SEA SHIPPING EMISSIONS 2016: NETHERLANDS CONTINENTAL SHELF, 12-MILE ZONE AND PORT AREAS

Draft Report

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GLOSSARY OF DEFINITIONS AND ABBREVIATIONS

Definitions:

Ship characteristics database	IHS-database (Lloyds Register of ships) 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
IHS	IHS Maritime World Register of Ships
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 and fishing vessels for 2016. In contrast to the study performed over 2015, the results of the fishing vessels are included in the current document. The totals and the spatial distribution for the Netherlands Continental Shelf, the 12-mile zone, the Wadden Sea and the port areas Rotterdam, Amsterdam, the Ems, the Western Scheldt, Den Helder and Harlingen are all based on AIS data. For the OSPAR region II a traffic database and the SAMSON model has been used The emissions for 2016 are determined for CH_4, VOC, SO_2, NO_x, CO, CO_2 and Particulate Matter (PM).

The grid size for the port area emissions, the Wadden Sea and the 12-mile zone is 500 x 500 m, for the Netherlands Continental Shelf area and the OSPAR region II 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 2016.
Chapter 3 describes the procedure used for the emission calculation based on either AIS data or the SAMSON traffic database.
Chapter 4 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 5 contains the level of shipping activity in the Dutch port areas, and the Netherlands sea area.
Chapter 6 summarises the emissions for 2016 for the Dutch port areas and the Netherlands sea area and makes a comparison with 2015.
Chapter 7 contains the emissions results for 2016 for the fishing activities
Chapter 8 summarises the emissions for 2016 for the OSPAR region II
Chapter 9 presents conclusions and recommendations.

2 2016 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 Western Scheldt, Den Helder and Harlingen
- OSPAR region II

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 (in between brackets the date of delivery)::

- Emissies_zeeschepen_MARIN_2016.accdb (19-12-2017)
- RESULTS_ MARIN_ fishery_def.accdb (13-12-2017)

The emissions have been calculated on a 5000 x 5000 m grid for the NCS and the OSPAR region II 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 different areas are indicated by plotting the centre points of the grid cells with different colours:

- The red points at sea are the cells outside the 12-mile zone;
- The light blue points at sea are the cells within the 12-mile zone;
- The green, pink, light green, dark blue, light orange and orange points are respectively the port areas Ems, Harlingen, Den Helder, Amsterdam, Rotterdam and the Western Scheldt.
- The Wadden Sea area, here defined as the area between Harlingen and the Ems is added for the calculation of the emissions of fishing vessels.

The six port areas are illustrated in more detail in Figure 2-2 to Figure 2-4. At some places, there are grid points on land. There are several reasons for this. In general, the detail of the charts presented here is such that not all existing waterways and/or quays are visible, though they do exist. Also, it has been observed that the determination of the GPS position is disturbed by container cranes, so that the AIS message is not fed with the correct position. When, for whatever reason, AIS signals are disturbed or lost, positions are extrapolated and this is done before MARIN receives the data.

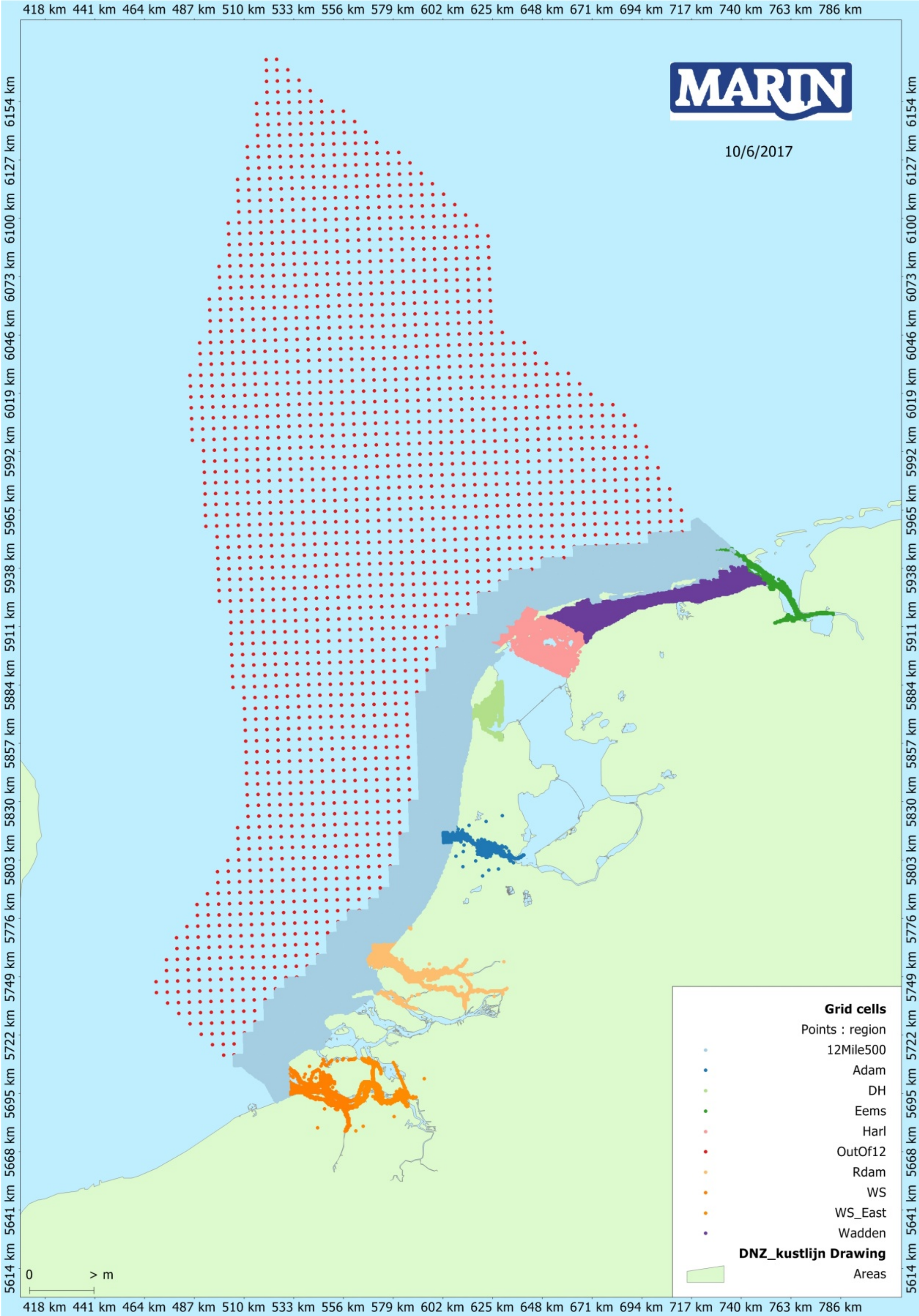

Figure 2-1 **Grid points for The Netherlands Continental Shelf, 12-mile zone, The Wadden Sea and six port areas**

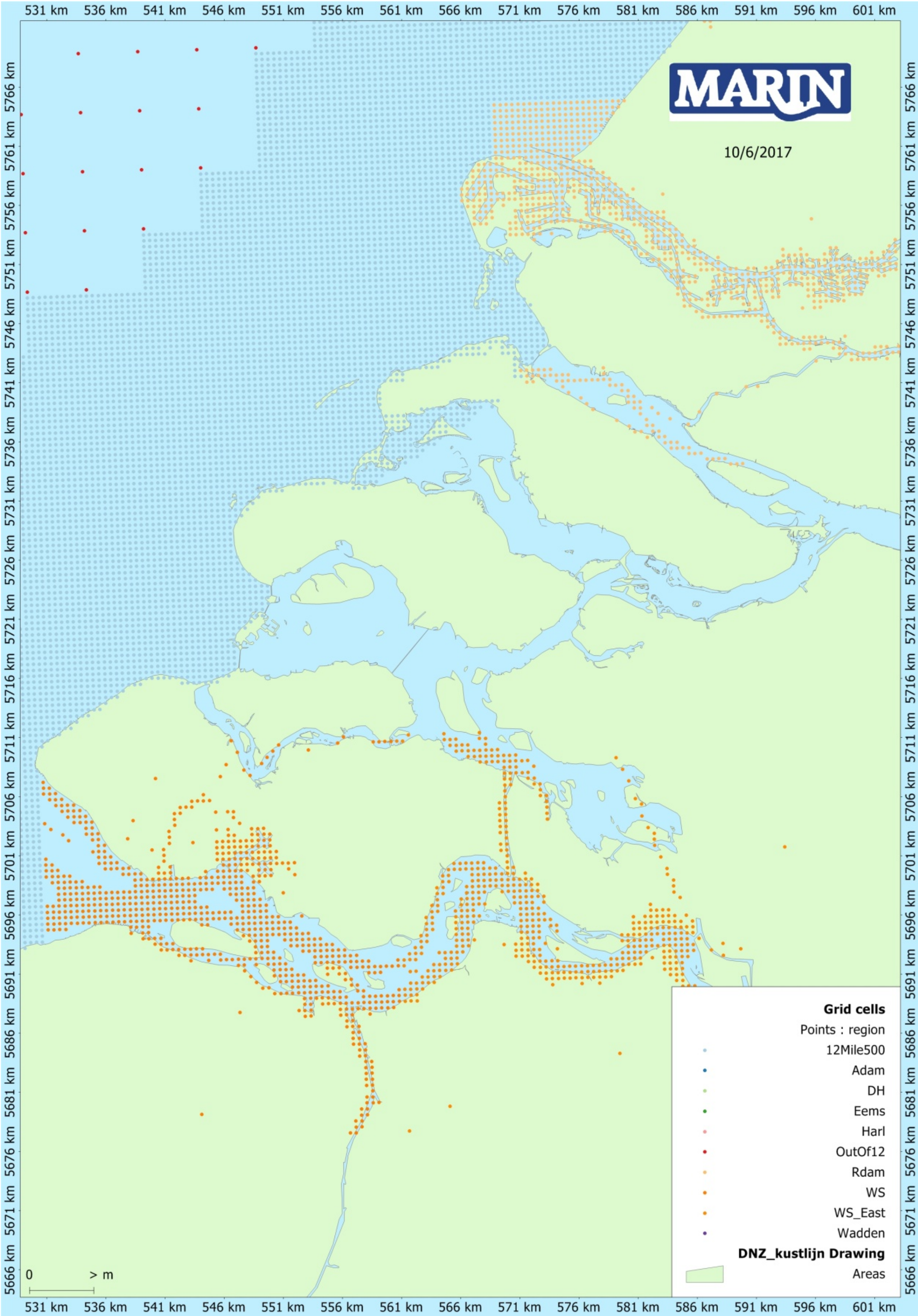

Figure 2-2 Rotterdam and the Western Scheldt: The points indicate the centres of grid cells for which emissions are calculated

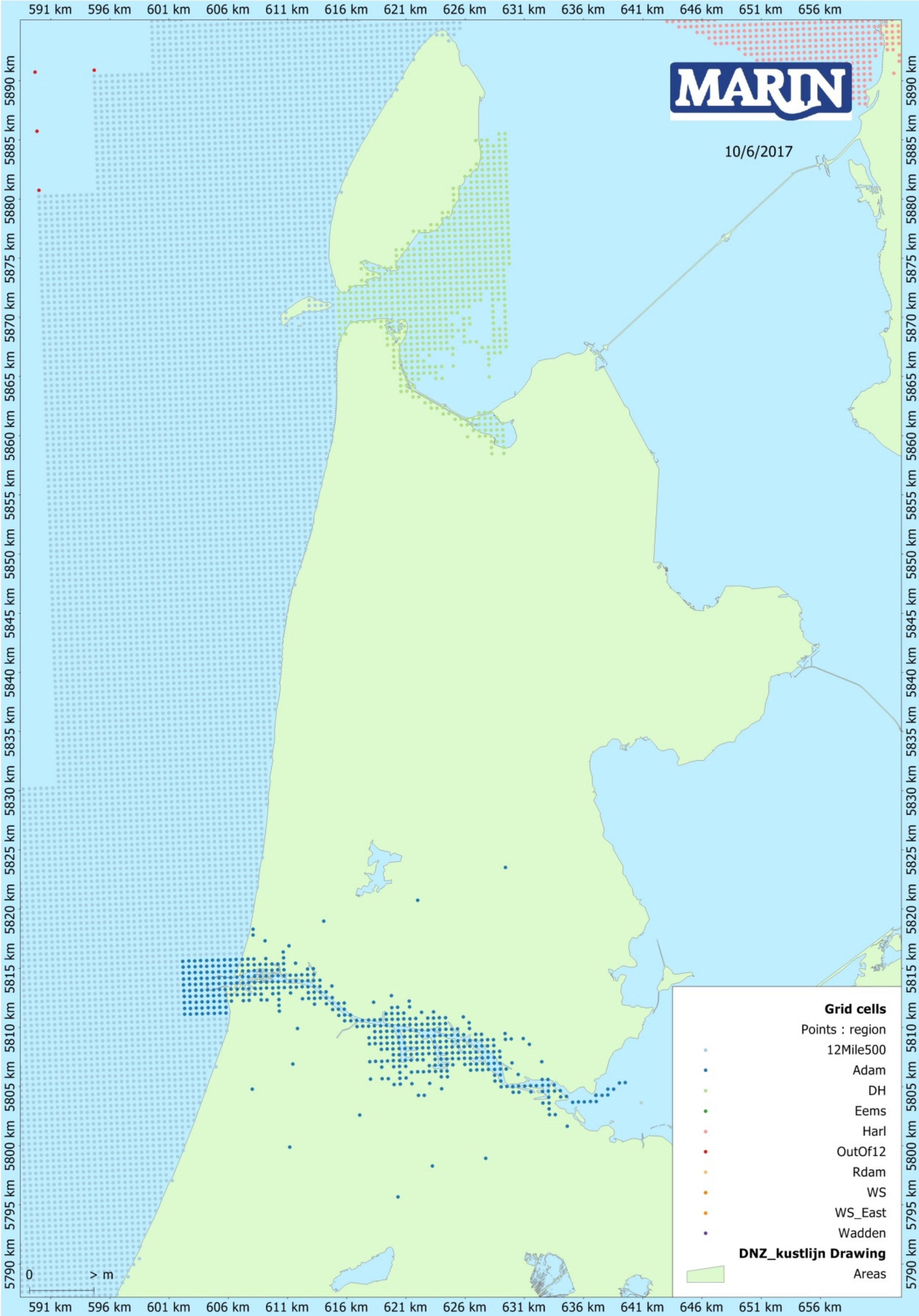

Figure 2-3 Amsterdam and Den Helder: The points indicate the centres of grid cells for which emissions are included calculated

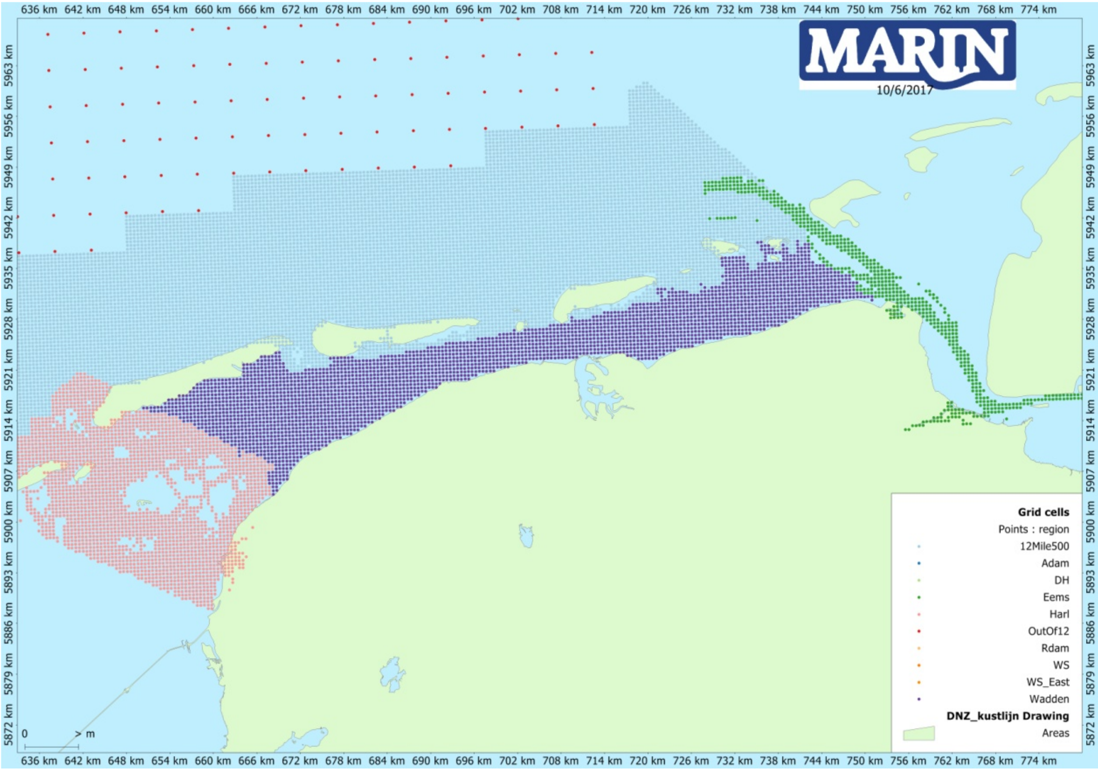

Figure 2-4 **Harlingen, the Wadden Sea and Ems: The points indicate the centres of grid cells for which emissions are calculated**

2.1 OSPAR region II

The emissions in OSPAR region II are stored in:

Emissies_OSPAR 2016_v2.accdb (10-1-2018)

The data is based on the SAMSON traffic database of 2012, which was updated in 2013. The calculated emissions have been corrected for the changes in the traffic volumes and composition between 2012 and 2016. For more information on the calculation and the correction method refer to chapter 3.2, and to [1].

The emissions have been calculated on a 5000 x 5000 m grid. The area covered is shown in Figure 2-. The results contain all route bound, moving ships. These also contain part of the fishing vessels. However, all figures and tables in the report are based on the data excluding fishing vessels.

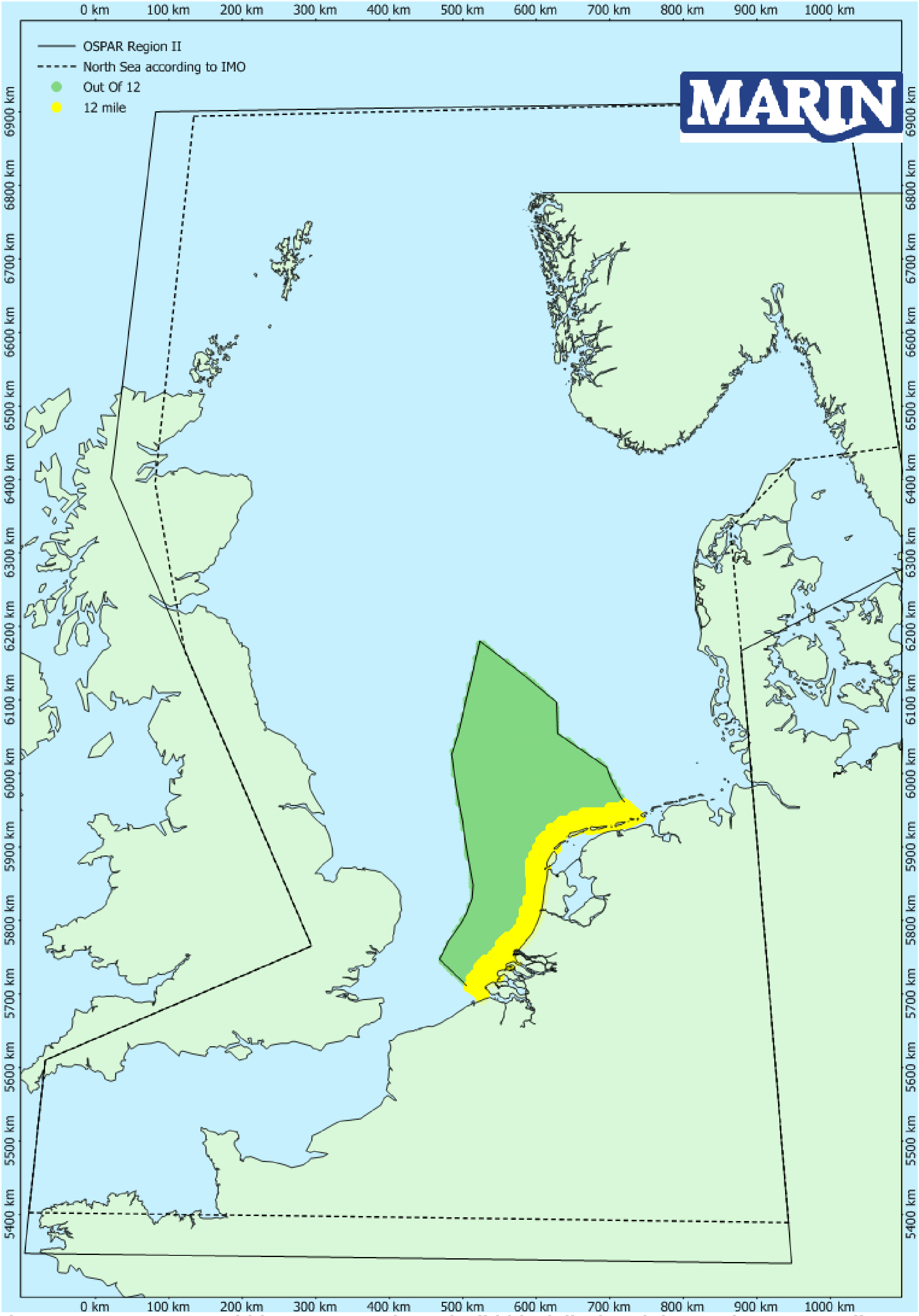

Figure 2-5 Areas within OSPAR region II (solid black line) and the North Sea according to IMO (dotted black line)

3 PROCEDURE FOR EMISSION CALCULATION

This chapter describes two procedures for the emission calculation.

