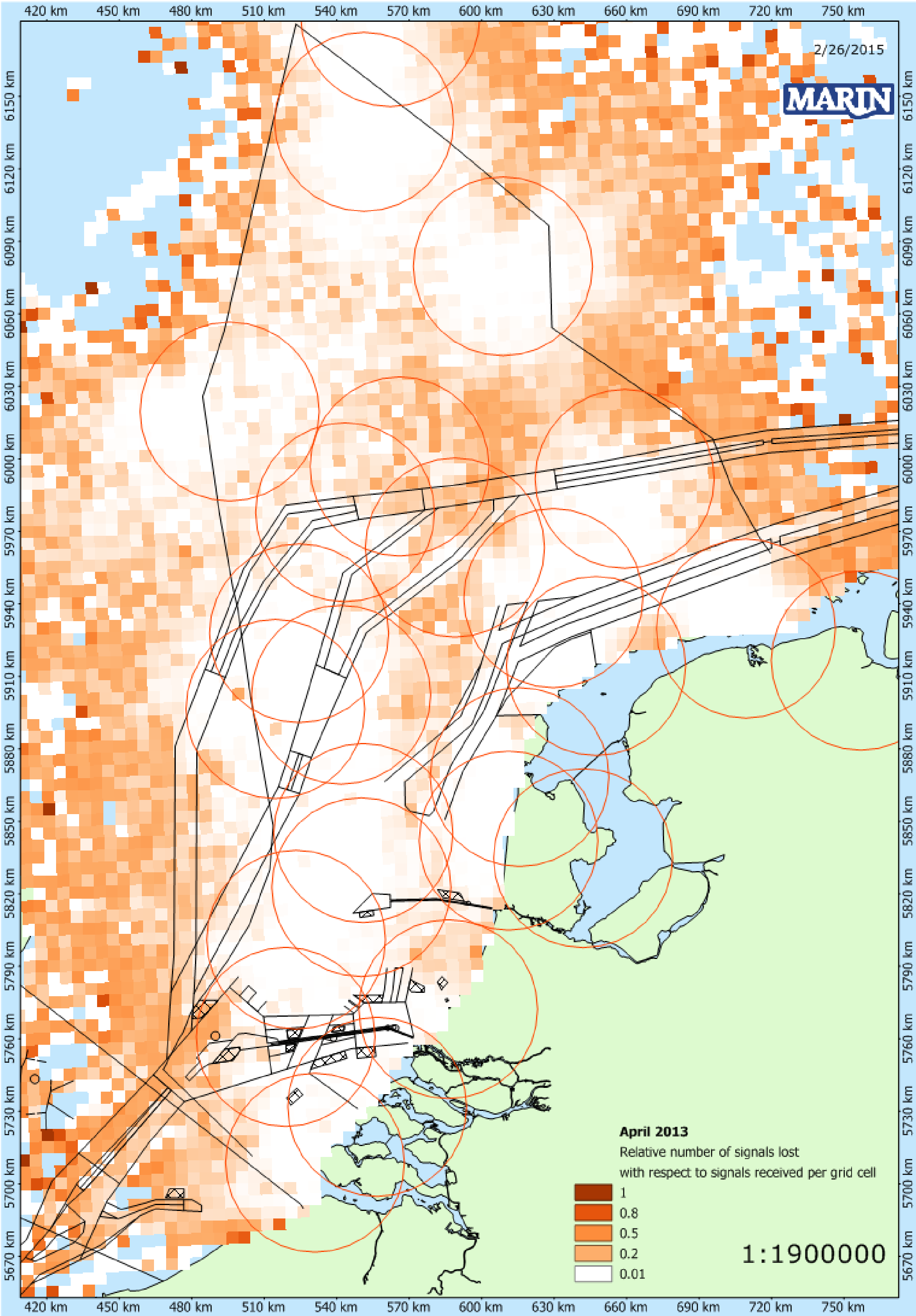

Figure 5-2 **April 2013, relative number of signals lost with respect to signals received per grid cell, red circles mark the 20 nautical miles zones around the Dutch base stations**

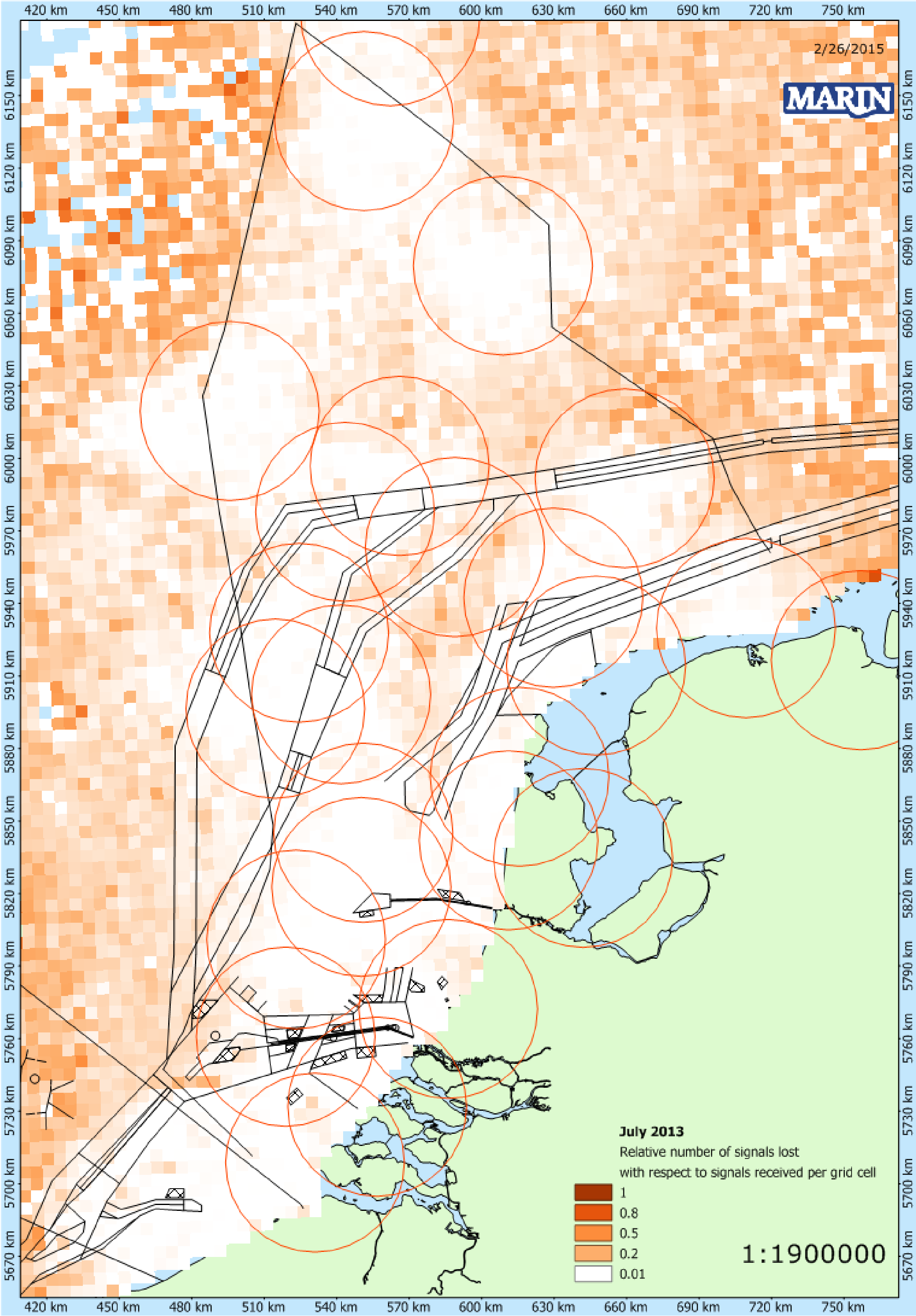

Figure 5-3 **July 2013, relative number of signals lost with respect to signals received per grid cell, red circles mark the 20 nautical miles zones around the Dutch base stations**

5.2.4 Coverage in the Dutch port areas

It is possible that certain areas are not covered by AIS base stations during some time. Although it is impossible to carry out a complete check on this, some checks on coverage have been performed, as described in [1], for the port areas excluding the Western Scheldt. These checks did not show suspicious behaviour in the port areas. The coverage on the Western Scheldt is described in the next section.

5.2.5 Correction for bad AIS coverage of moving ships in the Western Scheldt close to the Belgian border

In previous years, the results for moving ships in the Western Scheldt close to the Belgian border were scaled up to compensate for the bad AIS coverage. This was done by multiplying with a correction factor, which was determined by using a location-based linear regression. For each ship type and size class a specific factor was determined. However, already in 2012 the coverage problems seemed to be more complicated. In 2013 it was concluded that it was no longer possible to account for the bad coverage by only making use of a correction factor. Close to the Belgian border, for some ship type and size class combinations no signals were received at all, which makes it impossible to correct for the bad coverage by multiplying with a factor.

Therefore, this year a new approach is followed. Although Section 6.2 indicates that the coverage in the area west of and including the port of Terneuzen is not 100%, the AIS data for this area is used as always. For the area east of the port of Terneuzen towards the Belgium border, the coverage reduces dramatically and, therefore, the traffic database as implemented in SAMSON was extended to the Western Scheldt and used for the calculations. To this end, the method for the OSPAR area (see Chapter 4 and [1]) is used to calculate the total emission of sailing ships on the Western Scheldt. A visualization of the traffic database used for the Western Scheldt is given in Figure 5-4. Unfortunately, the SAMSON traffic database does not include information on berthed ships. However, in 2011 and 2012 the emissions of berthed ships on the eastern part of the Western Scheldt accounted for only 0.5% of the total emissions on the Western Scheldt.

However, as Figure 5-4 indicates, the results from the method as used for the OSPAR area, do not give proper information on the spatial distribution of the emissions, as the traffic is modeled over links. Therefore, the spatial distribution of the emissions on the eastern part of the Western Scheldt is based on the spatial distribution of 2011. For 2012 the coverage problems on the Western Scheldt already seemed too complicated to be corrected by just multiplying with a factor. Hence, the choice for the spatial distribution of 2011 when the coverage problems were less severe. The distribution of the emissions was determined for each EMS type and size class combination in 2011, as well as the total emission in the area for this EMS type and size class. This results in a percentage of the total emission for each grid cell for every EMS type and size class combination. This distribution is then used to distribute the total emissions as were calculated using the SAMSON traffic database over the area. For EMS type and size class combinations that were not present in 2011, the distribution of only the EMS type is used. The spatial distribution is determined for CO_2 only; it is assumed that the other substances are distributed similarly. For the other substances only the total emission in the area was determined using the traffic database.

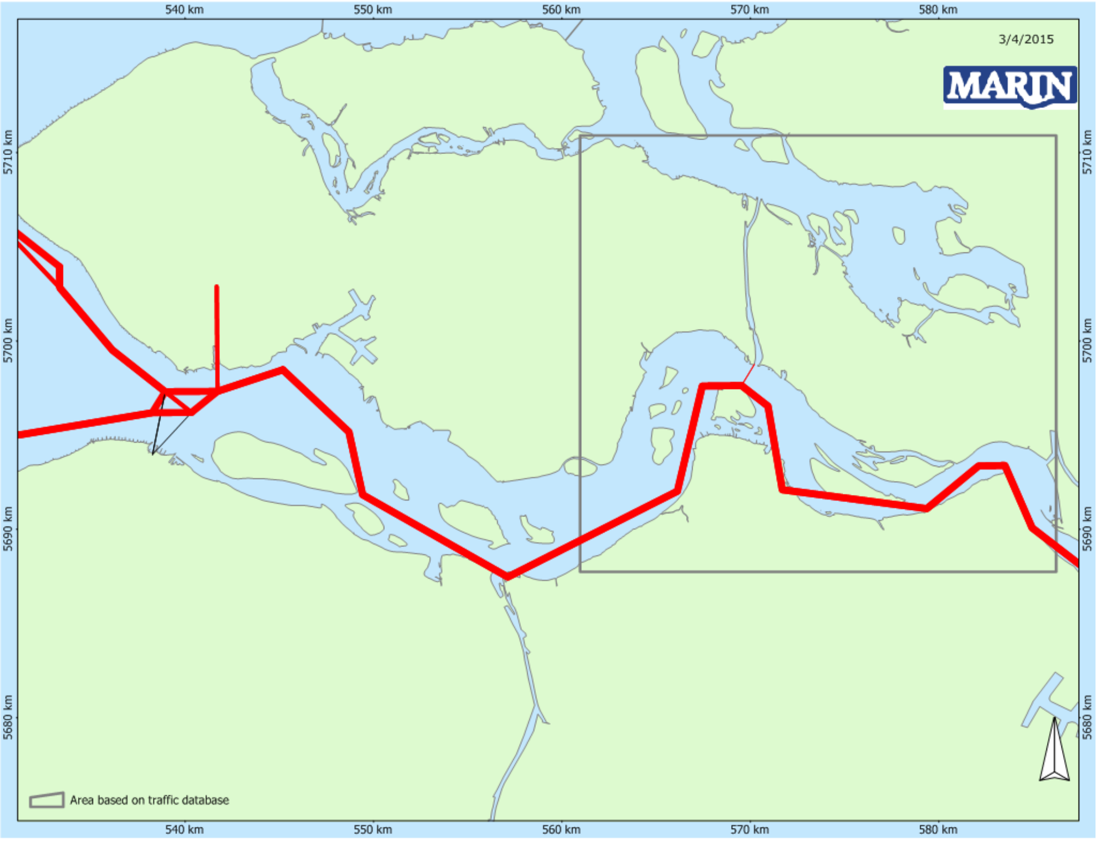

Figure 5-4 **Traffic database Western Scheldt**

6 ACTIVITIES OF SEAGOING VESSELS FOR 2013 AND COMPARISON WITH 2012 FOR THE DUTCH PORT AREAS AND THE NETHERLANDS SEA AREA

6.1 Introduction

This chapter presents the activities of seagoing vessels for 2013 in the Dutch port areas and in the Netherlands sea area. The activities of 2013 are compared to those of 2012. Values are presented as calculated and are not rounded off. Section 6.2 describes the activities in the port areas, Section 6.3 the activity in the Netherlands sea area and Section 6.4 the number of ships in these areas.

6.2 Activities of seagoing vessels in the Dutch port areas

Shipping activities in the six Dutch port areas are determined to calculate the emissions in these areas. The activities extracted from AIS are important explanatory parameters for the total emissions. The other parameter is the emission factor, which has been discussed in [1].

Table 6-1 presents activity numbers that could be extracted from the websites of some of the ports. For the port of Harlingen no figures are available. These numbers can be used to check the information on activity as extracted from the AIS data. First, the values of 2013 are shown and then the percentages with respect to 2012. The table contains the number of calls and the cargo handling for the main ports in each port area. Table 6-1 shows a decrease in the number of calls for the Western Scheldt and for Rotterdam, a stable number for Amsterdam and Den Helder and an increase for the Ems.

Table 6-1 Number of calls extracted from websites of the ports

Port area	Ports	Number of calls		Cargo handling x 1000 tons	
		2013	2013/2012	2013	2013/2012
Western Scheldt	Antwerp	14,220	97.7%	329,634	103.5%
	Zeeland seaports (Vlissingen en Terneuzen)	5,599	89.5%	33,028	97.1%
Rotterdam	Rijn- en Maasmondgebied	29,488	92.6%	440,464	99.8%
Amsterdam	Noordzeekanaalgebied	7,294	100%	95,747	101.5%
Ems	Delfzijl/Eemshaven	5,151	121.1%	3,145	87.5%
Den Helder	Port of Den Helder	2,600	99.0%	5,200	101,4%

The emission explaining variables for each port area are presented in a table per ship type and a table per ship size class in Table 6-2 through Table 6-13.

Western Scheldt
Note that the activities in Table 6-2 and Table 6-3 of seagoing vessels on the Western Scheldt only include the part from Terneuzen to the west. For the part based on the SAMSON traffic database, there is no additional information on activities.

For moving ships on the Western Scheldt, the ships towards the port of Antwerp are most important. Table 6-2 and Table 6-3 show that the hours of moving ships decreased by more than 10%, while the GT.nm is almost unchanged. Based on Table 6-1, which indicates the number of calls of the port of Antwerp and Zeeland Seaports decreased by only 4.8%, the expected decrease would be less. The average speed increased with 1.87%. For berthed ships in the Dutch part of the Western Scheldt, the ports of Terneuzen and Vlissingen are important. The cargo handled in Terneuzen and Vlissingen, as well as the hours and GT.hours, decrease. Also in this case, the hours and GT.hours decreased more than expected based on Table 6-1.

Rotterdam
Table 6-4 and Table 6-5 for Rotterdam show that the activities have decreased in 2013 compared with 2012. The reduction in activities is somewhat more than the reduction in the number of calls in Table 6-1. Only miscellaneous ships show an increase in moving activities, this can also be due to the fact that more ships of this type have an AIS transponder. The decrease for non-moving ships is strongest for chem/gas tankers, reefers, miscellaneous and non-merchant ships. The average speed increased by 3.5%, only for reefers, miscellaneous, tug/supply and non-merchant ships the average speed decreased. The increase in average speed is highest for larger ships (30,000-100,000 GT).

Amsterdam
Note that the area for the port of Amsterdam was extended in 2013. Table 6-6 and Table 6-7 show the activities for the new area, but the comparison with 2012 is made only for the area that was already included in 2012.

Table 6-6 and Table 6-7 for Amsterdam indicate that bulk carriers are the pre-dominant ship type in this port area, followed by tankers. The hours and GT.hours for berthed tankers and container ships decreased significantly. In general the activities decreased, although Table 6-1 indicates that the number of calls has not changed. Only for bulk carriers all activities increased. Table 6-7 shows that the activities increased for larger ships (>60,000 GT). This can also be seen in Table 6-6, as the GT.hours and GT.nm decreased less than the hours for both moving and berthed ships. The average speed in the area increased by 1.86%.

Ems
Table 6-1 shows an increase in the number of calls in Delfzijl and Eemshaven. The number of berthed hours in Table 6-8 and Table 6-9 decreased a little. The moving ships on the Ems show a larger decrease in hours, but not in GT.nm. The average speed increased with 3.08%

Den Helder
Table 6-10 and Table 6-11 show that berthed activities in the area increased, for both small and large ships. The moving activities decreased by 5%, for oil tankers the activities decreased far more. The average speed in the area increased a little by 1.03%. Larger size classes hardly occur in this area. The activities in this area are much lower than in other areas.

Harlingen

Table 6-12 and Table 6-13 show an increase in activities. Especially for chem/gas tankers this increase is large, for berthed hours almost a multiplication by ten. However, for most other ship types the berthed hours decreased. The average speed in the area is almost constant, it decreased with 0.4%. The activities in this area are much lower than in other areas.

Table 6-2 Shipping activities per EMS type for the Dutch part of the Western Scheldt from Terneuzen to the west

Ship type	Totals for Western Scheldt in 2013					2013 as percentage of 2012				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	7,379	235,799,032	4,072	910,729,542	10.20	121.7%	137.2%	114.6%	129.1%	103.2%
Chem.+Gas tanker	24,772	266,877,142	20,514	1,897,302,394	10.61	81.1%	86.6%	91.7%	104.5%	102.3%
Bulk carrier	10,121	430,115,557	4,651	1,126,617,937	8.46	51.2%	65.1%	83.2%	86.9%	100.5%
Container ship	2,952	62,299,182	12,624	6,899,257,840	12.58	49.7%	52.9%	89.3%	100.5%	100.7%
General Dry Cargo	39,727	343,344,242	21,253	1,112,383,966	9.89	62.5%	68.4%	81.2%	89.4%	103.2%
RoRo Cargo / Vehicle	8,884	174,975,465	6,637	2,882,310,029	11.71	63.1%	80.9%	94.0%	100.7%	102.3%
Reefer	6,757	60,744,957	1,709	236,704,555	11.92	80.8%	78.8%	95.5%	94.1%	99.1%
Passenger	10,144	18,119,101	5,683	264,805,124	11.49	74.9%	110.9%	100.5%	115.0%	100.5%
Miscellaneous	81,222	208,954,888	16,115	282,076,437	7.88	84.7%	76.0%	98.5%	92.5%	99.8%
Tug/Supply	90,565	54,147,425	11,367	30,959,157	6.72	94.0%	130.5%	82.8%	107.4%	108.1%
Non Merchant	2,918	2,176,354	71	159,721	5.25	68.6%	39.3%	72.6%	20.7%	74.6%
Total	285,442	1,857,553,346	104,696	15,643,306,703	11.24	79.7%	77.7%	89.9%	100.2%	101.9%

Table 6-3 Shipping activities per EMS ships size classes for the Dutch part of the Western Scheldt from Terneuzen to the west

Ship size in GT	Totals for Western Scheldt in 2013					2013 as percentage of 2012				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	150,432	81,271,702	25,307	151,070,961	8.79	84.4%	83.2%	84.8%	83.8%	100.5%
1,600-3,000	46,068	105,076,770	22,063	447,831,496	8.76	93.2%	93.3%	90.6%	89.6%	99.2%
3,000-5,000	17,820	70,336,791	12,202	485,826,440	10.16	72.3%	72.5%	83.6%	87.1%	104.1%
5,000-10,000	22,465	157,460,532	11,969	907,451,257	10.74	64.2%	65.3%	91.7%	90.9%	99.9%
10,000-30,000	31,060	584,791,660	17,525	3,695,499,381	11.10	61.5%	65.5%	93.6%	98.2%	102.1%
30,000-60,000	14,642	616,607,491	11,531	5,641,080,567	11.31	82.9%	86.5%	94.5%	97.5%	101.6%
60,000-100,000	2,924	236,910,760	3,325	3,051,422,957	11.94	102.3%	101.7%	106.6%	108.8%	101.2%
>100,000	31	5,097,640	774	1,263,123,644	12.18	118.3%	122.1%	124.4%	124.1%	99.9%
Total	285,442	1,857,553,346	104,696	15,643,306,703	11.24	79.7%	77.7%	89.9%	100.2%	101.9%

