Sea Shipping Emissions 2018: Netherlands Continental Shelf, 12 Mile Zone and Port Areas

Final Report

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Sea Shipping Emissions 2018: 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 2018. The results of both the seagoing vessels as 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. The emissions for 2018 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 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 2018.
Chapter 3 describes the procedure used for the emission calculation based on AIS data.
Chapter 4 describes the completeness of the AIS data with respect to missing files and 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 2018 for the Dutch port areas and the Netherlands sea area and makes a comparison with 2017.
Chapter 7 contains the emissions results for 2018 for the fishing activities.
Chapter 8 presents conclusions and recommendations.

2 2018 EMISSION DATABASES

2.1 General information

A set of comma separated 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 Harlingen and the Wadden Sea.

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

2.2 Netherlands sea area and Dutch port areas

The emissions in the Netherlands sea area and the six Dutch port areas have been delivered in MARIN nextCloud (https://nextcloud.marin.nl):

- db_emissionsresults_12Miles500.txt
- db_emissionsresults_OutOf12.txt
- db_emissionresults_portareas.txt

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 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.

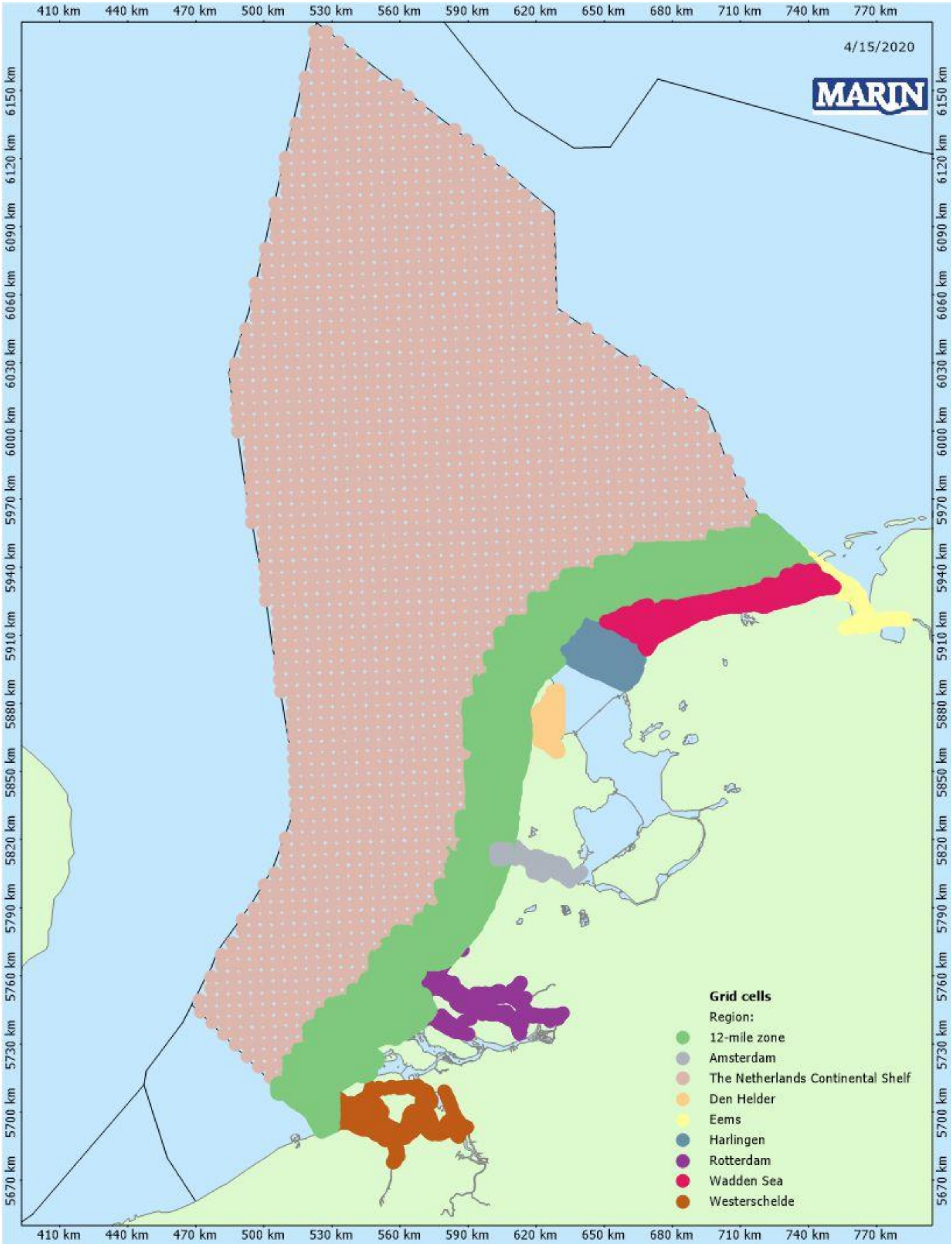

Figure 2-1 **Grid points for The Netherlands Continental Shelf, 12-mile zone, The Wadden Sea and six port areas**

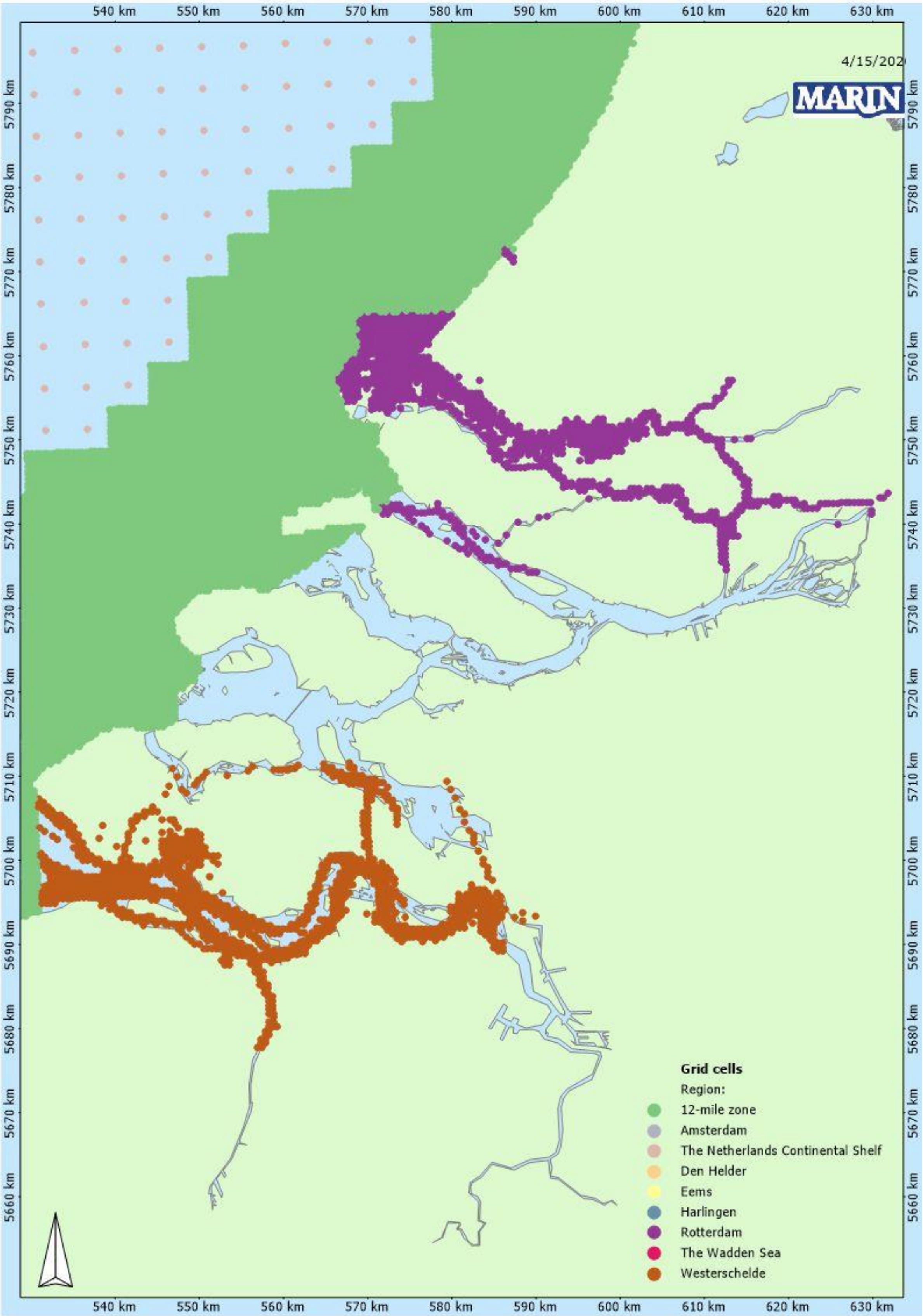

Figure 2-2 **Rotterdam and the Western Scheldt: The points indicate the centres of grid cells for which emissions are calculated**

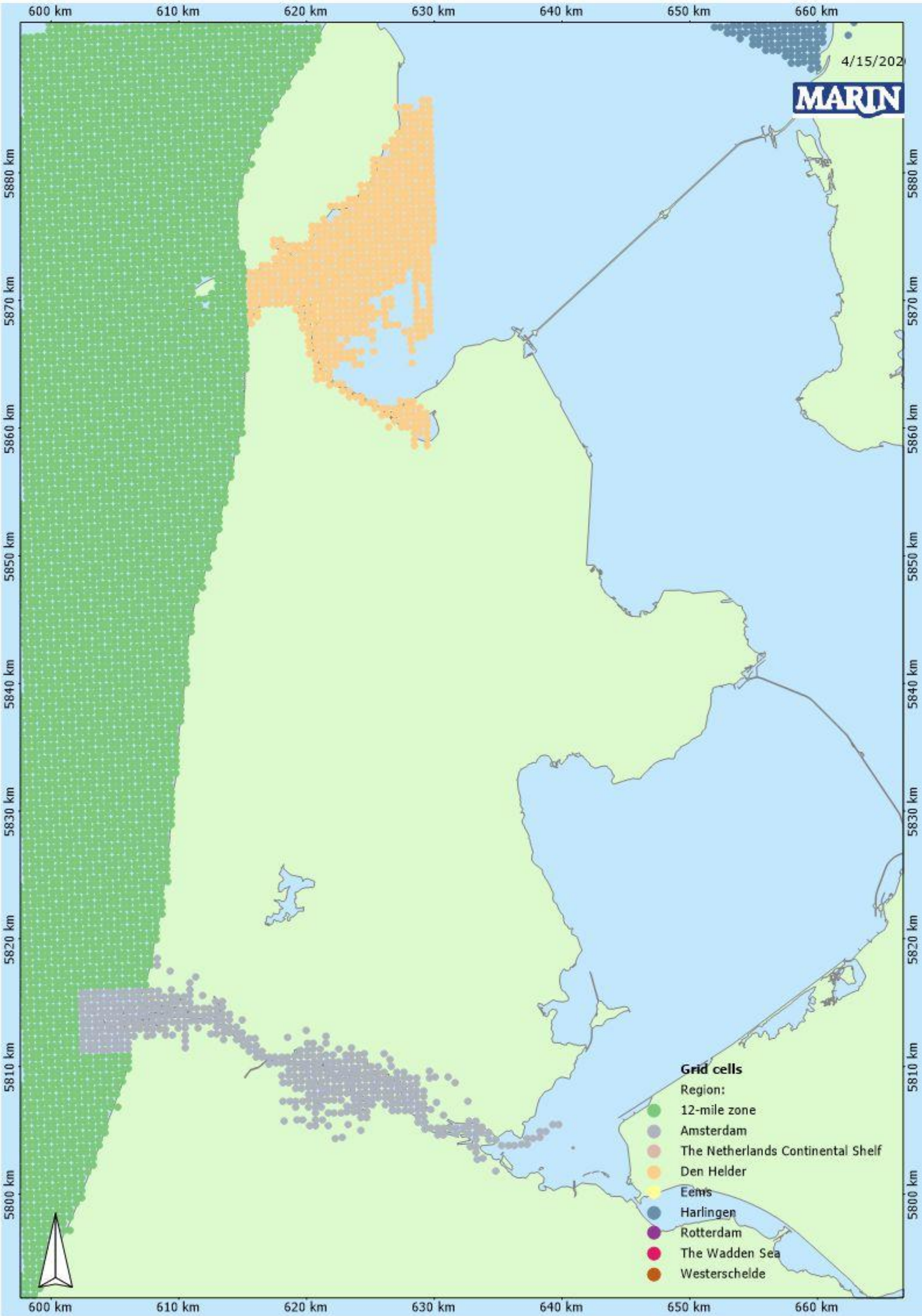

Figure 2-3 **Amsterdam and Den Helder: The points indicate the centres of grid cells for which emissions are included calculated**

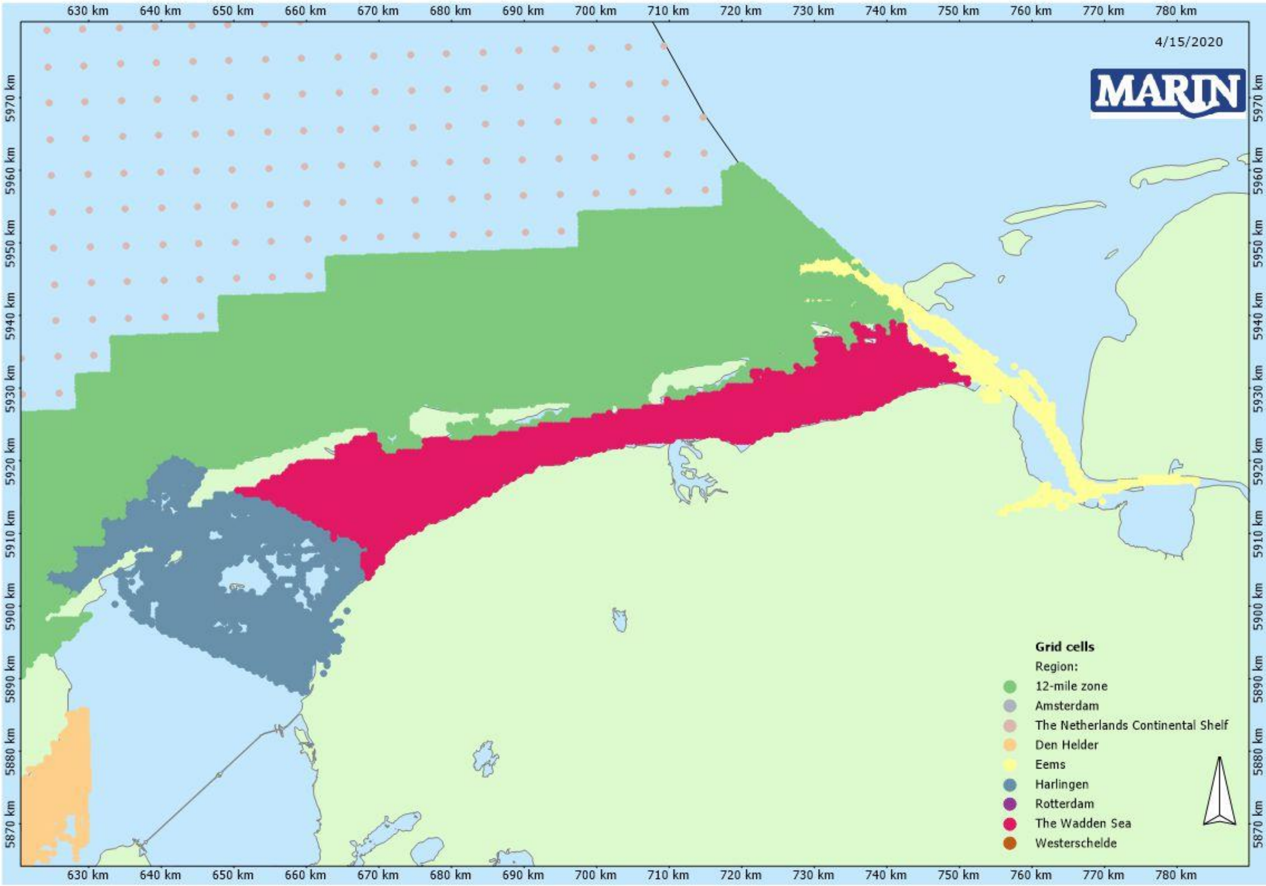

Figure 2-4 **Harlingen, the Wadden Sea and Ems: The points indicate the centres of grid cells for which emissions are calculated**

3 PROCEDURE FOR EMISSION CALCULATION

This chapter describes the procedures for the emission calculation, which 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 method to calculate the emissions is improved since the previous study of 2017 [5]. In the appendix TNO provides more information about the current calculation method.

3.1 AIS data

AIS data for 2018

In this study, AIS data of 2018 received by the Netherlands Coastguard has been used to calculate the emissions. Refer to [1] for background information about the AIS data.

IHS and The Port of Rotterdam

Just like in the previous study, the emission calculation of 2017, 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 AIS data the identifier for the ship is the MMSI number, not the IMO-number. The identifier for the emission factor based on the ship database of IHS is the IMO-number of a vessel. 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. The available AIS-data for the study area in 2018, comprised 37,391 individual MMSI of which 36,167 were valid MMSI format. Based on these MMSI-numbers, 12,797 commercial seagoing vessels could be identified (see Table 3-1). About 43% of all messages obtained, were sent by the 12,797 commercial vessels that were identified in emission factors.

Table 3-1 Link between AIS data (MMSI number) and IHS data (IMO number)

	2017		2018	
Total individual valid mmsi	33,612		36,167	
mmsi with emission factors	12,952	39%	12,797	35%
Total valid mmsi messages obtained	733,405,583		865,399,825	
Total valid mmsi messages with emission factors	328,970,302	45%	375,120,674	43%

Samples taken of unidentified MMSI - thus without IMO number and emission factor - learned that far most of these MMSI could be attributed to non-commercial small vessels and fixed objects (like ATON's, wind turbines and oil and gas installations), which are not directly relevant with respect to shipping emissions. Based on experience from earlier studies it is estimated that very roughly that at maximum 250 commercial vessels could not be identified, representing at maximum about 2% of shipping emissions. This statement is based the strategy that most effort that has been directed on identification of MMSI with large number of messages by IMO-number.

3.2 Comparison emission results 2017 and 2018

In chapter 6 and 7 the emission results of this study will be compared with the results of 2017. This year some of the emission factors has been changed. To make a reliable comparison between both years the results of the previous study (over 2017) has been recalculated on the basis of the emissions correction factors (CEF) for the substance NOx of the current year (2018).

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 of 2017 is missing several minute files 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. The sum of periods missing which are larger than 10 minutes is about one day. To compensate for this missing period, the results are multiplied with 365/364.
In 2018 there is no missing period longer than 10 minutes, so the results of that year are not compensated.

