SEA SHIPPING EMISSIONS 2015: NETHERLANDS CONTINENTAL SHELF, 12-MILE ZONE AND PORT AREAS

Final 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 2015. The results of the fishing vessels is reported in a separate document prepared by Jan Hulskotte, TNO [4]. The totals and the spatial distribution for the Netherlands Continental Shelf, the 12-mile zone and the port areas Rotterdam, Amsterdam, the Ems, the Western Scheldt, Den Helder and Harlingen are all based on AIS data. In previous years there was not enough AIS data available for the Western Scheldt, however, for 2015 we received data of the Schelde Radar Keten. Therefore the standard AIS procedure also holds for this area. The emissions for 2015 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 and the 12-mile zone is 500 x 500 m, for the Netherlands Continental Shelf area 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 2015.
Chapter 3 describes the procedure used for the emission calculation based on AIS data.
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 2015 for the Dutch port areas and the Netherlands sea area and makes a comparison with 2014.
Chapter 7 presents conclusions and recommendations.

2 2015 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,

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)::

- MARIN_RESULTS_12Miles.accdb (14-02-2016)
- MARIN_ RESULTS_NCP.accdb (14-02-2016)
- MARIN_ RESULTS_ports.accdb (14-02-2016)

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

The Netherlands sea area and the port areas are presented in Figure 2-1. The different areas are indicated by plotting the centre points of the grid cells with different colours:

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

The six port areas are illustrated in more detail in Figure 2-2 to Figure 2-7. At some places, there are orange points on land. There are several reasons for this. In general, the detail of the charts presented here is such that not all existing waterways and/or quays are visible, though they do exist. Also, it has been observed that the determination of the GPS position is disturbed by container cranes, so that the AIS message is not fed with the correct position. When, for whatever reason, AIS signals are disturbed or lost, positions are extrapolated and this is done before MARIN receives the data.

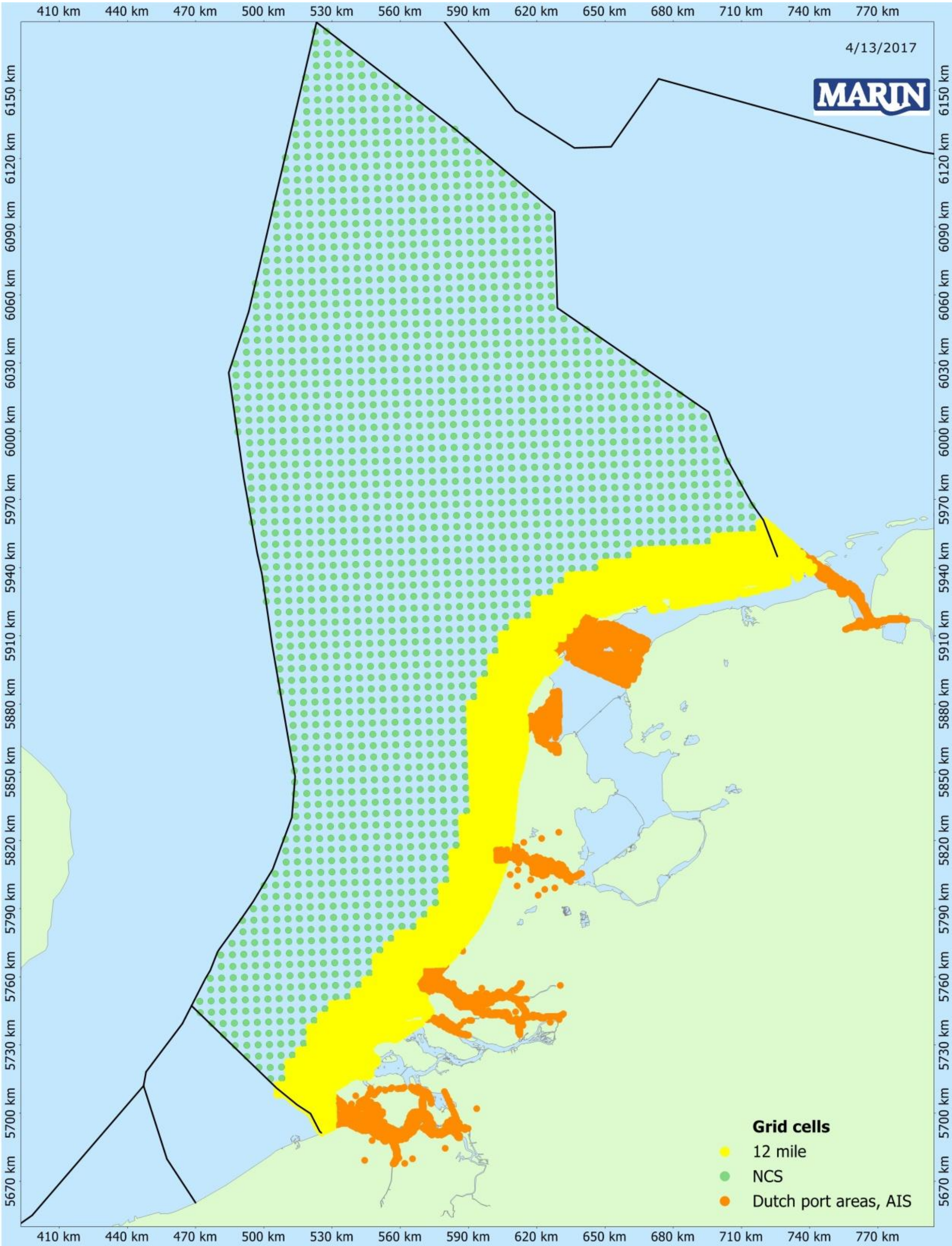

Figure 2-1 **The Netherlands Continental Shelf, 12-mile zone and six port areas**

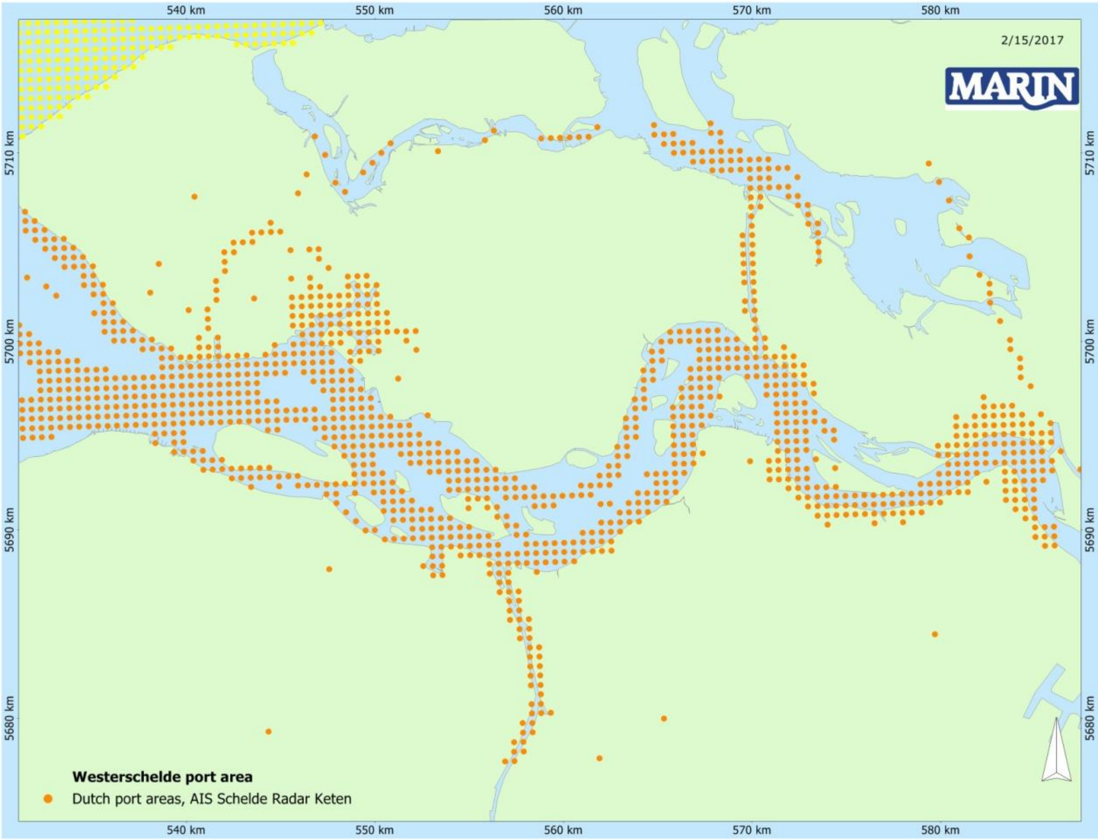

Figure 2-2 **Western Scheldt: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

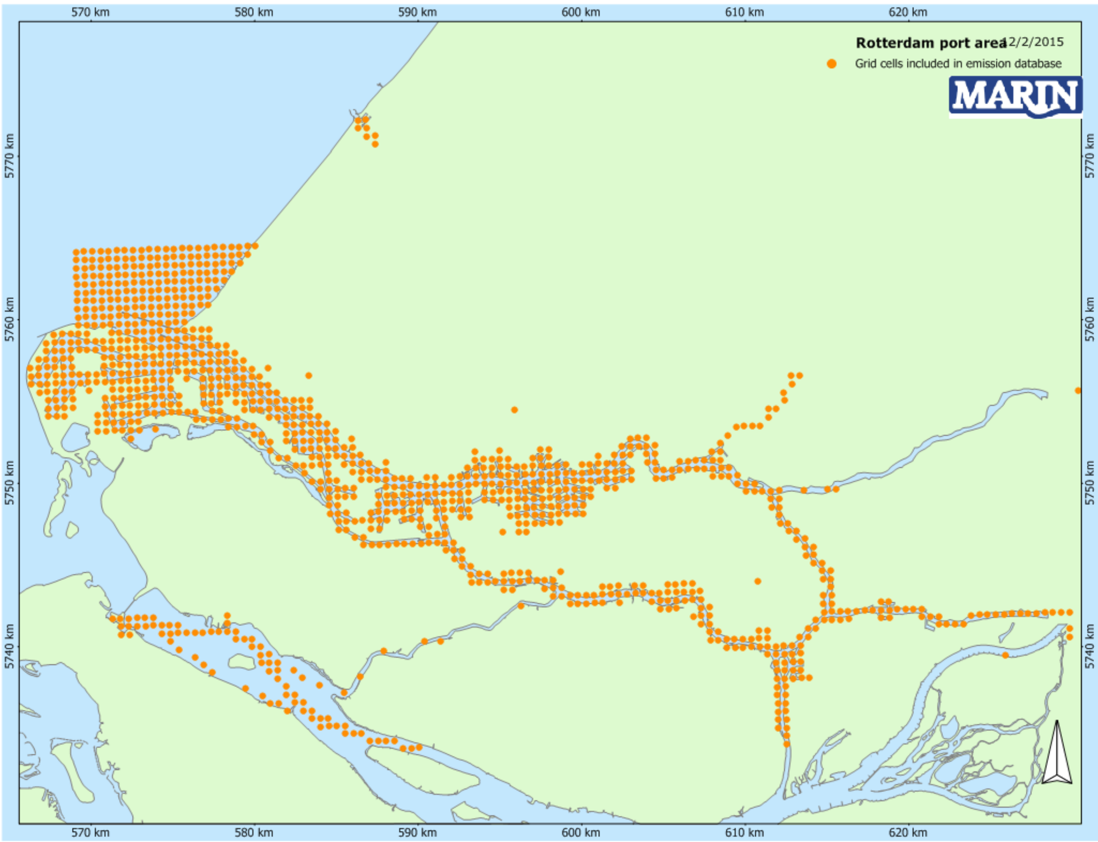

Figure 2-3 **Rotterdam: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

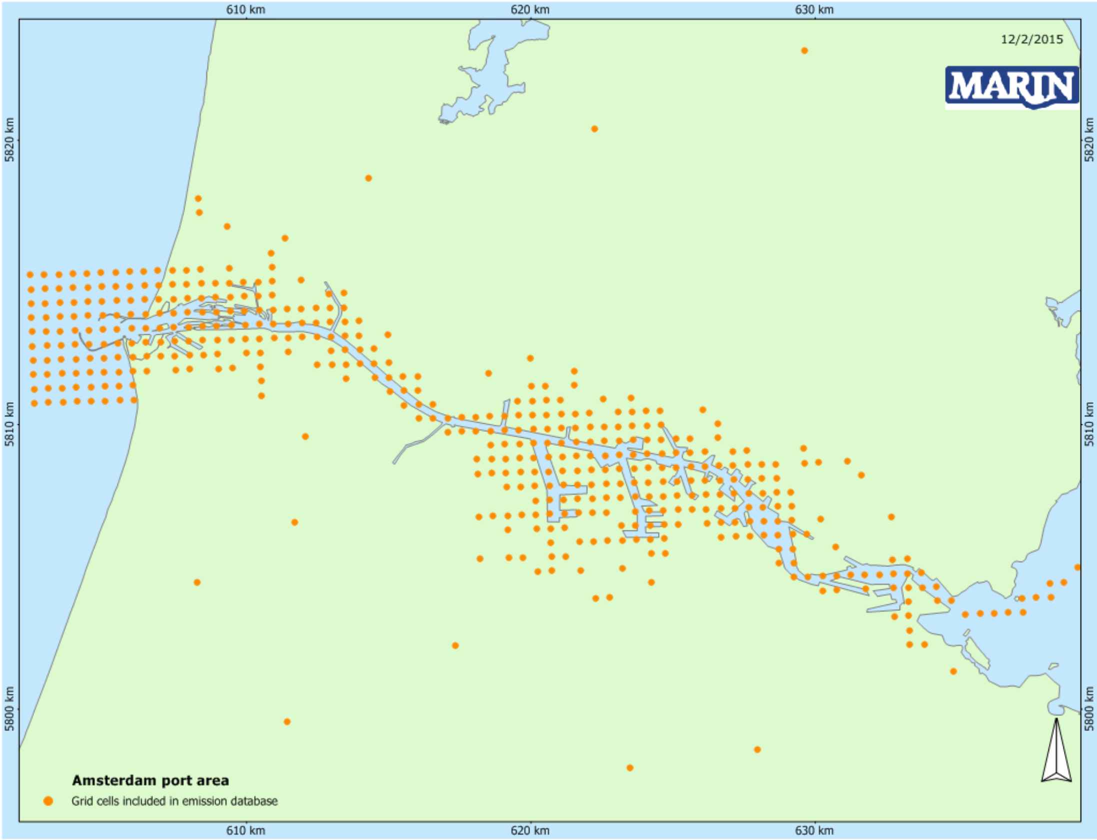

Figure 2-4 **Amsterdam: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

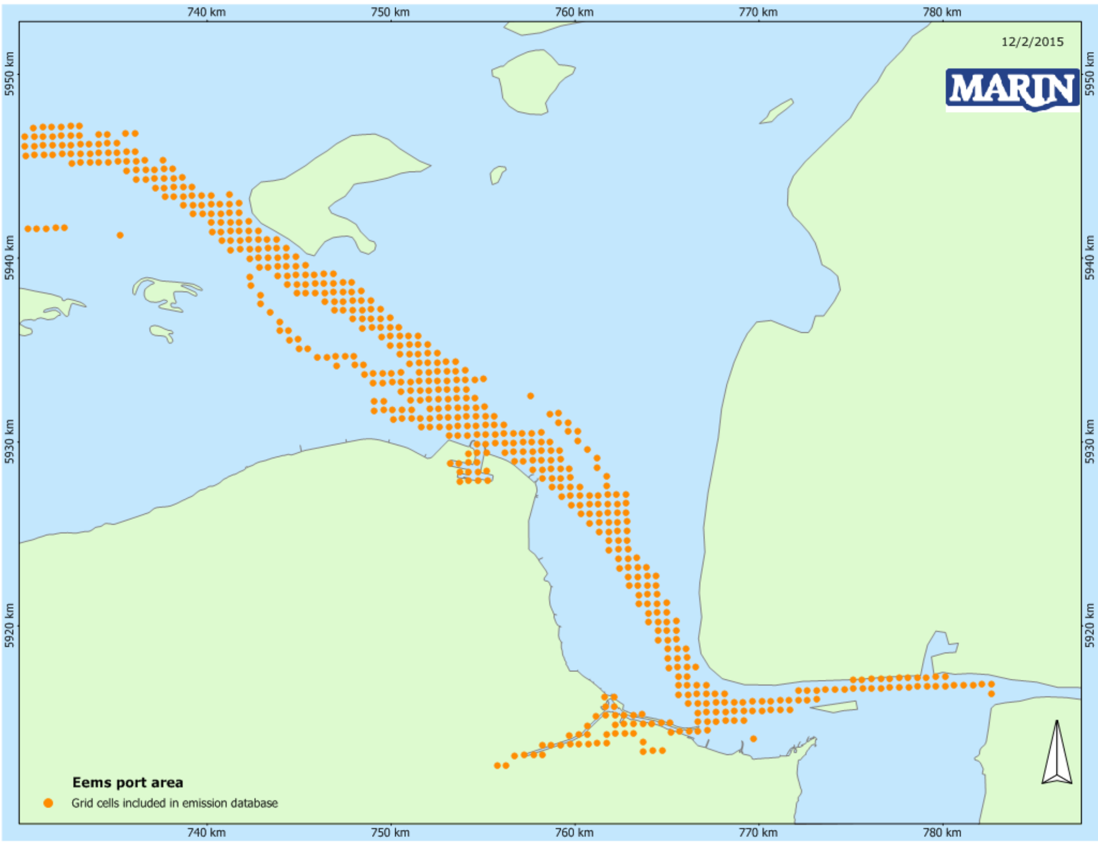

Figure 2-5 **Ems: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

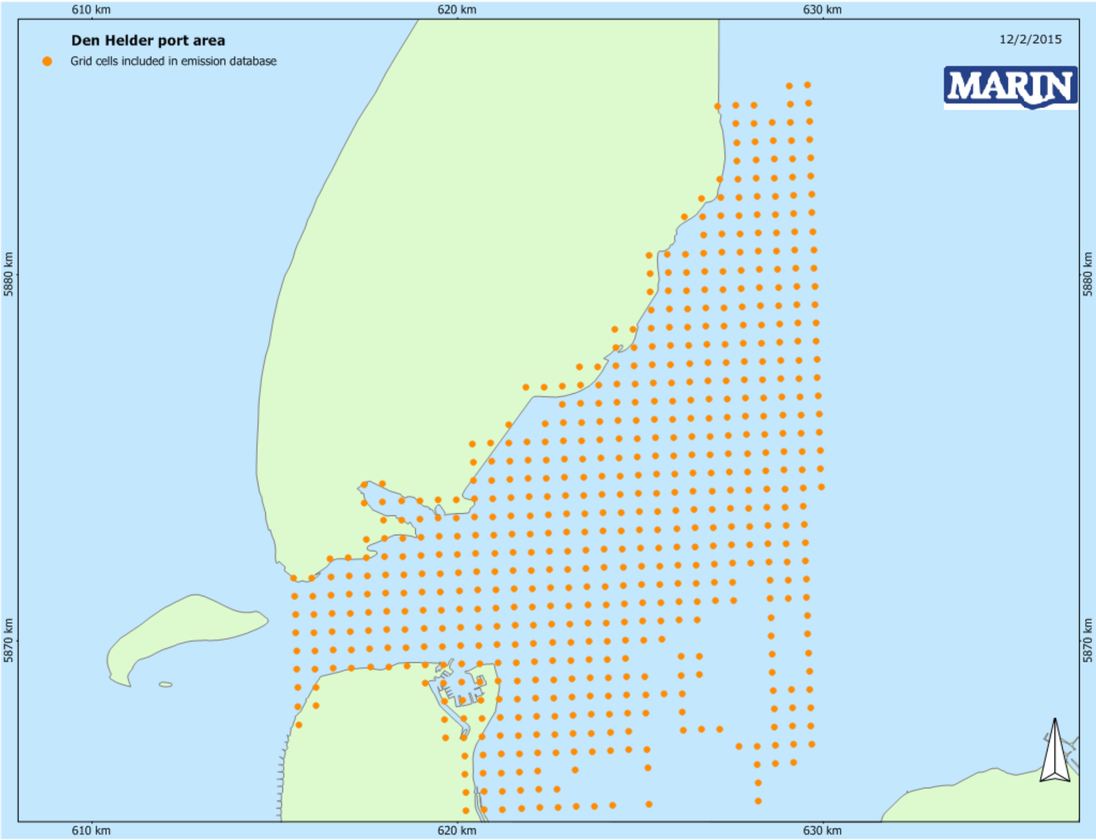

Figure 2-6 **Den Helder: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

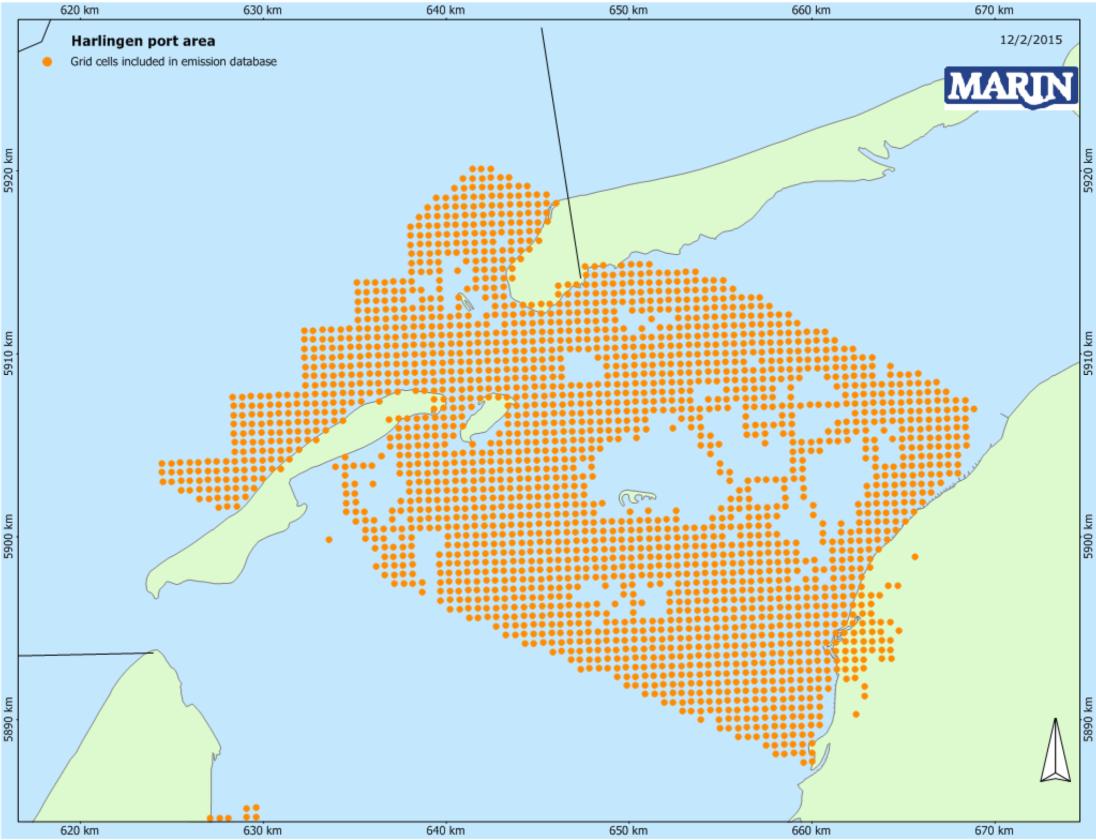

Figure 2-7 **Harlingen: The orange points indicate the centres of grid cells for which emissions are included in the Dutch port areas database**

3 PROCEDURE FOR EMISSION CALCULATION BASED ON AIS DATA

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

3.1 Input

AIS data for 2015
In this study, AIS data of 2015 received by the Netherlands Coastguard has been used to calculate the emissions. Refer to [1] for background information about the AIS data. Additionally, AIS data of 2015 delivered by the 'Schelde Radar Keten' has been used for the emission calculations of the Western Scheldt. In previous years the emissions of the eastern part of the Western Scheldt were based on a traffic database prepared by MARIN , and the western part was based on AIS data

IHS and The Port of Rotterdam
This year 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 made available by The Port of Rotterdam on behalf of this project, the emissions factors for all ships seen in the areas of interest of this study were based on this database. Therefore the LLI ship characteristics database was not purchased this year. Except practical and economic advantages also qualitative advantages were observed by using the IHS-data. Less imputations for missing data were necessary for instance for propulsive engine power and assumptions about type fuels used for many vessels could be replaced by available data.