Table 6-4 Shipping activities per EMS type for the Rotterdam port area

Ship type	Totals for Rotterdam in 2013					2013 as percentage of 2012				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	49,100	3,020,342,762	5,626	1,788,274,621	6.64	78.3%	70.6%	90.1%	93.8%	104.7%
Chem.+Gas tanker	58,791	846,035,297	19,987	1,629,703,765	8.34	55.9%	59.3%	87.4%	91.3%	104.1%
Bulk carrier	68,080	4,311,871,106	3,179	935,292,023	6.35	96.5%	98.2%	91.7%	98.7%	106.6%
Container ship	126,342	5,997,076,909	24,080	4,588,962,852	7.32	73.2%	94.5%	82.8%	89.4%	103.5%
General Dry Cargo	56,306	336,969,922	18,166	676,559,691	9.22	64.9%	71.7%	84.2%	93.7%	102.9%
RoRo Cargo / Vehicle	19,381	457,728,680	6,582	1,559,044,824	9.71	65.6%	65.3%	89.6%	91.8%	102.1%
Reefer	1,084	9,258,859	750	63,193,418	9.31	52.5%	58.1%	98.8%	100.9%	97.1%
Passenger	11,179	627,094,288	1,551	981,591,650	11.46	82.1%	88.9%	87.0%	96.0%	108.6%
Miscellaneous	51,912	639,643,598	20,687	533,597,592	6.17	66.5%	52.0%	117.3%	111.2%	95.7%
Tug/Supply	178,736	87,275,619	45,504	108,234,131	5.97	92.1%	89.3%	86.9%	78.7%	92.3%
Non Merchant	542	246,644	199	519,810	7.54	24.9%	44.7%	58.9%	42.7%	99.2%
Total	621,451	16,333,543,683	146,310	12,864,974,376	7.70	76.1%	83.1%	89.5%	92.6%	103.5%

Table 6-5 Shipping activities per EMS ships size class for the Rotterdam port area

Ship size in GT	Totals for Rotterdam in 2013					2013 as percentage of 2012				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average Speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	203,433	89,243,179	55,546	154,053,247	6.46	87.0%	85.6%	85.9%	88.1%	100.2%
1,600-3,000	35,340	85,846,845	14,530	320,416,464	9.27	59.1%	58.7%	82.4%	82.8%	102.8%
3,000-5,000	31,966	127,095,400	15,755	540,854,081	8.56	56.9%	56.0%	93.3%	93.0%	100.5%
5,000-10,000	77,585	578,014,294	24,550	1,607,111,201	8.94	64.4%	64.3%	100.0%	98.5%	100.4%
10,000-30,000	92,854	1,787,829,072	21,644	3,461,184,317	8.75	66.5%	64.6%	93.1%	91.3%	103.1%
30,000-60,000	67,110	2,945,945,751	7,026	2,411,522,162	8.03	74.1%	75.5%	81.8%	87.5%	106.1%
60,000-100,000	78,593	5,916,418,234	5,483	2,921,217,080	6.98	99.7%	93.8%	93.1%	97.5%	105.1%
>100,000	34,571	4,803,150,909	1,776	1,448,615,824	5.71	90.9%	90.5%	88.8%	91.7%	102.2%
Total	621,451	16,333,543,683	146,310	12,864,974,376	7.70	76.1%	83.1%	89.5%	92.6%	103.5%

Table 6-6 Shipping activities per EMS type for the Amsterdam port area, totals for complete area, percentages for area of 2012

Ship type	Totals for Amsterdam in 2013					2013 as percentage of 2012				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	14,460	489,955,170	2,009	303,781,713	5.42	54.1%	53.6%	89.4%	91.1%	100.9%
Chem.+Gas tanker	32,511	598,003,291	6,133	521,083,006	5.96	64.3%	62.7%	86.8%	86.3%	101.4%
Bulk carrier	54,919	2,849,161,191	2,828	701,106,536	5.19	106.6%	107.6%	103.6%	108.0%	103.9%
Container ship	298	4,290,465	51	4,928,886	5.69	39.8%	30.9%	49.2%	42.1%	94.8%
General Dry Cargo	69,125	297,220,759	9,097	191,613,926	6.74	70.5%	78.0%	104.6%	102.0%	103.0%
RoRo Cargo / Vehicle	8,344	220,403,930	1,779	253,978,792	6.33	86.5%	80.1%	92.4%	96.4%	102.7%
Reefer	14,791	62,452,575	403	9,838,234	5.96	85.8%	71.5%	74.1%	64.0%	103.6%
Passenger	4,478	187,764,809	1,100	367,067,544	6.47	98.8%	100.7%	82.4%	94.7%	100.9%
Miscellaneous	32,291	146,618,546	2,555	65,233,023	5.75	83.2%	58.0%	89.2%	90.0%	99.9%
Tug/Supply	107,237	75,499,679	17,933	34,343,715	5.61	83.1%	102.1%	91.5%	90.9%	104.2%
Non Merchant	5,788	3,124,309	330	740,122	5.92	50.3%	54.7%	48.1%	56.3%	111.6%
Total	344,243	4,934,494,723	44,219	2,453,715,496	5.79	78.5%	85.2%	92.6%	95.7%	101.9%

Table 6-7 Shipping activities per EMS ships size classes for the Amsterdam port area, totals for complete area, percentages for area of 2012

Ship size in GT	Totals for Amsterdam in 2013					2013 as percentage of 2012				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	118,953	52,903,971	20,663	48,948,343	5.99	76.5%	72.3%	92.7%	96.8%	103.8%
1,600-3,000	53,373	124,832,284	6,539	109,482,117	6.92	74.3%	72.5%	101.6%	105.1%	102.9%
3,000-5,000	29,316	115,054,210	2,854	77,831,279	6.86	104.1%	102.2%	91.7%	91.8%	101.3%
5,000-10,000	32,501	234,540,439	4,162	211,542,009	6.53	67.0%	68.3%	92.1%	96.9%	103.5%
10,000-30,000	47,416	947,761,728	5,206	613,092,328	5.90	71.9%	64.4%	81.6%	83.6%	101.6%
30,000-60,000	43,360	1,803,090,284	3,526	833,126,329	5.67	87.1%	89.4%	90.3%	93.1%	101.0%
60,000-100,000	19,278	1,650,796,067	1,248	546,829,857	5.30	102.1%	103.2%	112.1%	115.8%	104.3%
>100,000	47	5,515,740	18	12,863,235	6.00	190.4%	187.5%	146.9%	150.7%	101.6%
Total	344,243	4,934,494,723	44,219	2,453,715,496	5.79	78.5%	85.2%	92.6%	95.7%	101.9%

Table 6-8 Shipping activities per EMS type for the Dutch part of the Ems area

Ship type	Totals for Ems in 2013					2013 as percentage of 2012				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	794	1,649,733	623	8,113,360	9.49	169.7%	18.3%	114.3%	56.6%	110.1%
Chem.+Gas tanker	4,052	16,114,423	1,944	96,913,767	10.56	91.6%	64.4%	96.3%	92.0%	100.7%
Bulk carrier	3,233	49,757,111	597	72,343,283	9.79	89.1%	72.3%	86.2%	101.0%	102.4%
Container ship	1,043	3,051,194	195	11,323,930	11.25	74.8%	80.3%	138.0%	105.8%	97.4%
General Dry Cargo	64,395	230,332,139	8,634	304,791,449	10.06	108.0%	102.3%	97.1%	108.3%	102.2%
RoRo Cargo / Vehicle	12,014	410,744,221	8,119	1,467,885,419	12.72	85.5%	83.2%	101.1%	98.6%	101.5%
Reefer	1,352	4,507,099	135	5,114,115	11.57	82.2%	76.0%	75.2%	82.9%	114.8%
Passenger	4,099	42,236,331	2,592	61,262,280	11.18	241.3%	70.7%	100.3%	83.1%	108.1%
Miscellaneous	33,779	78,258,404	11,252	293,501,345	7.93	94.1%	155.5%	82.4%	94.6%	106.9%
Tug/Supply	109,325	79,166,291	9,153	61,797,617	9.12	92.2%	98.9%	87.3%	109.9%	107.4%
Non Merchant	52	18,721	30	62,267	5.67	248.9%	168.8%	47.2%	41.4%	91.7%
Total	234,137	915,835,668	43,273	2,383,108,831	11.14	97.0%	89.7%	91.5%	98.5%	103.1%

Table 6-9 Shipping activities per EMS ships size classes for the Dutch part of the Ems area

Ship size in GT	Totals for Ems in 2013					2013 as percentage of 2012				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	129,957	49,484,237	16,749	74,010,697	10.68	96.3%	89.9%	86.3%	84.2%	113.6%
1,600-3,000	49,339	112,870,665	11,371	257,321,397	10.50	83.6%	81.6%	92.6%	97.3%	105.8%
3,000-5,000	25,691	103,632,944	5,346	196,372,355	8.68	149.4%	155.7%	84.0%	90.9%	104.3%
5,000-10,000	12,988	81,229,388	6,242	492,676,966	11.09	96.8%	93.1%	111.1%	116.3%	101.3%
10,000-30,000	8,419	151,945,501	1,992	381,412,225	11.39	125.8%	121.0%	104.4%	105.2%	104.1%
30,000-60,000	6,298	312,456,396	1,283	758,206,202	12.09	72.6%	73.1%	89.5%	87.3%	99.8%
60,000-100,000	1,259	77,315,162	276	209,731,426	12.25	118.0%	117.7%	116.6%	121.5%	104.9%
>100,000	185	26,901,375	14	13,377,563	6.50	42.1%	49.0%	50.8%	58.4%	98.7%
Total	234,137	915,835,668	43,273	2,383,108,831	11.14	97.0%	89.7%	91.5%	98.5%	103.1%

Table 6-10 Shipping activities per EMS type for the port area of Den Helder

Ship type	Totals for Den Helder in 2013					2013 as percentage of 2012				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	1,068	18,571,594	25	2,070,792	5.70	38.5%	37.4%	31.0%	27.9%	108.6%
Chem.+Gas tanker	116	766,931	20	420,272	7.94	120.4%	229.3%	688.2%	262.1%	83.4%
Bulk carrier	46	378,830	3	178,865	5.90	-	-	4922.8%	166.2%	20.6%
General Dry Cargo	1,366	3,039,031	136	3,188,953	8.44	107.7%	80.4%	95.3%	111.6%	132.8%
RoRo Cargo / Vehicle	0	641	-	-	-	-	-	-	-	-
Passenger	5,199	66,313,159	2,843	335,375,356	8.98	72.5%	84.0%	96.2%	96.2%	99.9%
Miscellaneous	46,484	225,397,539	1,730	19,478,280	5.02	137.2%	257.9%	87.1%	134.1%	102.9%
Tug/Supply	110,003	145,604,584	4,843	48,150,649	6.20	141.9%	107.2%	98.0%	83.5%	101.9%
Non Merchant	1,335	557,836	118	263,781	5.39	208.5%	192.6%	215.1%	141.6%	61.3%
Total	165,617	460,630,145	9,718	409,126,949	8.21	134.3%	129.3%	95.6%	94.8%	101.0%

Table 6-11 Shipping activities per EMS ships size classes for the port area of Den Helder

Ship size in GT	Totals for Den Helder in 2013					2013 as percentage of 2012				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	96,413	41,577,836	3,316	9,019,446	5.98	174.7%	130.4%	121.6%	95.8%	99.3%
1,600-3,000	48,515	113,250,595	3,108	43,748,341	6.11	97.5%	100.7%	77.9%	84.0%	104.7%
3,000-5,000	5,335	19,099,056	331	7,084,850	5.98	81.4%	82.3%	97.2%	95.7%	99.6%
5,000-10,000	1,143	8,539,009	45	2,071,859	6.70	104.4%	111.6%	66.8%	82.1%	119.3%
10,000-30,000	14,195	277,455,177	2,915	346,471,860	8.76	132.6%	153.2%	96.1%	96.2%	99.6%
30,000-60,000	17	705,507	3	730,592	5.32	2850.7%	2287.1%	-	-	-
60,000-100,000	0	2,964	-	-	-	-	-	-	-	-
Total	165,617	460,630,145	9,718	409,126,949	8.21	134.3%	129.3%	95.6%	94.8%	101.0%

Table 6-12 Shipping activities per EMS type for the port area of Harlingen

Ship type	Totals for Harlingen in 2013					2013 as percentage of 2012				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.hours	Average speed	Hours	GT.Hours	Hours	GT.nm	Average speed
Oil tanker	1,519	7,039,591	19	741,228	8.51	-	-	-	-	-
Chem.+Gas tanker	5,023	12,842,052	284	5,081,333	7.47	942.6%	516.9%	521.9%	224.2%	86.5%
Container ship	1,216	4,306,933	10	205,621	7.46	2006.0%	2991.6%	64.7%	53.0%	82.8%
General Dry Cargo	22,066	77,584,215	1,402	33,376,522	8.57	91.3%	105.6%	96.6%	108.2%	108.1%
RoRo Cargo / Vehicle	5,022	9,519,113	2,115	33,518,015	9.01	92.3%	99.9%	88.3%	86.8%	97.4%
Reefer	3,510	15,363,851	272	10,617,976	8.98	91.1%	75.7%	93.8%	85.7%	103.6%
Passenger	12,280	23,653,754	5,147	165,957,740	12.38	93.0%	97.6%	100.8%	100.2%	101.2%
Miscellaneous	28,871	22,912,135	4,623	38,692,498	7.11	91.3%	107.0%	109.4%	117.7%	96.7%
Tug/Supply	21,348	14,551,341	949	3,885,550	8.26	116.7%	153.6%	109.2%	123.2%	103.5%
Non Merchant	3,751	4,547,614	186	1,721,628	8.62	51.7%	72.3%	86.0%	171.6%	106.5%
Total	104,607	192,320,599	15,007	293,798,110	10.09	100.1%	114.9%	102.7%	102.3%	99.6%

Table 6-13 Shipping activities per EMS ships size classes for the port area of Harlingen

Ship size in GT	Totals for Harlingen in 2013					2013 as percentage of 2012				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.hours	Average speed	Hours	GT.Hours	Hours	GT.nm	Average speed
100-1,600	54,872	24,586,355	7,220	51,735,602	10.37	87.4%	77.3%	106.0%	101.4%	98.2%
1,600-3,000	25,882	59,557,075	3,371	57,701,261	8.73	107.2%	107.2%	94.6%	92.6%	100.0%
3,000-5,000	16,098	62,807,446	3,728	149,715,590	11.12	134.1%	137.4%	96.8%	97.7%	100.7%
5,000-10,000	7,652	44,151,811	682	34,088,735	8.55	138.4%	128.7%	173.9%	166.1%	103.7%
10,000-30,000	102	1,212,546	5	556,922	8.54	291186.1%	225785.8%	-	-	-
>100,000	0	5,366	-	-	-	-	-	-	-	-
Total	104,607	192,320,599	15,007	293,798,110	10.09	100.1%	114.9%	102.7%	102.3%	99.6%

6.3 Activities of seagoing vessels in the Netherlands sea area

The shipping activities in the Netherlands sea area are presented in Table 6-14 and Table 6-15. Again, 2013 is compared to 2012. The tables contain per ship type and size class:

- hours and GT.hours for not moving ships (at anchor), and
- hours, GT.nm and average speed for moving ships.

Mostly, the tables show decreases. For ship at anchor, the average number of hours decreased, but the average GT.hours increased, since there were more large ships at anchor (oil tankers, and bulk carriers). The number of hours and GT.nm of moving ships have decreased with 6.4% and 2.6% respectively. The decrease was largest for small ship size classes and there was an increase for the fewer ships in the larger ship size classes. The average speed decreased with only 0.5%. The decrease in numbers at the NCS is in line with the decrease seen in the previous section for the port areas.

Table 6-14 Shipping activities per EMS type for the Netherlands Continental Shelf and 12-mile zone

Ship type	Totals for NCS and 12-mile zone in 2013					2013 as percentage of 2012				
	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	135,854	6,579,183,507	81,770	39,925,159,115	10.74	110.78%	124.57%	99.46%	98.87%	98.48%
Chem.+Gas tanker	310,455	3,744,132,461	244,141	28,836,339,931	11.56	92.12%	88.75%	92.21%	91.40%	101.06%
Bulk carrier	67,920	3,568,529,091	88,868	33,676,406,979	11.10	130.70%	147.21%	98.74%	102.41%	100.23%
Container ship	39,990	1,231,785,378	167,972	104,364,496,801	14.41	50.50%	55.56%	91.40%	96.27%	98.83%
General Dry Cargo	80,541	388,092,016	390,668	16,814,110,552	10.79	97.15%	93.75%	93.48%	97.26%	99.49%
RoRo Cargo / Vehicle	6,654	240,297,406	113,316	52,025,034,511	15.35	94.79%	102.19%	95.13%	96.14%	98.81%
Reefer	3,844	33,009,977	14,695	1,820,991,849	15.33	71.96%	81.03%	85.55%	89.15%	101.08%
Passenger	5,722	14,456,965	24,806	19,226,591,275	17.13	102.51%	96.87%	102.98%	108.84%	99.24%
Miscellaneous	63,509	227,219,314	98,694	2,636,395,816	7.27	107.44%	89.27%	92.27%	87.49%	101.79%
Tug/Supply	90,136	148,170,796	154,888	1,434,486,351	7.06	107.89%	121.86%	91.97%	103.21%	104.56%
Non Merchant	8,198	1,005,973	4,110	18,545,063	9.57	89.19%	97.82%	88.28%	57.62%	84.76%
Total	812,825	16,175,882,883	1,383,928	300,778,558,243	12.94	96.36%	106.26%	93.57%	97.41%	99.45%

Table 6-15 Shipping activities per ship size class for the Netherlands Continental Shelf and 12-mile zone

Ship size in GT	Totals for NCS and 12-mile zone in 2013					2013 as percentage of 2012				
	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
100-1,600	99,205	54,494,103	197,466	973,437,987	6.85	99.77%	90.68%	86.76%	84.63%	103.18%
1,600-3,000	108,819	263,963,710	325,764	6,998,209,306	8.93	99.51%	99.82%	96.55%	95.65%	98.41%
3,000-5,000	114,900	450,046,311	167,606	7,028,485,301	10.65	97.46%	96.86%	88.71%	87.86%	99.32%
5,000-10,000	121,563	915,133,037	190,482	16,902,830,288	12.23	99.13%	99.13%	95.85%	95.82%	100.04%
10,000-30,000	205,405	4,066,319,661	255,396	63,013,941,243	12.87	82.84%	82.79%	92.11%	92.39%	100.91%
30,000-60,000	86,410	3,710,590,351	144,415	86,536,565,175	13.66	93.64%	96.03%	96.15%	96.23%	99.35%
60,000-100,000	64,041	4,896,706,917	82,970	81,737,936,865	12.96	141.78%	142.93%	104.79%	101.66%	96.91%
>100,000	12,482	1,818,628,793	19,830	37,587,152,077	13.70	142.20%	138.88%	100.46%	104.05%	101.14%
Total	812,825	16,175,882,883	1,383,928	300,778,558,243	12.94	96.36%	106.26%	93.57%	97.41%	99.45%

6.4 Overview of ships in the port areas and in the Netherlands sea area

The average number of ships in the port areas and at sea is given in Table 6-16 and graphically depicted in Figure 6-1. Large differences between ports in the ratio of not moving ships over moving ships are observed. This is explained by the length of the route to the berth: the longer the route, the smaller the ratio. For Amsterdam with short routes a high ratio is found, for the Western Scheldt a small ratio is observed due to long sailing distances but also because most ships berth outside the area. Table 6-16 shows in addition that the average speed is quite different between the port areas, with an average of 5.40 knots for Amsterdam and 11.24 knots in the Western Scheldt.

Remark: The percentages in Table 6-16 for the average number of ships in 2013 compared with 2012 are almost the same as found earlier in Table 6-2 through Table 6-9 and Table 6-15 under the column ”Hours”. This is because the average number of ships is calculated by dividing the number of hours of ship observations by the number of hours in a year. The percentages differ slightly since 2013 had 365 days where 2012 had 366 days.

The average GT of the ships is given in Table 6-17. The average GT of a ship in Rotterdam is more than 6 times higher than that of a ship in the Ems. Den Helder and Harlingen have even smaller vessels visiting their ports. In Rotterdam and Amsterdam, the average GT of not moving (thus mostly berthed) ships is larger than that of moving ships. This is due to the fact that larger ships have a shorter sailing distance because their berths are closer to the sea and because the time needed for cargo handling is larger for larger ships. The total average GT shows an increase in five out of seven areas. Only for the Ems and Den Helder a decrease of more than 5% is seen. In the other areas the increase in average GT varies from 3.9% for the Western Scheldt to almost 13% for Harlingen.

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 activities in large detail, in order to determine the emissions in these areas. The AIS data offer the opportunity to incorporate all these characteristics in the calculations.

