MARIN

SEA SHIPPING EMISSIONS 2014: 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
TSS	Traffic Separation Scheme

1 INTRODUCTION

1.1 Objective

This study aims to determine the emissions to air of seagoing vessels above 100 GT for 2014. The totals and the spatial distribution for the Netherlands Continental Shelf, the 12-mile zone and the port areas Rotterdam, Amsterdam, the Ems, the Western Scheldt (west of Terneuzen), 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 2014 in the OSPAR region II area and the Western Scheldt from Terneuzen to the east.
The emissions for 2014 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 2014.
Chapter 3 describes the procedure used for the emission calculation based on AIS data.
Chapter 4 describes the work done on the completeness of AIS data.
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 2014 for the Dutch port areas and the Netherlands sea area and makes a comparison with 2013.
Chapter 8 summarises the 2014 emission for OSPAR region II. It also contains a comparison with 2013.
Chapter 9 presents conclusions and recommendations.

2 2014 EMISSION DATABASES

2.1 General information

A set of 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 six Dutch port areas Rotterdam, Amsterdam, the Ems, the west part of the Western Scheldt[1], Den Helder and Harlingen,
- the east part of the Western Scheldt[2] based on the SAMSON traffic database,
- the OSPAR region II at sea.

For the information on what can be found in the databases, refer to [1].

2.2 Netherlands sea area and Dutch port areas

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

- Emissions_2014_MARIN_12Miles.accdb (27-11-2015)
- Emissions_2014_MARIN_NCP.accdb (27-11-2015)
- Emissions_2014_MARIN_Dutch_port_areas.accdb (3-12-2015)

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_2014_MARIN_Westerschelde.accdb (11-12-2015)

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 separation schemes. 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.

[1] The part based on AIS, from Terneuzen to the west.
[2] The part based on the SAMSON traffic database, from Terneuzen to the east.

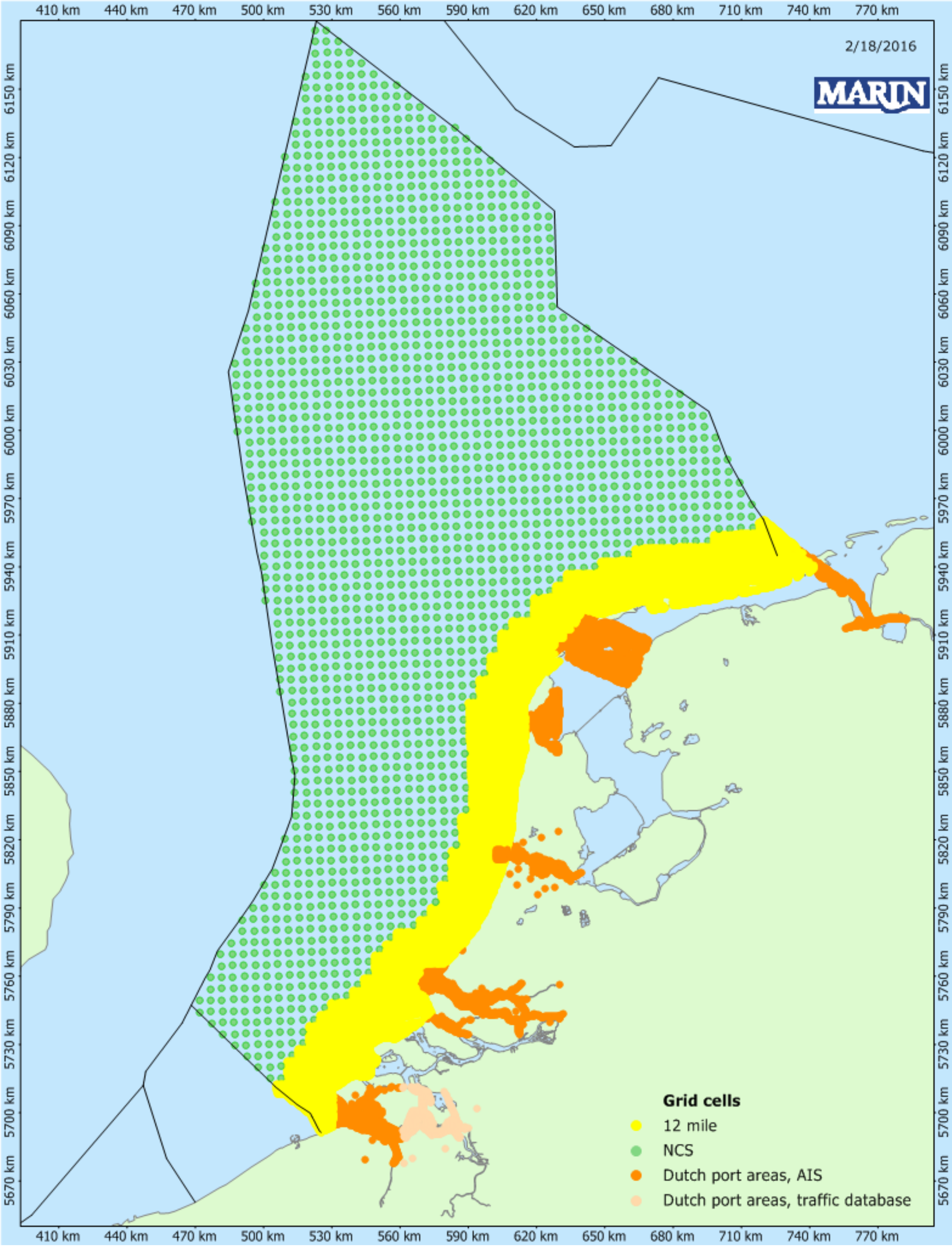

Figure 2-1 The Netherlands Continental Shelf, 12-mile zone and six port areas

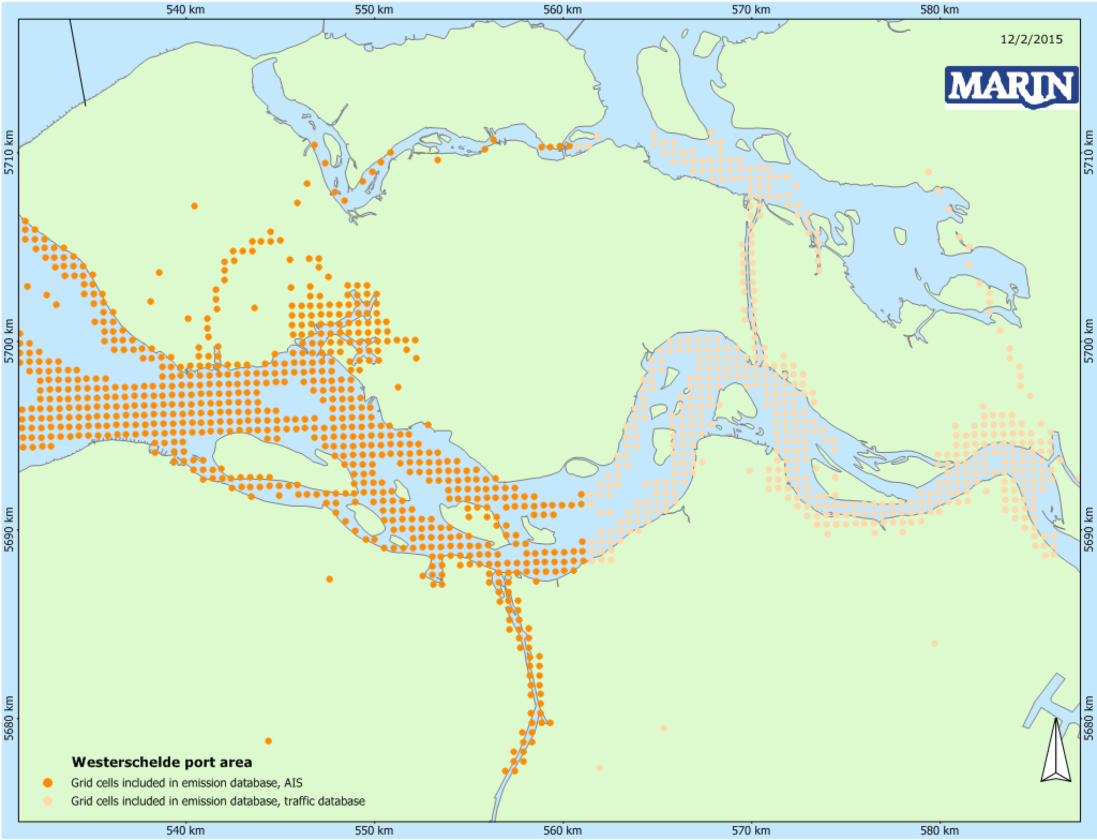

Figure 2-2 **Western Scheldt: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

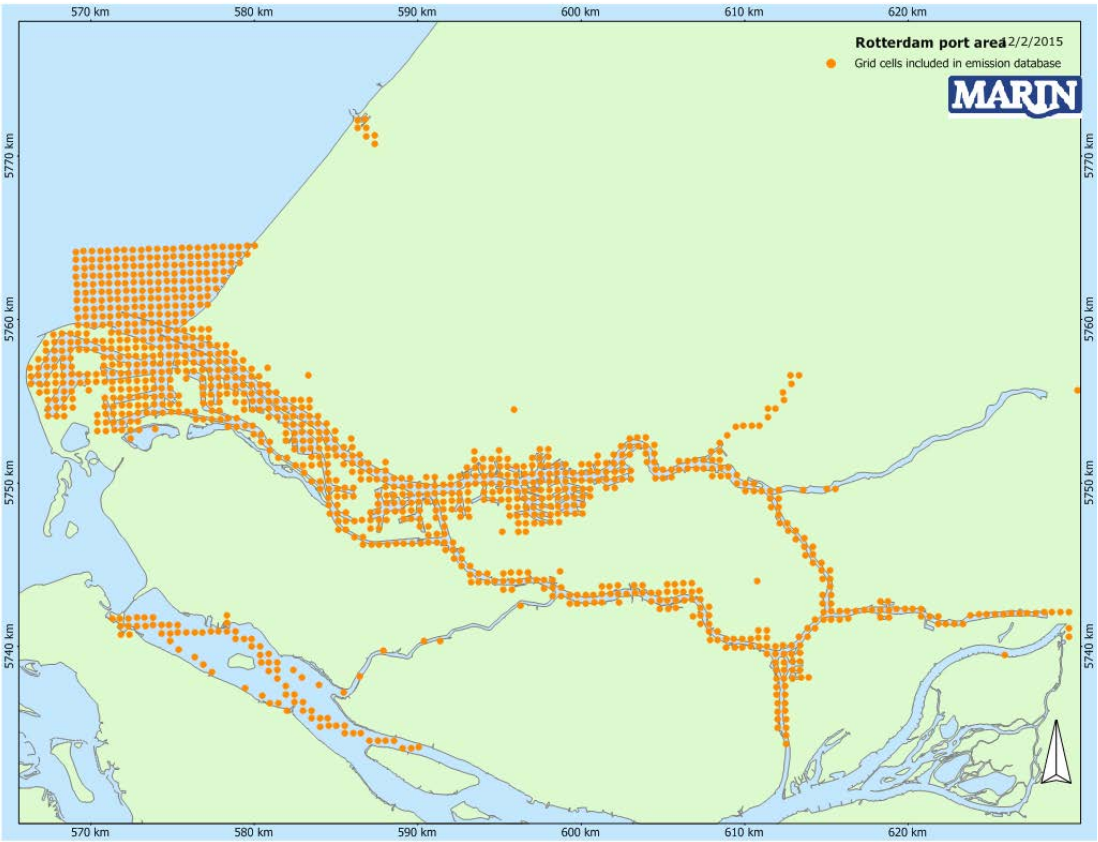

Figure 2-3 **Rotterdam: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

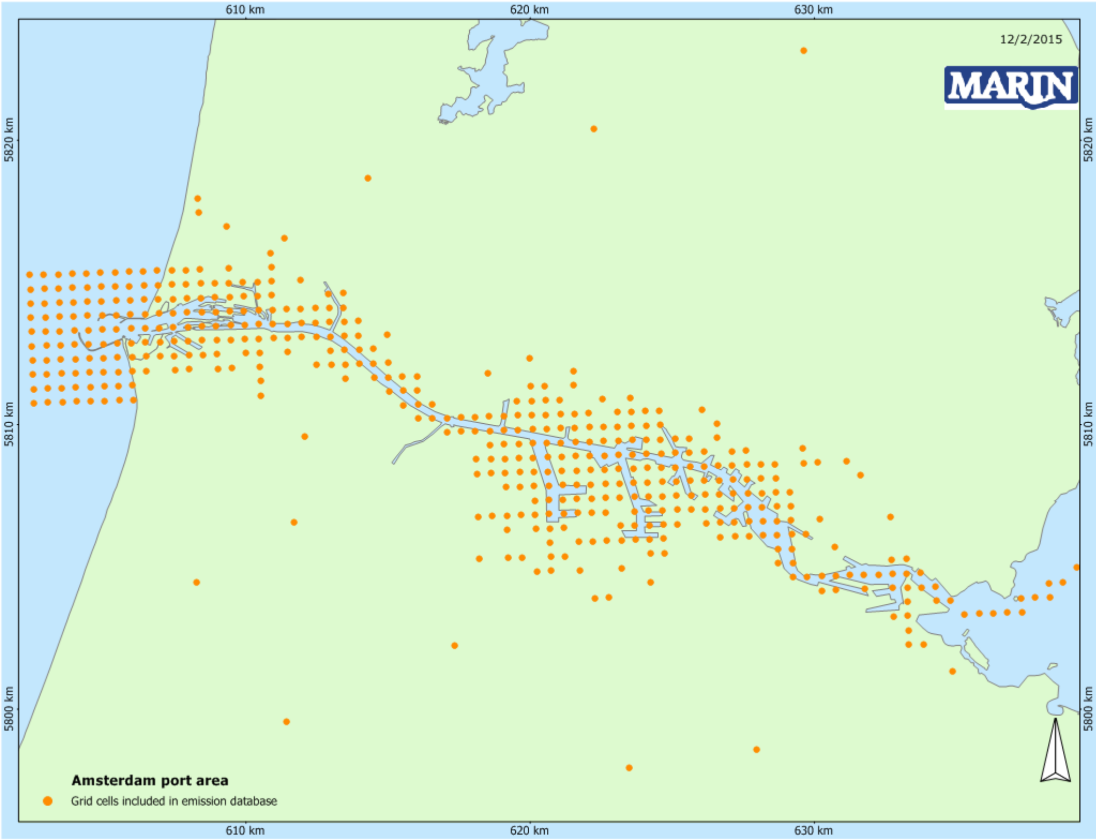

Figure 2-4 **Amsterdam: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

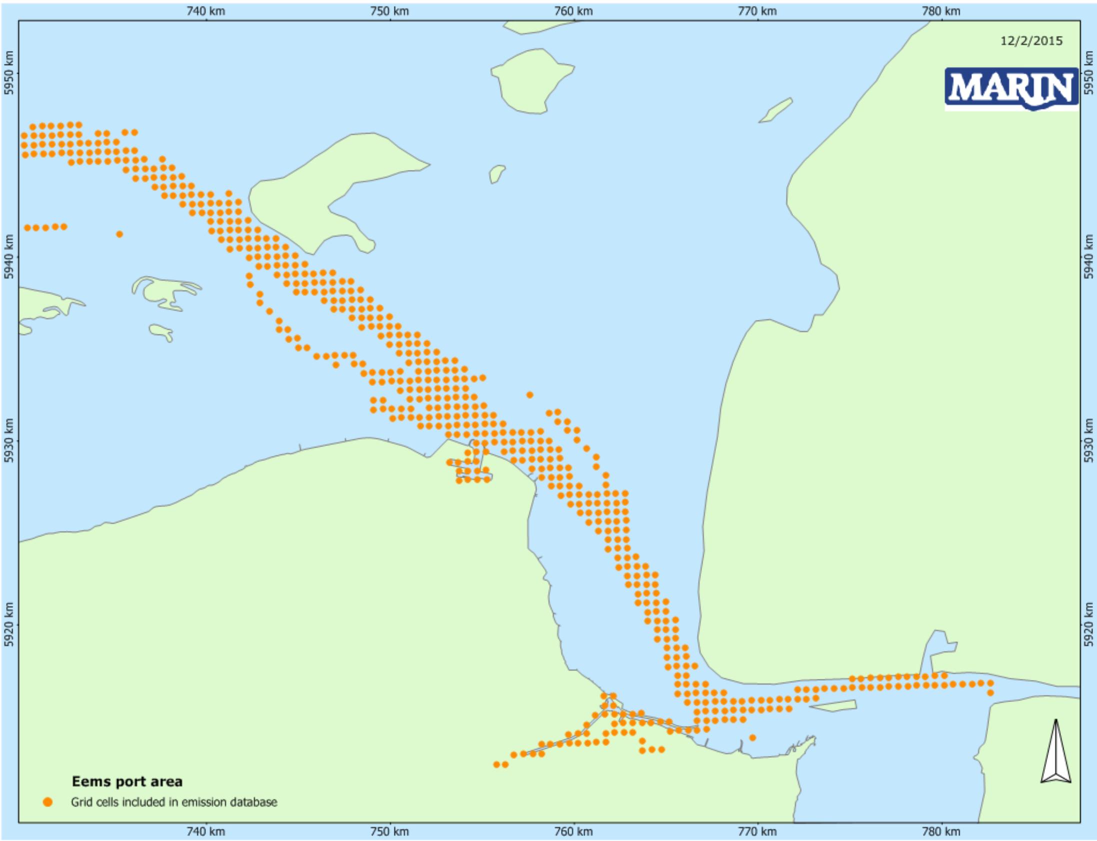

Figure 2-5 **Ems: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

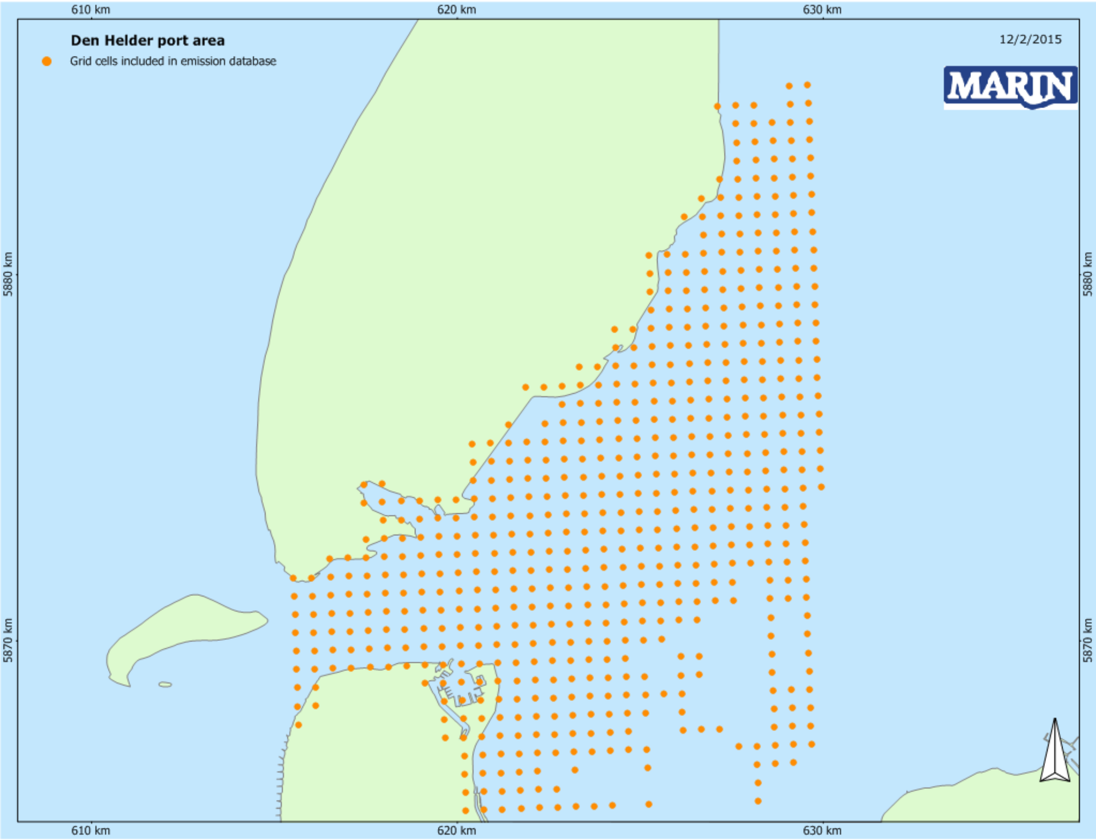

Figure 2-6 **Den Helder: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

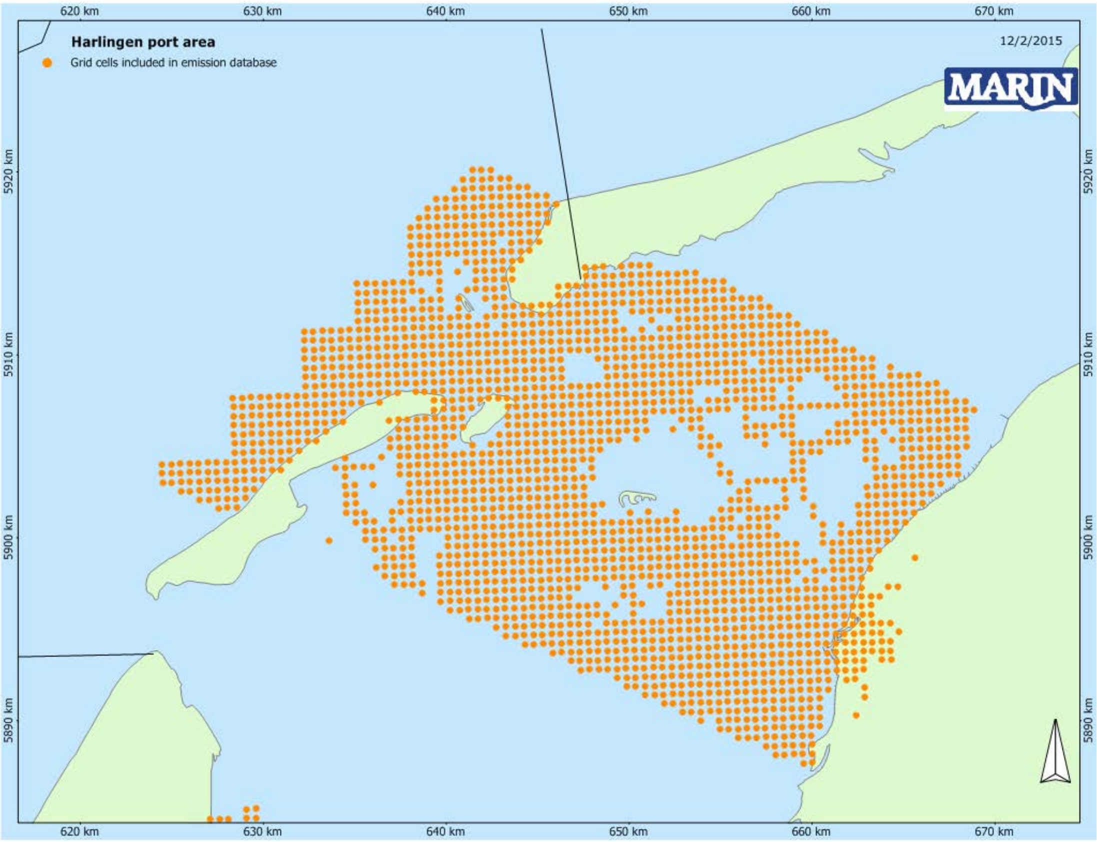

Figure 2-7 **Harlingen: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

2.3 OSPAR region II

The emissions in OSPAR region II are stored in:

- Emissions_ 2014_MARIN_OSPAR_region_II_sea.accdb (11-12-2015)

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 2014. 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.