The first procedure for emission calculation is based on AIS data. The AIS data has been used to calculate the emissions for both NCS, the 12-mile zone, the Wadden Sea area and the six Dutch port areas.
The second procedure is based on the SAMSON traffic database. This database has been used to calculate the emissions for OSPAR region II.

3.1 AIS data

AIS data for 2016
In this study, AIS data of 2016 received by the Netherlands Coastguard has been used to calculate the emissions. Refer to [1] for background information about the AIS data.

The emissions of 2015 (see [2]) for the Western Scheldt was based on AIS data of the 'Schelde Radar Keten'. Unfortunately, due to privacy issues, the AIS data of the 'Schelde Radar Keten' was not available for this study. However, the Netherlands Coastguard improved the coverage of the eastern part of the Western Scheldt halfway 2016. The Western Scheldt was calculated separately for the eastern and western part, for both the first and the second half of 2016. This resulted in a ratio between the first and second part of 2016 for the Western area. Which could be used to scale up the activity of the Eastern part of the western Scheldt, using the AIS data of the second half of 2016.

Furthermore a scaling factor had been applied to deal with the slightly worse coverage of the AIS data of the Netherlands Coastguard compared to the AIS data of the 'Schelde Radar Keten'.

IHS and The Port of Rotterdam
Just like in the previous study, the emission calculation of 2015, TNO has calculated emission factors for The Port of Rotterdam, using ship characteristics provided by IHS Maritime World Register of Ships to The Port of Rotterdam. Since the IHS database was available to TNO, the emissions factors for all ships seen in the areas of interest of this study were based on this database. In the previous study, the procedure for combining ship data with the IMO number, necessary as input for the emission factors, has been done by The Port of Rotterdam. This year MARIN also coupled the IMO number with the SAMSON and EMS numbers to compare any differences.

In the AIS data the identifier for the ship is the MMSI number, not the IMO-number. Therefore, a link is necessary between the MMSI-numbers in the AIS messages and the emission factors based on the ship database of IHS, identified by IMO-number. About 89% of all the AIS messages (including repeating MMSI numbers) can be coupled to the IMO-number, and therefore to the ship database containing the necessary information. For the resulting 11% no emissions are calculated. Generally, these are small vessels with a small contribution to the emissions. This is a slightly better coupling compared to last year, due to an additional manual coupling of ships details.
In the database of IHS, the MMSI numbers are directly coupled to the EMS types (Emissieregistratie en Monitoring Scheepvaart). In the previous study, it was noticed that this resulted in a shift of the results over the EMS types compared to emission study of

2014. In 2014 the Lloyds List Intelligence database was used and coupled to the MMSI numbers of AIS. These MMSI numbers were than coupled to SAMSON number, and thereafter coupled to an EMS type. The Lloyds List Intelligence database contains much less ship types that the IHS database does.
Since IHS defines many more ship type distinctions than are defined by Lloyds List Intelligence, and uses a direct coupling to EMS types. this method gives a more accurate coupling. Therefore, the direct coupling of EMS-types by IHS is used in this emission study.

3.2 SAMSON traffic database

Because AIS data outside the NCS is not available to MARIN, the emissions in OSPAR region II were estimated with the SAMSON traffic database. This traffic database contains a route structure (traffic links) and the traffic intensity on each link (see Figure 3-1). It was processed from all voyages crossing the North Sea in 2012 collected by Lloyd's List Intelligence (LLI) database. This database contains all route bound traffic, however, on busy ferry routes some voyages are missing. An inventory of missing ferries was made, and added to the SAMSON traffic database. Therefore, in contrast to earlier studies, the ferry movements didn't have to be treated separately for the emission calculation in OSPAR region II. For calculation of the 2016 emissions, an in 2013 updated SAMSON traffic database was used. Herein, some traffic links are relocated, but the traffic intensities are still from 2012.

With SAMSON the sailing time per ship class ij (type i and size j) in each grid cell c was calculated. This was converted into the sailed distance per cij, by multiplying it with the harmonious speed of each ij. Hence, the emission per cij was calculated multiplying the sailed distance with the emission per sailed distance for each ij as found on the NCS with the AIS 2016 data. Finally, a scaling factor was applied, to correct for intensity changes between 2012 and 2016, which is based on intensity changes on the NCS found with AIS data. A detailed description of each step is given in [1].

Above described method is based on two main assumptions:

- The emission per sailed distance for each ship class in OSPAR region II is identical to emission per sailed distance for each ship class in the NCS.
- The changes in traffic intensities in the NCS are representative for changes in traffic intensities in the entire OSPAR region II.

Moreover, the method does not account for ship classes that have disappeared since the year of the traffic database, or for ship classes that are newly introduced since then. For these ships an estimation is made. Due to these assumptions and limitations, the method decreases in accuracy when the age gap between the year of the traffic database, and the year interest for the emissions grows. For now, this age gap is 4 years, but should not become any larger.

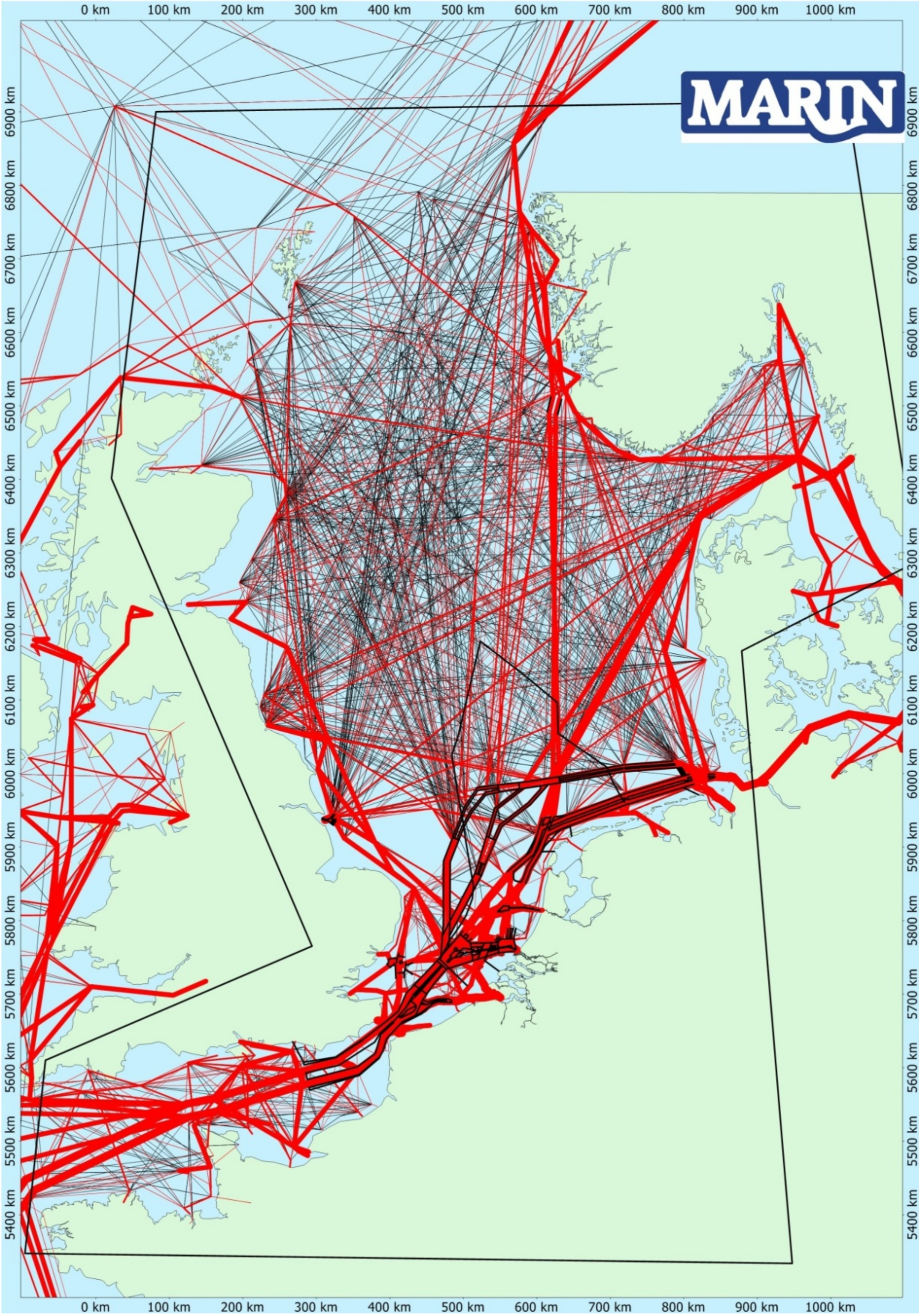

Figure 3-1 Traffic links of the SAMSON traffic database of 2012 in OSPAR region II, the width of the links indicates the intensity of the ships on the links, red links represent a higher traffic intensity than black links.

4 COMPLETENESS OF AIS DATA

This chapter describes the completeness of the AIS data. In 4.1 the missing minute files are described, 4.2 describes the analysis of the coverage of the AIS data for the NCS and the Dutch port areas.

4.1 Missing AIS minute files

Each AIS data file contains the AIS messages of all ships received in exactly one minute. The AIS data collection of 2016 is missing several minute files and several complete days of AIS data for all areas of interest. 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. Unfortunately, the AIS data of 2016 contains several gaps of a whole day. The sum of periods missing which are larger than 10 minutes is 12 days. To compensate for the missing period, the results are multiplied with 366/354.

4.2 Bad AIS coverage in certain areas

4.2.1 Base stations

In section 4.1, 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 4-1, 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.

4.2.2 Known weak spots

In reality, the covered area varies with the atmospheric conditions. Figure 4-1 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 close to the border with Belgium,
- 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. Furthermore, the coverage of the AIS data of the Netherlands Coastguard seems to be slightly worse than last years. A meeting has been planned with the Netherlands Coastguard to understand the coverage problems and to find a solution for coming years.

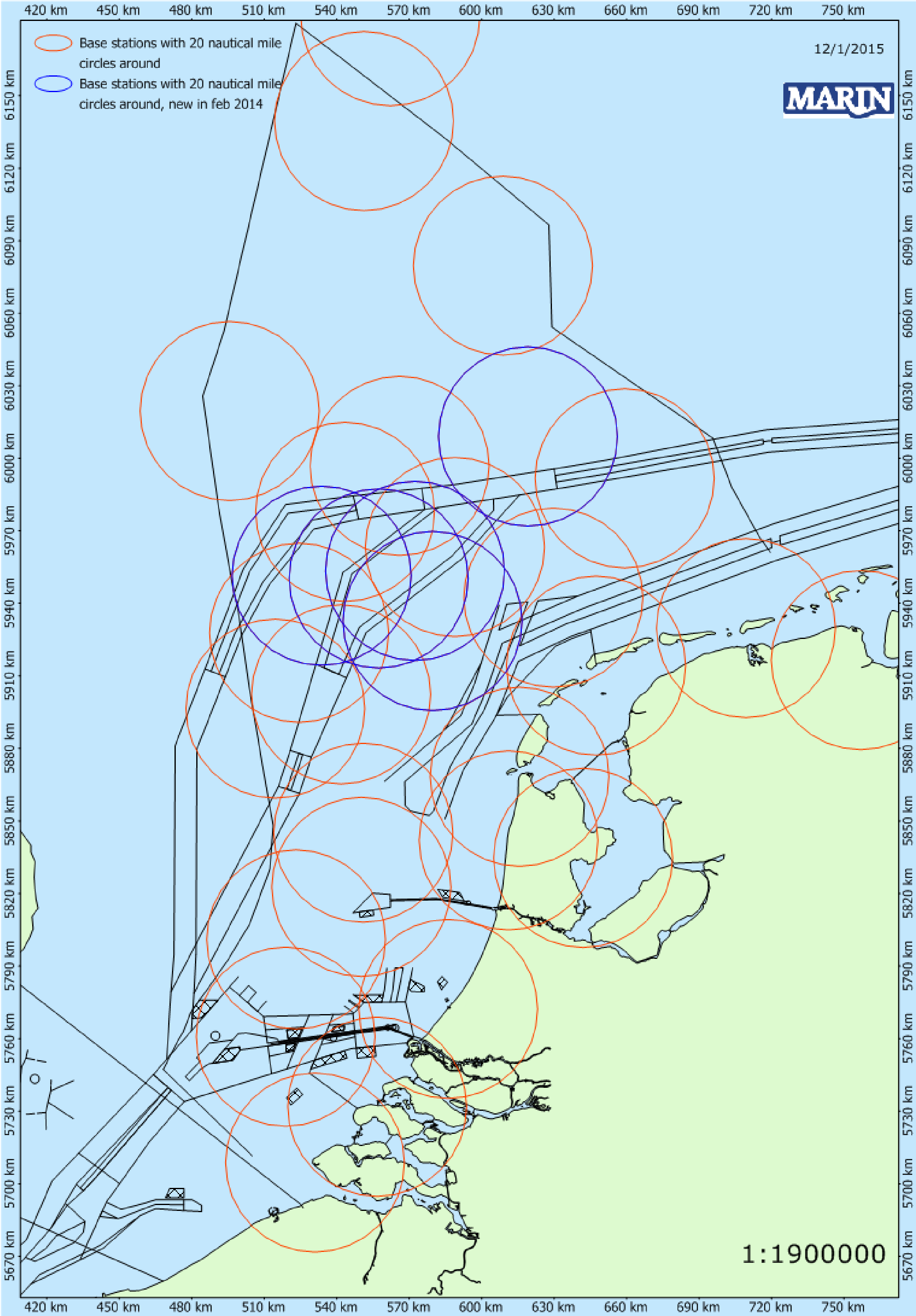

Figure 4-1 **AIS base stations in 2016 delivering data to the Netherlands Coastguard.**

4.2.3 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 4-2 and Figure 4-3 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 of ships in this grid cell. Sometimes the data reception 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.

These figures show the coverage for June and September 2016. These months were chosen so that the data can be compared with last year. The overall coverage of AIS data of 2016 seems slightly worse compared to the AIS coverage of 2015. However, fluctuations in coverage are expected due to the dependency on atmospheric conditions.

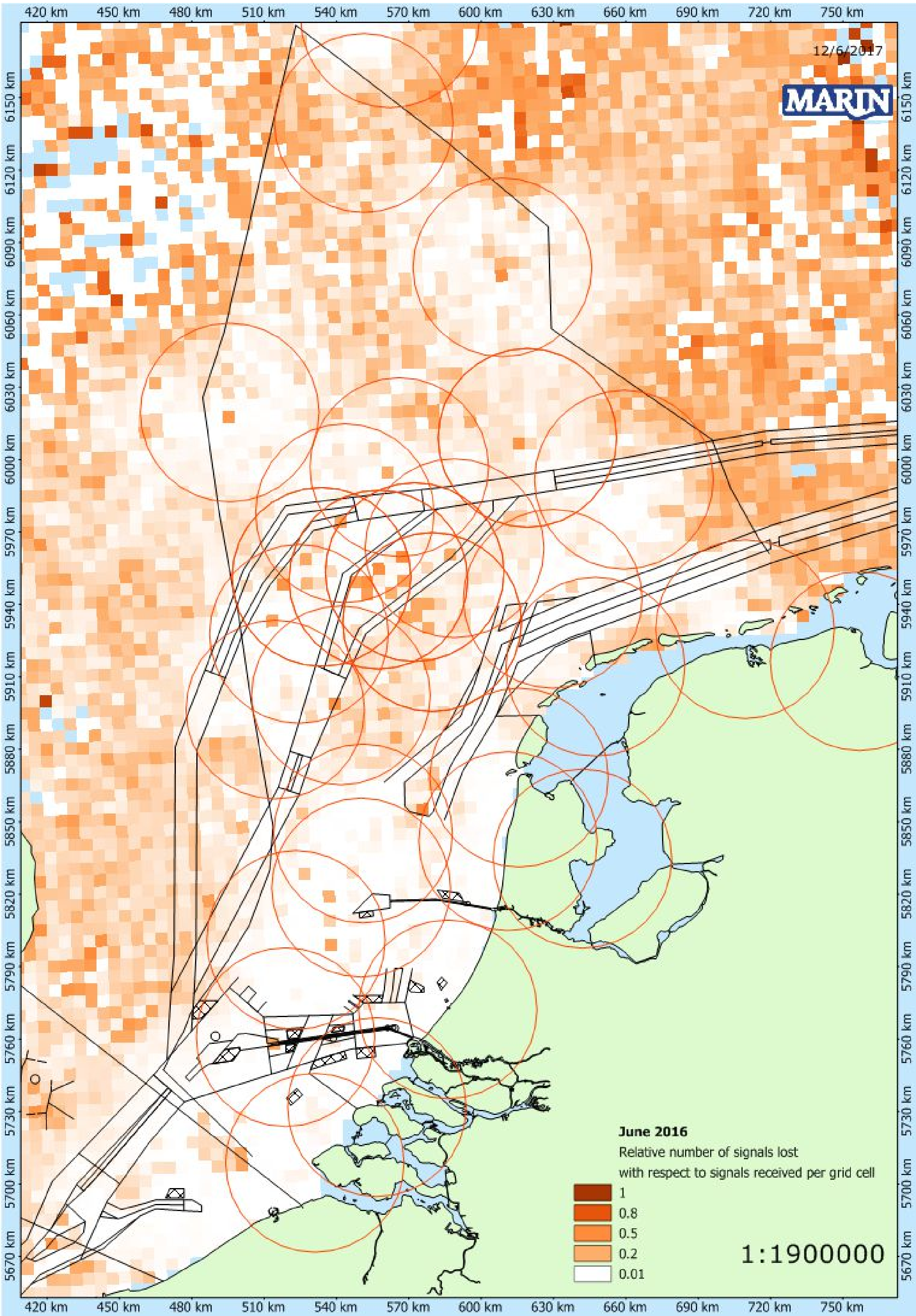

Figure 4-2 June 2016, relative number of signals lost with respect to signals received per grid cell, circles mark the 20 nautical miles zones around the Dutch base stations

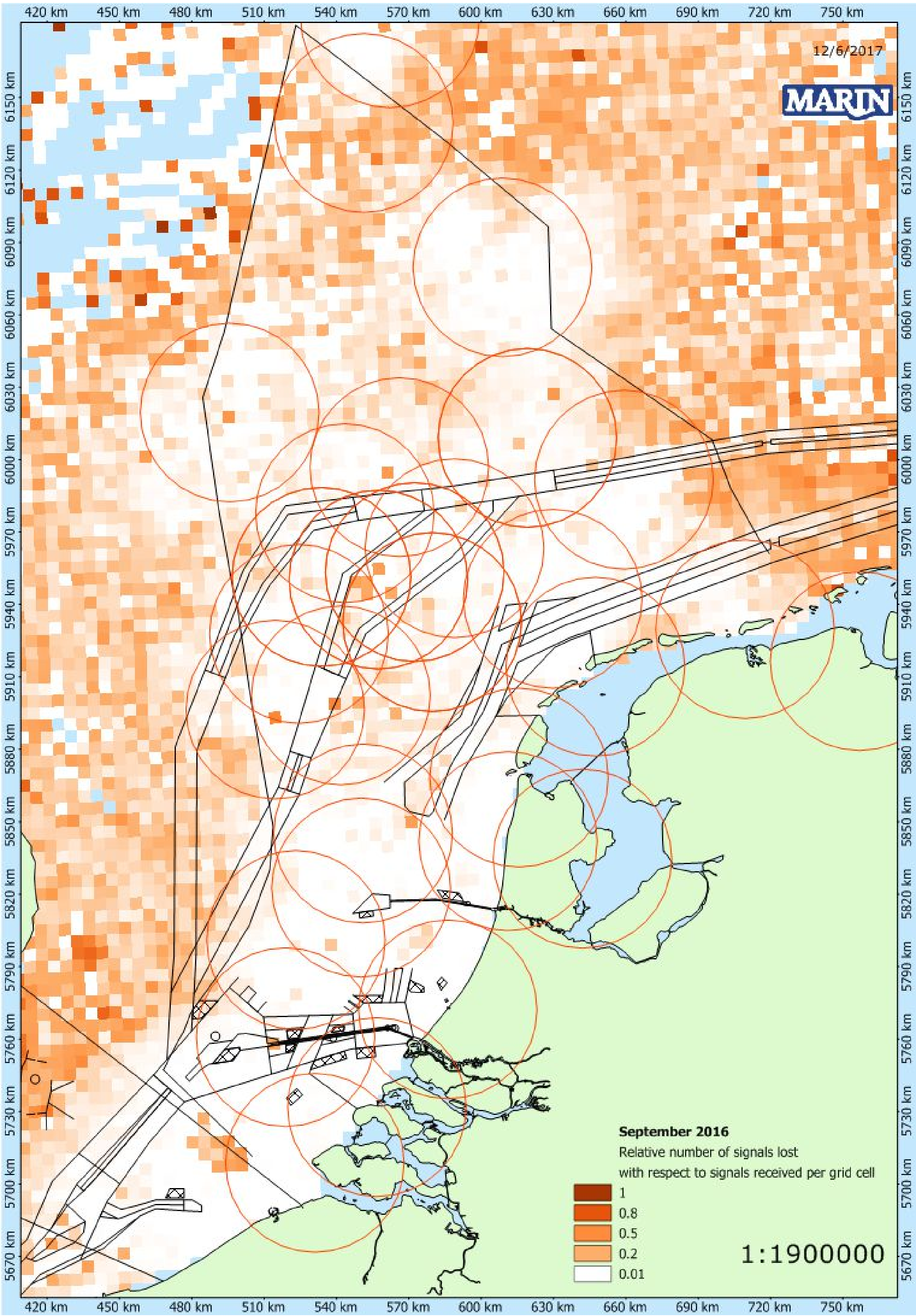

Figure 4-3 **September 2016, relative number of signals lost with respect to signals received per grid cell, circles mark the 20 nautical miles zones around the Dutch base stations**

4.2.4 Coverage in the Western Scheldt port area

Figure 4-4 shows the coverage of the Western Scheldt based on the AIS data of the Netherlands Coastguards. Clearly some spots are missing. Last year, AIS data of the 'Schelde Radar Keten' was used. Unfortunately, this year it was not possible to use data of the 'Schelde Radar Keten' due to privacy issues. The coverage of the AIS data of the Netherlands Coastguard for the Western Part of the Western Scheldt was greatly improved for the second part of the year 2016. Although, the coverage was not as good compared to the coverage of the data of the 'Schelde Radar Keten'. Therefore a small scaling factor has been applied to the emission results based on the AIS data of previous year.