Table 6-16 Average number of ships in distinguished areas

Area	In 2013				In 2013 as percentage of 2012			
	Average # ships			Speed	Average # ships			Speed
	Not moving	Moving	Total	Knots	Not moving	Moving	Total	Knots
Western Scheldt	32.58	11.95	44.54	11.24	79.9%	90.1%	82.4%	101.9%
Rotterdam	70.94	16.70	87.64	7.70	76.3%	89.7%	78.5%	103.5%
Amsterdam[1]	39.30	5.05	44.34	5.79	78.7%	92.9%	80.0%	101.9%
Ems	26.73	4.94	31.67	11.14	97.3%	91.8%	96.4%	103.1%
Den Helder	18.91	1.11	20.02	8.21	134.7%	95.9%	131.7%	101.0%
Harlingen	11.94	1.71	13.65	10.09	100.4%	102.9%	100.7%	99.6%
NCS + 12-mile zone	92.79	157.98	250.77	12.94	96.6%	93.8%	94.8%	99.5%

[1] The numbers are for the area of 2013, the percentage for the area of 2012

Table 6-17 Average GT in distinguished areas

Area	In 2013			In 2013 as percentage of 2012		
	Average GT of ships			Average GT of ships		
	Not moving	Moving	Total	Not moving	Moving	Total
Western Scheldt	6,508	13,294	8,329	97.5%	109.5%	103.9%
Rotterdam	26,283	11,413	23,449	109.2%	99.9%	106.8%
Amsterdam[2]	14,334	9,586	13,794	108.5%	101.5%	107.5%
Ems	3,912	4,943	4,072	92.5%	104.4%	94.4%
Den Helder	2,781	5,131	2,912	96.3%	98.1%	94.9%
Harlingen	1,839	1,940	1,851	114.7%	100.1%	112.6%
NCS + 12-mile zone	19,901	16,799	17,947	110.3%	104.7%	107.0%

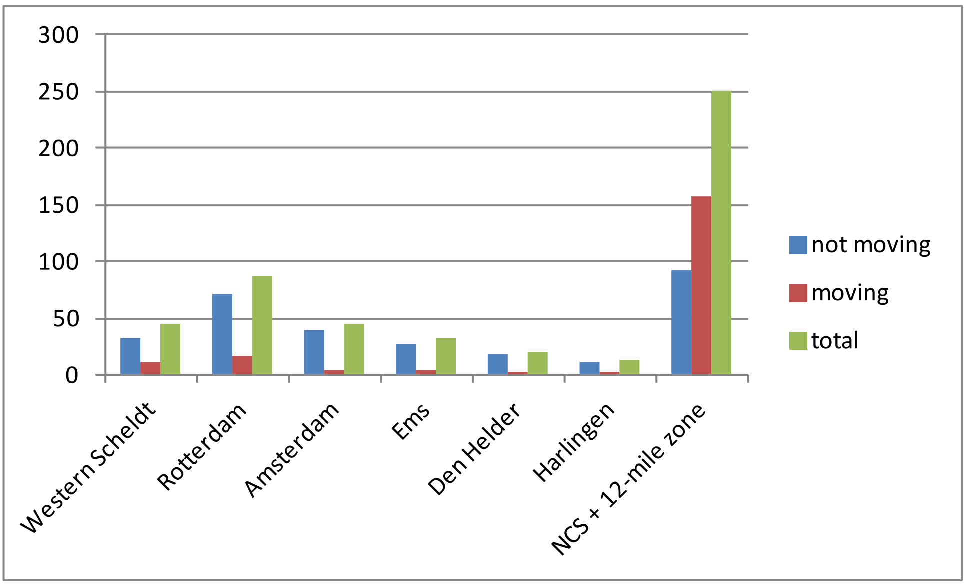

Figure 6-1 Average number of ships in areas considered

[2] The numbers are for the area of 2013, the percentage for the area of 2012

7 EMISSIONS FOR THE DUTCH PORT AREAS AND THE NETHERLANDS SEA AREA

7.1 Introduction

This chapter presents the results of the emission calculations for 2013 for the Dutch port areas and the Netherlands sea area. To see the change in emissions, all values for 2013 are compared with the values of 2012. Values are presented as calculated and are not rounded off.

The emissions for the port areas are given in Section 7.2 and for the NCS and 12-mile zone in Section 7.3. Section 7.4 presents the spatial distribution of the 2013 NO_x emissions. Also the change in these emissions compared to 2012 is presented.

Appendix A includes an updated description of the methodology used to determine the emission factors.

7.2 Emissions in port areas

Table 7-1 contains the emissions for the six Dutch port areas, calculated for ships berthed and sailing within the port area. Table 7-2 contains the same emissions expressed as a percentage of the corresponding emissions in 2012. Note that values for at berth include all vessels with zero speed, so also the vessels at anchor.

Table 7-2 shows a decrease in emission between 2012 and 2013 for all substances in the port areas Western Scheldt, Rotterdam and Amsterdam. In the port areas of the Ems, Den Helder and Harlingen there is an increase. Only for VOC there is also a small decrease in the Ems area. The decrease is largest in the port area of the Western Scheldt. Summarized over all port areas there is a decrease of 14.6%.

Summarized for the port areas, it can be concluded that without looking at the emission changes per ship type and size, it remains difficult to explain changes in emissions by changes in total number of ships, hours, GT.hours or GT.nm. The reason is that underlying changes in the traffic composition and used speed are not described by these totals. Therefore, it is important that emissions are calculated for each individual ship observed in the AIS data.

Table 7-1 Total emissions in ton in each port area for 2013 based on AIS data

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Total
1011 Methane	Berthed	-	-	-	-	-	-	
	Sailing	0.1	0.1	-	-	-	-	0.1
	Total	0.1	0.1	-	-	-	-	**0.1**
1237 VOC	Berthed	27	205	56	13	10	4	314
	Sailing	218	143	27	26	4	7	416
	Total	244	348	84	39	13	11	**730**
4001 SO_2	Berthed	49	419	108	29	20	7	632
	Sailing	2,006	1,129	179	207	24	34	3487
	Total	2,055	1,548	287	236	44	40	**4,119**
4013 NO_x	Berthed	612	4,260	1,289	319	265	90	6,834
	Sailing	7,783	3,989	691	793	92	204	13,268
	Total	8,395	8,249	1,980	1,112	356	294	**20,102**
4031 CO	Berthed	133	1,014	282	71	56	18	1,573
	Sailing	1,490	1,061	197	162	27	37	2,918
	Total	1,623	2,075	478	233	83	56	**4,491**
4032 CO_2	Berthed	54,319	498,182	119,002	23,305	16,835	5,892	717,535
	Sailing	337,210	196,060	33,662	40,024	5,389	9,695	604,952
	Total	391,529	694,242	152,664	63,329	22,224	15,587	**1,322,487**
6601 Aerosols MDO	Berthed	13	104	28	7	5	2	159
	Sailing	17	16	5	7	2	5	49
	Total	30	120	34	14	6	7	**208**
6602 Aerosols HFO	Berthed	0	0	0	0	0	0	0
	Sailing	337	184	27	29	2	1	575
	Total	337	184	27	29	2	1	**575**
6598 Aerosols MDO+HFO	Berthed	13	104	28	7	5	2	159
	Sailing	354	199	32	36	4	7	624
	Total	367	304	61	43	9	8	**783**

Table 7-2 Emissions in each port area for 2013 as percentage of the emissions in 2012

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Total
1237 VOC[3]	Berthed	83.0%	88.6%	84.8%	105.5%	160.4%	117.5%	89.4%
	Sailing	79.1%	87.5%	87.7%	97.1%	95.7%	101.1%	82.1%
	Total	79.5%	88.2%	85.7%	99.7%	135.9%	106.0%	85.1%
4001 SO_2	Berthed	80.4%	92.6%	89.3%	107.1%	167.1%	113.6%	93.0%
	Sailing	82.4%	89.2%	89.0%	107.9%	92.6%	105.6%	84.0%
	Total	82.3%	90.1%	89.1%	107.8%	116.7%	106.9%	85.3%
4013 NO_x	Berthed	81.3%	85.8%	90.9%	107.1%	156.9%	112.5%	89.0%
	Sailing	82.1%	87.9%	89.0%	99.8%	95.3%	100.5%	83.5%
	Total	82.1%	86.8%	90.3%	101.8%	134.5%	103.8%	85.3%
4031 CO	Berthed	87.7%	93.6%	90.5%	115.8%	167.7%	125.0%	95.0%
	Sailing	79.5%	87.7%	88.9%	100.6%	93.4%	104.3%	82.6%
	Total	80.2%	90.5%	89.9%	104.7%	133.0%	110.3%	86.6%
4032 CO_2	Berthed	83.4%	89.8%	73.8%	103.1%	149.0%	123.4%	87.5%
	Sailing	82.1%	89.2%	90.2%	104.6%	94.0%	102.8%	83.9%
	Total	82.3%	89.6%	76.6%	104.0%	130.5%	109.7%	85.8%
6601 Aerosols MDO	Berthed	-	-	-	-	-	-	-
	Sailing	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-
6602 Aerosols HFO	Berthed	-	-	-	-	-	-	-
	Sailing	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-
6598 Aerosols MDO+HFO	Berthed	78.9%	86.5%	85.0%	101.6%	157.4%	111.0%	87.4%
	Sailing	82.2%	89.0%	89.4%	107.6%	93.6%	104.3%	84.9%
	Total	82.1%	88.1%	87.2%	106.7%	119.7%	105.8%	85.4%

[3] Emission in ton in 2013 for 1237, comparison for 1011+1237 in 2013 with 1327 in 2012

7.3 Emissions in the Netherlands sea area

The emissions in the NCS and the 12-mile zone are calculated for moving and non-moving ships. Ships are counted as non-moving when the speed is less than 1 knot. Mostly this concerns ships at anchor in one of the anchorage areas. However, some ships may have 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 has been calculated for the main engine and for the auxiliary engines.

The calculated emissions for 2013 are summarised in Table 7-3. This table also contains a comparison with 2012. The average number of moving ships has decreased significantly with 6.2%. The decrease in emissions for moving ships is for most substances a little higher because also the average speed that was observed has decreased. Only for CO the emission decrease was smaller. The number for Aerosols MDO and Aerosols HFO cannot be compared separately, because of the change that was described in section 2.1. The decrease for Aerosols MDO+HFO combined is in line with the decreases for other substances.

Also the average number of not moving ships (mainly anchored ships) decreased, with 3.4%. For all substances, the decrease in emissions was even stronger. This can be explained by a reduction in the power of the auxiliary engines compared to 2012.

Table 7-3 Emissions of ships in ton in the Netherlands sea area for 2013 compared with 2012

Nr	Substance	Emission in ton in 2013			Emission in 2013 as percentage of 2012		
		Not moving	Moving	Total	Not moving	Moving	Total
1011	Methane	-	5	5	-	-	-
1237[4]	VOC	72	1,946	2,018	88.2%	92.6%	92.4%
4001	SO_2	653	19,451	20,104	86.1%	92.8%	92.6%
4013	NO_x	2,122	72,754	74,876	87.4%	92.0%	91.8%
4031	CO	447	12,906	13,353	89.1%	94.4%	94.2%
4032	CO_2	129,417	3,233,255	3,362,672	88.9%	93.0%	92.8%
6601	Aerosols MDO	25	122	147	-	-	-
6602	Aerosols HFO	88	3,269	3,356	-	-	-
6598	Aerosols MDO+HFO	113	3,390	3,503	85.8%	92.9%	92.6%
Ships		92.79	157.98	250.77	96.6%	93.8%	94.8%

[4] Emission in ton in 2013 for 1237, comparison for 1011+1237 in 2013 with 1327 in 2012

7.4 Spatial distribution of the emissions

Because of the strong relation between shipping routes and location of the emissions, all substances show more or less the same spatial distribution. Therefore, only the spatial distribution of NO_x is presented for the six Dutch port areas and the Netherlands sea area in Figure 7-1 to Figure 7-21.

Three figures are presented for each area. The first figure represents the total emission (emissions of auxiliary and main engine of moving and not moving ships together) expressed as NO_x in ton/km^2. The second one shows the *absolute* change in emission between 2012 and 2013 and the third one shows the *relative* change in emission between 2012 and 2013. To make a comparison between areas easier the same colour table has been used for all areas. Only for the NCS a different scale has been used to illustrate the absolute difference. This is necessary because at the NCS differences are more smoothed due to the larger grid cells, these are 25 km^2 instead of 0.25 km^2 as used in the port areas.

In the figures, large differences between 2012 and 2013 are visualized by darker colours. Absolute differences are often larger at locations with high traffic intensity, while relative differences are often larger at locations with low traffic intensity. This has to be kept in mind when interpreting the figures.

Some of the comparisons require some extra explanations that will be given here.

For the Western Scheldt, the box indicates the area for which the traffic database has been used to determine the emissions. This means that outside this box, the same method is used as in 2012 and inside the box the method has changed. Figure 7-2 shows a decrease in absolute emissions for most of the area. The decrease is larger in the most eastern part. This is the part where in previous years a correction factor was applied to account for the bad coverage. Since the spatial resolution of the emissions of 2013 is based on the spatial resolution of 2011, where this correction factor was also applied, this should not affect the difference. The fact that the difference is larger in the eastern side, indicates that the simple method for the correction resulted in an overcompensation in 2012. In 2012 it was already concluded that the coverage problems were probably more complicated and could not be fully accounted for by the correction factor as in earlier years.

For the port area of Rotterdam, an increase is shown for Maasvlakte 1 and 2. More ships visit these terminals close to the sea, which means the sailing time in the port area decreases. This corresponds to the figures in Table 6-16, which shows that the average number of ships in the area decreased with more than 20%.

Figure 7-20 shows that there is an absolute emission reduction on the busiest routes north of Amsterdam. Furthermore, the change of the traffic separation scheme (TSS) on August 1, 2013, can be seen. This change of the TSS means that ships have to follow different routes. This is illustrated in Figure 7-22, which zooms in on the Eurogeul near Rotterdam. In this figure both the new and the old TSS are shown, there is an increase in emission on the routes of the new TSS and a decrease in emission on the routes of the old TSS.

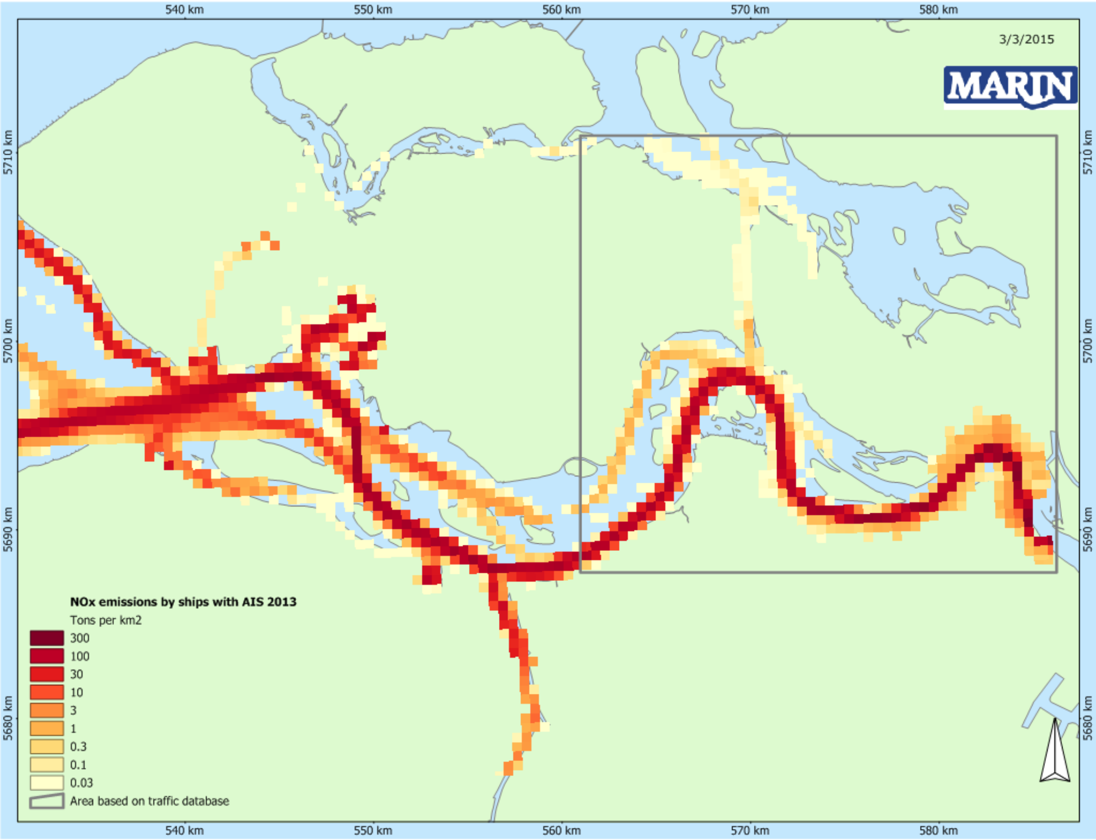

Figure 7-1 NO_x emission in 2013 in the Dutch part of the Western Scheldt by ships with AIS. For the emissions on the Western Scheldt east of Terneuzen the SAMSON traffic database is used.

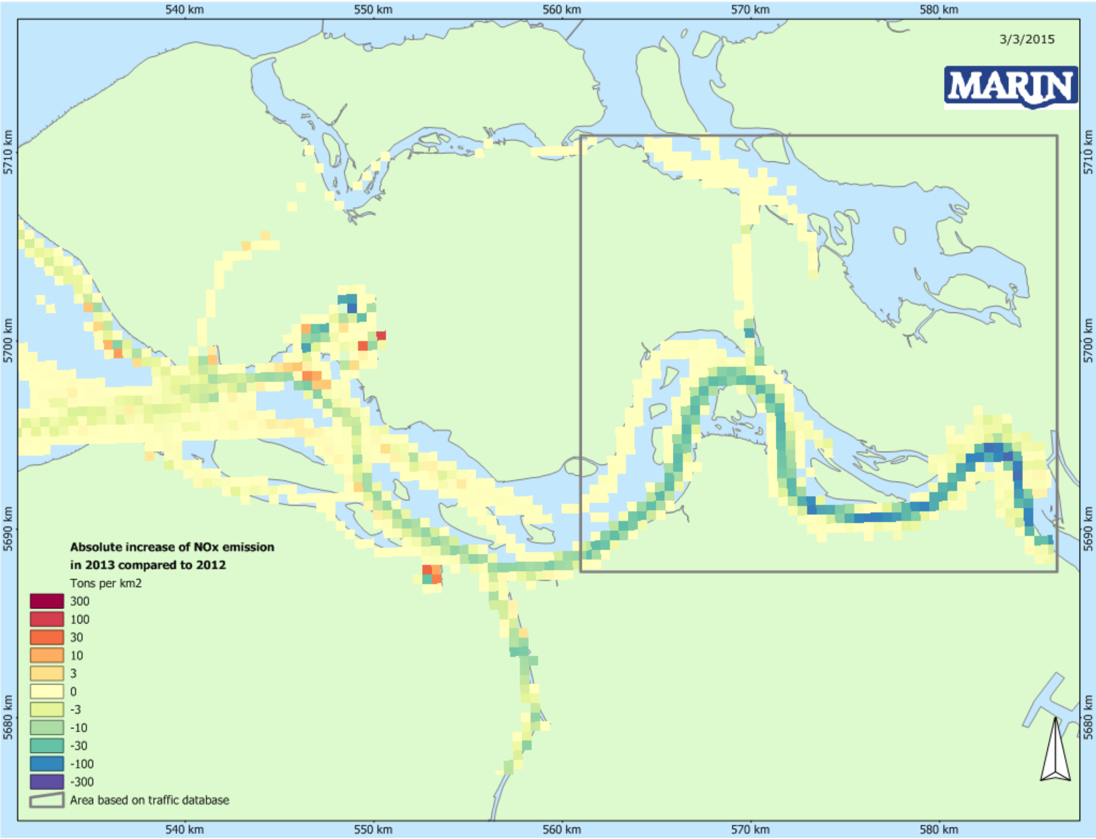

Figure 7-2 Absolute change in NO_x emission from 2012 to 2013 in the Dutch part of the Western Scheldt by ships with AIS.

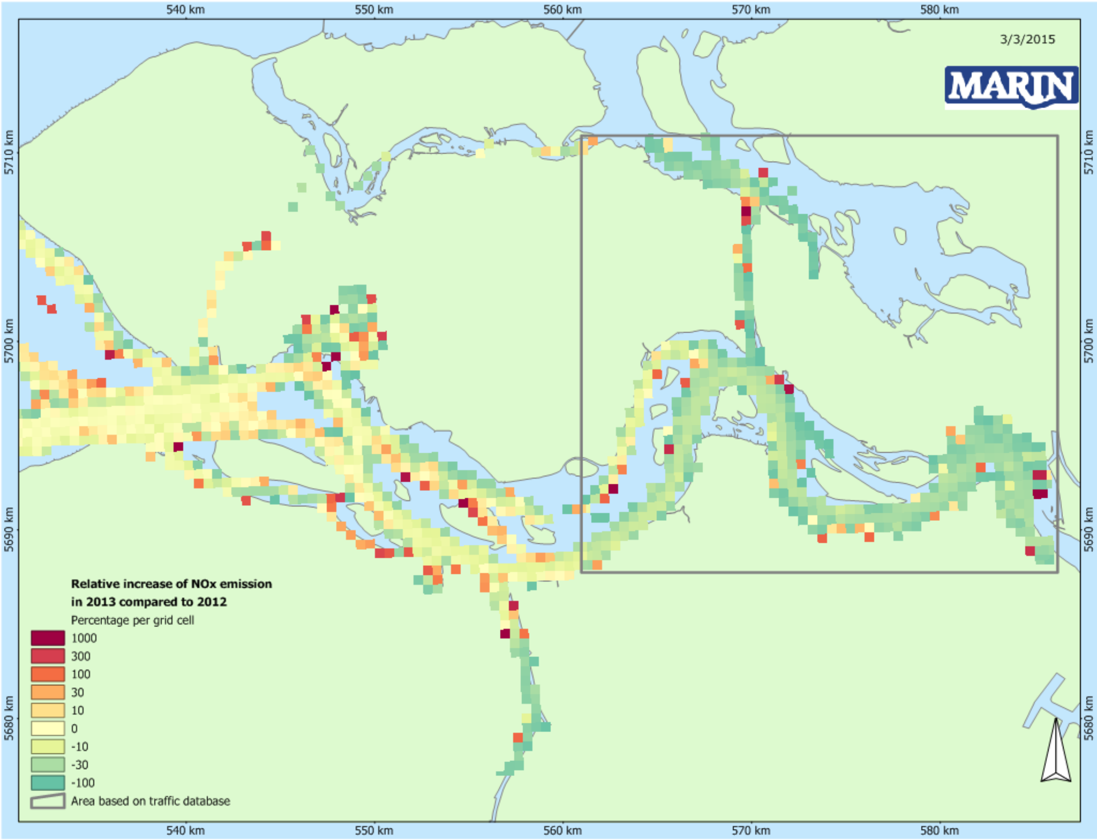

Figure 7-3 **Relative change in NO_x emission from 2012 to 2013 in the Dutch part of the Western Scheldt by ships with AIS.**