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.

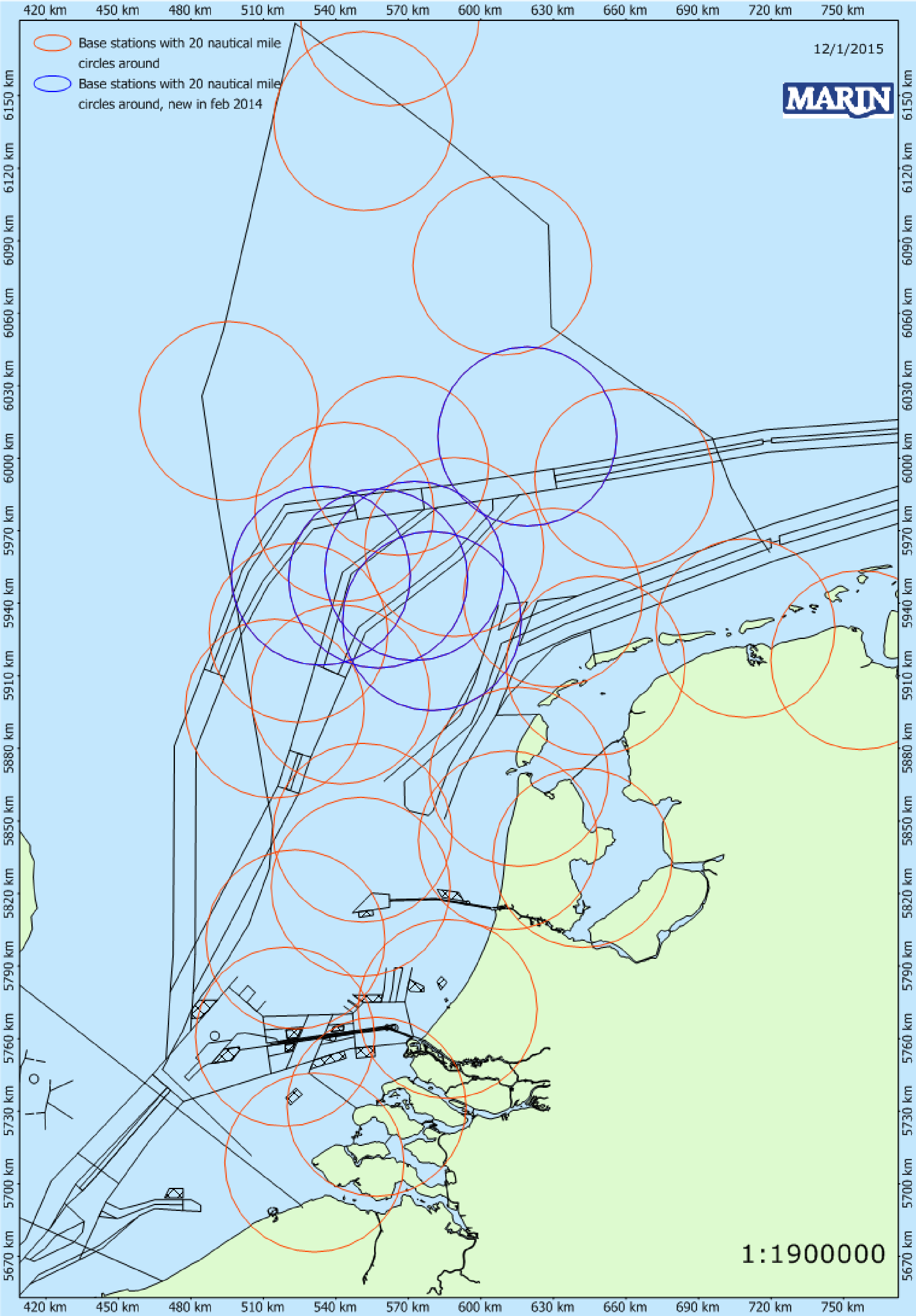

Figure 4-1 **AIS base stations in 2018 delivering data to the Netherlands Coastguard.**

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 2018. These months were chosen so that the data can be compared with last year. The overall coverage of AIS data of 2018 seems in most places of the same order of magnitude compared to the AIS coverage of 2017. However, fluctuations in coverage are expected due to the dependency on atmospheric conditions.

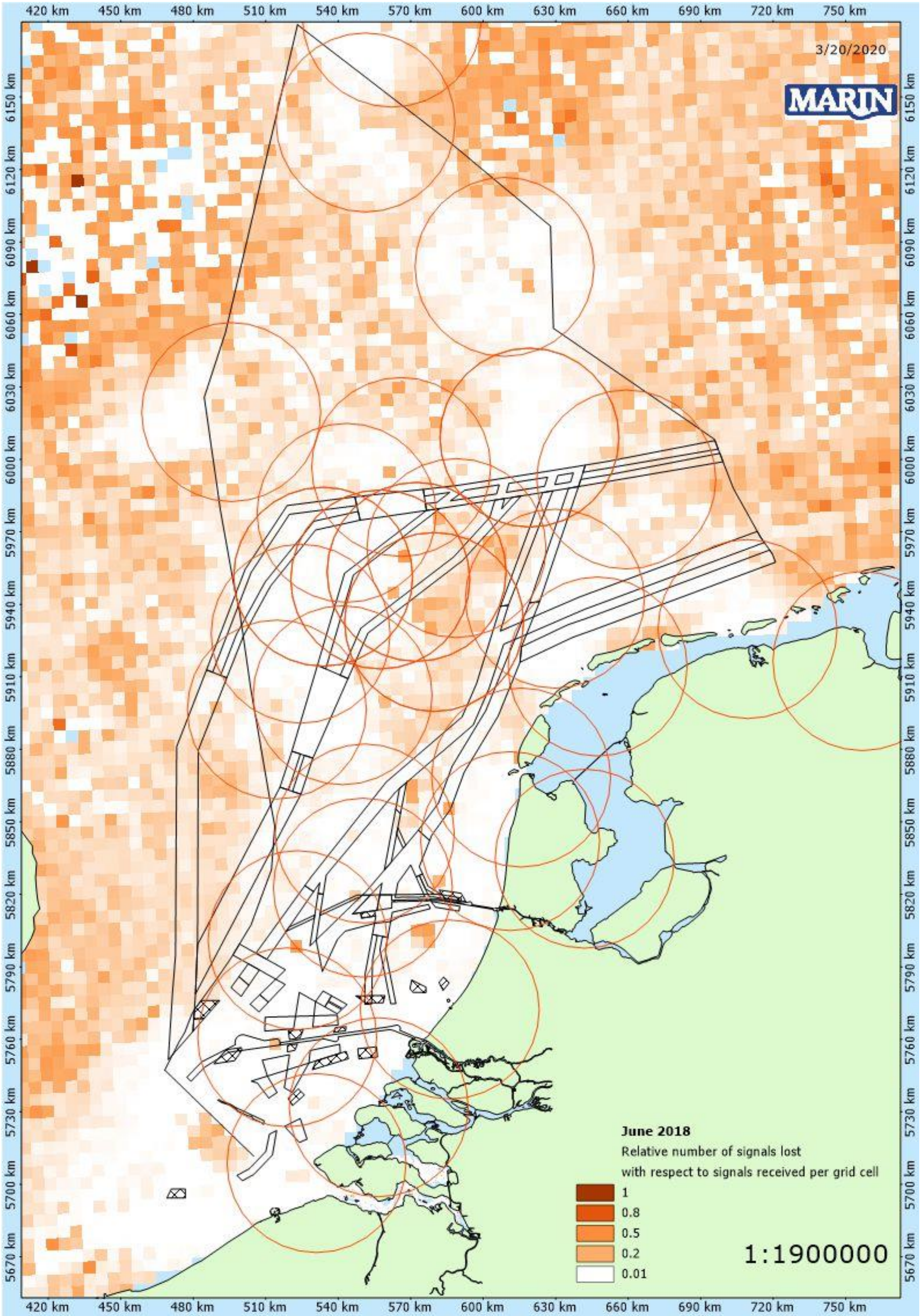

Figure 4-2 **June 2018, relative number of signals lost with respect to signals received per grid cell, circles mark the 20 nautical miles zones around the Dutch base stations**

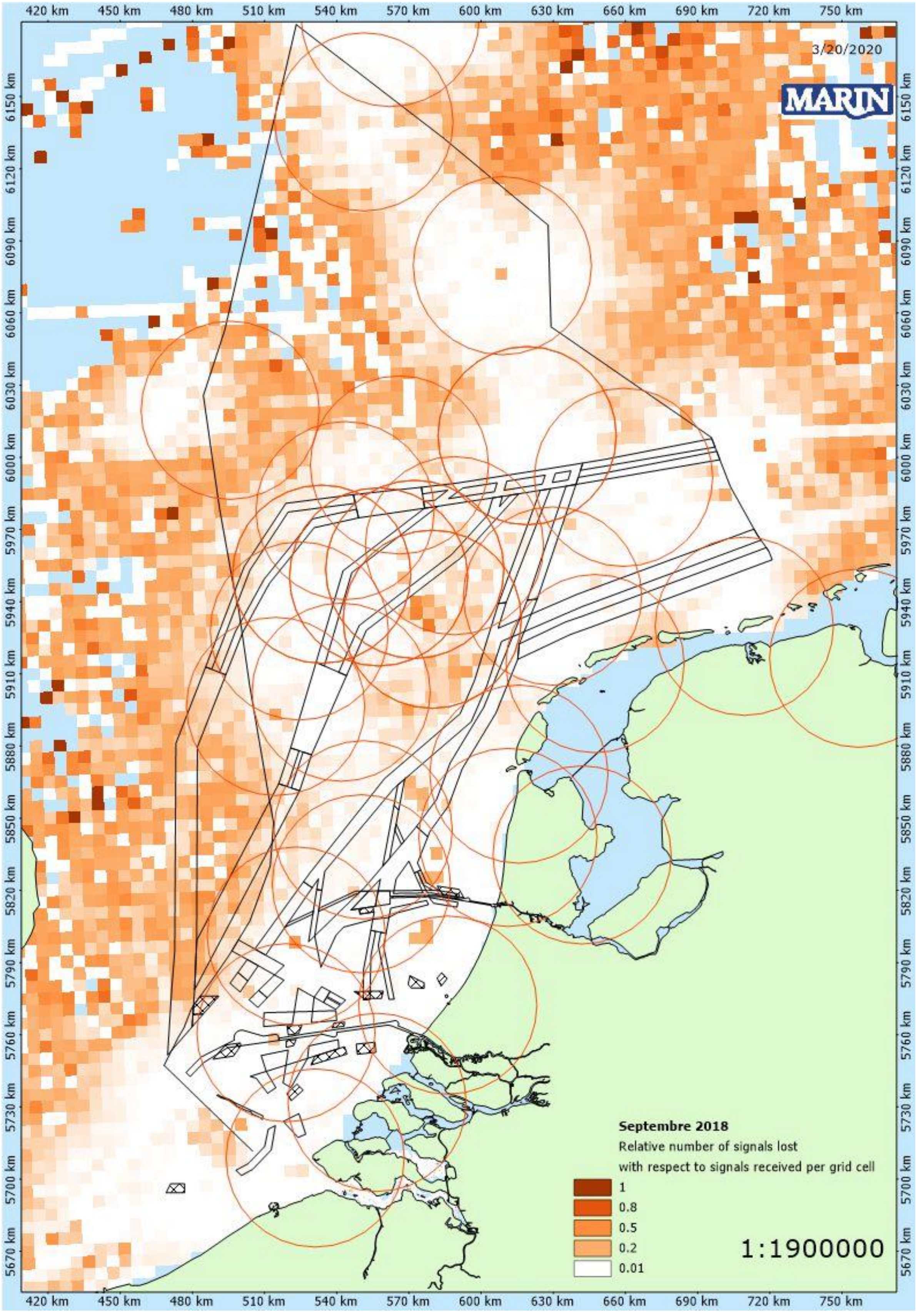

Figure 4-3 **September 2018, relative number of signals lost with respect to signals received per grid cell, circles mark the 20 nautical miles zones around the Dutch base stations**

5 ACTIVITIES OF SEAGOING VESSELS FOR 2018 AND COMPARISON WITH 2017 FOR THE DUTCH PORT AREAS AND THE NETHERLANDS SEA AREA

5.1 Introduction

This chapter presents the activities of seagoing vessels for 2018 in the Dutch port areas and in the Netherlands sea area. The activities of 2018 are compared to those of 2017. 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 [6]. 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 2017 and 2018 are shown and then the percentages with respect to 2017. The table contains the number of calls and the cargo handling for the main ports in each port area.

Except for the number of calls in port area of Rotterdam, Table 5-1 show an overall increase in the number of calls and cargo handling. In the annual report of Rotterdam is stated that the number of seagoing vessels decreased but the number of ship movements increased [6].

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

Port area	Ports	Number of calls			Cargo handling x 1000 tons		
		2017	2018	[%]	2017	2018	[%]
Western Scheldt	Antwerp	14,223	14,595	102.6%	223,655	235,331	105.2%
	Zeeland seaports (Vlissingen en Terneuzen)	Not available	-	-	Not available	-	-
Rotterdam	Rijn- en Maasmondgebied	29,646	29,476	99.4%	467,400	469,000	100.3%
Amsterdam	Noordzeekanaalgebied	7,011	7,525	107.3%	100,800	101,800	101.0%

The shipping activities of 2018 are presented for each port area in a table per ship type and a table per ship size class and compared with the activities observed in 2017. Take into account that some percentages can vary a lot due to the low absolute numbers. Another cause of variation may be due to the AIS responder being turned off or not by the responsible officer upon arrival in the port.

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 Coastguard. This year the hours of moving ships slightly decreased with 2.6% compared to 2017 and GT.nm (gross tonnage times nautical miles) decreased with 6.8%.

For berthed ships the hours increased by 19.2% in 2018 and GT.hours increased with 25.7%.

Rotterdam
The activity tables, Table 5-4 and Table 5-5, for Rotterdam show that for the moving activities, the hours decreased with 4.8% and the GT.nm (gross tonnage times nautical miles) decreased with 1.8% in 2018 compared to 2017.

Berthed activities, hours and GT.hours, increased with 44.6% and 69.8% respectively. This growth can be seen in most ship segments. In the annual report of Rotterdam is stated that the increase of transhipment is mainly due to the container ships [6].

Amsterdam
The activity tables, Table 5-6 and Table 5-7, for Amsterdam show an increase in moving vessels. The increase in hours moving is 17.7% and the increase in GT.nm is 9.0%.

The hours at berth also increased. The berthed activities for Amsterdam, hours and GT.hours, increased respectively with 48.7% and 67.9%. The significant increase in container transhipment is mainly due to the new regular service from Samskip to England [6]. This is also derived from the AIS data.

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 a bit by respectively 1.2% and 3.4%.
The number of berthed hours and GT.hours increased respectively by 126.8% and 172.4%.

Den Helder
Table 5-10 and Table 5-11, for Den Helder show that the moving activities increased. The moving hours and GT.nm increased respectively by 2.6% and 8.3%.

Compared to 2017, the berthed hours increased with 2.6% and the berthed GT.hours decreased with 12.8%.

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 15.4% and 12.7%.

The berthed hours and GT.hours increased respectively by 35.4% and 58.7%. The contribution of container ships has clearly increased in the port of Harlingen.

Overall
In comparison with the activities observed in 2017 there is a clear increase of not moving or berthed ships, especially in the ports of Ems, Rotterdam and Amsterdam. In case of the ports of Rotterdam and Amsterdam container transhipment has grown. For moving ships the increase of activities is much smaller or about the same.

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

Ship type	Totals for Western Scheldt in 2018					2018 as percentage of 2017				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	7,183	271,649,237	5,869	1,662,639,746	10.0	120.40%	137.00%	94.70%	100.10%	101.60%
Chem.+Gas tanker	69,088	807,482,841	42,450	4,684,011,060	10.9	108.10%	113.50%	100.60%	102.10%	104.30%
Bulk carrier	30,843	926,539,287	7,817	1,958,202,068	8.3	123.40%	120.90%	98.40%	99.00%	94.90%
Container ship	5,342	106,357,348	27,158	19,391,700,992	12.6	128.30%	105.10%	103.80%	99.90%	97.00%
General Dry Cargo	97,177	733,192,993	36,668	1,794,469,197	9.5	110.10%	107.30%	100.30%	96.50%	99.70%
RoRo Cargo / Vehicle	12,498	276,103,349	6,787	3,326,177,293	10.6	117.50%	117.50%	65.80%	57.60%	87.10%
Reefer	10,760	139,250,658	1,224	173,817,516	10.9	108.50%	114.80%	119.30%	132.10%	103.70%
Passenger	17,994	40,694,896	5,011	79,590,697	9.8	104.60%	131.60%	85.40%	57.50%	96.70%
Miscellaneous	115,868	277,451,944	22,921	414,194,088	7.1	120.10%	145.70%	91.00%	97.20%	95.40%
Tug/Supply	200,756	570,011,911	24,849	101,440,334	6.0	129.80%	217.90%	102.70%	135.10%	85.20%
Total	567,509	4,148,734,464	180,754	33,586,242,991	9.5	119.20%	125.70%	97.40%	93.20%	97.60%

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 2018					2018 as percentage of 2017				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	258,721	129,506,553	40653	192,655,828	8.4	118.40%	113.80%	96.70%	98.90%	106.50%
1,600-3,000	82,722	195,772,550	33665	712,784,147	8.0	108.00%	107.10%	100.70%	102.70%	89.20%
3,000-5,000	52,078	207,151,043	23371	899,891,672	8.8	122.70%	121.70%	94.30%	96.20%	95.30%
5,000-10,000	43,262	299,799,395	23244	1,683,258,919	10.4	115.90%	121.70%	105.20%	104.00%	99.20%
10,000-30,000	96,920	1,781,633,414	31461	6,956,552,171	10.6	127.70%	125.30%	97.80%	96.70%	97.20%
30,000-60,000	29,769	1,220,369,005	19629	9,897,509,577	10.6	136.20%	138.00%	104.00%	103.90%	100.00%
60,000-100,000	4,012	309,926,363	4135	3,698,003,591	11.0	116.40%	120.10%	48.70%	45.10%	91.70%
>100,000	28	4,576,139	4698	8,469,835,592	11.2	19.20%	20.40%	109.50%	109.20%	97.80%
Total	567,512	4,148,734,462	180856	32,510,491,497	9.4	119.20%	125.70%	97.10%	90.00%	97.40%