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 82% 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 18% no emissions are calculated. Generally, these are small vessels with a small contribution to the emissions. These numbers are similar to the numbers for the study over 2014, and this leads to a similar accuracy of the results.

Since the database of IHS has been used, the MMSI numbers are directly coupled to the EMS types (Emissieregistratie en Monitoring Scheepvaart). This resulted in a shift of the results over the EMS types, because in previous years the MMSI numbers were first identified and categorised in 40 SAMSON types, and then translated to 13 EMS numbers. This shift has partly been recovered by using former used linkage between IMO-nr and EMS type. However, research needs to be done to the difference in translation matrices of the Port of Rotterdam (MMSI to EMS) and MARIN (MMSI to SAMSON to EMS). The new method which directly links MMSI to EMS might be an improvement, depending on the translation matrix. This needs to be investigated further next year.

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 2015 is missing several minute files and 1 full day 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. To compensate for the missing day, the results are multiplied with 365/364.

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.

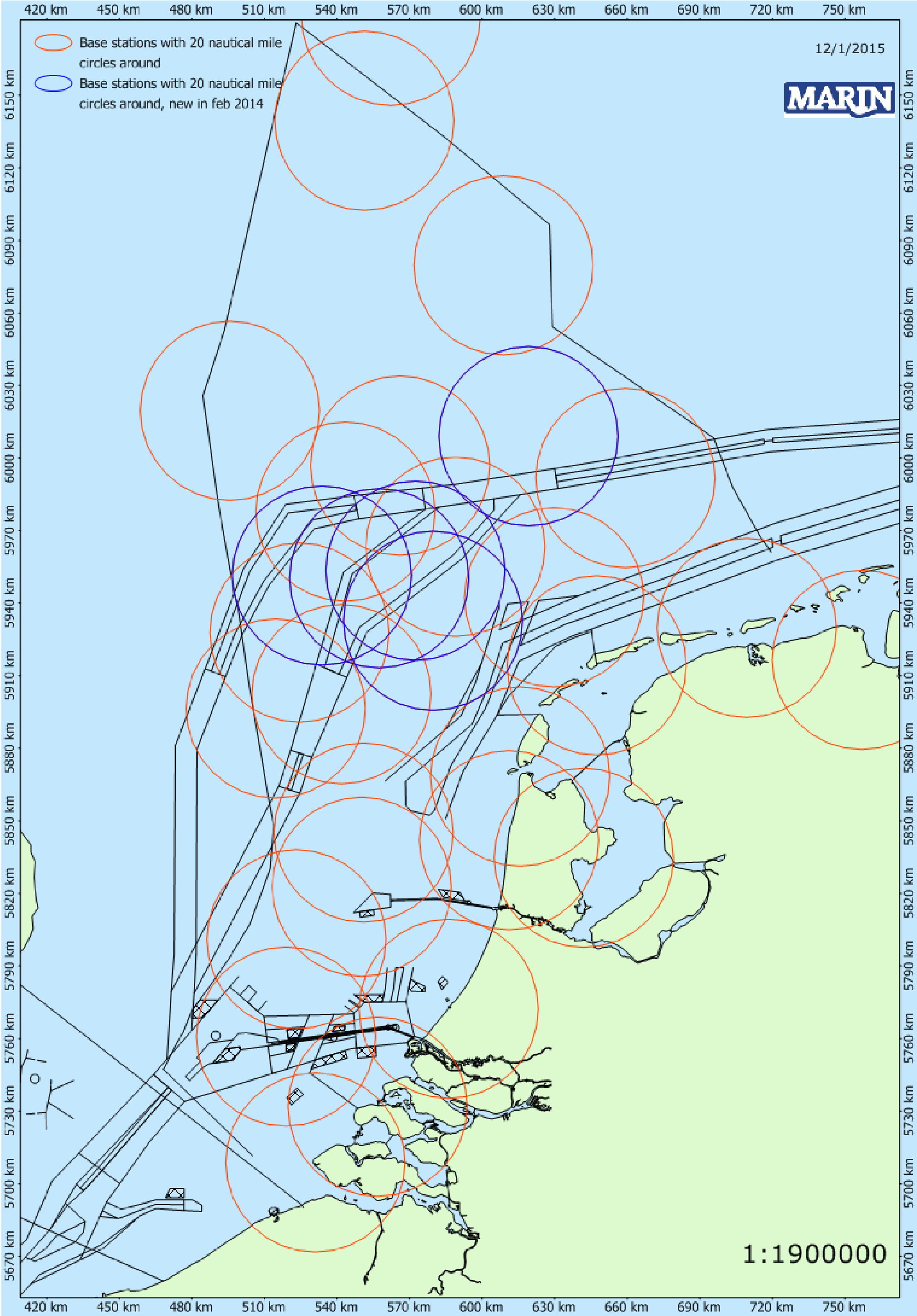

Figure 4-1 **AIS base stations in 2015 delivering data to the Netherlands Coastguard [excluding the base station for the Schelde Radar Keten.]**

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 receipt of AIS messages is recovered after some time, which is the case in the center area of the Netherlands sea area. However, on most locations near the border of the Netherlands sea area it means that the ship has left the system until its next journey through the Netherlands sea area. Thus, the figure shows more or less the locations where ships are removed from the system. The ideal situation would be if the ships that leave the system are located outside the Netherlands sea area, which is the case on a large part of the west side of the NCS.

These figures show the coverage for June and September 2015. These months were chosen so that the data can be compared with last year. For the previous year (2014) clearly some AIS messages were missing in the most southwestern point of the NCS, which is not the case for 2015. Fluctuations in coverage are expected due to the dependency on atmospheric conditions.

Figure 4-3 shows that one base station in the middle north probably did not function optimally in September. This area is better covered in June.

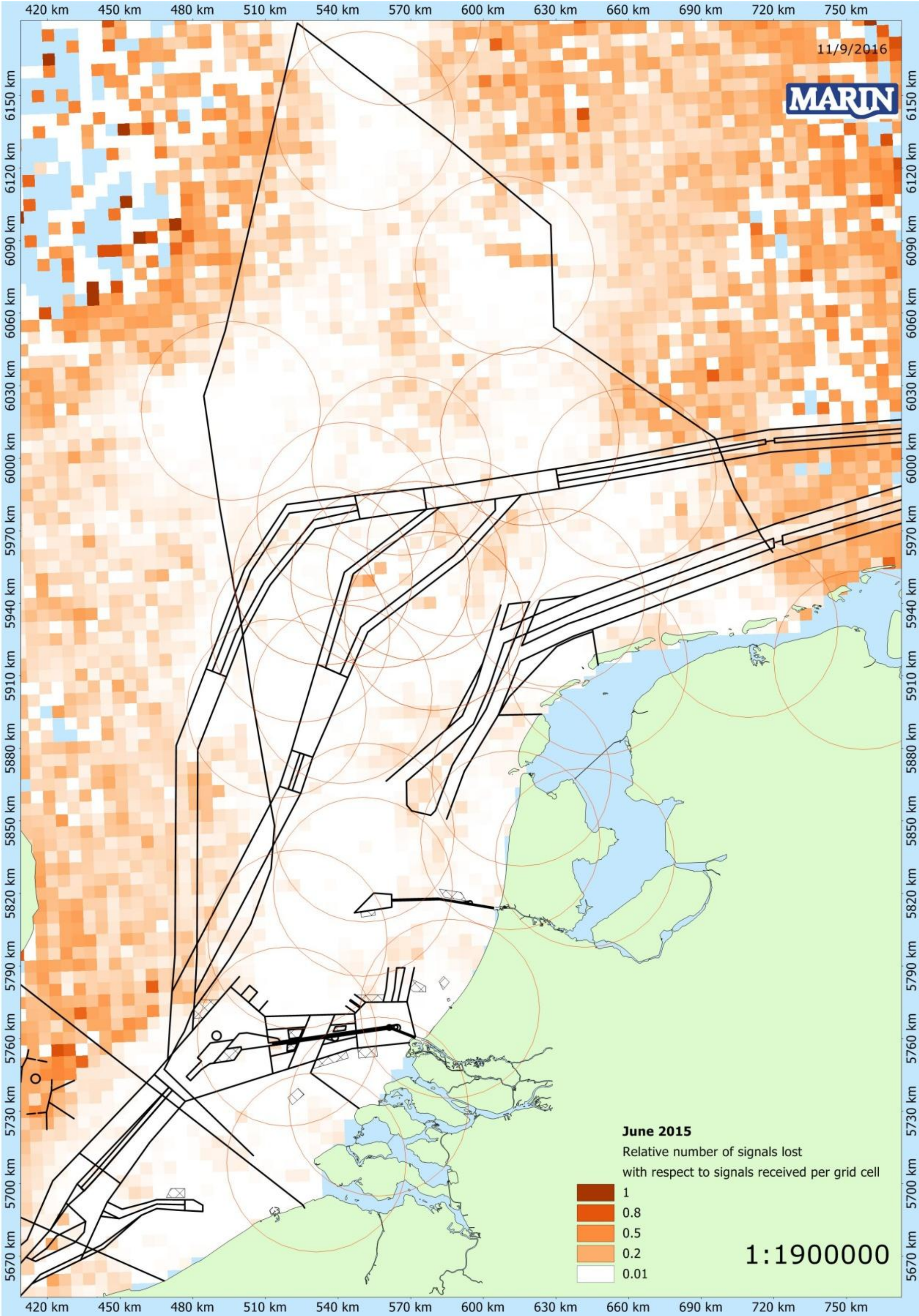

Figure 4-2 **June 2015, relative number of signals lost with respect to signals received per grid cell, circles mark the 20 nautical miles zones around the Dutch base stations**

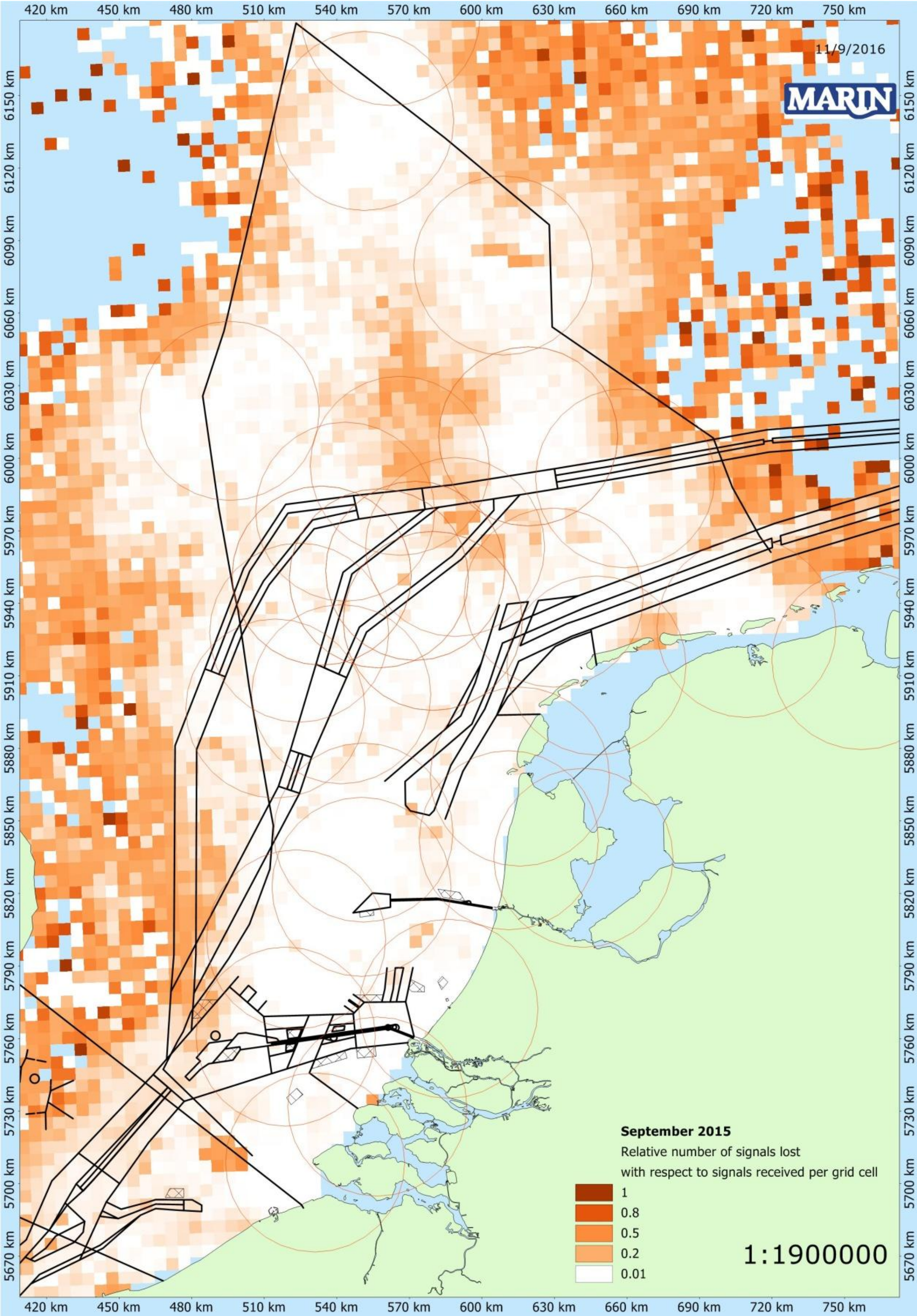

Figure 4-3 **September 2015, relative number of signals lost with respect to signals received per grid cell, circles mark the 20 nautical miles zones around the Dutch base stations**

4.2.4 Coverage in the Dutch port areas

Also in the port areas, it is possible that certain areas are not covered by AIS base stations during some time. Although it is very time-consuming to carry out a complete check on this, some checks on coverage have been performed, as described in [1]. These checks did not show suspicious behaviour in the port areas.

There is a new source of AIS data available for the Western Scheldt area, which solves the bad coverage problems in previous years. The coverage of the Schelde Radar Keten AIS data for the Western Scheldt is presented in Figure 4-4.

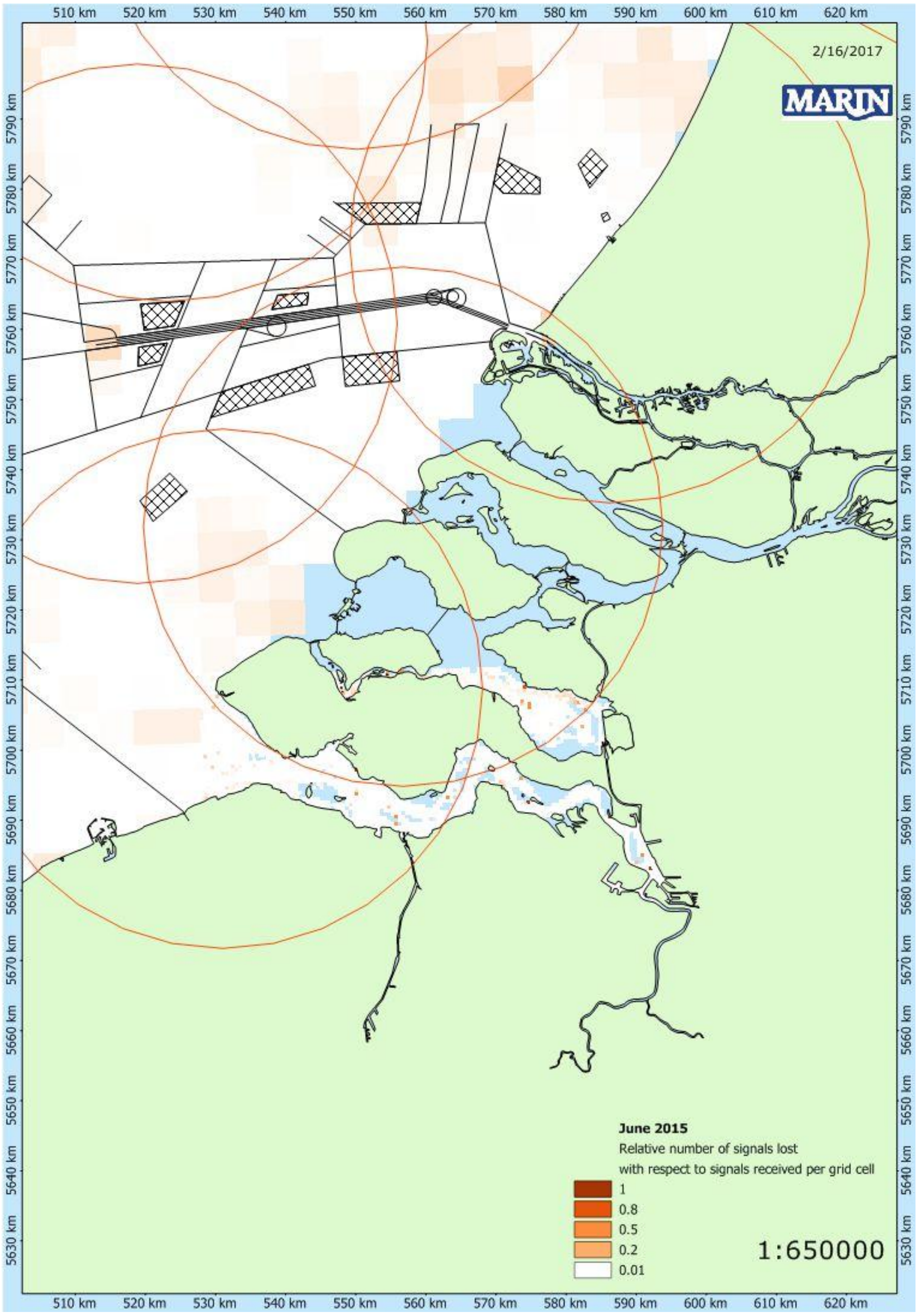

Figure 4-4 **June 2015, relative number of signals lost with respect to signals received per grid cell, based on AIS data of the Schelde radar Keten.**

5 ACTIVITIES OF SEAGOING VESSELS FOR 2015 AND COMPARISON WITH 2014 FOR THE DUTCH PORT AREAS AND THE NETHERLANDS SEA AREA

5.1 Introduction

This chapter presents the activities of seagoing vessels for 2015 in the Dutch port areas and in the Netherlands sea area. The activities of 2015 are compared to those of 2014. Values are presented as calculated and are not rounded off. 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. These numbers can be used to check the information on activity as derived from the AIS data. First, the values of 2015 are shown and then the percentages with respect to 2014. The table contains the number of calls and the cargo handling for the main ports in each port area. Table 5-1 shows that Antwerp has grown both in the number of calls (3%) as well as in the GT's (10%). Rotterdam has a slightly larger number of calls in 2015 compared to 2014 and 5% increase in cargo handling. The port of Amsterdam show 4% decrease of the number of calls, and a similar number of cargo handling compared to 2014.