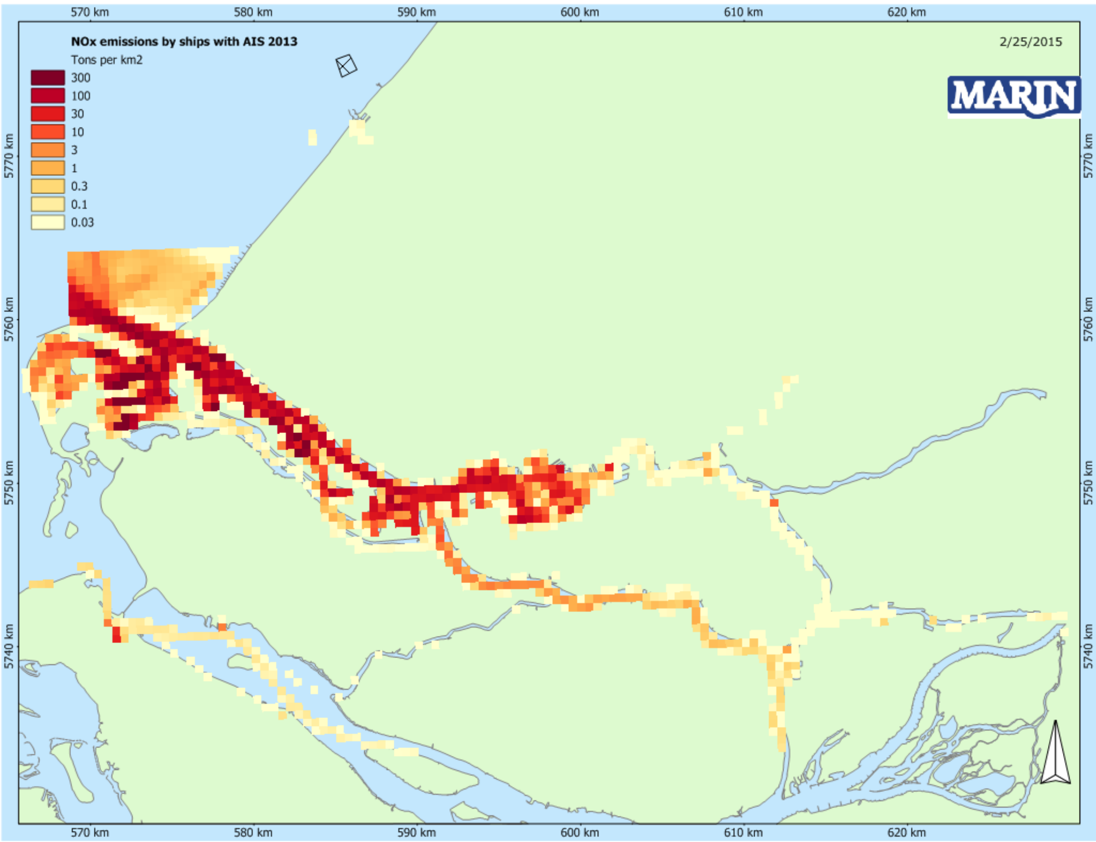

Figure 7-4 **NO_x emission in 2013 in the port area of Rotterdam by ships with AIS.**

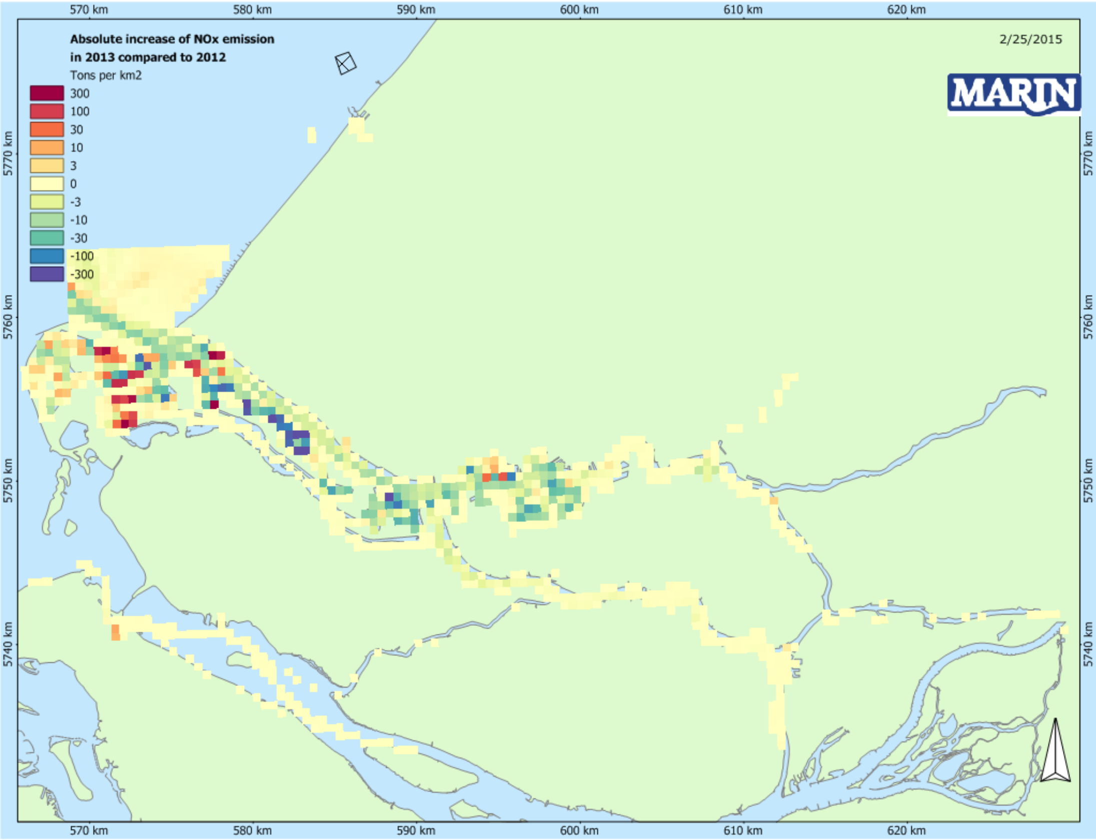

Figure 7-5 **Absolute change in NO_x emission from 2012 to 2013 in the port area of Rotterdam by ships with AIS.**

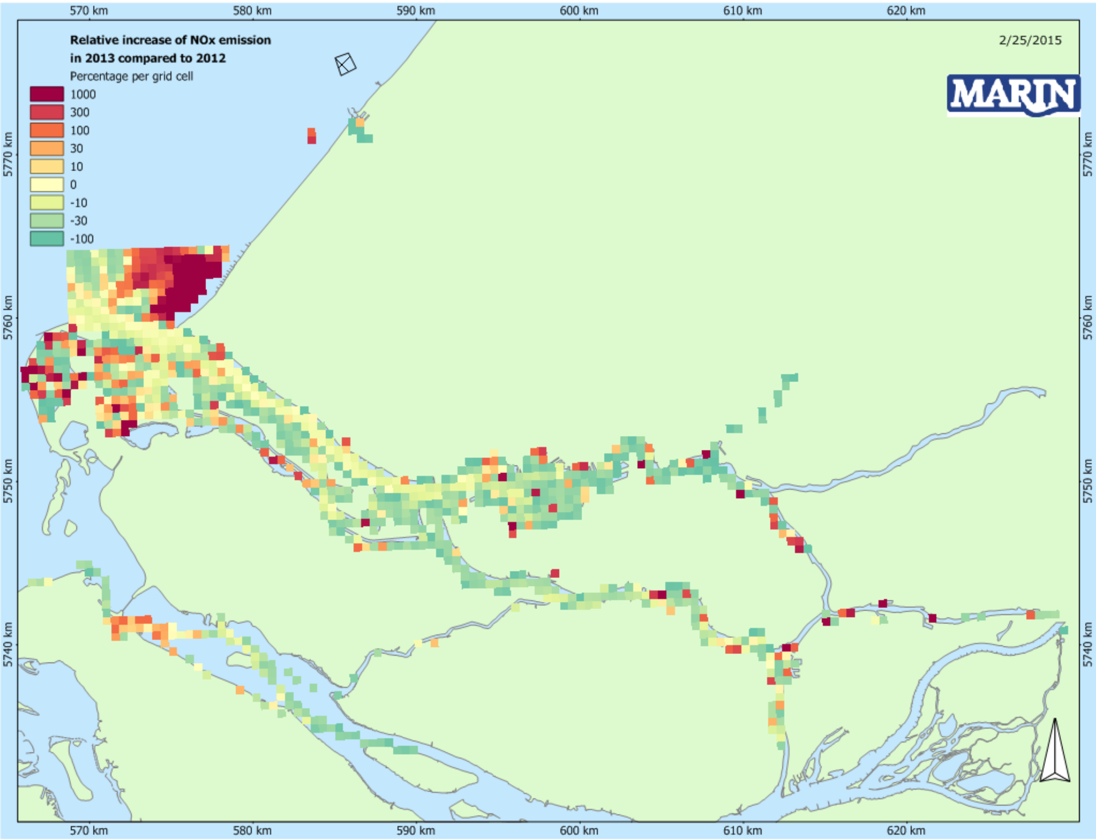

Figure 7-6 **Relative change in NO_x emission from 2012 to 2013 in the port area of Rotterdam by ships with AIS.**

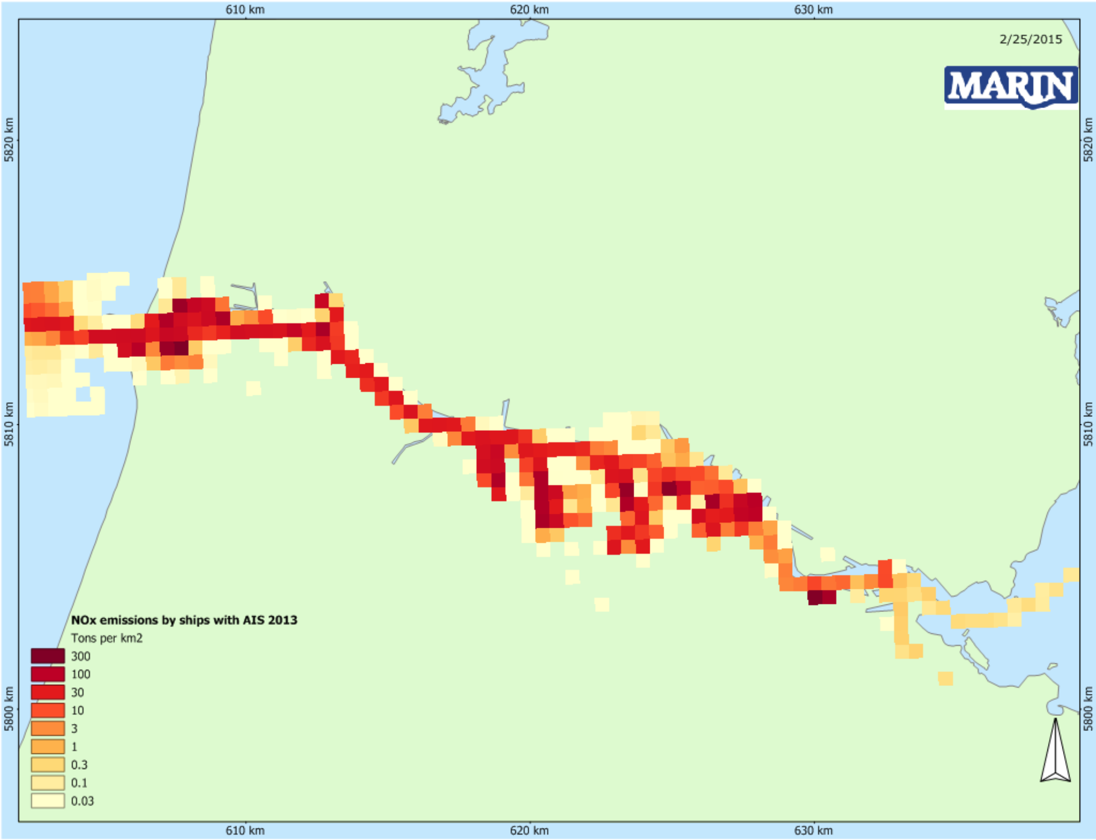

Figure 7-7 **NO_x emission in 2013 in the port area of Amsterdam by ships with AIS. The area has been enlarged in 2013 to fill a gap between the port area and the 12 mile zone.**

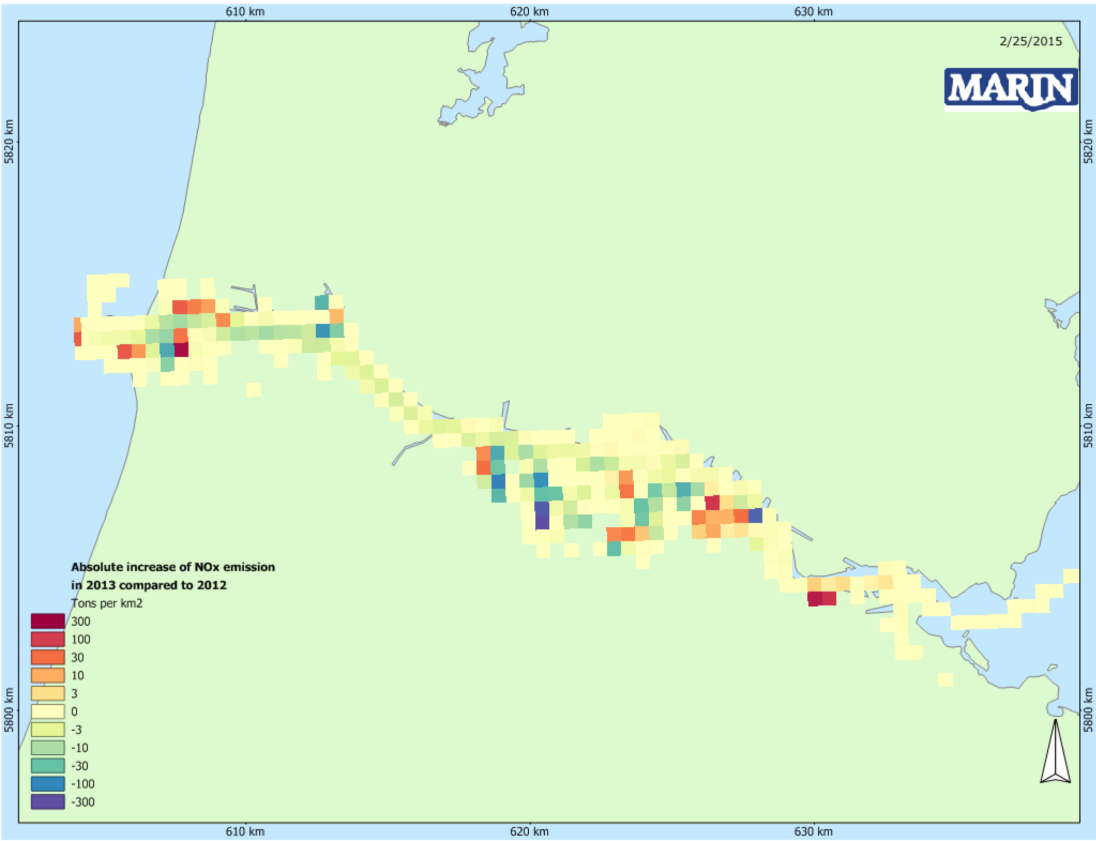

Figure 7-8 **Absolute change in NO_x emission from 2012 to 2013 in the port area of Amsterdam by ships with AIS, for the port area in 2012.**

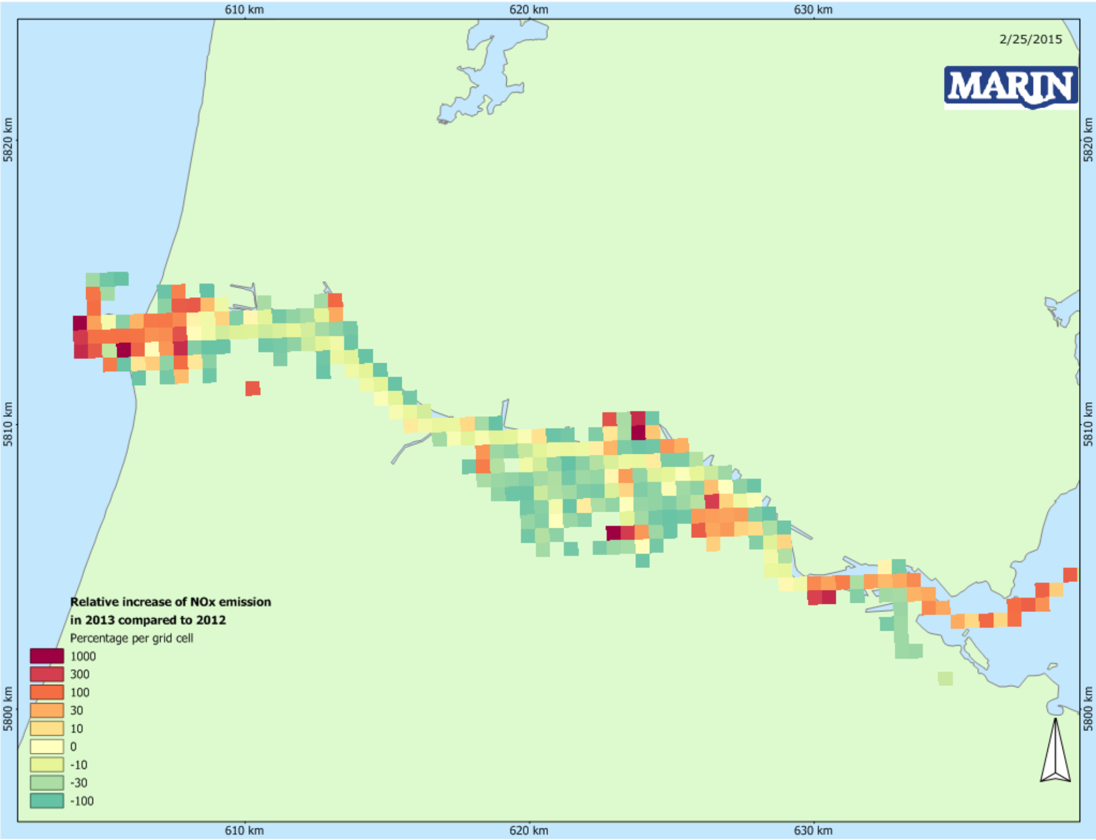

Figure 7-9 **Relative change in NO_x emission from 2012 to 2013 in the port area of Amsterdam by ships with AIS, for the port area in 2012.**

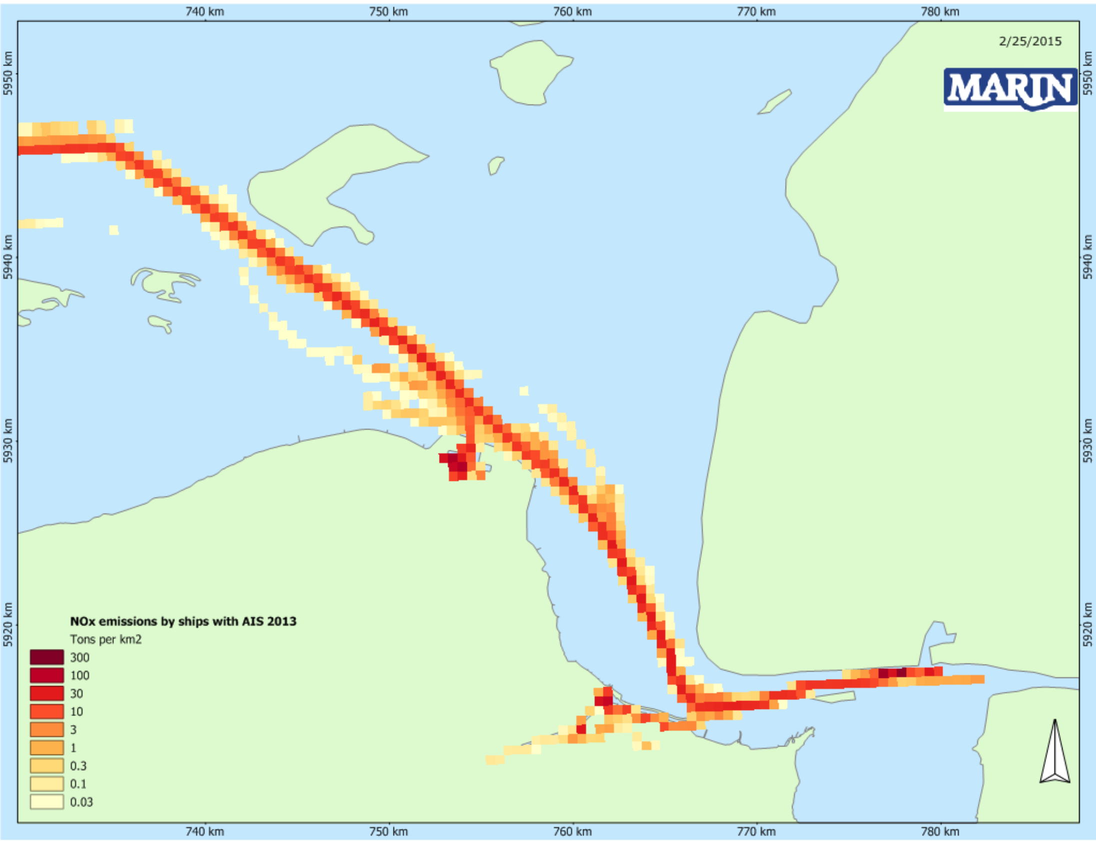

Figure 7-10 **NO_x emission in 2013 in the Ems area by ships with AIS.**

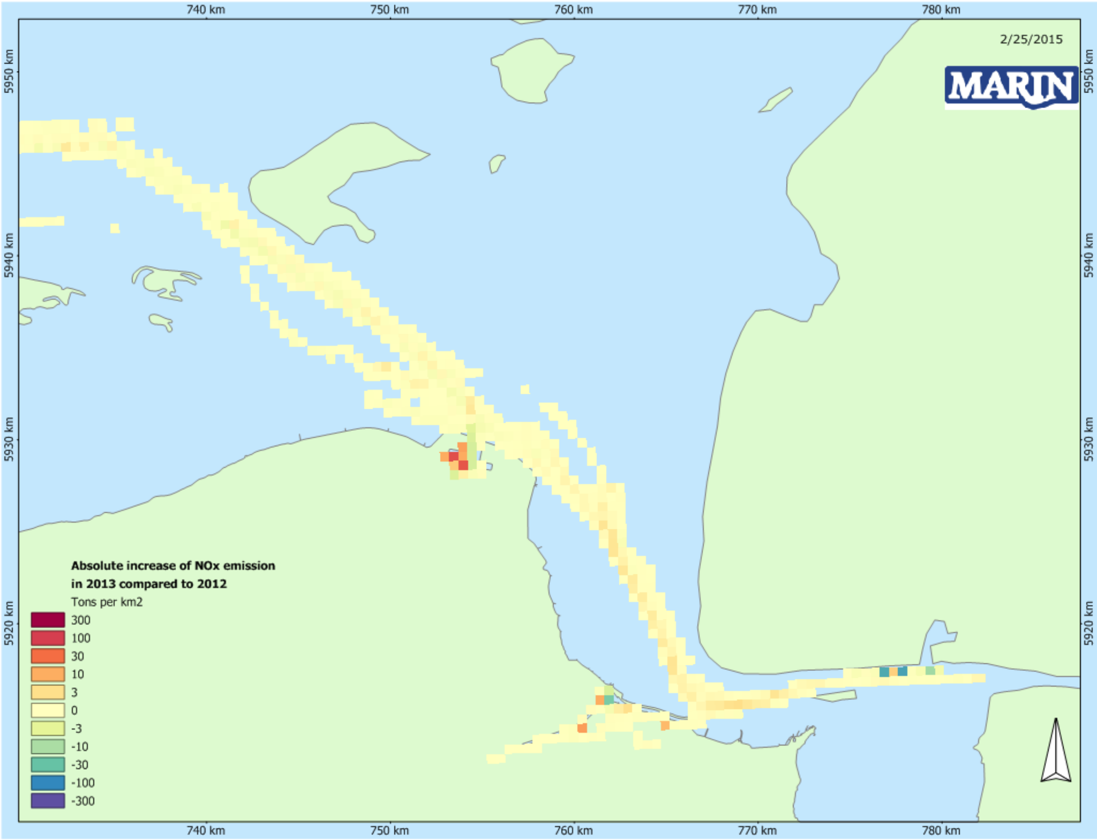

Figure 7-11 **Absolute change in NO_x emission from 2012 to 2013 in the Ems area by ships with AIS.**