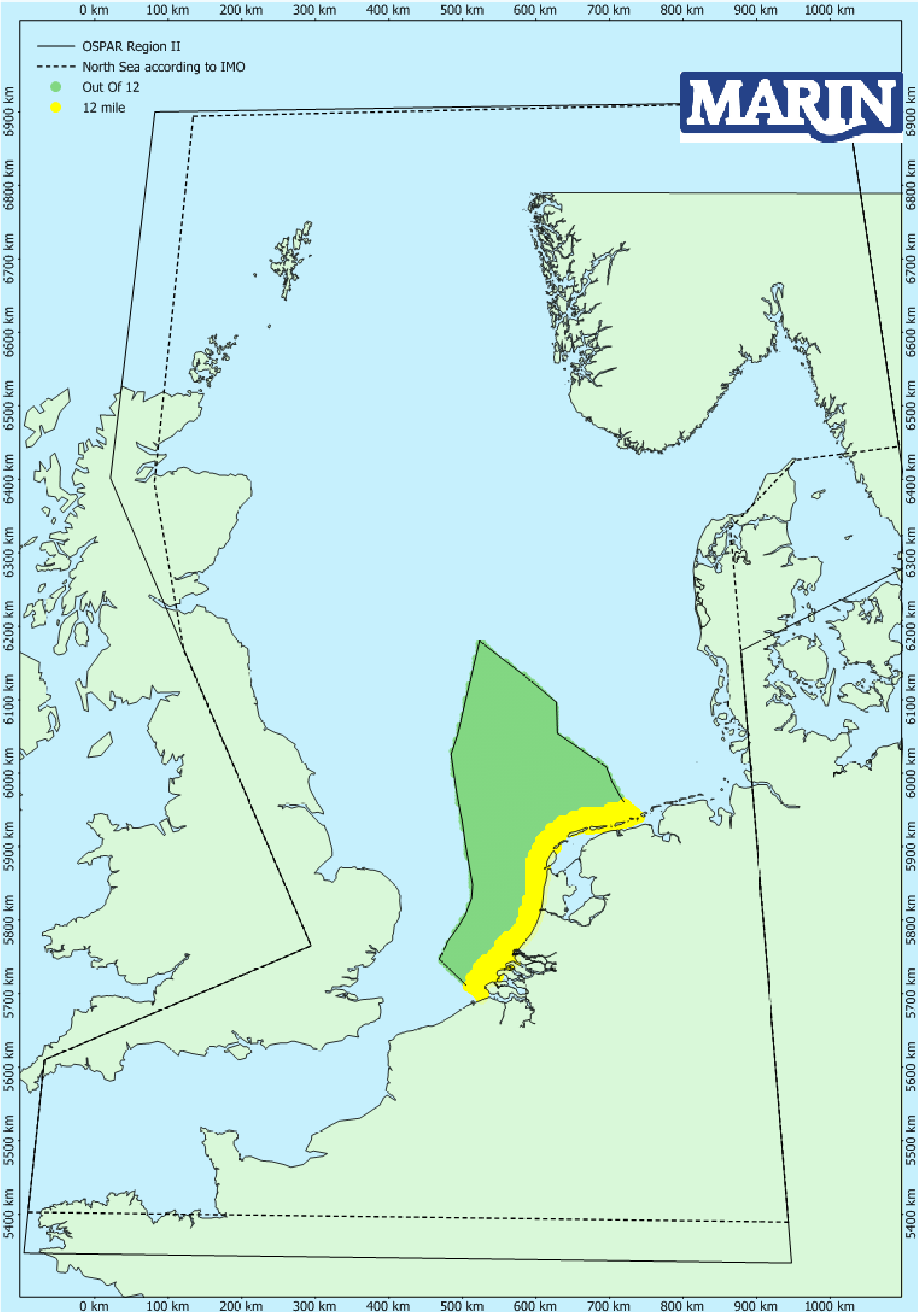

Figure 2-8 **Areas within OSPAR region II (solid black line) and the North Sea according to IMO (dotted black line)**

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 six 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 2014
In this study, AIS data of 2014 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 September 2015
The LLI ship characteristics database of September 2015 has been purchased. This database, combined with earlier issues, contains vessel characteristics of over 130,000 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. Two small errors in the implementation of formulas 2 and 4 of Appendix A of [1] were corrected this year. In formula 2, the factor 0.85 was missing in the implementation. In formula 4, the second term ‘Engines operational’ was erroneously replaced by ‘Engines Present’.

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 2014.

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 29,169 unique MMSI numbers in the AIS data of 2014 are divided into a group of 13,387 MMSI number with a corresponding IMO number that is not always equal to zero (so likely a relevant ship) and a group of 15,782 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 476 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 might be because they were <100GT, or inland ships.

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

Different MMSI numbers in AIS data of 2014	IMO number in AIS message	Coupled	Not coupled
29,169	13,387 IMO≠0	12,911	476
	15,782 IMO=0	276	15,506

From the second group, containing 15,782 ships with IMO always equal to zero, 276 could be coupled with a ship in the LLI database and 15,506 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 276 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 (192 are in size class 1 < 1600GT) with a small contribution to the emissions. Of the 276 ships there are only 21 ships in the larger size classes (5 to 8 together).

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].

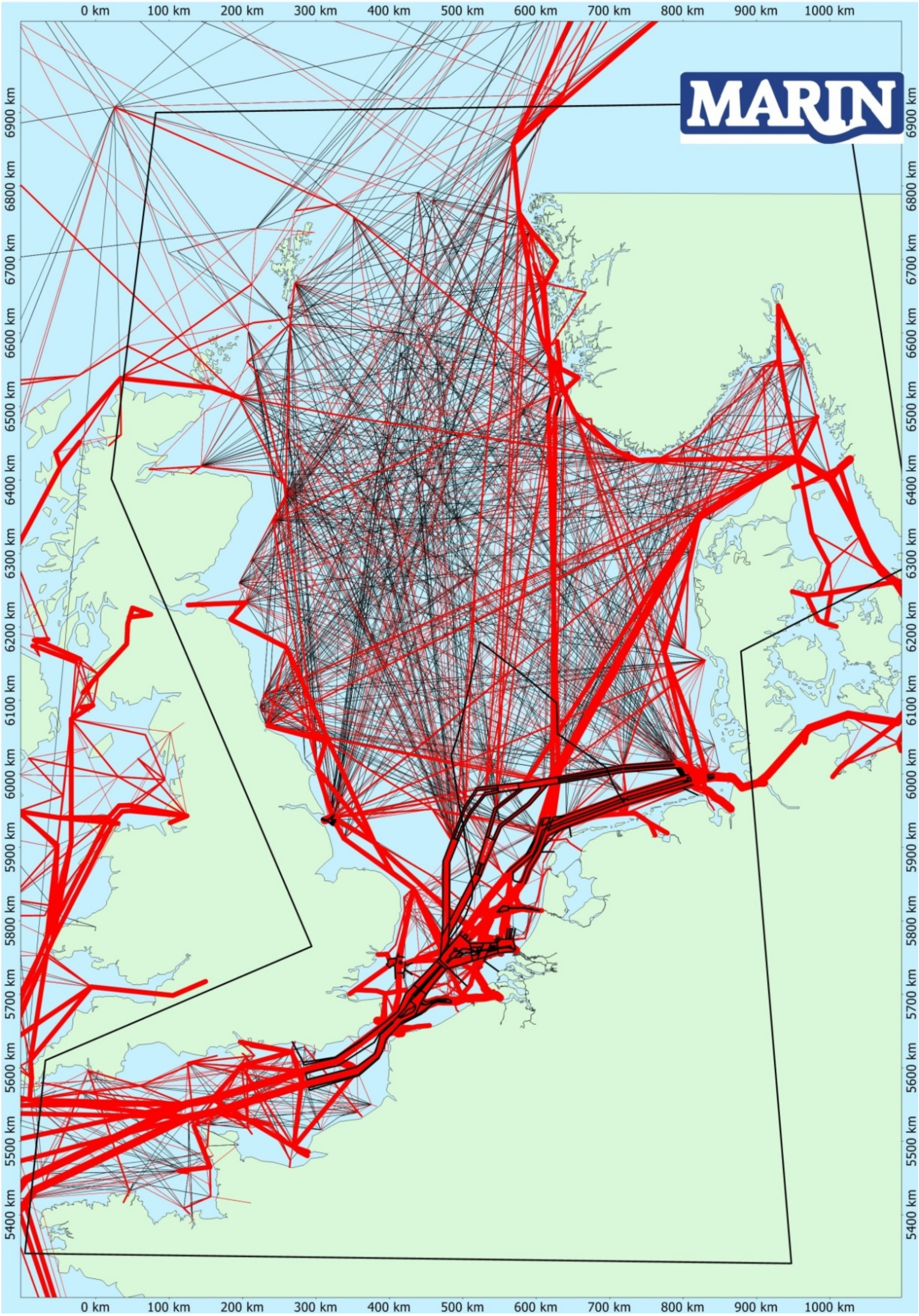

Figure 4-1 **Traffic links of the SAMSON traffic database of 2012 in OSPAR region II, the width of the links indicates the intensity of the ships on the links, red links represent a higher traffic intensity than black links**

5 COMPLETENESS OF AIS DATA

This chapter describes the completeness of the AIS data. In 5.1 the missing minute files are described, 5.2 describes the analysis of the coverage of the AIS data for the NCS and the Dutch port areas.

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 2014 contains 525,583 files, which is 99.997% of the expected number of 525,600 files (365 days times 24 hours times 60 minutes). Therefore, in total 17 minutes 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 2014 there was no gap in the data of more than 10 minutes, therefore no completion factor has been used.

5.2 Bad AIS coverage in certain areas

5.2.1 Base stations

In section 5.1, 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 minute 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. In February 2014 four new base stations were installed, indicated by the blue circles in Figure 5-1. Especially the upper right new base station covers a spot that was not covered before. Furthermore, the lower right new base station covers a spot between the circles of the existing base stations in the Traffic Separation Scheme (TSS) north west of Texel.

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 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.
The four new base stations cover the area north west of Texel, and also the area north of the Oost Friesland TSS.

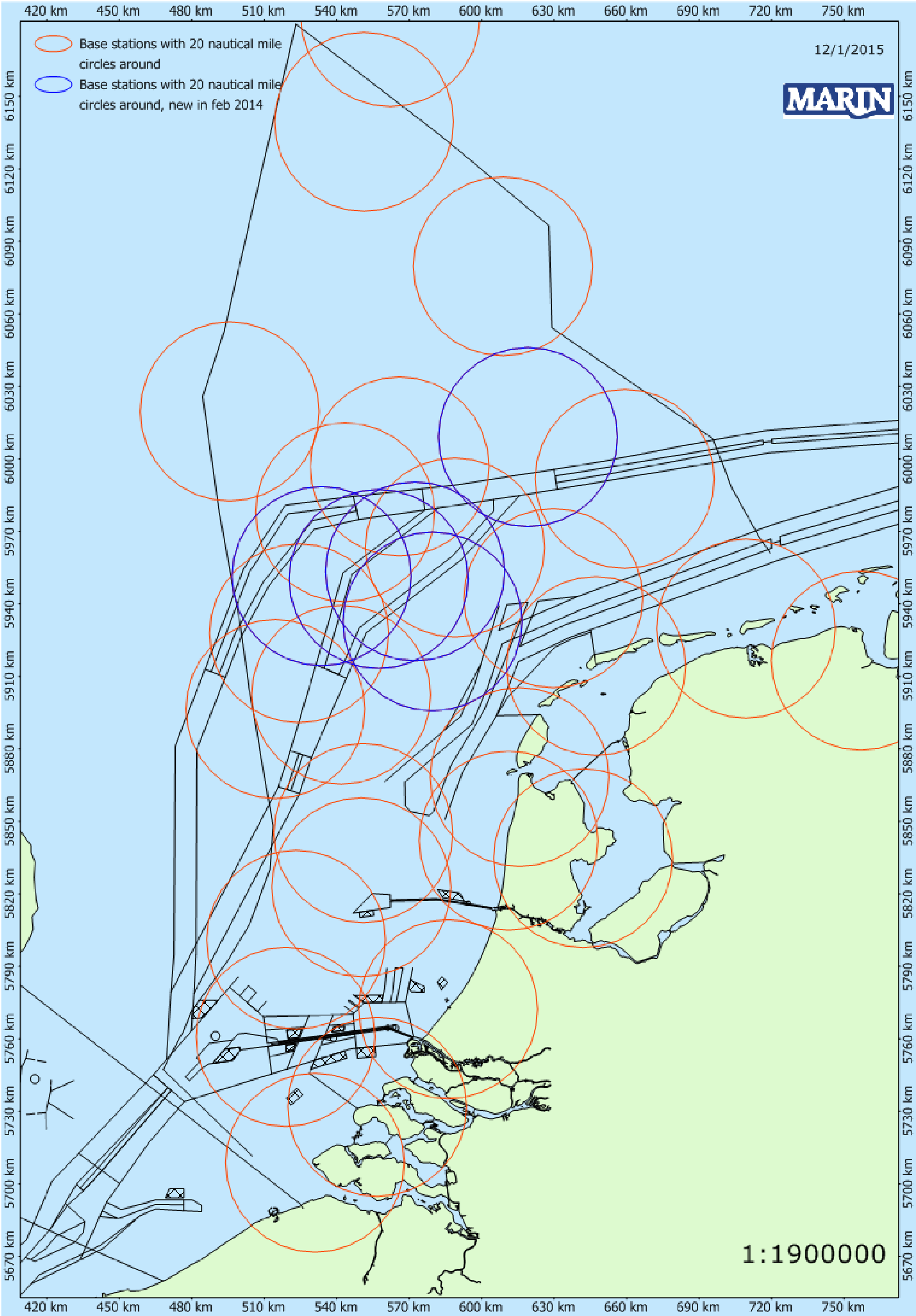

Figure 5-1 **AIS base stations in 2014 delivering data to the Netherlands Coastguard**

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 in this grid cell. 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 a large part of 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 June and September 2014. These months were chosen based on the size of the AIS logs. In June, the size of the AIS logs was lower than average for a while, which could mean that the coverage was bad. In September the size of the AIS logs was constantly around the average level, which implies the coverage was good. Figure 5-2 shows one base station in the upper right that did not function correctly, where Figure 5-3 shows that this problem was solved in September. One of the new base stations seems to have improved the coverage north of the Oost Friesland TSS, the traffic separation scheme in the northern part of the NCS, compared to the previous year (see [2]). Both figures show a better coverage of the area close to the border with the United Kingdom Continental Shelf, southwest of Rotterdam. This is not explained by a new base station, but might be caused by an existing base stations that has a better performance.

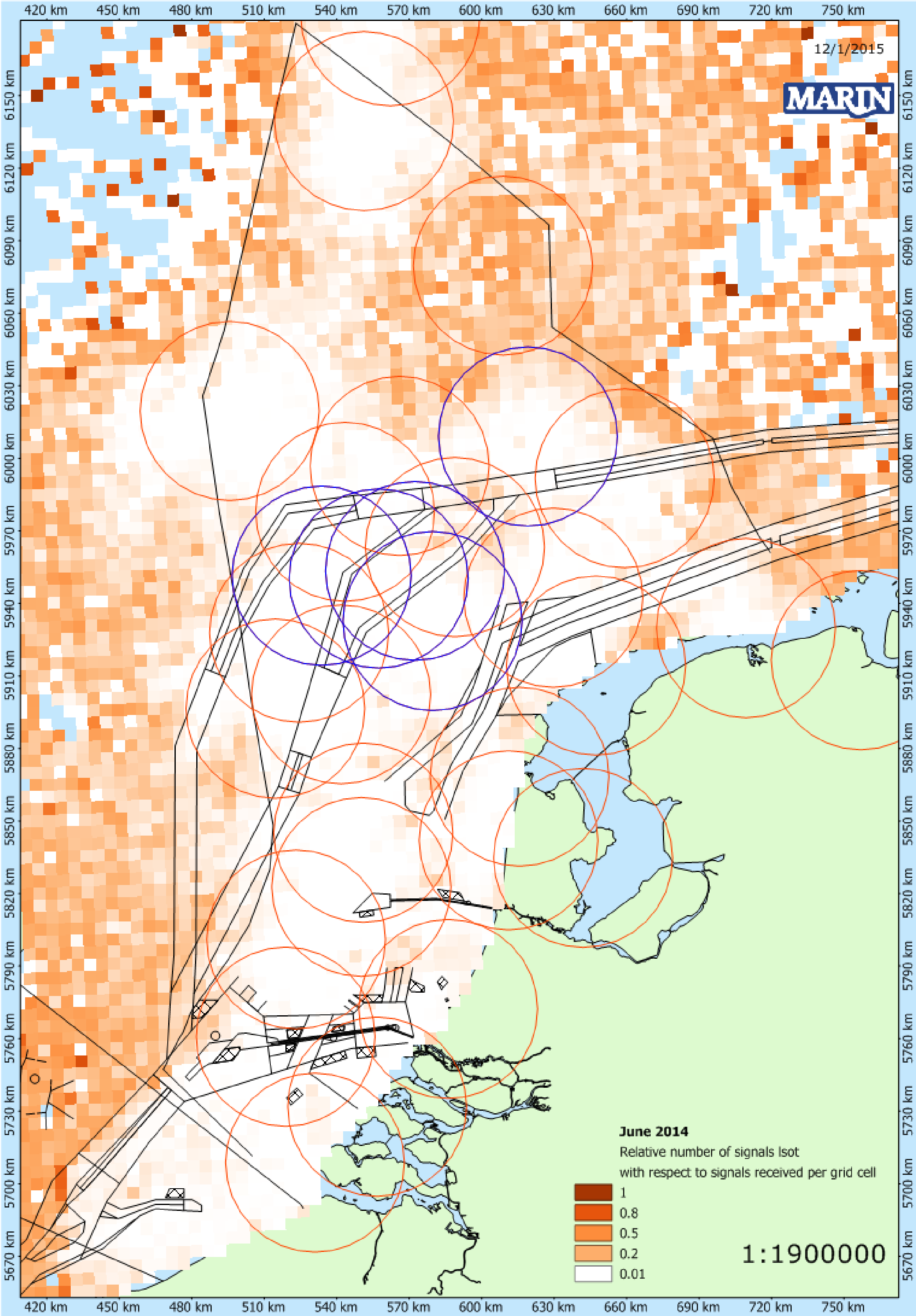

Figure 5-2 **June 2014, relative number of signals lost with respect to signals received per grid cell, circles mark the 20 nautical miles zones around the Dutch base stations**

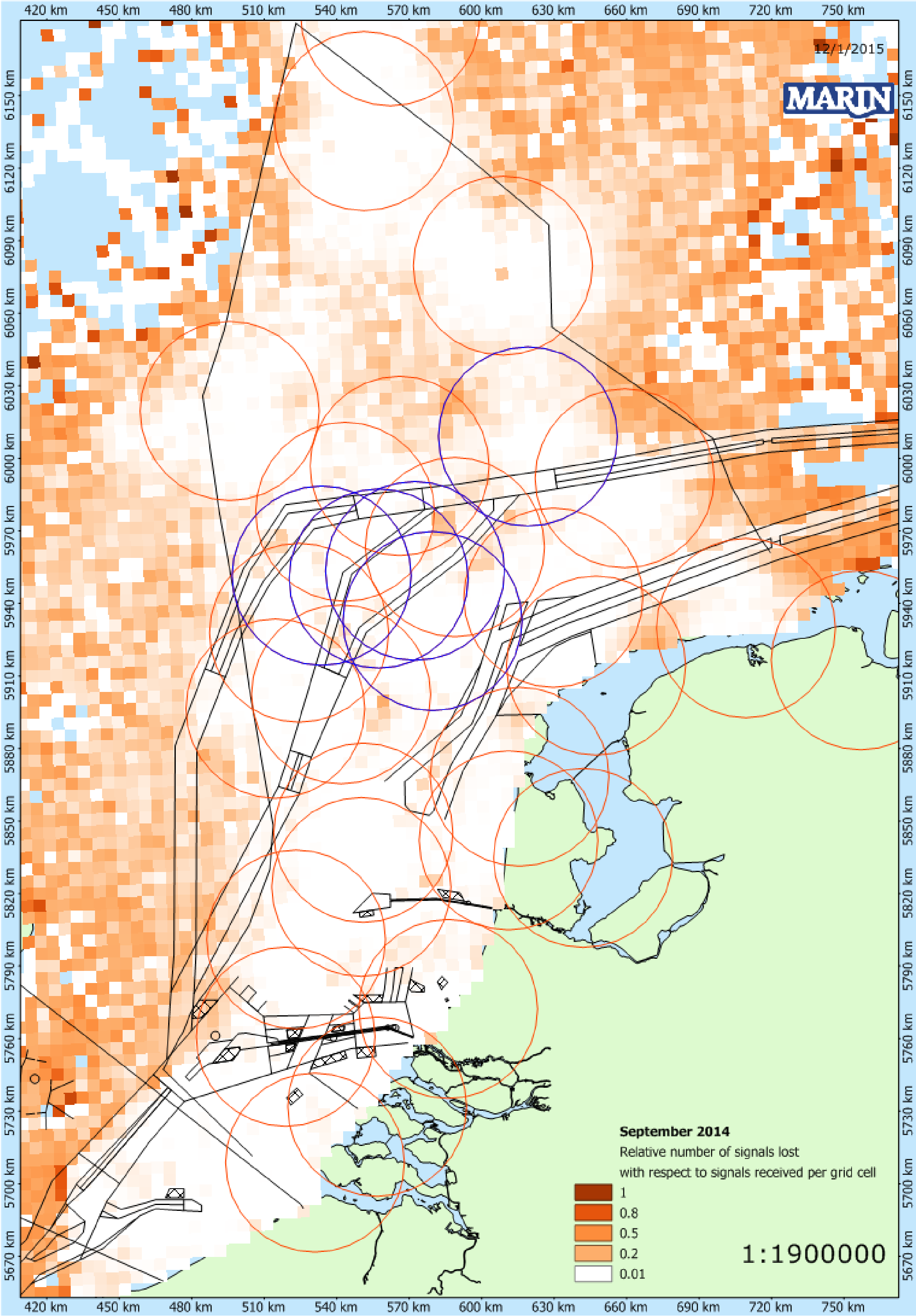

Figure 5-3 **September 2014, relative number of signals lost with respect to signals received per grid cell, circles mark the 20 nautical miles zones around the Dutch base stations**

5.2.4 Coverage in the Dutch port areas

Also in the 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]. These checks did not show suspicious behaviour in the port areas, except the known coverage problem in the Western Scheldt, which 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

Until two years ago, 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.