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

Port area	Ports	Number of calls		Cargo handling x 1000 tons	
		2015	2015/2014	2015	2015/2014
Western Scheldt	Antwerp*	14,417	103%	367,709	110%
	Zeeland seaports (Vlissingen en Terneuzen)	5,750	104%	33,069	94%
Rotterdam	Rijn- en Maasmondgebied	29,122	100%	466,000	105%
Amsterdam	Noordzeekanaalgebied	7,162	96%	97,000	99%

*not cargo handling but GT (in 1000 ton)

The emission explaining variables for each port area are presented in a table per ship type and a table per ship size class in Table 5-2 through Table 5-13.

Western Scheldt
Unlike for previous years the Western Scheldt activities are totally based on AIS data, since the Schelde Radar Keten made it possible to use their more complete AIS data source. Therefore, activities in Table 5-2 and Table 5-3 of seagoing vessels on the Western Scheldt also include the part from Terneuzen to the east. However, since this data is not available for 2014, the comparison of the activities is only done on the area west of Terneuzen.

The activity tables, Table 5-2 and Table 5-3, show that the hours of moving ships increased by 8.4%. Also the GT.nm (gross tonnage times nautical miles) increased, but only by 6.4%. The average speed increased with 0.6%.

There is a shift in ship types due to the different method of assigning the EMS types to the MMSI numbers, so it is hard to say if the number of hours moving in the port of Oil tankers and reefers truly decreased, or if this is due to the new method. It is fair to conclude that the number of hours of moving ships larger than 100,000 actually increased, since there is not a big shift in size classes due to the new assigning method.

For berthed ships the hours and GT.hours (Gross tonnage times hours) increased by respectively 27.1% and 18.0% compared to previous year. In the previous study the hours for the largest ship sizes increased from 30 hours in 2013 to 310 hours in 2014. In 2015 the numbers of hours for the largest ship size class went back to 19 (for the Western part of the Western Scheldt).

Rotterdam
The activity tables, Table 5-4 and Table 5-5, for Rotterdam show that the moving activities, hours and GT.nm, increased with respectively 4% and 4.9% in 2015 compared to 2014. The average speed stayed the same.

The largest increase in hours, for both moving and berthed, are caused by large vessels of over 100,000 GT.

The berthed activities, hours and GT.hours, increased respectively with 9.7% and 8.4%.

Amsterdam
The activity tables, Table 5-6 and Table 5-7, for Amsterdam, show that the increase in hours moving is 3.7% and the increase in GT.nm is only 0.7%. The average speed increased by 0.4 %.

The total hours and GT.hours for berthed ships increased with respectively 46.8% and 45.2%, with a remarkable increase for the ships with a GT over 100,000 (note that the total number is still small compared to the other size ranges).

Ems
The activity tables, Table 5-8 and Table 5-9, for the Ems area shows that the moving activities, hours and GT.nm, increased by respectively 19.8% and 18.7%. The moving hours of large ships of over 100,000GT even doubled. The average speed is about 2% lower.

The number of berthed hours and GT.hours increased respectively by 13.3% and 18.3%.

Den Helder

For Den Helder Table 5-10 and Table 5-11 show that the moving activities, hours and GT.nm, decreased respectively by 23.2% and 82.7%. The number of hours of visiting Oil tankers and passenger ships decreased significantly, as well as the amount of ships larger than 30,000 GT. The activities for the larger ship classes are based on such a small number of ships, that they are not compared to the results of 2014. The average speed is lowered by 26.1%.

Compared to 2014, the berthed hours and GT.hours in the Den Helder port area decreased by, respectively 0.4% and 60.9%.

Harlingen

The activity tables, Table 5-12 and Table 5-13 show a decrease in activities in the port of Harlingen. The moving activities hours and GT.nm decreased respectively by 35.5% and 65.3%.

The average speed in the area decreased by 26.1%, similarly to the decrease noted in Den Helder.

The berthed hour and GT.hours decreased respectively by 17.3% and 25.7%

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

Ship type	Totals for Western Scheldt in 2015					2015 as percentage of 2014 only for western part				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	7,141	201,111,546	6,079	1,701,220,352	10.73	71.8%	54.4%	79.2%	89.4%	100.2%
Chem.+Gas tanker	63,631	578,781,921	38,687	3,688,008,795	11.17	127.4%	113.9%	101.2%	102.6%	101.1%
Bulk carrier	25,198	844,385,742	7,479	1,947,449,581	9.11	169.1%	139.5%	112.6%	118.2%	103.1%
Container ship	2,964	42,915,849	24,479	16,202,174,122	12.92	121.4%	76.1%	101.9%	109.3%	99.6%
General Dry Cargo	96,262	648,543,366	34,590	1,917,877,497	10.51	169.6%	142.2%	100.8%	102.9%	98.9%
RoRo Cargo / Vehicle	10,091	208,700,129	11,123	5,626,445,453	12.66	114.4%	115.4%	110.7%	111.4%	100.1%
Reefer	8,758	79,753,186	1,825	270,052,079	12.06	106.1%	109.7%	71.9%	70.8%	95.4%
Passenger	17,370	72,564,474	5,801	261,421,639	12.69	114.5%	121.1%	90.3%	61.9%	104.9%
Miscellaneous	148,697	302,921,809	29,761	554,240,567	8.05	134.2%	110.9%	128.3%	103.8%	113.7%
Tug/Supply	144,378	130,863,131	22,200	48,635,016	6.81	109.8%	241.0%	129.9%	132.7%	108.4%
Non Merchant	7,621	12,681,060	473	6,261,693	11.09	79.7%	129.0%	337.5%	710.0%	129.7%
Total	532,111	3,123,222,213	182,497	32,223,786,795	11.92	127.1%	118.0%	108.4%	106.4%	100.6%

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 2015					2015 as percentage of 2014 only for western part				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Averag e speed	Hours	GT.hours	Hours	GT.nm	Average speed
<100	47,290	3,253,042	10,191	7,284,433	10.54	-	-	-	-	-
100-1,600	208,071	107,811,404	36,758	196,998,855	8.08	93.1%	94.8%	102.0%	98.1%	99.3%
1,600-3,000	103,786	244,261,857	29,803	671,355,619	9.40	172.8%	176.5%	100.0%	100.8%	99.7%
3,000-5,000	41,585	162,568,214	25,020	975,882,108	9.85	153.3%	151.6%	98.5%	100.7%	102.8%
5,000-10,000	39,673	280,474,601	20,590	1,583,318,744	11.18	118.4%	121.1%	103.4%	100.2%	98.6%
10,000-30,000	67,602	1,214,899,281	29,988	6,749,458,444	11.85	153.4%	146.1%	100.2%	103.5%	102.3%
30,000-60,000	20,156	806,004,971	20,972	10,877,439,933	11.97	99.6%	98.6%	104.1%	102.3%	99.0%
60,000-100,000	3,928	300,876,609	6,426	6,072,972,396	12.52	87.1%	86.0%	102.6%	103.2%	100.7%
>100,000	20	3,072,234	2,749	5,089,076,264	12.65	6.0%	6.0%	130.7%	137.2%	99.4%
Total	532,111	3,123,222,213	182,497	32,223,786,795	11.92	127.1%	118.0%	108.4%	106.4%	100.6%

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

Ship type	Totals for Rotterdam in 2015					2015 as percentage of 2014				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	72,603	5,142,816,501	5,736	2,001,837,066	6.63	125.7%	130.0%	103.1%	108.3%	100.6%
Chem.+Gas tanker	104,813	1,373,867,358	20,481	1,568,829,693	8.37	118.1%	117.8%	102.3%	100.4%	101.2%
Bulk carrier	89,531	4,883,253,264	3,354	943,287,517	6.45	112.0%	101.9%	99.3%	98.0%	101.3%
Container ship	155,974	7,946,427,831	25,776	5,400,151,452	7.14	102.9%	108.6%	101.5%	110.5%	99.2%
General Dry Cargo	77,251	460,462,799	20,030	720,053,102	9.21	92.6%	93.5%	94.3%	93.8%	101.3%
RoRo Cargo / Vehicle	24,746	549,266,609	7,273	1,717,175,051	9.73	99.3%	95.4%	101.0%	105.0%	101.8%
Reefer	1,423	14,958,998	552	56,336,385	9.32	135.3%	166.7%	82.5%	96.6%	97.6%
Passenger	11,035	603,787,940	1,584	1,019,027,292	11.60	97.1%	86.9%	101.8%	103.5%	101.8%
Miscellaneous	78,574	739,750,064	20,566	427,336,972	7.51	83.5%	67.3%	99.1%	84.1%	101.2%
Tug/Supply	253,260	182,015,734	55,034	147,551,416	6.46	123.1%	173.0%	113.4%	116.6%	104.0%
Non Merchant	8,076	3,963,544	201	1,566,844	8.39	806.5%	913.4%	109.8%	251.8%	116.8%
Total	877,286	21,900,570,644	160,587	14,003,152,790	7.69	109.7%	108.4%	104.0%	104.9%	100.1%

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

Ship size in GT	Totals for Rotterdam in 2015					2015 as percentage of 2014				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average Speed	Hours	GT.hours	Hours	GT.nm	Average speed
< 100	14,463	1,148,100	2,384	1,783,866	8.44	--	--	--	--	--
100-1,600	283,415	117,044,730	66,705	185,865,439	6.74	115.5%	104.5%	108.0%	103.6%	102.8%
1,600-3,000	52,187	121,334,384	15,240	337,480,594	9.23	111.4%	107.3%	97.3%	95.6%	99.9%
3,000-5,000	43,676	174,465,833	19,146	688,712,346	8.85	85.6%	86.2%	99.6%	103.9%	102.0%
5,000-10,000	108,132	812,903,511	19,848	1,398,992,252	9.29	96.6%	97.6%	91.4%	95.0%	100.7%
10,000-30,000	143,505	2,663,792,895	22,330	3,657,109,679	8.92	109.0%	107.6%	103.2%	102.4%	100.5%
30,000-60,000	93,839	4,068,677,970	6,927	2,396,704,660	8.16	114.4%	114.1%	101.4%	104.0%	102.2%
60,000-100,000	78,658	6,096,176,680	5,194	2,830,272,894	7.20	94.1%	94.1%	96.0%	97.2%	102.2%
>100,000	59,410	7,845,026,541	2,814	2,506,231,061	5.82	125.6%	122.0%	124.9%	132.7%	102.0%
Total	877,286	21,900,570,644	160,587	14,003,152,790	7.69	109.7%	108.4%	104.0%	104.9%	100.1%

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

Ship type	Totals for Amsterdam in 2015					2015 as percentage of 2014				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	33,684	1,145,619,007	1,955	312,864,516	5.44	247.2%	249.6%	88.6%	93.8%	102.5%
Chem.+Gas tanker	71,592	1,297,625,487	6,273	542,271,118	6.07	279.5%	280.9%	108.7%	109.4%	102.6%
Bulk carrier	71,463	3,290,607,745	3,194	713,012,235	5.12	129.0%	118.0%	111.2%	103.4%	98.7%
Container ship	534	8,663,547	23	1,659,479	5.73	504.7%	525.0%	144.8%	95.4%	96.4%
General Dry Cargo	110,206	376,904,185	8,460	178,832,657	6.82	160.2%	146.9%	97.0%	96.5%	101.2%
RoRo Cargo / Vehicle	9,099	274,328,929	1,161	275,942,632	6.32	100.2%	97.6%	72.3%	91.0%	100.9%
Reefer	20,081	90,687,645	530	13,655,810	5.74	120.4%	112.7%	117.9%	118.7%	100.0%
Passenger	7,691	274,918,345	1,264	375,465,980	6.81	167.4%	148.4%	111.4%	101.2%	100.4%
Miscellaneous	59,612	183,259,843	2,979	51,811,639	5.27	101.5%	69.5%	104.2%	88.4%	95.2%
Tug/Supply	147,786	90,581,436	18,910	33,374,366	5.47	139.7%	130.0%	107.6%	109.0%	98.1%
Non Merchant	14,625	14,850,686	583	1,914,891	5.46	106.3%	245.7%	128.5%	161.2%	83.9%
Total	546,373	7,048,046,856	45,333	2,500,805,324	5.81	146.8%	145.2%	103.8%	100.7%	100.4%

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

Ship size in GT	Totals for Amsterdam in 2015					2015 as percentage of 2014				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
< 100	8,750	411,170	1,106	501,806	7.20	--	--	--	--	--
100-1,600	193,516	87,103,974	21,738	45,845,140	5.74	144.5%	149.8%	105.5%	99.6%	97.0%
1,600-3,000	86,785	206,608,511	6,034	102,035,494	6.96	152.0%	153.8%	96.9%	97.8%	101.6%
3,000-5,000	44,005	173,068,489	3,181	85,037,138	6.69	117.7%	118.7%	101.9%	102.4%	99.9%
5,000-10,000	37,739	275,146,424	2,752	138,499,704	6.50	101.2%	106.6%	76.3%	76.9%	102.4%
10,000-30,000	83,265	1,797,427,221	5,228	634,310,602	5.96	192.9%	208.7%	108.0%	109.6%	101.8%
30,000-60,000	73,060	2,923,107,685	4,076	941,613,694	5.64	159.5%	153.5%	99.3%	97.1%	99.4%
60,000-100,000	18,861	1,538,561,412	1,071	446,436,923	5.37	107.0%	103.2%	93.0%	87.0%	98.1%
>100,000	392	46,611,968	146	106,524,823	6.36	1567.5%	1709.1%	1335.2%	1571.6%	111.1%
Total	546,373	7,048,046,856	45,333	2,500,805,324	5.81	146.8%	145.2%	103.8%	100.7%	100.4%

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

Ship type	Totals for Ems in 2015					2015 as percentage of 2014				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	159	307,884	439	9,014,568	10.06	24.7%	17.7%	71.1%	120.0%	111.1%
Chem.+Gas tanker	3,070	10,738,604	1,754	94,263,360	11.11	90.0%	87.3%	94.8%	104.7%	103.7%
Bulk carrier	3,733	48,081,506	920	147,563,917	9.40	148.8%	134.7%	140.2%	167.0%	98.2%
Container ship	848	11,473,266	82	4,808,693	11.39	45.5%	190.8%	59.3%	56.4%	106.3%
General Dry Cargo	62,067	211,567,457	7,579	279,974,605	10.34	103.5%	104.5%	104.6%	105.5%	102.0%
RoRo Cargo / Vehicle	16,307	564,443,497	7,688	1,809,687,020	12.79	127.3%	119.9%	106.3%	108.4%	101.7%
Reefer	1,356	3,759,978	186	5,495,831	10.39	88.9%	61.7%	108.9%	77.1%	93.0%
Passenger	2,825	62,805,069	3,470	105,802,905	12.63	63.2%	146.0%	120.4%	172.2%	105.9%
Miscellaneous	57,923	123,118,373	15,384	373,042,631	6.88	161.8%	107.2%	145.3%	154.9%	96.6%
Tug/Supply	104,481	111,685,412	13,795	137,993,457	9.30	104.5%	143.4%	189.1%	225.5%	101.6%
Non Merchant	19	9,343	44	175,185	8.78	19.1%	37.9%	119.8%	402.4%	140.4%
Total	252,788	1,147,990,390	51,341	2,967,822,174	10.91	113.3%	118.3%	132.6%	118.7%	97.9%

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 2015					2015 as percentage of 2014				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
< 100	10,052	626,713	622	431,089	12.02	--	--	--	--	--
100-1,600	127,570	41,697,967	21,399	78,331,705	9.81	107.0%	85.4%	146.1%	115.9%	92.0%
1,600-3,000	58,452	139,346,300	11,286	271,496,453	10.70	110.4%	111.3%	110.7%	112.5%	102.4%
3,000-5,000	20,552	82,774,990	3,571	133,010,506	9.50	94.9%	93.9%	77.9%	83.1%	109.6%
5,000-10,000	12,432	81,256,165	9,553	593,304,870	9.07	107.6%	109.6%	185.0%	155.9%	90.0%
10,000-30,000	13,859	252,155,010	2,923	627,219,528	11.40	154.7%	147.2%	128.7%	122.7%	98.8%
30,000-60,000	8,431	434,083,185	1,683	1,016,147,470	12.14	111.3%	115.6%	107.4%	111.6%	100.9%
60,000-100,000	1,203	76,427,227	288	231,053,526	12.74	113.0%	117.5%	101.5%	104.9%	101.2%
>100,000	237	39,622,832	16	16,827,026	6.83	176.0%	175.1%	208.4%	224.3%	116.7%
Total	252,788	1,147,990,390	51,341	2,967,822,174	10.91	113.3%	118.3%	132.6%	118.7%	97.9%

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

Ship type	Totals for Den Helder in 2015					2015 as percentage of 2014				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	59	3,243,981	1	278,122	4.09	2.2%	6.8%	8.1%	17.9%	70.0%
Chem.+Gas tanker	131	1,410,347	29	240,762	5.32	31.4%	43.9%	105.9%	34.0%	68.9%
Bulk carrier	58	2,855,654	2	417,627	4.39	--	--	--	--	--
Container ship	76	2,332,873	3	242,249	3.70	--	--	--	--	--
General Dry Cargo	2,797	4,002,766	145	863,242	5.32	130.4%	61.3%	196.9%	47.6%	74.5%
RoRo Cargo / Vehicle	27	918,765	2	190,988	4.19	--	--	49.6%	332.9%	42.0%
Reefer	3	18,418	0	0	--	--	--	--	--	--
Passenger	1,504	3,111,693	100	9,287,608	8.56	28.2%	4.9%	3.6%	2.8%	95.0%
Miscellaneous	34,055	28,878,048	1,605	9,819,641	6.02	75.0%	11.0%	104.6%	59.8%	112.5%
Tug/Supply	128,687	171,177,497	4,942	47,877,721	5.87	114.4%	98.4%	109.5%	95.6%	95.6%
Non Merchant	1,203	243,641	65	276,789	9.00	138.8%	44.3%	177.3%	154.9%	108.8%
Total	168,599	218,193,683	6,893	69,494,748	6.11	99.6%	39.1%	76.8%	17.3%	73.9%

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 2015					2015 as percentage of 2014				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
<100	4,173	255,127	187	108,834	9.41	--	--	--	--	--
100-1,600	98,550	38,888,217	3,355	9,612,138	5.79	121.6%	105.4%	130.0%	121.0%	88.7%
1,600-3,000	58,309	134,227,494	2,968	41,069,436	5.90	97.4%	96.1%	91.6%	90.6%	98.2%
3,000-5,000	6,131	22,881,494	251	5,787,516	6.08	56.4%	51.4%	88.6%	78.2%	91.4%
5,000-10,000	892	6,672,889	31	1,185,698	5.14	80.7%	86.0%	102.3%	81.3%	78.1%
10,000-30,000	423	7,013,894	96	10,866,169	8.07	2.6%	2.1%	3.4%	3.2%	91.5%
30,000-60,000	67	2,997,517	2	347,071	4.67	--	--	--	--	--
60,000-100,000	41	3,213,434	2	434,187	4.16	--	--	--	--	--
>100,000	13	2,043,617	0	83,699	2.02	--	--	--	--	--
Total	168,599	218,193,683	6,893	69,494,748	6.11	99.6%	39.1%	76.8%	17.3%	73.9%

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

Ship type	Totals for Harlingen in 2015					2015 as percentage of 2014				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.hours	Average speed	Hours	GT.Hours	Hours	GT.nm	Average speed
Oil tanker	26	1,205,776	12	3,065,562	5.65	--	--	--	--	--
Chem.+Gas tanker	978	1,855,563	271	2,136,439	6.07	15.7%	12.0%	75.6%	36.8%	76.3%
Bulk carrier	53	1,815,295	17	2,165,389	4.37	113.9%	755.9%	176.3%	487.2%	50.3%
Container ship	564	3,525,236	31	2,032,395	5.40	164.5%	395.8%	366.2%	856.5%	52.7%
General Dry Cargo	16,191	52,611,929	1,521	31,249,597	8.52	84.9%	76.8%	114.0%	100.1%	99.5%
RoRo Cargo / Vehicle	23	612,488	5	446,708	3.94	0.6%	9.6%	0.3%	1.9%	44.0%
Reefer	2,495	12,058,520	237	7,750,654	8.22	84.2%	87.0%	90.0%	77.5%	91.1%
Passenger	937	1,235,444	70	1,528,817	6.13	8.0%	5.2%	1.4%	1.0%	49.7%
Miscellaneous	31,240	20,357,379	4,448	37,119,110	8.26	100.4%	91.2%	166.3%	121.4%	97.0%
Tug/Supply	36,298	35,184,935	1,238	5,562,923	8.10	120.7%	144.4%	109.0%	81.0%	77.5%
Non Merchant	2,633	1,738,679	152	613,279	8.63	49.1%	85.7%	48.3%	65.9%	109.6%
Total	91,438	132,201,246	8,001	93,670,872	7.81	82.7%	74.3%	64.5%	34.7%	73.9%

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

Ship size in GT	Totals for Harlingen in 2015					2015 as percentage of 2014				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.hours	Average speed	Hours	GT.Hours	Hours	GT.nm	Average speed
<100	1,843	113,440	785	480,444	9.56	--	--	--	--	--
100-1,600	62,979	30,411,026	5,307	26,017,691	7.76	93.0%	96.1%	97.3%	55.5%	62.3%
1,600-3,000	16,151	41,560,948	1,167	24,172,771	8.63	75.9%	82.1%	41.6%	49.2%	99.2%
3,000-5,000	4,844	19,235,786	240	7,915,929	8.43	34.8%	36.8%	6.6%	5.4%	75.1%
5,000-10,000	5,421	32,407,073	461	26,281,526	8.66	70.3%	74.7%	93.2%	98.7%	97.6%
10,000-30,000	92	1,787,288	19	1,655,196	4.83	--	--	--	--	104.8%
30,000-60,000	73	3,081,228	13	2,383,245	4.28	--	--	--	--	--
60,000-100,000	21	1,538,781	6	2,735,146	5.58	--	--	--	--	--
>100,000	16	2,065,676	3	2,028,923	4.82	--	--	--	--	--
Total	91,438	132,201,246	8,001	93,670,872	7.81	82.7%	74.3%	64.5%	34.7%	73.9%

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 2015 are compared to the activities of 2014. 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 3.1% and an increase in GT.nm of 4.0%. The average speed only increased by 0.3% compared to the year before.