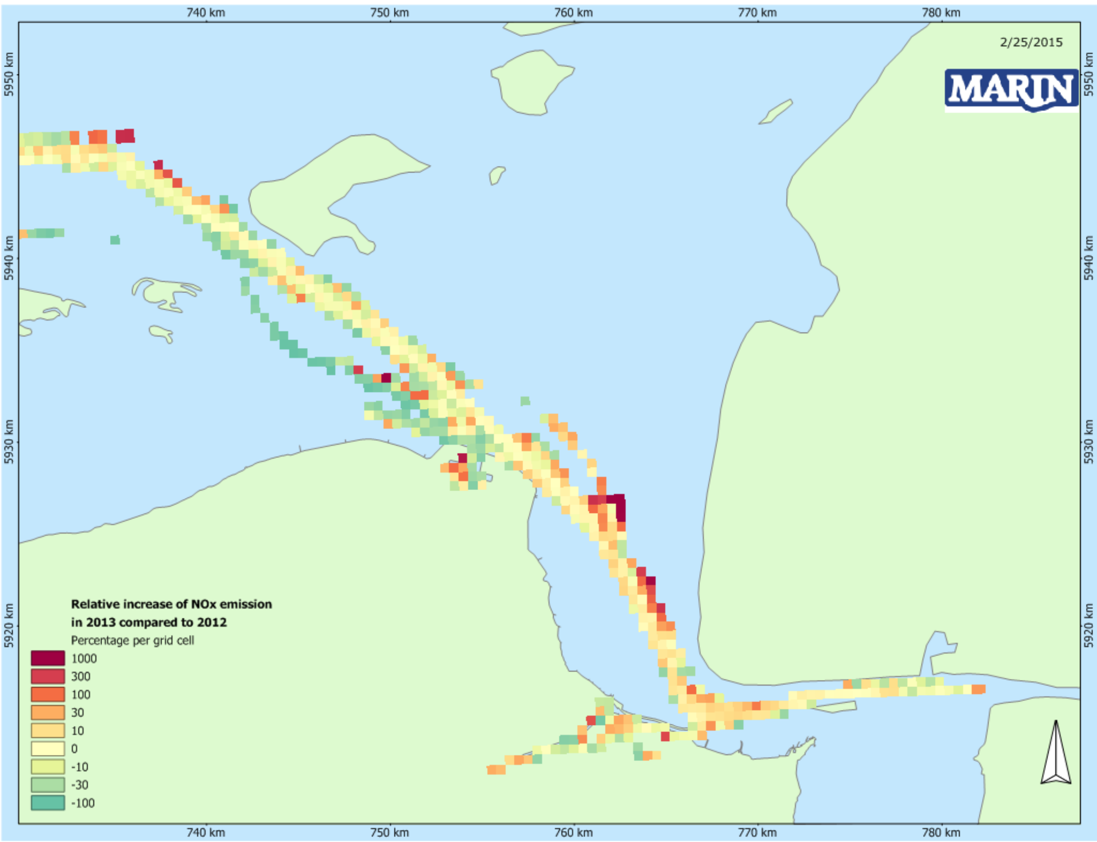

Figure 7-12 **Relative change in NO_x emission from 2012 to 2013 in the Ems area by ships with AIS.**

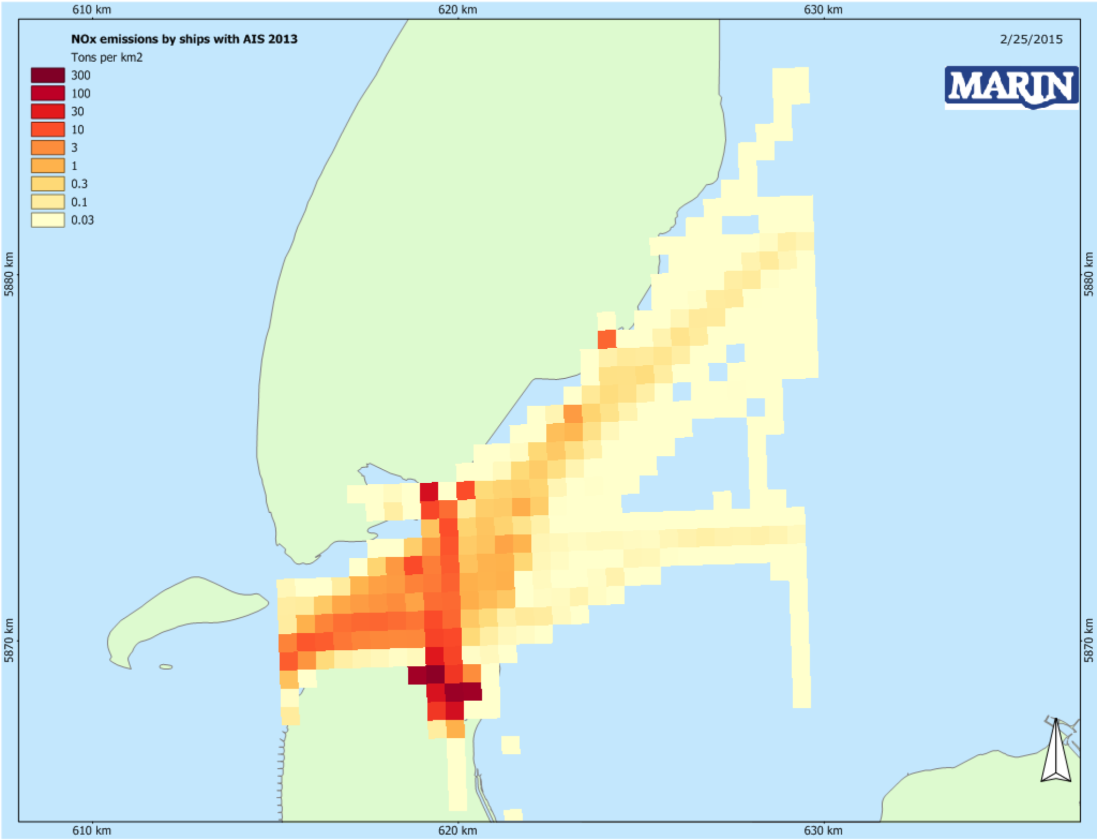

Figure 7-13 NO$_x$ emission in 2013 in the port area of Den Helder by ships with AIS.

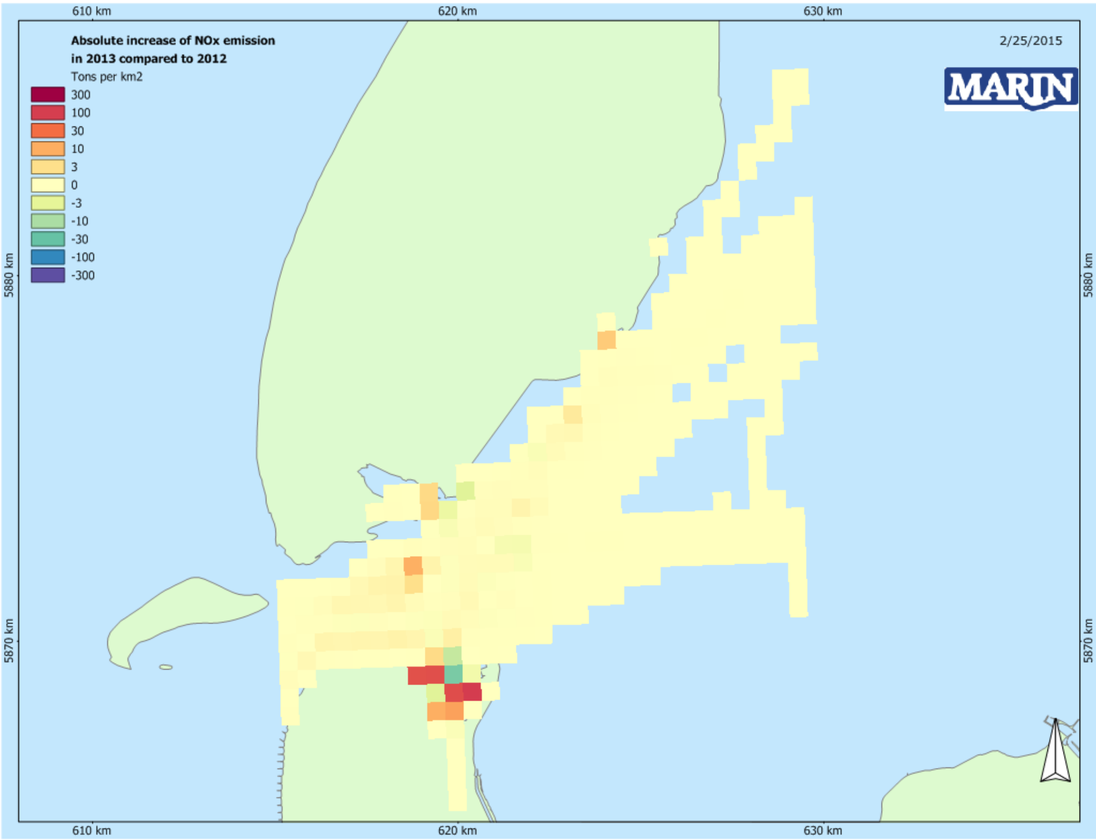

Figure 7-14 Absolute change in NO$_x$ emission from 2012 to 2013 in the port area of Den Helder by ships with AIS.

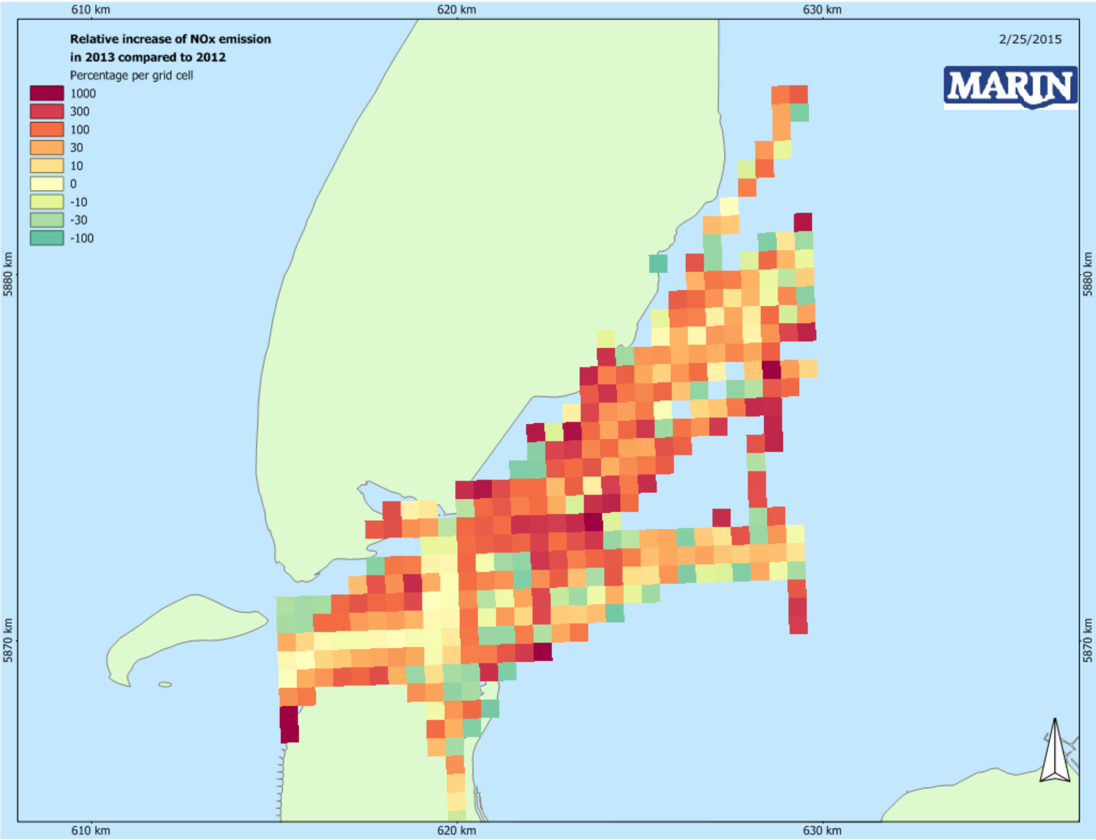

Figure 7-15 Relative change in NO_x emission from 2012 to 2013 in the port area of Den Helder by ships with AIS.

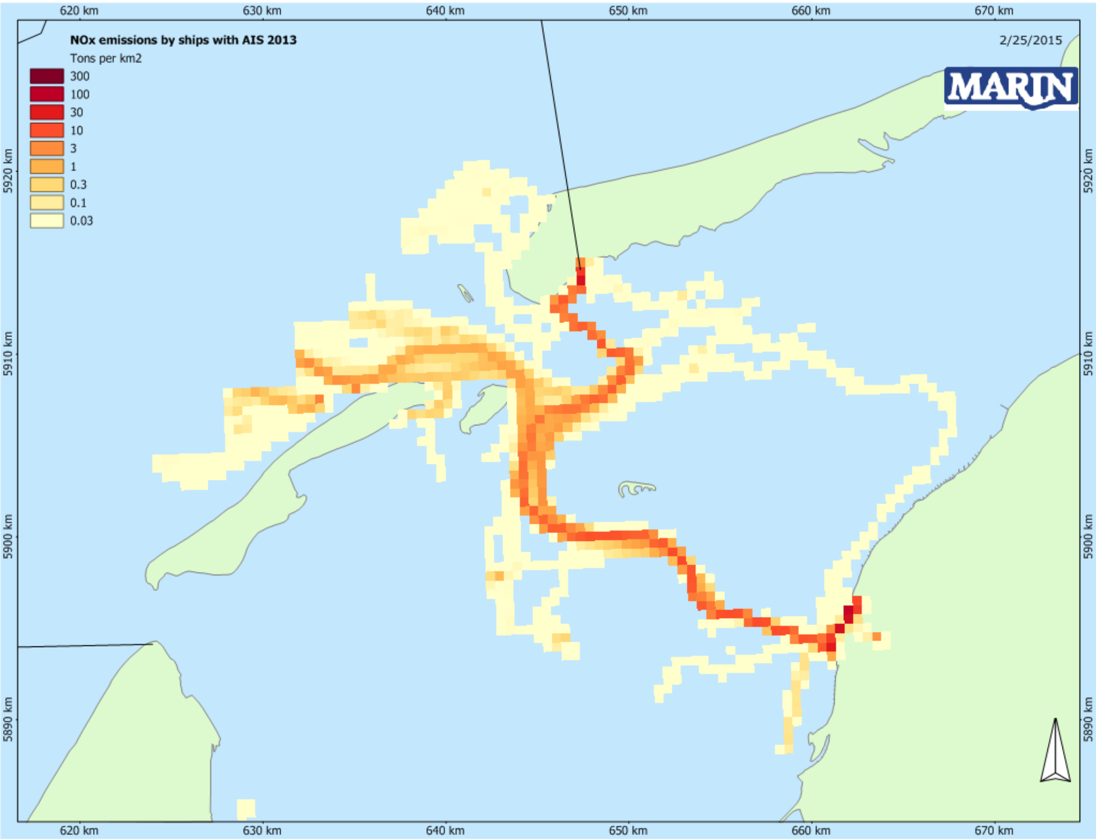

Figure 7-16 NO_x emission in 2013 in the port area of Harlingen by ships with AIS.

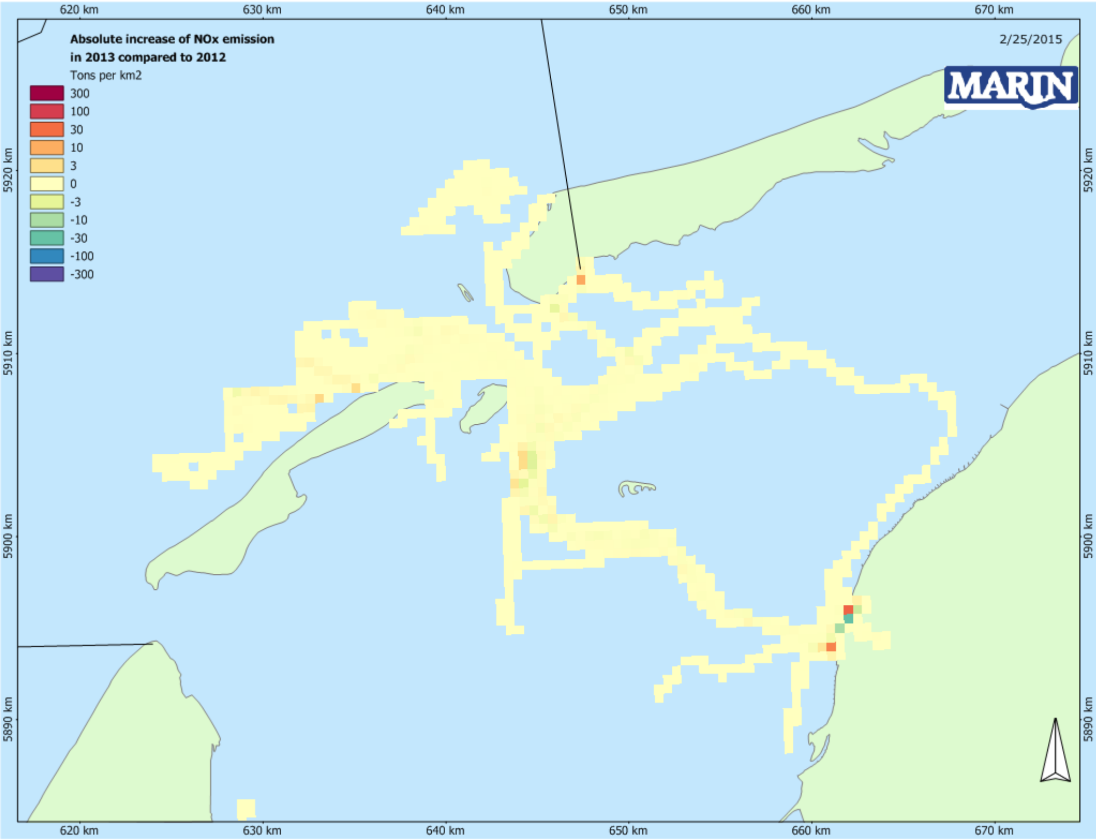

Figure 7-17 **Absolute change in NO_x emission from 2012 to 2013 in the port area of Harlingen by ships with AIS.**

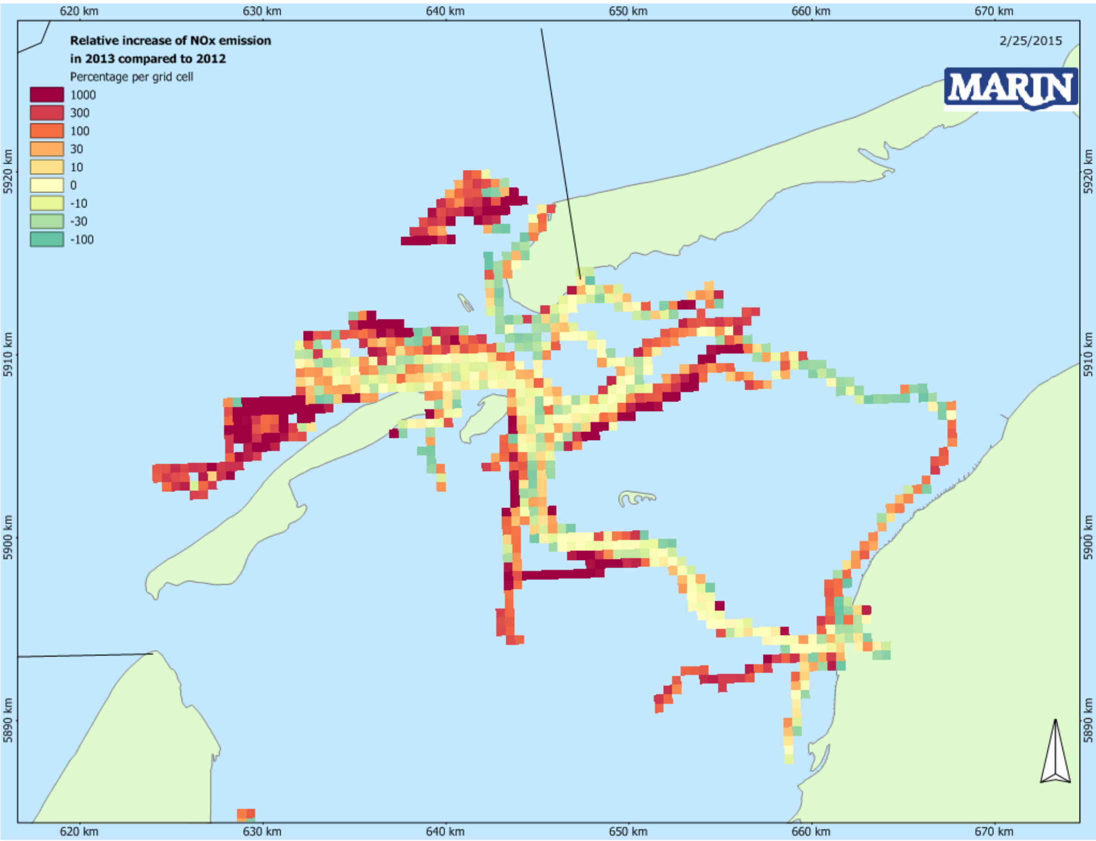

Figure 7-18 **Relative change in NO_x emission from 2012 to 2013 in the port area of Harlingen by ships with AIS.**