The approach followed in 2014 is similar to the approach of 2013, described in [2]. The area west of Terneuzen is based on the AIS data, the area east of Terneuzen to the Belgian border is based on the SAMSON traffic database and the spatial distribution of the emissions for this area is based on the results of 2011. The area where the traffic database is used is indicated in Figure 5-4. In 2013 the change in traffic between 2012 and 2013 was estimated based on the same method as for OSPAR region II, namely by determining the change in traffic on the NCS, but for 2014 this was not appropriate. This is because the number of visits to Antwerp increased, but of the most important ship types going to Antwerp, the number of ships on the NCS decreased between 2012 and 2014. So using the traffic composition of all of the NCS, does not give a good approximation of the traffic on the Western Scheldt towards Antwerp. Therefore, a different approach was followed. It is assumed that the coverage in the AIS is sufficient until Terneuzen, and it can be assumed that almost all ships passing Terneuzen will go to Antwerp, as there are few other destinations on that part of the Western Scheldt. The number of ships passing Terneuzen in 2014 was compared to the number of ships passing Terneuzen in 2012, for the different ship types and sizes. The change in the traffic passing Terneuzen is used to correct the traffic composition of the traffic database on the Western Scheldt. Finally, again the spatial distribution of 2011 is used for the area east of Terneuzen.

Figure 5-4 Traffic database Western Scheldt

6 ACTIVITIES OF SEAGOING VESSELS FOR 2014 AND COMPARISON WITH 2013 FOR THE DUTCH PORT AREAS AND THE NETHERLANDS SEA AREA

6.1 Introduction

This chapter presents the activities of seagoing vessels for 2014 in the Dutch port areas and in the Netherlands sea area. The activities of 2014 are compared to those of 2013. 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 most of the ports. For the port of Harlingen no figures are available, for the port of Den Helder the cargo handling of 2014 is not yet published. These numbers can be used to check the information on activity as derived from the AIS data. First, the values of 2014 are shown and then the percentages with respect to 2013. 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 all of the port areas, except for the Ems and Den Helder. On the other hand, all the ports report an increase in cargo handling.

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

Port area	Ports	Number of calls		Cargo handling x 1000 tons	
		2014	2014/2013	2014	2014/2013
Western Scheldt	Antwerp*	14,009	98.52%	335,276	101.71%
	Zeeland seaports (Vlissingen en Terneuzen)	5,496	98.16%	35,100	106.27%
Rotterdam	Rijn- en Maasmondgebied	29,027	98.57%	444,733	100.97%
Amsterdam	Noordzeekanaalgebied	7,486	98.55%	97,700	102.04%
Ems	Delfzijl/Eemshaven	5,274	102.39%	4,179	132.88%
Den Helder	Port of Den Helder	2,776	106.77%	--	--

*not cargo handling but GT (in 1000 ton)

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 increased by 9.1%, also the GT.nm increased, but only by 4%. Table 6-1 indicates that the number of calls of the port of Antwerp and Zeeland Seaports decreased by 1.5%. Based on this, a small decrease in moving ship hours would be expected. However, note that the observed *increase* is mainly caused by the ship type tug/supply, which does not show up in the number of calls. Furthermore, in the previous year, the decrease was larger than expected, which might also indicate that the coverage problems in 2013 were also present in the western part of the area. The average speed has not changed. 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, increased. The hours and GT.hours increased more than expected based on Table 6-1. The increase in percentage of the berthed hours and GT.hours for the largest ship size is enormous. This is due to the fact that the absolute numbers are very small. The hours went up from only 30 to 310.

Rotterdam
Table 6-4 and Table 6-5 for Rotterdam show that the activities have increased in 2014 compared with 2013. The berthed activities increased more than the moving activities. The number of calls in Table 6-1 decreased, and the cargo handling was almost constant. The largest increase is seen for General Dry Cargo ships, and only oil tankers, reefers and non merchant ships show a decrease. The average speed decreased a little.

Amsterdam
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 chem/gas tankers and General Dry Cargo ships decreased significantly. Table 6-1 indicates that the number of calls has decreased by 1.5%, the number of moving hours and berthed GT.hours also decreased by 1.5%, but the berthed hours and moving GT.nm increased.

Ems
Table 6-1 shows a small increase in the number of calls in Delfzijl and Eemshaven and a larger increase in the cargo handled. The number of berthed hours in Table 6-8 and Table 6-9 also increased significantly, the moving hours decreased a little, while the moving GT.nm increased. This is in line with what would be expected based on Table 6-1. The average speed increased with 2%.

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, only for chem./gas tankers there was an increase. The average speed has not changed. 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 a decrease in activities. For chem/gas tankers there was an increase. The average speed in the area increased by 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 2014					2014 as percentage of 2013				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	9,914	369,210,965	4,296	1,016,680,189	10.31	134.3%	156.6%	105.5%	111.6%	101.1%
Chem.+Gas tanker	44,423	498,734,079	22,975	2,037,764,970	10.60	179.3%	186.9%	112.0%	107.4%	100.0%
Bulk carrier	14,897	605,431,531	5,085	1,209,522,243	8.28	147.2%	140.8%	109.3%	107.4%	97.9%
Container ship	2,432	55,388,790	12,156	7,205,015,250	12.70	82.4%	88.9%	96.3%	104.4%	101.0%
General Dry Cargo	54,887	446,207,978	23,925	1,129,896,560	9.72	138.2%	130.0%	112.6%	101.6%	98.3%
RoRo Cargo / Vehicle	8,822	180,829,149	6,307	2,767,068,989	11.87	99.3%	103.3%	95.0%	96.0%	101.4%
Reefer	8,258	72,669,315	1,620	224,762,891	11.96	122.2%	119.6%	94.8%	95.0%	100.3%
Passenger	14,160	56,047,265	6,193	298,060,594	11.51	139.6%	309.3%	109.0%	112.6%	100.1%
Miscellaneous	91,958	248,047,990	16,295	345,734,953	7.88	113.2%	118.7%	101.1%	122.6%	100.0%
Tug/Supply	124,948	53,568,281	15,309	31,565,375	6.12	138.0%	98.9%	134.7%	102.0%	91.1%
Non Merchant	9,561	9,828,517	140	881,934	8.55	327.6%	451.6%	198.5%	552.2%	162.8%
Total	384,260	2,595,963,859	114,300	16,266,953,948	11.24	134.6%	139.8%	109.2%	104.0%	100.0%

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 2014					2014 as percentage of 2013				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Averag e speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	203,797	107,712,640	31,789	175,539,945	8.10	135.5%	132.5%	125.6%	116.2%	92.1%
1,600-3,000	57,308	131,995,386	22,137	471,238,773	9.03	124.4%	125.6%	100.3%	105.2%	103.1%
3,000-5,000	22,759	90,473,157	14,512	560,975,258	9.73	127.7%	128.6%	118.9%	115.5%	95.8%
5,000-10,000	31,308	219,094,091	11,789	872,705,694	10.62	139.4%	139.1%	98.5%	96.2%	98.9%
10,000-30,000	44,054	831,256,382	17,899	3,702,376,529	11.05	141.8%	142.1%	102.1%	100.2%	99.5%
30,000-60,000	20,220	817,165,147	11,872	5,745,998,422	11.31	138.1%	132.5%	103.0%	101.9%	100.0%
60,000-100,000	4,504	349,352,062	3,266	2,940,361,972	11.92	154.1%	147.5%	98.2%	96.4%	99.8%
>100,000	310	48,914,994	1,036	1,797,757,354	12.52	999.8%	959.6%	133.9%	142.3%	102.8%
Total	384,260	2,595,963,859	114,300	16,266,953,948	11.24	134.6%	139.8%	109.2%	104.0%	100.0%

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

Ship type	Totals for Rotterdam in 2014					2014 as percentage of 2013				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	57,743	3,955,437,449	5,562	1,847,618,327	6.59	117.6%	131.0%	98.9%	103.3%	99.3%
Chem.+Gas tanker	88,740	1,165,901,990	20,015	1,563,022,173	8.27	150.9%	137.8%	100.1%	95.9%	99.2%
Bulk carrier	79,953	4,794,413,065	3,377	962,543,479	6.37	117.4%	111.2%	106.2%	102.9%	100.2%
Container ship	151,607	7,319,806,827	25,395	4,888,528,106	7.20	120.0%	122.1%	105.5%	106.5%	98.3%
General Dry Cargo	83,385	492,599,375	21,240	768,016,239	9.09	148.1%	146.2%	116.9%	113.5%	98.7%
RoRo Cargo / Vehicle	24,925	575,713,237	7,204	1,635,912,608	9.56	128.6%	125.8%	109.4%	104.9%	98.4%
Reefer	1,052	8,973,908	669	58,338,546	9.55	97.0%	96.9%	89.2%	92.3%	102.6%
Passenger	11,366	694,475,245	1,555	984,580,540	11.40	101.7%	110.7%	100.3%	100.3%	99.5%
Miscellaneous	94,128	1,098,414,161	20,743	508,181,688	7.43	181.3%	171.7%	100.3%	95.2%	120.4%
Tug/Supply	205,772	105,187,261	48,523	126,553,003	6.21	115.1%	120.5%	106.6%	116.9%	104.1%
Non Merchant	1,001	433,918	183	622,274	7.18	92.5%	88.0%	46.0%	59.9%	95.2%
Total	799,673	20,211,356,436	154,466	13,343,916,983	7.68	128.6%	123.7%	105.4%	103.7%	99.7%

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

Ship size in GT	Totals for Rotterdam in 2014					2014 as percentage of 2013				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average Speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	245,367	112,028,943	61,739	179,481,467	6.55	120.3%	125.5%	111.1%	116.5%	101.4%
1,600-3,000	46,843	113,082,579	15,665	352,923,557	9.24	132.5%	131.7%	107.8%	110.1%	99.7%
3,000-5,000	51,001	202,374,680	19,217	663,174,905	8.68	159.5%	159.2%	122.0%	122.6%	101.4%
5,000-10,000	111,948	832,761,286	21,714	1,472,029,835	9.23	144.3%	144.1%	88.4%	91.6%	103.2%
10,000-30,000	131,596	2,476,615,559	21,643	3,569,774,226	8.88	141.7%	138.5%	100.0%	103.1%	101.6%
30,000-60,000	82,001	3,564,623,174	6,828	2,305,416,338	7.99	122.2%	121.0%	97.2%	95.6%	99.5%
60,000-100,000	83,631	6,481,510,414	5,408	2,911,904,229	7.04	106.4%	109.6%	98.6%	99.7%	101.0%
>100,000	47,284	6,428,359,802	2,253	1,889,212,426	5.70	136.8%	133.8%	126.9%	130.4%	99.8%
Total	799,673	20,211,356,436	154,466	13,343,916,983	7.68	128.6%	123.7%	105.6%	103.7%	99.7%

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

Ship type	Totals for Amsterdam in 2014					2014 as percentage of 2013				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	13,628	458,940,918	2,206	333,715,718	5.31	94.2%	93.7%	109.8%	109.9%	98.0%
Chem.+Gas tanker	25,613	462,001,781	5,769	495,600,033	5.92	78.8%	77.3%	94.1%	95.1%	99.3%
Bulk carrier	55,419	2,789,775,297	2,871	689,866,923	5.19	100.9%	97.9%	101.5%	98.4%	99.9%
Container ship	106	1,650,172	16	1,739,271	5.94	35.5%	38.5%	31.1%	35.3%	104.4%
General Dry Cargo	68,784	256,582,618	8,726	185,385,960	6.75	99.5%	86.3%	95.9%	96.7%	100.0%
RoRo Cargo / Vehicle	9,081	281,074,877	1,605	303,286,371	6.26	108.8%	127.5%	90.2%	119.4%	98.9%
Reefer	16,682	80,435,395	449	11,508,446	5.74	112.8%	128.8%	111.4%	117.0%	96.4%
Passenger	4,594	185,211,824	1,135	370,912,993	6.78	102.6%	98.6%	103.1%	101.0%	104.8%
Miscellaneous	58,748	263,583,263	2,859	58,614,615	5.53	181.9%	179.8%	111.9%	89.9%	96.1%
Tug/Supply	105,815	69,691,557	17,572	30,630,513	5.57	98.7%	92.3%	98.0%	89.2%	99.3%
Non Merchant	13,762	6,043,845	454	1,187,802	6.50	237.8%	193.4%	137.5%	160.5%	109.8%
Total	372,232	4,854,991,548	43,662	2,482,448,645	5.79	108.1%	98.4%	98.7%	101.2%	100.0%

Table 6-7 Shipping activities per EMS ships size classes for the Amsterdam port area

Ship size in GT	Totals for Amsterdam in 2014					2014 as percentage of 2013				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	133,878	58,129,931	20,600	46,024,099	5.92	112.5%	109.9%	99.7%	94.0%	98.8%
1,600-3,000	57,077	134,338,581	6,226	104,294,480	6.86	106.9%	107.6%	95.2%	95.3%	99.1%
3,000-5,000	37,385	145,770,487	3,122	83,066,460	6.70	127.5%	126.7%	109.4%	106.7%	97.6%
5,000-10,000	37,282	258,032,644	3,607	180,211,105	6.34	114.7%	110.0%	86.6%	85.2%	97.1%
10,000-30,000	43,165	861,130,733	4,841	578,992,498	5.85	91.0%	90.9%	93.0%	94.4%	99.1%
30,000-60,000	45,793	1,904,060,964	4,104	970,154,399	5.67	105.6%	105.6%	116.4%	116.4%	100.0%
60,000-100,000	17,628	1,490,800,959	1,152	512,927,564	5.47	91.4%	90.3%	92.3%	93.8%	103.3%
>100,000	25	2,727,250	11	6,778,041	5.72	52.9%	49.4%	59.3%	52.7%	95.3%
Total	372,232	4,854,991,548	43,662	2,482,448,645	5.79	108.1%	98.4%	98.7%	101.2%	100.0%

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

Ship type	Totals for Ems in 2014					2014 as percentage of 2013				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	643	1,740,320	617	7,515,196	9.06	81.0%	105.5%	99.1%	92.6%	95.4%
Chem.+Gas tanker	3,411	12,297,764	1,850	89,995,801	10.72	84.2%	76.3%	95.1%	92.9%	101.5%
Bulk carrier	2,509	35,687,082	656	88,382,208	9.57	77.6%	71.7%	109.8%	122.2%	97.7%
Container ship	1,861	6,013,850	139	8,523,587	10.71	178.4%	197.1%	71.4%	75.3%	95.2%
General Dry Cargo	59,988	202,541,133	7,249	265,471,125	10.14	93.2%	87.9%	84.0%	87.1%	100.8%
RoRo Cargo / Vehicle	12,810	470,649,109	7,232	1,668,789,773	12.58	106.6%	114.6%	89.1%	113.7%	98.9%
Reefer	1,525	6,091,660	170	7,126,062	11.17	112.7%	135.2%	126.6%	139.3%	96.5%
Passenger	4,469	43,015,606	2,882	61,441,846	11.92	109.0%	101.8%	111.2%	100.3%	106.6%
Miscellaneous	35,797	114,819,694	10,589	240,846,658	7.12	106.0%	146.7%	94.1%	82.1%	89.8%
Tug/Supply	99,950	77,873,800	7,294	61,195,001	9.15	91.4%	98.4%	79.7%	99.0%	100.3%
Non Merchant	99	24,654	37	43,540	6.25	192.2%	131.7%	124.5%	69.9%	110.3%
Total	223,063	970,754,671	38,716	2,499,330,796	11.14	95.3%	106.0%	89.5%	104.9%	99.9%

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 2014					2014 as percentage of 2013				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	119,182	48,814,415	14,643	67,564,661	10.67	91.7%	98.6%	87.4%	91.3%	99.8%
1,600-3,000	52,943	125,191,576	10,193	241,329,459	10.45	107.3%	110.9%	89.6%	93.8%	99.5%
3,000-5,000	21,646	88,128,936	4,587	160,002,888	8.67	84.3%	85.0%	85.8%	81.5%	99.9%
5,000-10,000	11,558	74,137,527	5,163	380,538,641	10.08	89.0%	91.3%	82.7%	77.2%	90.9%
10,000-30,000	8,956	171,243,357	2,272	511,282,713	11.54	106.4%	112.7%	114.1%	134.0%	101.3%
30,000-60,000	7,578	375,574,527	1,566	910,909,951	12.03	120.3%	120.2%	122.1%	120.1%	99.6%
60,000-100,000	1,065	65,039,300	284	220,199,001	12.58	84.6%	84.1%	103.0%	105.0%	102.7%
>100,000	135	22,625,033	8	7,503,483	5.86	73.0%	84.1%	54.0%	56.1%	90.1%
Total	223,063	970,754,671	38,716	2,499,330,796	11.14	95.3%	106.0%	89.5%	104.9%	99.9%

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

Ship type	Totals for Den Helder in 2014					2014 as percentage of 2013				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	2,703	47,543,096	16	1,555,657	5.84	253.0%	256.0%	67.3%	75.1%	102.4%
Chem.+Gas tanker	416	3,212,938	27	707,894	7.73	359.5%	418.9%	131.5%	168.4%	97.3%
General Dry Cargo	2,146	6,526,495	74	1,813,787	7.15	157.1%	214.8%	54.3%	56.9%	84.7%
RoRo Cargo / Vehicle	0	0	3	57,374	9.97	0.0%	0.0%	--	--	--
Passenger	5,326	63,048,004	2,777	330,354,492	9.01	102.4%	95.1%	97.7%	98.5%	100.3%
Miscellaneous	45,417	263,395,180	1,533	16,422,606	5.35	97.7%	116.9%	88.7%	84.3%	106.5%
Tug/Supply	112,474	174,028,248	4,513	50,071,692	6.14	102.2%	119.5%	93.2%	104.0%	99.0%
Non Merchant	867	549,671	36	178,641	8.27	64.9%	98.5%	30.9%	67.7%	153.4%
Total	169,348	558,303,632	8,980	401,162,145	8.27	102.3%	121.2%	92.4%	98.1%	100.7%

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 2014					2014 as percentage of 2013				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	81,046	36,905,708	2,580	7,941,907	6.52	84.1%	88.8%	77.8%	88.1%	109.0%
1,600-3,000	59,875	139,653,494	3,239	45,346,570	6.01	123.4%	123.3%	104.2%	103.7%	98.4%
3,000-5,000	10,872	44,521,611	283	7,398,846	6.65	203.8%	233.1%	85.7%	104.4%	111.2%
5,000-10,000	1,105	7,758,942	30	1,457,651	6.58	96.7%	90.9%	67.4%	70.4%	98.3%
10,000-30,000	16,450	329,463,877	2,846	338,994,081	8.82	115.9%	118.7%	97.6%	97.8%	100.7%
60,000-100,000	0	0	0	23,090	8.50	0.0%	0.0%	--	--	--
Total	169,348	558,303,632	8,980	401,162,145	8.27	102.3%	121.2%	92.4%	98.1%	100.7%

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

Ship type	Totals for Harlingen in 2014					2014 as percentage of 2013				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.hours	Average speed	Hours	GT.Hours	Hours	GT.nm	Average speed
Oil tanker	0	2,713	0	0	--	0.0%	0.0%	0.0%	0.0%	--
Chem.+Gas tanker	6,214	15,488,890	359	5,802,504	7.95	123.7%	120.6%	126.4%	114.2%	106.5%
Bulk carrier	47	240,156	9	444,463	8.69	--	--	--	--	--
Container ship	343	890,618	9	237,287	10.24	28.2%	20.7%	85.8%	115.4%	137.3%
General Dry Cargo	19,067	68,536,202	1,334	31,213,740	8.57	86.4%	88.3%	95.2%	93.5%	99.9%
RoRo Cargo / Vehicle	3,669	6,396,007	1,471	22,938,606	8.94	73.1%	67.2%	69.6%	68.4%	99.3%
Reefer	2,964	13,861,148	264	9,998,631	9.02	84.4%	90.2%	96.9%	94.2%	100.4%
Passenger	11,753	23,753,600	4,826	160,691,676	12.33	95.7%	100.4%	93.8%	96.8%	99.6%
Miscellaneous	31,118	22,318,467	2,675	30,574,487	8.52	107.8%	97.4%	57.9%	79.0%	119.8%
Tug/Supply	30,084	24,366,938	1,136	6,865,497	10.45	140.9%	167.5%	119.6%	176.7%	126.5%
Non Merchant	5,359	2,029,139	314	930,897	7.87	142.9%	44.6%	168.5%	54.1%	91.3%
Total	110,618	177,883,879	12,396	269,697,788	10.57	105.7%	92.5%	82.6%	91.8%	104.7%

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

Ship size in GT	Totals for Harlingen in 2014					2014 as percentage of 2013				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.hours	Average speed	Hours	GT.Hours	Hours	GT.nm	Average speed
100-1,600	67,707	31,643,269	5,455	46,839,610	12.45	123.4%	128.7%	75.5%	90.5%	120.0%
1,600-3,000	21,270	50,591,642	2,806	49,109,789	8.70	82.2%	84.9%	83.2%	85.1%	99.6%
3,000-5,000	13,928	52,241,596	3,641	147,069,686	11.22	86.5%	83.2%	97.7%	98.2%	100.9%
5,000-10,000	7,713	43,401,395	494	26,640,136	8.88	100.8%	98.3%	72.4%	78.1%	103.9%
10,000-30,000	0	1,975	0	8,079	4.61	0.2%	0.2%	2.4%	1.5%	54.0%
30,000-60,000	0	1,288	0	30,489	14.50	--	--	--	--	--
60,000-100,000	0	2,713	0	0	--	--	--	--	--	--
Total	110,618	177,883,879	12,396	269,697,788	10.57	105.7%	92.5%	82.6%	91.8%	104.7%

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, 2014 is compared to 2013. 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 increases. For ship at anchor, the average number of hours decreased only for oil and chemical/gas tankers. The number of hours and GT.nm of moving ships have increased for all types of ships. The average speed decreased by 2%.