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

Ship type	Totals for Rotterdam in 2018					2018 as percentage of 2017				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	49,099	3,478,949,235	4,316	1,566,547,598	7.0	156.70%	151.70%	94.60%	90.00%	94.60%
Chem.+Gas tanker	83,216	1,401,856,712	22,743	2,037,430,907	7.7	173.90%	192.60%	99.30%	102.20%	100.00%
Bulk carrier	79,192	4,306,852,947	2,946	766,607,606	7.4	283.90%	286.10%	85.00%	92.20%	93.70%
Container ship	196,924	10,227,782,218	31,958	6,343,293,035	8.1	157.60%	151.00%	98.00%	98.80%	100.00%
General Dry Cargo	53,731	397,081,630	18,123	662,481,404	8.9	139.20%	184.10%	81.50%	83.90%	103.50%
RoRo Cargo / Vehicle	46,608	1,548,940,754	10,104	3,070,028,562	9.0	243.40%	262.20%	92.10%	103.30%	92.80%
Reefer	657	7,323,524	337	34,932,029	9.0	181.50%	166.60%	62.80%	62.40%	92.80%
Passenger	6,309	18,852,632	549	256,565,105	8.9	1553.90%	102.30%	89.60%	81.10%	104.70%
Miscellaneous	56,545	271,904,059	22,802	561,541,124	6.9	126.80%	151.00%	99.20%	119.10%	106.20%
Tug/Supply	242,943	906,390,403	56,289	224,869,015	6.2	106.20%	92.00%	97.40%	104.60%	92.50%
Total	815,224	22,565,934,114	170,167	15,524,296,385	7.4	144.60%	169.80%	95.20%	98.20%	97.70%

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

Ship size in GT	Totals for Rotterdam in 2018					2018 as percentage of 2017				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average Speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	258,898	102,664,368	67,774	165,613,030	6.4	105.40%	107.90%	93.80%	92.70%	83.10%
1,600-3,000	37,502	89,403,517	13,740	297,588,136	8.9	133.80%	137.30%	82.80%	82.40%	100.00%
3,000-5,000	37,376	148,830,890	23,121	755,932,652	8.9	173.00%	173.80%	105.80%	99.30%	94.70%
5,000-10,000	90,445	721,099,750	21,188	1,478,540,559	8.7	142.50%	144.70%	94.60%	98.10%	103.60%
10,000-30,000	165,294	3,029,510,301	27,354	4,104,919,229	8.3	179.00%	185.00%	93.00%	91.40%	102.50%
30,000-60,000	102,268	4,408,504,703	8,033	2673752,823	7.5	277.40%	266.50%	122.80%	124.80%	97.40%
60,000-100,000	71,127	5,699,377,679	5,210	2,742,228,497	6.8	186.60%	187.40%	90.70%	91.60%	97.10%
>100,000	52,313	8,366,542,906	3,747	3,305,721,459	5.6	138.80%	134.60%	96.00%	98.20%	101.80%
Total	815,223	22,565,934,114	170,167	15,524,296,385	7.6	144.60%	169.80%	95.20%	98.20%	93.60%

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

Ship type	Totals for Amsterdam in 2018					2018 as percentage of 2017				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	18,677	761,947,347	1244	230,294,755	5.8	158.80%	152.00%	87.20%	80.50%	95.10%
Chem.+Gas tanker	71,759	1,432,241,250	7948	694,765,390	6.1	170.20%	177.20%	115.10%	107.80%	95.30%
Bulk carrier	69,484	3,022,870,603	3219	610,349,393	4.8	171.20%	165.00%	116.30%	101.90%	82.80%
Container ship	3,310	30,053,690	523	23,864,040	4.1	250.20%	298.50%	169.30%	168.40%	71.90%
General Dry Cargo	91,880	380,230,961	9790	193,695,459	5.6	155.70%	163.90%	124.90%	116.80%	88.90%
RoRo Cargo / Vehicle	7,088	251,707,938	1128	266,549,920	5.8	172.30%	160.50%	102.40%	97.90%	92.10%
Reefer	17,804	94,481,199	586	13,324,683	5.0	154.00%	156.60%	115.40%	101.20%	90.90%
Passenger	12,369	273,751,967	1992	445,787,458	6.1	145.40%	309.10%	149.20%	137.40%	98.40%
Miscellaneous	23,261	152,522,005	2882	87,096,748	5.3	135.60%	219.10%	156.10%	248.50%	94.60%
Tug/Supply	153,797	350,762,237	20819	48,886,693	4.3	128.80%	133.80%	112.20%	109.90%	81.10%
Total	469,429	6,750,569,197	50131	2,614,614,539	5.1	148.70%	167.90%	117.70%	109.00%	87.60%

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

Ship size in GT	Totals for Amsterdam in 2018					2018 as percentage of 2017				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	135,692	59,289,986	23,737	47,741,544	5.2	124.50%	134.40%	114.90%	112.00%	86.70%
1,600-3,000	74,532	176,671,483	7,146	108,982,930	5.1	133.80%	138.30%	122.80%	113.20%	79.70%
3,000-5,000	31,109	121,666,636	3,352	78,882,124	5.9	148.90%	148.40%	108.70%	103.30%	93.70%
5,000-10,000	58,050	411,565,872	3,868	155,332,157	5.6	179.10%	181.20%	138.80%	122.10%	91.80%
10,000-30,000	88,178	1,917,631,249	6,551	740,209,807	5.3	190.30%	194.40%	120.50%	112.90%	93.00%
30,000-60,000	62,013	2,455,347,673	3,916	820,899,868	5.0	156.30%	152.20%	112.90%	101.60%	89.30%
60,000-100,000	19,526	1,570,178,781	1,450	591,227,567	5.1	173.20%	173.90%	120.20%	121.20%	94.40%
>100,000	330	38,217,518	108	71,338,542	5.0	102.80%	101.70%	72.50%	67.60%	96.20%
Total	469,430	6,750,569,198	50,128	2,614,614,539	5.3	148.70%	167.90%	117.70%	109.00%	87.70%

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

Ship type	Totals for Ems in 2018					2018 as percentage of 2017				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	265	4,093,287	263	5,179,513	8.8	145.60%	348.80%	84.00%	108.60%	94.60%
Chem.+Gas tanker	3,738	23,277,513	1,524	103,238,001	10.3	154.30%	164.10%	90.40%	99.50%	102.00%
Bulk carrier	3,983	56,027,810	887	141,033,423	9.3	249.40%	235.70%	84.20%	75.20%	104.50%
Container ship	104	1,208,860	45	6,682,166	11.0	47.70%	78.10%	281.30%	468.90%	161.80%
General Dry Cargo	50,383	220,302,464	6,980	305,590,393	9.9	177.90%	183.60%	99.70%	107.00%	102.10%
RoRo Cargo / Vehicle	14,885	498,643,496	8,281	1,624,418,541	11.8	252.20%	266.20%	96.40%	98.80%	101.70%
Reefer	573	1,747,930	106	5,174,205	10.1	275.50%	187.60%	186.00%	294.50%	116.10%
Passenger	2,359	307,666,586	1,419	67,203,325	13.3	198.60%	526.70%	102.60%	102.60%	90.50%
Miscellaneous	22,230	46,566,751	13,503	304,005,190	7.0	212.40%	266.80%	87.00%	116.00%	90.90%
Tug/Supply	189,353	375,083,754	15,134	265,638,999	8.7	247.80%	270.50%	115.50%	149.50%	106.10%
Total	287,873	1,534,618,451	48,142	2,828,163,756	9.1	226.80%	272.40%	98.80%	103.40%	100.10%

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 2018					2018 as percentage of 2017				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	166,000	50,396,178	18,158	68,395,758	10.4	245.90%	234.80%	102.20%	116.20%	107.20%
1,600-3,000	43,233	102,461,262	11,309	250,864,017	9.5	193.30%	199.10%	113.10%	109.50%	105.60%
3,000-5,000	31,046	120,250,915	7,344	229,429,627	9.3	226.30%	216.60%	63.00%	68.80%	97.90%
5,000-10,000	20,126	153,872,816	6,870	547,643,469	10.2	145.40%	154.00%	146.40%	146.10%	100.00%
10,000-30,000	16,245	298,022,978	2,527	492,842,241	9.8	285.40%	320.60%	95.10%	91.00%	111.40%
30,000-60,000	8,434	432,011,158	1,633	968,522,001	10.2	305.20%	310.00%	104.00%	109.20%	102.00%
60,000-100,000	1,068	70,453,524	267	217,909,744	12.5	156.80%	158.20%	79.50%	84.50%	105.00%
>100,000	1,720	307,149,620	34	52,556,901	8.8	466.10%	527.40%	100.00%	101.70%	91.70%
Total	287,872	1,534,618,451	48,142	2,828,163,758	10.0	226.80%	272.40%	98.80%	103.40%	104.50%

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

Ship type	Totals for Den Helder in 2018					2018 as percentage of 2017				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	0	15,488	0	84,132	3.6	0.00%	4.80%	0.00%	609.80%	240.00%
Chem.+Gas tanker	38	231,665	3	125,791	8.1	100.00%	55.40%	0.00%	2712.20%	385.70%
Bulk carrier	0	2,351	0	13,019	3.9	0.00%	0.70%	0.00%	17.00%	59.10%
Container ship	0	237	0	11,162	4.7	0.00%	0.00%	0.00%	138.70%	313.30%
General Dry Cargo	140	397,250	29	996,631	10.1	59.10%	23.20%	93.50%	150.50%	174.10%
RoRo Cargo / Vehicle	5,321	82,390,077	1956	216,844,292	7.6	39.70%	53.20%	83.70%	86.10%	85.40%
Reefer	9,952	92,735,706	1247	130,199,326	7.9	101.40%	106.20%	111.30%	108.30%	111.30%
Passenger	35,421	36,333,889	2092	67,349,709	6.0	109.60%	108.60%	171.80%	941.60%	111.10%
Miscellaneous	110,152	139,137,590	2993	28,182,433	5.6	109.00%	112.90%	88.30%	94.10%	100.00%
Total	161,024	351,244,253	8320	443,806,495	6.5	102.60%	87.20%	102.60%	108.30%	97.00%

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 2018					2018 as percentage of 2017				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	104,888	39,649,248	3,200	7375077	6.1	112.60%	111.30%	116.50%	103.40%	107.00%
1,600-3,000	33,835	80,248,157	1,300	19631767	7.5	95.70%	100.50%	77.70%	84.40%	127.10%
3,000-5,000	7,919	31,949,619	220	4943268	7.6	145.20%	161.70%	99.10%	99.50%	92.70%
5,000-10,000	1,080	7,608,141	60	2749435	7.7	10.60%	9.20%	16.70%	12.70%	160.40%
10,000-30,000	13,304	191,759,700	3,539	409010023	6.7	104.90%	105.10%	114.00%	115.90%	117.50%
30,000-60,000	0	7,078	0	12793	4.5	0.00%	1.50%	0.00%	78.40%	225.00%
60,000-100,000	0	14,060	0	84132	3.6	0.00%	1.20%	0.00%	1045.10%	240.00%
>100,000	0	0	0	0	0	0.00%	0.00%	0.00%	0.00%	0.00%
Total	161,026	351,236,003	8,319	443806495	6.6	102.60%	87.30%	102.60%	108.30%	114.80%

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

Ship type	Totals for Harlingen in 2018					2018 as percentage of 2017				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.hours	Average speed	Hours	GT.Hours	Hours	GT.nm	Average speed
Oil tanker	0	0	0	0	0	-	-	-	-	-
Chem.+Gas tanker	564	1,554,730	27	413,497	6.3	85.10%	47.30%	128.60%	51.20%	94.00%
Bulk carrier	373	1,447,599	27	352,884	7.3	58.40%	53.80%	45.00%	69.60%	152.10%
Container ship	7,120	66,795,382	79	5,439,279	7.2	39555.60%	10205.90%	7900.00%	4702.70%	200.00%
General Dry Cargo	30,808	96,281,920	1534	32,895,396	8.0	146.70%	162.10%	58.80%	65.60%	98.80%
RoRo Cargo / Vehicle	18,642	47,869,085	8125	266,990,346	10.4	98.00%	98.50%	99.00%	103.00%	130.00%
Reefer	1,841	9,412,524	147	5,885,199	8.9	113.80%	123.60%	68.10%	68.60%	101.10%
Passenger	28,674	11,849,788	3103	34,473,887	13.9	277.10%	261.30%	308.80%	360.00%	87.40%
Miscellaneous	61,019	58,489,190	7478	78,446,880	7.8	152.00%	222.00%	130.40%	162.50%	105.40%
Tug/Supply	32,755	22,973,786	911	2,608,684	7.6	80.30%	50.20%	126.40%	114.60%	133.30%
Total	181,796	316,674,004	21431	427,506,052	9.7	135.40%	158.70%	115.40%	112.70%	118.50%

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

Ship size in GT	Totals for Harlingen in 2018					2018 as percentage of 2017				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.hours	Average speed	Hours	GT.Hours	Hours	GT.nm	Average speed
100-1,600	112,926	47,342,094	10,386	64,182,142	9.2	142.30%	135.90%	151.40%	194.50%	100.00%
1,600-3,000	40,319	97,704,459	5,833	151,851,085	8.5	101.50%	100.30%	78.20%	87.50%	96.60%
3,000-5,000	11,138	42,926,321	4,494	174,339,505	8.8	99.10%	105.00%	124.00%	123.00%	110.00%
5,000-10,000	17,412	128,696,855	718	37,127,486	8.4	456.40%	564.90%	115.60%	123.90%	123.50%
10,000-30,000	0	2,064	0	5,834	7.5	0.00%	0.30%	0.00%	1.10%	136.40%
30,000-60,000	0	0	0	0	0	0.00%	0.00%	0.00%	0.00%	0.00%
60,000-100,000	0	0	0	0	0	0.00%	0.00%	0.00%	0.00%	0.00%
>100,000	0	0	0	0	0	0.00%	0.00%	0.00%	0.00%	0.00%
Total	181,795	316,671,793	21,431	427,506,052	8.9	135.40%	158.70%	115.40%	112.70%	102.00%

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 2018 are compared to the activities of 2017. 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 average of the total hours and GT.nm for moving vessels is almost unchanged. There are mutual differences, for example passenger ships show a clear increase of 20% for GT.nm.

For ships at anchor there is an average increase for both hours and GT.nm of about 17%.

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 2018					2018 as percentage of 2017				
	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	114,694	6,357,605,221	67,041	37,241,499,016	9.5	117.10%	109.80%	94.40%	90.70%	97.90%
Chem.+Gas tanker	351,501	4,427,556,480	283,748	40,568,424,732	11.0	125.30%	127.00%	101.80%	115.90%	103.90%
Bulk carrier	109,413	5,436,047,637	103,365	37,446,869,663	9.7	139.20%	140.20%	96.30%	95.70%	98.20%
Container ship	75,113	2,494,397,165	180,537	123,715,930,796	13.1	95.80%	81.80%	97.70%	99.80%	99.80%
General Dry Cargo	73,689	417,171,789	391,288	17,540,663,199	10.6	90.00%	84.70%	100.80%	100.20%	100.00%
RoRo Cargo / Vehicle	15,703	205,683,381	121,703	67,620,991,910	13.7	104.30%	98.40%	90.60%	96.80%	107.50%
Reefer	3,130	22,519,446	9,822	1,119,674,308	12.0	125.70%	95.30%	83.40%	82.50%	103.10%
Passenger	,597	2,226,543	10,691	10,410,592,927	12.2	78.00%	120.20%	117.60%	120.50%	98.40%
Miscellaneous	47,774	765,278,409	94,301	2,394,160,599	7.4	148.80%	208.00%	103.90%	112.70%	101.60%
Tug/Supply	87,019	422,732,326	118,431	2,869,798,954	8.0	115.80%	114.20%	103.10%	115.70%	103.30%
Total	878,633	20,551,218,397	1,380,927	340,928,606,104	10.7	118.30%	116.30%	99.30%	100.00%	101.30%

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 2018					2018 as percentage of 2017				
	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	48,703	30,717,612	150,363	851,719,511	8.4	121.30%	121.90%	103.70%	103.60%	113.50%
1,600-3,000	94,005	228,995,567	302,936	6,515,576,540	9.1	102.80%	104.60%	99.60%	100.20%	99.70%
3,000-5,000	119,469	481,182,884	183,425	7,472,186,589	10.2	116.80%	117.60%	99.60%	100.00%	98.20%
5,000-10,000	146,065	1,088,625,631	186,765	16,167,691,068	11.3	126.80%	128.40%	102.80%	104.10%	99.20%
10,000-30,000	241,295	4,709,462,854	277,266	66,517,923,106	12.1	115.50%	119.30%	92.30%	91.70%	100.60%
30,000-60,000	128,949	5,447,653,460	145,462	80,838,582,936	11.4	135.80%	132.50%	103.60%	103.10%	99.00%
60,000-100,000	88,269	6,782,188,854	94,433	84,062,422,623	11.5	121.40%	121.80%	96.40%	95.00%	98.60%
>100,000	11,880	1,782,391,535	40,281	78,502,503,730	11.9	68.30%	70.20%	108.10%	110.20%	102.10%
Total	878,635	20,551,218,397	1,380,931	340,928,606,103	10.6	118.30%	116.30%	99.30%	100.00%	100.30%

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 increase of berthed ships in the port of Eems. This is mainly due to an increase of the number of RoRo Cargo, Bulk and Passenger ships.

For the NCS combined with the 12-miles zone the average number of ships decreased slightly for moving ships, and increased for non-moving ships by 18%.

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

Area	In 2018			In 2018 as percentage of 2017		
	Average # ships/day		Speed	Average # ships/day		Speed
	Not moving	Moving	Knots	Not moving	Moving	Knots
Amsterdam	53	6	5	148.7%	117.7%	87.6%
Den Helder	18	1	7	102.6%	102.6%	97.0%
Ems	33	5	9	226.8%	98.8%	100.1%
Harlingen	21	2	10	135.4%	115.4%	118.5%
Rotterdam	93	19	7	144.6%	95.2%	97.7%
Western Scheldt	65	21	10	119.2%	97.4%	97.6%
NCS +12-mile zone	100	157	11	118.3%	99.3%	101.3%

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 2018 for the Dutch port areas and the Netherlands sea area. To indicate the change in emissions, all values for 2018 are compared with the values of 2017.

The emissions for the port areas are given in Section 6.2, those for the NCS and 12-mile zone in Section 6.3. Section 6.4 presents the spatial distribution of the 2018 NO_x emissions. Also the absolute and relative change in this spatial distribution compared to 2017 is presented in figures.

For both years (2017 and 2018) all emissions were calculated using the same improved method, see paragraph 3.2.

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 2017. 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.

Regarding the total emission for all port areas Table 6-2 shows a clear increase of emissions between 2017 and 2018, especially for berthed ships (54% on average). This is in line with the a grow of activities in these ports. For sailing ships within port areas there is an increase around 10% on average.