For ships at anchor, the average number of hours decreased by 2.3% and the average number of GT.hours increased by 3.8%.

Also in these activity tables of the Netherlands sea area, a shift of activities over the ship types is observed, caused by the different method of coupling MMSI numbers to EMS types.

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 2015					2015 as percentage of 2014				
	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	123,079	6,023,665,272	87,766	43,867,253,441	10.54	102.8%	100.8%	104.2%	103.8%	99.1%
Chem.+Gas tanker	268,255	3,165,215,402	267,454	31,505,411,237	11.54	89.8%	95.3%	100.9%	101.0%	99.9%
Bulk carrier	98,031	5,170,825,684	112,781	40,485,424,320	10.73	113.2%	115.6%	107.1%	103.6%	98.6%
Container ship	45,348	1,659,797,289	170,786	120,854,554,976	13.96	76.4%	101.7%	97.4%	107.3%	99.4%
General Dry Cargo	97,940	514,272,498	390,399	17,212,537,890	10.86	116.7%	132.3%	94.4%	97.3%	101.7%
RoRo Cargo / Vehicle	6,797	311,559,467	121,104	59,380,552,873	15.54	96.9%	109.5%	103.8%	108.4%	101.7%
Reefer	2,180	17,896,784	14,218	1,692,599,637	15.23	47.7%	42.5%	89.3%	89.5%	101.6%
Passenger	1,820	11,676,502	22,033	17,936,661,160	17.01	28.7%	76.1%	85.5%	93.3%	100.5%
Miscellaneous	57,911	334,423,182	105,396	2,793,878,076	7.63	88.3%	73.4%	85.1%	71.8%	101.7%
Tug/Supply	106,043	164,642,046	171,026	1,597,058,872	7.17	111.5%	111.7%	92.6%	94.8%	102.7%
Non Merchant	1,409	419,063	5,369	39,133,054	10.90	152.3%	107.8%	107.9%	118.4%	106.1%
Total	808,813	17,374,393,189	1,468,332	337,365,065,537	12.74	97.7%	103.8%	96.9%	104.0%	100.3%

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 2015					2015 as percentage of 2014				
	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	2,451	180,066	8,759	2,904,998	5.47	--	--	--	--	--
100-1,600	83,497	44,378,344	208,898	980,881,506	6.63	107.2%	108.7%	93.1%	95.5%	101.7%
1,600-3,000	107,711	258,665,230	324,434	7,073,672,929	9.03	89.5%	88.4%	93.6%	94.9%	101.9%
3,000-5,000	106,092	421,455,233	186,037	7,654,288,289	10.42	86.4%	87.2%	93.0%	93.9%	101.8%
5,000-10,000	122,779	884,113,242	181,532	16,026,302,971	12.16	91.8%	90.6%	92.3%	94.4%	101.1%
10,000-30,000	202,665	3,874,095,356	289,053	71,773,096,538	12.84	102.6%	101.7%	102.4%	104.8%	101.7%
30,000-60,000	99,452	4,281,034,965	152,615	89,270,529,292	13.40	100.3%	101.0%	99.7%	98.9%	99.3%
60,000-100,000	68,399	5,293,649,921	82,521	76,779,132,044	12.52	109.7%	108.9%	96.6%	93.8%	98.6%
>100,000	15,768	2,316,820,832	34,556	67,815,767,000	13.25	112.1%	114.0%	129.3%	135.4%	100.1%
Total	808,813	17,374,393,189	1,468,332	337,365,065,537	12.74	97.7%	103.8%	96.9%	104.0%	100.3%

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 and Figure 5-1. Compared to the results presented in the previous study, most remarkable is the increase of 46.8% of berthed ships in the port of Amsterdam. The increase in not moving ships in Rotterdam is a little lower compared to last year, an increase of 9.7% in 2015 compared to an increase of 29% in 2014 (a total increase of 41.5 % in 2015 compared to 2013). This is mainly due to the large dependency on the offshore industry in the Port of Den Helder. For the NCS combined with the 12-miles zone the average number of ships decreased, both for moving and not moving ships. The average speed in the larger ports stayed the same and decreased significantly for the smallest ports: Den Helder and Harlingen.

The average GT of the ships is given in Table 5-17. For the NCS + 12-mile zone the average GT of moving and not moving ships together increased by 6.7% (0.6% in 2014). This average shows a decrease of 61.6% for Den Helder, which was the only port with an increase (of 16.9%) in the previous year. The average GT of the ships in Rotterdam, Amsterdam and Ems is similar to last year. For the Western Scheldt this is decreased by 7.5% and for the Harlingen the decrease is 12.3%.

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

Table 5-16 Average number of ships per day, in distinguished areas, excluding Fishing vessels, EMS-type 11.

Area	In 2015				In 2015 as percentage of 2014			
	Average # ships/day			Speed	Average # ships/day			Speed
	Not moving	Moving	Total	Knots	Not moving	Moving	Total	Knots
Western Scheldt[1]	55.73	14.15	69.88	11.31	127.1%	108.4%	122.8%	100.6%
Rotterdam	100.15	18.33	118.48	7.69	109.7%	104.0%	108.8%	100.1%
Amsterdam	62.37	5.17	67.55	5.81	146.8%	103.8%	142.3%	100.4%
Ems	28.86	5.86	34.72	10.91	113.3%	132.6%	116.2%	97.9%
Den Helder	19.25	0.79	20.03	6.11	99.6%	76.8%	98.4%	73.9%
Harlingen	10.44	0.91	11.35	7.81	82.7%	64.5%	80.8%	73.9%
NCS + 12-mile zone	92.33	167.62	259.95	12.74	97.7%	96.9%	97.2%	100.3%

[1] Only part from Terneuzen to the west, to be able to compare with the results of 2014.

Table 5-17 Average GT in distinguished areas, excluding fishing vessels, EMS-type 11.

Area	In 2015			In 2015 as percentage of 2014		
	Average GT of ships			Average GT of ships		
	Not moving	Moving	Total	Not moving	Moving	Total
Western Scheldt[2]	6,275	12,344	7,503	92.9%	97.5%	92.5%
Rotterdam	24,964	11,335	22,855	98.8%	100.8%	99.4%
Amsterdam	12,900	9,489	12,638	98.9%	96.6%	99.5%
Ems	4,541	5,300	4,669	104.4%	91.4%	102.3%
Den Helder	1,294	1,651	1,308	39.3%	30.6%	38.4%
Harlingen	1,446	1,499	1,450	89.9%	72.8%	87.7%
NCS + 12-mile zone	21,481	18,037	19,261	106.3%	107.0%	106.7%

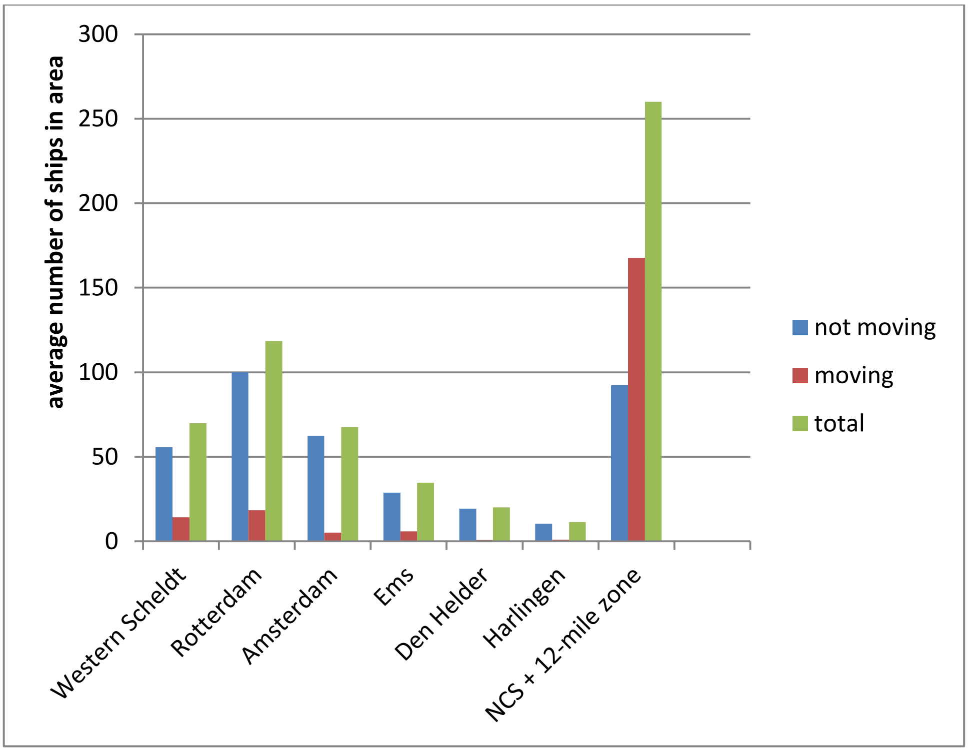

Figure 5-1 Average number of ships per day in 2015, moving, not moving and in total, excl. Fishing vessels, EMS-type 11.

[2] Based on the western part of the Western Scheldt only, because of the bad receipt of AIS data from the eastern part in 2014.

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 2015 for the Dutch port areas and the Netherlands sea area. To indicate the change in emissions, all values for 2015 are compared with the values of 2014. Values are presented as calculated and are not rounded off.

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 2015 NO_x emissions. Also the absolute and relative change in this spatial distribution compared to 2014 is presented.

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 2014. 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 decrease in emission of SO_2 and aerosols MDO between 2014 and 2015 for all port areas. Note the berthed emission numbers for the aerosols MDO are very small. The extreme drop of SO_2 emission for sailing ships is the consequence of IMO-regulations of sulphur content in marine fuels per 1-1-2015. In the SECA-areas the maximum sulphur content of marine fuels has been limited on 0.1% m/m. It has been assumed in the calculations that in harbour areas the rules were obeyed. In the North Sea area a partial implementation of 50% has been assumed. The changes are implemented within the tables **A-3**, **A-4**, **A-5**, **A-6**, **A-8**, **A-9**) for substances SO2 and Aerosols (PM). For the port areas of the Western Scheldt, Rotterdam and Amsterdam, an increase in emissions of VOC, NO_x, CO, CO_2 is observed. For the Aerosols HFO only the Western Scheldt shows a decrease. The increase in percentage of the methane emission in the Western Scheldt is enormous, but this is due to the very low absolute numbers, the absolute differences are small. For the port of Amsterdam the emissions of CO_2 and Aerosols HFO increased the most.
Besides the decrease of the sulphur content also the usage of another version of the ships register (IHS instead of LLI) has influenced the emission factors of individual ships via changes in installed power and fuel used.

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

Table 6-1 Total emissions in ton in each port area for 2015, excluding Fishing vessels, EMS-type 11.

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Total
1011 Methane	Berthed	-	-	-	-	-	-	-
	Sailing	1.5	0.5	0	4	0	0	6.0
	Total	1.5	0.5	0	4	0	0	6.0
1237 VOC	Berthed	46	311	85	17	6	3	467
	Sailing	280	185	35	42	3	3	548
	Total	326	496	120	59	9	6	1,016
4001 SO_2	Berthed	86	579	149	35	13	6	868
	Sailing	249	154	26	35	3	2	469
	Total	335	733	175	70	16	8	1,337
4013 NO_x	Berthed	1,069	6,290	1,829	431	165	73	9,858
	Sailing	8,746	4,788	823	1,100	84	68	15,608
	Total	9,815	11,078	2,652	1,531	248	141	25,466
4031 CO	Berthed	247	1,655	433	101	36	16	2,487
	Sailing	1,957	1,333	245	245	22	16	3,818
	Total	2,204	2,988	677	345	58	31	6,305
4032 CO_2	Berthed	92,350	765,062	197,167	32,142	10,282	4,649	1,101,651
	Sailing	394,813	244,640	41,160	56,252	5,067	3,810	745,742
	Total	487,162	1,009,702	238,327	88,394	15,348	8,459	1,847,393
6601 Aerosols MDO	Berthed	8	9	8	3	2	1	32
	Sailing	18	20	5	8	1	1	52
	Total	26	29	13	11	3	2	84
6602 Aerosols HFO	Berthed	14	139	33	5	1	0	193
	Sailing	247	155	24	32	3	1	461
	Total	261	294	57	37	4	1	654
6598 Aerosols MDO+HFO	Berthed	22	149	41	9	3	1	225
	Sailing	265	174	29	39	3	2	513
	Total	287	323	70	48	6	3	738

Table 6-2 **Emissions in each port area (including the total Western Scheldt area) for 2015 as percentage of the emissions in 2014, 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	250.3%	483.1%	-	-	-	-	839.0%
	Total	-	-	-	-	-	-	-
1237 VOC	Berthed	117.5%	121.3%	151.8%	126.8%	45.5%	78.1%	122.6%
	Sailing	113.1%	120.0%	121.5%	171.0%	97.1%	40.5%	117.8%
	Total	113.7%	120.8%	141.5%	155.2%	55.9%	53.7%	120.0%
4001 SO_2	Berthed	120.7%	110.0%	136.7%	111.9%	42.6%	82.4%	111.9%
	Sailing	11.7%	13.2%	14.9%	20.2%	13.7%	7.8%	12.7%
	Total	15.3%	43.4%	61.8%	34.2%	30.0%	21.4%	30.0%
4013 NO_x	Berthed	119.6%	110.5%	136.2%	118.5%	45.8%	77.9%	112.7%
	Sailing	106.0%	116.3%	122.2%	154.4%	94.2%	36.2%	111.3%
	Total	107.3%	112.9%	131.6%	142.3%	55.4%	50.2%	111.8%
4031 CO	Berthed	128.4%	128.3%	153.7%	131.5%	46.6%	86.8%	128.5%
	Sailing	110.0%	113.4%	115.9%	159.3%	84.4%	45.4%	113.0%
	Total	111.8%	121.2%	137.5%	150.1%	56.1%	59.8%	118.6%
4032 CO_2	Berthed	111.9%	125.0%	170.7%	129.6%	39.9%	83.1%	127.2%
	Sailing	111.0%	120.4%	125.0%	164.9%	95.7%	43.4%	116.5%
	Total	111.1%	123.9%	160.5%	150.0%	49.4%	58.8%	122.6%
6601 Aerosols MDO	Berthed	40.8%	7.1%	29.1%	45.6%	29.7%	53.7%	16.4%
	Sailing	108.0%	117.7%	96.3%	111.3%	62.9%	22.6%	101.2%
	Total	72.4%	19.7%	39.3%	77.5%	35.7%	31.4%	34.4%
6602 Aerosols HFO	Berthed	-	-	-	-	-	-	-
	Sailing	68.3%	81.3%	91.0%	133.5%	104.1%	82.8%	76.1%
	Total	72.3%	154.4%	214.6%	155.9%	148.4%	115.1%	108.0%
6598 Aerosols MDO+HFO	Berthed	116.1%	114.7%	144.5%	118.4%	46.3%	74.5%	116.6%
	Sailing	70.1%	84.2%	91.9%	128.5%	88.7%	34.8%	78.1%
	Total	72.3%	95.9%	116.8%	126.5%	62.2%	44.3%	86.8%

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 2015 are summarised in Table 6-3. This table also contains a comparison with 2014. The average emissions of moving ships has decreased with 3.1%, where in 2014 the emissions increased with almost 10%. The emissions of non-moving ships has also decreased by 2.3%.

Table 6-3 Emissions of ships in ton in the Netherlands sea area for 2015 compared with 2014, excluding Fishing vessels, EMS-type 11.

Nr	Substance	Emission in ton in 2015			Emission in 2015 as percentage of 2014		
		Not moving	Moving	Total	Not moving	Moving	Total
1011	Methane	-	36	36	-	269.1%	269.1%
1237	VOC	92	2407	2498	119.1%	110.2%	110.5%
4001	SO_2	443	11424	11867	61.6%	55.6%	55.8%
4013	NO_x	2683	82891	85574	114.4%	108.1%	108.3%
4031	CO	571	16031	16602	117.1%	104.9%	105.2%
4032	CO_2	163,924	3,797,379	3,961,303	116.0%	110.9%	111.1%
6601	Aerosols MDO	23	150	173	85.4%	113.3%	108.7%
6602	Aerosols HFO	131	3104	3236	134.2%	89.3%	90.5%
6598	Aerosols MDO+HFO	154	3255	3409	123.9%	90.2%	91.3%
Number of Ships		92	168	260	97.7%	96.9%	97.2%

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 2014 and 2015 and the third one shows the *relative* change in emission between 2014 and 2015. 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 2014 and 2015 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 emissions for some grid cells on the western part of the Western Scheldt, and a decrease for the eastern part. No conclusions can be drawn for the difference for this eastern part of the Western Scheldt, since only this year this has been calculated with AIS data of the Schelde Radar Keten. For 2014 a traffic database has been used, and the SAMSON model. The coverage of the AIS is probably also a bit better for the canal to the South of Terneuzen.

For the port area of Rotterdam, a ‘random’ decrease and increase over the grid cells is observed. The port of Amsterdam clearly shows an increase of the NO_x for the whole port area.

The Ems, Harlingen and Den Helder show small absolute changes, but higher relative changes, in almost all grid cells. The changes are both increases and decreases. For Harlingen there is a clear decrease over the whole main sailing route. This corresponds with the fact that the average number of moving ships has decreased by 35%.

On the NCS there is a spatial shift of emissions around the traffic separation schemes, especially in the Northern part. This is due to a change in the separation scheme active since June 2015.