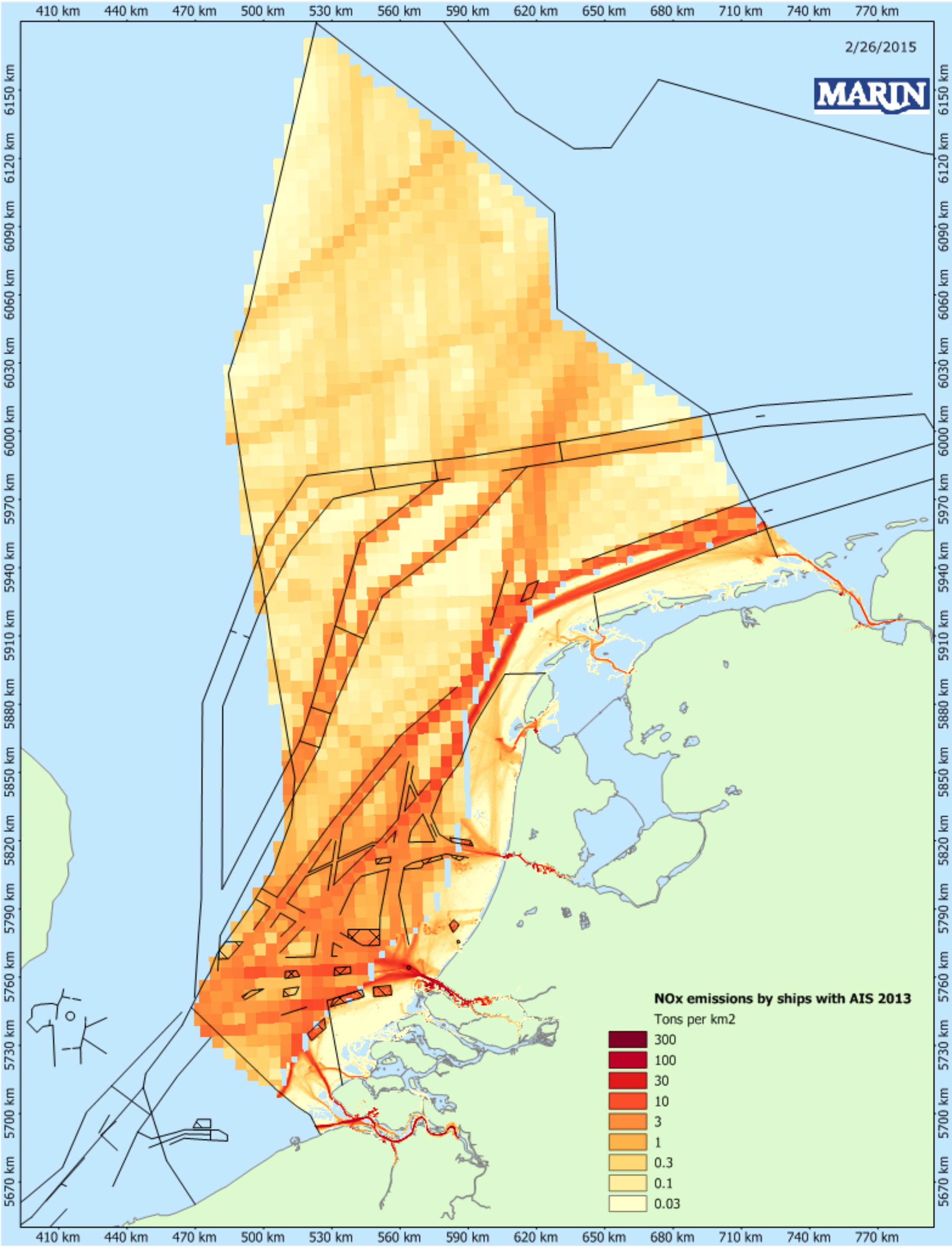

Figure 7-19 **NO_x emission in 2013 in the NCS, the 12-mile zone and the Dutch port areas by ships with AIS.**

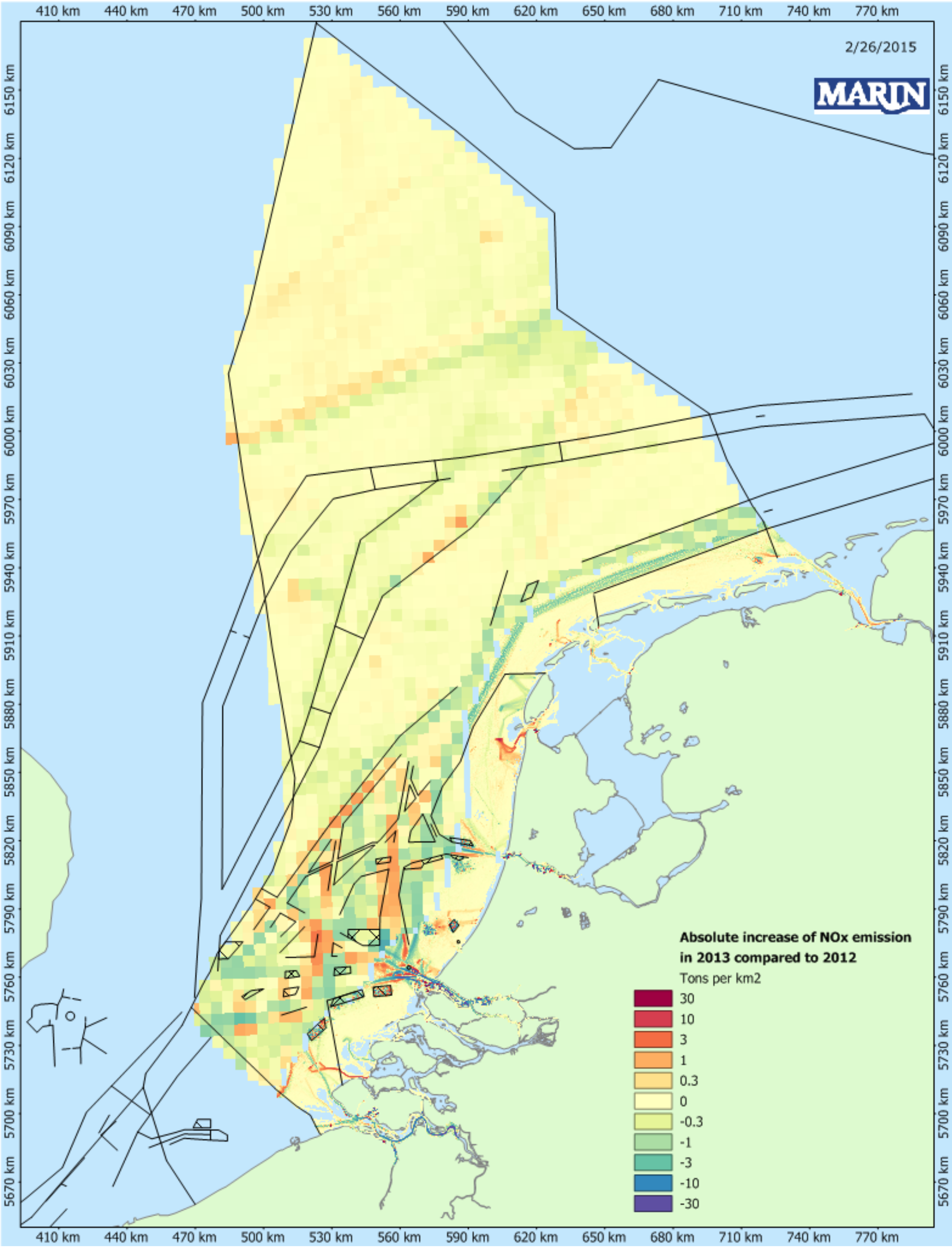

Figure 7-20 **Absolute change in NO_x emission from 2012 to 2013 in the NCS, the 12-mile zone and in the Dutch port areas by ships with AIS.**

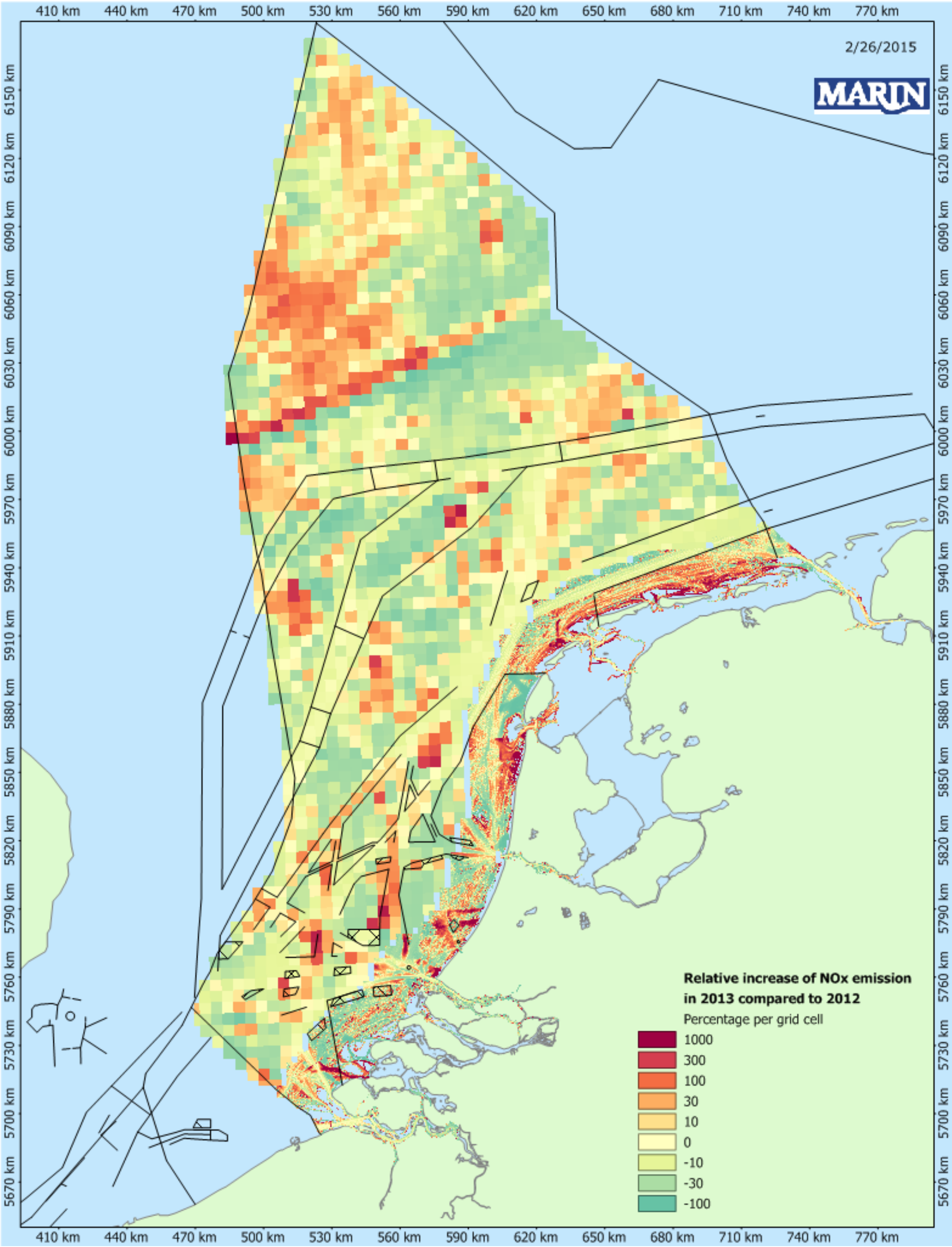

Figure 7-21 **Relative change in NO_x emission from 2012 to 2013 in the NCS, the 12-mile zone and in the Dutch port areas by ships with AIS.**

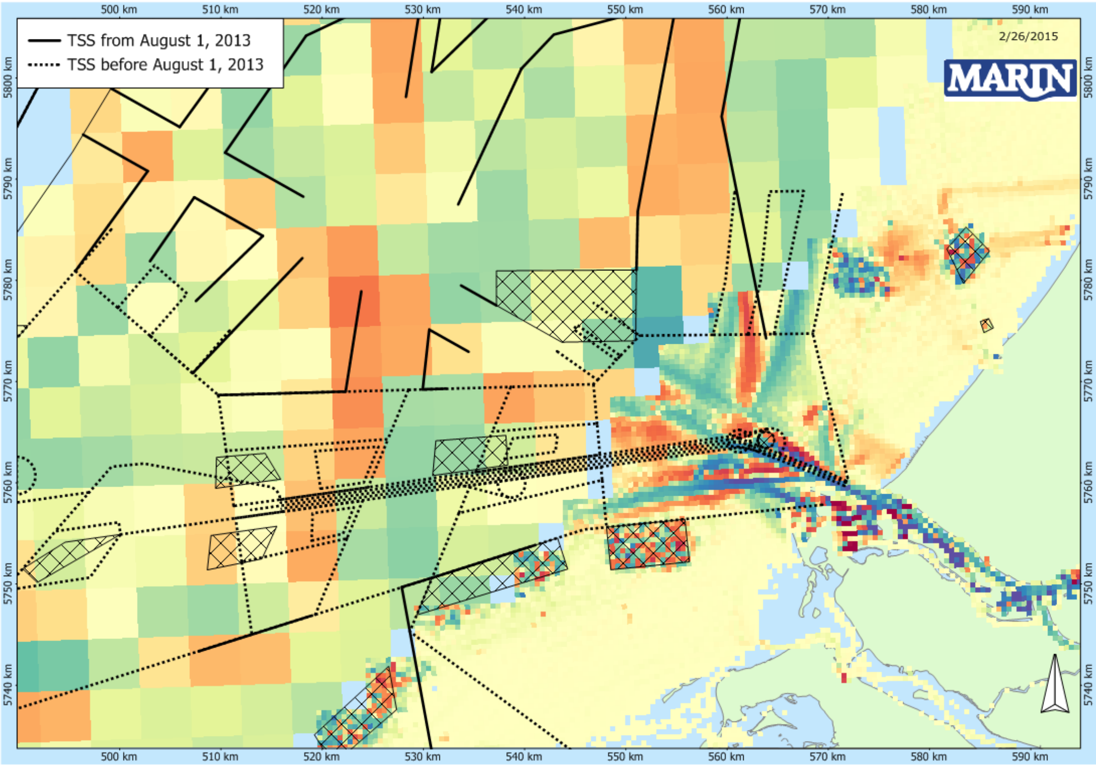

Figure 7-22 **Change of the TSS near the Eurogeul. On the background the absolute change in emissions as in Figure 7-20.**

8 EMISSIONS IN OSPAR REGION II

The emissions in OSPAR region II are calculated for moving ships only, because not moving ships are not modelled in the traffic database.

The calculated emissions for 2013 are summarised in Table 8-1. This table also contains a comparison with 2012. The average number of moving ships in OSPAR region II has decreased with 6%. Again, the emissions for Aerosols MDO and HFO cannot be compared separately with 2012, only the sum can be compared.

Figure 8-1 contains the spatial distribution of the NO_X emission in OSPAR region II.

Table 8-1 Emissions at sea in OSPAR region II for 2013, based on SAMSON

Nr	Substance	Emission in ton in 2013 of moving ships	Emission in 2013 as percentage of 2012 for moving ships
1011	Methane	122	-
1237[5]	VOC	10,521	93.1%
4001	SO2	106,910	93.1%
4013	NOx	397,777	92.5%
4031	CO	67,997	93.6%
4032	CO2	17,864,344	93.5%
6601	Aerosols MDO	708	-
6602	Aerosols HFO	17,868	-
6598	Aerosols MDO+HFO	18,576	88.4%
Average number of ships in area		863.84	94.0%

[5] Emission in ton in 2013 for 1237, comparison for 1011+1237 in 2013 with 1327 in 2012

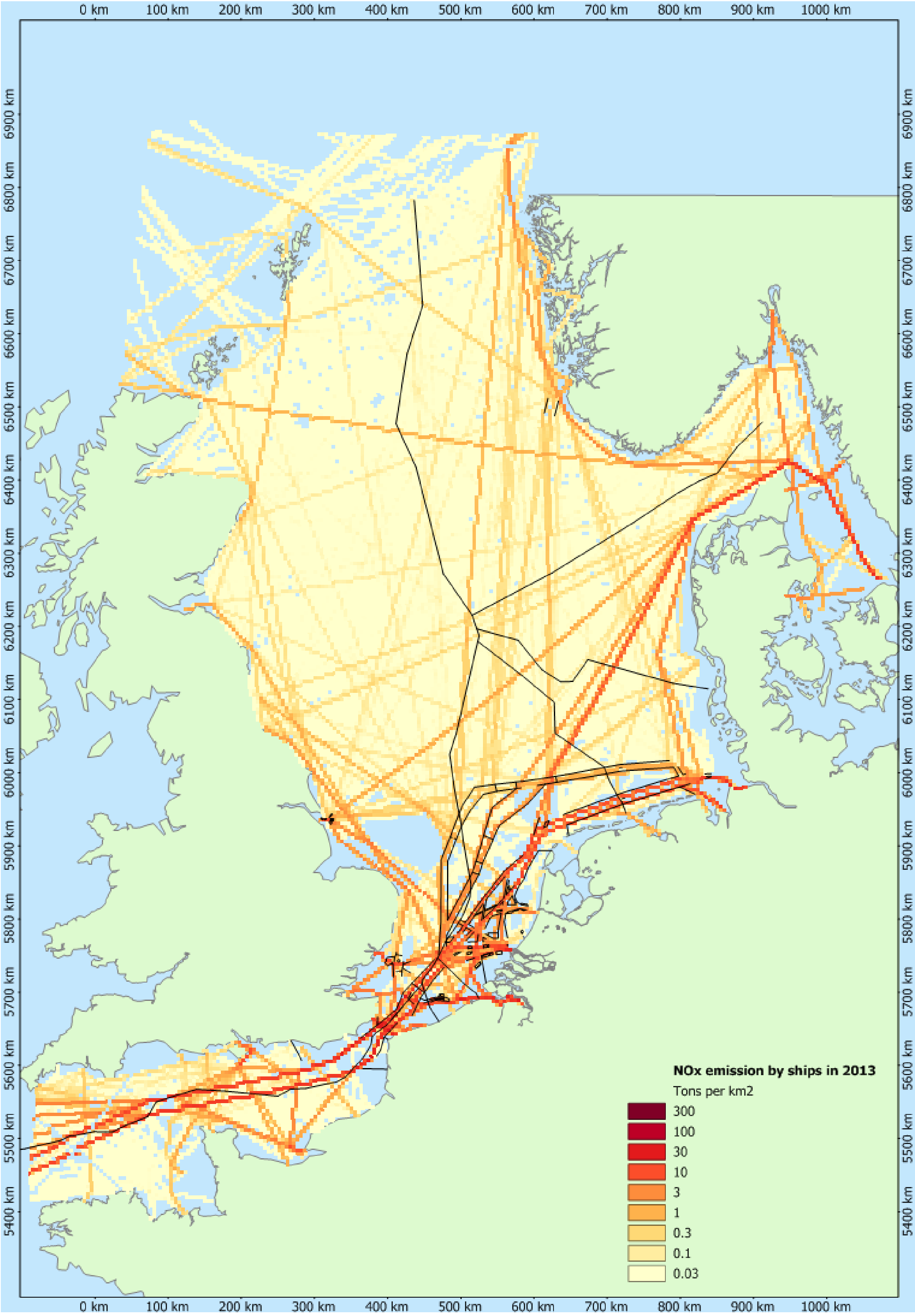

Figure 8-1 **NO_X emission in OSPAR region II at sea by route bound ships**

9 SUMMARY AND CONCLUSIONS

Deliveries

The main delivery of this study is a set of databases containing gridded emissions of seagoing ships at sea and in the Dutch port areas. These emissions are distinguished into ship type and size. Where applicable, the emissions are also distinguished into moving / not moving and EU / non-EU flag. These databases can be used in studies for which a detailed spatial distribution of the emissions is required.

Method changes with respect to 2012

This year, the method to determine the emission factors was updated. The updated method is described in Appendix A. Furthermore, an incorrect assumption on the type of fuel used by the auxiliary engine is corrected and the substance methane with substance number 1011 was added for LNG tankers.

Ship characteristics database

Almost all relevant ships that were observed in the AIS data could be coupled with a ship in the ship characteristics database of Lloyd's List Intelligence. This is necessary, because the emissions can only be calculated for coupled ships.

Completeness of AIS data

A limited number of minute files of the AIS data was missing in 2013, a small correction was used to account for these missing minute files. The coverage of ships on the Western Scheldt close to the Belgian border was again worse than in the previous year. It was decided that it is not possible anymore to correct for this bad coverage by only using a correction factor. Therefore, the SAMSON traffic database of 2012 was extended to the Western Scheldt and used to determine the emissions east of the port of Terneuzen. The spatial distribution is derived from the results of 2011.