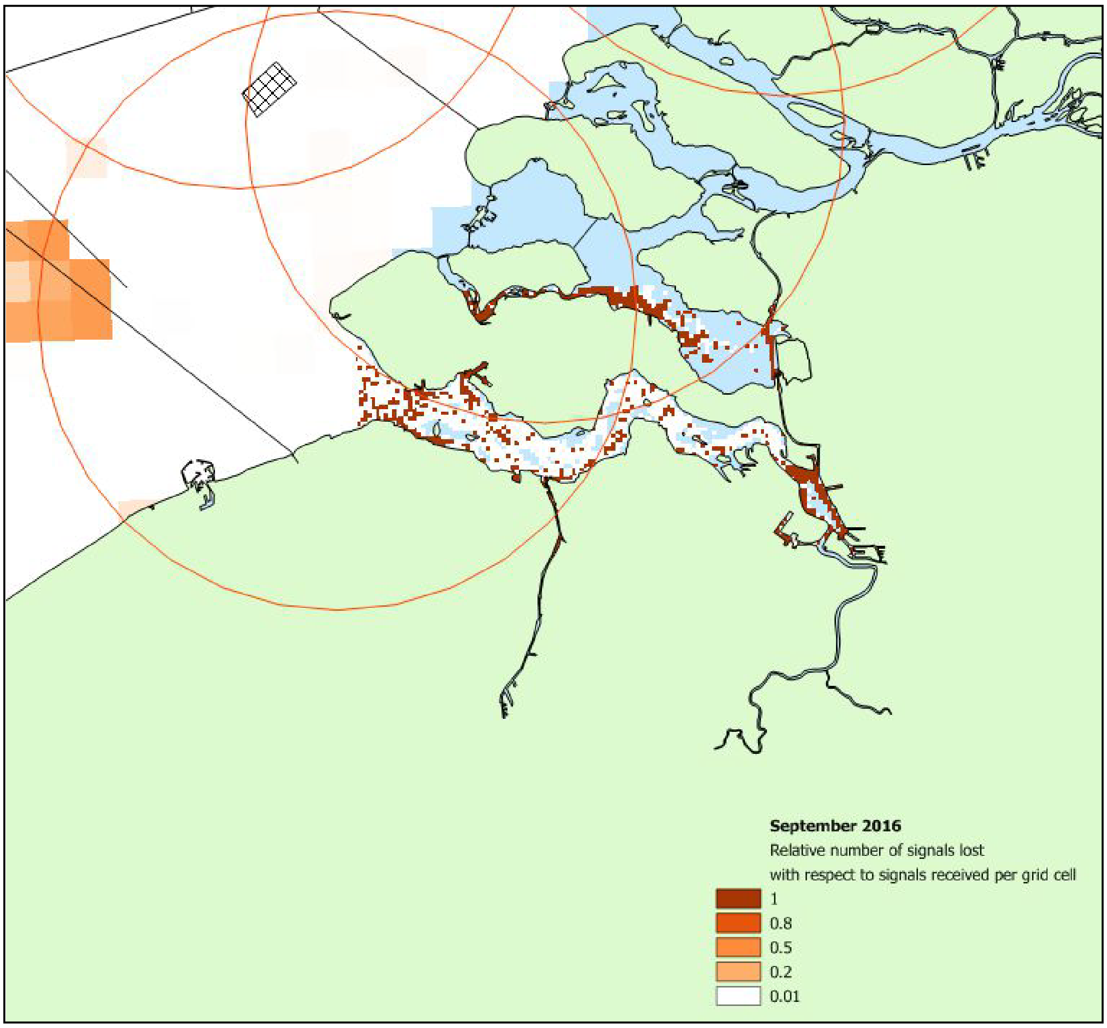

Figure 4-4 September 2016, relative number of signals lost with respect to signals received per grid cell for the Western Scheldt area.

5 ACTIVITIES OF SEAGOING VESSELS FOR 2016 AND COMPARISON WITH 2015 FOR THE DUTCH PORT AREAS AND THE NETHERLANDS SEA AREA

5.1 Introduction

This chapter presents the activities of seagoing vessels for 2016 in the Dutch port areas and in the Netherlands sea area. The activities of 2016 are compared to those of 2015. Section 5.2 describes the activities in the port areas, Section 5.3 the activity in the Netherlands sea area and Section 5.4 the number of ships in these areas.

5.2 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 5-1 presents activity numbers that could be extracted from the websites of the ports. For the port of Harlingen, Den Helder and Ems no figures are available, therefore, only the activities for the ports Western Scheldt, Rotterdam and Amsterdam are given here. These numbers can be used to check the information on activity as derived from the AIS data. First, the values of 2016 are shown and then the percentages with respect to 2015. The table contains the number of calls and the cargo handling for the main ports in each port area. Table 5-1 shows that there are no significant changes in calls or cargo handling compared to 2015. Zeeland seaports has a slightly smaller number (5%) of calls in 2016 compared to 2015. The port of Amsterdam show 3% decrease of the number of calls compared to 2015. The number of cargo handling only increased for the port of Antwerp, and only with 3%.

Table 5-1 Number of calls extracted from websites of the ports

Port area	Ports	Number of calls		Cargo handling x 1000 tons	
		2016	2016/2015	2016	2016/2015
Western Scheldt	Antwerp	14,473	100%	214,000	103%
	Zeeland seaports (Vlissingen en Terneuzen)	5,521	95%	33,000	100%
Rotterdam	Rijn- en Maasmondgebied	29,022	100%	461,000	99%
Amsterdam	Noordzeekanaalgebied	6,982	97%	97,000	100%

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 5-2 through Table 5-13.

Western Scheldt

Table 5-2 and Table 5-3 show the activities of seagoing vessels on the Western Scheldt based on AIS data of the Netherlands Coastguards. Previous year the activities were bases on AIS data of the Schelde Radar Keten. Clearly, the data of the latter is more complete than the data used in this study. Last year (2015) the hours of moving ships increased by 8.4% compared to 2014 and this year (2016) the hours of moving ships decreased again with 7.1% compared to 2015. Since we believe that this is due to the accuracy of the AIS data, the emissions in the Western Scheldt are slightly increased with a correction factor based on the results of last year.

There is still a slight shift in ship types due to the different method of assigning the EMS types to the MMSI numbers. This will not be the case in the next study, since the EMS-types are now fully based on the IHS database. Which will be the same in the next study.

For berthed ships the hours decreased by 24.4% in 2016. This also seems to be caused by the difference in AIS data source, since it increased with 27.1% in 2015.

Rotterdam

The activity tables, Table 5-4 and Table 5-5, for Rotterdam show that for the moving activities, the hours decreased with 3.0% and the GT.nm increased with 5.2% in 2016 compared to 2015. Clearly this is due to the calls of larger vessels.

Remarkably is that the berthed activities, hours and GT.hours, decreased respectively with 38.1% and 40.9%. It seems that the number of calls is similar to 2015, but the amount of time the ship are at berth is much lower.

Amsterdam

The activity tables, Table 5-6 and Table 5-7, for Amsterdam show a slight decrease in moving vessels. The decrease in hours moving is 7.3% and the decrease in GT.nm is 4.6%.

The hours at berth also decreased, but not as much as for Rotterdam. The berthed activities for Amsterdam, hours and GT.hours, decreased respectively with 20.4% and 12.6%.

Ems

The activity tables, Table 5-8 and Table 5-9, for the Ems area shows that the moving activities, hours and GT.nm, decreased by respectively 15.7% and 18.1%. Back to the level of 2014.

The number of berthed hours and GT.hours decreased respectively by 51.4% and 61.3%.

Den Helder
Table 5-10 and Table 5-11, for Den Helder show that the moving activities increased remarkably. The moving hours and GT.nm increased respectively by 34.7% and 628.8%. This is mainly due to an increase of the number of visits of Roro Cargo/ Vehicle vessels and Reefer vessels.

Compared to 2015, the berthed hours and GT.hours in the Den Helder port area increased by, respectively 10.8% and 68.3%.

Harlingen
The activity tables, Table 5-12 and Table 5-13 show a clear increase in activities in the port of Harlingen. The moving activities hours and GT.nm increased respectively by 18% and 44.6%.

The berthed hour and GT.hours increased respectively by 15.4% and 13.7%

Table 5-2 Shipping activities per EMS type for the Dutch part of the Western Scheldt

Ship type	Totals for Western Scheldt in 2016					2016 as percentage of 2015				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	5,960	221,966,098	4,927	1,580,004,749	10.0	83.50%	110.40%	81.00%	92.90%	95.80%
Chem.+Gas tanker	59,964	775,119,168	39,770	4,316,896,570	10.7	94.20%	133.90%	102.80%	117.10%	101.00%
Bulk carrier	16,733	626,550,310	6,851	1,860,993,207	9.4	66.40%	74.20%	91.60%	95.60%	108.70%
Container ship	2,652	45,150,918	24,823	18,554,427,785	13. 4	89.40%	105.20%	101.40%	114.50%	107.20%
General Dry Cargo	63,953	542,244,741	32,125	1,794,525,988	9. 9	66.40%	83.60%	92.90%	93.60%	98.80%
RoRo Cargo / Vehicle	8,838	209,449,611	10,094	5,559,473,864	12.2	87.60%	100.40%	90.70%	98.80%	97.90%
Reefer	11,217	120,987,325	1,104	142,903,780	10.2	128.10%	151.70%	60.50%	52.90%	90.80%
Passenger	15,578	21,144,025	5,817	115,731,187	10.3	89.70%	29.10%	100.30%	44.30%	89.40%
Miscellaneous	78,840	192,134,257	23,545	490,194,331	8.2	53.00%	63.40%	79.10%	88.40%	78.10%
Tug/Supply	138,340	308,330,277	19,823	104,141,020	6.72	95.80%	235.60%	89.30%	214.10%	80.20%
Total	402,075	3,063,076,730	168,879	34,519,292,481	10.12	75.60%	98.10%	92.50%	107.10%	96.30%

Table 5-3 Shipping activities per EMS ships size classes for the Dutch part of the Western Scheldt

Ship size in GT	Totals for Western Scheldt in 2016					2016 as percentage of 2015				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	177,920	92,250,938	35,472	182,508,498	8.3	85.50%	85.60%	96.50%	92.60%	94.10%
1,600-3,000	71,729	168,653,448	29,399	651,040,360	9.0	69.10%	69.00%	98.60%	97.00%	94.20%
3,000-5,000	32,735	129,798,553	24,953	981,389,740	10.2	78.70%	79.80%	99.70%	100.60%	101.80%
5,000-10,000	30,379	217,551,478	18,537	1,405,235,327	10.7	76.60%	77.60%	90.00%	88.80%	99.40%
10,000-30,000	61,736	1,161,736,598	31,313	7,160,060,444	10.8	91.30%	95.60%	104.40%	106.10%	85.30%
30,000-60,000	23,673	983,297,436	19,138	10,140,642,027	10.9	117.40%	122.00%	91.30%	93.20%	100.10%
60,000-100,000	3,822	296,639,055	3,519	3,252,808,475	11.4	97.30%	98.60%	54.80%	53.60%	93.60%
>100,000	82	13,149,222	1,895	3,556,676,342	11.3	410.00%	428.00%	68.90%	69.90%	95.70%
Total	402,076	3,063,076,728	164,226	27,330,361,213	9.8	75.60%	98.10%	90.00%	84.80%	94.60%

Table 5-4 Shipping activities per EMS type for the Rotterdam port area

Ship type	Totals for Rotterdam in 2016					2016 as percentage of 2015				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	37,107	2,729,903,472	4,870	1,861,717,040	7.7	51.1%	53.1%	84.9%	93.0%	97.5%
Chem.+Gas tanker	53,147	775,558,604	20,982	1,852,499,561	8	50.7%	56.5%	102.4%	118.1%	101.3%
Bulk carrier	33,100	1,923,557,938	3,355	916,365,778	8.1	37.0%	39.4%	100.0%	97.1%	102.5%
Container ship	107,477	5,863,593,294	27,622	5,701,594,663	8.4	68.9%	73.8%	107.2%	105.6%	97.7%
General Dry Cargo	35,703	197,851,395	20,686	729,582,681	9.2	46.2%	43.0%	103.3%	101.3%	102.2%
RoRo Cargo / Vehicle	17,346	555,614,320	9,352	2,731,397,721	10.1	70.1%	101.2%	128.6%	159.1%	118.8%
Reefer	479	5,330,086	488	53,061,896	8.3	33.7%	35.6%	88.4%	94.2%	83.8%
Passenger	281	7,437,357	393	256,967,637	9.8	2.5%	1.2%	24.8%	25.2%	97.0%
Miscellaneous	45,910	129,838,853	22,935	427,441,439	7.2	58.4%	17.6%	111.5%	100.0%	110.8%
Tug/Supply	212,784	762,813,072	45,153	205,152,628	6.9	84.0%	419.1%	82.0%	139.0%	79.3%
Total	543,334	12,951,498,391	155,836	14,735,781,044	7.9	61.9%	59.1%	97.0%	105.2%	95.4%

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

Ship size in GT	Totals for Rotterdam in 2016					2016 as percentage of 2015				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average Speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	222,444	92,882,673	59,670	167,351,201	7.8	78.5%	79.4%	89.5%	90.0%	106.8%
1,600-3,000	27,534	64,356,909	16,015	359,758,747	8.6	52.8%	53.0%	105.1%	106.6%	94.5%
3,000-5,000	23,097	90,993,980	21,245	764,826,217	9.9	52.9%	52.2%	111.0%	111.1%	104.2%
5,000-10,000	58,319	450,183,073	20,185	1,431,120,004	9.2	53.9%	55.4%	101.7%	102.3%	102.2%
10,000-30,000	88,555	1,646,964,902	23,685	3,960,057,842	8.9	61.7%	61.8%	106.1%	108.3%	100.0%
30,000-60,000	41,380	1,674,070,965	6,445	2,162,247,952	8	44.1%	41.1%	93.0%	90.2%	100.0%
60,000-100,000	38,522	2,992,001,214	5,166	2,813,558,635	7.1	49.0%	49.1%	99.5%	99.4%	102.9%
>100,000	43,484	5,940,044,675	3,427	3,076,860,446	5.6	73.2%	75.7%	121.8%	122.8%	96.6%
Total	543,334	12,951,498,391	155,836	14,735,781,044	7.9	61.9%	59.1%	97.0%	105.2%	95.4%

Table 5-6 Shipping activities per EMS type for the Amsterdam port area

Ship type	Totals for Amsterdam in 2016					2016 as percentage of 2015				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	20,983	852,892,508	1,410	282,778,340	6.3	62.3%	74.4%	72.1%	90.4%	106.8%
Chem.+Gas tanker	72,693	1,452,615,958	6,568	636,615,204	6.1	101.5%	111.9%	104.7%	117.4%	100.0%
Bulk carrier	54,830	2,583,497,984	2,570	595,582,328	6	76.7%	78.5%	80.5%	83.5%	95.2%
Container ship	386	3,223,344	48	1,541,102	6.8	72.3%	37.2%	208.7%	92.9%	117.2%
General Dry Cargo	89,191	320,453,116	8,374	179,654,506	6.6	80.9%	85.0%	99.0%	100.5%	98.5%
RoRo Cargo / Vehicle	7,256	276,695,391	1,124	306,338,051	6.7	79.7%	100.9%	96.8%	111.0%	115.5%
Reefer	18,386	88,491,638	533	13,164,626	5.7	91.6%	97.6%	100.6%	96.4%	98.3%
Passenger	6,959	151,663,535	805	263,056,636	6.6	90.5%	55.2%	63.7%	70.1%	95.7%
Miscellaneous	28,043	64,242,721	2,774	56,873,072	5.4	47.0%	35.1%	93.1%	109.8%	98.2%
Tug/Supply	136,144	363,396,545	17,820	50,100,206	5.1	92.1%	401.2%	94.2%	150.1%	94.4%
Total	434,871	6,157,172,740	42,026	2,385,704,071	5.751347	79.6%	87.4%	92.7%	95.4%	97.6%

Table 5-7 Shipping activities per EMS ships size classes for the Amsterdam port area

Ship size in GT	Totals for Amsterdam in 2016					2016 as percentage of 2015				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	139,004	60,953,622	19,906	43,299,793	6.2	71.8%	70.0%	91.6%	94.4%	106.9%
1,600-3,000	77,711	178,602,110	5,730	98,024,740	6.9	89.5%	86.4%	95.0%	96.1%	103.0%
3,000-5,000	34,667	136,292,869	3,901	100,348,302	6.6	78.8%	78.8%	122.6%	118.0%	103.1%
5,000-10,000	32,434	233,768,329	2,572	122,498,097	6.1	85.9%	85.0%	93.5%	88.4%	100.0%
10,000-30,000	74,813	1,631,124,129	5,264	653,140,188	5.8	89.8%	90.7%	100.7%	103.0%	96.7%
30,000-60,000	56,220	2,256,065,494	3,443	838,732,428	6	77.0%	77.2%	84.5%	89.1%	105.3%
60,000-100,000	19,775	1,629,076,456	1,116	459,196,932	5.9	104.8%	105.9%	104.2%	102.9%	101.7%
>100,000	246	31,289,731	92	70,463,588	5.5	62.8%	67.1%	63.0%	66.1%	125.0%
Total	434,871	6,157,172,740	42,026	2,385,704,071	5.751347	79.6%	87.4%	92.7%	95.4%	97.6%

Table 5-8 Shipping activities per EMS type for the Dutch part of the Ems area

Ship type	Totals for Ems in 2016					2016 as percentage of 2015				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	35	54,742	139	1,980,703	8.2	22.0%	17.8%	31.7%	22.0%	78.1%
Chem.+Gas tanker	1,766	6,673,243	1,837	101,530,906	10.4	57.5%	62.1%	104.7%	107.7%	99.0%
Bulk carrier	1,351	18,669,269	842	164,478,108	9.4	36.2%	38.8%	91.5%	111.5%	98.9%
Container ship	38	274,935	46	6,538,746	7.9	4.5%	2.4%	56.1%	136.0%	73.8%
General Dry Cargo	30,739	114,886,136	7,129	292,116,166	10.4	49.5%	54.3%	94.1%	104.3%	100.0%
RoRo Cargo / Vehicle	5,308	157,427,657	7,712	1,359,961,181	12.1	32.6%	27.9%	100.3%	75.1%	98.4%
Reefer	257	604,354	74	2,087,812	9.2	19.0%	16.1%	39.8%	38.0%	91.1%
Passenger	560	22,568,135	1,761	36,727,709	12.3	19.8%	35.9%	50.7%	34.7%	106.0%
Miscellaneous	15,678	16,556,696	10,758	221,625,212	7.8	27.1%	13.4%	69.9%	59.4%	105.4%
Tug/Supply	67,023	106,822,268	12,995	244,324,681	9.7	64.1%	95.6%	94.2%	177.1%	90.7%
Total	122,755	444,537,435	43,293	2,431,371,224	9.892699	48.6%	38.7%	84.3%	81.9%	99.6%

Table 5-9 Shipping activities per EMS ships size classes for the Dutch part of the Ems area

Ship size in GT	Totals for Ems in 2016					2016 as percentage of 2015				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	70,589	23,022,261	16,565	70,096,246	10.6	55.3%	55.2%	77.4%	89.5%	102.9%
1,600-3,000	25,847	60,678,407	12,039	288,082,833	9.6	44.2%	43.5%	106.7%	106.1%	94.1%
3,000-5,000	10,367	43,228,121	5,095	189,242,777	9.7	50.4%	52.2%	142.7%	142.3%	97.0%
5,000-10,000	8,143	55,107,458	6,203	480,834,279	10.5	65.5%	67.8%	64.9%	81.0%	95.5%
10,000-30,000	5,064	92,078,472	1,847	378,588,349	10.2	36.5%	36.5%	63.2%	60.4%	94.4%
30,000-60,000	2,038	112,026,406	1,242	771,450,611	9.3	24.2%	25.8%	73.8%	75.9%	97.9%
60,000-100,000	562	36,154,755	287	232,697,052	7.6	46.7%	47.3%	99.7%	100.7%	67.9%
>100,000	145	22,241,557	16	20,379,078	8.2	61.2%	56.1%	100.0%	121.1%	134.4%
Total	122,755	444,537,435	43,293	2,431,371,224	9.892699	48.6%	38.7%	84.3%	81.9%	99.6%

Table 5-10 Shipping activities per EMS type for the port area of Den Helder

Ship type	Totals for Den Helder in 2016					2016 as percentage of 2015				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	21	986,176	0	3,789	2.8	35.6%	30.4%	0.0%	1.4%	62.2%
Chem.+Gas tanker	64	625,471	6	212,291	4.5	48.9%	44.3%	20.7%	88.2%	69.2%
Bulk carrier	26	1,520,516	1	87,683	3.6	44.8%	53.2%	50.0%	21.0%	80.0%
Container ship	451	5,297,404	3	123,076	4.5	593.4%	227.1%	100.0%	50.8%	109.8%
General Dry Cargo	2,107	7,458,789	56	1,222,304	6	75.3%	186.3%	38.6%	141.6%	88.2%
RoRo Cargo / Vehicle	6,857	90,444,932	1,502	144,580,997	6.8	25396.3%	9844.2%	75100.0%	75701.6%	130.8%
Reefer	5,704	62,018,619	2,750	319,097,534	6.6	379.3%	1993.1%	2750.0%	3435.7%	122.2%
Passenger	42,703	33,002,969	1,147	6,162,526	4.6	125.4%	114.3%	71.5%	62.8%	55.4%
Miscellaneous	128,884	165,747,770	3,820	34,961,922	6	100.2%	96.8%	77.3%	73.0%	98.4%
Total	186,817	367,102,646	9,285	506,452,122	6.132461	110.8%	168.3%	134.7%	728.8%	92.3%