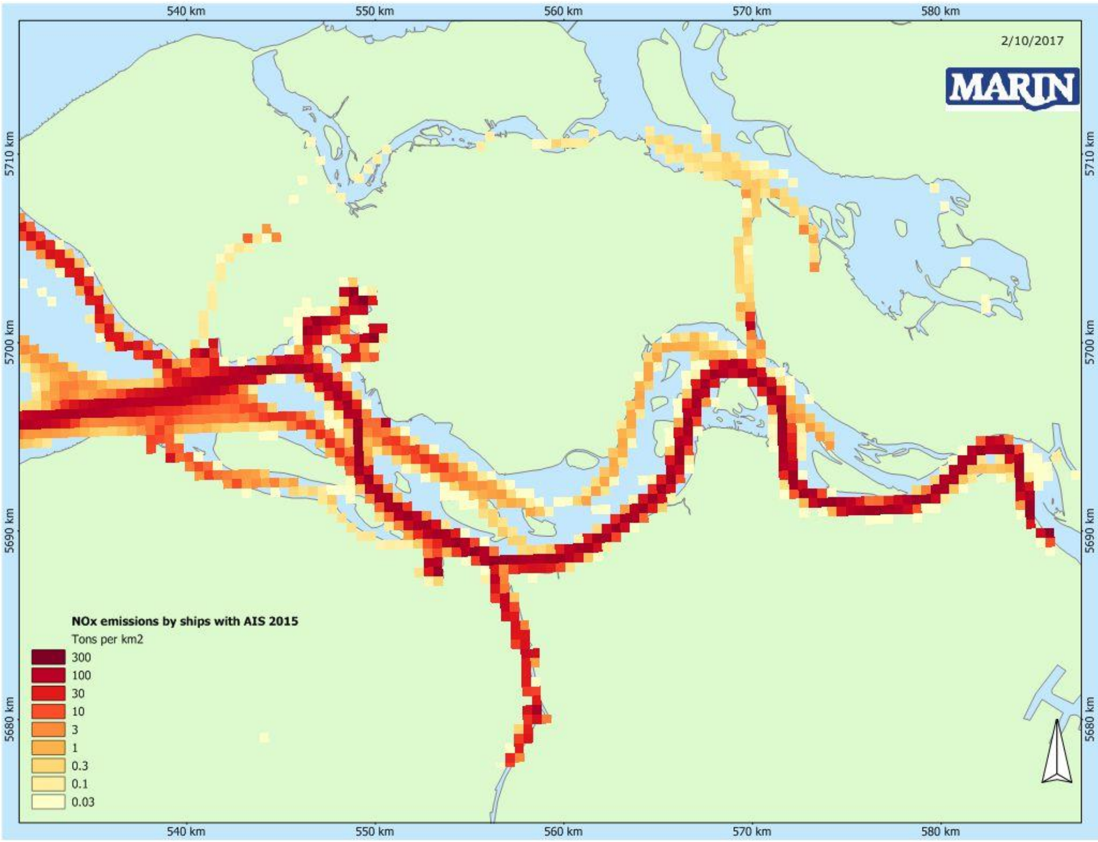

Figure 6-1 **NO_x emission in 2015 in the Dutch part of the Western Scheldt by ships with AIS.**

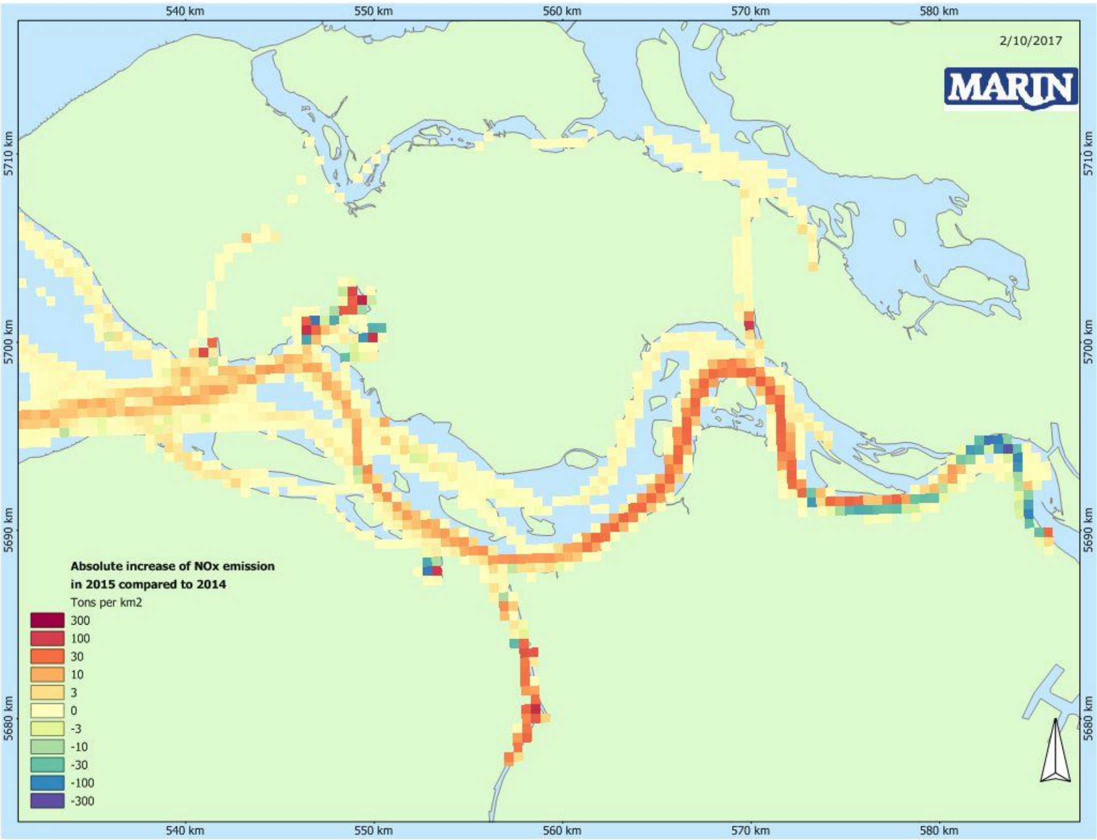

Figure 6-2 **Absolute change in NO_x emission from 2014 to 2015 in the Dutch part of the Western Scheldt by ships with AIS.**

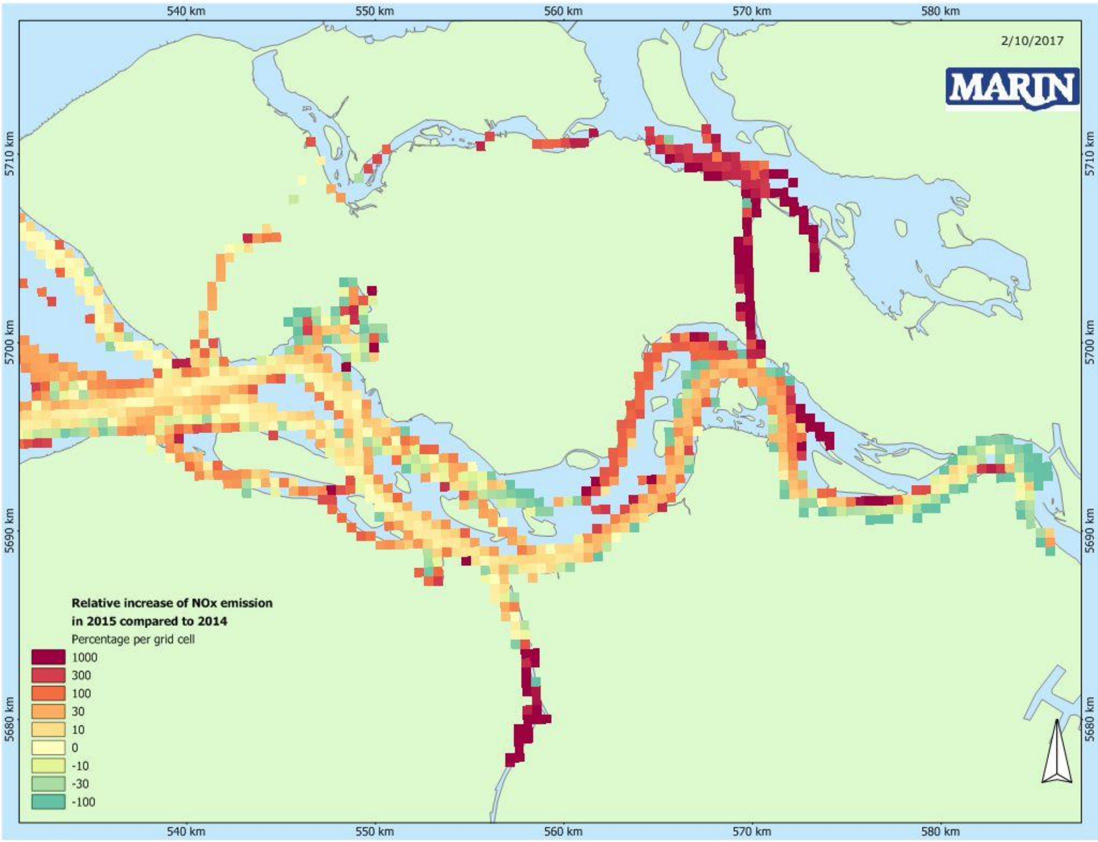

Figure 6-3 **Relative change in NO_x emission from 2014 to 2015 in the Dutch part of the Western Scheldt by ships with AIS.**

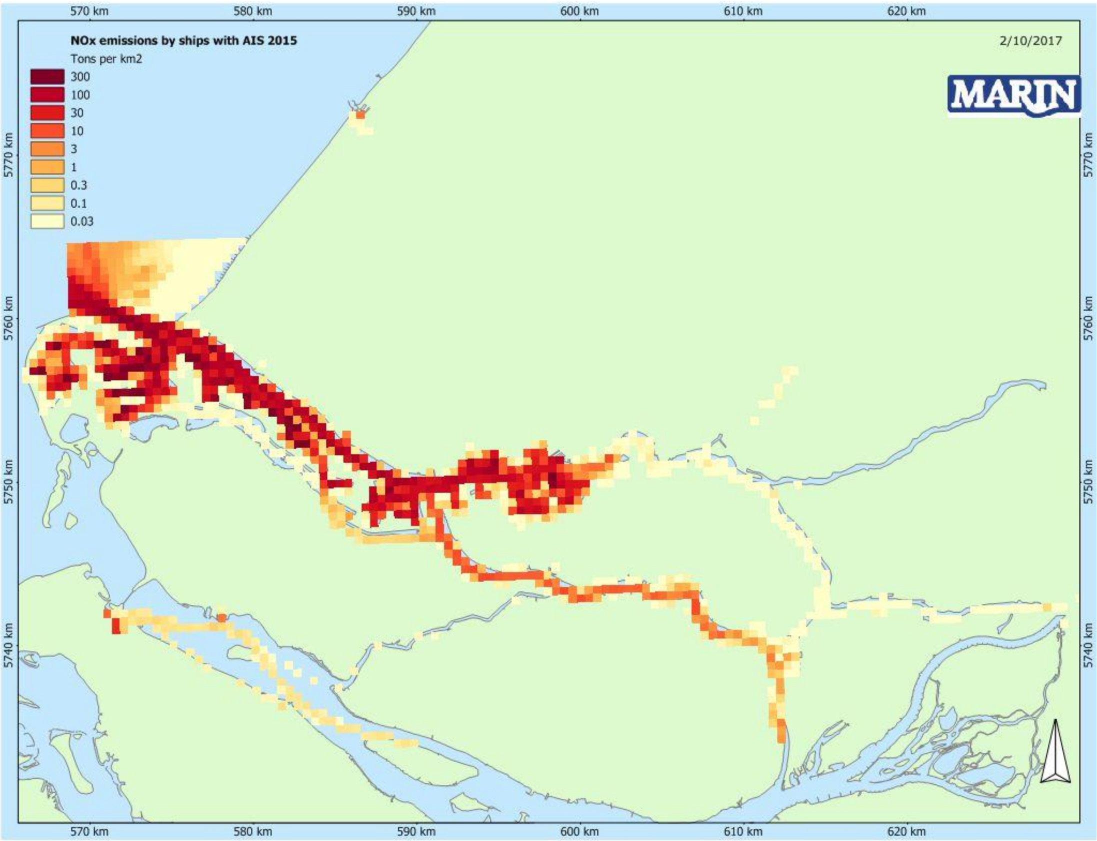

Figure 6-4 **NO_x emission in 2015 in the port area of Rotterdam by ships with AIS.**

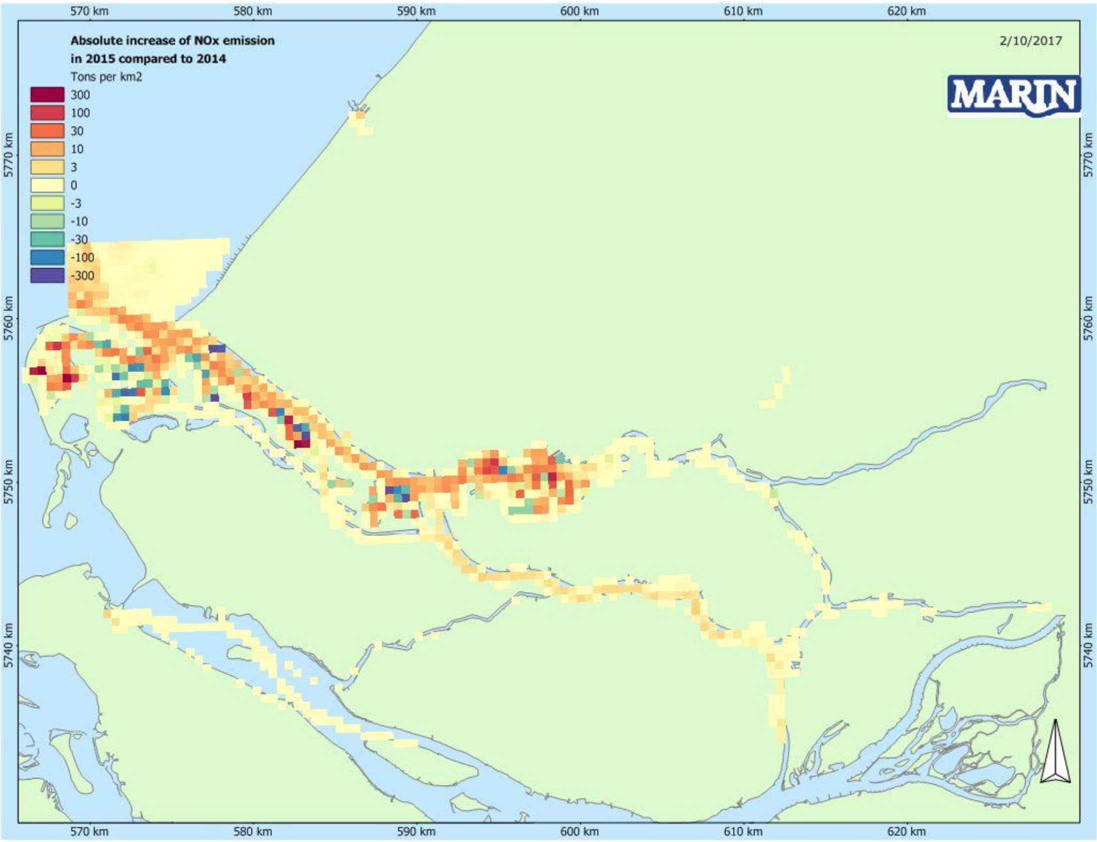

Figure 6-5 **Absolute change in NO_x emission from 2014 to 2015 in the port area of Rotterdam by ships with AIS.**

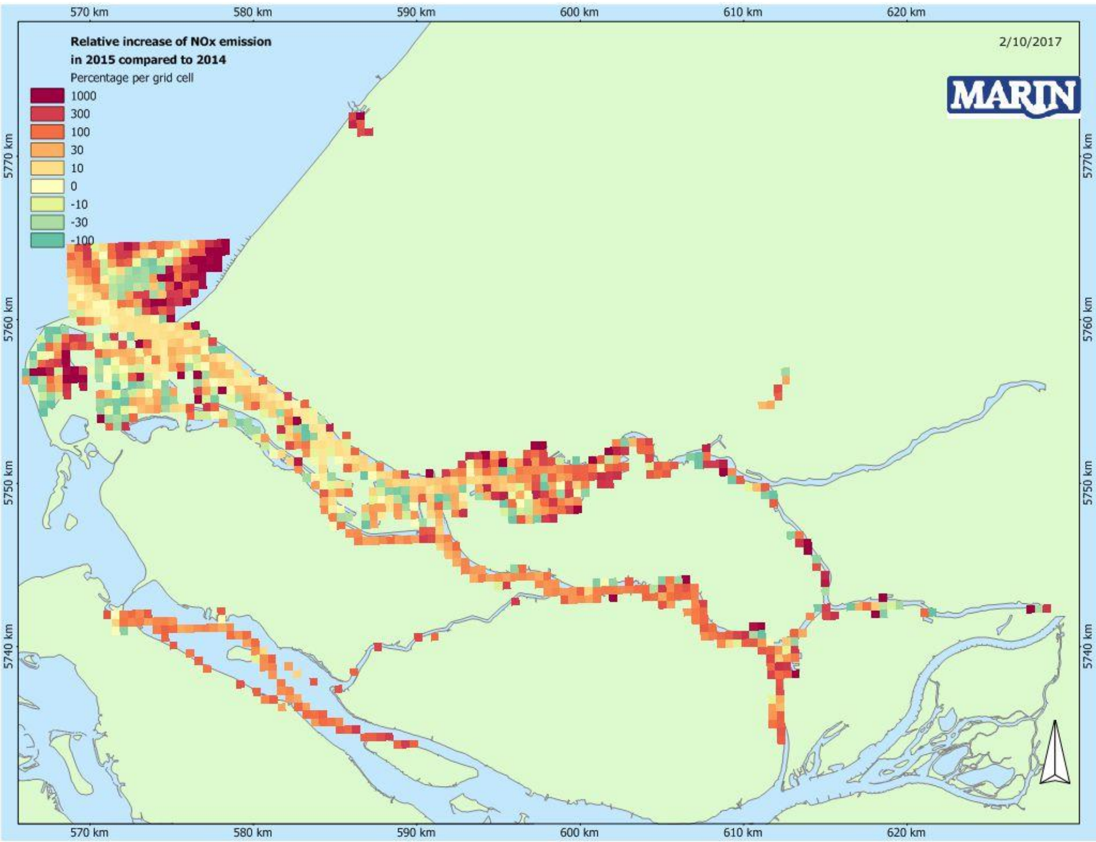

Figure 6-6 **Relative change in NO_x emission from 2014 to 2015 in the port area of Rotterdam by ships with AIS.**

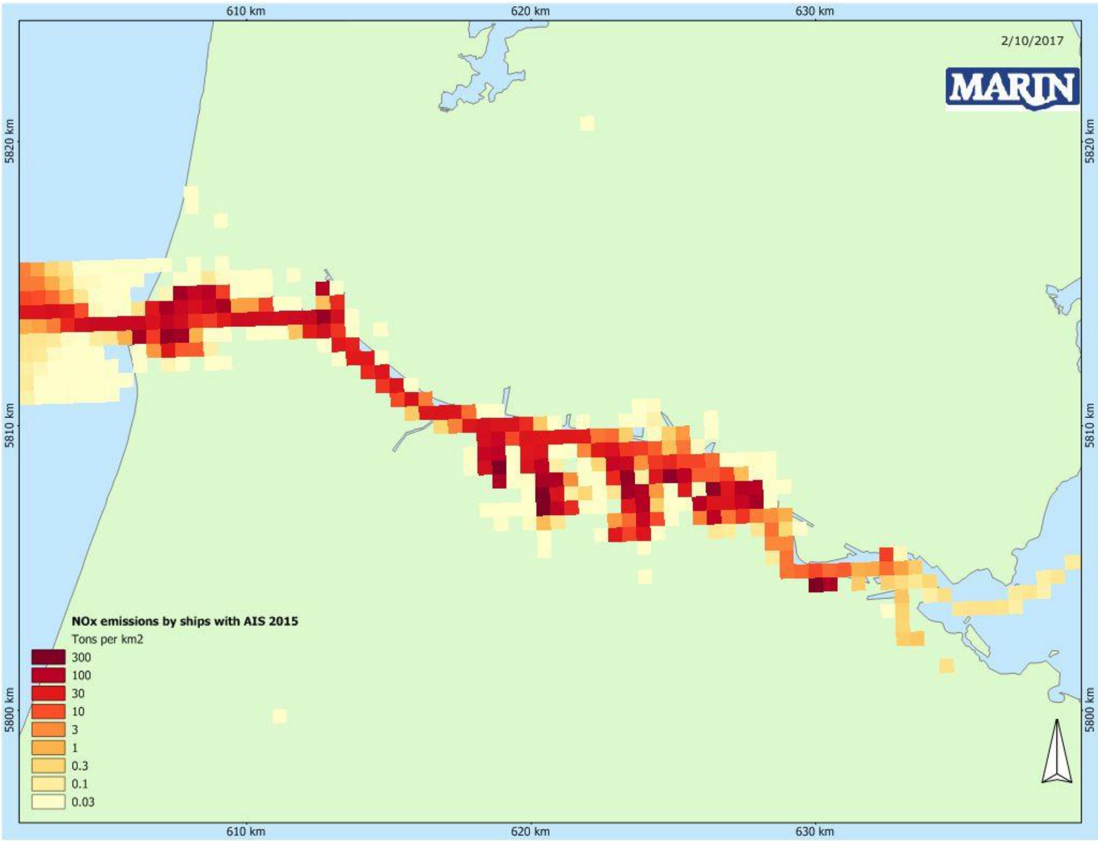

Figure 6-7 **NO_x emission in 2015 in the port area of Amsterdam by ships with AIS.**

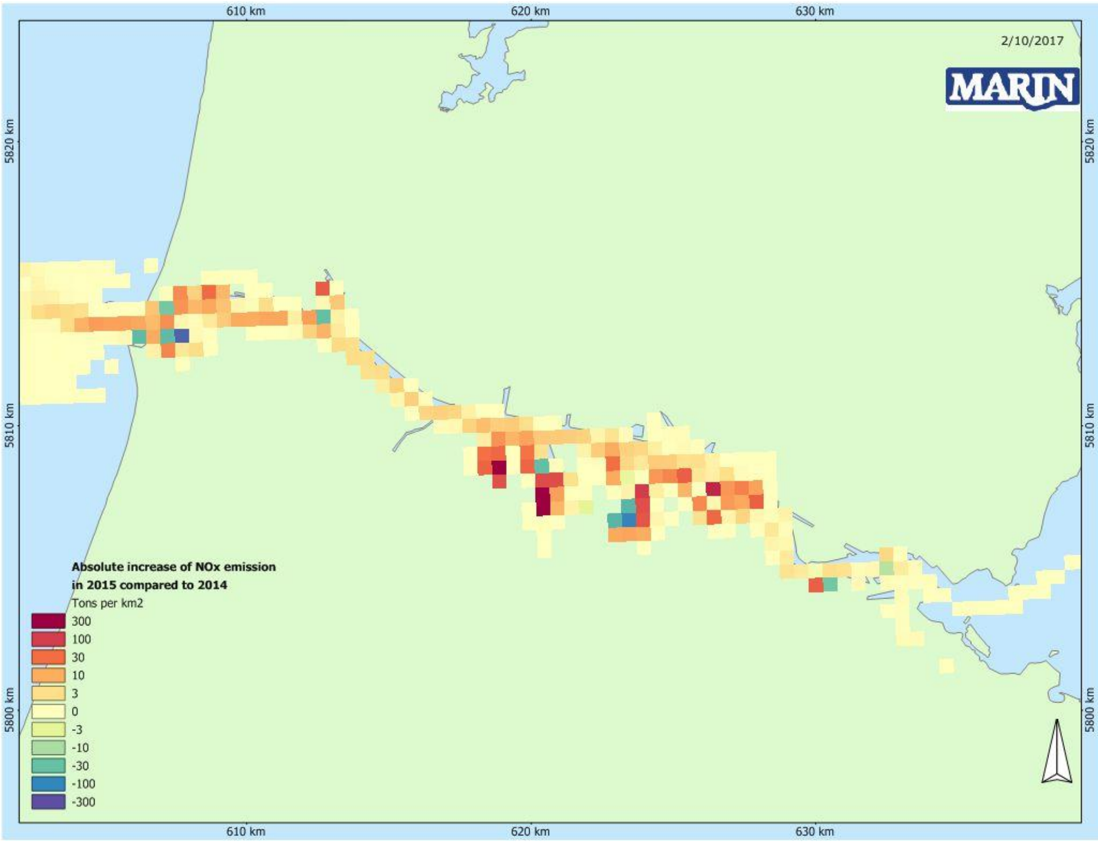

Figure 6-8 **Absolute change in NO_x emission from 2014 to 2015 in the port area of Amsterdam by ships with AIS.**