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 2014					2014 as percentage of 2013				
	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	119,796	5,976,932,154	84,342	42,249,933,322	10.63	88.2%	90.8%	103.1%	105.8%	99.0%
Chem.+Gas tanker	298,776	3,321,175,040	265,474	31,222,576,545	11.55	96.2%	88.7%	108.7%	108.3%	100.0%
Bulk carrier	86,604	4,473,424,098	105,467	39,090,371,876	10.88	127.5%	125.4%	118.7%	116.1%	98.1%
Container ship	59,339	1,631,796,674	175,303	112,585,623,403	14.05	148.4%	132.5%	104.4%	107.9%	97.5%
General Dry Cargo	84,420	390,143,658	414,987	17,764,860,769	10.68	104.8%	100.5%	106.2%	105.7%	98.9%
RoRo Cargo / Vehicle	7,010	284,467,032	117,479	55,152,629,707	15.28	105.4%	118.4%	103.7%	106.0%	99.6%
Reefer	4,913	43,778,213	15,982	1,894,263,694	14.99	127.8%	132.6%	108.8%	104.0%	97.8%
Passenger	6,676	15,417,186	25,841	19,232,089,414	16.94	116.7%	106.6%	104.2%	100.0%	98.9%
Miscellaneous	89,417	487,469,376	125,172	3,925,301,288	7.51	140.8%	214.5%	126.8%	148.9%	103.2%
Tug/Supply	110,303	156,763,699	185,911	1,703,887,904	7.01	122.4%	105.8%	120.0%	118.8%	99.2%
Non Merchant	9,093	1,275,182	5,149	33,052,487	10.20	110.9%	126.8%	125.3%	178.2%	106.6%
Total	876,348	16,782,642,311	1,521,107	324,854,590,412	12.69	107.8%	103.8%	109.9%	108.0%	98.1%

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 2014					2014 as percentage of 2013				
	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	117,078	64,537,529	226,553	1,038,274,389	6.55	118.0%	118.4%	114.7%	106.7%	95.6%
1,600-3,000	128,946	311,824,048	348,138	7,483,173,782	8.86	118.5%	118.1%	106.9%	106.9%	99.2%
3,000-5,000	123,076	484,540,904	200,776	8,173,883,465	10.23	107.1%	107.7%	119.8%	116.3%	96.1%
5,000-10,000	134,133	977,370,612	197,505	17,051,570,022	12.03	110.3%	106.8%	103.7%	100.9%	98.3%
10,000-30,000	197,552	3,808,866,250	282,626	68,606,732,792	12.63	96.2%	93.7%	110.7%	108.9%	98.1%
30,000-60,000	99,120	4,240,315,256	153,322	90,493,617,975	13.50	114.7%	114.3%	106.2%	104.6%	98.8%
60,000-100,000	62,375	4,862,990,794	85,462	81,925,339,769	12.70	97.4%	99.3%	103.0%	100.2%	98.0%
>100,000	14,069	2,032,196,918	26,724	50,081,998,216	13.23	112.7%	111.7%	134.8%	133.2%	96.6%
Total	876,348	16,782,642,311	1,521,107	324,854,590,412	12.69	107.8%	103.8%	109.9%	108.0%	98.1%

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 5.79 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 2014 compared with 2013 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 average GT of the ships is given in Table 6-17. The average GT of a ship in Rotterdam is almost 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 a decrease in four out of seven areas. Only for Den Helder an increase of nearly 17% is seen. For the Ems and the NCS + 12-mile zone the average GT did not really change.

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 2014				In 2014 as percentage of 2013			
	Average # ships			Speed	Average # ships			Speed
	Not moving	Moving	Total	Knots	Not moving	Moving	Total	Knots
Western Scheldt[3]	43.87	13.05	56.91	11.24	135.0%	109.5%	128.1%	100.0%
Rotterdam	91.29	17.63	108.92	7.68	129.0%	105.9%	124.6%	99.7%
Amsterdam	42.49	4.98	47.48	5.79	108.4%	99.0%	107.4%	100.0%
Ems	43.89	4.90	48.79	10.92	164.7%	99.4%	154.5%	98.0%
Den Helder	19.33	1.03	20.36	8.27	102.5%	92.7%	102.0%	100.7%
Harlingen	12.63	1.42	14.04	10.57	106.0%	82.8%	103.1%	104.7%
NCS + 12-mile zone	94.51	172.97	267.48	12.69	102.1%	109.8%	107.0%	98.1%

[3] Only part based on AIS, from Terneuzen to the west.

Table 6-17 Average GT in distinguished areas

Area	In 2014			In 2014 as percentage of 2013		
	Average GT of ships			Average GT of ships		
	Not moving	Moving	Total	Not moving	Moving	Total
Western Scheldt[4]	6,756	12,662	8,110	103.8%	95.2%	97.4%
Rotterdam	25,275	11,244	23,003	96.2%	98.5%	98.1%
Amsterdam	13,043	9,821	12,705	91.0%	102.4%	92.1%
Ems	3,949	5,410	4,096	101.0%	109.4%	100.6%
Den Helder	3,297	5,405	3,403	118.5%	105.3%	116.9%
Harlingen	1,608	2,059	1,653	87.5%	106.1%	89.3%
NCS + 12-mile zone	20,215	16,861	18,046	101.6%	100.4%	100.6%

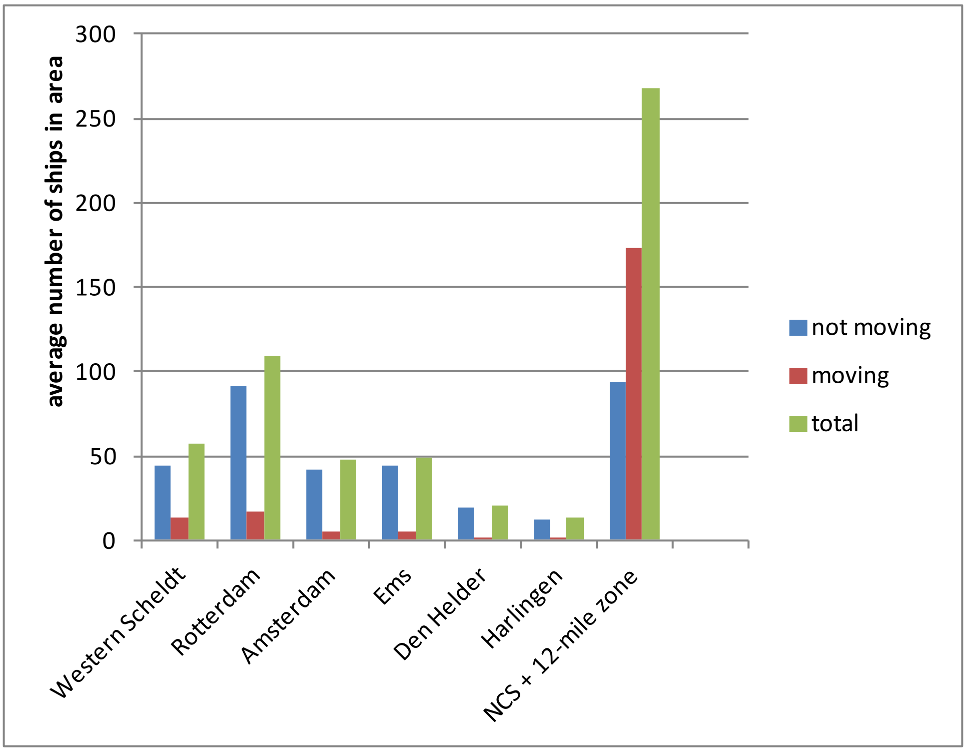

Figure 6-1 Average number of ships in areas considered

[4] Only part based on AIS, from Terneuzen to the west.

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 2014 for the Dutch port areas and the Netherlands sea area. To indicate the change in emissions, all values for 2014 are compared with the values of 2013. 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 2014 NO_x emissions. Also the change in this spatial distribution compared to 2013 is presented.

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 areas. Table 7-2 contains the same emissions expressed as a percentage of the corresponding emissions in 2013. Note that values for at berth include all vessels with zero speed, so also the vessels at anchor.

Table 7-2 shows an increase in emission between 2013 and 2014 for all substances in the port areas Western Scheldt and Rotterdam. In the port area of Harlingen almost all emissions decreased, for the Ems and Den Helder the berthed emissions increased and the sailing emissions mostly decreased. The increase in percentage of the methane emission in the Western Scheldt is enormous, but this is due to the very low absolute numbers.

When looking at the sailing emissions of VOC and CO, the increase is higher (or the decrease lower) than for other substances. This can be explained by the error in the implementation of formula 2 of the Appendix A of [1], as mentioned in Section 3.2. This error caused the %MCR used for single engine ships to be overestimated. For VOC and CO the correction factor decreases with an increasing %MCR used, which makes that the calculated emissions were too low. For the other substances this effect is less clear, since the correction factor varies for different types of engines and does not only increase or decrease with an increasing %MCR used. The reported differences with 2013 can therefore be real differences, or also due to the error in the implementation. The influence of the second error described in Section 3.2 is negligible, as there are very few multi engine ships, and the error only influences part of those few ships.

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 2014 based on AIS data

Substance	Source	Western Scheldt[5]	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Total
1011 Methane	Berthed	-	-	-	-	-	-	-
	Sailing	0.6	0.1	-	-	-	-	0.7
	Total	0.6	0.1	-	-	-	-	0.7
1237 VOC	Berthed	39	256	56	14	13	4	381
	Sailing	248	154	29	25	3	7	465
	Total	286	410	85	38	16	10	847
4001 SO_2	Berthed	71	527	109	31	30	7	775
	Sailing	2,121	1,165	174	173	23	30	3,685
	Total	2,192	1,691	283	204	53	37	4,460
4013 NO_x	Berthed	894	5,695	1,343	364	359	94	8,749
	Sailing	8,249	4,116	673	712	89	188	14,027
	Total	9,143	9,810	2,016	1,076	448	282	22,775
4031 CO	Berthed	192	1,289	281	77	78	18	1,936
	Sailing	1,779	1,175	211	154	26	34	3,379
	Total	1,971	2,465	493	230	104	52	5,315
4032 CO_2	Berthed	82,560	611,898	115,538	24,804	25,793	5,596	866,188
	Sailing	355,801	203,197	32,933	34,118	5,295	8,785	640,128
	Total	438,360	815,095	148,470	58,921	31,089	14,381	1,506,316
6601 Aerosols MDO	Berthed	19	129	28	7	7	2	193
	Sailing	17	17	5	7	1	5	52
	Total	36	146	33	14	8	7	244
6602 Aerosols HFO	Berthed	-	-	-	-	-	-	-
	Sailing	361	190	26	24	2	1	606
	Total	361	190	26	24	2	1	606
6598 Aerosols MDO+HFO	Berthed	19	129	28	7	7	2	193
	Sailing	378	207	31	31	4	6	657
	Total	397	337	60	38	10	8	850

[5] Complete Dutch part of the Western Scheldt

Table 7-2 Emissions in each port area for 2014 as percentage of the emissions in 2013

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Total
1011 Methane	Berthed	-	-	-	-	-	-	-
	Sailing	751.6%	208.8%	-	-	-	-	543.5%
	Total	751.6%	208.8%	-	-	-	-	543.5%
1237 VOC	Berthed	145.4%	125.0%	99.4%	108.1%	134.8%	99.8%	121.5%
	Sailing	113.8%	108.1%	104.5%	94.8%	93.8%	92.4%	109.6%
	Total	117.2%	118.1%	101.1%	99.2%	123.9%	94.9%	114.6%
4001 SO_2	Berthed	145.8%	125.8%	100.8%	106.9%	147.7%	99.2%	122.6%
	Sailing	105.7%	103.2%	97.2%	83.5%	98.6%	89.7%	103.0%
	Total	106.7%	109.3%	98.5%	86.4%	121.3%	91.3%	105.9%
4013 NO_x	Berthed	146.1%	133.7%	104.2%	114.0%	135.6%	105.0%	128.0%
	Sailing	106.0%	103.2%	97.5%	89.9%	96.9%	91.8%	103.5%
	Total	108.9%	118.9%	101.8%	96.8%	125.7%	95.8%	111.7%
4031 CO	Berthed	144.6%	127.2%	99.9%	108.4%	140.5%	100.4%	123.1%
	Sailing	119.4%	110.8%	107.5%	94.6%	96.1%	91.5%	113.6%
	Total	121.4%	118.8%	103.0%	98.8%	126.0%	94.4%	116.9%
4032 CO_2	Berthed	152.0%	122.8%	97.1%	106.4%	153.2%	95.0%	120.7%
	Sailing	105.5%	103.6%	97.8%	85.2%	98.3%	90.6%	102.9%
	Total	112.0%	117.4%	97.3%	93.0%	139.9%	92.3%	112.4%
6601 Aerosols MDO	Berthed	145.2%	124.0%	99.3%	110.9%	140.9%	99.4%	121.0%
	Sailing	100.8%	106.7%	99.7%	94.8%	96.1%	92.7%	100.7%
	Total	120.3%	121.8%	99.4%	102.4%	129.9%	94.5%	116.0%
6602 Aerosols HFO	Berthed	-	-	-	-	-	-	-
	Sailing	107.1%	103.6%	97.6%	81.7%	99.4%	84.2%	104.2%
	Total	107.1%	103.6%	97.6%	81.7%	99.4%	84.2%	104.2%
6598 Aerosols MDO+HFO	Berthed	145.2%	124.0%	99.3%	110.9%	140.9%	99.4%	121.0%
	Sailing	106.8%	103.9%	98.0%	84.3%	98.1%	90.9%	103.9%
	Total	108.2%	110.8%	98.6%	88.4%	121.1%	92.8%	107.4%

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 2014 are summarised in Table 7-3. This table also contains a comparison with 2013. The average number of moving ships has increased with almost 10%, where in 2013 the average number of moving ships decreased with about 6%. The number of non-moving ships has also increased by 2%. The increases might at least partly be explained by a better coverage of the AIS. The moving emissions for CO (and VOC) have increased more than for the other substances. This can be explained by an error in the previous implementation of the calculations as explained in Section 7.2.

Table 7-3 Emissions of ships in ton in the Netherlands sea area for 2014 compared with 2013

Nr	Substance	Emission in ton in 2014			Emission in 2014 as percentage of 2013		
		Not moving	Moving	Total	Not moving	Moving	Total
1011	Methane	-	13	13	-	286.4%	286.4%
1237	VOC	77	2,184	2,261	107.4%	112.2%	112.1%
4001	SO_2	719	20,547	21,267	110.2%	105.6%	105.8%
4013	NO_x	2,345	76,648	78,992	110.5%	105.4%	105.5%
4031	CO	488	15,287	15,775	109.1%	118.4%	118.1%
4032	CO_2	141,320	3,423,453	3,564,773	109.2%	105.9%	106.0%
6601	Aerosols MDO	26	133	159	103.7%	109.0%	108.1%
6602	Aerosols HFO	98	3,476	3,574	111.8%	106.3%	106.5%
6598	Aerosols MDO+HFO	124	3,609	3,733	110.0%	106.4%	106.6%
Ships		92.79	94.51	172.97	102.1%	109.8%	107.0%

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 2013 and 2014 and the third one shows the *relative* change in emission between 2013 and 2014. 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 2013 and 2014 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.

Figure 7-2 shows a increase in absolute emissions for some grid cells on the Western Scheldt, and a decrease for very few grid cells. This indicates a better coverage by AIS near Terneuzen than in the previous year.

For the port area of Rotterdam, a decrease is shown at sea, and an increase further inland, both in areas where the absolute emissions are low. The increase further inland might be explained by a better AIS coverage. In the areas with higher emissions, also mainly increases are seen. This increase corresponds with the increase in activity seen in Chapter 6.

The Ems, Harlingen and Den Helder show small absolute changes, but higher relative changes, in almost all grid cells. The changes are both increases and decreases.

On the NCS the effect of the new base stations can be seen. There are two spots with an emission increase compared to 2013, which is caused by improved coverage.

The change of the traffic separation scheme (TSS) on August 1, 2013, can be still be seen, as this was halfway through the previous year. 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.

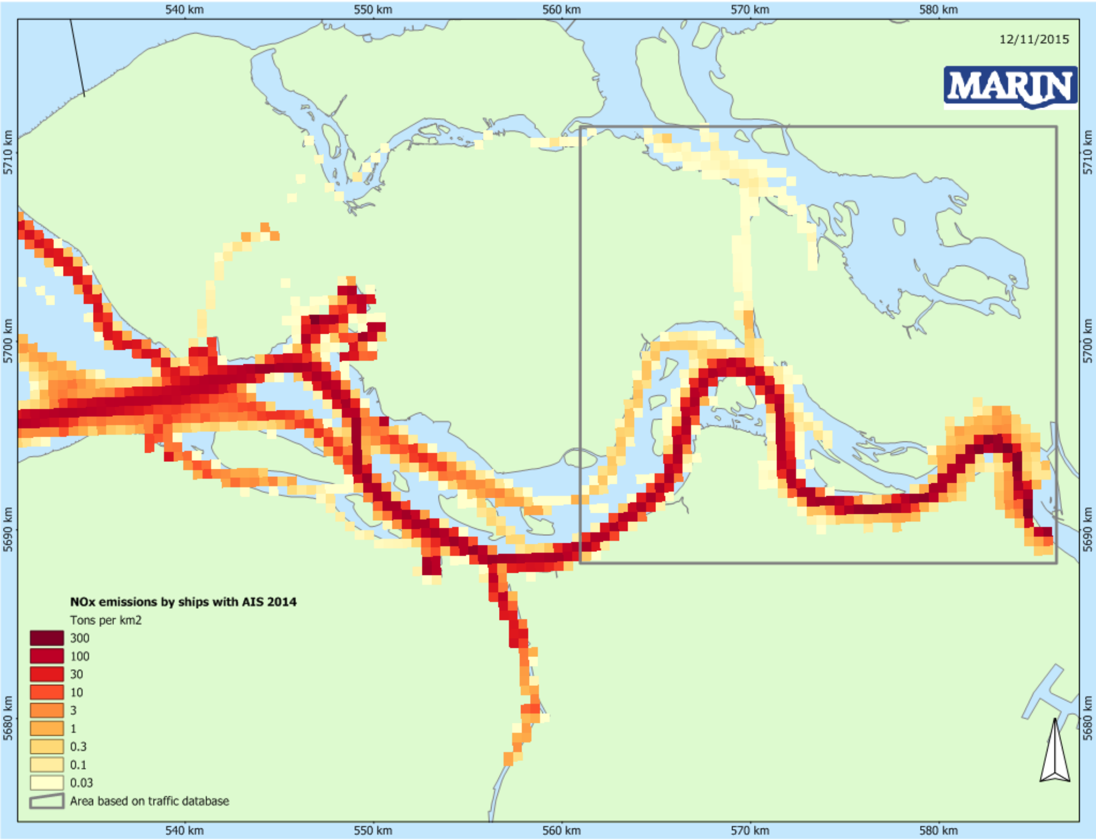

Figure 7-1 **NO_x emission in 2014 in the Dutch part of the Western Scheldt by ships with AIS. For the emissions on the Western Scheldt east of Terneuzen (boxed area) the SAMSON traffic database is used.**

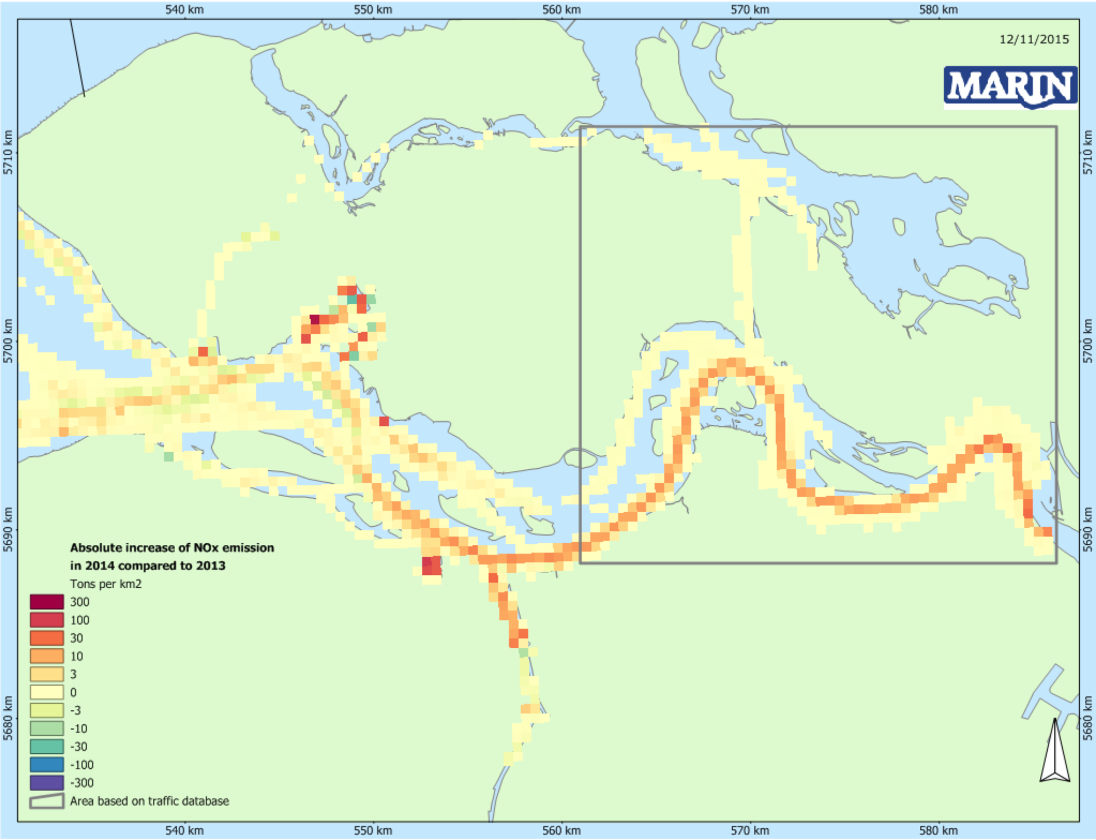

Figure 7-2 **Absolute change in NO_x emission from 2013 to 2014 in the Dutch part of the Western Scheldt by ships with AIS.**