Table 5-11 Shipping activities per EMS ships size classes for the port area of Den Helder

Ship size in GT	Totals for Den Helder in 2016					2016 as percentage of 2015				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	115,452	47,940,425	2,705	6,872,753	6.2	117.2%	123.3%	80.6%	71.5%	88.6%
1,600-3,000	47,439	105,395,077	2,047	27,175,892	6.8	81.4%	78.5%	69.0%	66.2%	107.9%
3,000-5,000	10,545	42,721,959	266	6,370,426	4.5	172.0%	186.7%	106.0%	110.1%	80.4%
5,000-10,000	4,543	36,222,984	955	66,499,034	5.4	509.3%	542.8%	3080.6%	5608.4%	108.0%
10,000-30,000	8,783	129,861,511	3,310	399,244,205	5.2	2076.4%	1851.5%	3447.9%	3674.2%	89.7%
30,000-60,000	28	1,225,209	1	132,527	2.8	41.8%	40.9%	50.0%	38.2%	38.9%
60,000-100,000	23	1,848,861	0	123,974	5	56.1%	57.5%	0.0%	28.6%	128.2%
>100,000	11	1,919,244	0	33,311	5.5	84.6%	93.9%		39.8%	275.0%
Total	186,817	367,102,646	9,285	506,452,122	6.132461	110.8%	168.3%	134.7%	728.8%	92.3%

Table 5-12 Shipping activities per EMS type for the port area of Harlingen

Ship type	Totals for Harlingen in 2016					2016 as percentage of 2015				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.hours	Average speed	Hours	GT.Hours	Hours	GT.nm	Average speed
Oil tanker	21	1,349,051	4	1,061,562	3.5	80.8%	111.9%	33.3%	34.6%	66.0%
Chem.+Gas tanker	578	2,592,837	33	1,082,358	7	59.1%	139.7%	12.2%	50.7%	109.4%
Bulk carrier	36	1,187,766	8	637,575	5.3	67.9%	65.4%	47.1%	29.4%	103.9%
Container ship	43	2,012,096	6	1,406,942	5.8	7.6%	57.1%	19.4%	69.2%	103.6%
General Dry Cargo	15,867	40,665,690	3,044	54,124,874	8	98.0%	77.3%	200.1%	173.2%	102.6%
RoRo Cargo / Vehicle	6,363	12,174,257	1,231	25,960,860	6.4	27665.2%	1987.7%	24620.0%	5811.6%	133.3%
Reefer	1,147	6,624,139	180	7,870,397	8.9	46.0%	54.9%	75.9%	101.5%	108.5%
Passenger	2,094	710,543	150	623,878	8.7	223.5%	57.5%	214.3%	40.8%	129.9%
Miscellaneous	33,475	23,901,472	4,270	40,295,801	7.2	107.2%	117.4%	96.0%	108.6%	101.4%
Tug/Supply	45,880	59,103,084	514	2,363,004	6.3	126.4%	168.0%	41.5%	42.5%	98.4%
Total	105,504	150,320,935	9,440	135,427,251	7.356123	115.4%	113.7%	118.0%	144.6%	102.8%

Table 5-13 Shipping activities per EMS ships size classes for the port area of Harlingen

Ship size in GT	Totals for Harlingen in 2016					2016 as percentage of 2015				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.hours	Average speed	Hours	GT.Hours	Hours	GT.nm	Average speed
100-1,600	69,419	39,834,796	5,119	28,490,059	8.7	110.2%	131.0%	96.5%	109.5%	120.8%
1,600-3,000	28,915	70,615,172	3,565	67,642,346	8.8	179.0%	169.9%	305.5%	279.8%	103.5%
3,000-5,000	3,925	14,798,534	227	7,858,097	8.8	81.0%	76.9%	94.6%	99.3%	111.4%
5,000-10,000	3,084	18,432,799	502	26,527,788	6.9	56.9%	56.9%	108.9%	100.9%	106.2%
10,000-30,000	94	1,479,143	15	1,329,601	5	102.2%	82.8%	78.9%	80.3%	102.0%
30,000-60,000	34	1,493,988	8	1,618,731	5	46.6%	48.5%	61.5%	67.9%	104.2%
60,000-100,000	18	1,411,813	2	562,129	3	85.7%	91.7%	33.3%	20.6%	55.6%
>100,000	13	2,254,688	2	1,398,500	4.1	81.3%	109.2%	66.7%	68.9%	67.2%
Total	105,504	150,320,935	9,440	135,427,251	7.356123	115.4%	113.7%	118.0%	144.6%	102.8%

5.3 Activities of seagoing vessels in the Netherlands sea area

The shipping activities in the Netherlands sea area are presented in Table 5-14 and Table 5-15, where the activities of 2016 are compared to the activities of 2015. 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.

The activities for moving vessels show an average decrease of hours of 7.2% and the GT.nm remained about the same.

For ships at anchor, the average number of hours increased by 5% and the average number of GT.hours increased by 17.2%.

Table 5-14 Shipping activities per EMS type for the Netherlands Continental Shelf and 12-mile zone

Ship type	Totals for NCS and 12-mile zone in 2016					2016 as percentage of 2015				
	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	125,352	6,574,216,584	69,859	41,262,856,413	10	101.80%	109.10%	79.60%	94.10%	100.60%
Chem.+Gas tanker	337,789	4,318,775,574	271,576	34,605,044,924	11	125.90%	136.40%	101.50%	109.80%	97.50%
Bulk carrier	99,440	5,300,557,694	102,979	38,520,836,755	10	101.40%	102.50%	91.30%	95.10%	100.50%
Container ship	60,497	2,503,945,270	168,371	121,251,567,814	13.7	133.40%	150.90%	98.60%	100.30%	101.50%
General Dry Cargo	98,360	481,083,338	394,268	18,192,262,892	11.1	100.40%	93.50%	101.00%	105.70%	104.30%
RoRo Cargo / Vehicle	6,415	246,777,021	125,587	67,793,572,235	13.7	94.40%	79.20%	103.70%	114.20%	104.40%
Reefer	4,830	34,472,564	13,090	1,581,405,236	12.4	221.60%	192.60%	92.10%	93.40%	101.90%
Passenger	209	2,532,969	8,999	8,061,684,595	13.2	11.50%	21.70%	40.80%	44.90%	98.90%
Miscellaneous	26,348	162,694,589	76,096	1,727,921,563	8.3	45.50%	48.60%	72.20%	61.80%	112.30%
Tug/Supply	90,261	740,401,209	132,140	2,498,012,941	8.3	85.10%	449.70%	77.30%	156.40%	97.70%
Total	849,501	20,365,456,812	1,362,965	335,495,165,368	11.1	105.00%	117.20%	92.80%	99.40%	103.00%

Table 5-15 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 2016					2016 as percentage of 2015				
	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	41,611	27,487,656	156,170	874,542,531	8.1	49.80%	61.90%	74.80%	89.20%	104.70%
1,600-3,000	93,746	227,099,524	308,908	6,852,101,283	9.51	87.00%	87.80%	95.20%	96.90%	98.80%
3,000-5,000	112,442	448,356,575	181,032	7,657,979,501	11	106.00%	106.40%	97.30%	100.00%	101.40%
5,000-10,000	140,634	1,025,381,636	171,735	15,330,260,953	11.5	114.50%	116.00%	94.60%	95.70%	97.90%
10,000-30,000	247,957	4,739,154,941	282,618	71,196,840,678	12. 9	122.30%	122.30%	97.80%	99.20%	99.60%
30,000-60,000	116,831	5,063,230,411	141,544	82,935,713,928	12.4	117.50%	118.30%	92.70%	92.90%	96.40%
60,000-100,000	74,326	5,655,295,786	84,389	78,119,149,413	12.1	108.70%	106.80%	102.30%	101.70%	93.40%
>100,000	21,952	3,179,450,281	36,572	72,528,577,079	11.9	139.20%	137.20%	105.80%	106.90%	98.90%
Total	849,501	20,365,456,812	1,362,965	335,495,165,368	11.1	105.00%	117.20%	92.80%	99.40%	100.40%

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

The average number of ships per day, in the port areas and at sea, are presented in Table 5-16. Compared to the results presented in the previous study, most remarkable is the decrease of 38% of berthed ships in the port of Rotterdam and the increase of moving ships in Den Helder, by 35%. The increase in Den Helder might be due to the large dependency on the offshore industry. For the NCS combined with the 12-miles zone the average number of ships decreased slightly for moving ships, and increased slightly for non-moving ships. The average speed in the larger ports decreased slightly.

Table 5-16 Average number of ships per day, in distinguished areas, excluding Fishing vessels.

Area	In 2016			In 2016 as percentage of 2015		
	Average # ships/day		Speed	Average # ships/day		Speed
	Not moving	Moving	Knots	Not moving	Moving	Knots
Amsterdam	50	5	5.8	80%	93%	98%
Den Helder	21	1	6.1	111%	135%	92%
Ems	14	5	9.9	49%	84%	100%
Harlingen	12	1	7.4	115%	118%	103%
Rotterdam	62	18	7.9	62%	97%	95%
Western Scheldt	46	19	10.1	76%	93%	96%
NCS + 12-mile zone	97	155	11.1	105%	93%	103%

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

6.1 Introduction

This chapter presents the results of the emission calculations for 2016 for the Dutch port areas and the Netherlands sea area. To indicate the change in emissions, all values for 2016 are compared with the values of 2015.

The emissions for the port areas are given in Section 6.2 and for the NCS and 12-mile zone in Section 6.3. Section 6.4 presents the spatial distribution of the 2016 NO_x emissions. Also the absolute and relative change in this spatial distribution compared to 2015 is presented in figures.

6.2 Emissions in port areas

Table 6-1 contains the emissions for the six Dutch port areas, calculated for ships berthed and sailing within the port areas. Table 6-2 contains the same emissions expressed as a percentage of the corresponding emissions in 2015. Similar to the procedure in the previous studies, the values for at berth include all vessels with speed below 1 knots, so also the vessels at anchor.

Table 6-2 shows a clear decrease of CO emissions between 2015 and 2016. This is due to a change in the emission factor (for further details see appendix A: Emission Factors). The emission factor for CO has been reduced by a factor 4. The emission factor for NO_x has been increased slightly, resulting in a slight increase in NO_x for moving ships. However, the NO_x still decreased for berthed ships. The emission factor for SO_2 has also been lowered, but only the emissions for berthed ships decreased. For moving ships there is a slight increase in SO_2. Furthermore, mainly the emissions for berthed ships decreased, due to the large decrease of berthed hours in the ports.

Table 6-1 Total emissions in ton in each port area for 2016, excluding Fishing vessels, EMS-type 11.

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Total
1011 Methane	Berthed	-	-	-	-	-	-	-
	Sailing	2	0	0	6	2		
	Total	2	0	0	6	2		
1237 VOC	Berthed	56	229	83	7	8	3	386
	Sailing	290	184	33	32	7	3	548
	Total	346	413	116	39	15	7	934
4001 SO_2	Berthed	107	456	146	15	16	7	747
	Sailing	267	153	24	29	7	3	482
	Total	373	609	170	44	22	9	1,229
4013 NO_x	Berthed	1,347	5,198	1,818	192	208	87	8,850
	Sailing	9,631	4,905	783	898	185	85	16,486
	Total	10,978	10,103	2,600	1,089	393	173	25,336
4031 CO	Berthed	90	396	138	12	12	5	652
	Sailing	507	334	58	48	12	5	964
	Total	597	730	196	60	24	10	1,616
4032 CO_2	Berthed	116,639	529,355	190,665	13,874	13,567	5,517	869,616
	Sailing	424,293	243,342	38,671	47,235	11,037	4,471	769,048
	Total	540,932	772,696	229,336	61,109	24,603	9,988	1,638,664
6601 Aerosols MDO	Berthed	21	57	36	2	3	1	121
	Sailing	36	29	6	7	1	2	81
	Total	58	86	42	9	4	3	202
6602 Aerosols HFO	Berthed	5	54	4	2	1	0	67
	Sailing	215	130	19	24	6	1	395
	Total	221	184	23	26	8	1	462

Table 6-2 Emissions in each port area (including the total Western Scheldt area) for 2016 as percentage of the emissions in 2015, excluding Fishing vessels, EMS-type 11. The percentages in grey are based on very low absolute numbers, and not very reliable.

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Total
1011 Methane	Berthed							
	Sailing	125.6%	81.7%	572.7%	155.9%	8143.5%		
	Total	125.6%	81.7%	572.7%	155.9%	8143.5%		
1237 VOC	Berthed	122.2%	73.7%	97.8%	42.5%	127.1%	114.4%	82.5%
	Sailing	103.4%	99.5%	93.5%	75.6%	214.8%	127.6%	100.0%
	Total	106.1%	83.3%	96.6%	65.9%	157.8%	120.9%	92.0%
4001 SO_2	Berthed	123.9%	78.7%	97.9%	44.1%	124.4%	119.7%	86.1%
	Sailing	107.3%	99.5%	93.9%	82.7%	207.1%	119.4%	102.8%
	Total	111.6%	83.1%	97.3%	63.4%	140.9%	119.6%	91.9%
4013 NO_x	Berthed	125.8%	82.6%	99.3%	44.4%	126.2%	118.7%	89.8%
	Sailing	110.1%	102.4%	95.1%	81.6%	221.3%	125.7%	105.6%
	Total	111.8%	91.2%	98.0%	71.1%	158.3%	122.1%	99.5%
4031 CO	Berthed	36.4%	23.9%	32.0%	11.7%	32.2%	30.9%	26.2%
	Sailing	25.9%	25.1%	23.7%	19.8%	53.5%	32.0%	25.2%
	Total	27.1%	24.4%	29.0%	17.4%	40.2%	31.4%	25.6%
4032 CO_2	Berthed	126.1%	69.2%	96.7%	43.2%	131.8%	118.0%	78.9%
	Sailing	107.5%	99.5%	94.0%	84.0%	217.8%	117.4%	103.1%
	Total	111.0%	76.5%	96.2%	69.1%	160.2%	117.7%	88.7%
6601 Aerosols MDO	Berthed	275.7%	619.3%	440.3%	55.5%	138.6%	136.4%	383.1%
	Sailing	199.1%	148.4%	123.7%	93.3%	153.5%	148.9%	155.2%
	Total	221.9%	299.6%	322.1%	81.9%	143.4%	142.9%	240.7%
6602 Aerosols HFO	Berthed	38.2%	38.7%	13.1%	34.2%	106.2%	65.4%	34.7%
	Sailing	87.2%	84.1%	79.4%	75.3%	254.4%	68.0%	85.7%
	Total	84.5%	62.6%	41.2%	69.4%	210.2%	67.3%	70.7%

6.3 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, just like in the previous studies. 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 2016 are summarised in Table 6-3. This table also contains a comparison with 2015. In this table the changes in CO and SO_2 are also very clearly visible. Furthermore, there is a large increase in percentage of Aerosols MDO, however, this is only a small absolute amount.
The total average number of ships on the north sea is very similar to previous year. For the moving ships is decreased by 7% and for the non moving ships this increased by 5%.

Table 6-3 Emissions of ships in ton in the Netherlands sea area for 2016 compared with 2015, excluding Fishing vessels, EMS-type 11.

Nr	Substance	Emission in ton in 2016			Emission in 2016 as percentage of 2015		
		Not moving	Moving	Total	Not moving	Moving	Total
1011	Methane	-	33	33	-	91.0%	91.0%
1237	VOC	103	2,293	2,397	112.7%	95.3%	95.9%
4001	SO_2	236	4,604	4,841	53.3%	40.3%	40.8%
4013	NO_x	3,040	82,462	85,502	113.3%	99.5%	99.9%
4031	CO	163	3,859	4,022	28.5%	24.1%	24.2%
4032	CO_2	187,432	3,666,339	3,853,771	114.3%	96.5%	97.3%
6601	Aerosols MDO	75	247	322	333.0%	164.2%	186.3%
6602	Aerosols HFO	20	2,228	2,248	15.1%	71.8%	69.5%
Number of Ships		97	155	252	105%	93%	97%

6.4 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 6-1 to Figure 6-21.

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 2015 and 2016 and the third one shows the *relative* change in emission between 2015 and 2016. 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 2015 and 2016 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 6-2 shows an increase in absolute NO_x emissions for the main shipping routes in the Western Scheldt.

Figure 6-5 clearly shows the decrease of berthed NO_x emissions, but also an increase of emissions in the Maasvlakte 2.

The increase of emissions for moving ships in Den Helder is clearly demonstrated in Figure 6-14. Where especially the fairway between Den Helder and Texel show an increase in NO_x emissions.

On the NCS the absolute changes are rather small, see Figure 6-20.

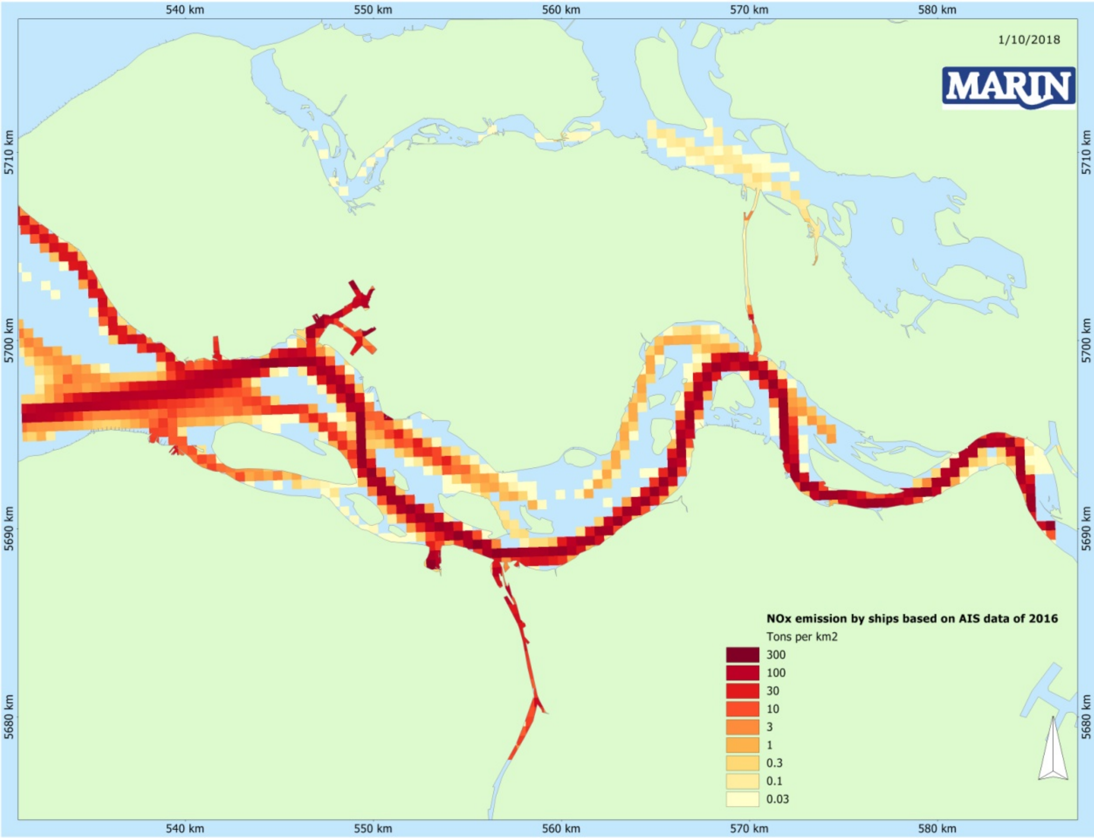

Figure 6-1 **NO_x emission in 2016 in the Dutch part of the Western Scheldt by ships with AIS.**