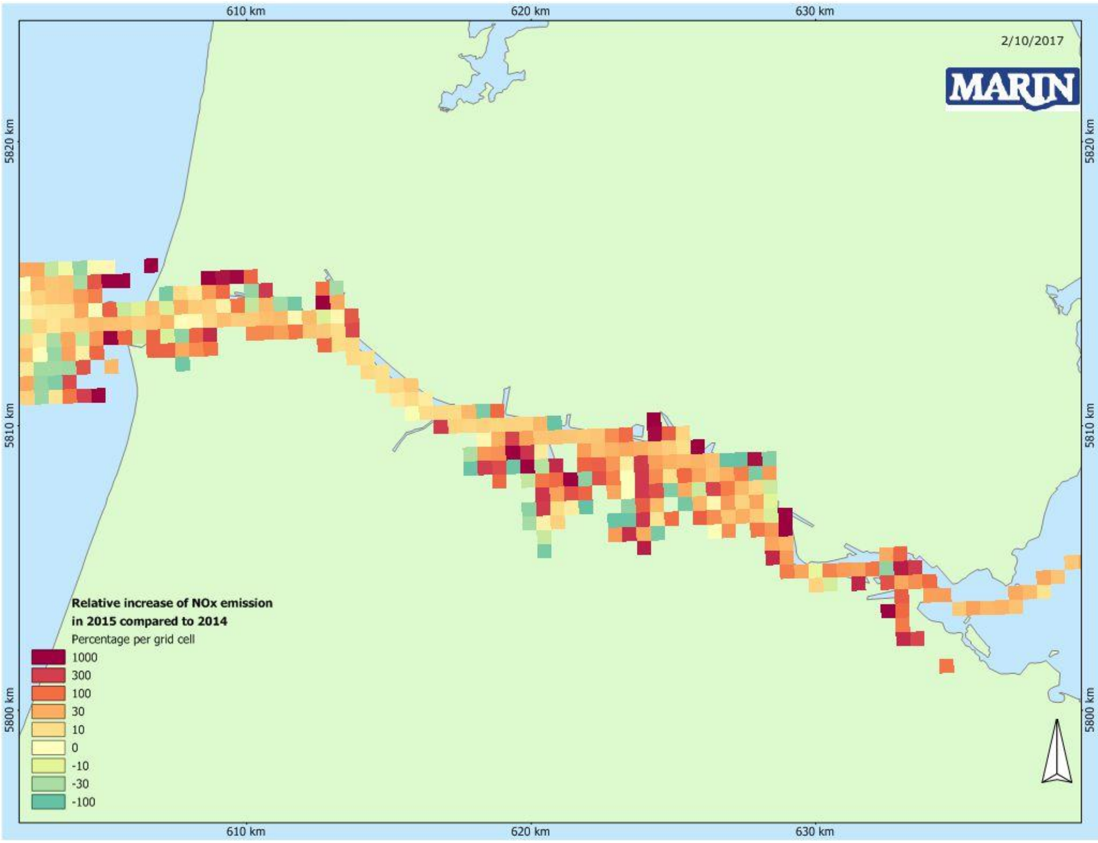

Figure 6-9 **Relative change in NO_x emission from 2014 to 2015 in the port area of Amsterdam by ships with AIS.**

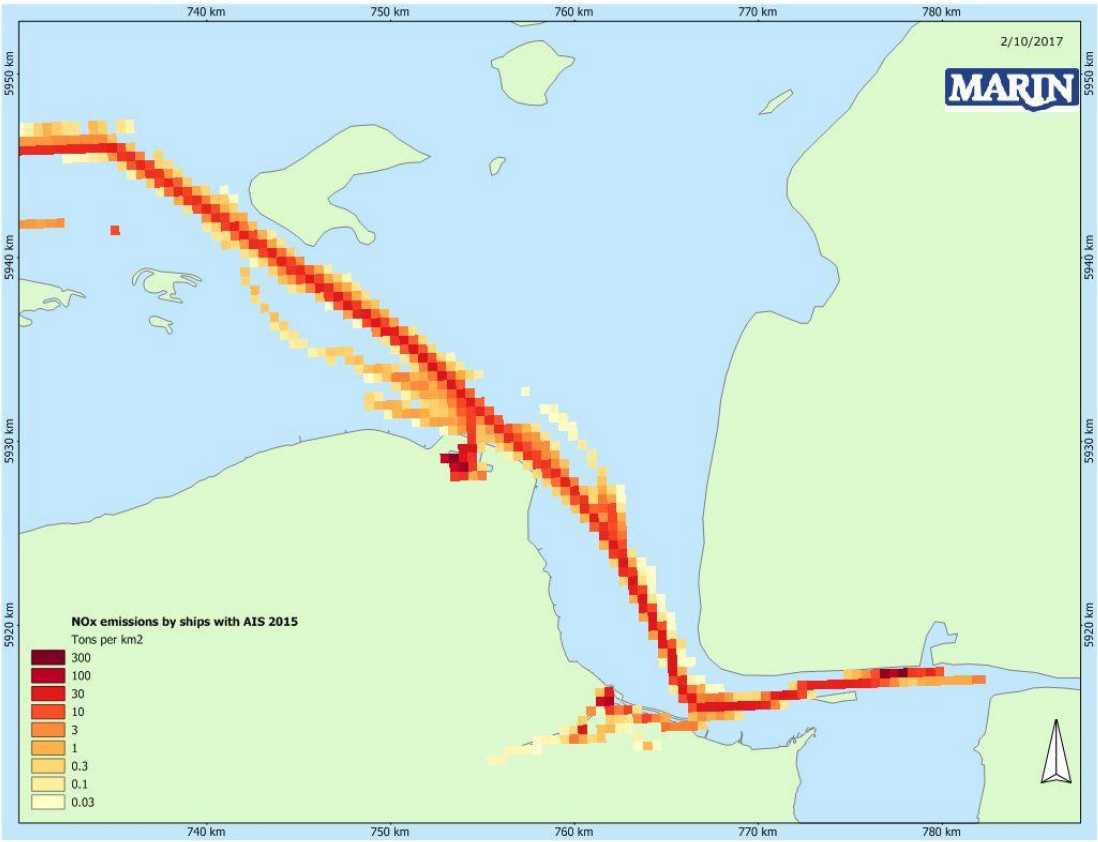

Figure 6-10 **NO_x emission in 2015 in the Ems area by ships with AIS.**

Figure 6-11 **Absolute change in NO_x emission from 2014 to 2015 in the Ems area by ships with AIS.**

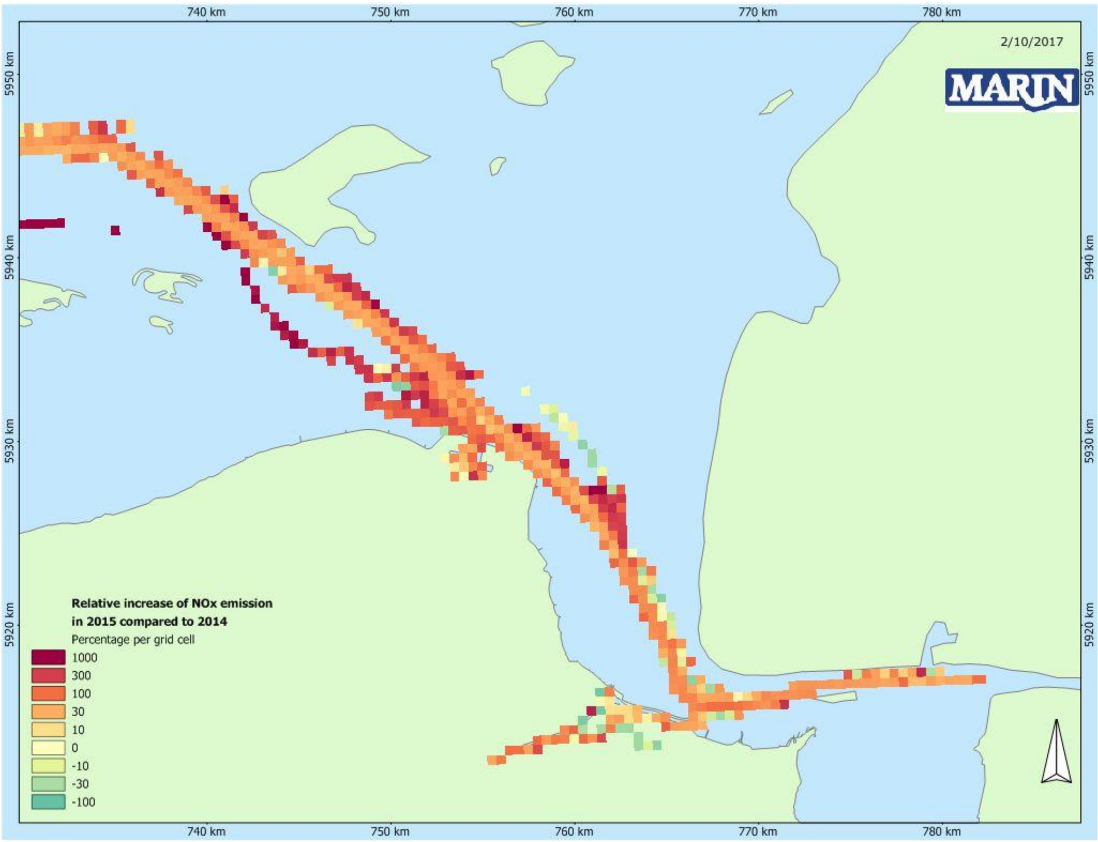

Figure 6-12 **Relative change in NO_x emission from 2014 to 2015 in the Ems area by ships with AIS.**

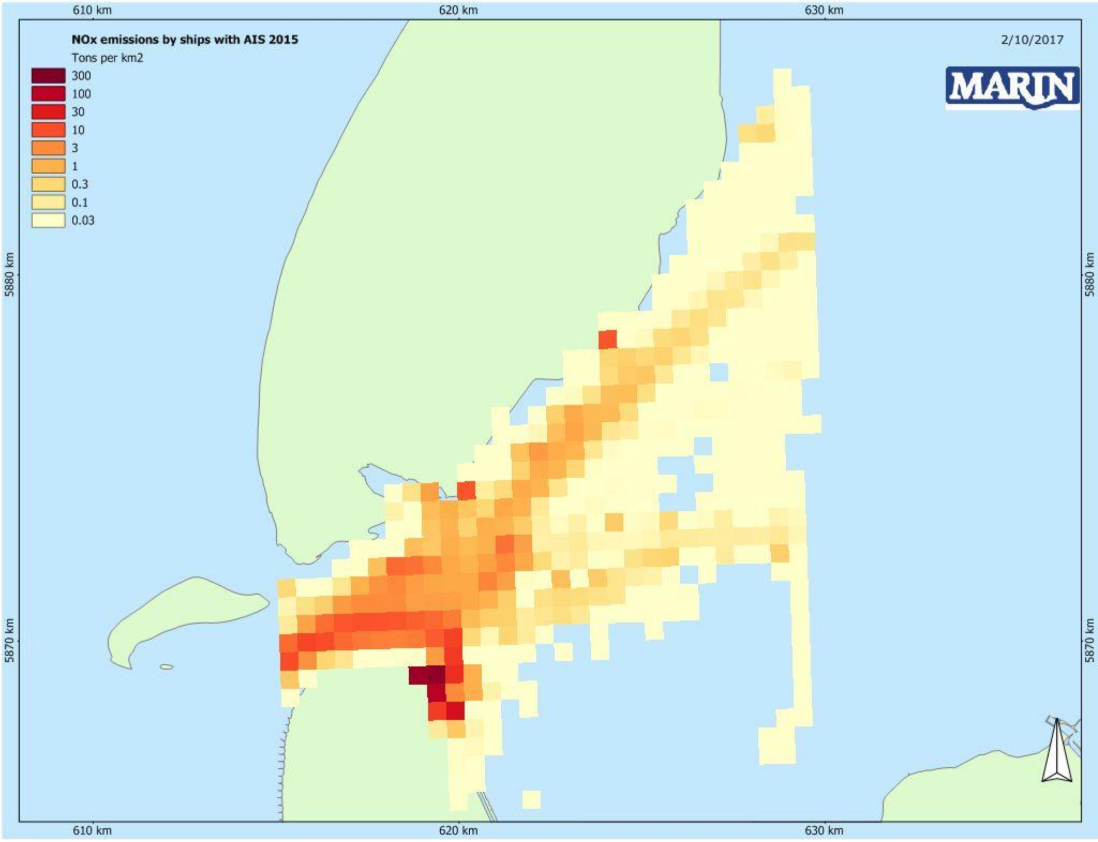

Figure 6-13 NO_x emission in 2015 in the port area of Den Helder by ships with AIS.

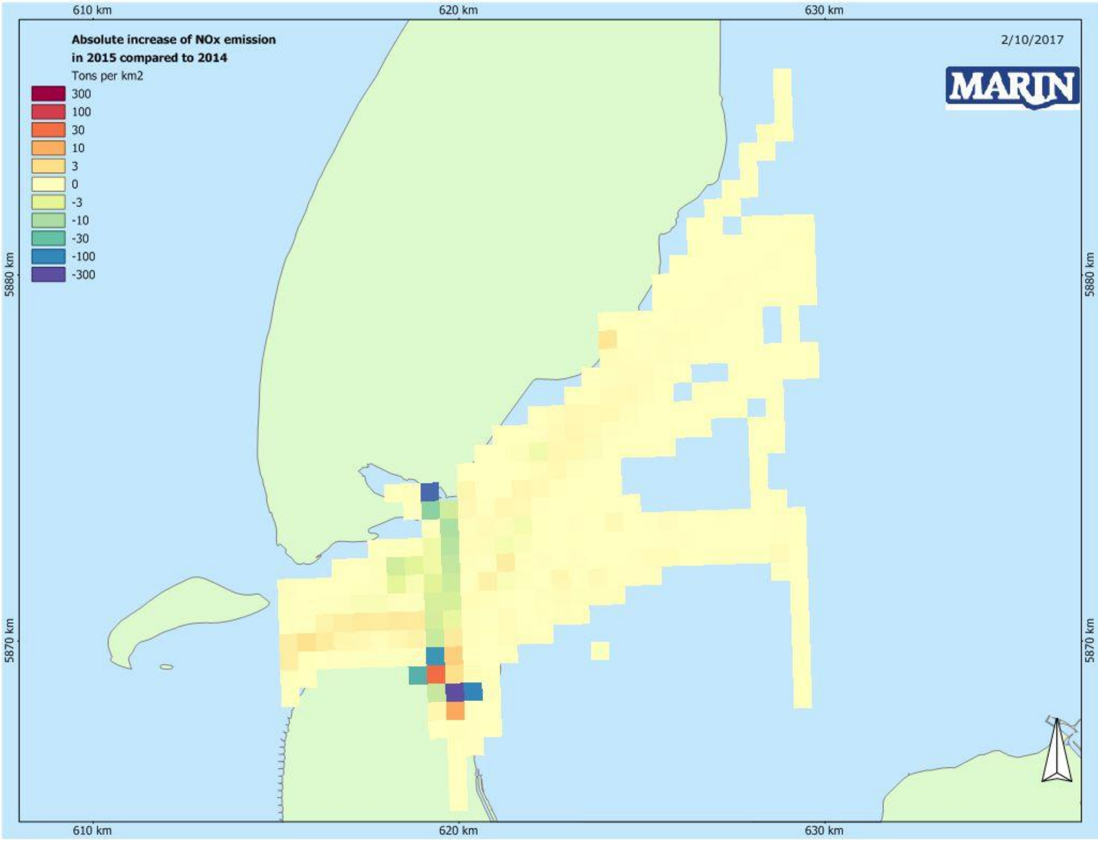

Figure 6-14 Absolute change in NO_x emission from 2014 to 2015 in the port area of Den Helder by ships with AIS.

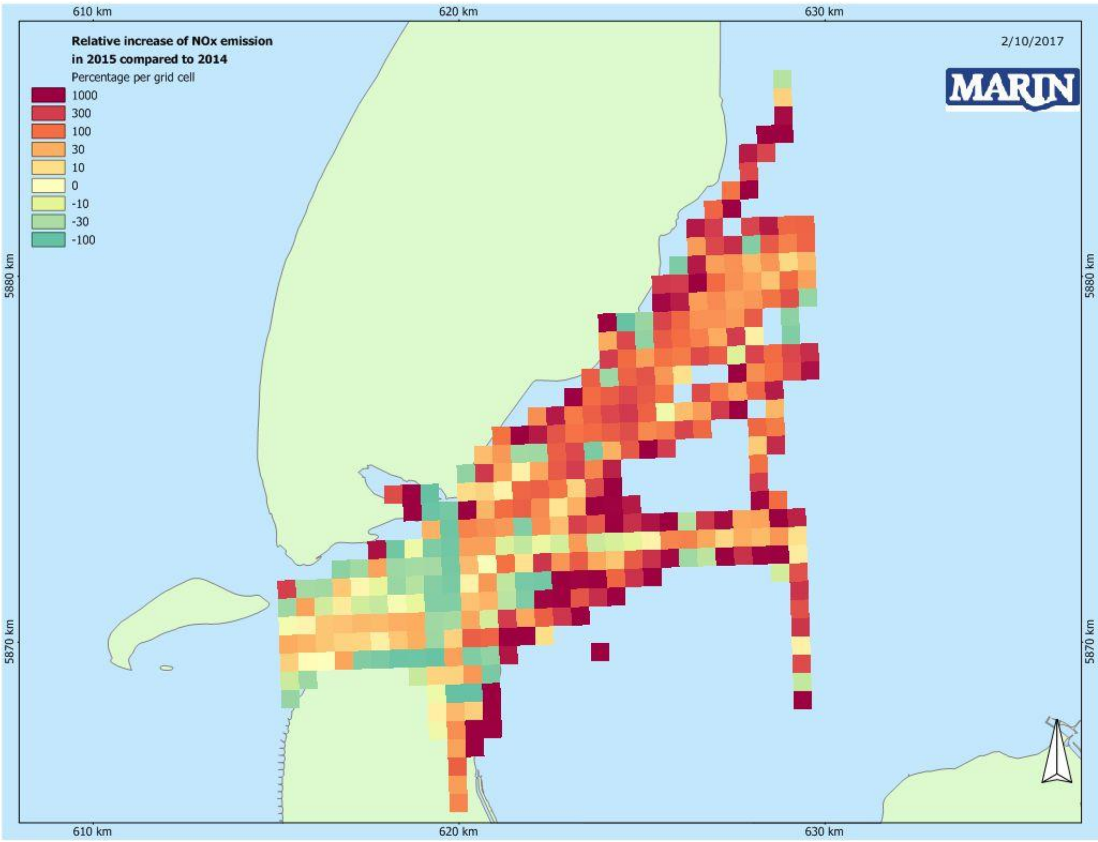

Figure 6-15 Relative change in NO_x emission from 2014 to 2015 in the port area of Den Helder by ships with AIS.