For the emissions of CO_2 there is an overall increase around 27%, mainly due to the increase of emissions in the port of Ems, Rotterdam and Amsterdam.

Table 6-1 Total emissions in ton in each port area for 2018, excluding fishing vessels (EMS-type 11).

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Total
1011 Methane	Berthed							
	Sailing	11	7	1	18	42	0	78
	Total	11	7	1	18	42	0	78
1237 VOC	Berthed	64	237	88	32	7	5	433
	Sailing	276	187	38	34	5	11	552
	Total	340	424	127	67	11	16	985
4001 SO_2	Berthed	97	393	134	63	12	8	707
	Sailing	339	200	36	43	8	14	639
	Total	436	593	170	106	19	22	1346
4013 NO_x	Berthed	1,540	5,047	2,005	815	177	126	9,709
	Sailing	8,516	4,445	780	942	150	279	15,112
	Total	10,056	9,492	2,785	1,757	327	404	24,821
4031 CO	Berthed	102	420	149	54	11	7	743
	Sailing	504	344	71	58	19	16	1011
	Total	606	764	220	112	30	23	1754
4032 CO_2	Berthed	131,427	598,088	204,837	67,615	12,529	8,251	1,022,746
	Sailing	359,059	212,395	37,983	46,585	11,177	14,754	681,954
	Total	490,486	810,484	242,820	114,200	23,707	23,005	1,704,700
6601 Aerosols MDO	Berthed	31	121	42	17	3	2	217
	Sailing	40	34	9	10	2	4	99
	Total	72	156	51	27	5	6	317
6602 Aerosols HFO	Berthed	0	0	2	1	1	0	4
	Sailing	182	110	16	20	4	6	337
	Total	183	110	18	20	4	6	341

Table 6-2 Emissions in each port area (including the total Western Scheldt area) for 2018 as percentage of the emissions in 2017[1], 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	466%	1018%	526%	296%	259%		308%
	Total	466%	1018%	526%	296%	259%		308%
1237 VOC	Berthed	133%	140%	175%	327%	91%	120%	150%
	Sailing	99%	95%	120%	115%	109%	113%	100%
	Total	104%	116%	154%	168%	98%	115%	117%
4001 SO_2	Berthed	108%	120%	143%	292%	80%	103%	128%
	Sailing	150%	145%	176%	167%	194%	181%	151%
	Total	138%	128%	149%	224%	104%	143%	138%
4013 NO_x	Berthed	134%	137%	175%	319%	92%	120%	148%
	Sailing	100%	97%	115%	113%	109%	115%	101%
	Total	104%	115%	153%	161%	99%	116%	115%
4031 CO	Berthed	134%	141%	174%	327%	96%	122%	151%
	Sailing	100%	96%	126%	120%	219%	120%	102%
	Total	104%	117%	155%	173%	150%	121%	118%
4032 CO_2	Berthed	133%	145%	174%	333%	96%	126%	153%
	Sailing	100%	97%	117%	110%	107%	121%	101%
	Total	107%	128%	162%	183%	101%	123%	127%
6601 Aerosols MDO	Berthed	139%	149%	179%	364%	91%	122%	158%
	Sailing	105%	105%	124%	126%	142%	108%	109%
	Total	118%	137%	166%	214%	106%	113%	139%
6602 Aerosols HFO	Berthed	63%	80%	311%	227%	130%	687%	191%
	Sailing	104%	98%	121%	111%	132%	161%	104%
	Total	104%	98%	131%	113%	132%	162%	104%

[1] These are the results for 2017 recalculated with the same method as the current 2018 results. So not the results of the study performed in 2018 over the data of 2017.

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 2018 are summarised in Table 6-3. This table also contains a comparison with 2017. These figures indicates that the increase of emissions of not moving ships is about 15% on average. The most substances show an increase, except for SO_2. There is slight decrease of emissions of sailing ships in the NCS and the 12-mile zone, except for the substance methane and CO.

For the NCS combined with the 12-miles zone the average number of ships decreased slightly for moving ships, and increased for not moving ships. Overall, the total average number of ships on the North Sea is of the same order of magnitude.

Table 6-3 Emissions of ships in ton in the Netherlands sea area for 2018 compared with 2017[2], excluding fishing vessels (EMS-type 11). The percentages in grey are based on very low absolute numbers, and not very reliable.

Nr	Substance	Emission in ton in 2018			Emission in 2018 as percentage of 2017		
		Not moving	Moving	Total	Not moving	Moving	Total
1011	Methane		526	526		1604%	1604%
1237	VOC	109	2,172	2,280	118%	97%	98%
4001	SO_2	190	3,004	3,194	89%	74%	75%
4013	NO_x	3,218	74,781	77,999	118%	98%	99%
4031	CO	175	3,959	4,133	119%	102%	103%
4032	CO_2	200,767	3,219,636	3,420,404	119%	99%	100%
6601	Aerosols MDO	83	255	338	112%	95%	99%
6602	Aerosols HFO	5	1,804	1,809	126%	94%	94%
Average number of ships present in the area		100	157	257	118%	99%	106%

[2] These are the results for 2017 recalculated with the same method as the current 2018 results. So not the results of the study performed in 2018 over the data of 2017.

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 2017 and 2018 and the third one shows the *relative* change in emission between 2017[3] and 2018. 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 2017 and 2018 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.

Figure 6-2 and Figure 6-14 show no major differences in absolute NO_x emissions for the main shipping routes in the Western Scheldt and Den Helder.

Figure 6-6 and Figure 6-9 clearly shows the increase of berthed NO_x emissions in the port of Rotterdam and Amsterdam.

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

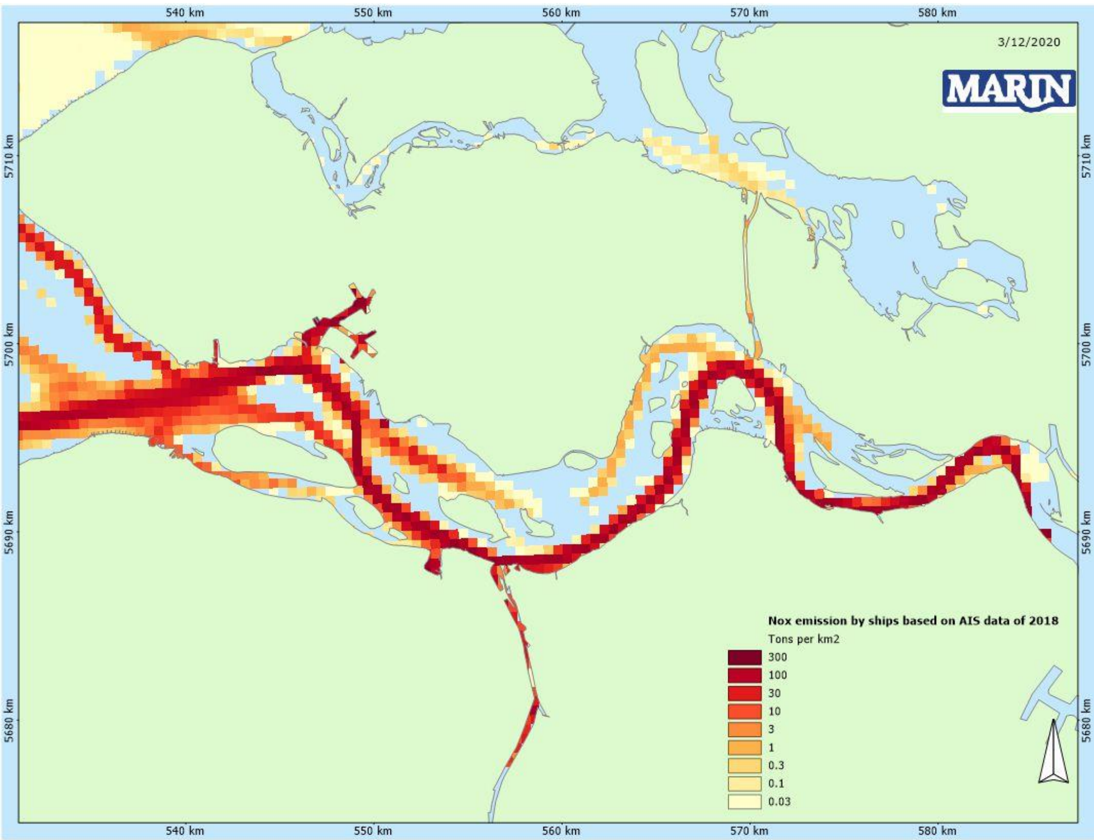

Figure 6-1 **NO_x emission in 2018 in the Dutch part of the Western Scheldt by ships with AIS.**

[3] These are the results for 2017 recalculated with the same method as the current 2018 results. So not the results of the study performed in 2018 over the data of 2017.

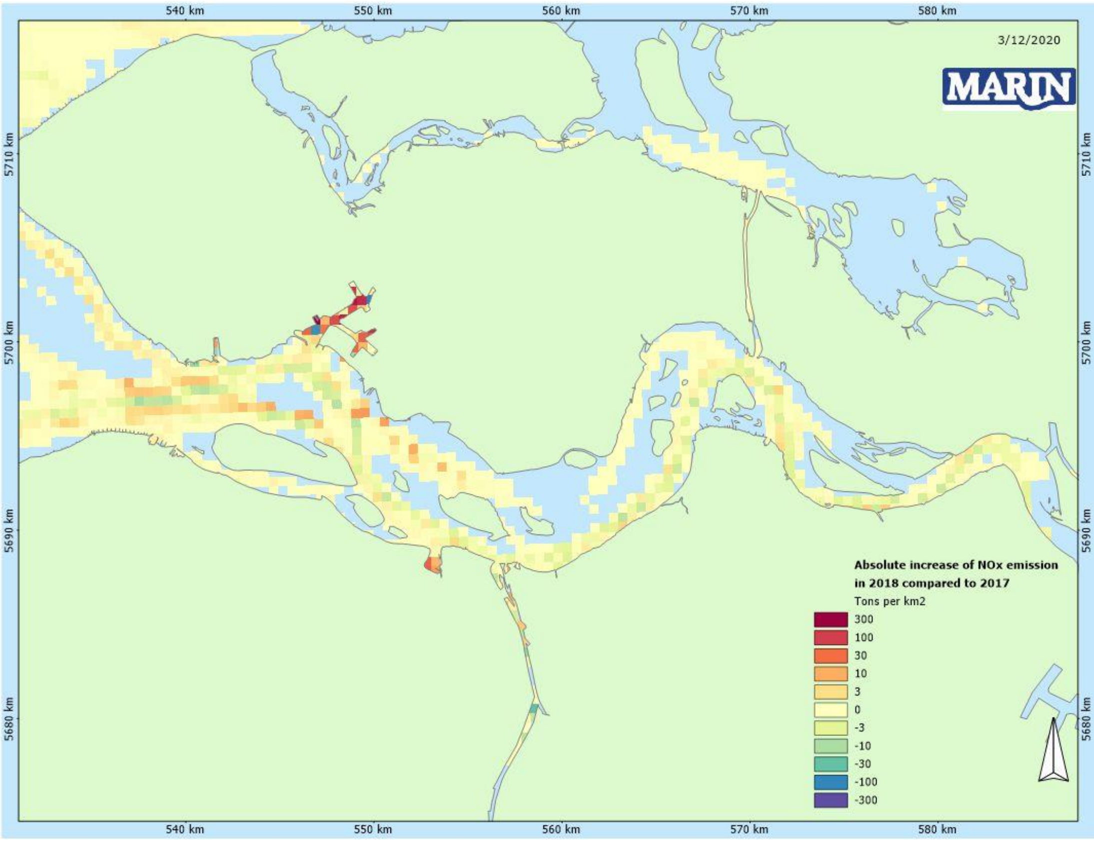

Figure 6-2 **Absolute change in NO_x emission from 2017 to 2018 in the Dutch part of the Western Scheldt by ships with AIS.**

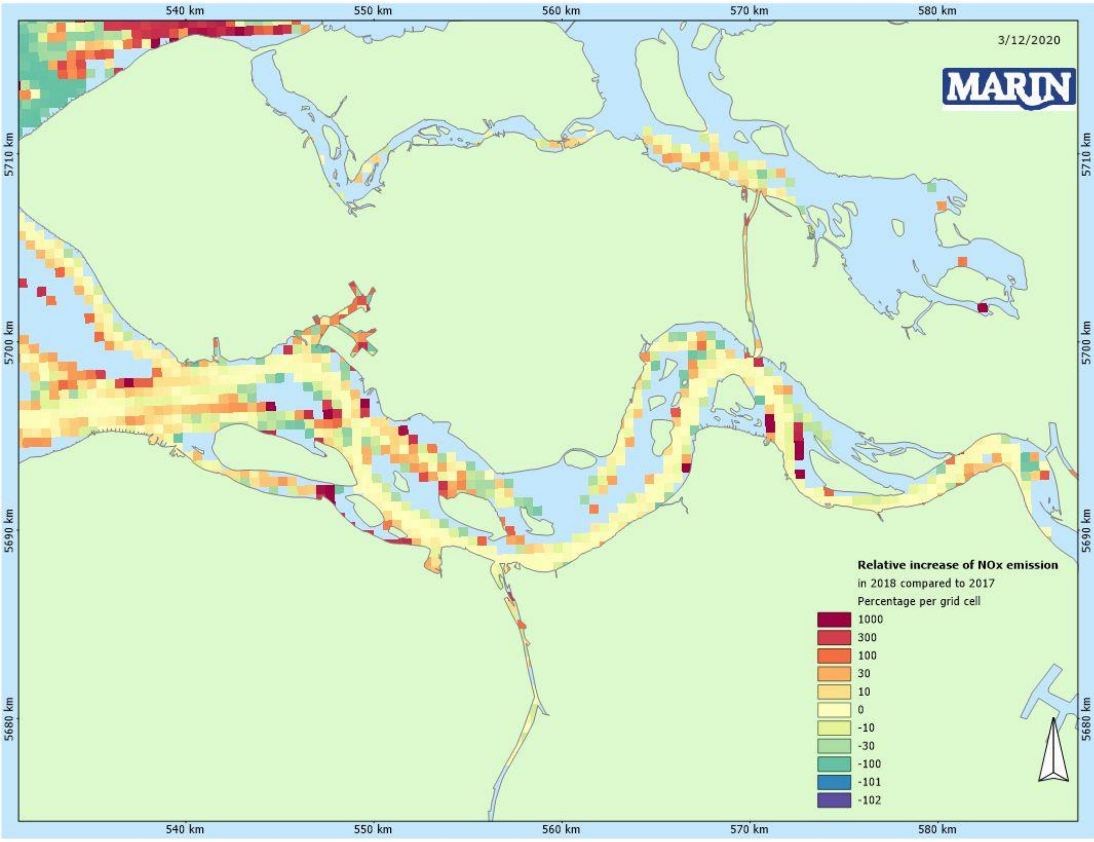

Figure 6-3 **Relative change in NO_x emission from 2017 to 2018 in the Dutch part of the Western Scheldt by ships with AIS.**

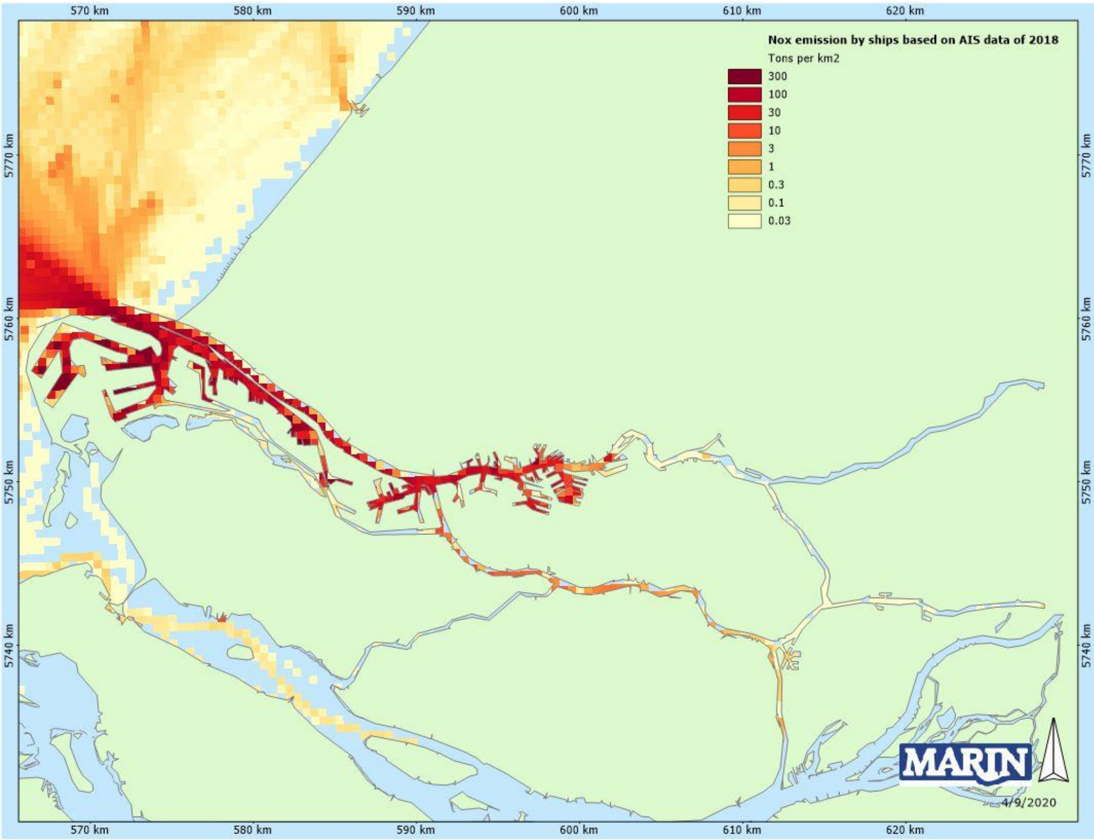

Figure 6-4 **NO_x emission in 2018 in the port area of Rotterdam by ships with AIS.**