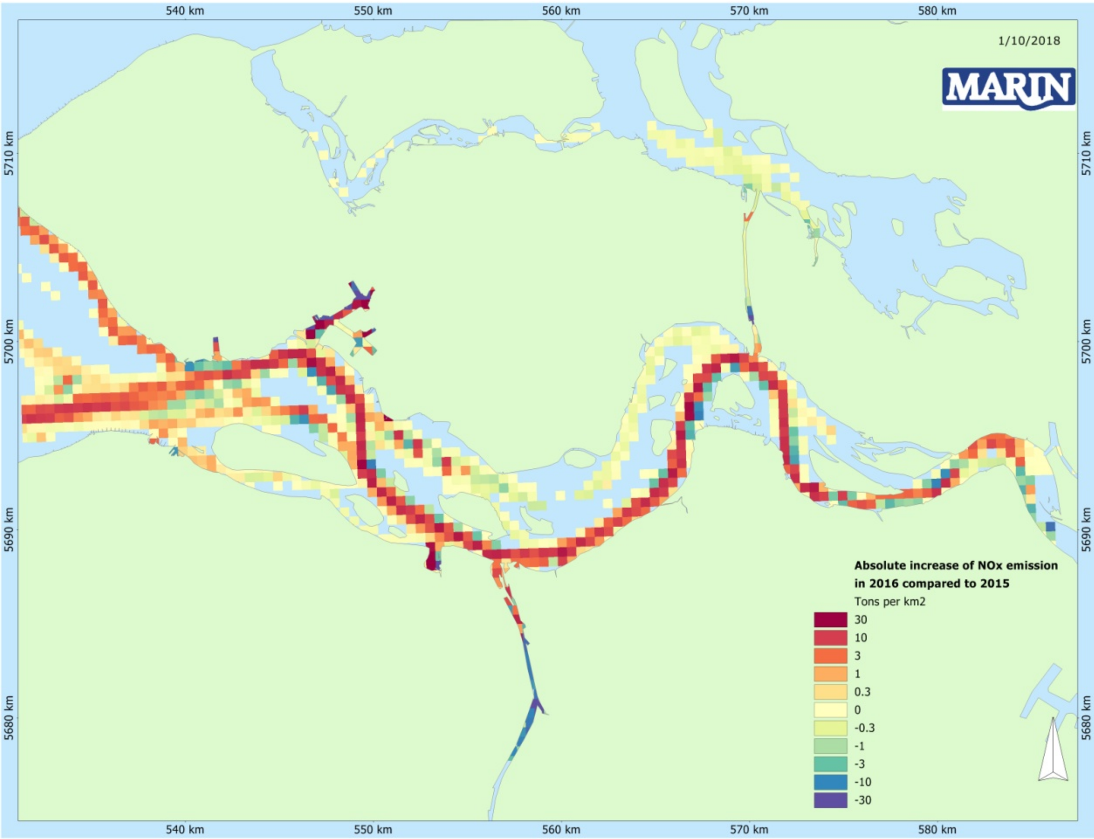

Figure 6-2 **Absolute change in NO_x emission from 2015 to 2016 in the Dutch part of the Western Scheldt by ships with AIS.**

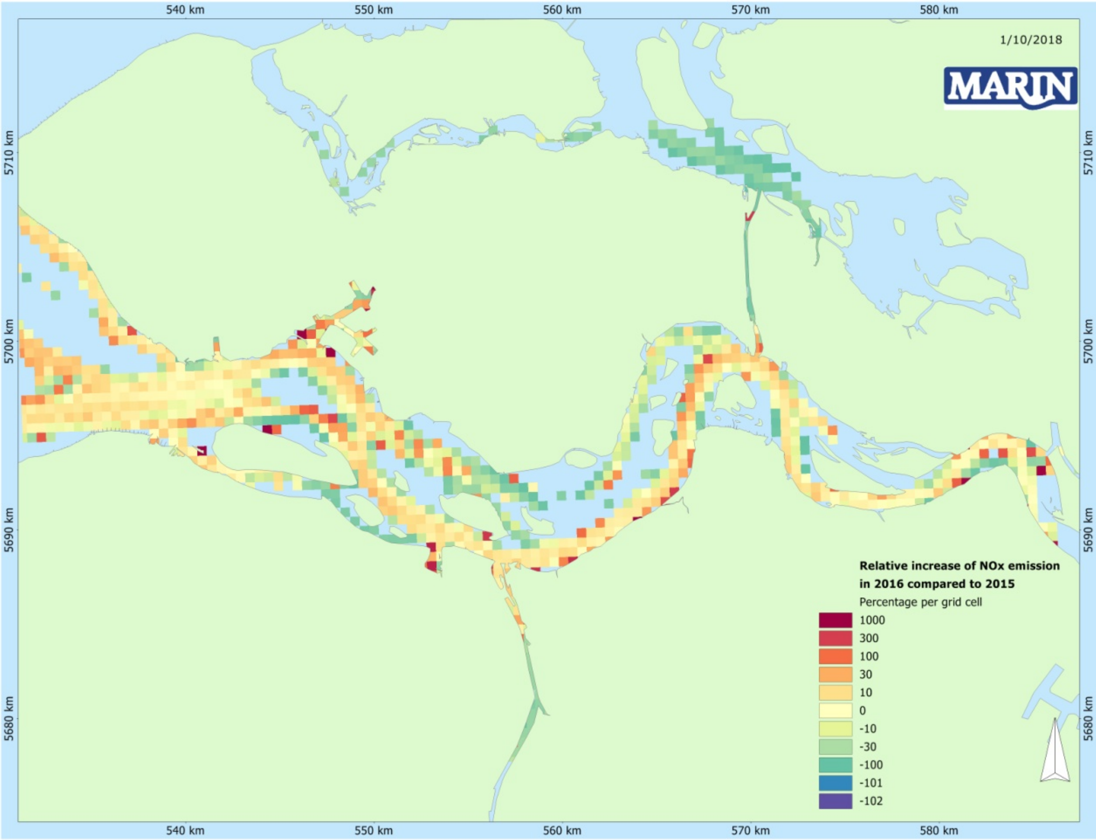

Figure 6-3 Relative change in NO_x emission from 2015 to 2016 in the Dutch part of the Western Scheldt by ships with AIS.

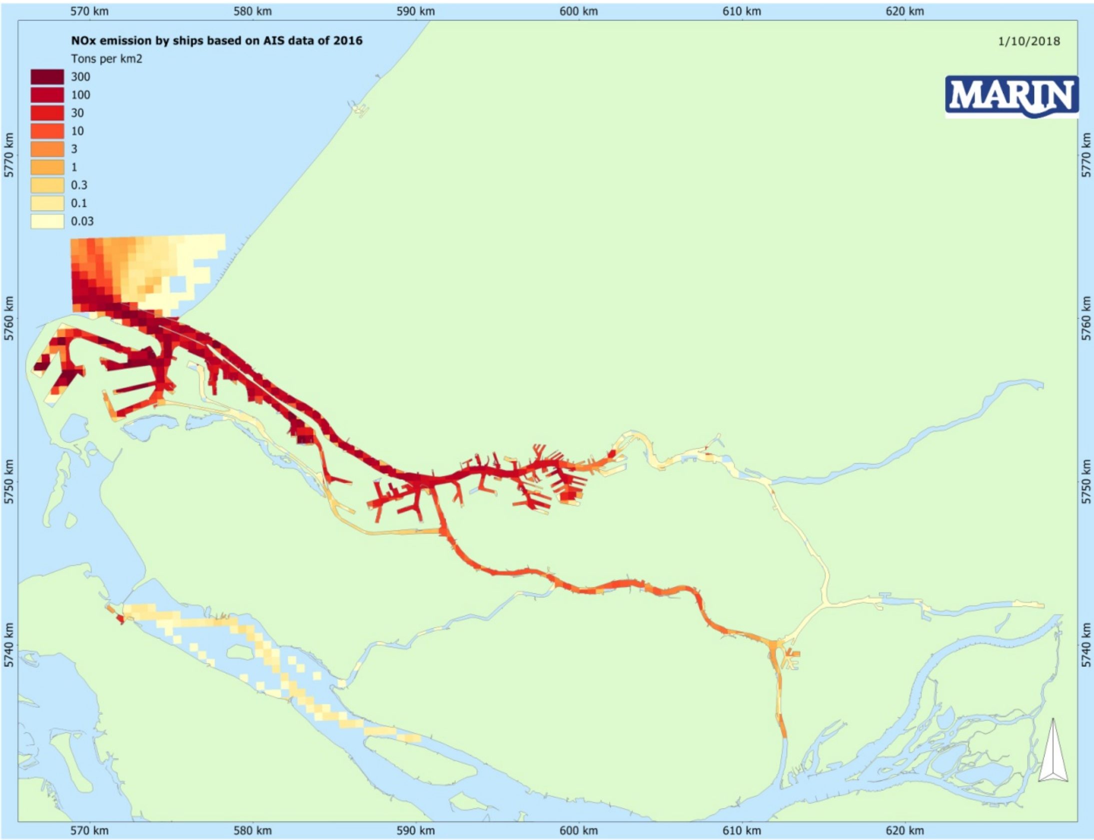

Figure 6-4 NO_x emission in 2016 in the port area of Rotterdam by ships with AIS.

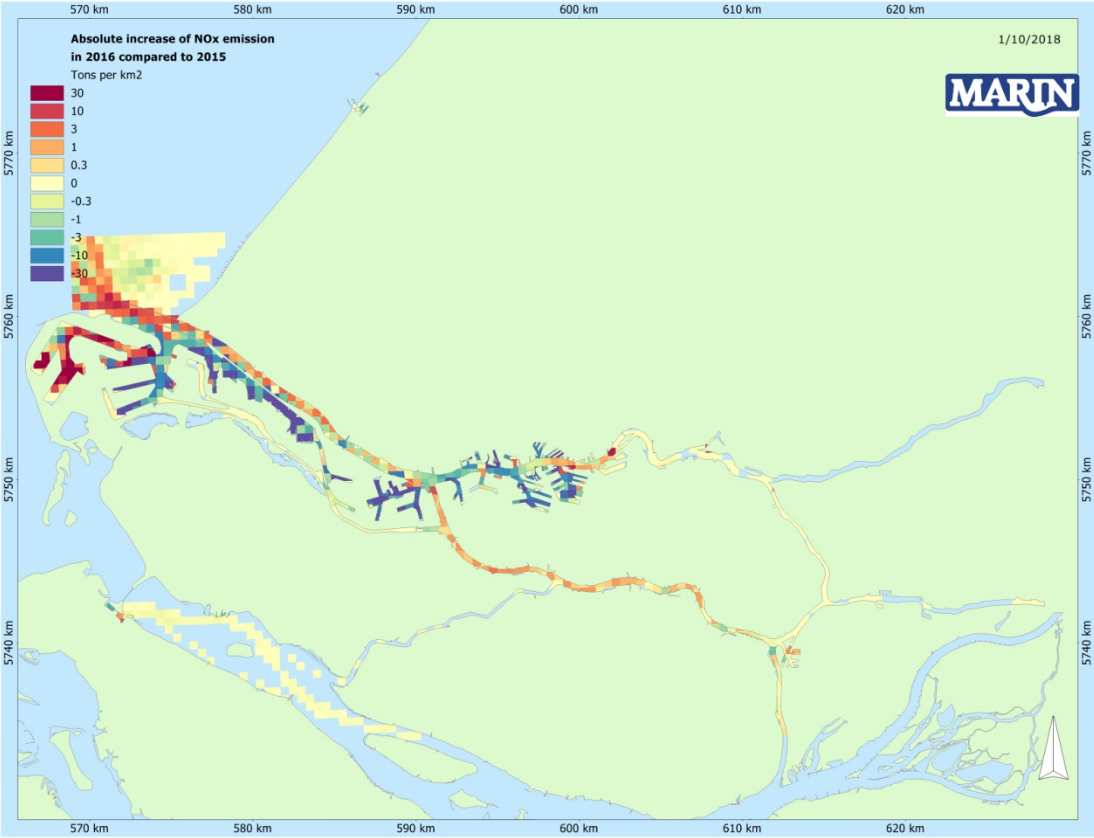

Figure 6-5 Absolute change in NO_x emission from 2015 to 2016 in the port area of Rotterdam by ships with AIS.

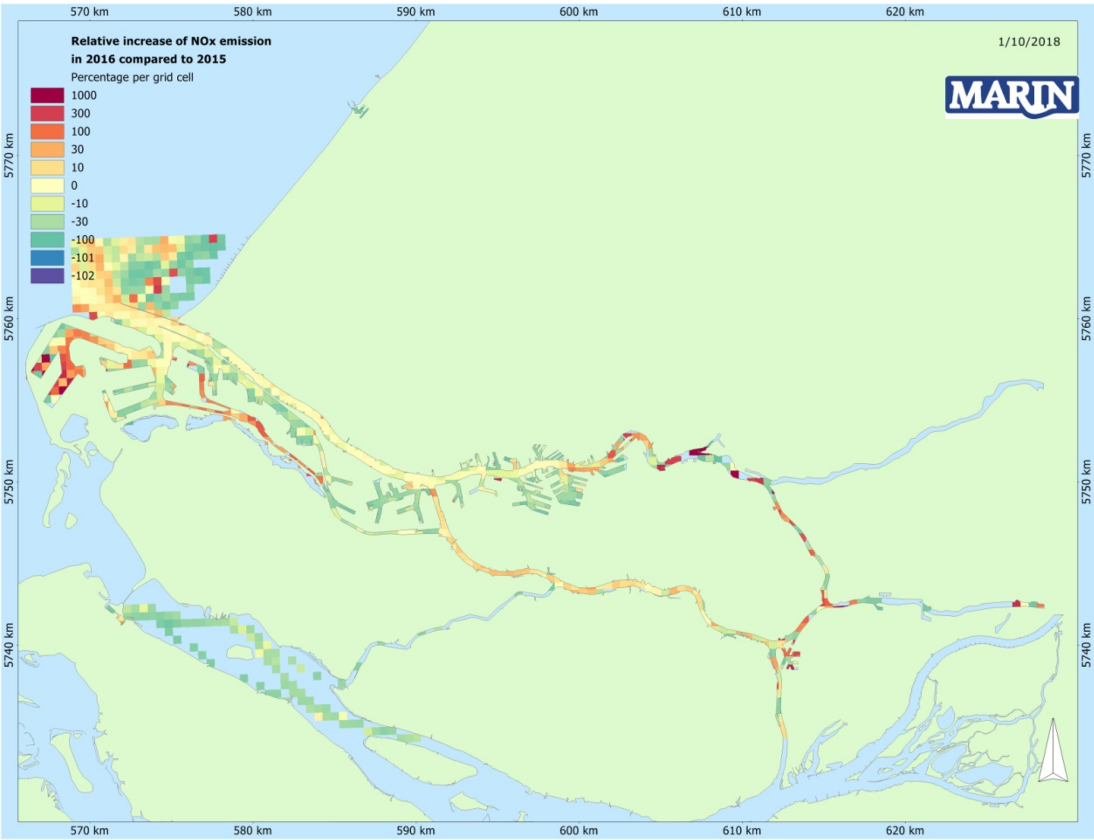

Figure 6-6 Relative change in NO_x emission from 2015 to 2016 in the port area of Rotterdam by ships with AIS.

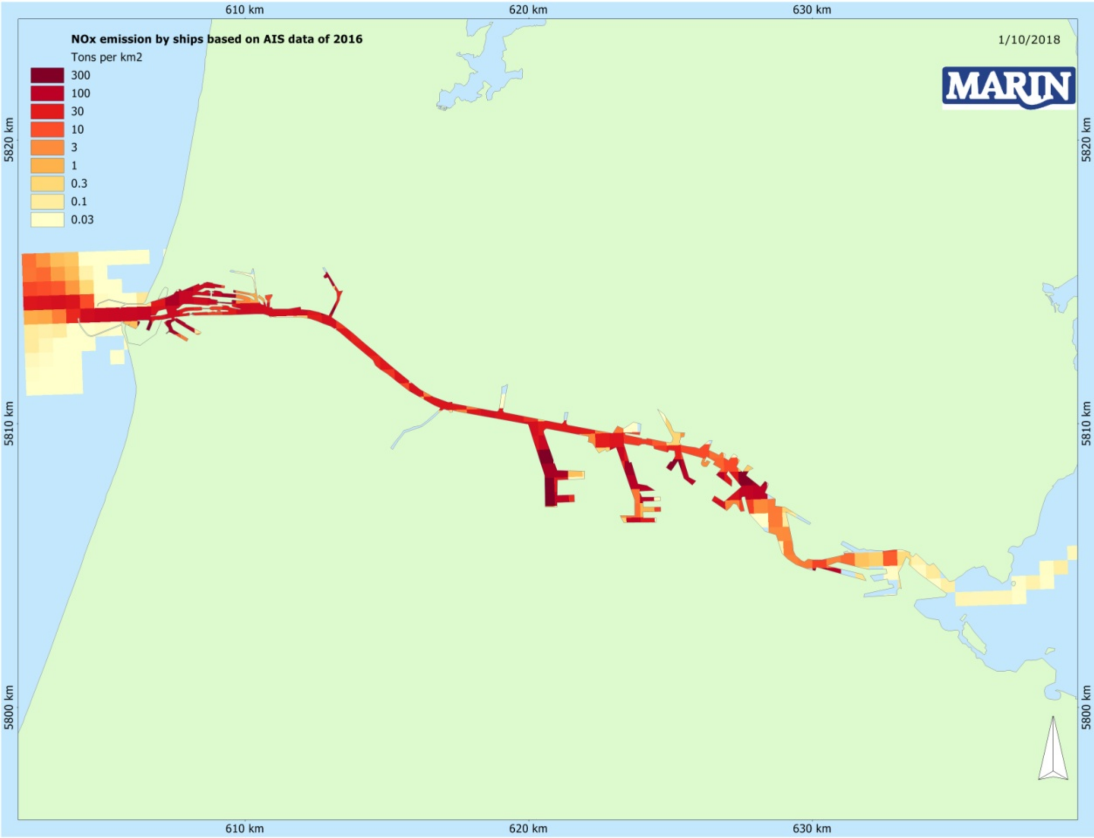

Figure 6-7 **NO$_x$ emission in 2016 in the port area of Amsterdam by ships with AIS.**

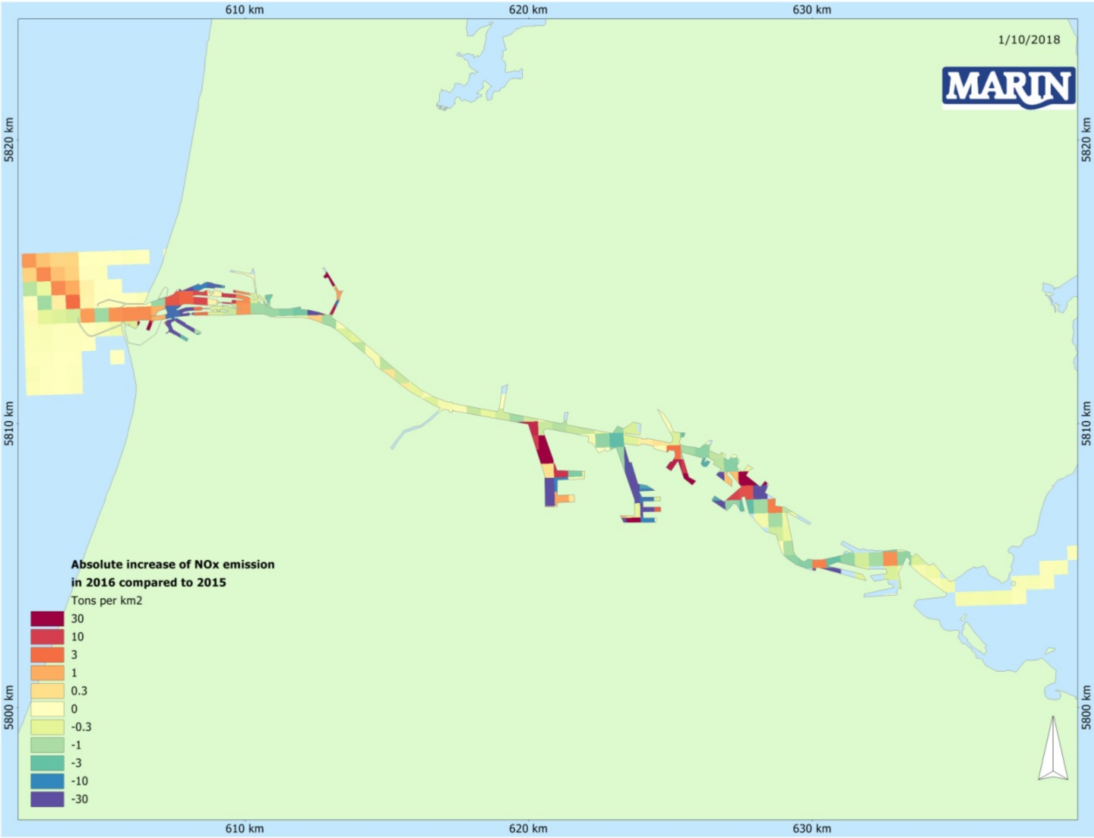

Figure 6-8 **Absolute change in NO$_x$ emission from 2015 to 2016 in the port area of Amsterdam by ships with AIS.**

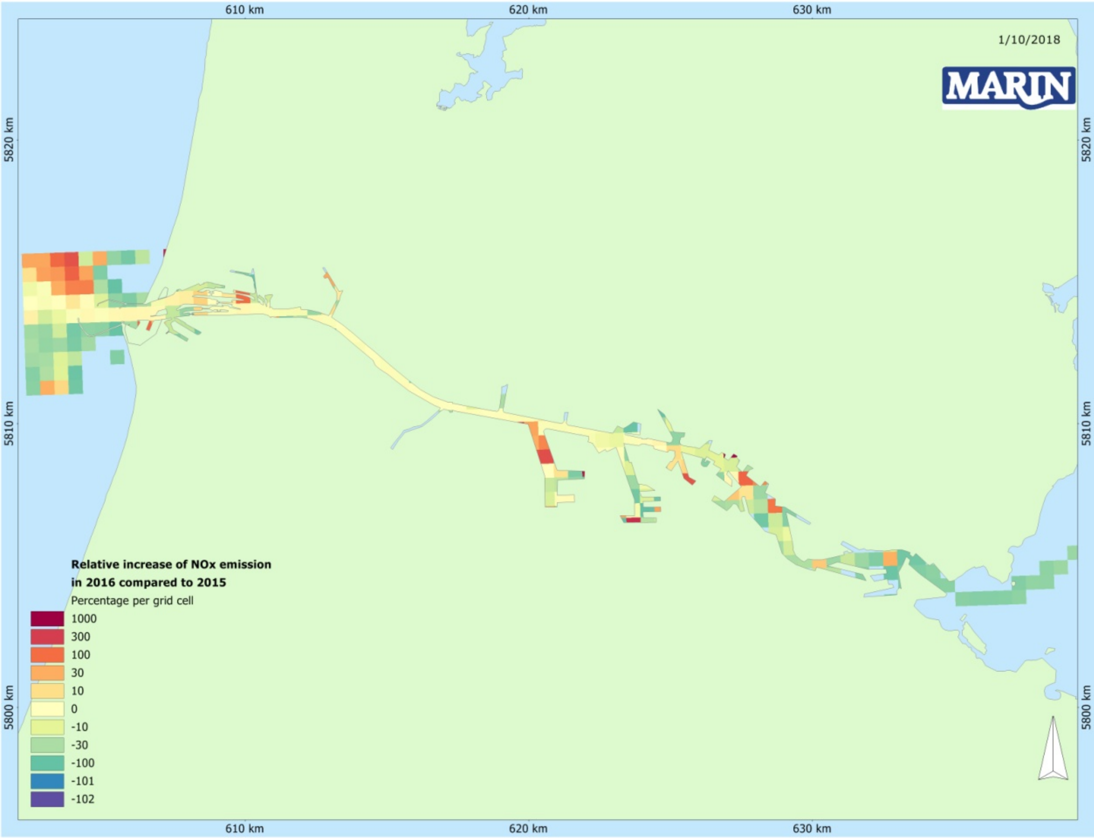

Figure 6-9 Relative change in NO_x emission from 2015 to 2016 in the port area of Amsterdam by ships with AIS.