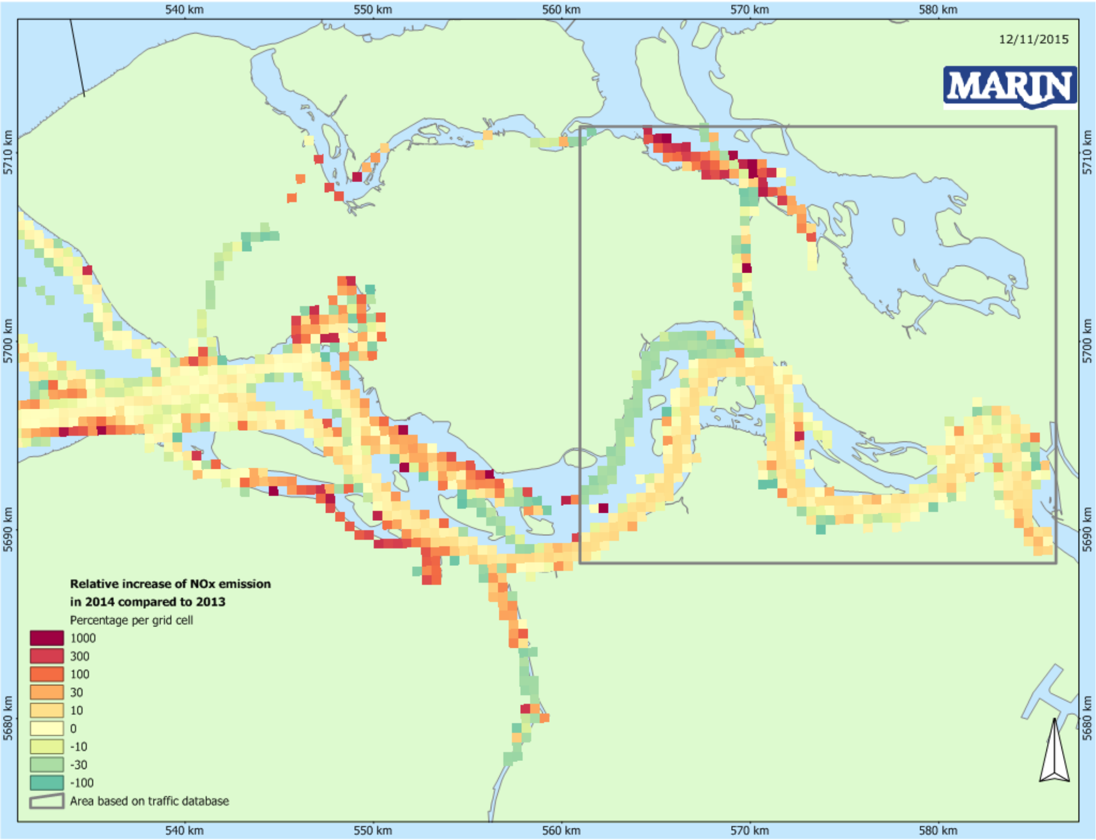

Figure 7-3 **Relative change in NO_x emission from 2013 to 2014 in the Dutch part of the Western Scheldt by ships with AIS.**

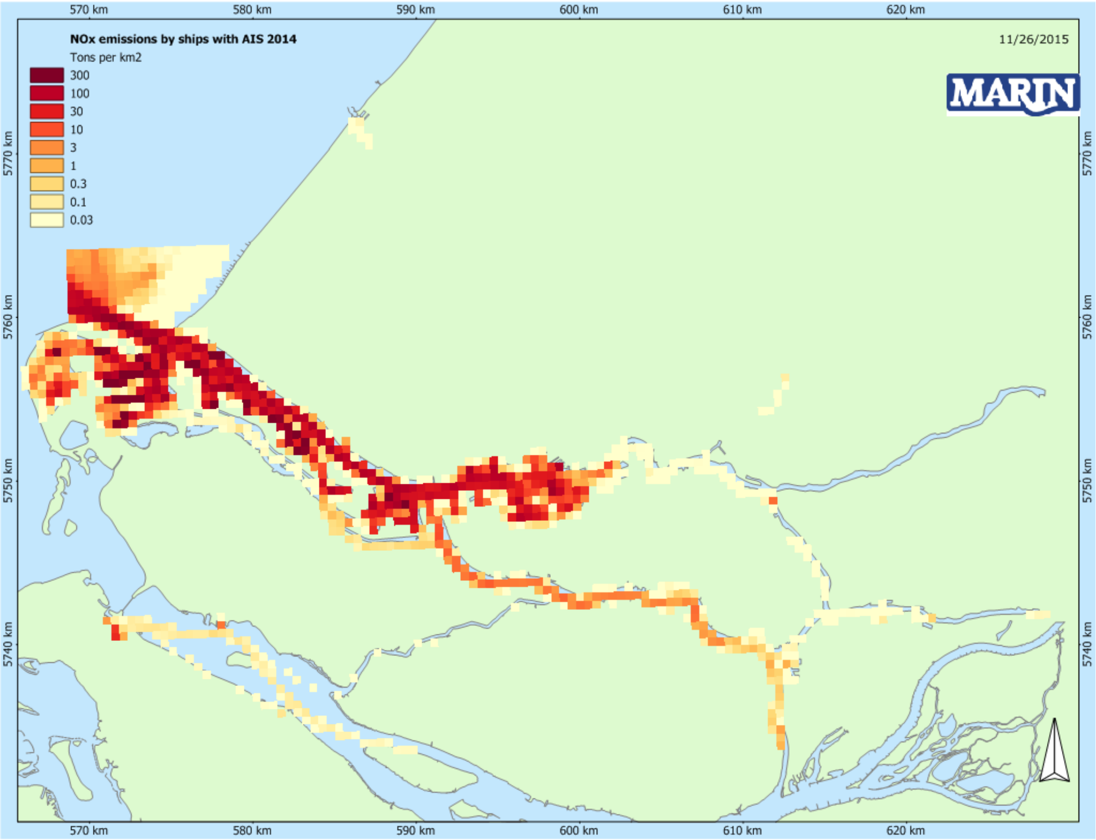

Figure 7-4 **NO_x emission in 2014 in the port area of Rotterdam by ships with AIS.**

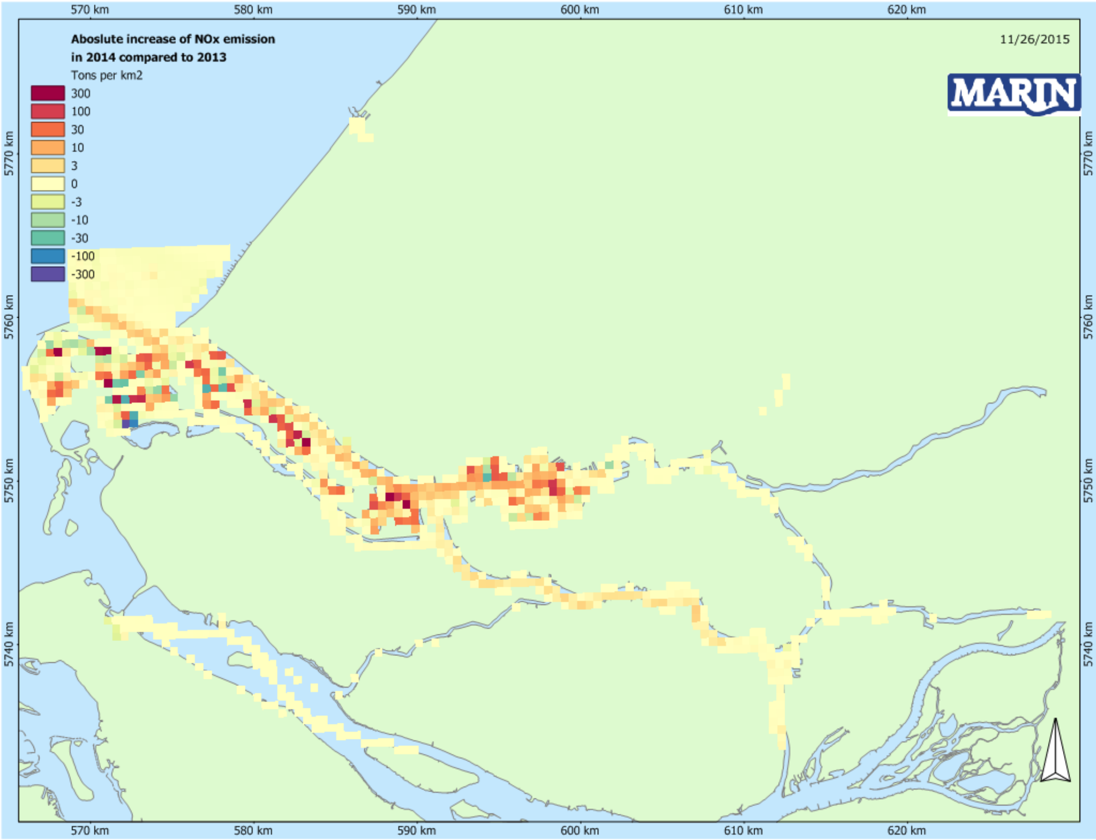

Figure 7-5 **Absolute change in NO_x emission from 2013 to 2014 in the port area of Rotterdam by ships with AIS.**

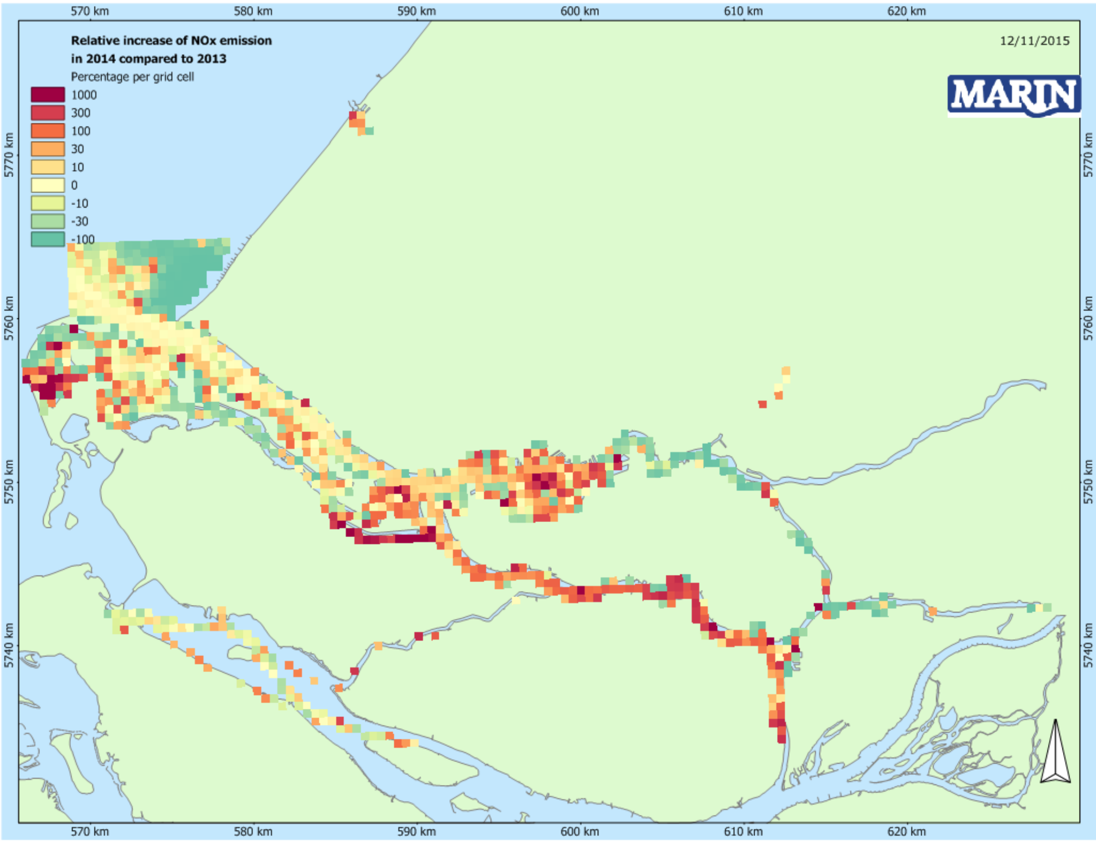

Figure 7-6 **Relative change in NO_x emission from 2013 to 2014 in the port area of Rotterdam by ships with AIS.**

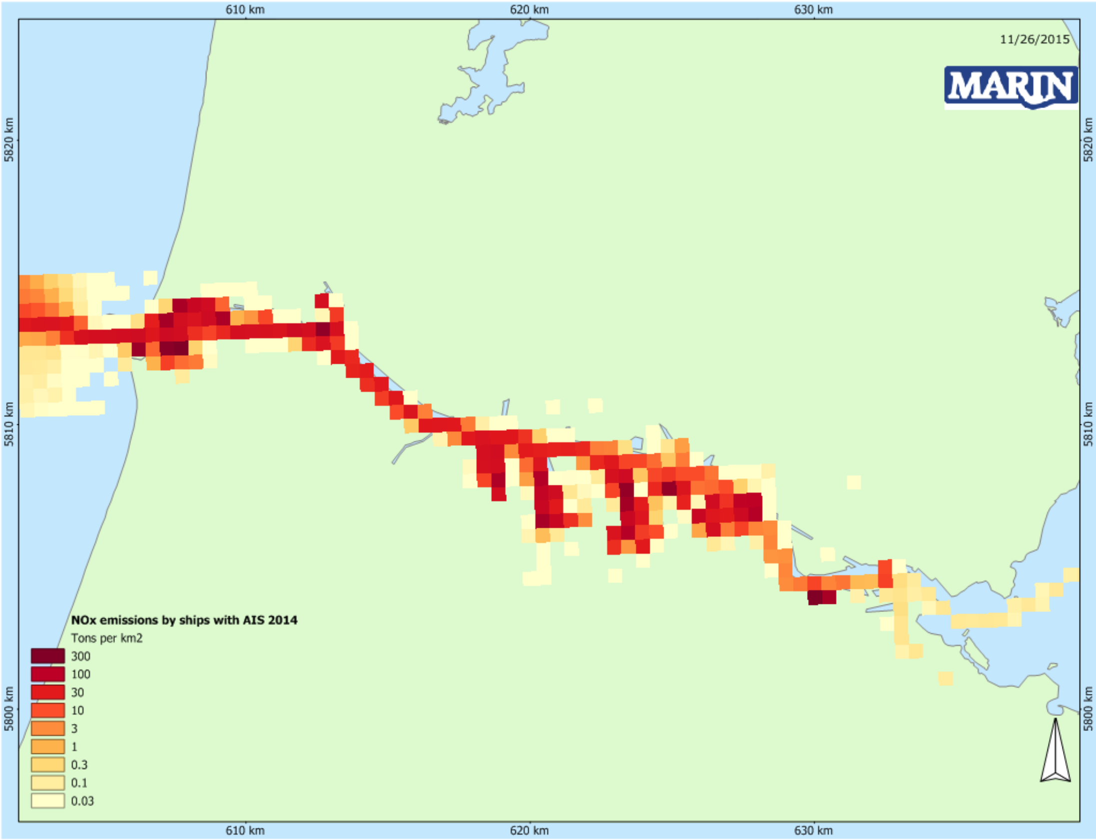

Figure 7-7 NO_x emission in 2014 in the port area of Amsterdam by ships with AIS.

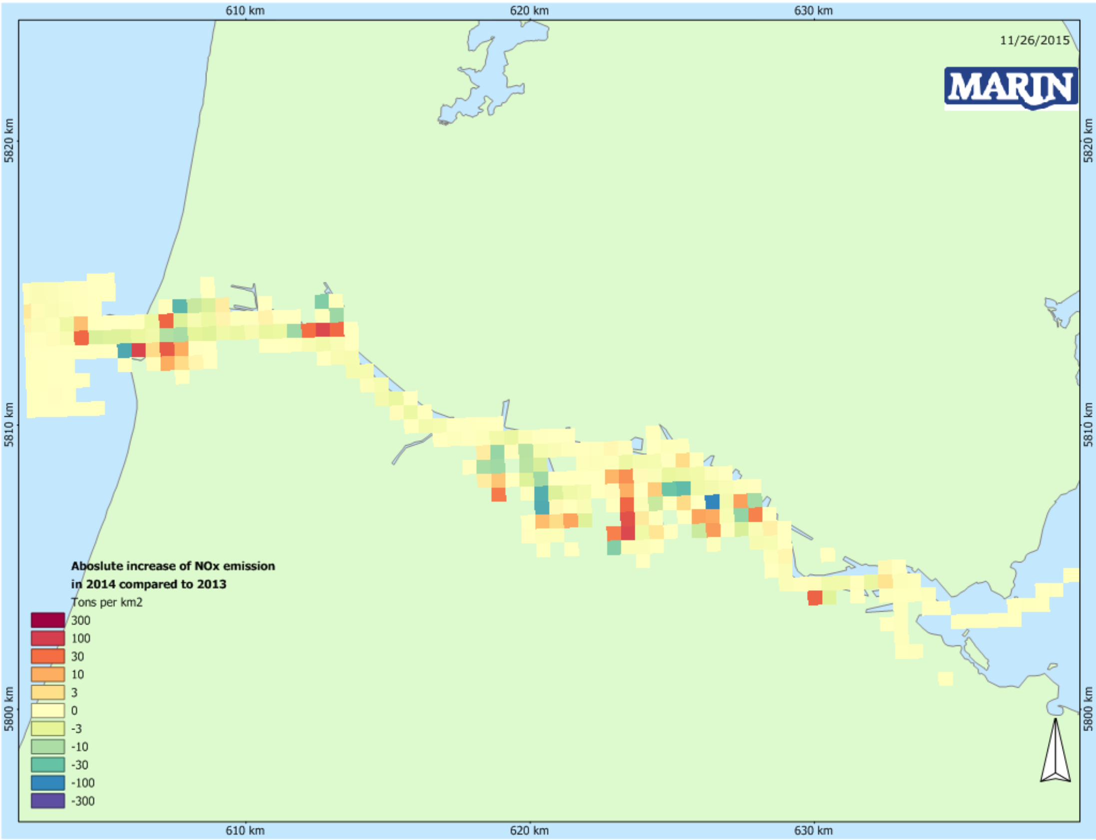

Figure 7-8 Absolute change in NO_x emission from 2013 to 2014 in the port area of Amsterdam by ships with AIS.