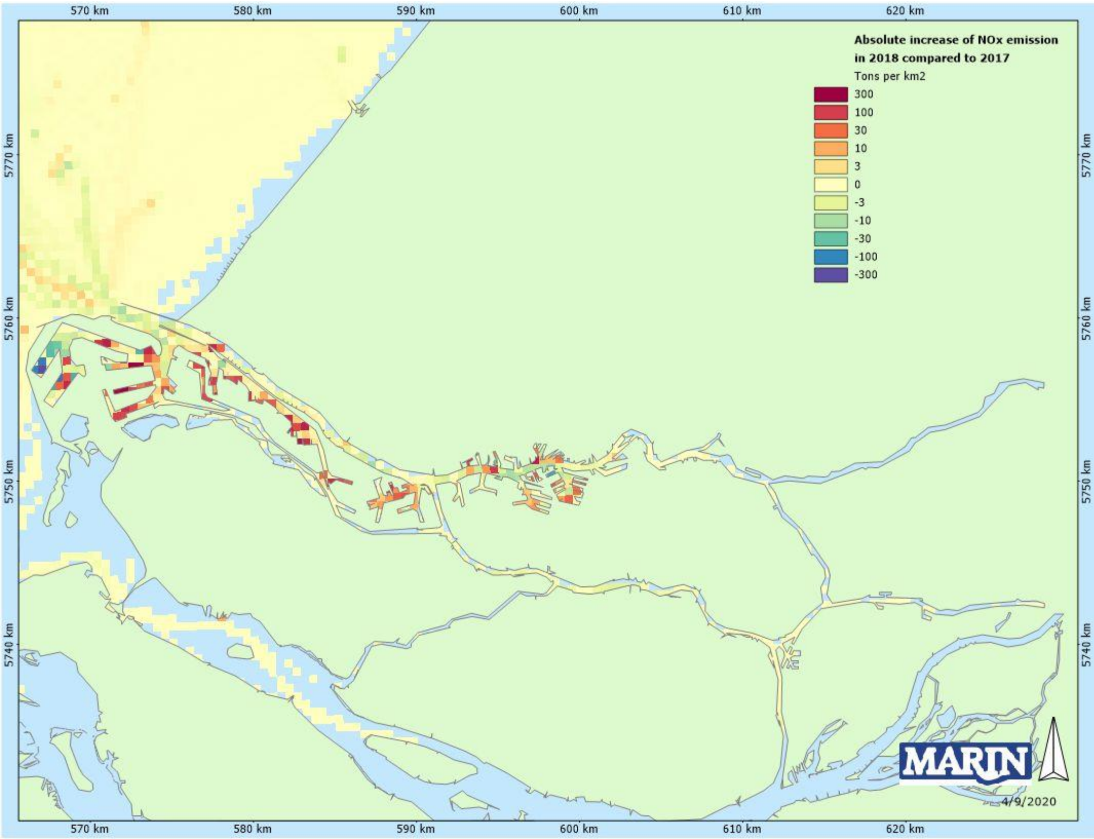

Figure 6-5 **Absolute change in NO_x emission from 2017 to 2018 in the port area of Rotterdam by ships with AIS.**

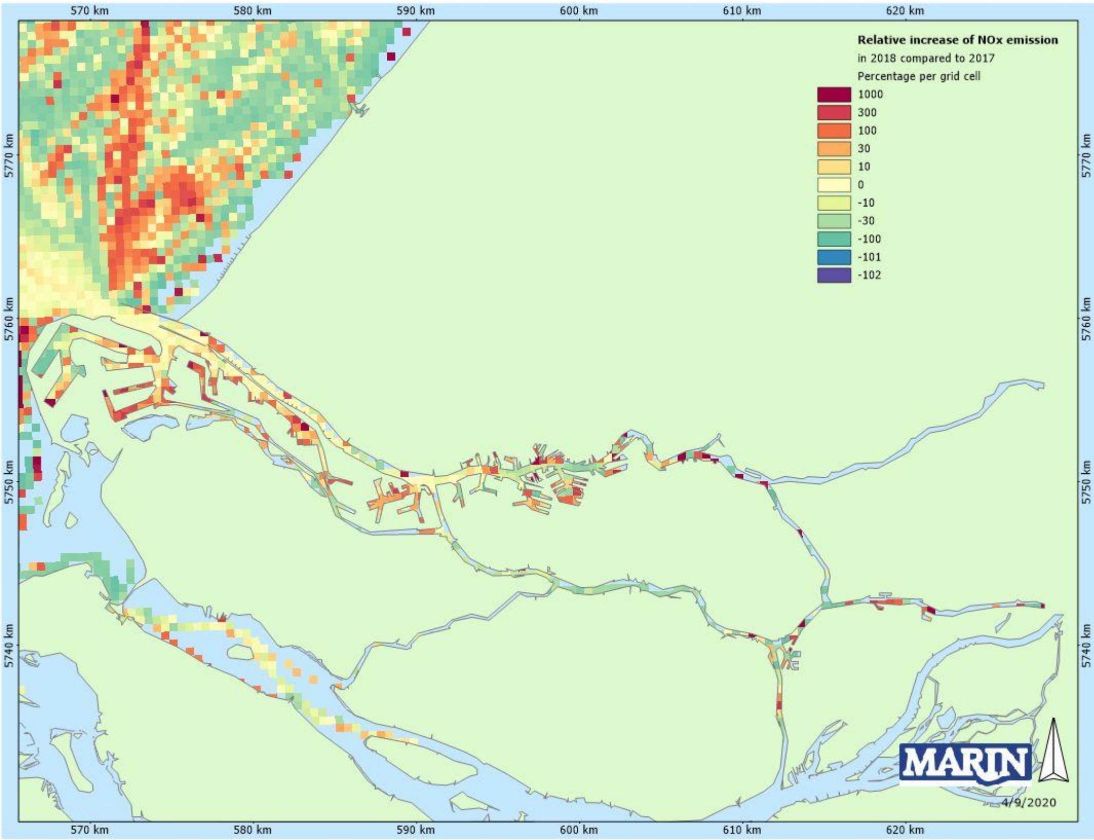

Figure 6-6 Relative change in NO_x emission from 2017 to 2018 in the port area of Rotterdam by ships with AIS.

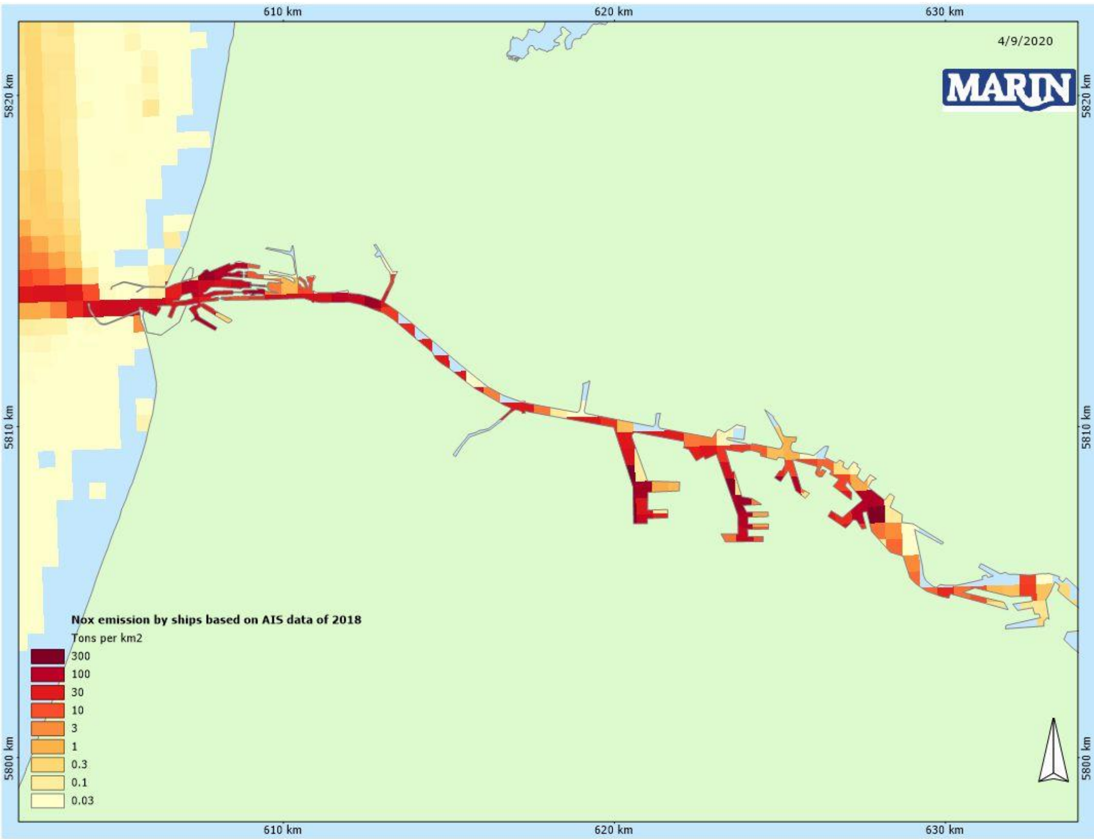

Figure 6-7 NO_x emission in 2018 in the port area of Amsterdam by ships with AIS.

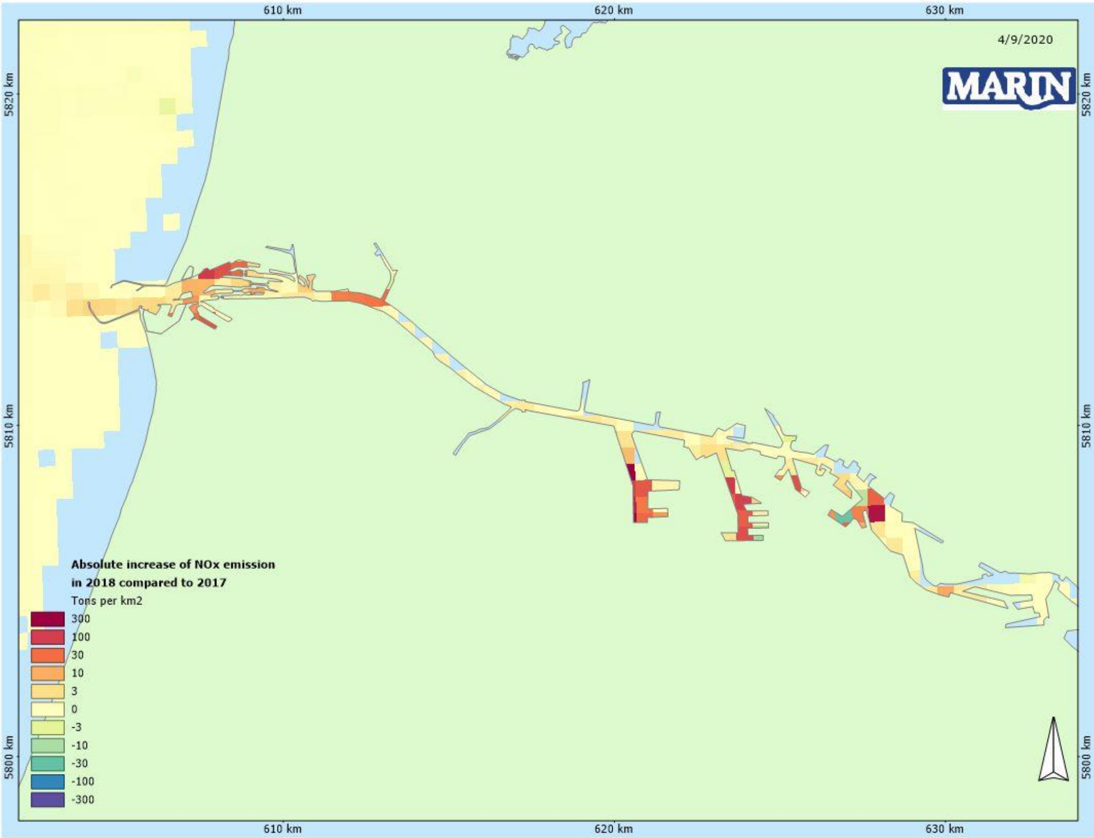

Figure 6-8 **Absolute change in NO_x emission from 2017 to 2018 in the port area of Amsterdam by ships with AIS.**

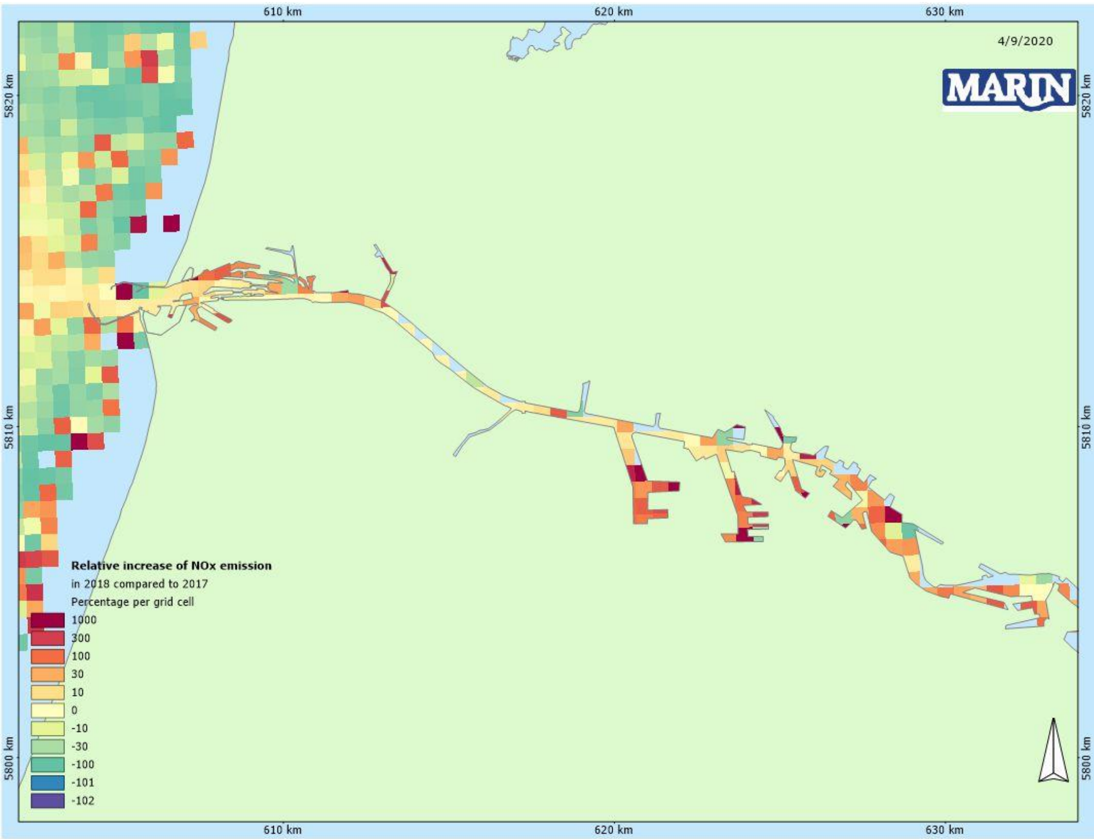

Figure 6-9 **Relative change in NO_x emission from 2017 to 2018 in the port area of Amsterdam by ships with AIS.**

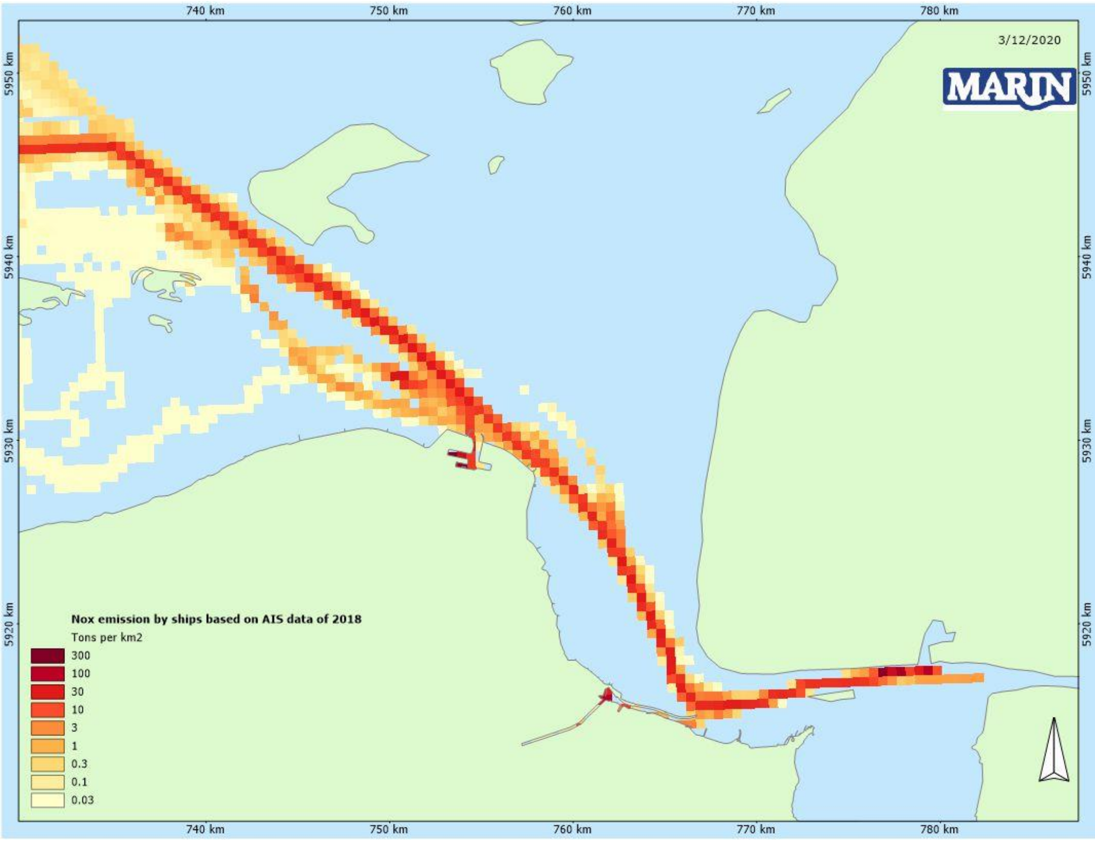

Figure 6-10 **NO_x emission in 2018 in the Ems area by ships with AIS.**

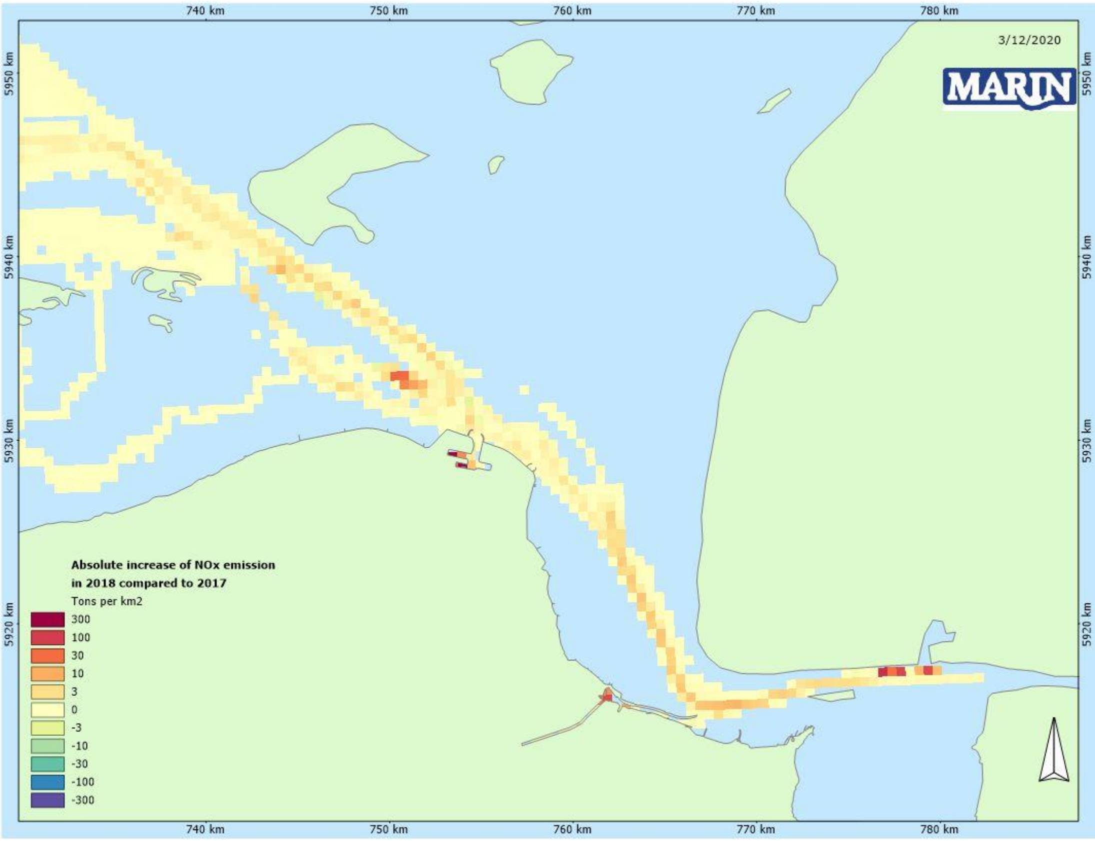

Figure 6-11 **Absolute change in NO_x emission from 2017 to 2018 in the Ems area by ships with AIS.**