Figure 6-10 NO_x emission in 2016 in the Ems area by ships with AIS.

Figure 6-11 Absolute change in NO_x emission from 2015 to 2016 in the Ems area by ships with AIS.

Figure 6-12 Relative change in NO_x emission from 2015 to 2016 in the Ems area by ships with AIS.

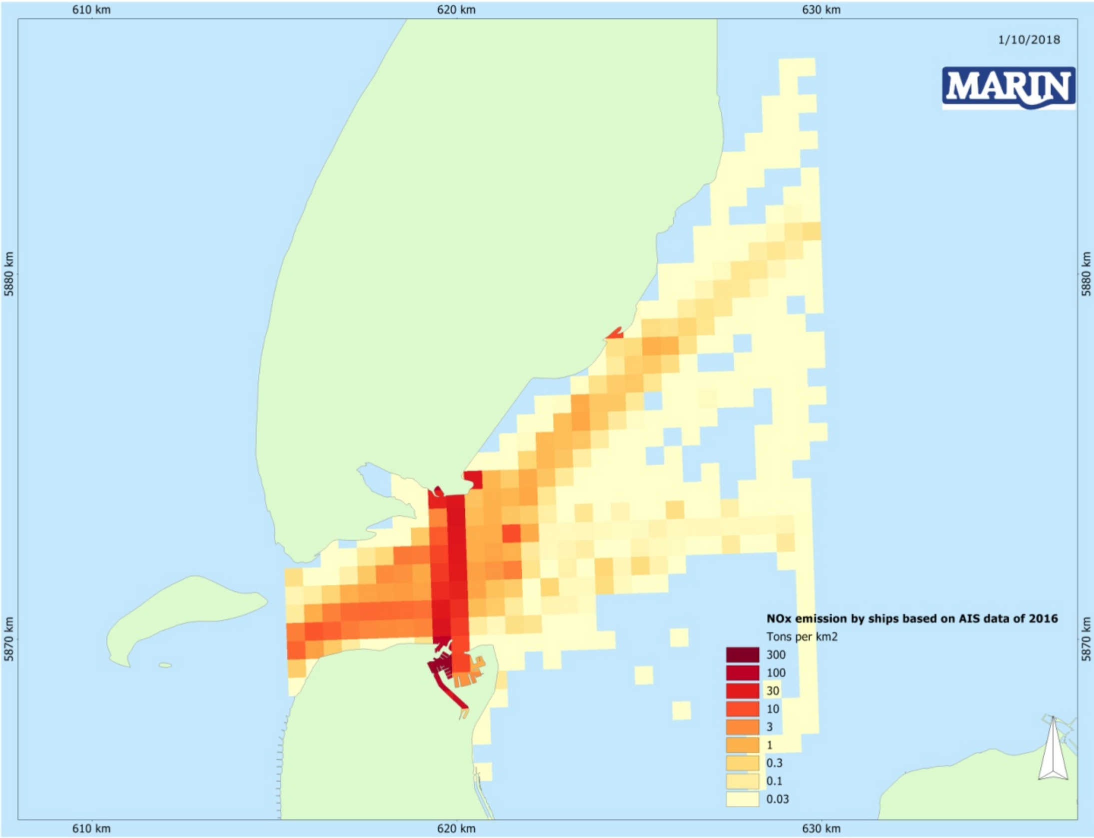

Figure 6-13 **NO_x emission in 2016 in the port area of Den Helder by ships with AIS.**

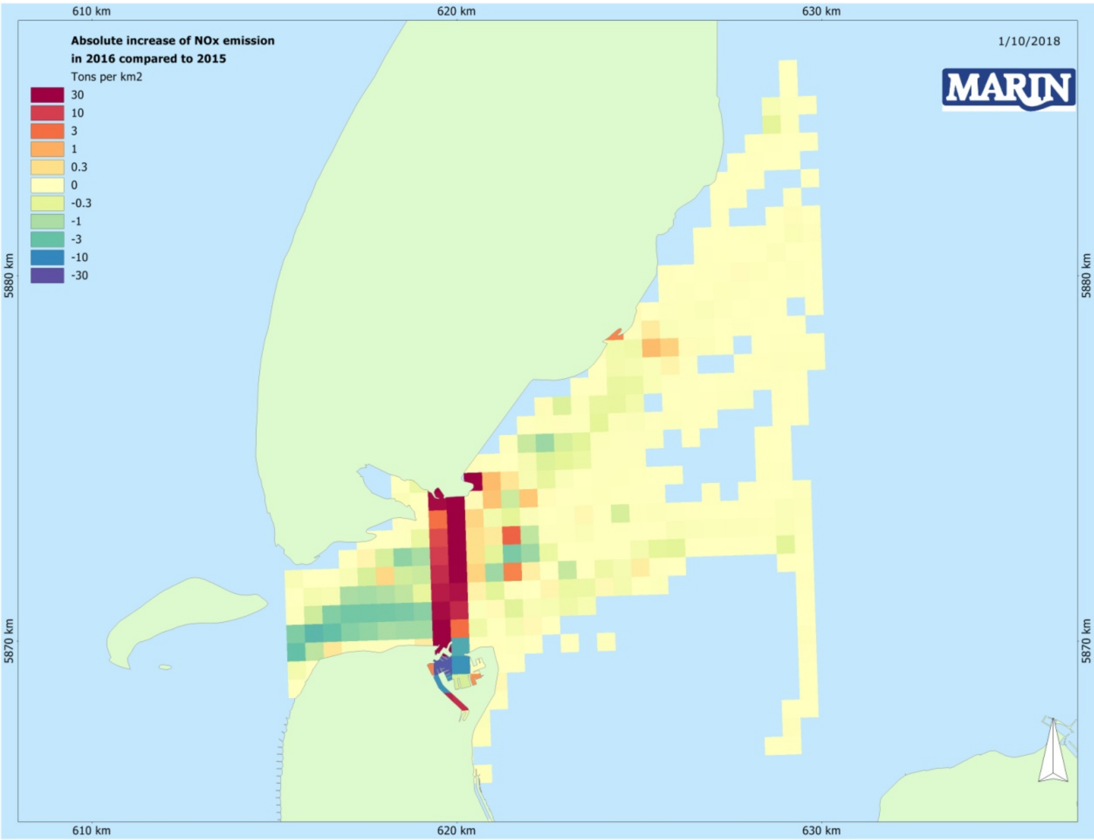

Figure 6-14 **Absolute change in NO_x emission from 2015 to 2016 in the port area of Den Helder by ships with AIS.**

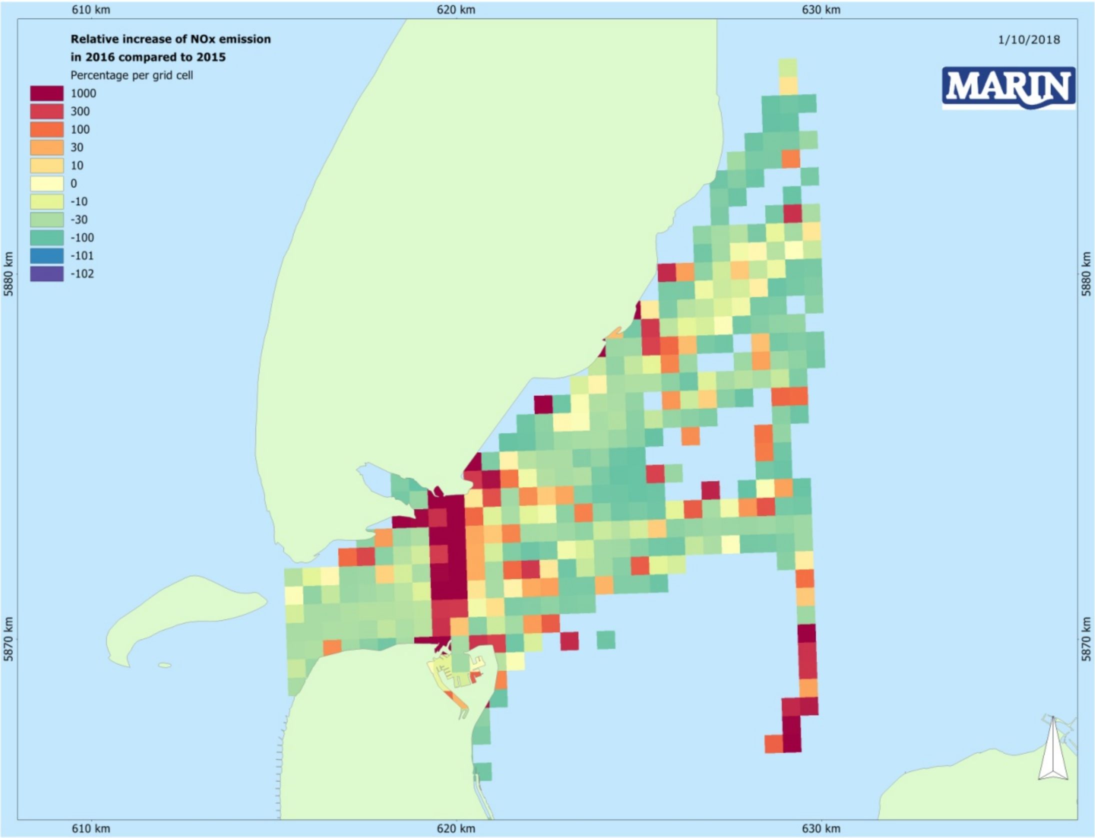

Figure 6-15 Relative change in NO_x emission from 2015 to 2016 in the port area of Den Helder by ships with AIS.

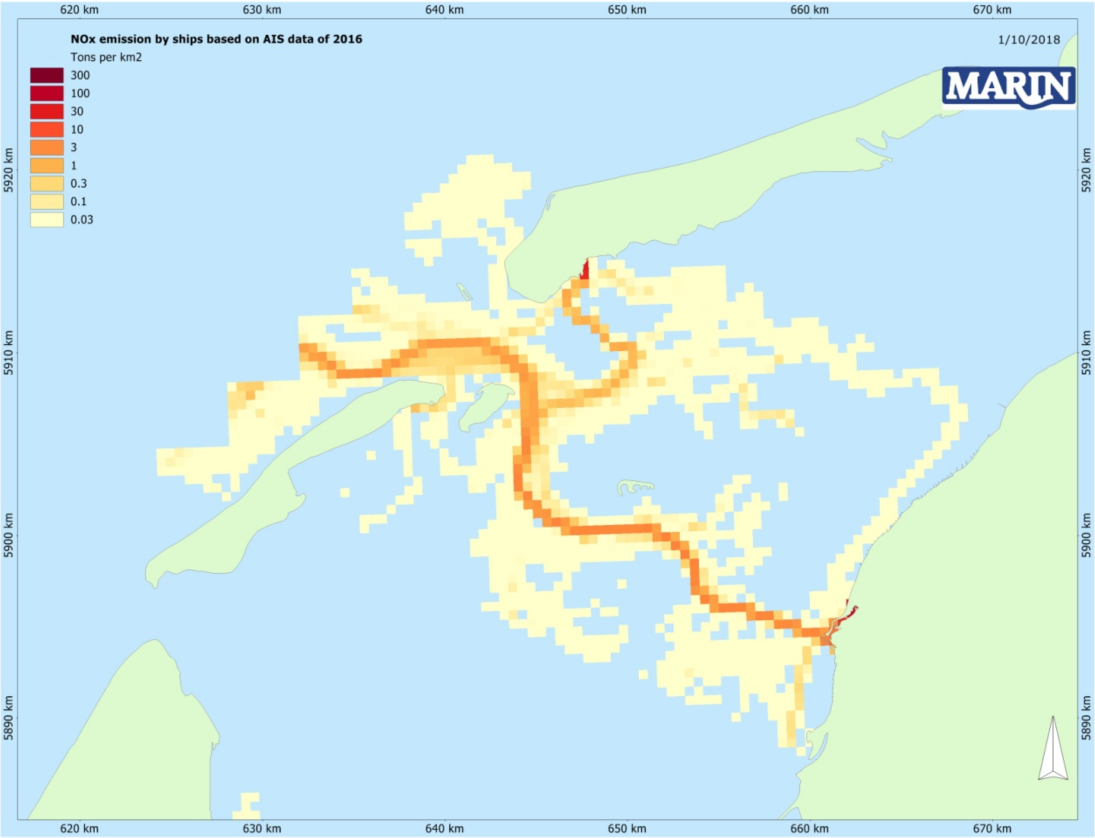

Figure 6-16 NO_x emission in 2016 in the port area of Harlingen by ships with AIS.

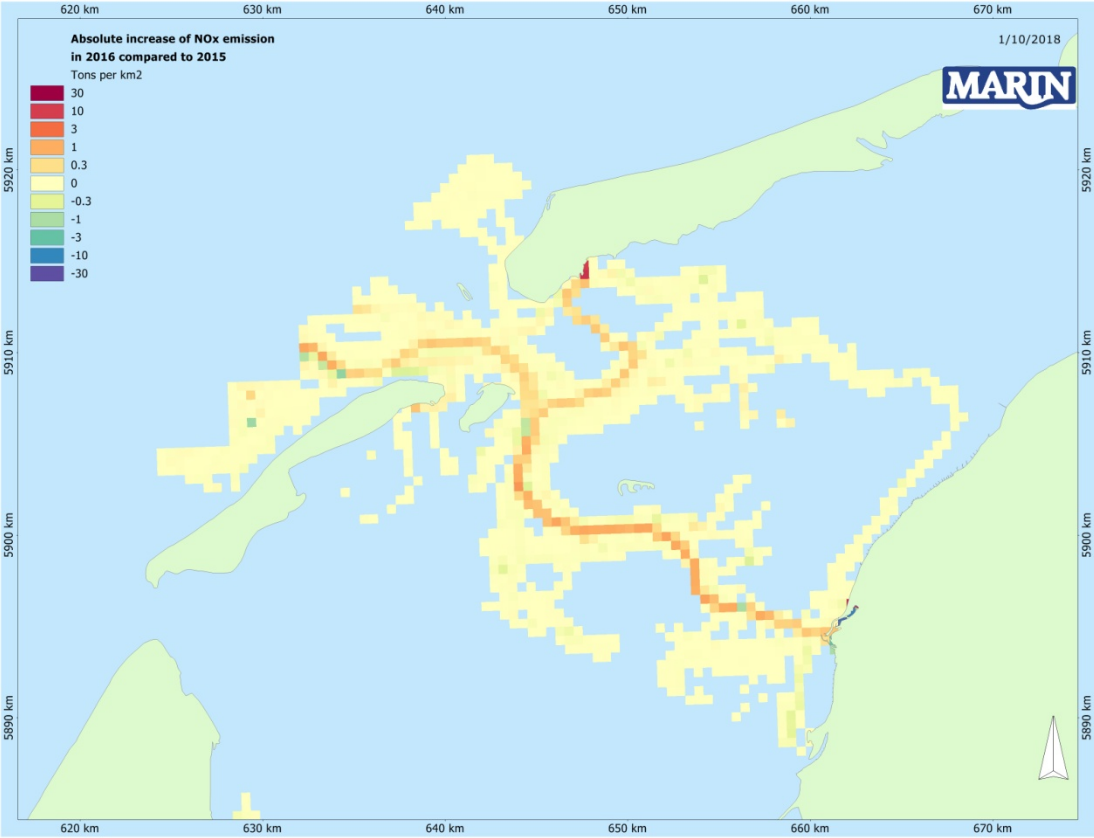

Figure 6-17 **Absolute change in NO_x emission from 2015 to 2016 in the port area of Harlingen by ships with AIS.**

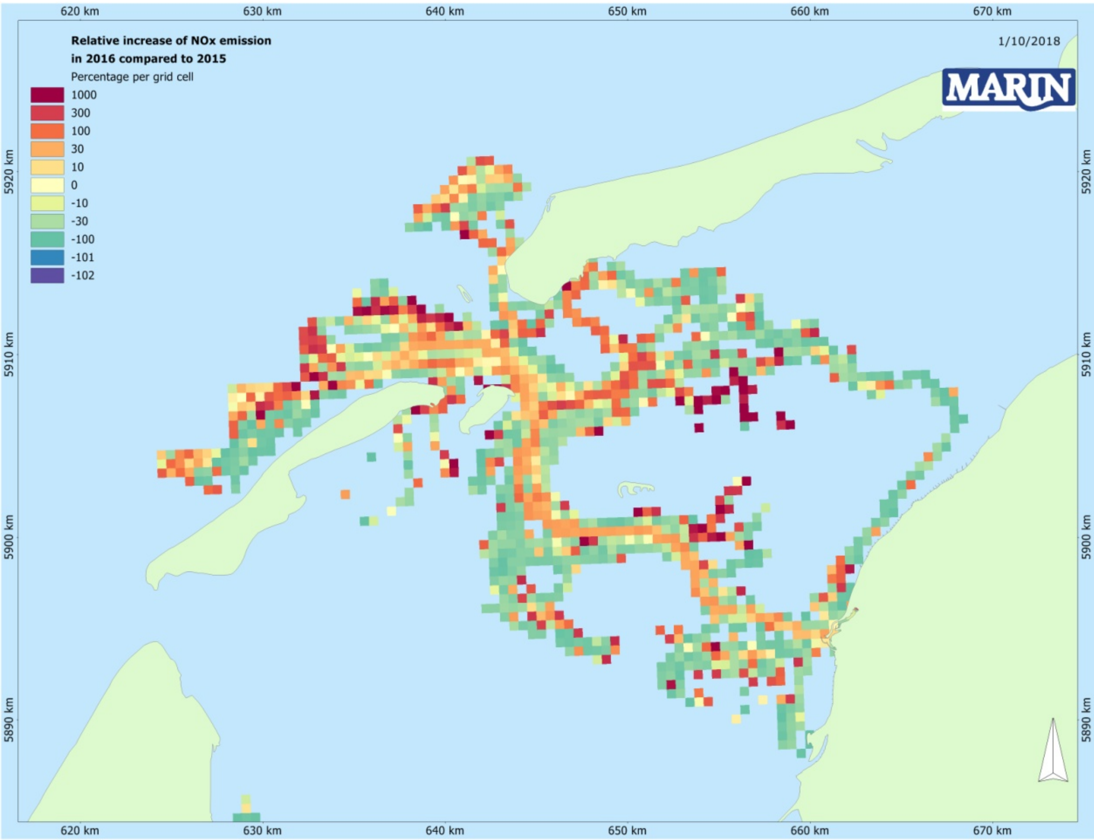

Figure 6-18 **Relative change in NO_x emission from 2015 to 2016 in the port area of Harlingen by ships with AIS.**

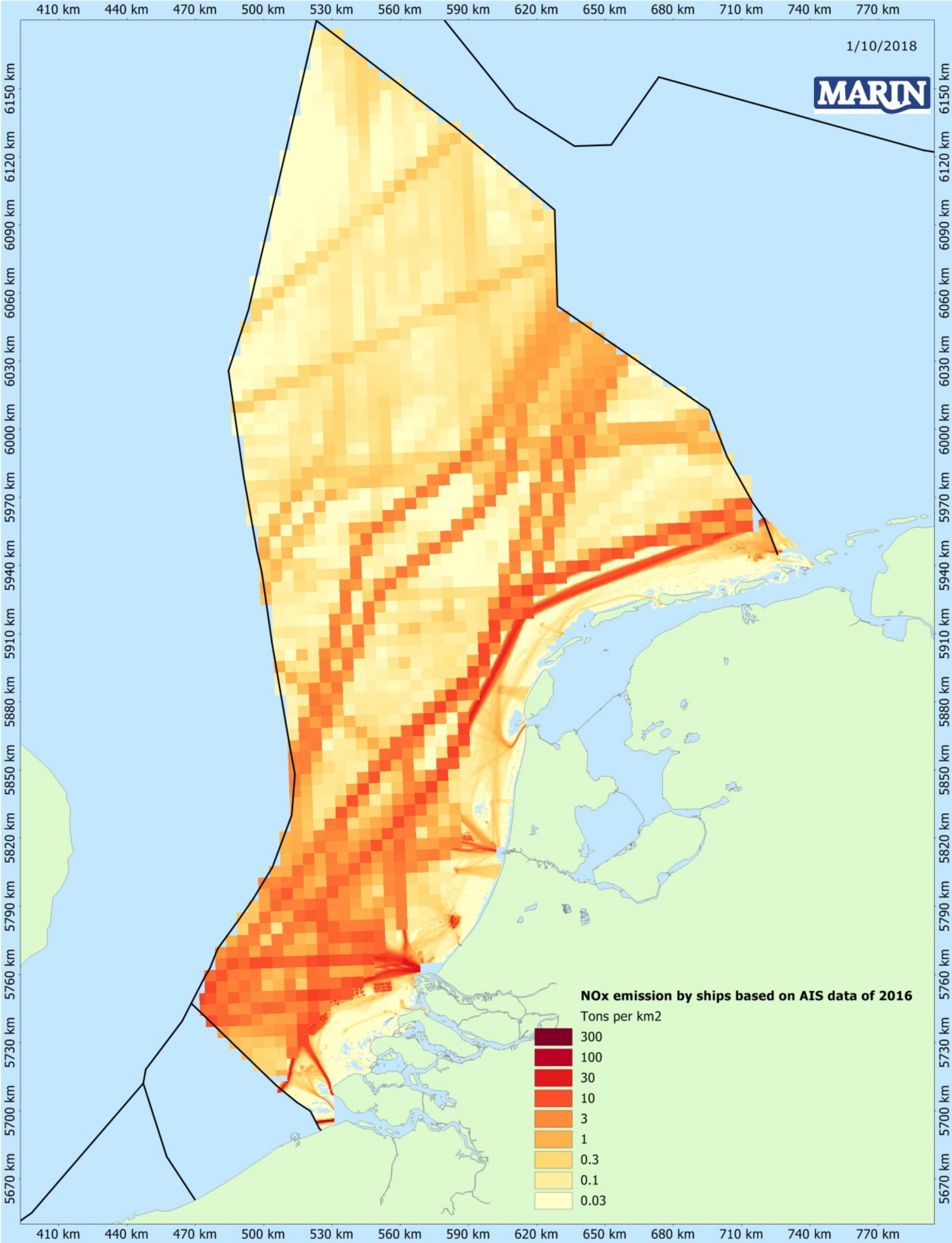

Figure 6-19 **NO_x emission in 2016 in the NCS, the 12-mile zone and the Dutch port areas by ships with AIS.**