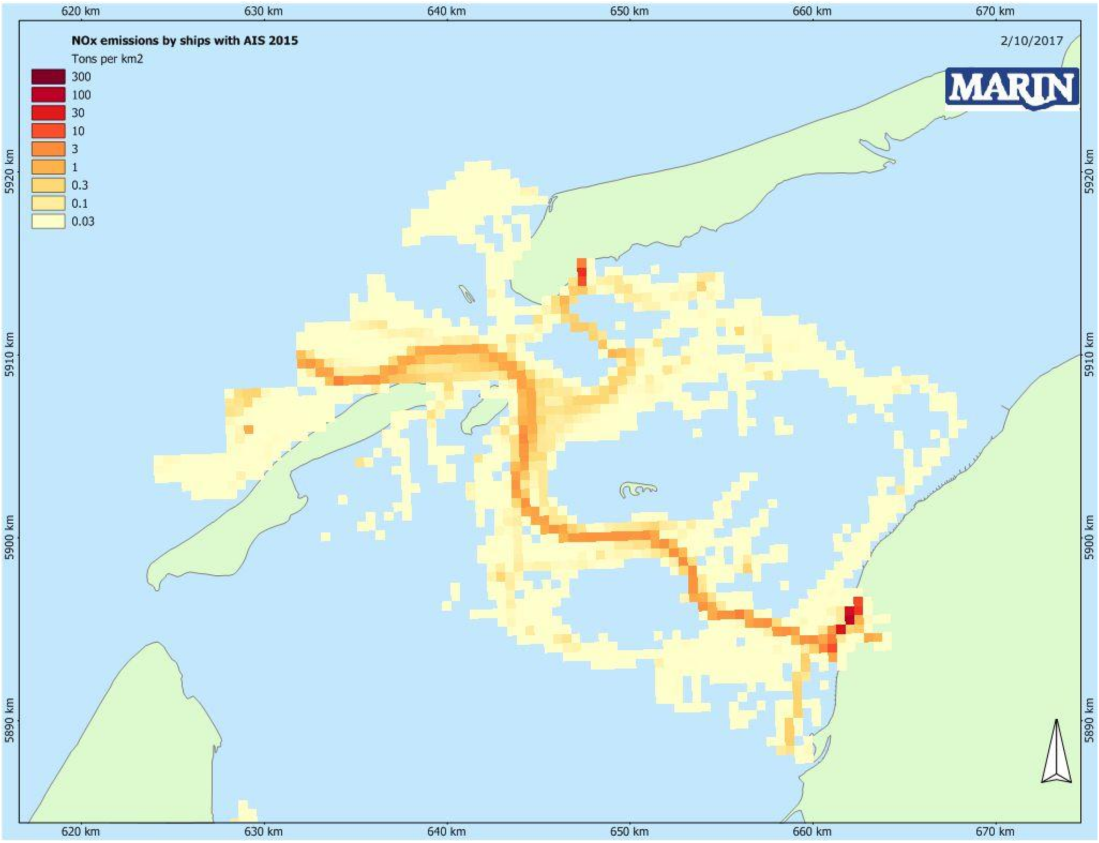

Figure 6-16 **NO_x emission in 2015 in the port area of Harlingen by ships with AIS.**

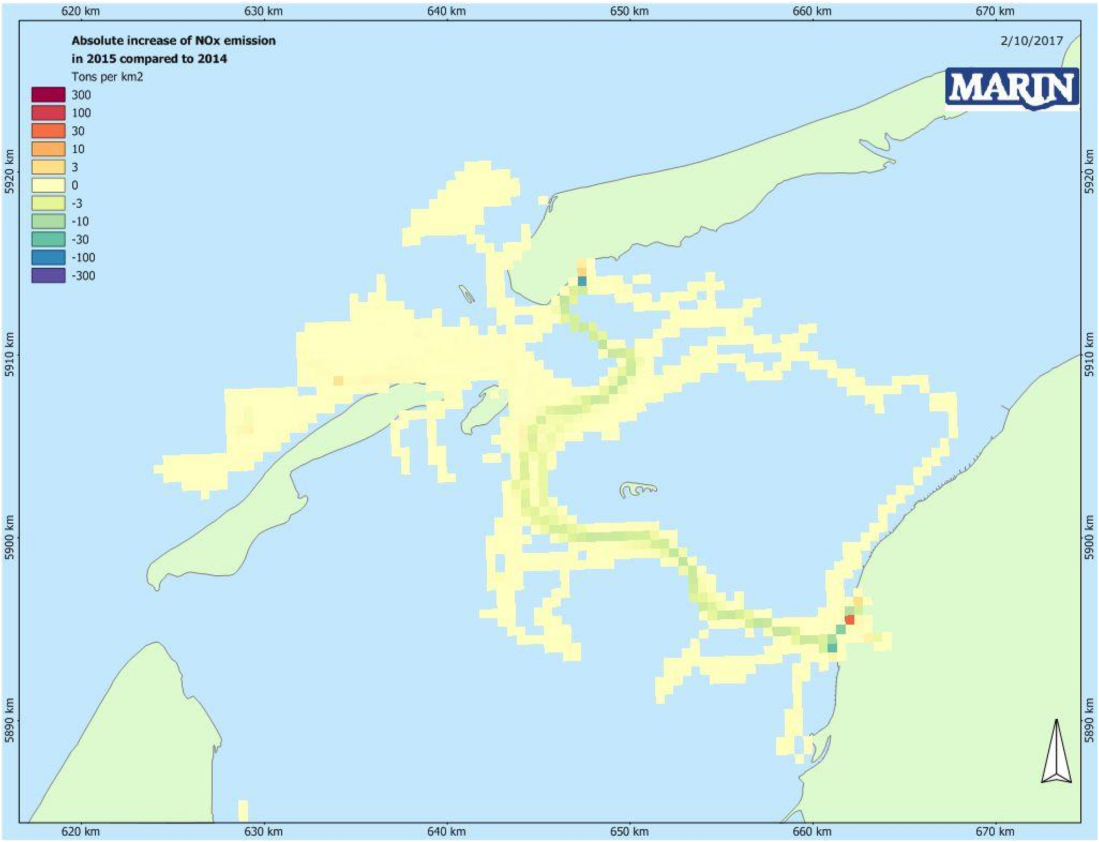

Figure 6-17 **Absolute change in NO_x emission from 2014 to 2015 in the port area of Harlingen by ships with AIS.**

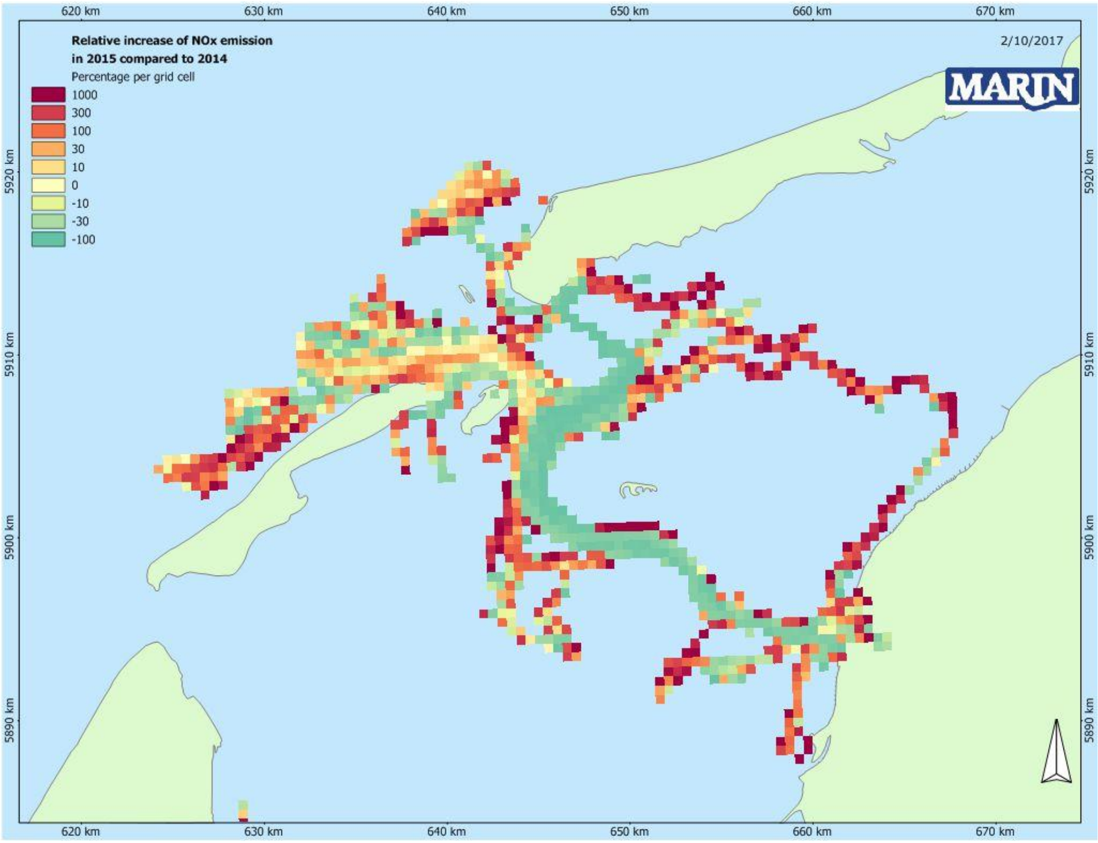

Figure 6-18 **Relative change in NO_x emission from 2014 to 2015 in the port area of Harlingen by ships with AIS.**

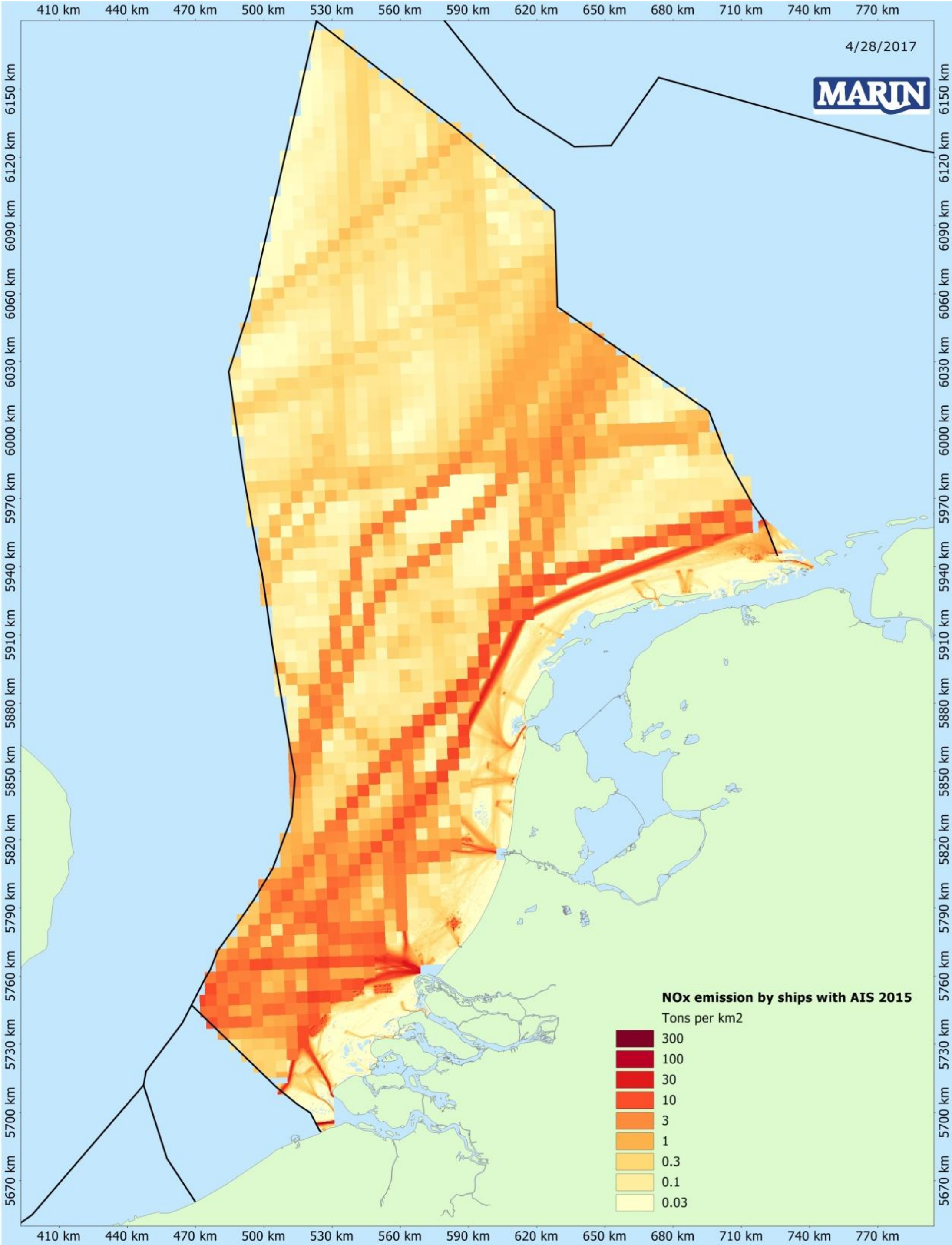

Figure 6-19 **NO_x emission in 2015 in the NCS, the 12-mile zone and the Dutch port areas by ships with AIS.**

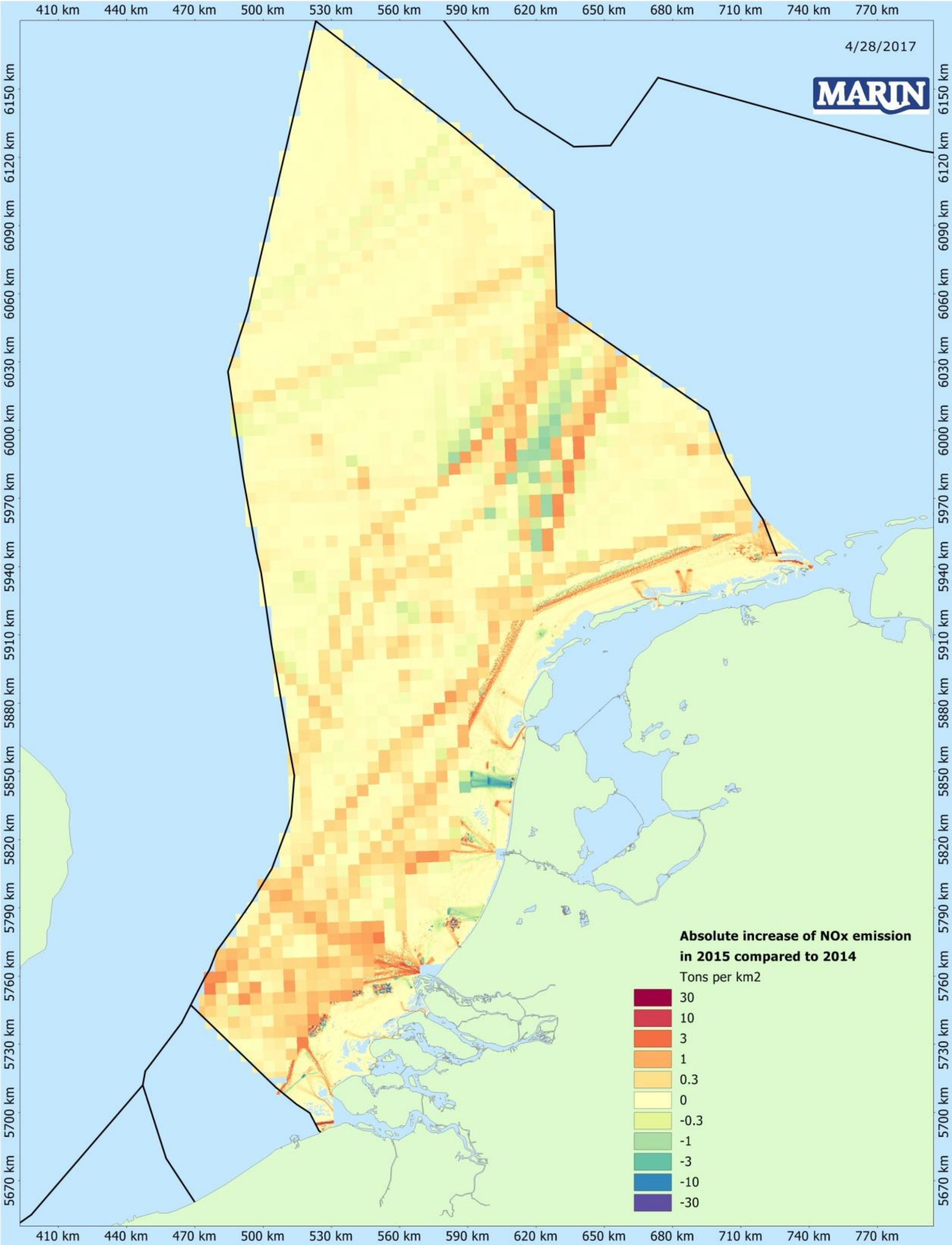

Figure 6-20 **Absolute change in NO_x emission from 2014 to 2015 in the NCS, the 12-mile zone and in the Dutch port areas by ships with AIS.**

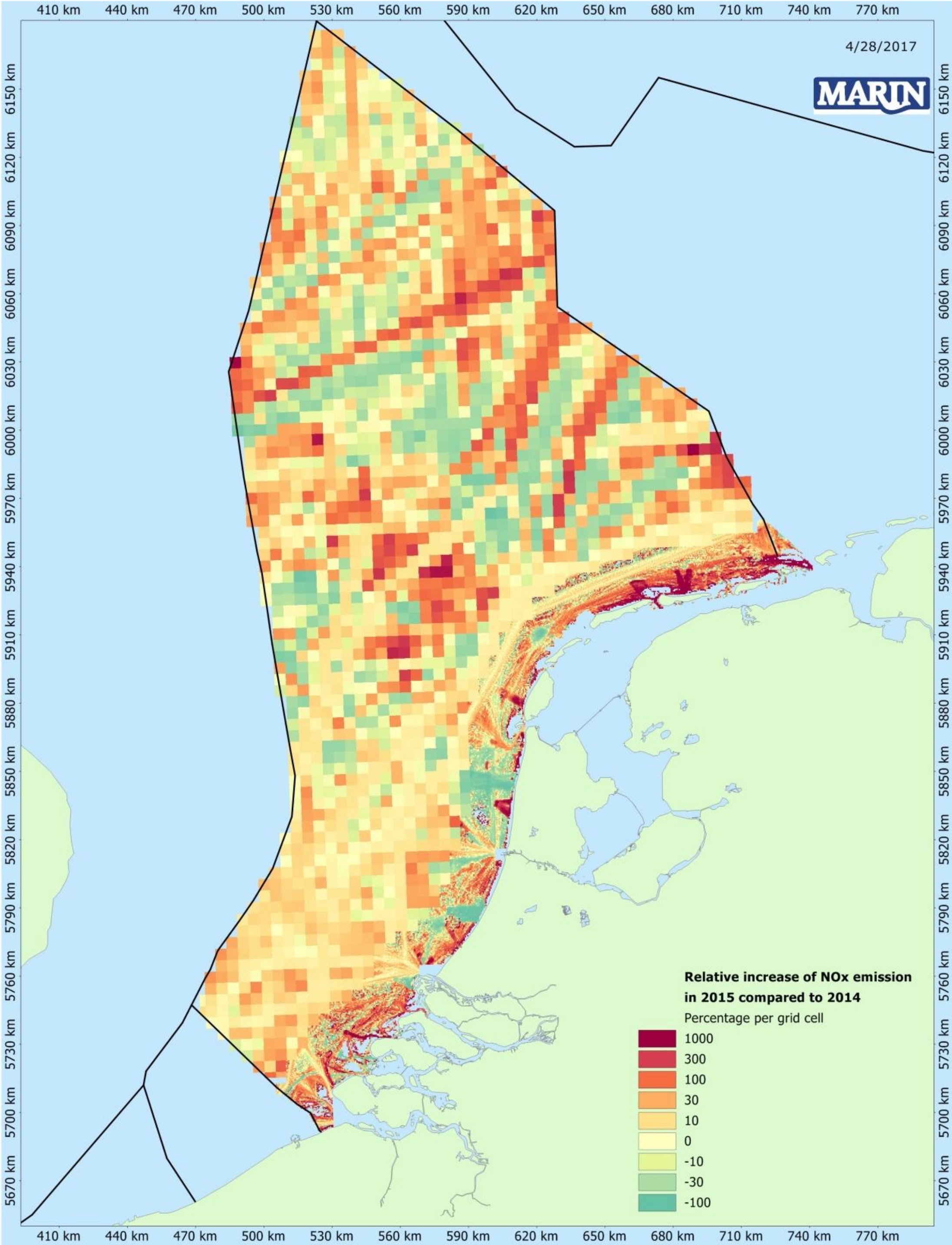

Figure 6-21 **Relative change in NO_x emission from 2014 to 2015 in the NCS, the 12-mile zone and in the Dutch port areas by ships with AIS.**

7 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

One full day and a limited number of additional minute files of the AIS data was missing in 2015. A correction was carried out for the one missing day to account for these missing minute files. Due to the additional AIS database of the Schelder Radar Keten, the coverage of ships on the Western Scheldt close to the Belgian border was sufficiently improved compared the previous year. Therefore, the emission calculation of the whole Western Scheldt was based on AIS data.

Activity data

Comparing 2015 with 2014, there was a decrease in the number of calls for the Amsterdam port area, and an increase in the Rotterdam and Western Scheldt port area. The port of Antwerp and Rotterdam show an increase in cargo handled. The number of not moving ships increased for the three largest port areas, Rotterdam, Western Scheldt, Amsterdam, and the Ems port area, the same holds for the number of moving ships. The largest decrease for both not moving and moving has been seen in Harlingen. On the NCS there is a slight decrease of 2.3% in the average number of not moving ships, while in 2014 the number of moving ships increased by almost 10%. For moving ships the increase is 3.1%. The average speed remained the same in the three largest port areas as well as in the NCS and the 12 miles-zone, however, in Den Helder and Harlingen area it decreased by 26%. Note that the increase in activity in the Amsterdam port area does not correspond well with the decrease in port calls, it might be concluded that this is due to an improved AIS coverage.

Emission results

The emissions in the port areas Table 6-2show a decrease in emission of SO_2,and aerosols MDO. For the port areas of the Western Scheldt, Rotterdam and Amsterdam, an increase in emissions of VOC, NO_x, CO, CO_2 is observed. For the Aerosols HFO only the Western Scheldt shows a decrease.

In the Netherland Sea area both the emissions of moving and non-moving ships decreased.