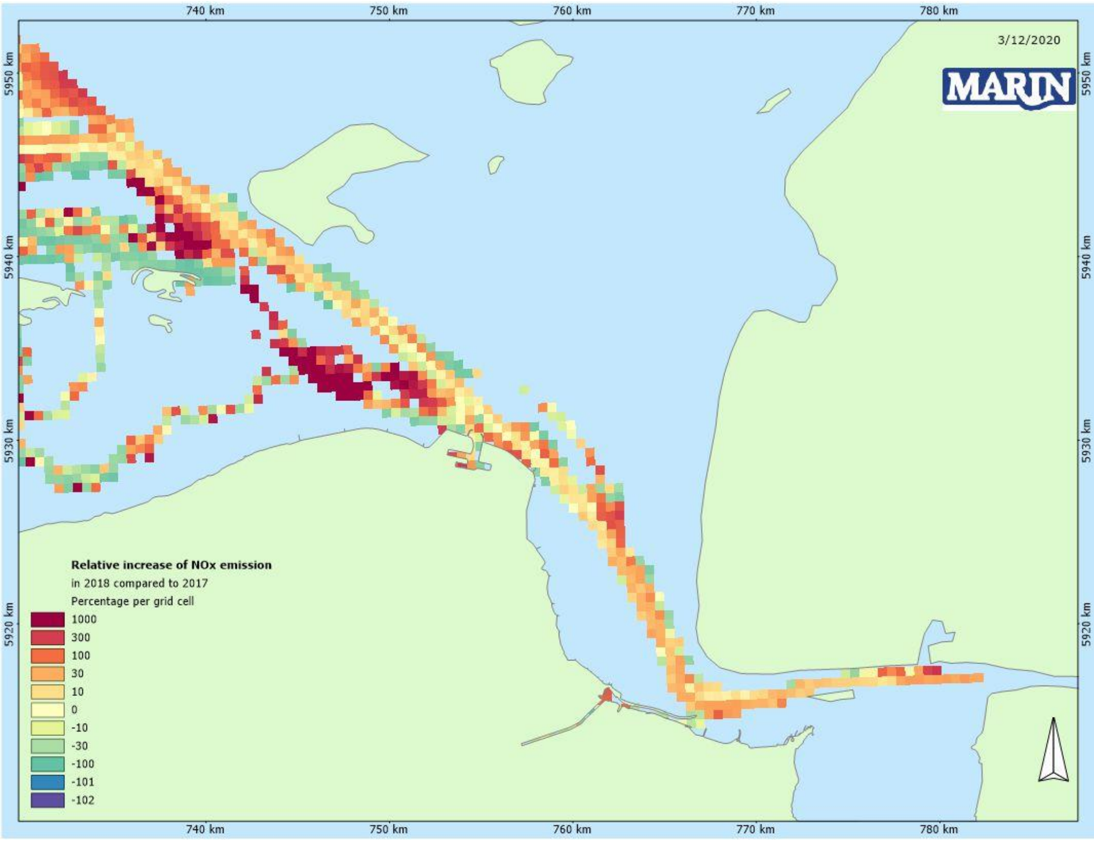

Figure 6-12 **Relative change in NO_x emission from 2017 to 2018 in the Ems area by ships with AIS.**

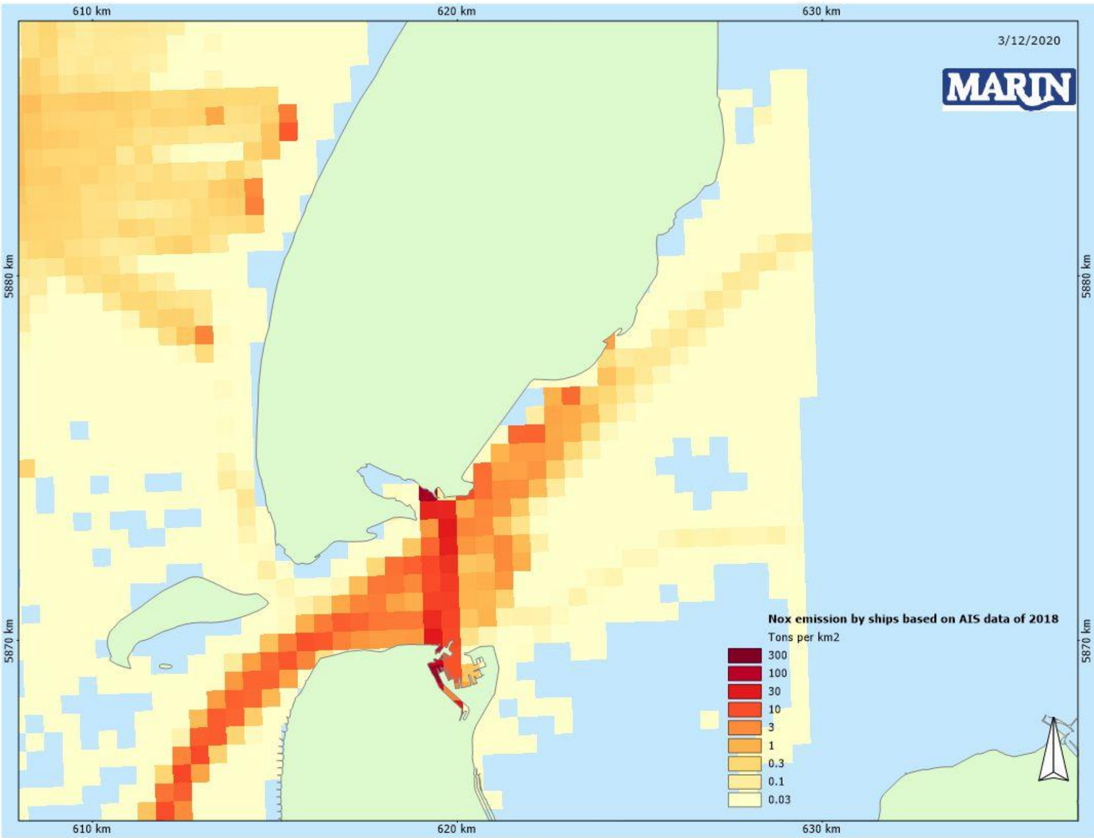

Figure 6-13 **NO_x emission in 2018 in the port area of Den Helder by ships with AIS.**

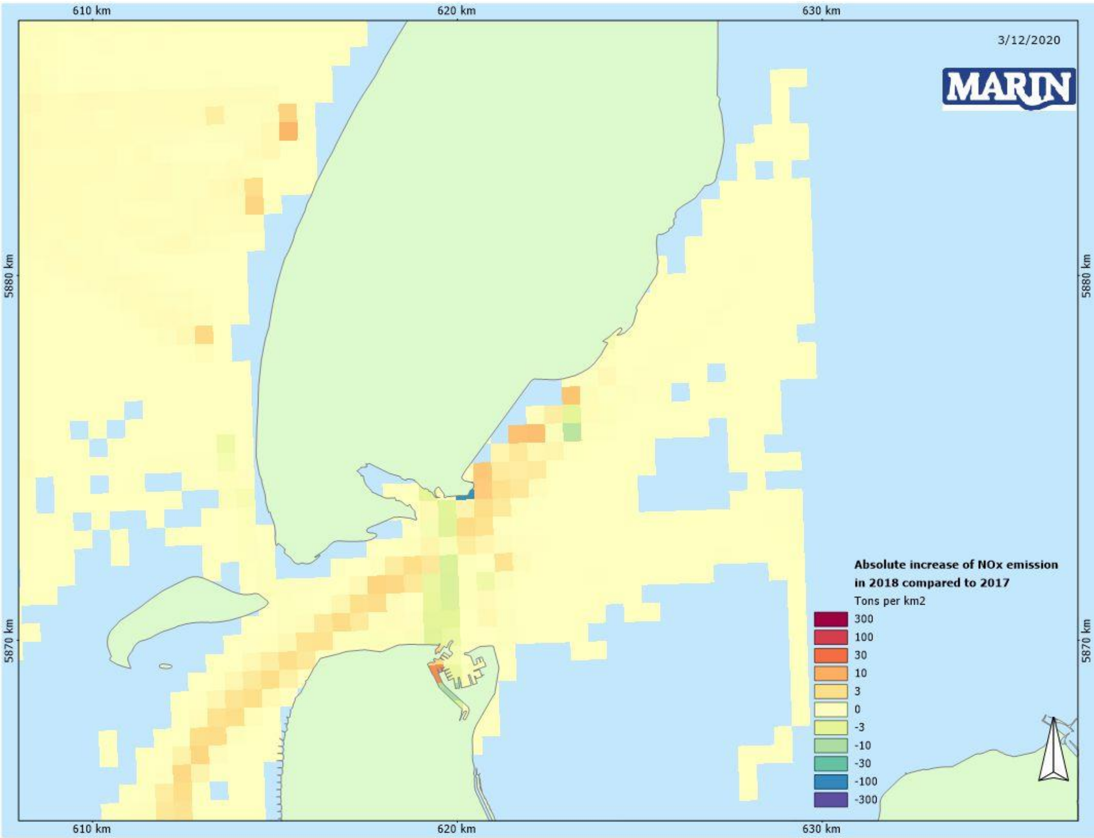

Figure 6-14 **Absolute change in NO_x emission from 2017 to 2018 in the port area of Den Helder by ships with AIS.**

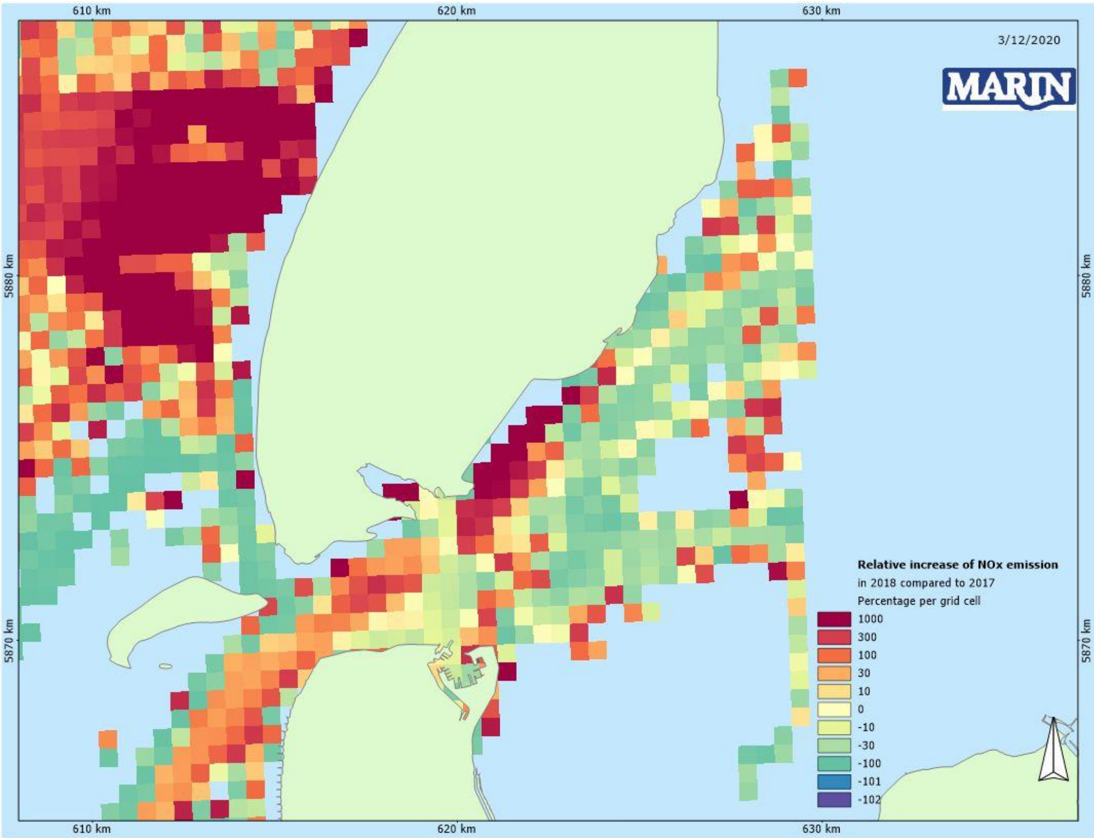

Figure 6-15 **Relative change in NO_x emission from 2017 to 2018 in the port area of Den Helder by ships with AIS.**

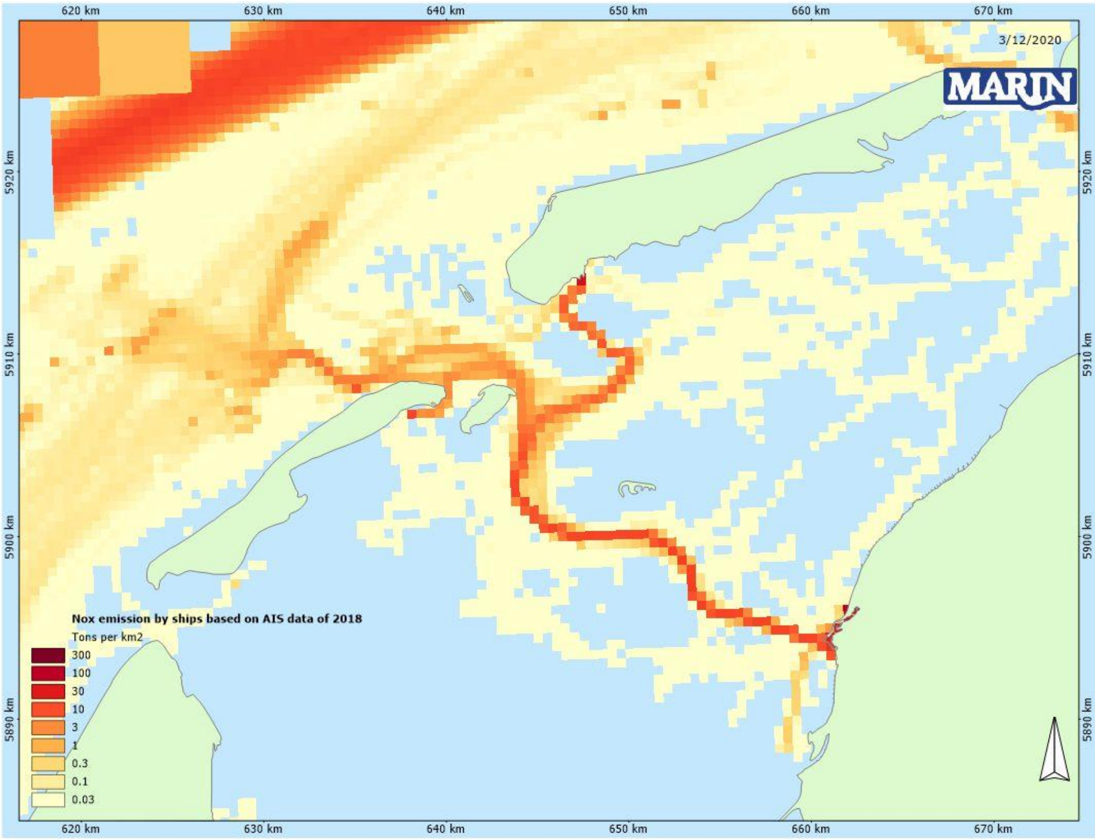

Figure 6-16 NO$_x$ emission in 2018 in the port area of Harlingen by ships with AIS.