Activity data

Comparing 2013 with 2012, there was a decrease in the number of calls for the Western Scheldt and for Rotterdam, a stable number for Amsterdam and Den Helder and an increase for the Ems. The average number of ships derived from the AIS data decreased for five out of seven areas. Only for the port area of Den Helder and Harlingen the average number of ships increased. The decrease in the average number of ships for Rotterdam and Amsterdam is 22.5% and 20% respectively. The decrease for not moving ships is larger in these areas than the decrease for moving ships. At sea, the average number of ships decreased with 5.2%. The average speed increased for all port areas except Harlingen. For Harlingen and the NCS the speed decreased with 0.4% and 0.5%.

Emission results

The comparison of the emission results for the Western Scheldt, Rotterdam, Amsterdam and the NCS shows a decrease in emissions. For the Ems, Den Helder and Harlingen an overall increase is seen. This corresponds with the change in activities based on AIS, except for the Ems where the activities slightly decreased and the emissions slightly increased.

REFERENCES

[1] C. van der Tak
Sea Shipping emission 2011: Netherlands Continental Shelf, Port areas and OSPAR region II
MARIN, no: 26437-1-MSCN-rev. 2, July 24, 2013

APPENDIX A: EMISSION FACTORS

Written by Jan Hulskotte of TNO

A1 SAILING AND MANOEUVRING

A1.1 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]. An English language report [5] is available, which covers the emission calculations in accordance with the EMS protocols. In the emission factor calculation, the nominal engine power and speed are used. For this study these parameters were taken from the LLI database of October 2012. In the case that only one single main engine is present, it is assumed that a vessel requires 85% of its maximum continuous rating power (MCR) to attain the design speed (its service speed). When multiple main engines are present some more assumptions have to be made in order to calculate the required power of the main engines. This is described in the next paragraph A1.2.

The following formula is used to calculate the emission factor per nautical mile.

Formula 1:

$$EF' = EF * CEF * \frac{P * fMCR}{V}$$

where:

EF' Actual emission factor expressed as kg per nautical mile
EF Basic engine emission factor expressed as kg per KWh (Table A- 3/Table A- 11)
CEF Correction factors of basic engine emission factors (Table A- 12/Table A- 14)
P Engine power [Watts]
*f*MCR Actual fraction of the MCR
V Actual vessel speed [knots]

The correction factors of basic engine emission factors (CEF) reflect the phenomena that cause the emission factors to change when engines are active in sub-optimal power ranges.

Besides this change in emission factors 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:

$$fMCR = CRS_{cor} * 0.85 = \frac{\left[\left(V_{actual} / V_{design}\right)^3 + 0.2\right]}{1.2} * 0.85$$

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. In Figure A- 1 the relationship is shown between the speed relative to the service speed and the power relative to the rated power of the ships single propulsion engine as implied in formula 2.

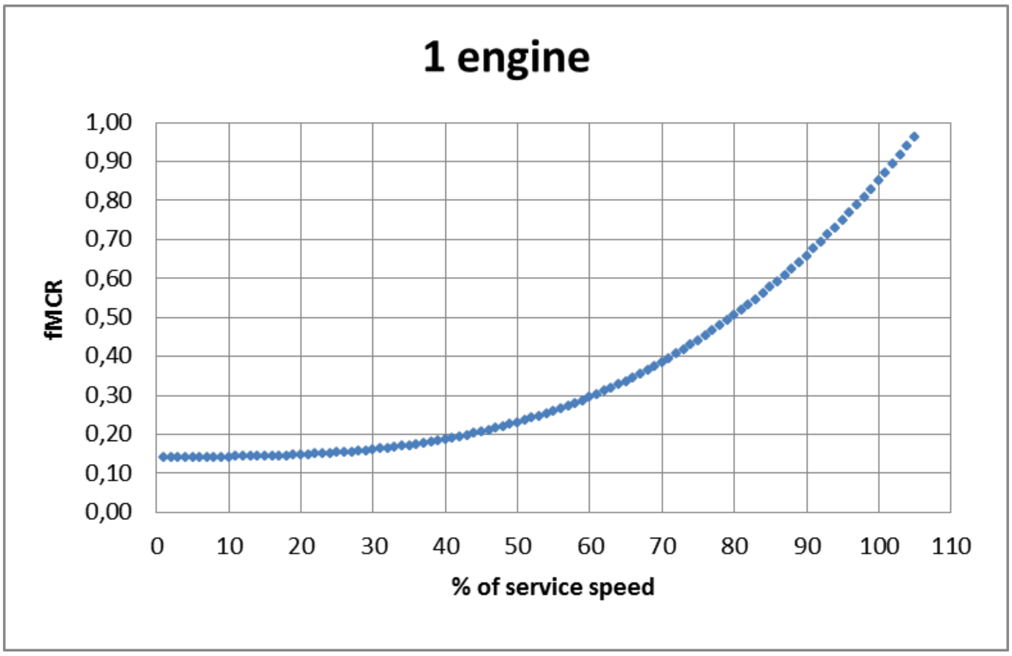

Figure A- 1 **The relationship between service speed and fMCR at ships with one single propulsion engine used in emission calculations**

A1.2 Multiple propulsion engines

When a ship has multiple main propulsion engines probably not all of these engines will be used in all situations. For instance many specialised ships have specialised installations that are only used when these ships are performing their specialised tasks (dredgers, supply ships, icebreakers, tugs etc.). Other ships may have redundant engine capacity for safety and other reasons (passenger ships, roro-ships). It is rather difficult to account for the usage of multiple engines within emission calculations since many differences will exist between individual ship designs. All kinds of possible situations which are not known from the AIS-data may have different influence on emissions from different ships types. Nevertheless, ignoring the existence of multiple engines is not realistic. The presence of multiple engines on some ship types (i.e. passenger and roro-ships) could lead to serious underestimation of total emissions because only the power of the largest engine was taken into account until now.

Before going into an analysis of the usage of main engines when multiple engines are present, it is interesting to analyse which number of engines occurs so often that it has a significant influence on total emissions. In table A-1 it is shown that only ships with 2 and 4 engines contribute significantly to the total installed power of the whole seagoing fleet. The same conclusion will probably hold with respect to the contribution to total emissions. Therefore, it can be justified to concentrate the analysis on ships with 2 and 4 propulsion engines.

Table A- 1 World seagoing fleet with number of installed main engines and their total installed power and average installed power per ship

Main Engine count	Ships count	Total power installed MW	Average power installed per ship MW	% of total power installed
1	97797	452,767	4.6	78.7%
2	22125	83,889	3.8	14.6%
3	820	4,684	5.7	0.8%
4	1746	25,717	14.7	4.5%
5	82	1,617	19.7	0.3%
6	146	4,719	32.3	0.8%
7	3	99	33.2	0.0%
8	29	1,268	43.7	0.2%
9	6	261	43.5	0.0%
10	1	3	3.0	0.0%
12	1	15	15.3	0.0%
	122,756	575,040	4.7	100.0%

As a data source for daily fuel usage of ships, the ship characteristic database-item FUEL_CONSUMPTION of the LLI database was analysed. Daily fuel consumption is given for only about 10.000 ships out of 122.000. By far most of these 10.000 ships are ships with a single main engine. In order to perform a check on the emission calculation, a check on the fuel consumption serves as a very good proxy. When fuel consumption is modelled properly, emission calculation probably will give results with comparable accuracy.

To estimate the daily fuel consumption of a ship (ton/day) we applied a very simple formula:

FC = Active_Engines * MCRss * Power * SFOC * 24/1000.

FC : Daily fuel oil consumption (ton/day)
Active_Engines : number of active engines involved in normal propulsion (-)
MCRss : fraction of power to reach service speed (0.85 for single engine ships, for more engines see table A-2)
Power : power of a single engine (MW)
SFOC : specific fuel oil consumption (kg/MWh)
24/1000 : 24 hours/day;1000 kg/ton

Note that the calculation of fuel consumptions is completely parallel to the calculation of emissions. Instead of EF, approximate values of the SFOC are used. Because (in the LLI database) the service speed is assumed, the values of CEF in the calculation can be ignored because the values will be very close to 1.

The SFOC (specific fuel oil consumption) applied is 0.175 (kg/kWh) for engines above 3 MW and 0.200 (kg/kWh) for engines equal to and below 3 MW. As a reference for these values see for instance the tables A-3 to A-6.

As a reference for ships with multiple engines, the fuel consumption of ships with 1 main engine is shown. So far, a power setting of 85% MCR is assumed in modelling ship's emissions. It can be seen in Figure A- 2 that this assumption gives rather accurate results for the majority of ships (but not all ships) with one main engine. The 7918 ships of which data on fuel consumption was available had an average *calculated* fuel consumption of 24.8 ton/day by the main engine while the average *specified* fuel consumption was 26.1 ton/day. This implies that calculated fuel consumption (on average) on the service speed seems to be 5% lower than the specified fuel consumption. Given the number of possible uncertainties this does not seem to be a major difference.

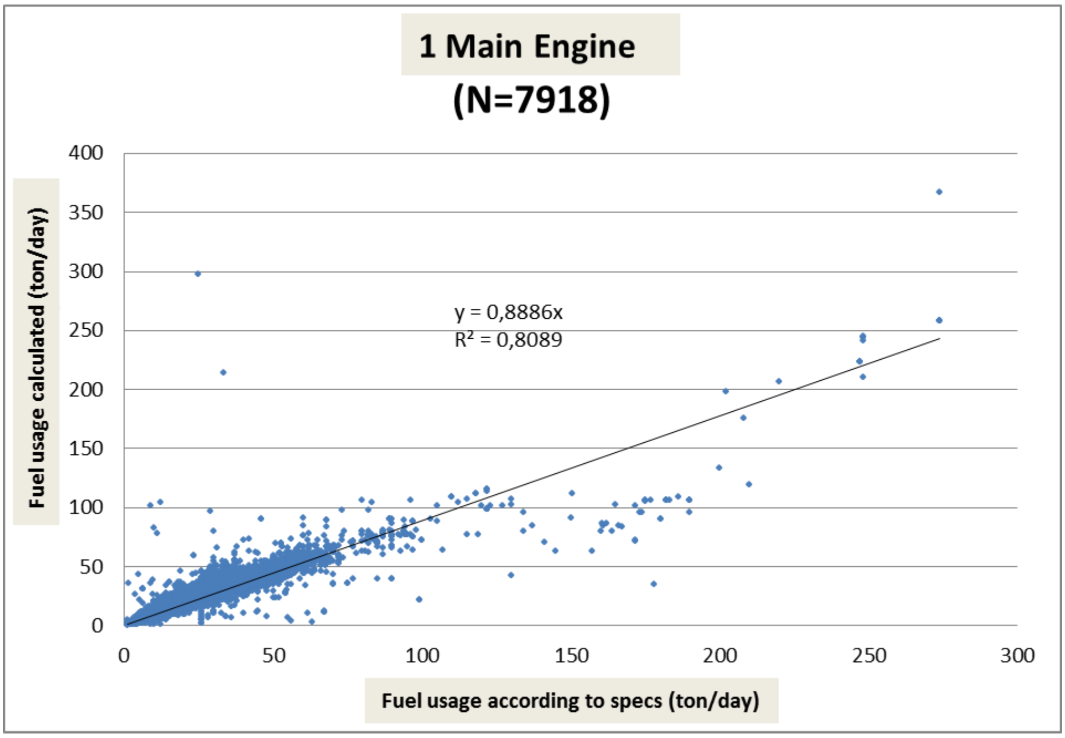

Figure A- 2 **Calculated daily fuel usage of one engine ships compared with specifications**

For ships with two main engines two active engines were assumed and 75% MCR (instead of the standard of 85% [13]) to reach the service speed. It can be seen in Figure A- 3 that these assumptions give rather accurate results for the majority of ships with two main engines. The 546 ships of which data on fuel consumption are available show an average calculated fuel consumption of 35.7 ton/day while the average specified fuel consumption is 35.6 ton/day.

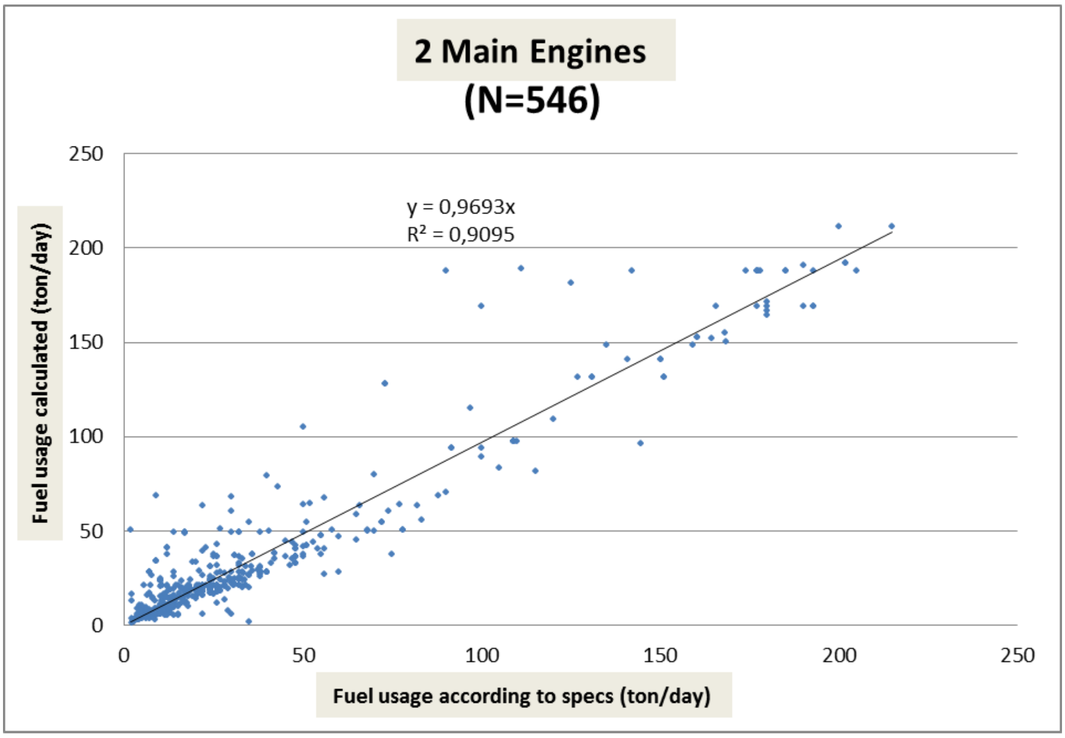

Figure A- 3 Calculated daily fuel usage of two engine ships compared with specifications

For ships with four main engines four active engines were assumed and also 75% MCR (instead of the standard of 85%) to reach the service speed. As can be seen in Figure A-4 much less data is available for four engine ships which causes more scatter in the data. The 29 ships of which data are available show an average *calculated* fuel consumption of 39.2 ton/day while the average *specified* fuel consumption is 32.8 ton/day.

It has to be mentioned that some data filtering was applied to four engine ships. Excluded in the analysis are special cases such as high speed ferries, supply and service vessels, tugs and fishing ships and one ship mainly propelled by LNG.

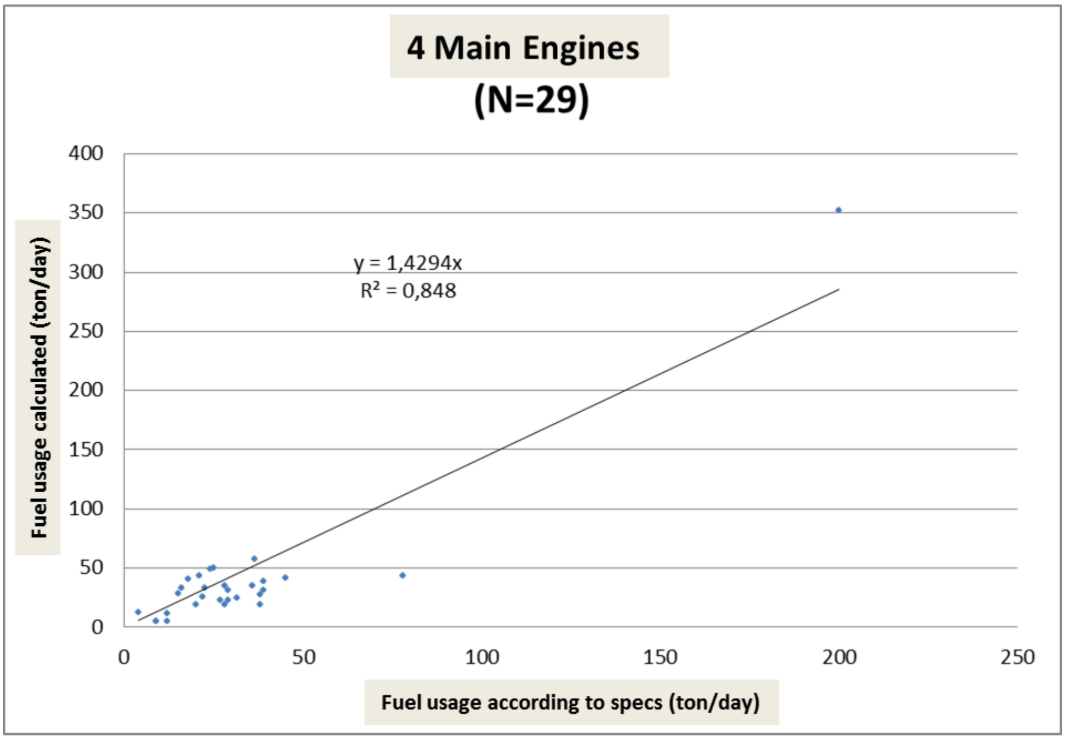

Figure A- 4 Calculated daily fuel usage of four engine ships compared with specifications

It can be argued that energy consumption of four engine ships seems to be overestimated by the assumptions that are applied but with such a small dataset it is hard to determine whether the assumptions on ships with four main engines are correct or not. Even if there is an overestimation this will probably not lead to big differences in total emissions, since the contribution of four engine ships in total installed power is below 5% (Table A- 1).

For ships with other numbers of main engines the available data did not allow any check of possible assumptions on the fuel consumption.

Apart from the check of fuel consumption of two and four engine ships as presented above, for ships with three or five to twelve engines additional assumptions had to made in order to enable calculation of emissions of these ships. These assumptions are shown in Table A-2 and are rather uncertain. However, the total installed power is only 2% and therefore, the influence on total emissions will be minimal.

Table A- 2 Maximum number of engines assumed to be operational for propulsion with multiple engines present and the fraction of MCR assumed (MCR_{ss}) to attain the service speed

Ship type	Engines Present → / Engines Operational ↓	2	3	4	5	6	7	8	9	10	12
Oil tanker	2	0.75	0.85								
	4			0.75	0.75	0.75					
Chem.+ Gas tanker	2	0.75	0.85								
	4			0.75	0.75	0.75					
Bulk carrier	2	0.75	0.85								
	4			0.75							
Container ship	2	0.75	0.85								
	4			0.75		0.75					
	6								0.75		
General Dry Cargo	2	0.75	0.85								
	4			0.75	0.75						
RoRo Cargo / Vehicle	2	0.75	0.85								
	4			0.75	0.75	0.75		0.75			
Reefer	2	0.75									
	4			0.75							
Passenger	2	0.75	0.85								
	4			0.75	0.75	0.75	0.75	0.75			
	6								0.75	0.75	
Miscellaneous	2	0.5	0.85	0.75	0.75	0.75	0.75	0.75	0.75		0.75
Tug/Supply	2	0.5	0.85	0.75	0.75	0.75	0.75				
Fishing	2	0.5	0.85	0.75		0.75			0.75		
Non Merchant	2	0.5	0.85	0.75	0.75						

The calculation of emissions with multiple engines becomes more complicated because the number of active engines has to be calculated separately. For this reason the calculation of EF' is slightly different from formula 1.

Formula 3:

$$EF' = EF * CEF * \frac{NoEA * P * fMCR}{V}$$

EF' Actual emission factor expressed as kg per nautical mile
EF Basic engine emission factor expressed as kg per KWh (table A-1/-7)
CEF Correction factors of basic engine emission factors (table-A-8/-10)
NoEA Number of active engines (engines that actually are working on a certain moment)
P Engine power of one single engine [Watts]
*f*MCR Actual fraction the MCR of active engines
V Actual vessel speed [knots]

Formula 4:

NoEA =
minimum (Engines Operational, round (CRS_{cor} * Engines Operational * MCR_{ss})+1)

(Note that the Number of active engines depends on the level of CRScor, which depends on the ships speed, and that the maximum number of active engines is equal to Engines Operational).

Formula 5:

*f*MCR= [Engines Operational]/NoEA * CRScor * MCRss

The *f*MCR for individual ship engines is linear inversely related to the Number of active engines (more engines active give lighter work for individual engines). In essence Formula 3 is the same as Formula 1 except the accounting of Engines Active in the available total Engine power and the application of modified *f*MCR in the selection of the CEF-values (Formula 5).

In Figure A- 5 the relationship is shown between the speed relative to the service speed and the power relative to the rated power of the ships propulsion engines at ships with 4 propulsion engines as implied in formula 4 and 5.

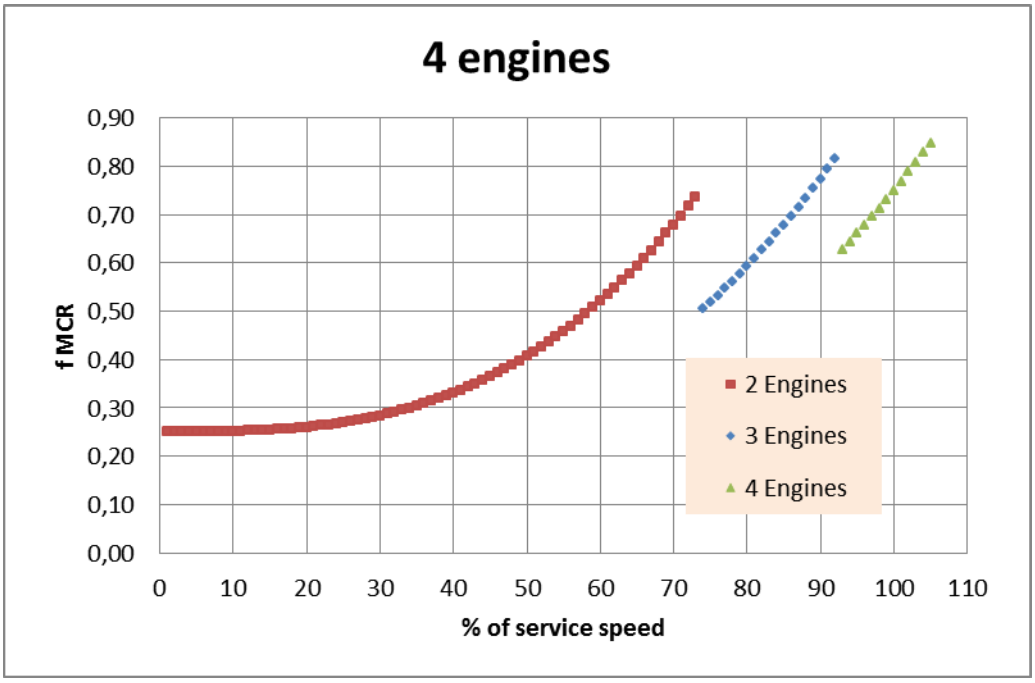

Figure A- 5 The relationship between service speed and fMCR at ships with four propulsion engines as used in emission calculations (formula 4 and 5)

A1.3 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 [3] was used in this study. The percentage taken from Buhaug was multiplied with the main power of each individual ship of which no details of auxiliary power are included in the LLI-database. For those ships of which the auxiliary power was included LLI-database the loadfactor of auxiliary engines given by Buhaug specified per ship type was applied on the biggest auxiliary engine of the individual ship as inferred from the LLI-database.