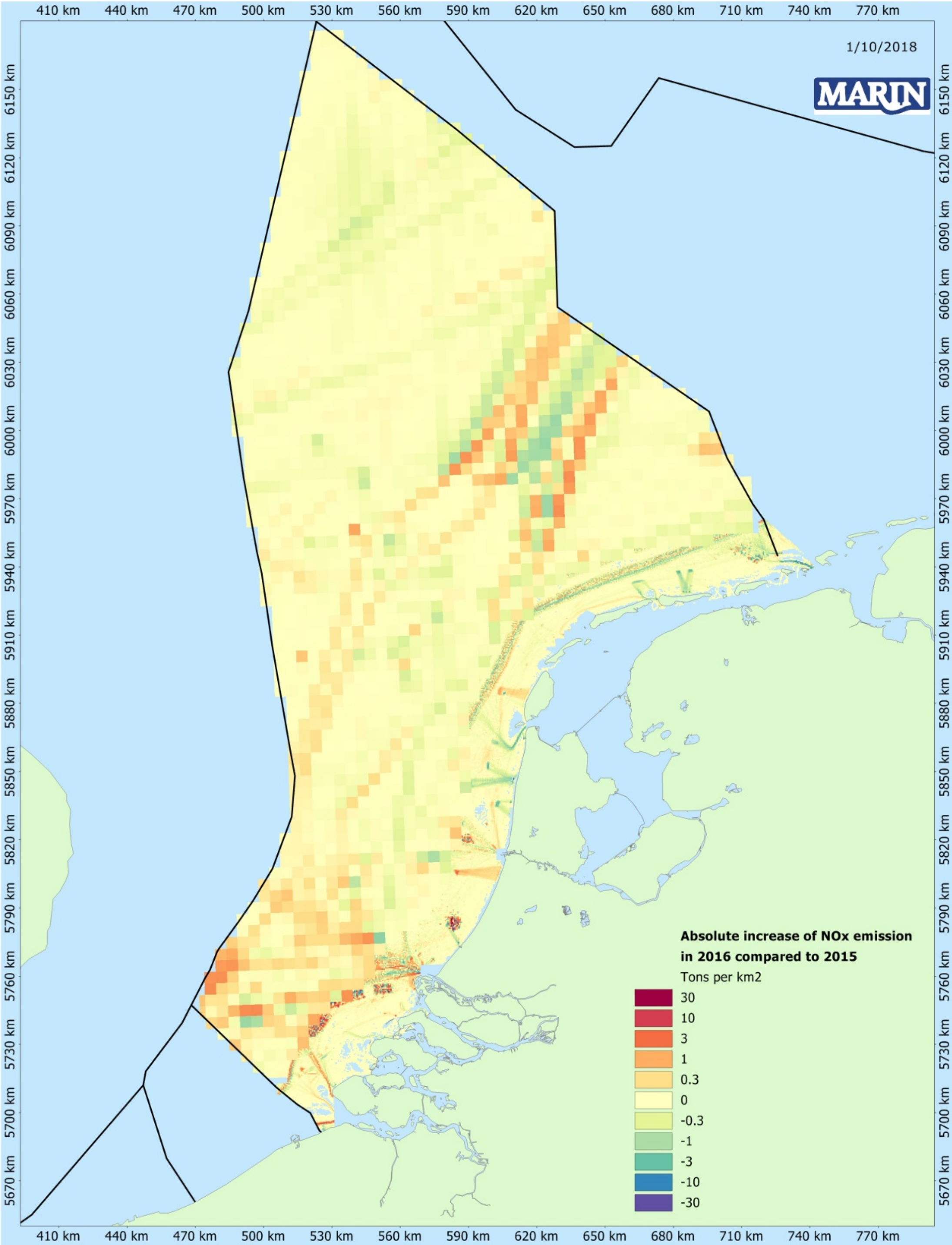

Figure 6-20 Absolute change in NO_x emission from 2015 to 2016 in the NCS, the 12-mile zone and in the Dutch port areas by ships with AIS.

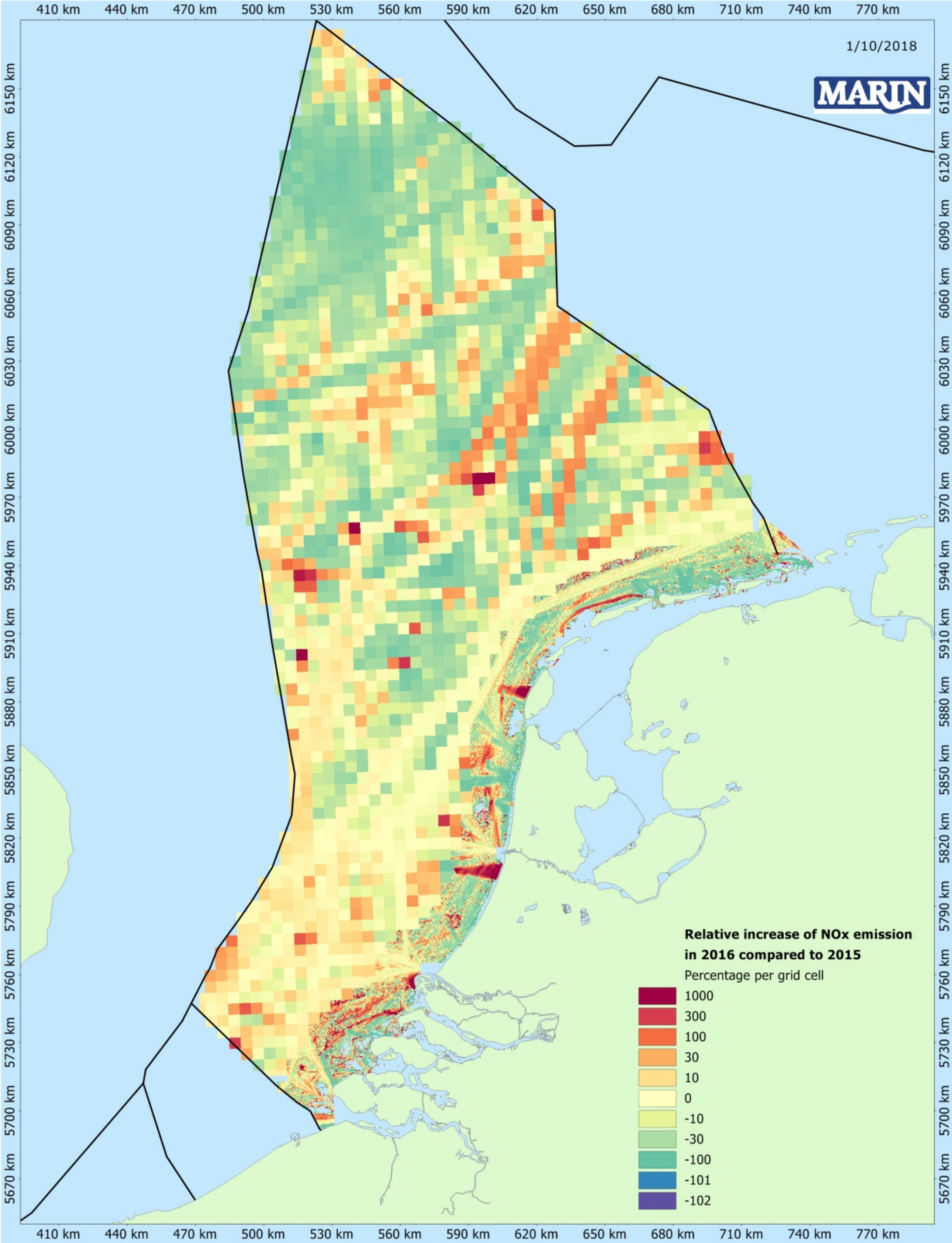

Figure 6-21 Relative change in NO_x emission from 2015 to 2016 in the NCS, the 12-mile zone and in the Dutch port areas by ships with AIS.

7 EMISSIONS FOR THE FISHING ACTIVITIES IN THE DUTCH PORT AREAS, THE WADDEN SEA AND THE NETHERLANDS SEA AREA

7.1 Introduction

This chapter presents the results of the totals of the emission calculations for 2016 for the fishing activities in the Dutch port areas, the Wadden Sea and the Netherlands sea area. The emissions of fishing vessels was introduced in the previous study, and the method and results were reported by TNO in reference [3].

7.2 Emissions of fishing activities

In Table 7-1 total emissions of fishing vessels is given in ton for each port area and the Wadden Sea. Since the CO_2 is the dominant emission substance, Figure 7-1 and Figure 7-2 show the spatial distribution of CO_2 instead of the NO_x. It is clear from both the table and the figures that the contribution of CO_2 emissions by fishing vessels is largest in Den Helder and Harlingen.

Table 7-1 Total emissions in ton in each port area for 2016 for the Fishing vessels.

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Wadden	Total
1237 VOC	Berthed	2	2	2	1	5	4	0	16
	Sailing	1	0	0	1	3	10	1	17
	Total	3	2	2	1	8	14	1	33
4001 SO_2	Berthed	0	0	0	0	0	0	0	0
	Sailing	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0
4013 NO_x	Berthed	38	46	47	13	122	99	4	369
	Sailing	18	5	8	23	76	235	27	392
	Total	57	50	55	36	198	334	31	761
4031 CO	Berthed	8	9	10	3	24	20	1	74
	Sailing	4	1	2	5	15	47	6	78
	Total	12	9	12	7	39	66	7	152
4032 CO_2	Berthed	2,709	3,360	3,304	926	8,674	7,016	303	26,291
	Sailing	1,283	333	583	1,680	5,445	16,708	1,921	27,953
	Total	3,992	3,692	3,887	2,606	14,119	23,724	2,225	54,244
6598 Aerosols MDO/HFO	Berthed	1	2	2	0	4	3	0	13
	Sailing	1	0	0	1	3	8	1	14
	Total	2	2	2	1	7	12	1	27

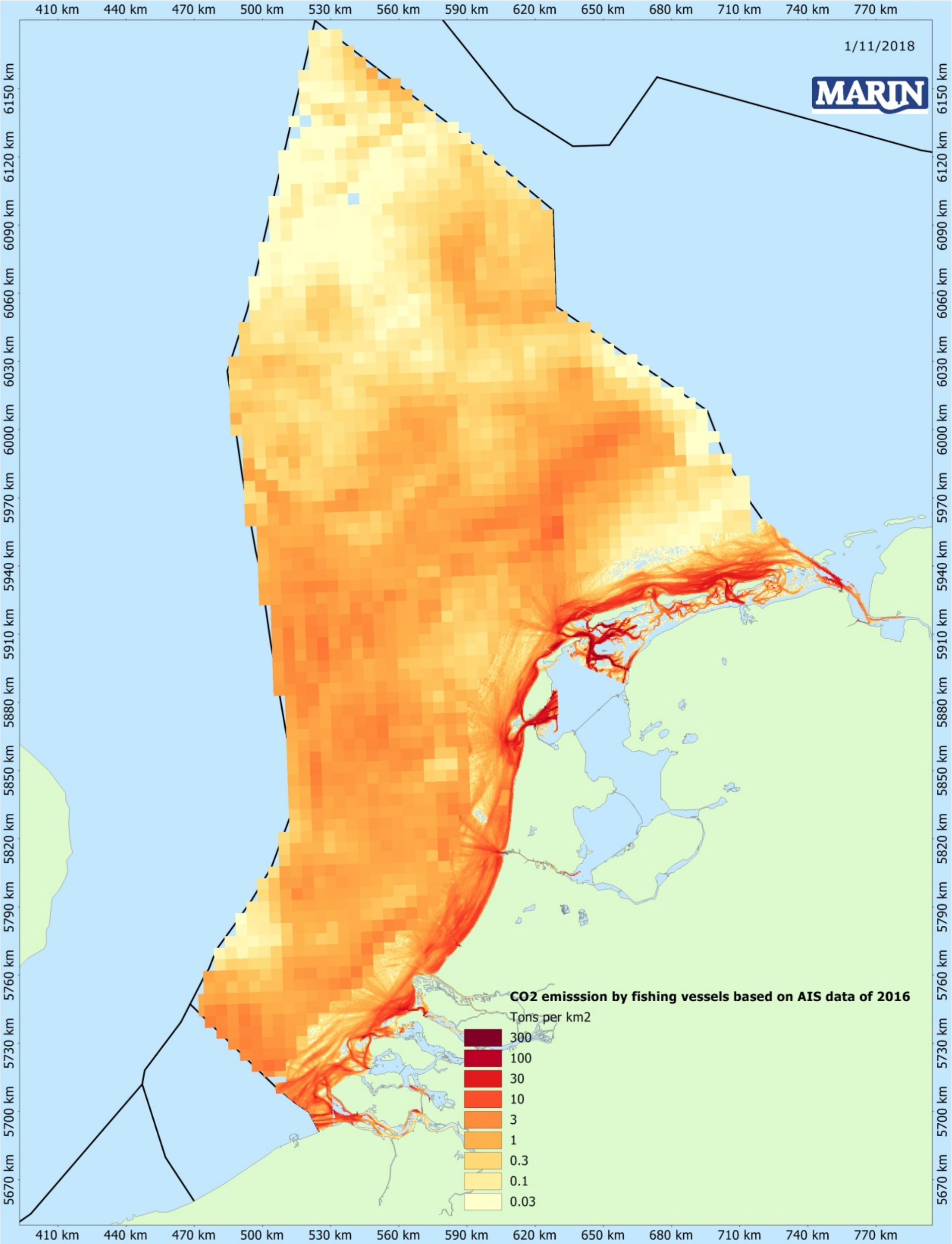

Figure 7-1 CO_2 emission of fishing vessels observed in the NCS, based on AIS data of 2016.

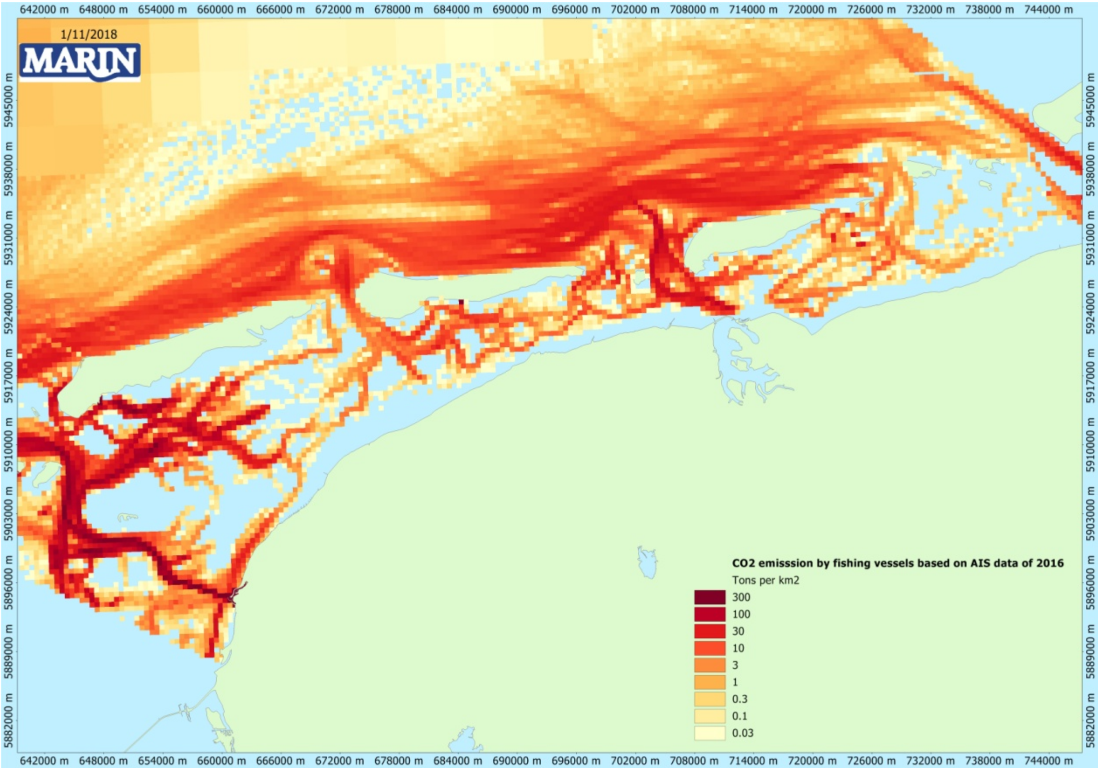

Figure 7-2 CO_2 emission of fishing vessels observed in the Dutch Wadden Sea, based on AIS data of 2016.

8 EMISSIONS IN THE OSPAR REGION II AREAS

8.1 Introduction

This chapter presents the results of the totals of the emission calculations for 2016 for OSPAR region II. The emissions in OSPAR region II are calculated for moving ships only, because nonmoving ships were not modelled in the traffic database.

8.2 Emissions in the OSPAR region II

The calculated emissions for 2016 are summarised in Table 8-1. This table also contains a comparison with the results from 2014. There is an increase in emission for VOC, NO_X, CO_2 and Aerosols MDO. The emissions for Methane, SO_2, CO and aerosols HFO are decreased. 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 2016, based on SAMSON

Nr	Substance	Emission in ton in 2016 of moving ships	Emission in 2016 as percentage of 2014 for moving ships
1011	Methane	286	96.30%
1237	VOC	11737	103.33%
4001	SO_2	23699	21.76%
4013	NO_X	423275	104.77%
4031	CO	19384	24.90%
4032	CO_2	18921970	103.52%
6601	Aerosols MDO	1334	178.34%
6602	Aerosols HFO	11557	63.12%
6598	Aerosols MDO+HFO	12891	67.64%

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. These databases can be used in studies for which a detailed spatial distribution of the emissions is required.

Completeness of AIS data
Several full days and a limited number of additional minute files of the AIS data was missing in 2016. A correction was carried out for the one missing day to account for these missing minute files. This year there was no additional AIS database of the Schelder Radar Keten available. Since the coverage of the available AIS data for the Western Scheldt showed a slight gap in total emissions, a small correction factor has been used to catch this gap.

Activity data
Comparing 2016 with 2015, there was a decrease in berthing activities in Rotterdam, and also a decrease in berthing activities in the Western Scheldt, the port of Amsterdam and Ems. A clear increase in both berthed and moving ships has been observed in the port of Harlingen and Den Helder. No distinctive differences are observed in the NCP.

Emission results
There are large differences in emission results for CO, this is entirely due to changes in the emission factor for CO, since the corresponding emission factor was reduces by a factor 4. There is also in general a slight increase in NO_x, which is partly due to an increase in the emission factor for NO_x.

There is, for some substances, a large shift of emissions between the ports. Den Helder, Harlingen and the Western Scheldt show an increase in emissions and Rotterdam and Ems show a decrease. The port of Amsterdam show a slight decrease, but in general very similar results compares to 2015. The emissions of all substances show a increase for the sailing vessels (excluding CO and Aerosols HFO).

For the NCS we generally see an increase in emissions for almost all substances for not moving vessels and a small decrease for moving vessels.

The contribution of the fishing vessels to the emissions is dominated by CO2 emissions in Harlingen and Den Helder.

In the emissions in the OSPAR region II we see a slight increase in CO_2, VOC and NO_x. Also for the OSPAR region II the changes in the emission factor for CO and SO_2 (in 2015) are evident in the results.

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[2] M.C. ter Brake & J. Hulskotte
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TNO R10784, 29 June 2017

APPENDIX A: EMISSION FACTORS

Written by Jan Hulskotte of TNO

A1 SAILING AND MANOEUVRING

A1.1 Main Engines

During sailing and manoeuvring, the main engine(s) are used to propel/manoeuvre the ship. Their emission factors per ship, in g per kWh, were determined by TNO according to the EMS protocols [1, 2]. An English language report [5] is available, which covers the emission calculations in accordance with the EMS protocols. In the emission factor calculation, the nominal engine power and speed are used. For this study these parameters were taken from the LLI database of September 2016 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.