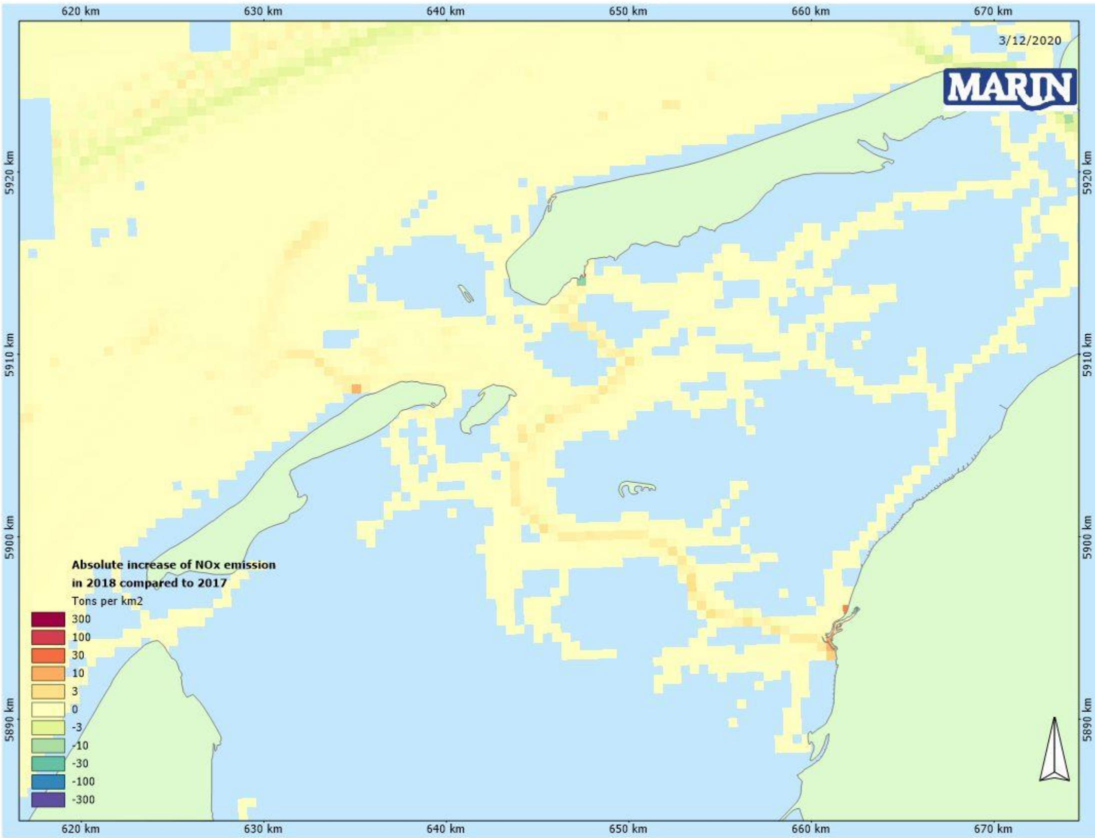

Figure 6-17 Absolute change in NO$_x$ emission from 2017 to 2018 in the port area of Harlingen by ships with AIS.

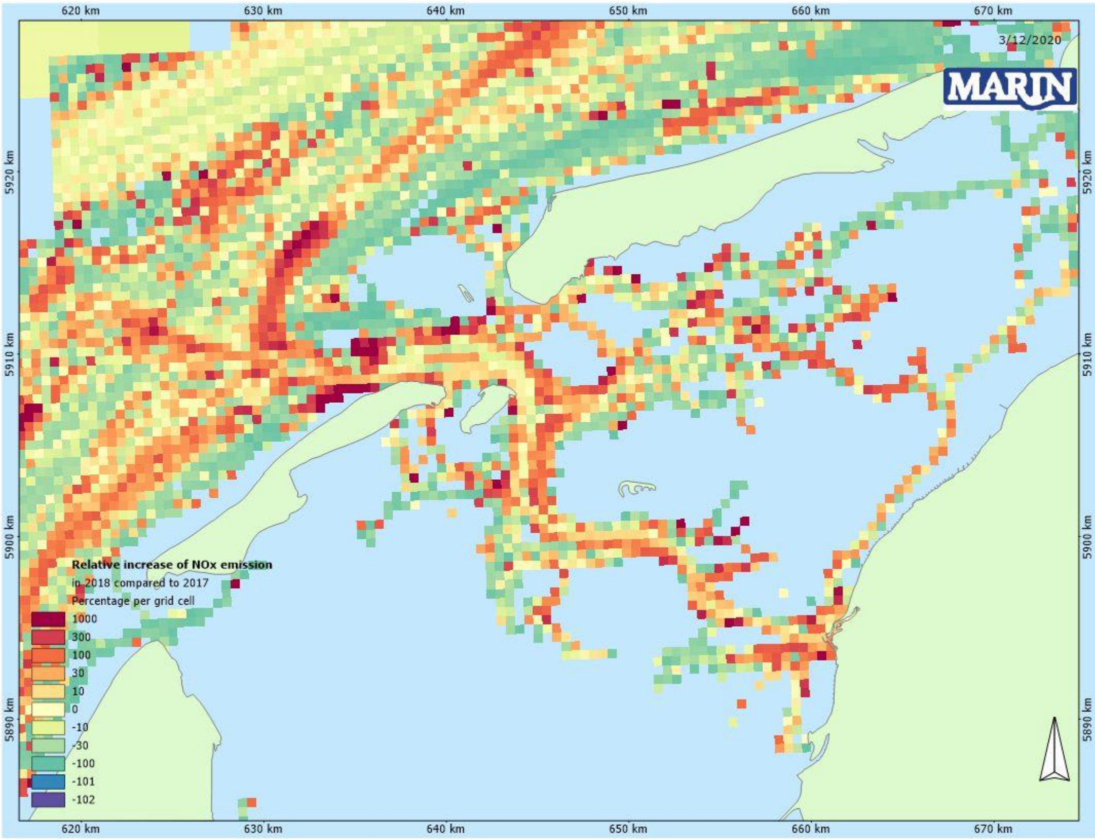

Figure 6-18 **Relative change in NO_x emission from 2017 to 2018 in the port area of Harlingen by ships with AIS.**

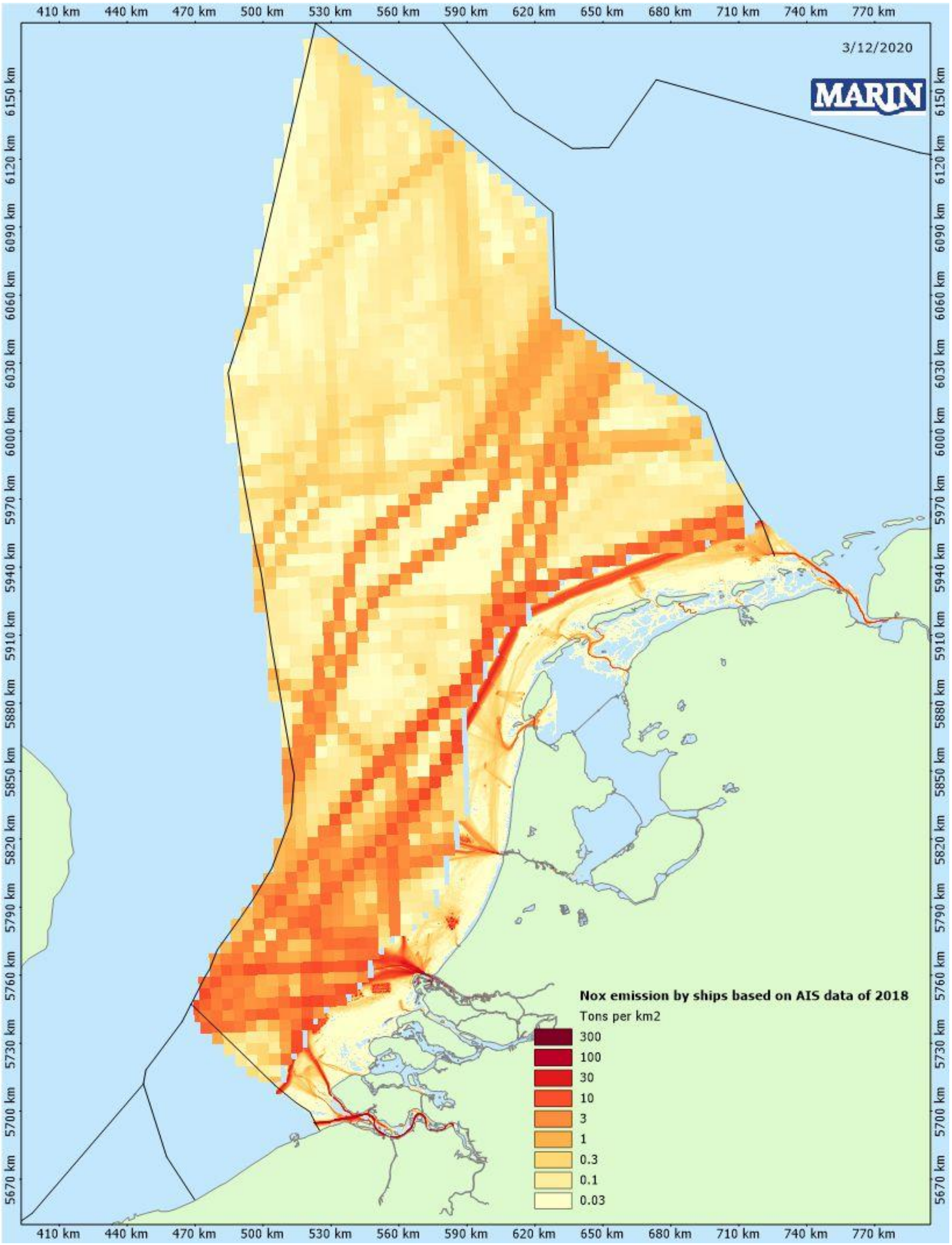

Figure 6-19 NO_x emission in 2018 in the NCS, the 12-mile zone and the Dutch port areas by ships with AIS.

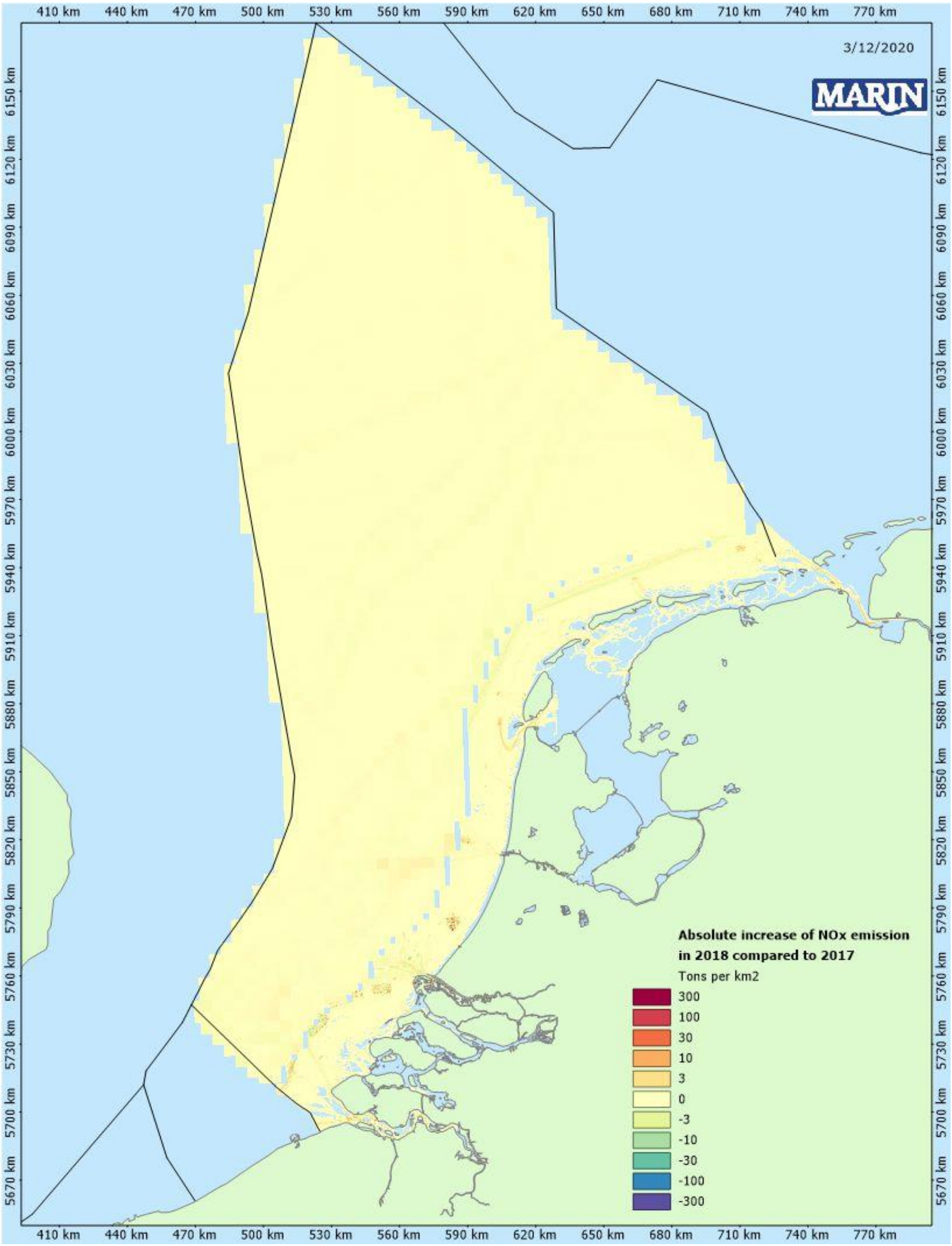

Figure 6-20 **Absolute change in NO_x emission from 2017 to 2018 in the NCS, the 12-mile zone and in the Dutch port areas by ships with AIS.**

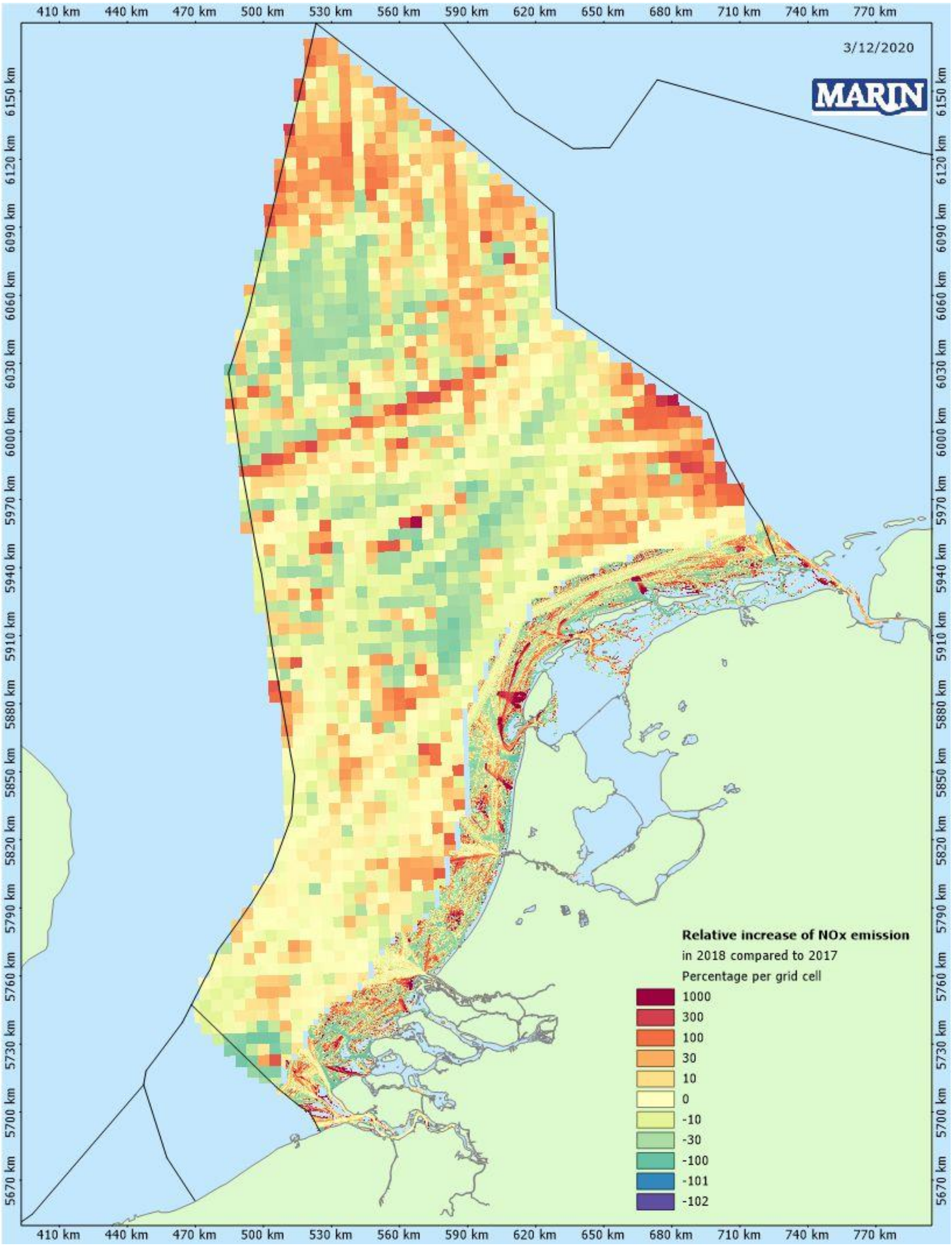

Figure 6-21 Relative change in NO_x emission from 2017 to 2018 in the NCS, the 12-mile zone and in the Dutch port areas by ships with AIS.

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 emission calculations for 2018 for the fishing activities in the Dutch port areas, the Wadden Sea and the Netherlands sea area. The emissions of fishing vessels were introduced in the previous study, and the method and results were reported by TNO in reference [3] and in the Appendix A3.

7.2 Emissions of fishing vessels (EMS type 11)

In Table 7-1 the total emissions of fishing vessels are given in ton for each port area and the Wadden Sea and Table 7-2 presents the percentages compared with the results of the re-run of previous year (2017). Table 7-3 gives the total emissions of fishing vessels for the 12 miles zone and the NCP and Table 7-4 presents the percentages compared with 2017. Figure 7-1 up to Figure 7-6 presents the spatial distribution of CO_2 for the NCS and the Dutch Wadden Sea. This substance is most emitted by fishing vessels.

It is clear from both the table and the figures that the contribution of CO_2 emissions by fishing vessels is largest in Harlingen, WesternScheldt and Amsterdam. Compared to the previous year there is a clear increase of CO_2 emissions in the port of WesternScheldt, Amsterdam and Harlingen.

For all ports together we see an increase of CO_2 emissions for berthed ships, around 14 percent. The average for sailing ships in ports is approximately the same.

For the NCP and the 12-miles zone the average increase of CO_2 emissions by fishing vessels is around 20 percent.

Table 7-1 Total emissions in ton in each port area for 2018, fishing vessels including trawlers.