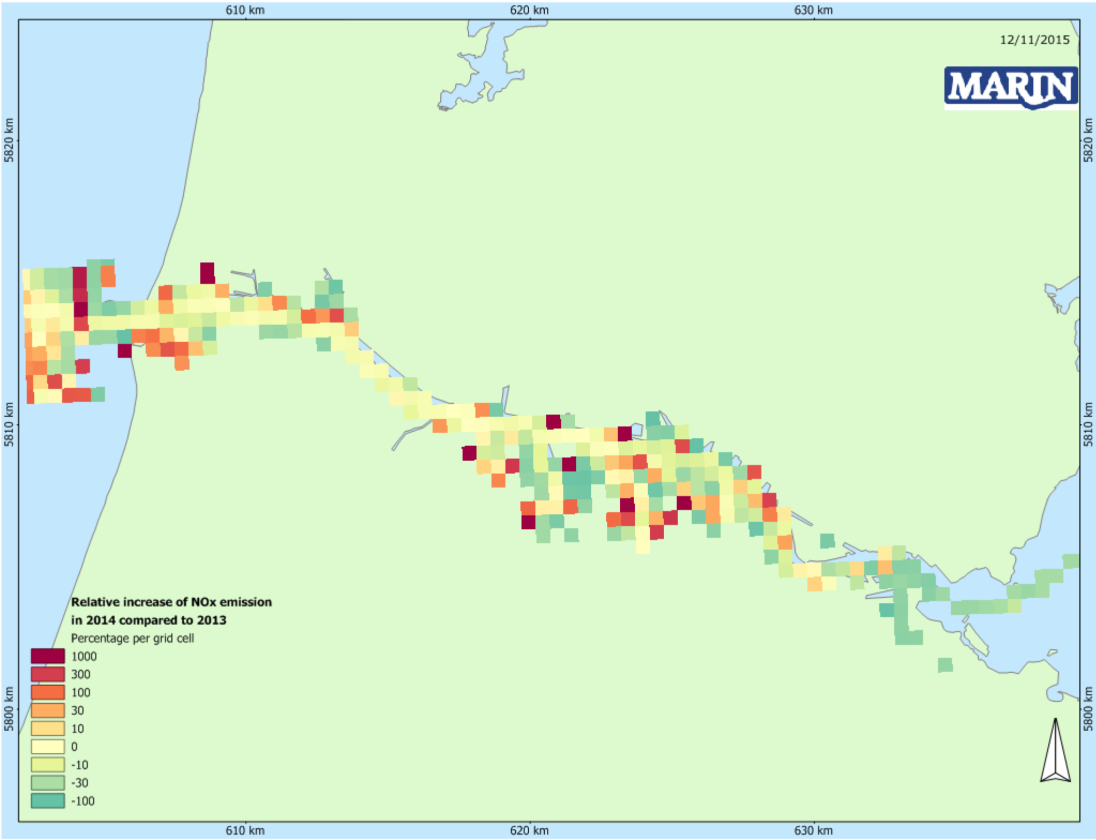

Figure 7-9 **Relative change in NO_x emission from 2013 to 2014 in the port area of Amsterdam by ships with AIS.**

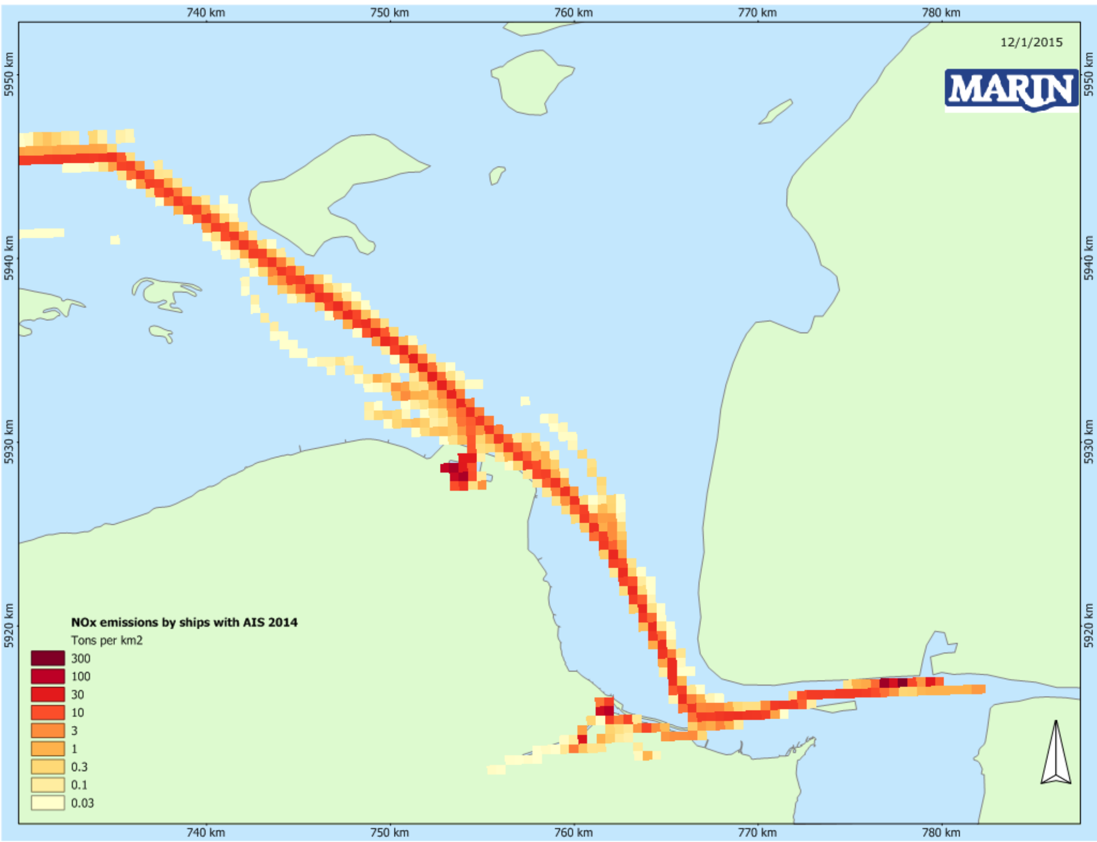

Figure 7-10 **NO_x emission in 2014 in the Ems area by ships with AIS.**

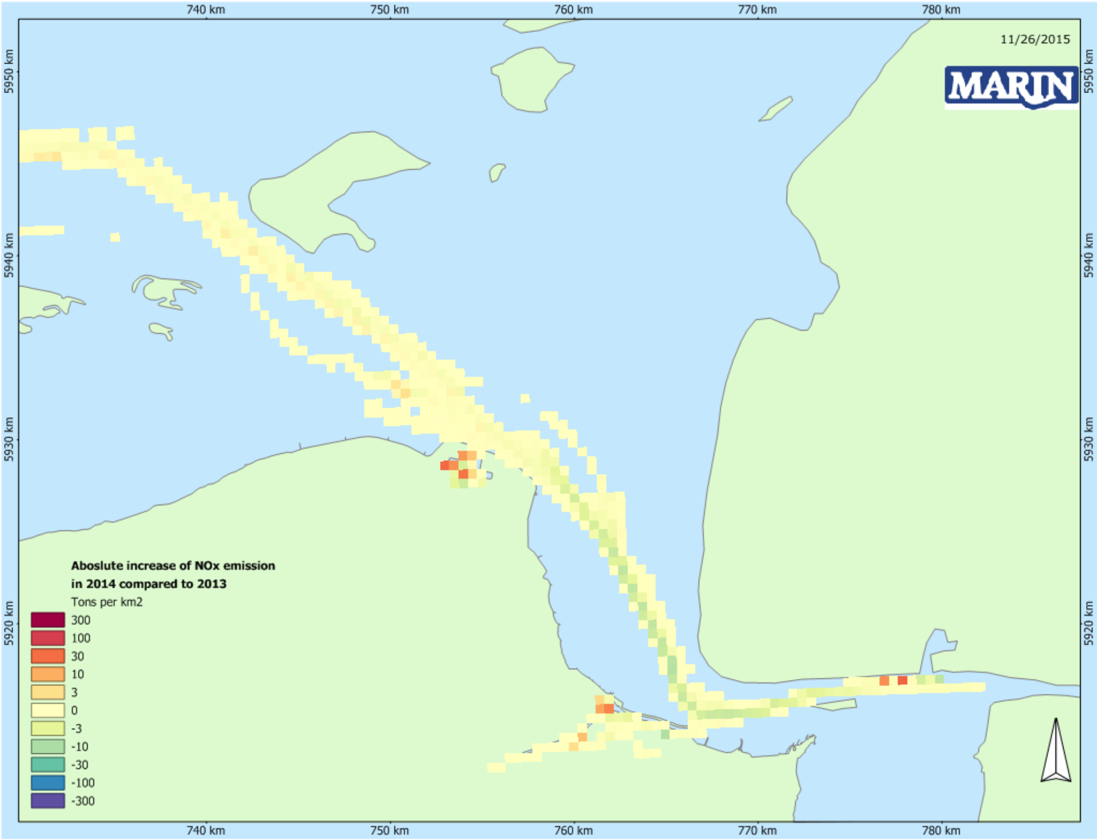

Figure 7-11 **Absolute change in NO_x emission from 2013 to 2014 in the Ems area by ships with AIS.**

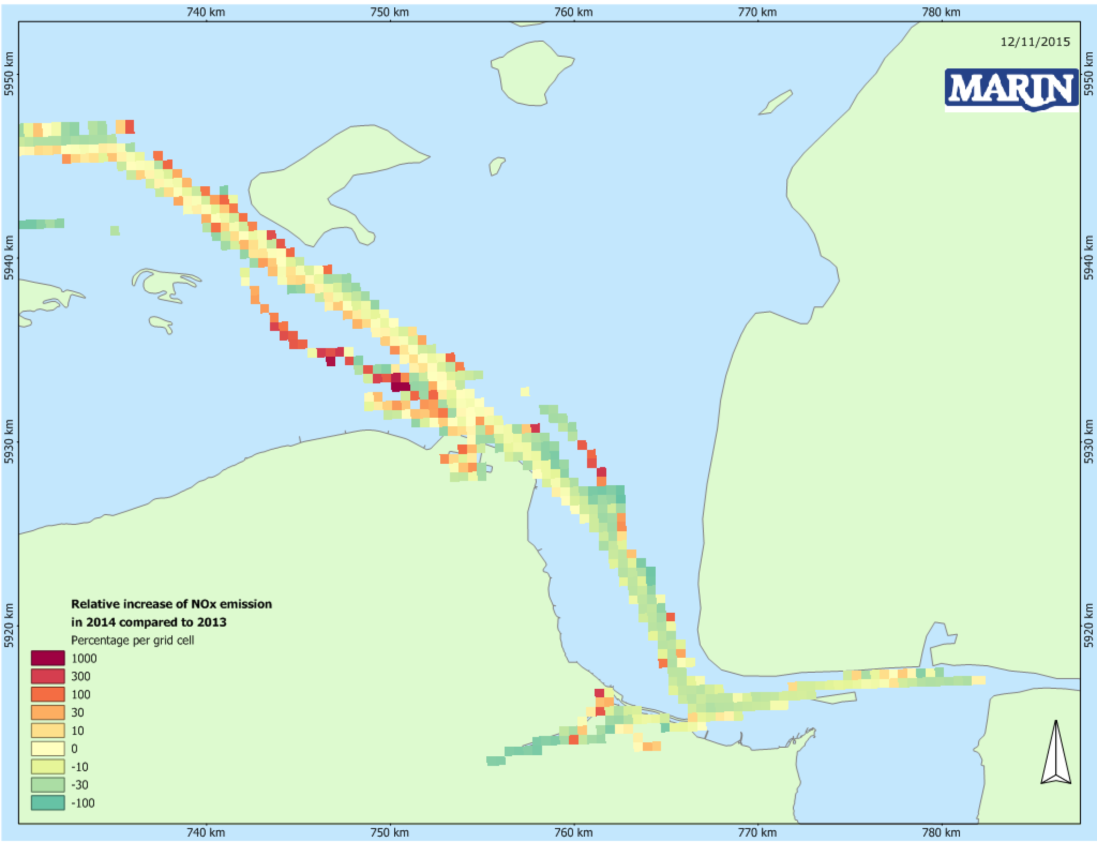

Figure 7-12 **Relative change in NO_x emission from 2013 to 2014 in the Ems area by ships with AIS.**

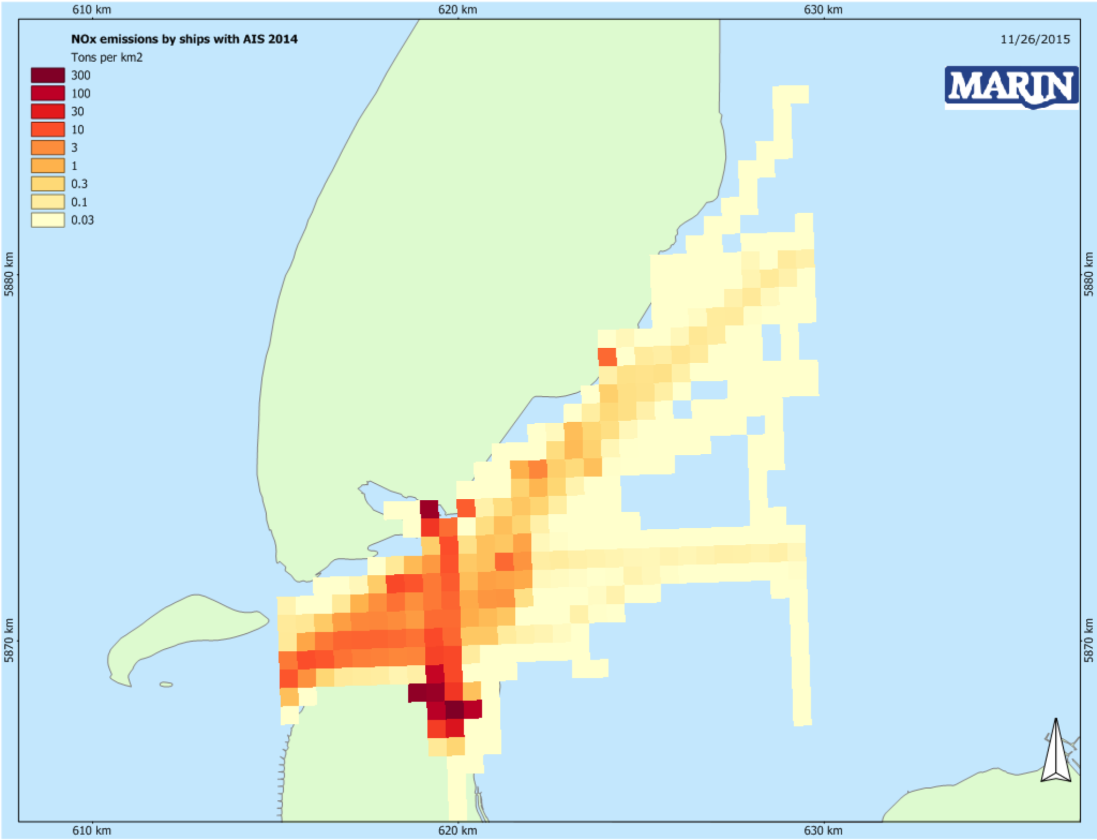

Figure 7-13 NO$_x$ emission in 2014 in the port area of Den Helder by ships with AIS.

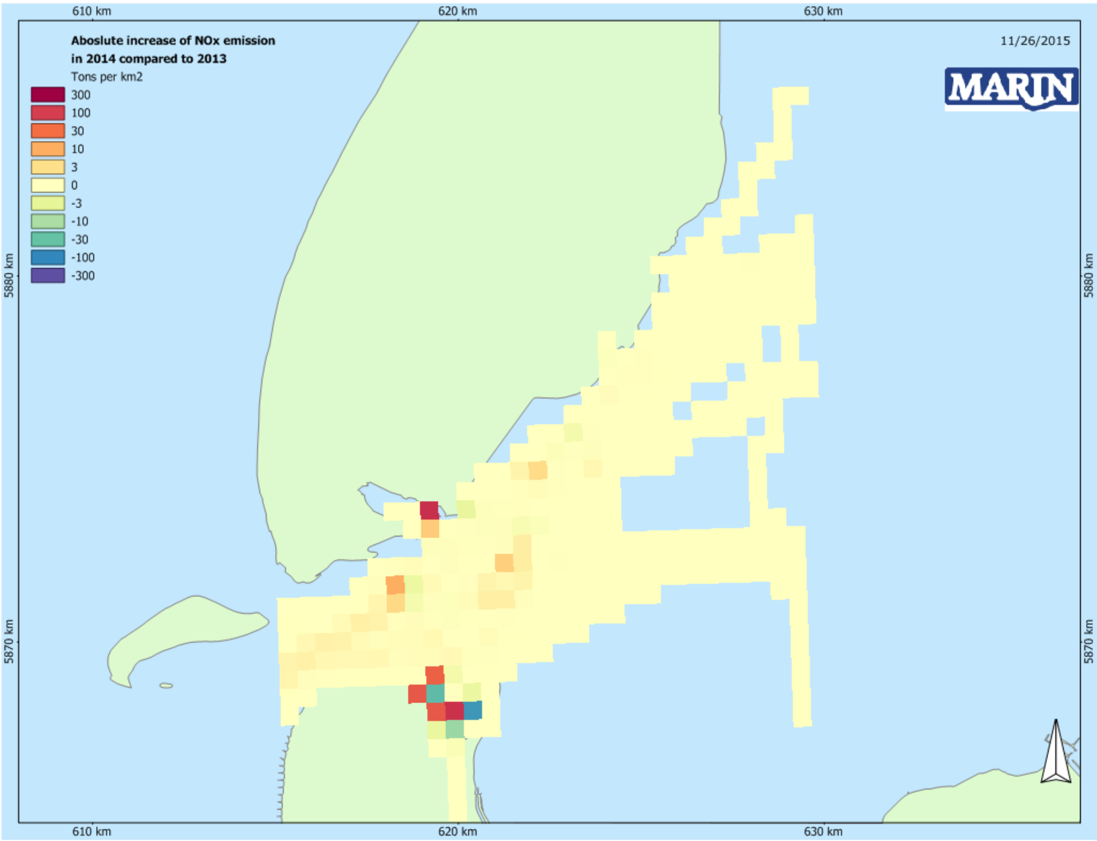

Figure 7-14 Absolute change in NO$_x$ emission from 2013 to 2014 in the port area of Den Helder by ships with AIS.

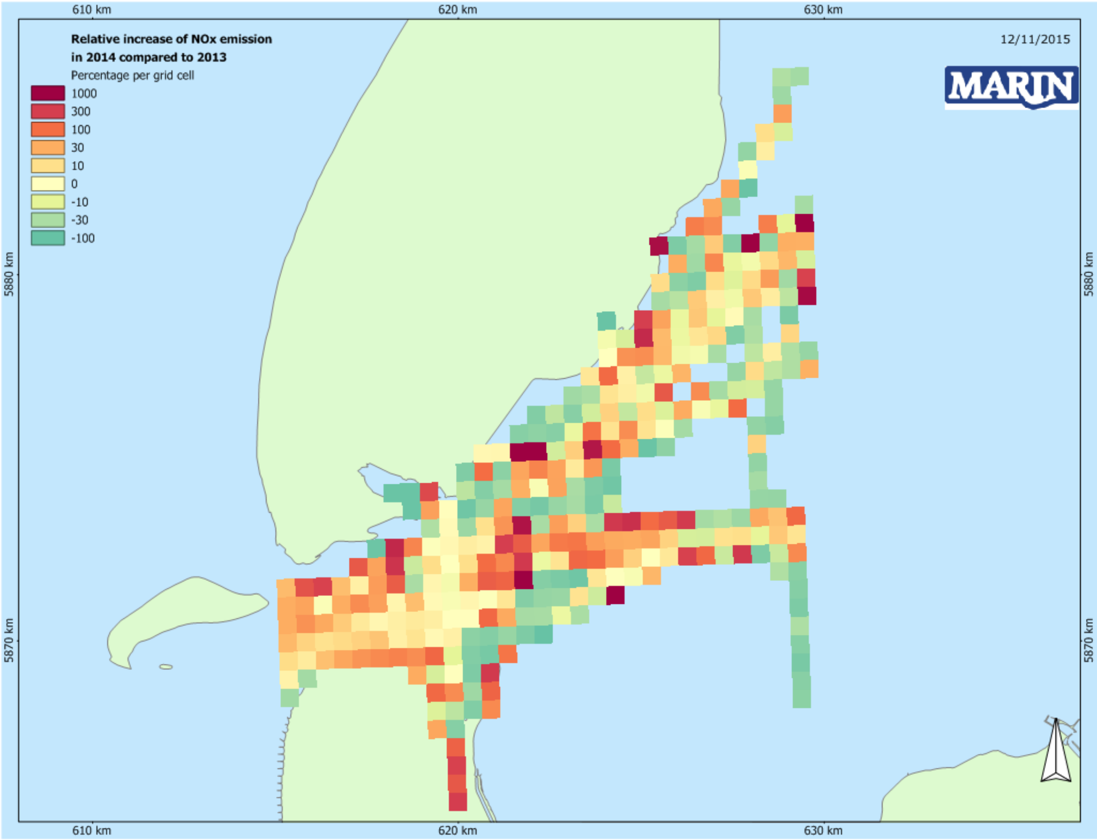

Figure 7-15 **Relative change in NO_x emission from 2013 to 2014 in the port area of Den Helder by ships with AIS.**

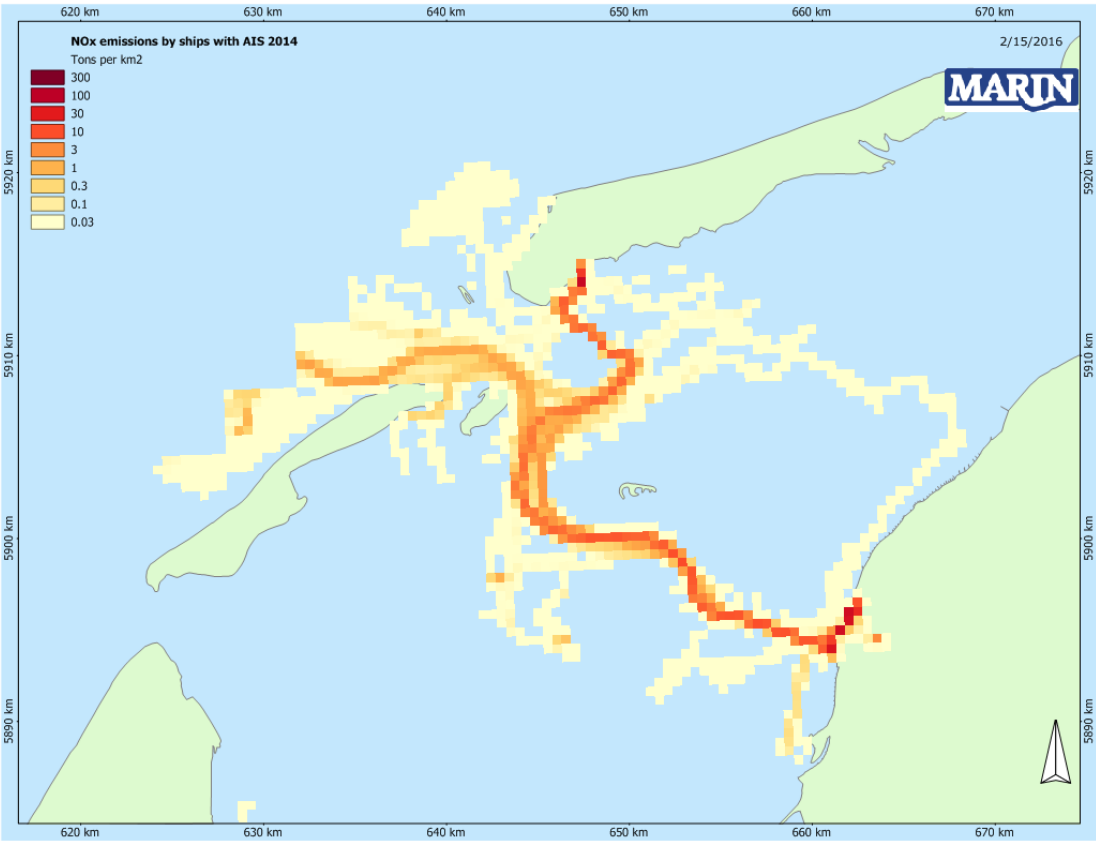

Figure 7-16 **NO_x emission in 2014 in the port area of Harlingen by ships with AIS.**