A1.4 Engine Emission Factor

Table A- 3 to Table A- 11 show the engine emission factors [1], [2] 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 MARPOL Annex VI in 2011 has been assumed because the supplementary reduction on the sulphur content already was obliged per July 2010. As a consequence, the sulphur percentage in heavy fuel oil is set on 1.0% and the sulphur percentage in marine diesel oil is assumed to be 0.5%. Linear relations exist between SFOC and SO2 and CO2 depending on fuel quality. SFOC values as such are not used in emission calculations.
PM-reduction is associated with sulphur reduction because a certain fraction of oxidised sulphur is emitted as sulphuric acid which easily condenses to sulphuric acid particles (PM) in exhaust gases. Based on the sulphur reductions additional PM reductions were estimated applying a linear relationship between sulphur and PM as demonstrated in [12].

Table A- 3 Emission factors and specific fuel oil consumption (SFOC) applied on slow speed engines (SP) operated on heavy fuel oil (HFO), (g/kWh)

Year of build	NO_x	PM	SO_2	VOC	CO	CO_2	SFOC
1900 – 1973	16	0.8	4.2	0.6	3	666	210
1974 – 1979	18	0.8	4	0.6	3	635	200
1980 – 1984	19	0.8	3.8	0.6	3	603	190
1985 – 1989	20	0.8	3.6	0.6	2.5	571	180
1990 – 1994	18	0.8	3.5	0.5	2	555	175
1995 – 1999	15	0.6	3.4	0.4	2	539	170
2000 – 2010	~rpm[6]	0.6	3.36	0.3	2	533	168
2011 – 2015		0.6	3.3	0.3	2	524	165

Table A- 4 Emission factors and specific fuel oil consumption (SFOC) applied on slow speed engines (SP) operated on marine diesel oil (MDO), (g/kWh)

Year of build	NO_x	PM	SO_2	VOC	CO	CO_2	SFOC
1900 - 1973	16	0.5	2.1	0.6	3	666	210
1974 - 1979	18	0.5	2	0.6	3	635	200
1980 - 1984	19	0.5	1.9	0.6	3	603	190
1985 – 1989	20	0.5	1.8	0.6	2.5	571	180
1990 – 1994	18	0.4	1.75	0.5	2	555	175
1995 – 1999	15	0.3	1.7	0.4	2	539	170
2000 – 2010	~rpm[1]	0.3	1.68	0.3	2	533	168
2011 – 2015		0.3	1.65	0.3	2	523	165

[6] Dependant on revolutions per minute (Table A-7)

Table A- 5 Emission factors and specific fuel oil consumption (SFOC) applied on medium/high speed engines (MS) operated on Heavy fuel oil (HFO), (g/kWh)

Year of build	NO_x	PM	SO_2	VOC	CO	CO_2	SFOC
1900 – 1973	12	0.7	4.5	0.6	3	714	225
1974 – 1979	14	0.7	4.3	0.6	3	682	215
1980 – 1984	15	0.7	4.1	0.6	3	651	205
1985 – 1989	16	0.7	3.9	0.6	2.5	619	195
1990 – 1994	14	0.7	3.8	0.5	2	603	190
1995 – 1999	11	0.65	3.7	0.4	2	587	185
2000 – 2010	~rpm[1] 9[2]	0.65	3.66	0.3	2	581	183
2011 - 2015	~rpm 7[2]	0.65	3.6	0.3	2	571	180

[2] applied on auxiliary engines only

Table A- 6 Emission factors and specific fuel oil consumption (SFOC) applied on medium/high speed engines (MS) operated on marine diesel oil (MDO), (g/kWh)

Year of build	NO_X	PM	SO_2	VOC	CO	CO_2	SFOC
1900 - 1973	12	0.5	2.25	0.6	3	714	225
1974 - 1979	14	0.5	2.15	0.6	3	682	215
1980 - 1984	15	0.5	2.05	0.6	3	650	205
1985 - 1989	16	0.5	1.95	0.6	2.5	619	195
1990 - 1994	14	0.4	1.9	0.5	2	603	190
1995 - 1999	11	0.3	1.85	0.4	2	587	185
2000 - 2010	~rpm[1] 9[2]	0.3	1.83	0.3	2	581	183
2011 - 2015	~rpm[1] 7[2]	0.3	1.8	0.3	2	571	180

[2] applied on auxiliary engines only

Emission factors of gas turbines were adjusted according to Cooper [9].

Table A- 7 Emission factors and specific fuel oil consumption (SFOC) of gas turbines (TB) operated on marine diesel oil (MDO), (g/kWh)

Fuel	NO_X	PM	SO_2	VOC	CO	CO_2	SFOC
MDO	5.7	0.146	3.1	0.1	0.32	984	310

Emission factors of steam turbines were partially adjusted according to Cooper [9].

Table A- 8 Emission factors and specific fuel oil consumption (SFOC) of steam turbines (ST) operated on LNG, HFO or MDO

Fuel	NO_X	PM	SO_2	CH4	VOC	CO	CO_2	SFOC
LNG	1.94	0.01	0.0	0.045		0.06	688	250
HFO	2.0	0.59	6.12		0.1	0.15	971	306
MDO	2.0	0.49	2.91		0.1	0.15	923	291

Emissions of more modern LNG tanker propelled mostly propelled by medium speed diesel engines fuelled by LNG were calculated by means of emission factors as shown in the table below.

Table A- 9 Emission factors and specific fuel oil consumption (SFOC) of medium speed engines (MS) operated on LNG, (g/kWh)

Fuel	NO_X	PM	SO_2	CH4	CO	CO_2	SFOC
LNG	2.0	0.02	0.0	2.43	0.2	450	162

The change-over from fuels at LNG-tankers in the model calculations is assumed dependent on the speed of the ships expressed as CRScor. Below a value of CRScor of 0.2 LNG-tankers switch from gaseous LNG to liquid fuel used by main engines according to the scheme presented in the table below. The fuels assumed to be used by auxiliary engines are also presented in the same table A-10.

Table A- 10 Fuel switch scheme of LNG-tankers in dependence of operational speed

Engine type	Main engines		Auxiliary engines	
	0.2 <= CRScor < 1.2	0 <= CRScor < 0.2	0.2 <= CRScor < 1.2	0 <= CRScor < 0.2
MS	LNG	MDO	MDO	MDO
MS	LNG	HFO	HFO	MDO
ST	LNG	MDO	MDO	MDO
ST	LNG	HFO	HFO	MDO

Table A- 11 Emission factors of NO_X dependant on engines RPM

Year of build	RPM range	IMO-limits (g/kWh)	Emission factor NO_X (g/kWh)
2000 - 2010	< 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
2011 - 2015	< 130 RPM	14.4	0.85 x 14.4
	Between 130 and 2000 RPM	$44 \times n^{-0.23}$	$0.85 \times 44 \times n^{-0.23}$
	> 2000 RPM	7.7	0.85 x 7.7

A1.5 Correction factors of engine Emission Factors

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 were extended by distinction of different engine types in order to get more accurate calculations. Three engine groups were discerned: reciprocating engines, steam turbines and gas turbines.
The correction factors used are shown in Table A- 12 to Table A- 14 The list was extended by some values provided in the documentation of the EXTREMIS model [4].

Table A- 12 Correction factors for reciprocating diesel engines

Power % of MCR	CO_2, SO_2 SP	CO_2, SO_2 MS	NO_X	PM	VOC, CH4	CO
10	1.2	1.21	1.34	1.63	4.46	5.22
15	1.15	1.18	1.17	1.32	2.74	3.51
20	1.1	1.15	1.1	1.19	2.02	2.66
25	1.07	1.13	1.06	1.12	1.65	2.14
30	1.06	1.11	1.04	1.08	1.42	1.8
35	1.05	1.09	1.03	1.05	1.27	1.56
40	1.045	1.07	1.02	1.03	1.16	1.38
45	1.035	1.05	1.01	1.01	1.09	1.23
50	1.03	1.04	1.00	1.01	1.03	1.12
55	1.025	1.03	1.00	1.00	1.00	1.06
60	1.015	1.02	0.99	1.00	0.98	1.00
65	1.01	1.01	0.99	0.99	0.95	0.94
70	1.00	1.01	0.98	0.99	0.92	0.88
75	1.00	1.00	0.98	0.98	0.89	0.82
80	1.01	1.00	0.97	0.98	0.87	0.76
85	1.02	1.00	0.97	0.97	0.84	0.7
90	1.03	1.01	0.97	0.97	0.85	0.7
95	1.04	1.02	0.97	0.97	0.86	0.7
100	1.05	1.02	0.97	0.97	0.87	0.7

The correction factors for CO_2 en SO_2 are assumed to be equal. These newly added factors for CO_2 en SO_2 were derived from two recent publications [10] and [11] by taking interpolated values. A distinction was made for Slow-speed engines (referred as SP) and Medium and high-speed engines (referred as MS). Although correction factors for other substances may differ by engine type also, a numerical distinction was not possible so far.

Since steam turbines are predominantly used by LNG-carriers two types of fuels were assumed to be consumed: Boil-off Gas (BOG) and HFO. It was assumed that at lower engine loads (below 30%) engines are mainly operated by HFO. This is expressed in the correction factors for SO_2 and CO_2. On higher loads (above 30%) the average fuel mixture between BOG and HFO is assumed. The source of the correction factors of steam turbines was taken from the EXTREMIS model [4].

Table A- 13 Correction factors for steam turbines

Power % of MCR	CO_2	SO_2	NO_X	PM	VOC, CH4	CO
10	1.4	3.04	0.3	3	5.44	11.65
15	1.4	3.04	0.34	2.8	5.11	10.83
20	1.4	3.04	0.37	2.8	4.72	9.96
25	1.4	3.04	0.41	2.8	4.39	9.09
30	1.2	2.02	0.44	1.5	4.00	8.26
35	1.00	1.00	0.47	1.00	3.61	7.39
40	1.00	1.00	0.51	1.00	3.28	6.57
45	1.00	1.00	0.54	1.00	2.89	5.7
50	1.00	1.00	0.57	1.00	2.56	4.83
55	1.00	1.00	0.61	1.00	2.17	4
60	1.00	1.00	0.64	1.00	1.83	3.13
65	1.00	1.00	0.68	1.00	1.44	2.26
70	1.00	1.00	0.76	1.00	1.33	1.96
75	1.00	1.00	0.84	1.00	1.22	1.65
80	1.00	1.00	0.92	1.00	1.11	1.30
85	1.00	1.00	1.00	1.00	1.00	1.00
90	1.00	1.00	1.00	1.00	1.00	1.00
95	1.00	1.00	1.00	1.00	1.00	1.00
100	1.00	1.00	1.00	1.00	1.00	1.00

Correction factors for gas turbines were estimated with data from the ICAO Aircraft Engine Emissions Databank [7]. The emission behaviour of the GE CF6-6D (marine derivative: GE LM2500) and the Allison 501 (AN 501) was taken as representative for the two most occurring gas turbines in marine applications. CEF values in low power ranges have been changed for the 2011 calculation because an adapted interpolation scheme has been applied.

Table A- 14 Correction factors for gas turbines

Power % of MCR	CO_2, SO_2	NO_X	PM	VOC	CO
10	1.26	0.23	0.98	48.71	64.4
15	1.17	0.3	0.95	37.73	51.15
20	1.04	0.41	0.9	22.35	32.6
25	0.96	0.48	0.88	13.02	21.34
30	0.87	0.55	0.85	2.58	8.75
35	0.88	0.58	0.84	2.46	7.98
40	0.89	0.61	0.84	2.33	7.2
45	0.91	0.64	0.83	2.21	6.42
50	0.92	0.67	0.82	2.08	5.65
55	0.93	0.7	0.81	1.96	4.88
60	0.94	0.74	0.8	1.83	4.1
65	0.95	0.77	0.8	1.71	3.32
70	0.96	0.8	0.79	1.58	2.55
75	0.97	0.83	0.78	1.46	1.77
80	0.98	0.86	0.78	1.33	1
85	0.99	0.93	0.89	1.17	1
90	0.99	0.95	0.92	1.1	1
95	1	0.98	0.96	1.05	1
100	1	1	1	1	1

A2 EMISSIONS OF SHIPS AT BERTH

When a ship is berthed, in most cases the main engines are stopped. The auxiliary engines and equipment will be kept in service to provide (electrical) power to the ship's systems, on board cargo handling systems and accommodations.

The procedure for the calculation of emissions from ships at berth is derived from the EMS protocol with some minor modifications. The methodology was published in Atmospheric Environment [8]. 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 were 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 tonnage. 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 [2].

Table A- 15 Fuel rate of ships at berth, (kg/1000 GT.hour)

Ship type	Fuel rate
Bulk carrier	2.4
Container ship	6
General Cargo	6.1
Passenger <=30000 GT	8.9
Passenger > 30000 GT	32.4
RoRo Cargo	6.1
Oil Tanker	19.3
Other Tanker	14.5
Reefer	19.6
Other	9.2
Tug/Supply	15.6

Table A- 16 specifies total fuel use over fuel types in dependence of ship types.

Since January 1st 2010 the sulphur content of marine fuels used for ships at berth is regulated to a maximum of 0.1 percent. This implies that only marine gas oil with a sulphur content below 0.1 percent may be used in harbours. The specification of fuel types at berth is adapted according to this new regulation.

Table A- 16 Specification of fuel types of ships at berth per ship type (%)

Ship type	HFO	MDO	MGO/ULMF
Bulk carrier	0	0	100
Container ship	0	0	100
General Cargo	0	0	100
Passenger	0	0	100
RoRo Cargo	0	0	100
Oil Tanker	0	0	100
Other Tanker	0	0	100
Fishing	0	0	100
Reefer	0	0	100
Other	0	0	100
Tug/Supply	0	0	100

Table A- 17 gives figures about allocation of fuel amount over engine types and apparatus during berth.

Table A- 17 Allocation of fuels usage in engine types and apparatus per ship type (%)

Ship type	Power (MS)	Boiler
Bulk carrier	90	10
Container ship	70	30
General Cargo	90	10
Passenger	70	30
RoRo Cargo	70	30
Oil Tanker	20	80
Other Tanker	50	50
Reefer	90	10
Other	100	0
Tug/Supply	100	0

In following tables, Table A- 18 to Table A- 20, the emission factors used for emissions at berth are presented.

Table A- 18 Emission factors of medium/high speed engines (MS) at berth, (g/kg fuel)

Year of build	NO_X	PM	VOC	CO
Fuel	all	MGO/ULMF	all	all
1900 – 1973	53	1.4	2.7	13
1974 – 1979	65	1.5	2.8	14
1980 – 1984	73	1.6	2.9	15
1985 – 1989	82	1.8	3.1	13
1990 – 1994	74	1.3	2.6	11
1995 – 1999	59	0.8	2.2	11
2000 – 2010	49	0.8	1.6	11
2011 – 2015	39	0.8	1.6	11

Table A- 19 Emission factors of slow speed engines (SP) at berth, (g/kg fuel)

Year of build	NO_X	PM	VOC	CO
Fuel	all	MGO/ULMF	all	all
1900 – 1973	76	1.6	2.9	14
1974 – 1979	90	1.7	3.0	15
1980 – 1984	100	1.8	3.2	16
1985 - 1989	111	2.0	3.3	14
1990 - 1994	103	1.5	2.9	11
1995 - 1999	88	1.0	2.4	12
2000 - 2010	71.4	1.0	1.8	12
2011 – 2015	60.0	1.0	1.8	12

Table A- 20 Emission factors of boilers of boilers at berth, (g/kg fuel)

Fuel	NO_X	PM	VOC	CO
MGO/ULMF	3.5	0.7	0.8	1.6

Table A- 21 Emission factors of all engines and apparatus, (g/kg fuel)

Fuel	SO_2	CO_2
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.

A3 CONNECTION BETWEEN EMISSION FACTORS AND SHIP DATA WITHIN THE SHIP CHARACTERISTICS 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 or 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 of the ship characteristics database containing data for 122,756 individual ships. In this way, emission factors can be derived for almost any seagoing ship sailing the high seas.

A3.1 Year of Build of Main Engines

For 76,817 ships, the ship engine year of build was directly taken from the field “ENGINE_DOB” from the ship characteristics database. In 40,307 cases, the ship engine year of build was assumed to be equal to the ship year of build. For 5,632 cases, the ship engine year build was assumed to be the average of the ship type and/or a ship’s size.

Table A- 22 Method of assessment of engines year of build

Method of assessment	Number	Share
Directly taken from “ENGINE_DOB	76,817	62.6%
Directly taken from “BUILD”	40,307	32.8%
Average of ship type and/or Size	5,632	4.6%
Total	**122,756**	**100.0%**

The uncertainty in a ship engine year of build probably is not a major factor in overall uncertainty in ships emission factors.

A3.2 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, whereas all other diesel engines were classified as MS.
For 42% of ships, the maximum RPM was provided by the ship characteristics database. A good approximation of RPM was derived from most frequent occurring RPM in the “ENGINE_DESIGNATION” records for 18% of ships.

A rougher approximation was derived from the average engine RPM per ship type and/or ships size. Because bigger ships mostly operate slow speed engines it is expected that an average RPM value derived from ships size still will result in a reasonable approximation especially when also the ship type is taken into account.

Table A- 23 Assessment method of ships diesel engines RPM

Method of assessment	Number	Share
Directly taken from "RPM"	52,030	42%
Most frequent occurring RPM derived from "ENGINE_DESIGNATION"	21,638	18%
Average of ship type and/or size	49,088	40%
Total	**122,756**	**100%**

A3.3 Engine types

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- 24 gives a complete overview of all engine types, which were observed in the ship characteristics 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 allocation 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.

A better assignment of engine types was achieved by combining information in the ship characteristics database. Considering the values in ENGINE_DESIGNATION it was decided that for some engines where ENGINE_TYPE was coded as "DSL" in fact the code had to be "GST". In the same manner for some engines where no data were given in ENGINE_TYPE it was decided that these engines were most probably steam turbines ("ST").
The distinction between "MS" and "SP" of diesel engines is based on RPM values as explained in paragraph A3.2.

Table A- 24 Engine types in the ship characteristics database

ENGINE_TYPE	ENGINE_TYPE_DECODE	Number	Engine type			
			MS	SP	ST	TB
STM	Steam	519			518	1
STT	Steam Turbine	3			3	
No data	No data	45,507	41,666	3,677	164	
DSE	Diesel Electric	248	222	26		
DSL	Diesel	76,375	36,482	39,882		11
ELC	Electric	19	18	1		
GST	Gas Turbine	85				85

A3.4 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 ship characteristics 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, in a little more than 100 cases prevalence was given to the value of "POWER_KW" over "BHP". When the value of "BHP" was not available the value of "POWER_KW" was taken. In the case of no data for both fields, engine power was estimated by linear regression (power functions) per ship type against a ship's gross tonnage (GT), or averages per ship type and ship size class.

Table A- 25 Assessment method of main engine power

Method of assessment (kW)	Number	Share Number	Share Power
Directly via BHP * 0.746*)	87,727	71%	85.0%
Directly via POWER_KW	2,936	2%	4.7%
Via linear regression	28,764	23%	10.3%
Average of ship type and/or size	3,329	3%	0.01%
	122,756	**100%**	**100%**

*) 1 BHP (brake horse power) = 0.746 KW (kilowatt)

Parameters for the applied regression functions are given in Table A- 26. The resulting fitting functions which were created by means of the least squares approach, taking the mathematical from of:

$$\text{Power} = \text{Coefficient} \times \text{Gross}^{n}$$

Wherein:
Power : Calculated ships main engine power (kW)
Coefficient : Function parameter assessed by linear regression
Gross : Volume of the ship measured in Gross tonnage (GT)
n : Function parameter assessed by linear regression

Considering the R^2-coëfficiënts, it can be seen that the relationship between power and ship 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 ship GT.

Table A- 26 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

It was discovered that ships that are equipped with multiple main engines in far most cases the value of BHP in the LLI-database contains the power of the individual engine. In the calculation scheme as presented in paragraph A1.2 this observation is applied.

A3.5 Power of Auxiliary Engines

Details on the power of installed auxiliary engines are only available in a minority of records within the ship characteristics database Furthermore, the information given about auxiliary engines 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- 27 Parameters used for calculation of auxiliary engine power in case of lack of data

Method of assessment	Number	Share %
Directly from ship characteristics database	29,133	23,7%
Derived from main engine power based on ratios within IMO-report	92,859	75,6%
10% of main engine power	764	0,7%
	122,756	100%

For just 24% of ships, a value of ship auxiliary engine power could be derived from the ship characteristics database. The completeness of 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]).

A3.6 Type of Fuel Used in Main Engines

Obtaining a confirmation from the ships characteristics database of the fuel type used by the main engines 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 is lacking in the current available database and in order to compensate, an algorithm was derived. Generally, it is assumed that large ships are guided by economic 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 than 1000 was introduced. According to this formula a ship with 3,000 kW and 2,500 RPM will use MDO.

Table A- 28 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

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