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TNO report (in preparation)

APPENDIX A: EMISSION FACTORS

Written by Jan Hulskotte of TNO

A1 SAILING AND MANOEUVRING

A1.1Main Engines

During sailing and manoeuvring, the main engine(s) are used to propel/manoeuvre the ship. Their emission factors per ship, in g per kWh, were determined by TNO according to the EMS protocols [1, 2]. An English language report [5] is available, which covers the emission calculations in accordance with the EMS protocols. In the emission factor calculation, the nominal engine power and speed are used. For this study these parameters were taken from the LLI database of September 2015 as far as new valid data were available. In the case that only one single main engine is present, it is assumed that a vessel requires 85% of its maximum continuous rating power (MCR) to attain the design speed (its service speed). When multiple main engines are present some more assumptions have to be made in order to calculate the required power of the main engines. This is described in the next paragraph A1.2.

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

Formula 1:

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

where:

EF’	Actual emission factor expressed as kg per nautical mile
EF	Basic engine emission factor expressed as kg per KWh (Table A- 3/Table A- 10)
CEF	Correction factors of basic engine emission factors (Table A- 12/Table A- 14)
P	Engine power [KiloWatts]
fMCR	Actual fraction of the MCR
V	Actual vessel speed [knots]

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

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

Formula 2:

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

Note that the Correction Reduced Speed factor CRS_{cor} has to be capped at a maximum of 1.176, since this is the value for which 100% engine power is reached. In Figure A- 1 the relationship is shown between the speed relative to the service speed and the power relative to the rated power of the ships single propulsion engine as implied in formula 2.

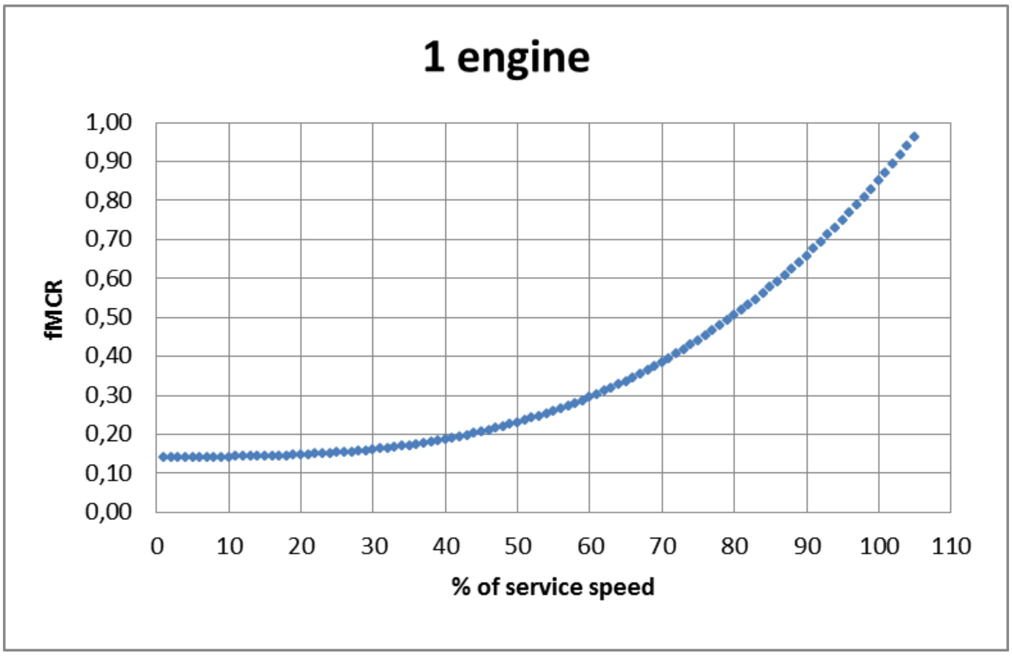

Figure A- 1 **The relationship between service speed and fMCR at ships with one single propulsion engine used in emission calculations**

A1.2Multiple propulsion engines

When a ship has multiple main propulsion engines, probably not all of these engines will be used in all situations. For instance, many specialised ships have specialised installations that are only used when these ships are performing their specialised tasks (dredgers, supply ships, icebreakers, tugs etc.). Other ships may have redundant engine capacity for safety and other reasons (passenger ships, roro-ships). It is rather difficult to account for the usage of multiple engines within emission calculations, since many differences will exist between individual ship designs. All kinds of possible situations which are not known from the AIS-data may have different influence on emissions from different ships types. Nevertheless, ignoring the existence of multiple engines is not realistic. The presence of multiple engines on some ship types (i.e. passenger and roro-ships) could lead to serious underestimation of total emissions because only the power of the largest engine was taken into account until the emission calculation for 2010.

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

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

Main Engine count	Ships count	Total power installed MW	Average power installed per ship MW	% of total power installed
1	109,489	534,901	4.9	80.9%
2	24,011	87,343	3.6	13.2%
3	926	4,459	4.8	0.7%
4	1,912	25,822	13.5	3.9%
5	89	1,551	17.4	0.23%
6	177	5,992	33.9	0.91%
7	4	139	34.8	0.02%
8	31	1,017	32.8	0.15%
9	6	261	43.5	0.04%
10	1	3.0	3.0	0.00%
12	2	15.6	7.8	0.00%
	136,648	661,504	4.8	100.0%

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

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

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

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

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

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

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

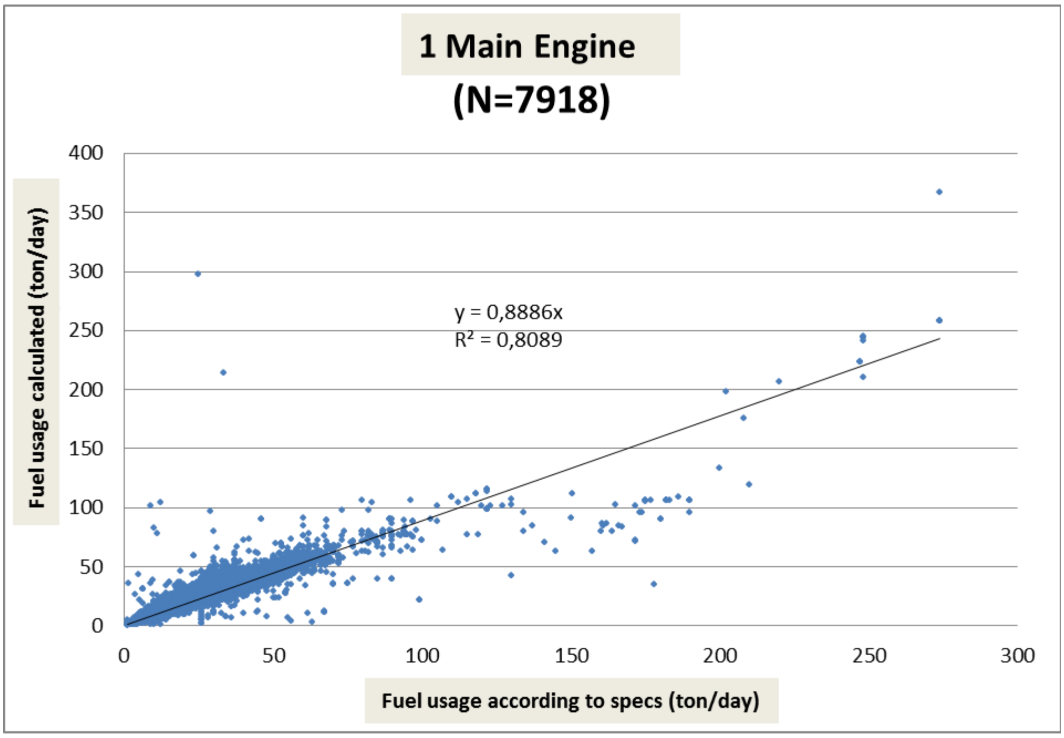

Figure A- 2 Calculated daily fuel usage of one engine ships compared with specifications

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

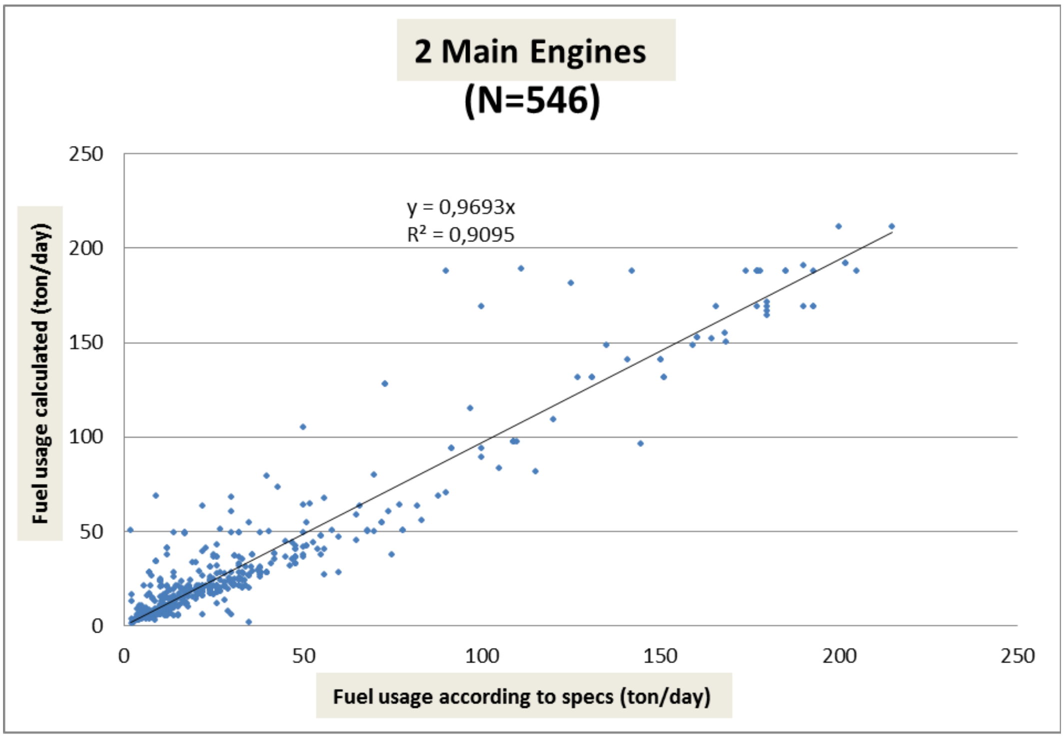

Figure A- 3 Calculated daily fuel usage of two engine ships compared with specifications

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

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

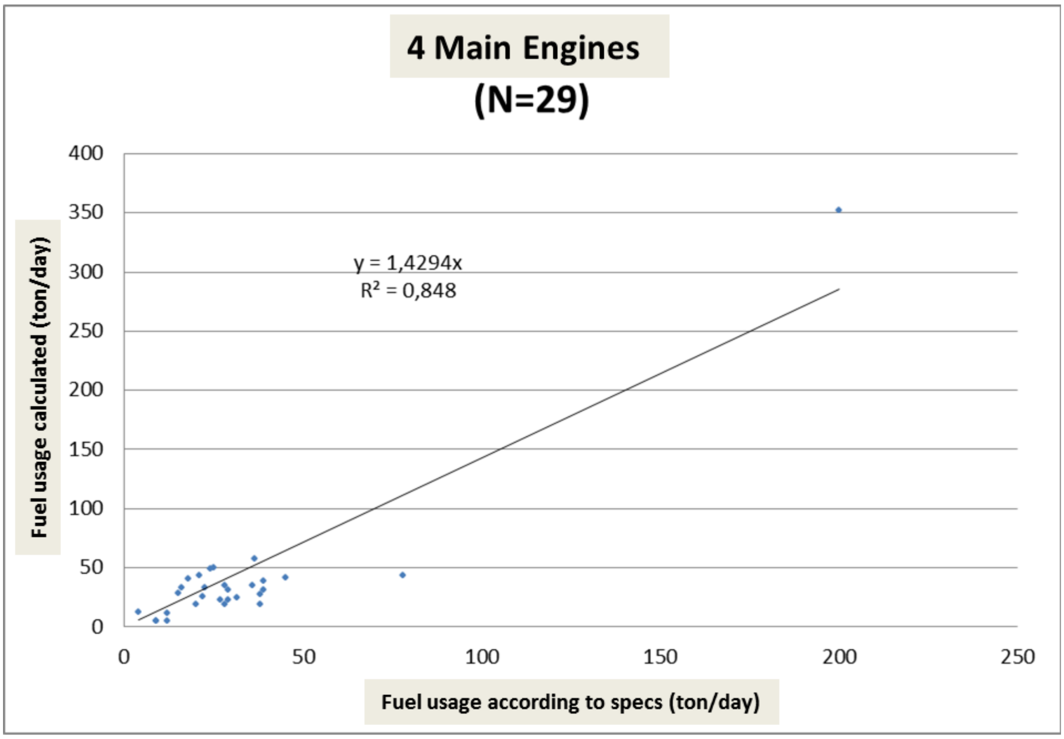

Figure A- 4 Calculated daily fuel usage of four engine ships compared with specifications

It can be argued that energy consumption of four engine ships seems to be overestimated by the assumptions that are applied, but with such a small dataset it is hard to determine whether the assumptions on ships with four main engines are correct or not. Even if there is an overestimation, this will probably not lead to big differences in total emissions, since the contribution of four engine ships in total installed power is below 4% (Table A- 1).

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

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

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

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

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

Formula 3:

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

EF' Actual emission factor expressed as kg per nautical mile
EF Basic engine emission factor expressed as kg per KWh (Table A- 3/Table A- 10)
CEF Correction factors of basic engine emission factors (Table A- 12/Table A- 14)
NoEA Number of active engines (engines that actually are working on a certain moment)
P Engine power of one single engine [Watts]
*f*MCR Actual fraction the MCR of active engines
V Actual vessel speed [knots]

Formula 4:

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

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

Formula 5:

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

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

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

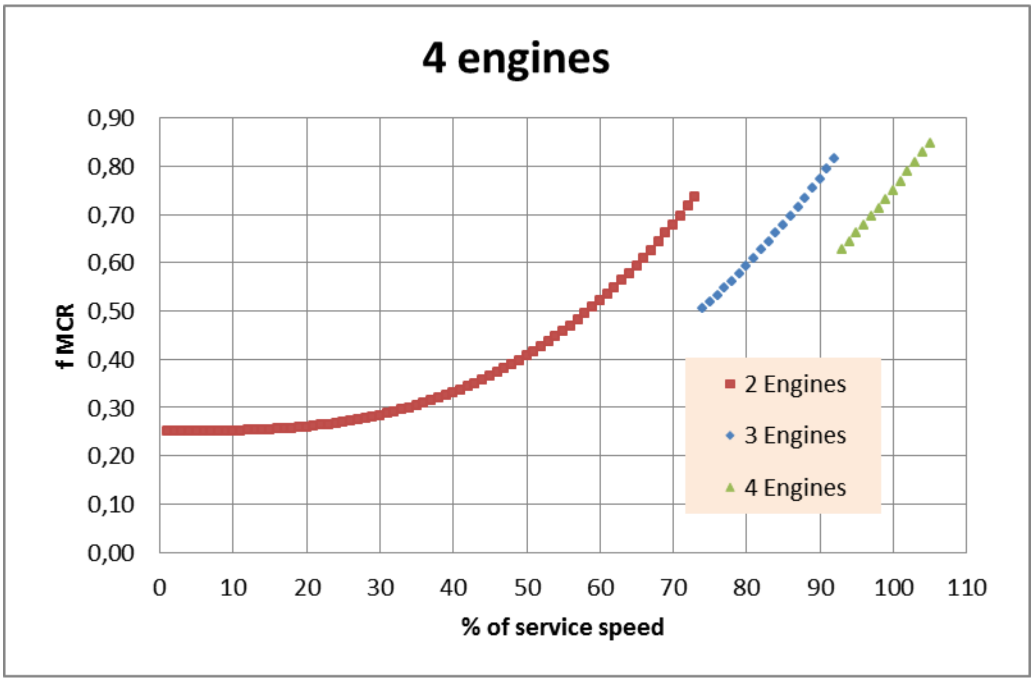

Figure A- 5 The relationship between service speed and fMCR at ships with four propulsion engines as used in emission calculations (formula 4 and 5)

A1.3 Auxiliary Engines and Equipment

Aside from the main engines, most vessels have auxiliary engines and equipment that provide (electrical) power to the ship's systems. There is very little information available on the use of auxiliary engines. Perhaps the best estimate to date has been made in the *Updated 2000 Study on Greenhouse Gas Emissions from Ships* report (Buhaug et al., 2008, [3]), to which many ship experts contributed. The percentage of the auxiliary power compared to the main engine power as presented in Table 14 of the Buhaug et al report [3] was used in this study. The percentage taken from Buhaug was multiplied with the main power of each individual ship of which no details of auxiliary power are included in the LLI-database. For those ships of which the auxiliary power was included LLI-database the loadfactor of auxiliary engines given by Buhaug specified per ship type was applied on the biggest auxiliary engine of the individual ship as inferred from the LLI-database.

A1.4 Engine Emission 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 2015 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[3]	PM-HFO Other[4]	SO_2 NCP	SO_2 Other	VOC	CO	CO_2	SFOC
1900 – 1973	16	0.57	0.43	2.10	0.42	0.6	3	666	210
1974 – 1979	18	0.56	0.43	2.00	0.40	0.6	3	635	200
1980 – 1984	19	0.55	0.43	1.90	0.38	0.6	3	603	190
1985 – 1989	20	0.54	0.43	1.80	0.36	0.6	2.5	571	180
1990 – 1994	18	0.54	0.43	1.75	0.35	0.5	2	555	175
1995 – 1999	15	0.44	0.33	1.70	0.34	0.4	2	539	170
2000 – 2010	~rpm[5]	0.43	0.33	1.68	0.34	0.3	2	533	168
2011 – 2015		0.33	0.23	1.65	0.33	0.3	2	524	165

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

Year of build	NO_x	PM-MDO NCP	PM-MDO Other	SO_2 NCP	SO_2 Other	VOC	CO	CO_2	SFOC
1900 - 1973	16	0.38	0.33	1.05	0.42	0.6	3	666	210
1974 - 1979	18	0.38	0.33	1.00	0.40	0.6	3	635	200
1980 - 1984	19	0.38	0.33	0.95	0.38	0.6	3	603	190
1985 – 1989	20	0.37	0.33	0.90	0.36	0.6	2.5	571	180
1990 – 1994	18	0.37	0.33	0.88	0.35	0.5	2	555	175
1995 – 1999	15	0.27	0.23	0.85	0.34	0.4	2	539	170

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

2000 – 2010	~rpm[1]	0.27	0.23	0.84	0.34	0.3	2	533	168
2011 – 2015		0.27	0.23	0.82	0.33	0.3	2	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	0.78	0.64	2.25	0.45	0.6	3	714	225
1974 – 1979	14	0.77	0.63	2.15	0.43	0.6	3	682	215
1980 – 1984	15	0.76	0.63	2.05	0.41	0.6	3	651	205
1985 – 1989	16	0.76	0.63	1.95	0.39	0.6	2.5	619	195
1990 – 1994	14	0.75	0.63	1.90	0.38	0.5	2	603	190
1995 – 1999	11	0.65	0.53	1.85	0.37	0.4	2	587	185
2000 – 2010	~rpm[1] 9[2]	0.65	0.53	1.83	0.37	0.3	2	581	183
2011 - 2015	~rpm 7[2]	0.64	0.53	1.80	0.36	0.3	2	571	180

[2] applied on auxiliary engines only

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

Year of build	NO_X	PM-MDO NCP	PM-MDO Other	SO_2 NCP	SO_2 Other	VOC	CO	CO_2	SFOC
1900 - 1973	12	0.39	0.33	1.13	0.45	0.6	3	714	225
1974 - 1979	14	0.39	0.33	1.07	0.43	0.6	3	682	215
1980 - 1984	15	0.38	0.33	1.02	0.41	0.6	3	650	205
1985 - 1989	16	0.38	0.33	0.97	0.39	0.6	2.5	619	195
1990 - 1994	14	0.33	0.33	0.95	0.38	0.5	2	603	190
1995 - 1999	11	0.27	0.23	0.93	0.37	0.4	2	587	185
2000 - 2010	~rpm[1] 9[2]	0.27	0.23	0.92	0.37	0.3	2	581	183
2011 - 2015	~rpm[1] 7[2]	0.27	0.23	0.90	0.36	0.3	2	571	180

[2] applied on auxiliary engines only

Table A- 7 **Emission factors of NO_X dependant on engines RPM**

Year of build	RPM range	IMO-limits (g/kWh)	Emission factor NO_X (g/kWh)
2000 - 2010	< 130 RPM	17.0	0.85 x 17.0
	Between 130 and 2000 RPM	$45 \times n^{-0.2}$	$0.85 \times 45 \times n^{-0.2}$
	> 2000 RPM	9.8	0.85 x 9.8
2011 - 2015	< 130 RPM	14.4	0.85 x 17.0
	Between 130 and 2000 RPM	$44 \times n^{-0.23}$	$0.85 \times 44 \times n^{-0.23}$
	> 2000 RPM	7.7	0.85 x 7.7

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

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

Fuel	NO_X	PM-MDO 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

A1.5Correction 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 tables, Table A- 18 to Table A- 21, the emission factors used for emissions at berth are presented.

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

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

At berth usage of medium speed engines was assumed.

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

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

Table A- 20 Emission factors of all engines and apparatus, (g/kg fuel)

Fuel	SO_2	CO_2
MGO/ULMF	4	3150

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

A3 CONNECTION BETWEEN EMISSION FACTORS AND SHIP DATA WITHIN THE SHIP CHARACTERISTICS DATABASE

This annex has been skipped in this issue of the report. In the next issue a renewed version will be presented.

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