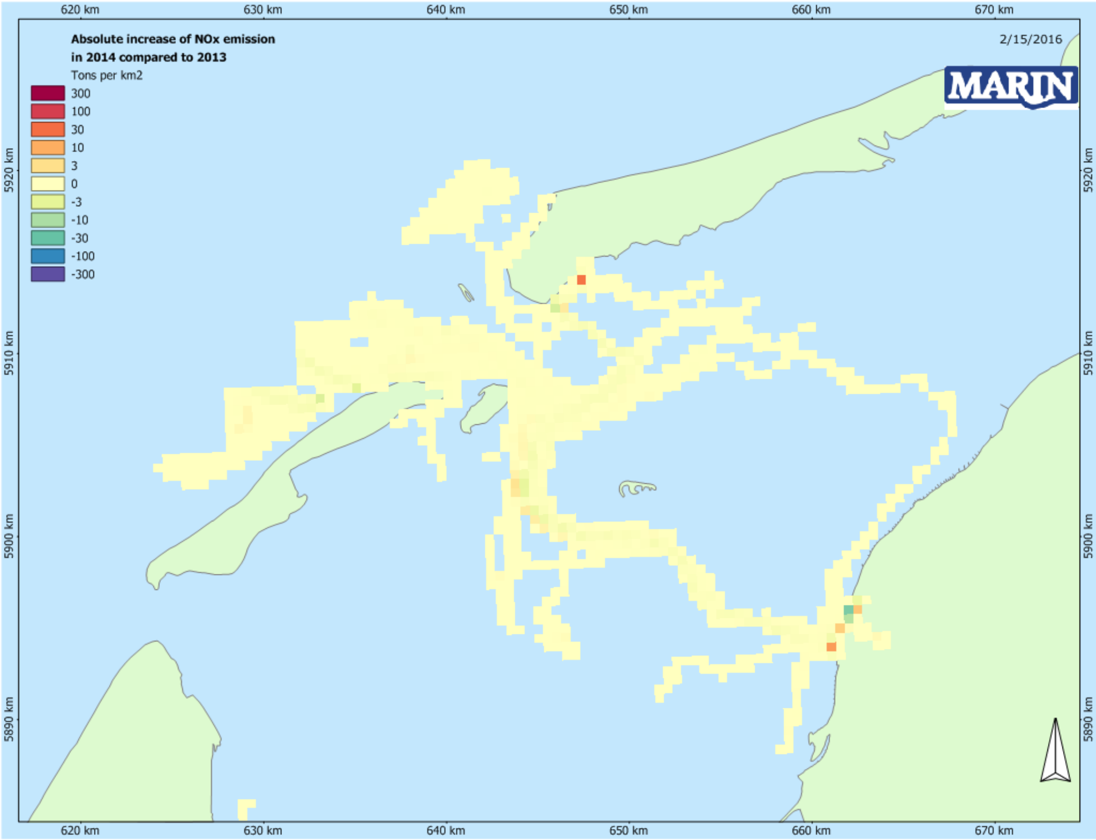

Figure 7-17 **Absolute change in NO_x emission from 2013 to 2014 in the port area of Harlingen by ships with AIS.**

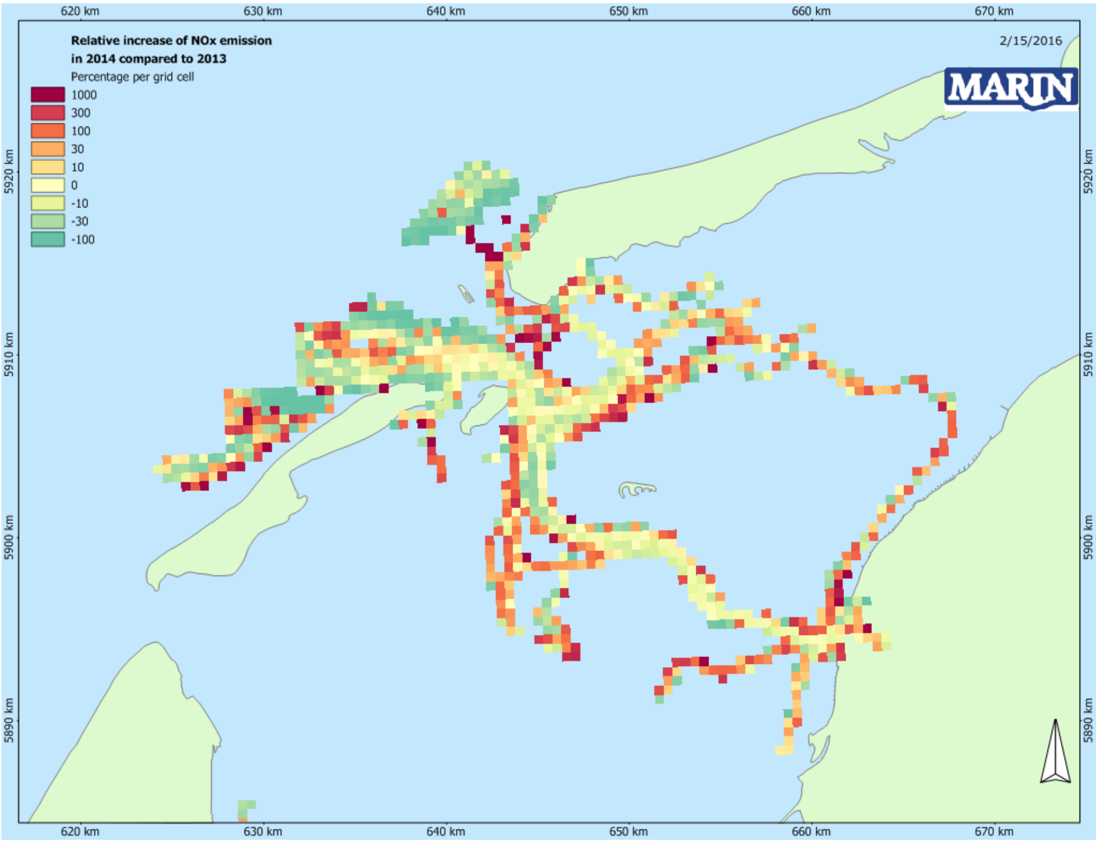

Figure 7-18 **Relative change in NO_x emission from 2013 to 2014 in the port area of Harlingen by ships with AIS.**

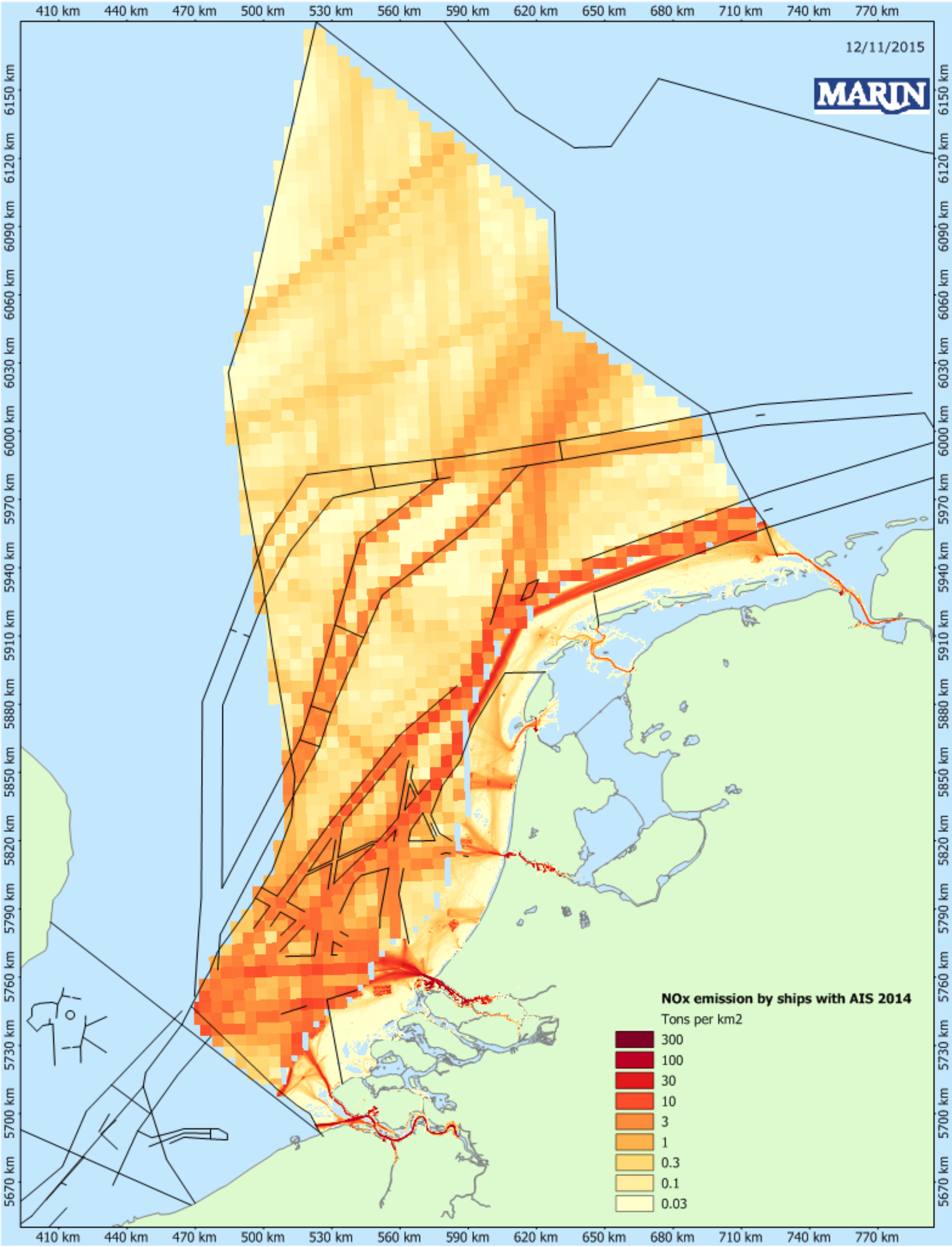

Figure 7-19 NO_x **emission in 2014 in the NCS, the 12-mile zone and the Dutch port areas by ships with AIS.**

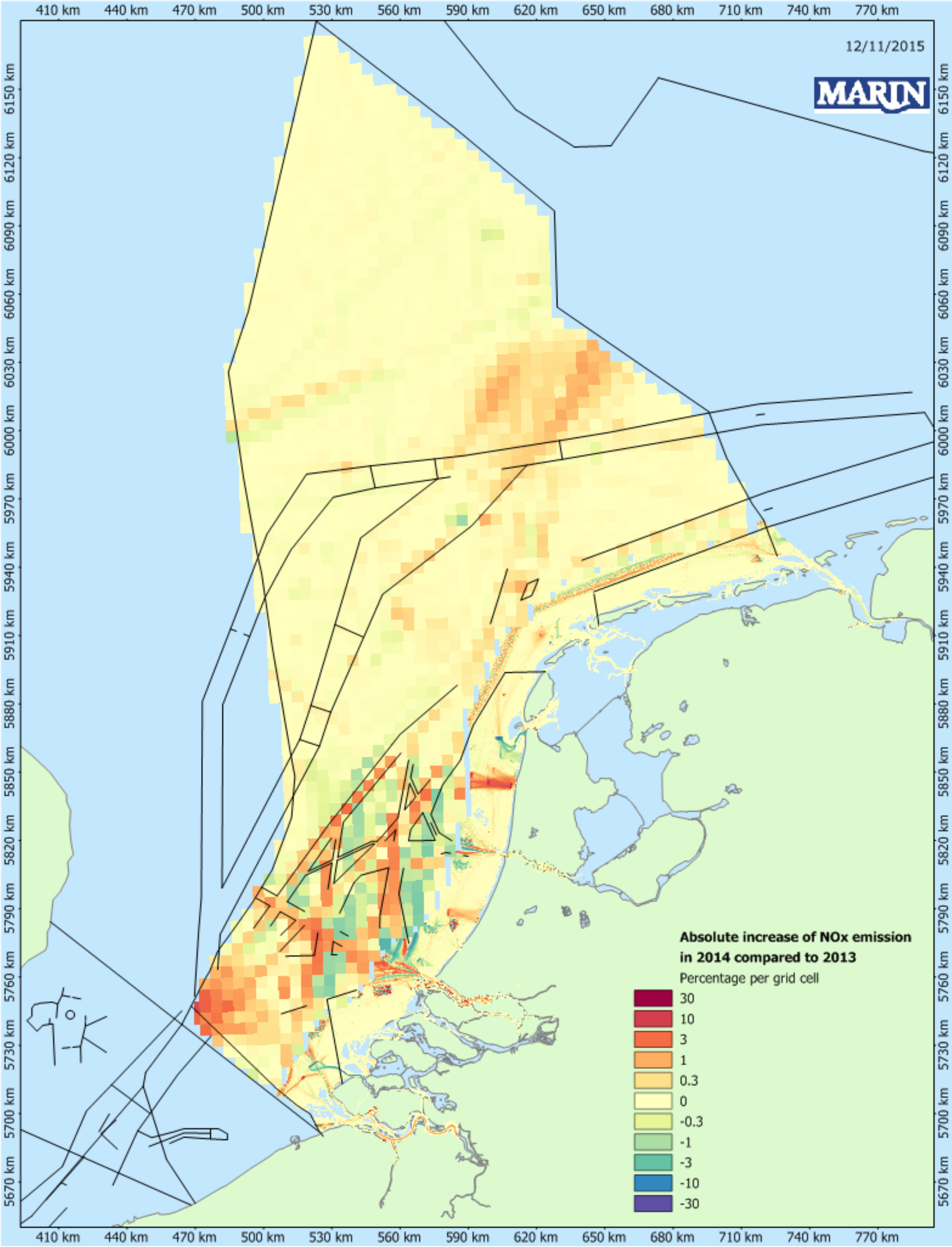

Figure 7-20 **Absolute change in NO_x emission from 2013 to 2014 in the NCS, the 12-mile zone and in the Dutch port areas by ships with AIS.**

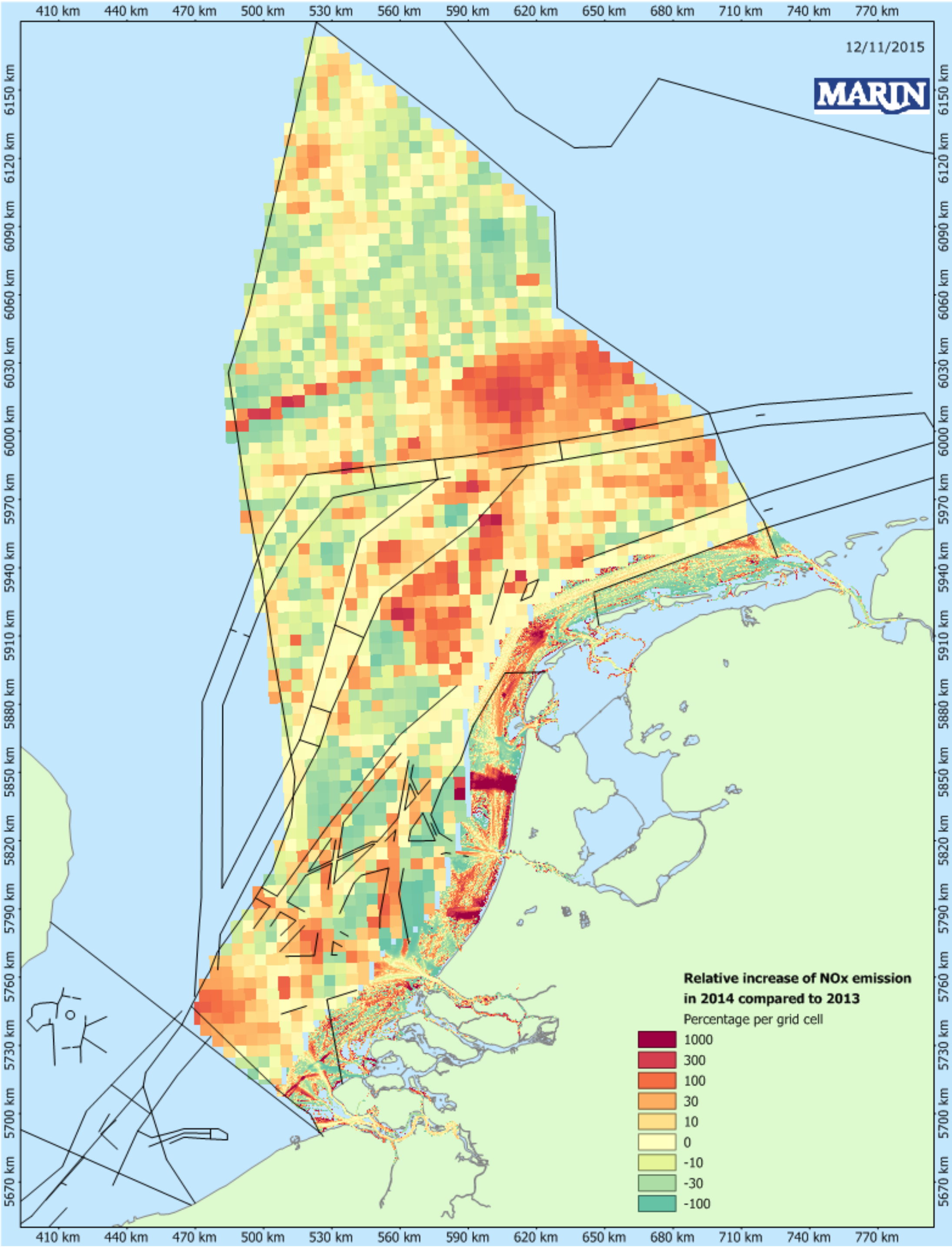

Figure 7-21 **Relative change in NO_x emission from 2013 to 2014 in the NCS, the 12-mile zone and in the Dutch port areas by ships with AIS.**

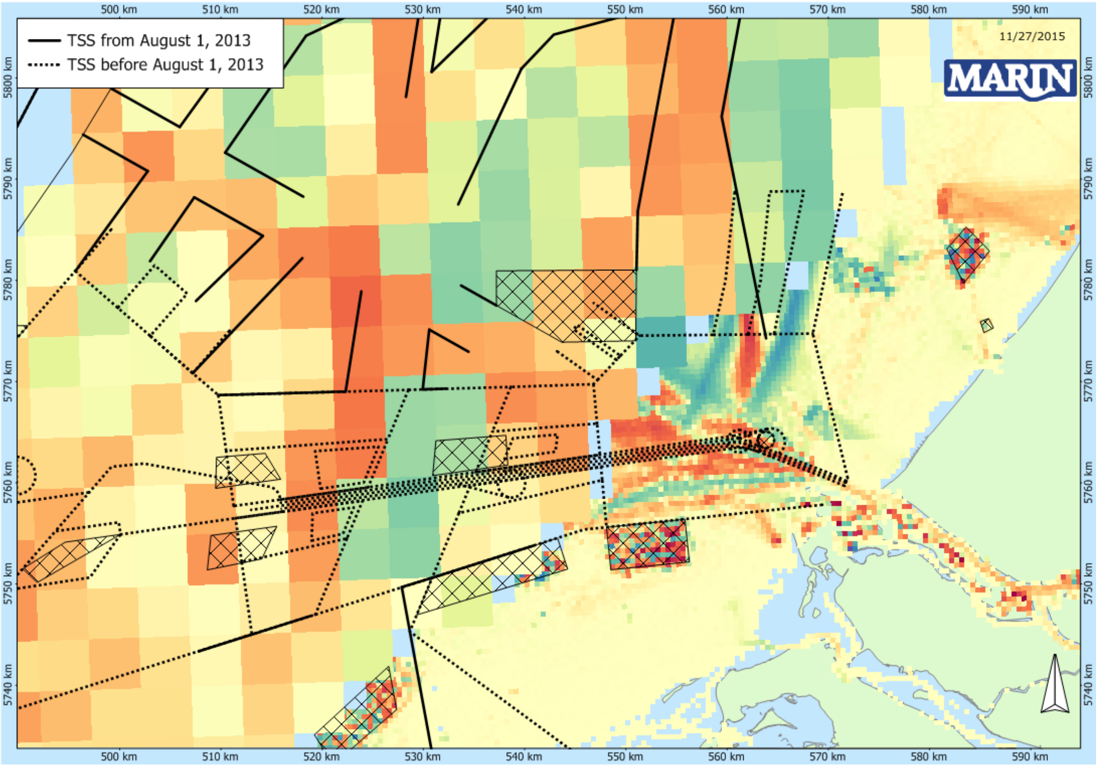

Figure 7-22 Change of the TSS near the Eurogeul. On the background the absolute change in emissions as in Figure 7-20.

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 2014 are summarised in Table 8-1. This table also contains a comparison with 2013. The average number of moving ships in OSPAR region II has increased with 5.6%. The increase in emissions for VOC and CO is different from the other substances, as the calculation method of the emissions on the NCS is corrected as explained before in Section 3.2 and 7.2. This also has an effect on the emissions in OSPAR Region II, as the emissions per nautical mile are calculated based on the results for the NCS.