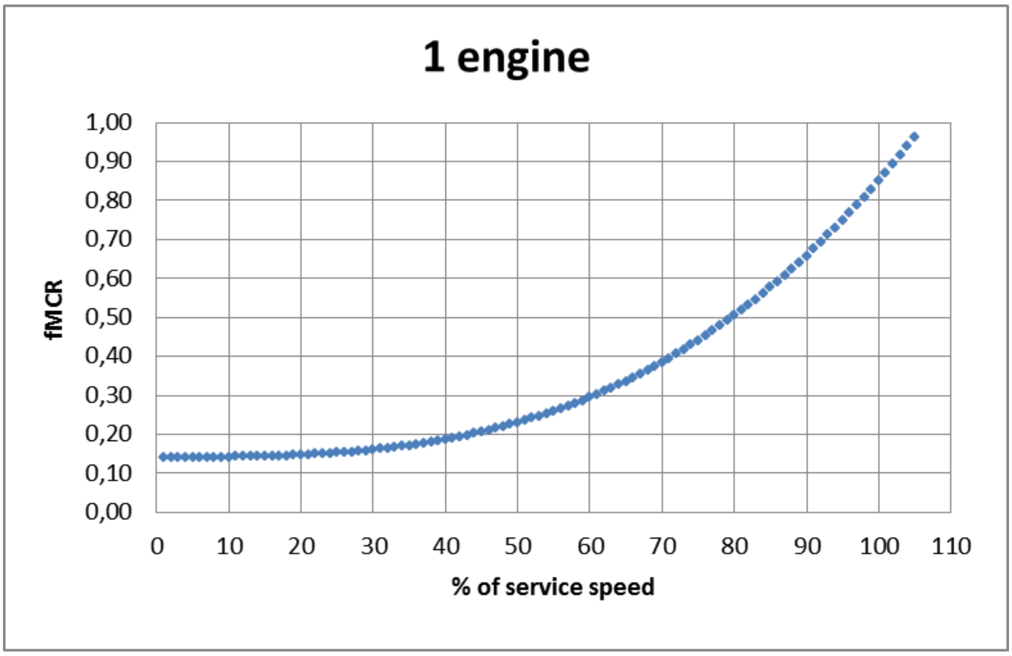

Figure A- 1 The relationship between service speed and fMCR at ships with one single propulsion engine used in emission calculations

A1.2 Multiple propulsion engines

When a ship has multiple main propulsion engines, probably not all of these engines will be used in all situations. For instance, many specialised ships have specialised installations that are only used when these ships are performing their specialised tasks (dredgers, supply ships, icebreakers, tugs etc.). Other ships may have redundant engine capacity for safety and other reasons (passenger ships, roro-ships). It is rather difficult to account for the usage of multiple engines within emission calculations, since many differences will exist between individual ship designs. All kinds of possible situations which are not known from the AIS-data may have different influence on emissions from different ships types. Nevertheless, ignoring the existence of multiple engines is not realistic. The presence of multiple engines on some ship types (i.e. passenger and roro-ships) could lead to serious underestimation of total emissions because only the power of the largest engine was taken into account until 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 A2 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.

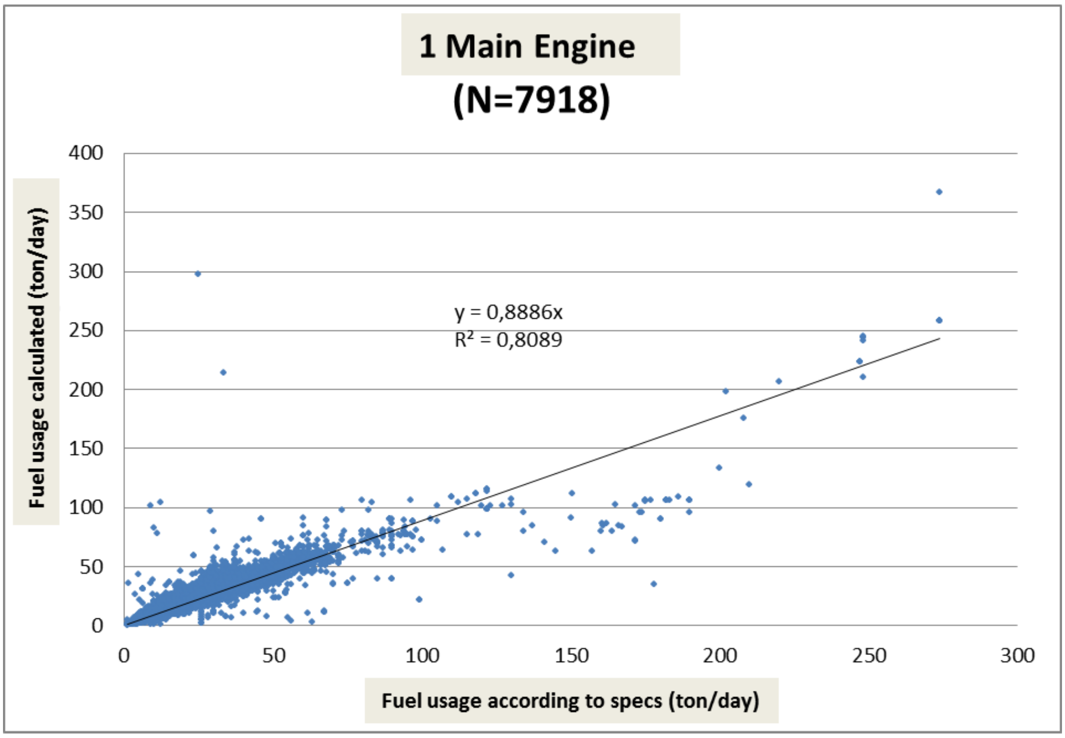

Figure A- 2 Calculated daily fuel usage of one engine ships compared with specifications

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.

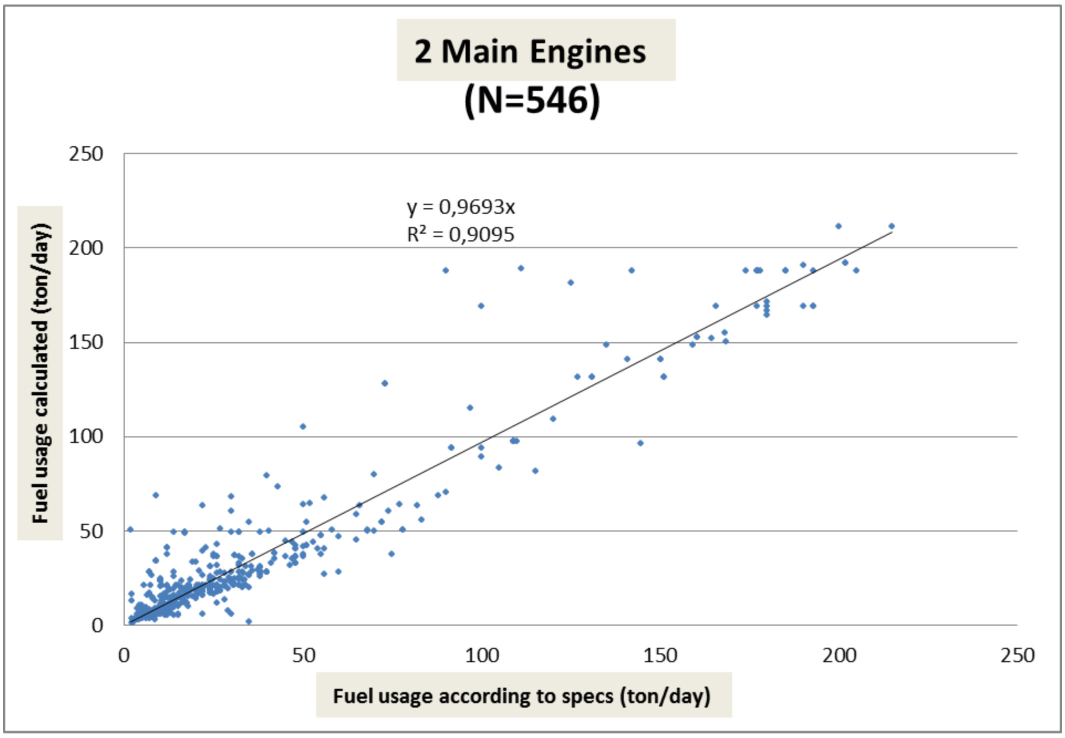

Figure A- 3 Calculated daily fuel usage of two engine ships compared with specifications

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.

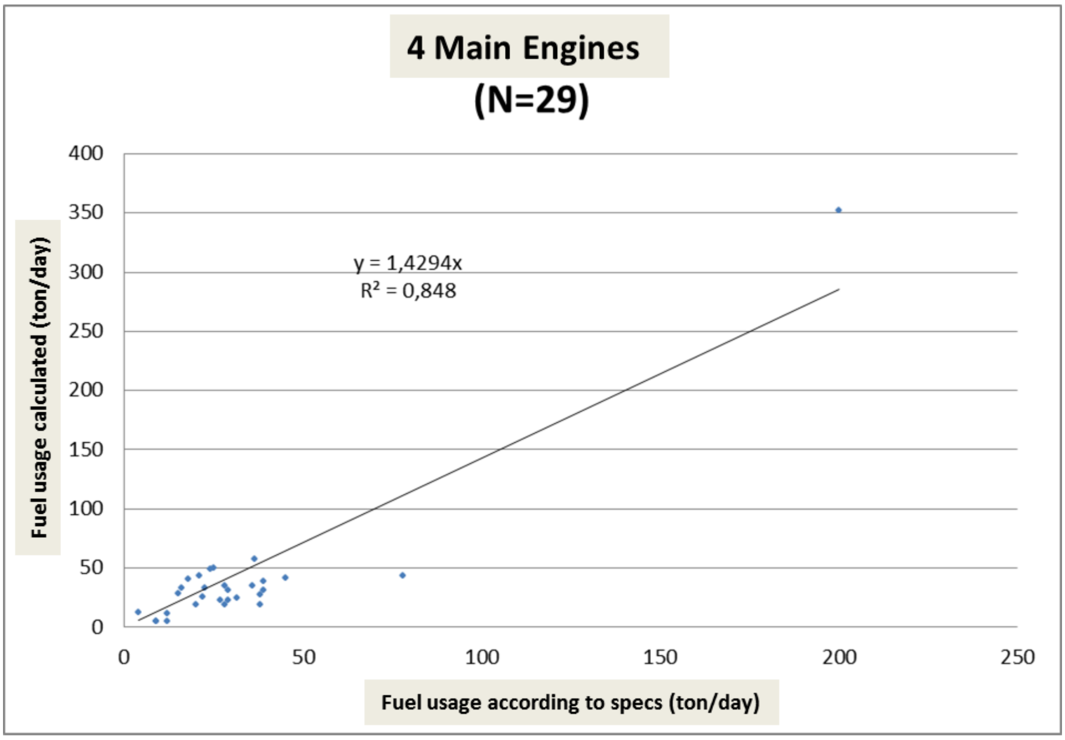

Figure A- 4 Calculated daily fuel usage of four engine ships compared with specifications

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	0.75	0.85	0.75		0.75			0.75		
Miscellaneous	2	0.75									
	4			0.75							
Tug/Supply	2	0.65	0.85	0.8	0.75	0.85	0.75	0.75	0.75		0.75
Fishing	2	0.75	0.85								
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 A12/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.

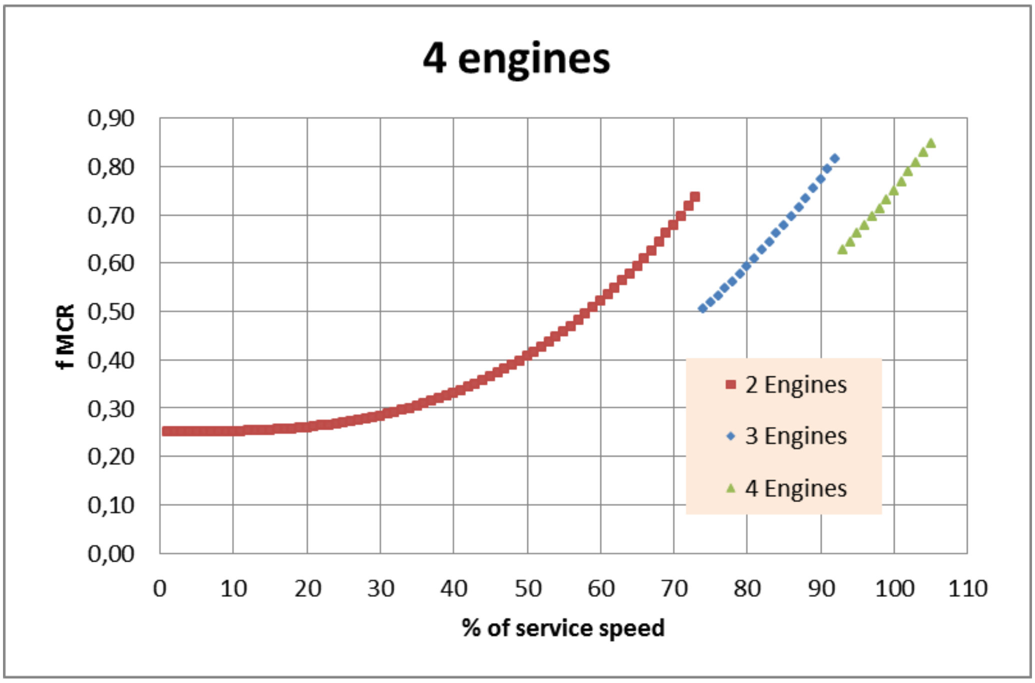

Figure A- 5 The relationship between service speed and fMCR at ships with four propulsion engines as used in emission calculations (formula 4 and 5)

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 Factors

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). Partial implementation of the SECA according to the MARPOL Annex VI in 2016 has been assumed. The reason behind this decision is that very little response by national government(s) in Europe has been observed on the Trident Alliance initiative (a group of important stakeholders demanding proper enforcement). As a consequence, the sulphur percentage in heavy fuel oil is set on 0.5% and the sulphur percentage in marine diesel oil is assumed to be 0.25% in the NCP part of the SECA. In the harbour areas, however, full implementation is assumed (all fuels set on 0.1% m/m sulphur).
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 NCP[1]	PM-HFO Other[2]	SO_2 NCP	SO_2 Other	VOC	CO	CO_2	SFOC
1900 – 1973	16	0.47	0.43	0.84	0.42	0.6	0.75	666	210
1974 – 1979	18	0.46	0.43	0.80	0.40	0.6	0.75	635	200
1980 – 1984	19	0.46	0.43	0.76	0.38	0.6	0.75	603	190
1985 – 1989	20	0.46	0.43	0.72	0.36	0.6	0.63	571	180
1990 – 1994	18	0.46	0.43	0.70	0.35	0.5	0.5	555	175
1995 – 1999	15	0.35	0.33	0.68	0.34	0.4	0.5	539	170
2000 – 2010	~rpm[3]	0.35	0.33	0.67	0.34	0.3	0.5	533	168
2011 – 2016		0.25	0.23	0.66	0.33	0.3	0.5	524	165

1 NCP: Dutch Continental Shelf
2 Other areas: Include harbours areas
3 Dependant on revolutions per minute (Table A-8)

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 NCP	PM-MDO Other	SO_2 NCP	SO_2 Other	VOC	CO	CO_2	SFOC
1900 - 1973	16	0.37	0.33	0.84	0.42	0.6	0.75	666	210
1974 - 1979	18	0.36	0.33	0.80	0.40	0.6	0.75	635	200
1980 - 1984	19	0.36	0.33	0.76	0.38	0.6	0.75	603	190
1985 – 1989	20	0.36	0.33	0.72	0.36	0.6	0.63	571	180
1990 – 1994	18	0.36	0.33	0.70	0.35	0.5	0.5	555	175
1995 – 1999	15	0.25	0.23	0.68	0.34	0.4	0.5	539	170
2000 – 2010	~rpm[1]	0.25	0.23	0.67	0.34	0.3	0.5	533	168
2011 – 2016		0.25	0.23	0.66	0.33	0.3	0.5	523	165

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 NCP	PM-HFO Other	SO_2 NCP	SO_2 Other	VOC	CO	CO_2	SFOC
1900 – 1973	12	0.67	0.64	0.90	0.45	0.6	0.75	714	225
1974 – 1979	14	0.67	0.63	0.86	0.43	0.6	0.75	682	215
1980 – 1984	15	0.67	0.63	0.82	0.41	0.6	0.75	651	205
1985 – 1989	16	0.66	0.63	0.78	0.39	0.6	0.63	619	195
1990 – 1994	14	0.66	0.63	0.76	0.38	0.5	0.5	603	190
1995 – 1999	11	0.56	0.53	0.74	0.37	0.4	0.5	587	185
2000 – 2010	~rpm[1] 9[2]	0.56	0.53	0.73	0.37	0.3	0.5	581	183
2011 - 2016	~rpm 7[2]	0.56	0.53	0.90	0.36	0.3	0.5	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 NCP	PM-MDO Other	SO_2 NCP	SO_2 Other	VOC	CO	CO_2	SFOC
1900 - 1973	12	0.37	0.33	0.90	0.45	0.6	0.75	714	225
1974 - 1979	14	0.37	0.33	0.86	0.43	0.6	0.75	682	215
1980 - 1984	15	0.37	0.33	0.82	0.41	0.6	0.75	650	205
1985 - 1989	16	0.36	0.33	0.78	0.39	0.6	0.63	619	195
1990 - 1994	14	0.31	0.33	0.76	0.38	0.5	0.5	603	190
1995 - 1999	11	0.26	0.23	0.74	0.37	0.4	0.5	587	185
2000 - 2010	~rpm[1] 9[2]	0.26	0.23	0.73	0.37	0.3	0.5	581	183
2011 - 2016	~rpm[1] 7[2]	0.26	0.23	0.72	0.36	0.3	0.5	571	180

[2] applied on auxiliary engines only

Emission factors of CO were reduced by a factor of 4 according to [16]. Emission factors of PM and SO2 at NCP were lowered based on observations of Chalmers University in commission of the Danish Ministry of Environment and Food concerning the enforcement of IMO SECA [17] .

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 (Tier I)	< 130 RPM	17.0	0.87 x 17.0
	Between 130 and 2000 RPM	$45 \times n^{-0.2}$	$0.87 \times 45 \times n^{-0.2}$
	> 2000 RPM	9.8	0.87 x 9.8
2011 – 2016 (Tier II)	< 130 RPM	14.4	0.93 x 17.0
	Between 130 and 2000 RPM	$44 \times n^{-0.23}$	$0.93 \times 44 \times n^{-0.23}$
	> 2000 RPM	7.7	0.93 x 7.7

The reduction factor for Tier II engines was adjusted from 0.85 to 0.93 and the reduction factor for Tier I engines was adjusted from 0.85 to 0.87. The information was based on IAPP-certificate engine data obtained in a project for the Port of London Authority (report still in preparation).

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 NCP	PM-MDO Other	SO_2 NCP	SO_2 Other	VOC	CO	CO_2	SFOC
MDO	5.7	0.140	0.065	1.55	0.62	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 NCP	PM Other	SO_2 NCP	SO_2 Other	CH4	VOC	CO	CO_2	SFOC
LNG	1.94	0.01	0.01	0.0	0.0	0.045		0.06	688	250
HFO	2.0	0.495	0.300	3.06	0.61		0.1	0.15	971	306
MDO	2.0	0.490	0.295	1.45	0.58		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- 12 Correction 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- 13 Correction 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- 14 Correction 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- 15 Fuel rate of ships at berth, (kg/1000 GT.hour)

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

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

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

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

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

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

In following 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 – 2016	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 FISHERIES

Fisheries source category covers emissions from fishing activities in the Netherlands, including inland fishing, coastal fishing and deep-sea fishing. Diesel engines are used to propel fishing vessels such as deep-sea trawlers and cutters, and to generate electrical power on-board fishing vessels. These diesel engines can be fuelled with either diesel oil (distillate) or residual fuel oil. The combustion process that takes place in these diesel engines causes emissions of greenhouse gases and air pollutants.

A3.1 Activity data

Two methodologies based on AIS-data are applied from 2016 onwards. For deep-sea trawlers the same AIS-based methodology as used for maritime navigation is applied (see A1 and A2) because essentially no fishing activities are performed on Dutch national territory, including the Dutch Continental Shelf. This means that these vessels essentially are only sailing towards and from remote fishing grounds. For the other fishing vessel categories (rather small vessels mostly cutters) another AIS-based methodology is described in detail by Hulskotte and ter Brake, 2017 [18]. This is essentially an energy based method whereby energy-rates of fishing vessels are split up by activity (sailing and fishing) with a distinction in available power of propulsion engine(s). For each fishery segment (combination of gear or catch method combined with power category) a fuel rate (kilogram/hour) for sailing or fishing was assessed by Turenhout et al., 2016 [19]. The distinction for each fishery segment between sailing and fishing is based on the actual speed of the fishing vessels as taken from AIS-data.

A3.2 Emission factors

The emission factors of small vessels (other than deep-sea trawlers) are assumed to be equal to emission factors of inland navigation because the engine types that are applied in these vessels are essentially the same.

Table A- 21 Emission factors and specific fuel consumption applied on fishing vessels, (g/kWh)

Engine year of build		VOC	NOx	CO	PM	SFOC
From	Till					
1959	1973	1.2	10.8	4.5	0.6	235
1975	1979	0.8	10.6	3.7	0.6	230
1980	1984	0.7	10.4	3.1	0.6	225
1985	1989	0.6	10.1	2.6	0.5	220
1990	1994	0.5	10.1	2.2	0.4	220
1995	2001	0.4	9.4	1.8	0.3	205
2002	2007	0.3	9.2	1.5	0.3	200
2008	2014	0.2	7	1.3	0.2	200
2015	2016	0.2	7	1.3	0.2	195

The year of build of the engines of (Dutch and former Dutch) fishing ships were initially purchased from Shipdata (http://www.shipdata.nl) in order to select the emission factors from table A-21. Part of this data concerned the engine type and model and the year of build. Data were enriched with engine changes when indicated on the website http://www.kotterfoto.nl and data of foreign fishing ships (including installing data of new engines) were added from the combined European fishing registers or the FIGIS-database managed by FAO.
As a fuel ultra low sulphur diesel fuel compliant with EN-590 specification was assumed to be used by the small fishery cutters.

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