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 2014, based on SAMSON

Nr	Substance	Emission in ton in 2014 of moving ships	Emission in 2014 as percentage of 2013 for moving ships
1011	Methane	297	243.1%
1237	VOC	11,359	108.0%
4001	SO2	108,917	101.9%
4013	NOx	404,016	101.6%
4031	CO	77,840	114.5%
4032	CO2	18,279,180	102.3%
6601	Aerosols MDO	748	105.6%
6602	Aerosols HFO	18,311	102.5%
6598	Aerosols MDO+HFO	19,059	102.6%
Average number of ships in area		912.39	105.6%

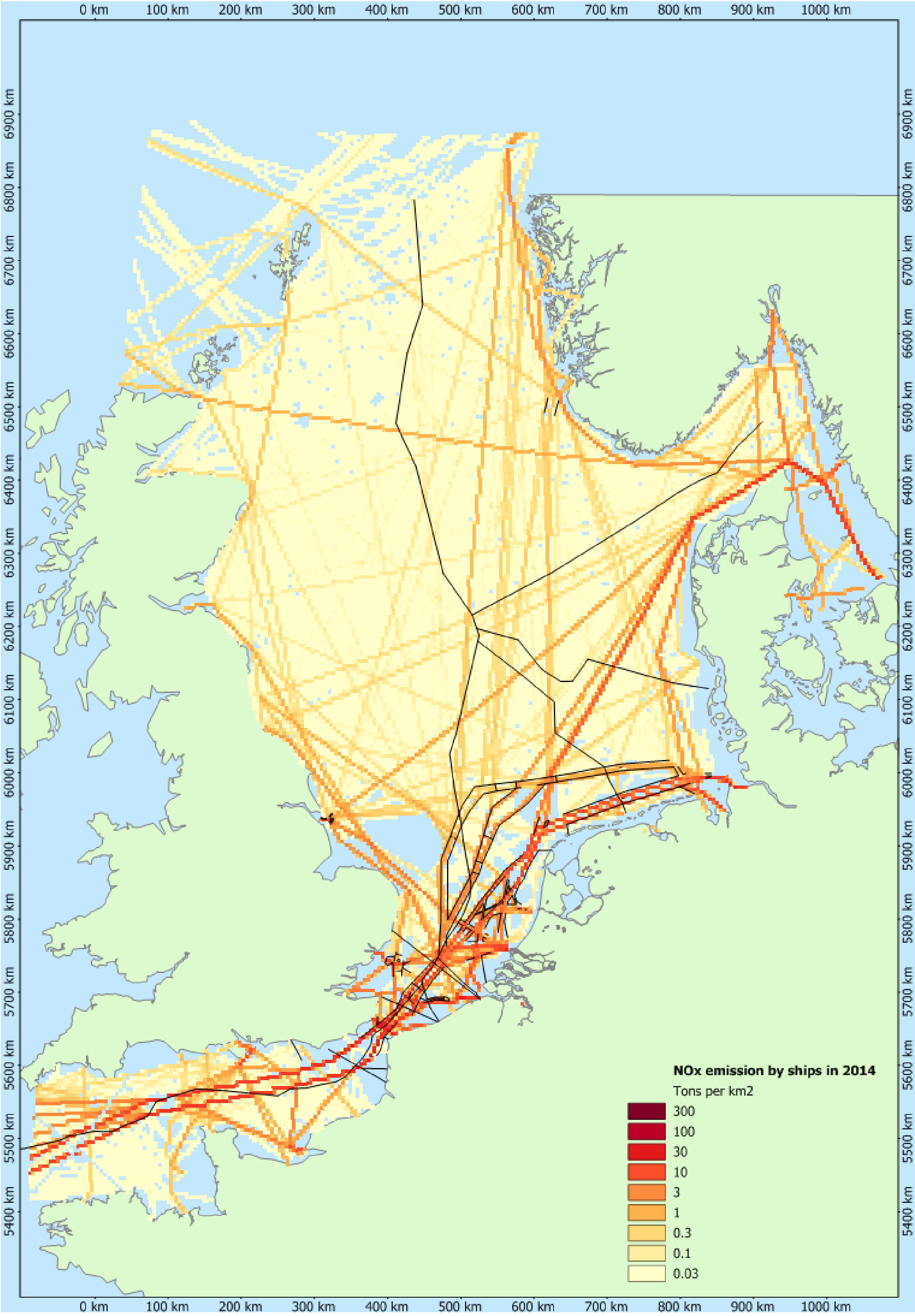

Figure 8-1 NO_x emission in OSPAR region II at sea by route bound ships.

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.

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 2014, no correction was necessary to account for these missing minute files. The coverage of ships on the Western Scheldt close to the Belgian border was still as bad as in the previous year. The approach followed this year was slightly different from the approach last year, as the change in composition of the traffic on the NCS was different from that on the Western Scheldt.

Activity data
Comparing 2014 with 2013, there was a decrease in the number of calls for all port areas, except for the Ems and Den Helder. All ports show an increase in cargo handled. The number of not moving ships increased for all areas, the number of moving ships decreased mainly in Harlingen and Den Helder, but also in Amsterdam. On the NCS and on the Western Scheldt, the number of moving ships increased by almost 10%. The average speed remained the same in most areas, only on the NCS and in the Ems area it decreased by 2%.

Emission results
The comparison of the emission results for almost all areas show an increase in emissions, both in the port areas and at sea. Only Amsterdam and Harlingen show an overall decrease in emissions, the other areas mainly show an increase. This corresponds with the activity data based on AIS. The change in emissions for CO and VOC are at least partly caused by a correction of the implementation of the calculation method, while this effect is less clear for the other substances. This has an effect on both the emissions based on AIS as well as the emissions based on the SAMSON traffic database.

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[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

[2] D. Looije
Sea Shipping emissions 2013: Netherlands Continental Shelf, Port areas and OSPAR Region II
MARIN, no: 28130-1-MSCN-rev.1, May 11, 2014

APPENDIX A: EMISSION FACTORS

Written by Jan Hulskotte of TNO

A1 SAILING AND MANOEUVRING

A1.1Main 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 September 2015 as far as new valid data were available. 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- 10)
CEF Correction factors of basic engine emission factors (Table A- 12/Table A- 14)
P Engine power [KiloWatts]
fMCR 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.

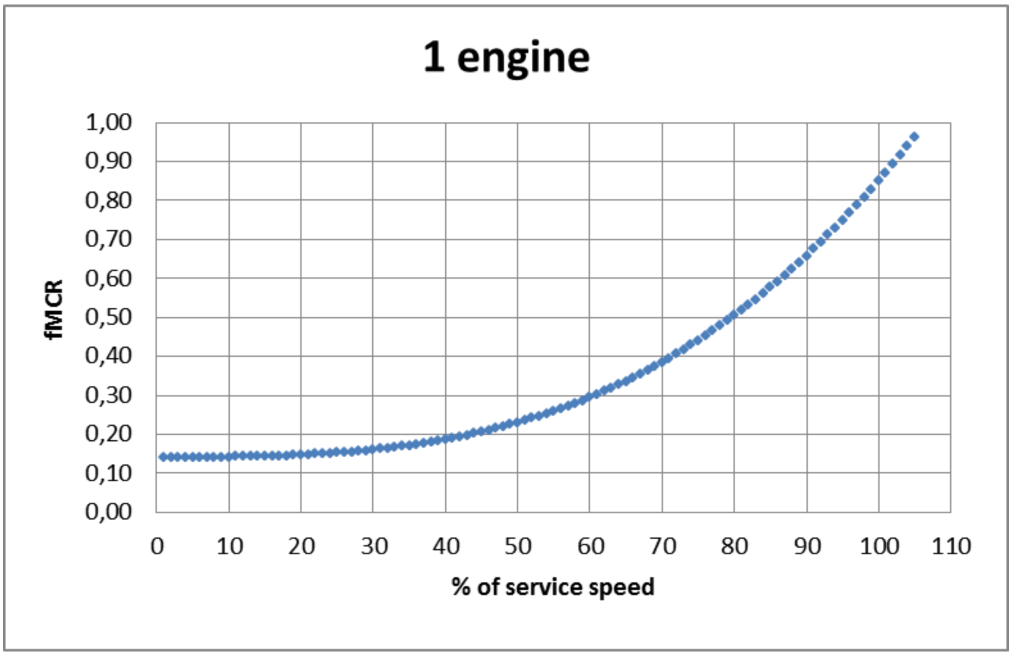

Figure A- 1 **The relationship between service speed and fMCR at ships with one single propulsion engine used in emission calculations**

A1.2Multiple 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 the emission calculation for 2010.

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 at ships with multiple engines, 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	109,489	534,901	4.9	80.9%
2	24,011	87,343	3.6	13.2%
3	926	4,459	4.8	0.7%
4	1,912	25,822	13.5	3.9%
5	89	1,551	17.4	0.23%
6	177	5,992	33.9	0.91%
7	4	139	34.8	0.02%
8	31	1,017	32.8	0.15%
9	6	261	43.5	0.04%
10	1	3.0	3.0	0.00%
12	2	15.6	7.8	0.00%
	136,648	661,504	4.8	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 was analysed. 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.

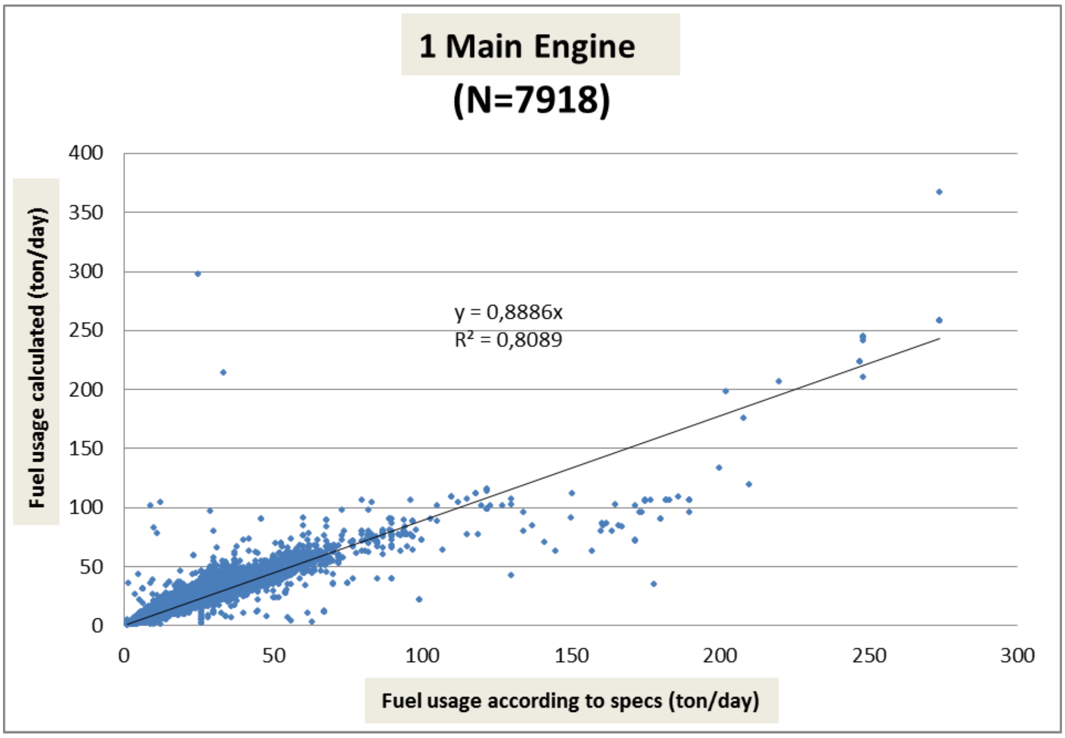

Figure A- 2 Calculated daily fuel usage of one engine ships compared with specifications

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.

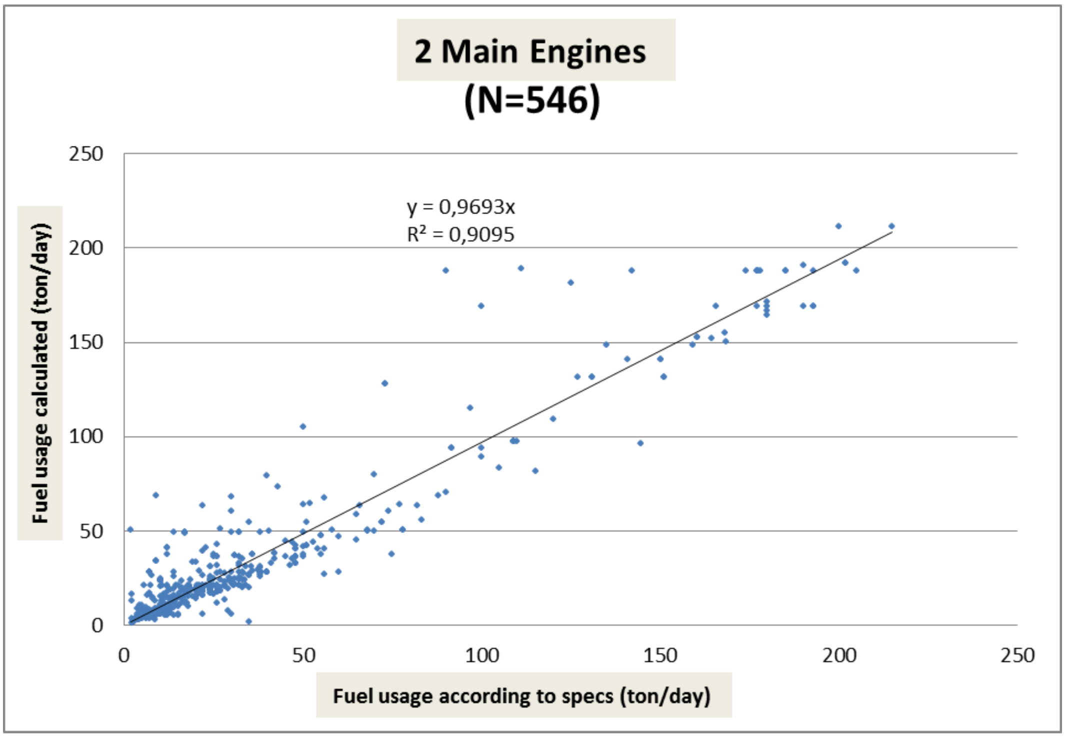

Figure A- 3 Calculated daily fuel usage of two engine ships compared with specifications

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.

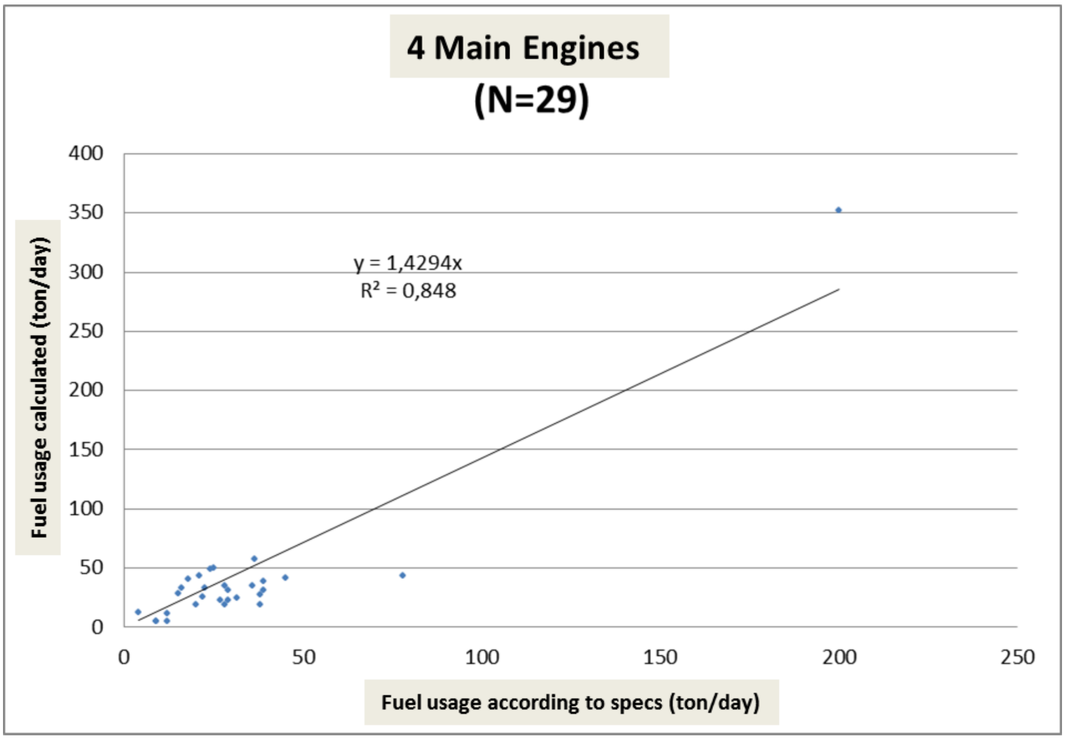

Figure A- 4 Calculated daily fuel usage of four engine ships compared with specifications

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 4% (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							
Chemical/LNG/LPG tanker	2	0.75	0.85								
	4			0.75		0.75					
	6								0.75		
Bulk carrier	2	0.75	0.85								
	4			0.75	0.75	0.75					
Container ship	2	0.75	0.85								
	4			0.75	0.75	0.75	0.75	0.75			
	6								0.75	0.75	
General Dry Cargo	2	0.75	0.85								
	4			0.75	0.75	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	0.85								
	4			0.75	0.75						
Passenger	2	0.5	0.85	0.75		0.75			0.75		
Miscellaneous	2	0.75									
	4			0.75							
Tug/Supply	2	0.5	0.85	0.75	0.75	0.75	0.75	0.75	0.75		0.75
Non Merchant	2	0.5	0.85	0.75	0.75	0.75	0.75	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- 3/Table A- 10)
CEF Correction factors of basic engine emission factors (Table A- 12/Table A- 14)
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.

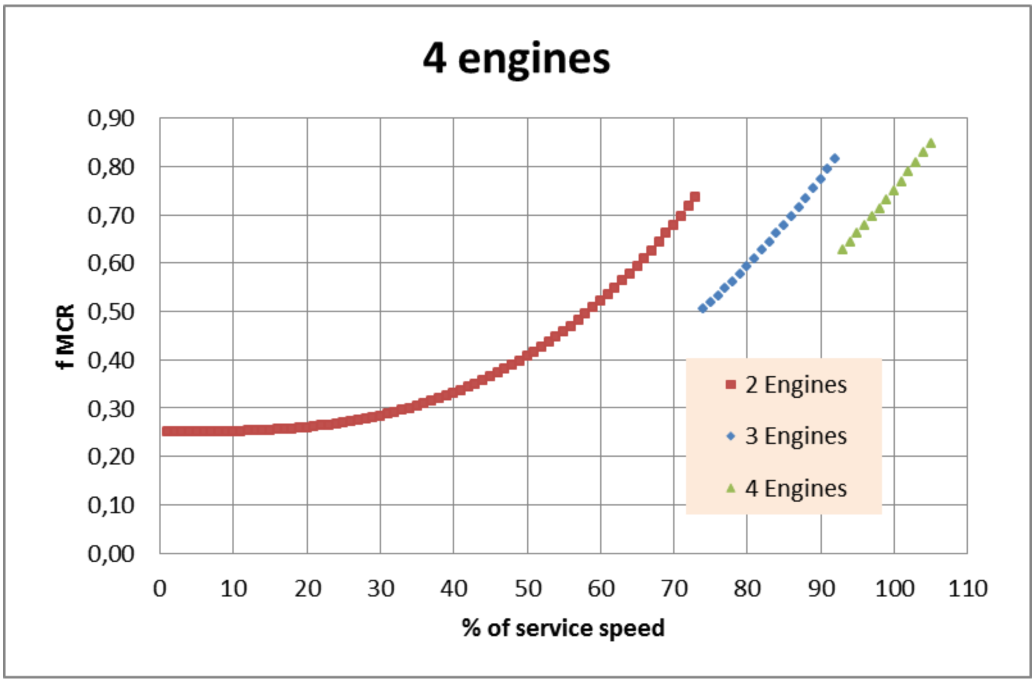

Figure A- 5 The relationship between service speed and fMCR at ships with four propulsion engines as used in emission calculations (formula 4 and 5)

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- 10 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-HFO	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-MDO	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-8)

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-HFO	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-MDO	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

Table A- 7 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 17.0
	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

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

Table A- 8 Emission factors and specific fuel oil consumption (SFOC) of gas turbines (TB) operated on marine diesel oil (MDO), (g/kWh)

Fuel	NO_X	PM-MDO	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- 9 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- 10 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-11.

Table A- 11 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

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- 12Correction factors for reciprocating diesel engines

Power % of MCR	CO_2, SO_2 SP	CO_2, SO_2 MS	NO_X	PM-HFO/ PM-MDO	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 and 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: LNG and HFO. It was assumed that at lower engine loads (up to CRScor = 0.2) steam turbines are operated by HFO. On higher loads (from CRScor = 0.2) usage of LNG (boil-off gas) is assumed. The source of the correction factors of steam turbines was taken from the EXTREMIS model [4].

Table A- 13Correction factors for steam turbines

Power % of MCR	CO_2	SO_2	NO_X	PM-HFO	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 since the 2011 calculation because an adapted interpolation scheme has been applied.

Table A- 14Correction factors for gas turbines

Power % of MCR	CO_2, SO_2	NO_X	PM-MDO	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. The amount of fuel used at berth is more accurately determined in two reports on behalf of the CNSS project [14] , [15].

Table A- 15Fuel 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

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 is allowed in harbours. The specification of fuel types at berth is adapted according to this new regulation (Table A- 16).

Table A- 16Specification 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- 21, 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-MDO	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

At berth usage of medium speed engines was assumed.

Table A- 19 Emission factors of boilers of boilers at berth, (g/kg fuel)

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

Table A- 20 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 for boilers (50% for PM and 90% for SO_2) is applied to the emission factors, 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 136,647 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 82,207 ships, the ship engine year of build was directly taken from the field “ENGINE_DOB” from the ship characteristics database. In 48,528 cases, the ship engine year of build was assumed to be equal to the ship year of build. For 5,912 cases, the ship engine year build was assumed to be the average of the ship type and/or a ship’s size.

Table A- 21Method of assessment of engines year of build

Method of assessment	Number	Share
Directly taken from “ENGINE_DOB	82,207	60.2%
Directly taken from “BUILD”	48,528	35.5%
Average of ship type and/or Size	5,912	4.3%
Total	**136,647**	**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 41% 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 19% 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- 22 Assessment method of ships diesel engines RPM

Method of assessment	Number	Share
Directly taken from "RPM"	56,140	41%
Most frequent occurring RPM derived from "ENGINE_DESIGNATION"	26,300	19%
Average of ship type and/or size	54,207	40%
Total	**136,647**	**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- 23** 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- 23 Engine types in the ship characteristics database

ENGINE_TYPE_DECODE	ENGINE_TYPE	Total number	MS	SP	ST	TB
Diesel	DSL	79,768	37,345	42,423		
No data	No data	55,985	50,177	5,726	81	1
Diesel Electric	DSE	280	255	25		
Electric	ELC	15	14	1		
Gas Turbine	GST	83				83
Steam	STM	515			515	
Steam Turbine	STT	3			3	
All types	**All**	**136,649**	**87,791**	**48,175**	**599**	**84**

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 averages by ship type and size or when the ship type was unknown ship size only.

Table A- 24 Assessment method of main engine power

Method of assessment (kW)	Number	Share Number	Share Power
Directly via BHP * 0.746*)	88,595	65%	73.3%
Directly via POWER_KW	4,580	3%	6.5%
Average of ship type and/or size	43,474	32%	20.3%
	136,649	**100%**	**100%**

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

The number of ships that doesn't have any power indication in the LLI-database is increasing steadily. It is advised to seek for a solution of this problem because data of modern ships especially are lacking in many cases.

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- 25 Parameters used for calculation of auxiliary engine power in case of lack of data

Method of assessment	Number	Share %
Directly from ship characteristics database	50,863	37.2%
Derived from main engine power based on ratios within IMO-report	84,159	61.6%
10% of main engine power	1627	1.2%
	136,649	**100%**

For just 37% 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- 26 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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