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Wadden	Total
1237 VOC	Berthed	4	2	4	1	2	7	0	21
	Sailing	1	0	1	1	2	5	1	11
	Total	6	2	5	1	4	13	2	33
4001 SO_2	Berthed	4	3	5	1	2	7	0	23
	Sailing	1	0	1	1	2	6	1	12
	Total	6	3	6	1	4	13	2	35
4013 NO_x	Berthed	103	54	113	13	56	165	8	511
	Sailing	30	5	19	15	38	125	26	258
	Total	132	59	132	29	94	290	34	769
4031 CO	Berthed	5	3	5	1	3	8	0	25
	Sailing	2	0	1	1	2	6	1	14
	Total	7	3	7	1	5	15	2	39
4032 CO_2	Berthed	6840	3946	6296	951	3901	11680	520	34133
	Sailing	1945	328	1099	1100	2678	8889	1824	17864
	Total	8784	4274	7395	2051	6579	20569	2344	51996
6598 Aerosols MDO/HFO	Berthed	3	2	1	0	2	6	0	15
	Sailing	1	0	0	1	1	4	1	8
4031 CO	***Total***	4	2	1	1	3	10	1	23

Table 7-2 Emissions in each port area for 2018 as percentage of the emissions in 2017[4], fishing vessels including trawlers. 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	Wadden	Total
1237 VOC	Berthed	106%	97%	133%	101%	100%	128%	78%	115%
	Sailing	87%	106%	132%	125%	129%	95%	91%	101%
	Total	101%	98%	133%	113%	110%	111%	87%	109%
4001 SO_2	Berthed	443%	720%	145%	5201%	5389%	5619%	3012%	448%
	Sailing	633%	608%	349%	2458%	5189%	3879%	2954%	1574%
	Total	475%	710%	158%	3253%	5305%	4705%	2967%	590%
4013 NO_x	Berthed	105%	101%	138%	102%	101%	128%	81%	116%
	Sailing	84%	109%	132%	116%	130%	97%	91%	101%
	Total	100%	102%	137%	109%	111%	112%	89%	111%
4031 CO	Berthed	106%	97%	132%	101%	100%	128%	79%	115%
	Sailing	86%	107%	135%	120%	129%	96%	91%	101%
	Total	100%	98%	132%	110%	110%	112%	88%	110%
4032 CO_2	Berthed	106%	99%	135%	99%	100%	127%	77%	114%
	Sailing	83%	106%	129%	112%	127%	96%	90%	100%
	Total	100%	100%	134%	106%	110%	111%	87%	109%
6598 Aerosols MDO/HFO	Berthed	111%	99%	119%	101%	98%	128%	72%	113%
	Sailing	88%	101%	112%	124%	124%	95%	90%	99%
4031 CO	***Total***	105%	99%	118%	112%	107%	112%	85%	107%

[4] These are the results for 2017 recalculated with the same method as the current 2018 results. So not the results of the study performed in 2018 over the data of 2017.

Table 7-3 Total emissions in ton in the 12 mile zone and the NCP for 2018, fishing vessels including trawlers.

Substance	Source	12 Miles	NCP	Total
1237 VOC	Berthed	3	1	3
	Sailing	20	53	73
	Total	23	54	76
4001 SO_2	Berthed	4	1	4
	Sailing	20	56	76
	Total	24	56	80
4013 NO_x	Berthed	74	16	90
	Sailing	451	1236	1687
	Total	525	1252	1777
4031 CO	Berthed	4	1	4
	Sailing	24	65	89
	Total	27	66	93
4032 CO_2	Berthed	4318	978	5297
	Sailing	31014	81616	112629
	Total	35332	82594	117926
6598 Aerosols MDO/HFO	Berthed	1	0	1
	Sailing	14	34	48
	Total	15	34	49

Table 7-4 Emissions in 12 miles and NCP for 2018 as percentage of the emissions in 2017[5], fishing vessels including trawlers. The percentages in grey are based on very low absolute numbers, and not very reliable.

Substance	Source	12 Miles	NCP	Total
1237 VOC	Berthed	112%	152%	117%
	Sailing	98%	138%	124%
	Total	99%	138%	124%
4001 SO_2	Berthed	134%	323%	149%
	Sailing	720%	450%	500%
	Total	436%	447%	444%
4013 NO_x	Berthed	116%	151%	121%
	Sailing	97%	136%	123%
	Total	100%	136%	123%
4031 CO	Berthed	115%	145%	120%
	Sailing	98%	138%	124%
	Total	100%	138%	124%
4032 CO_2	Berthed	114%	138%	118%
	Sailing	95%	134%	120%
	Total	97%	134%	120%
6598 Aerosols MDO/HFO	Berthed	94%	127%	102%
	Sailing	95%	134%	120%
	Total	95%	134%	119%

[5] These are the results for 2017 recalculated with the same method as the current 2018 results. So not the results of the study performed in 2018 over the data of 2017.

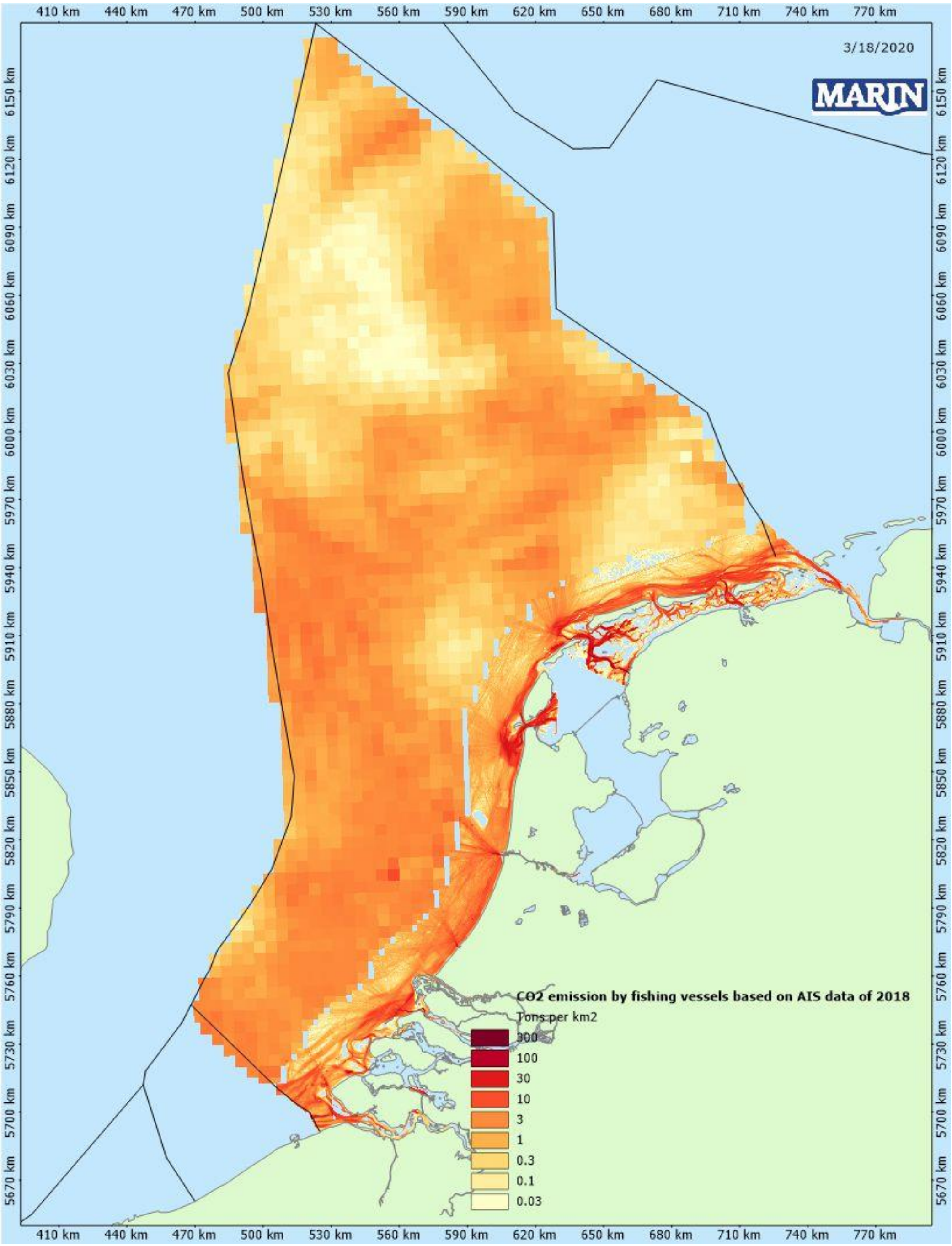

Figure 7-1 CO_2 emission observed in the NCS, fishing vessels including trawlers, based on AIS data of 2018

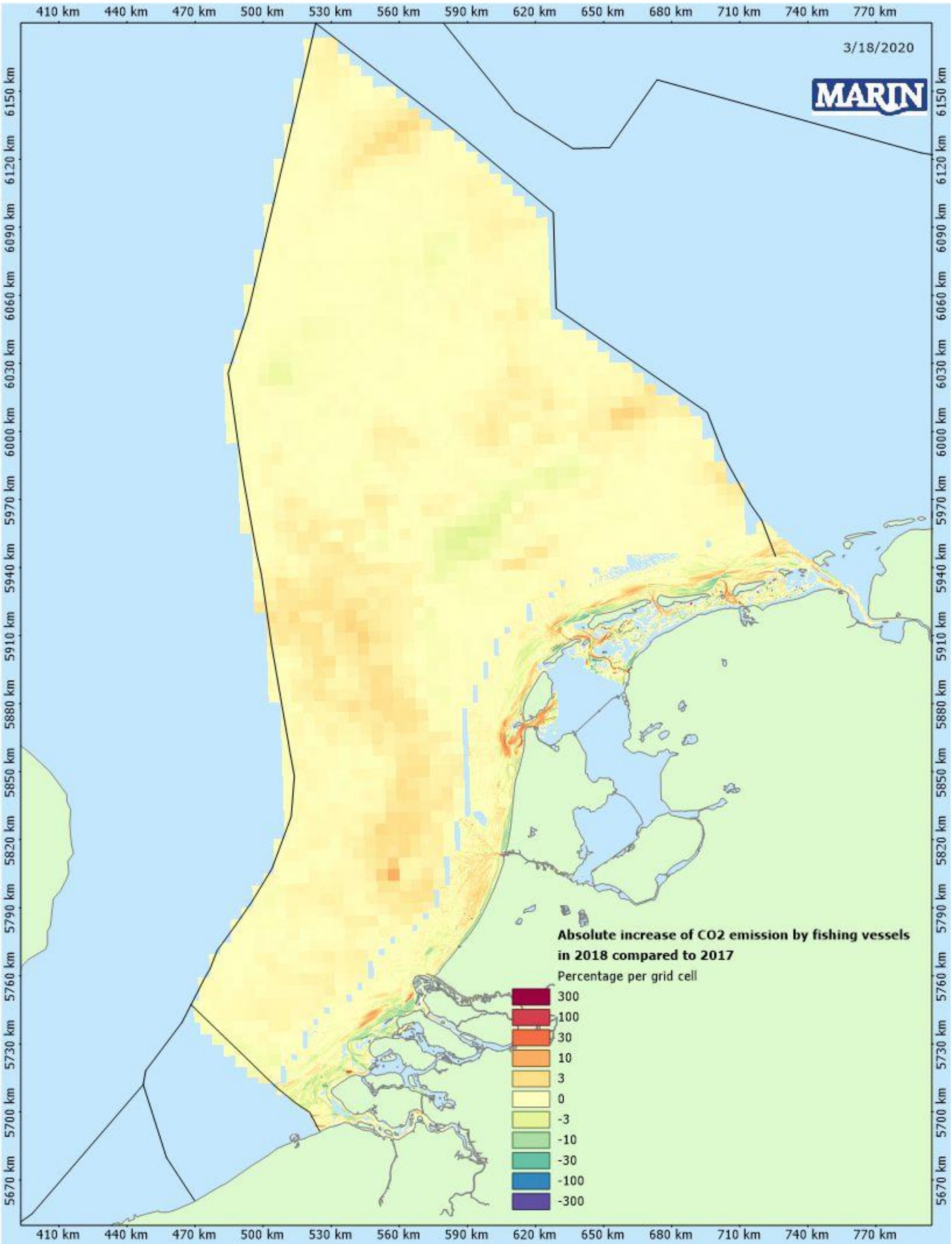

Figure 7-2 Absolute change in CO2 emission from 2017 to 2018 observed in the NCS, fishing vessels including trawlers.

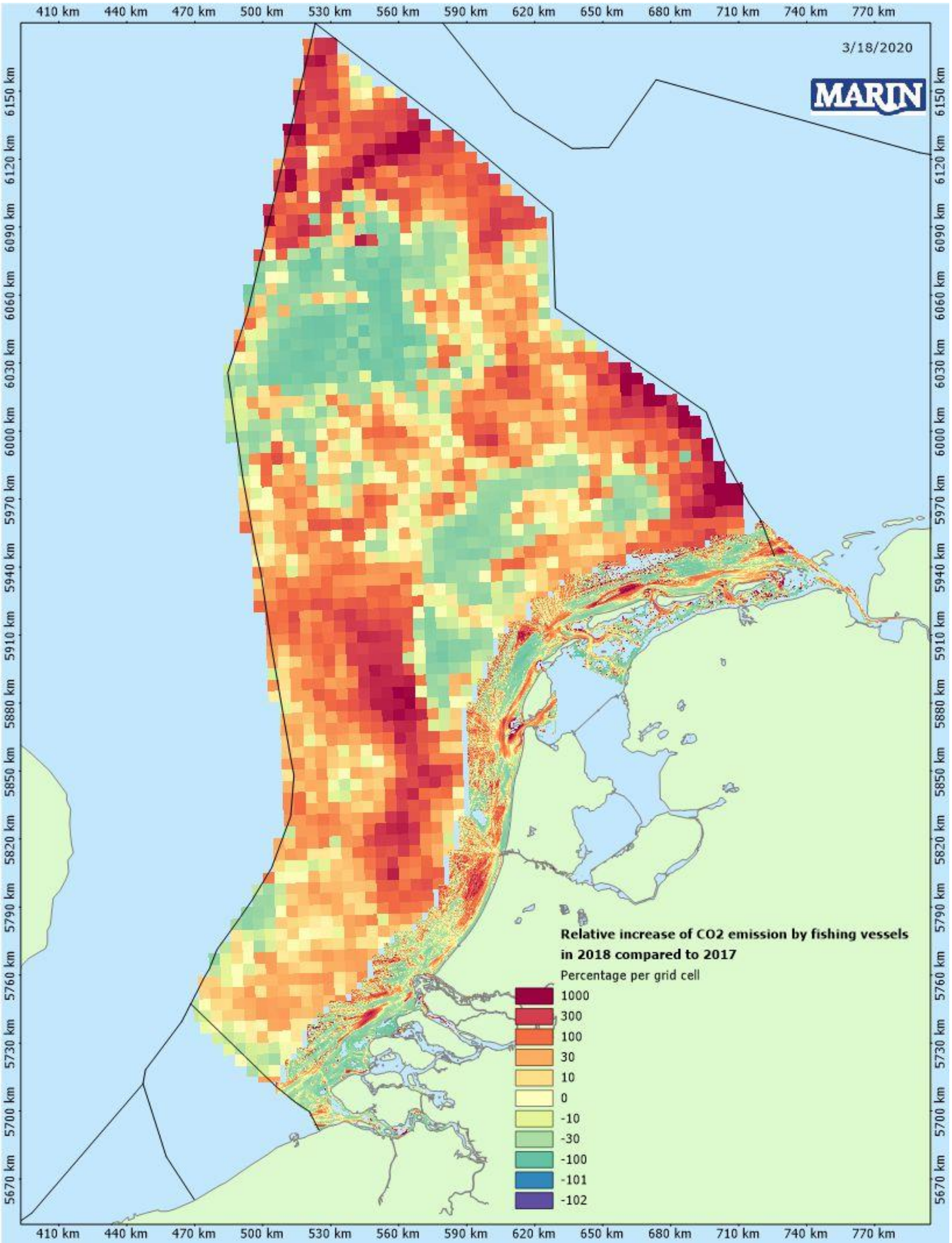

Figure 7-3 Relative change in CO2 emission from 2017 to 2018 observed in the NCS, fishing vessels including trawlers.

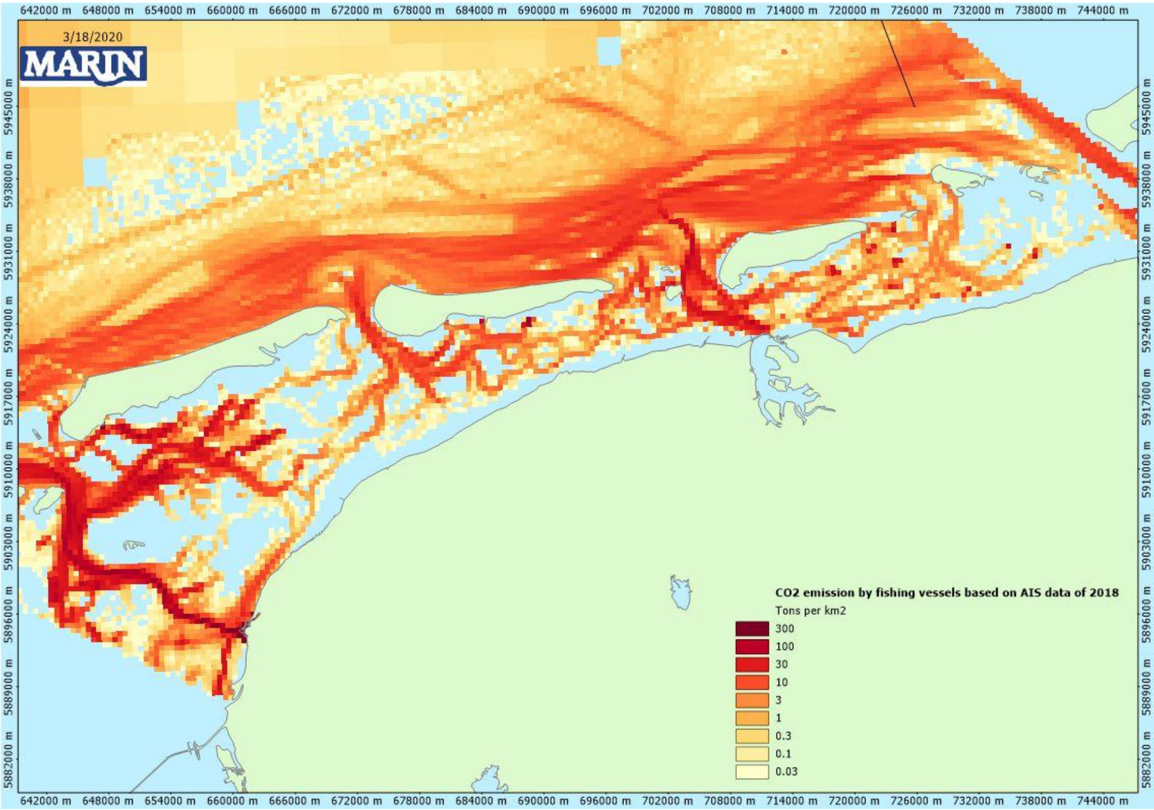

Figure 7-4 **CO_2 emission observed in the Dutch Wadden Sea, fishing vessels including trawlers, based on AIS data of 2018**

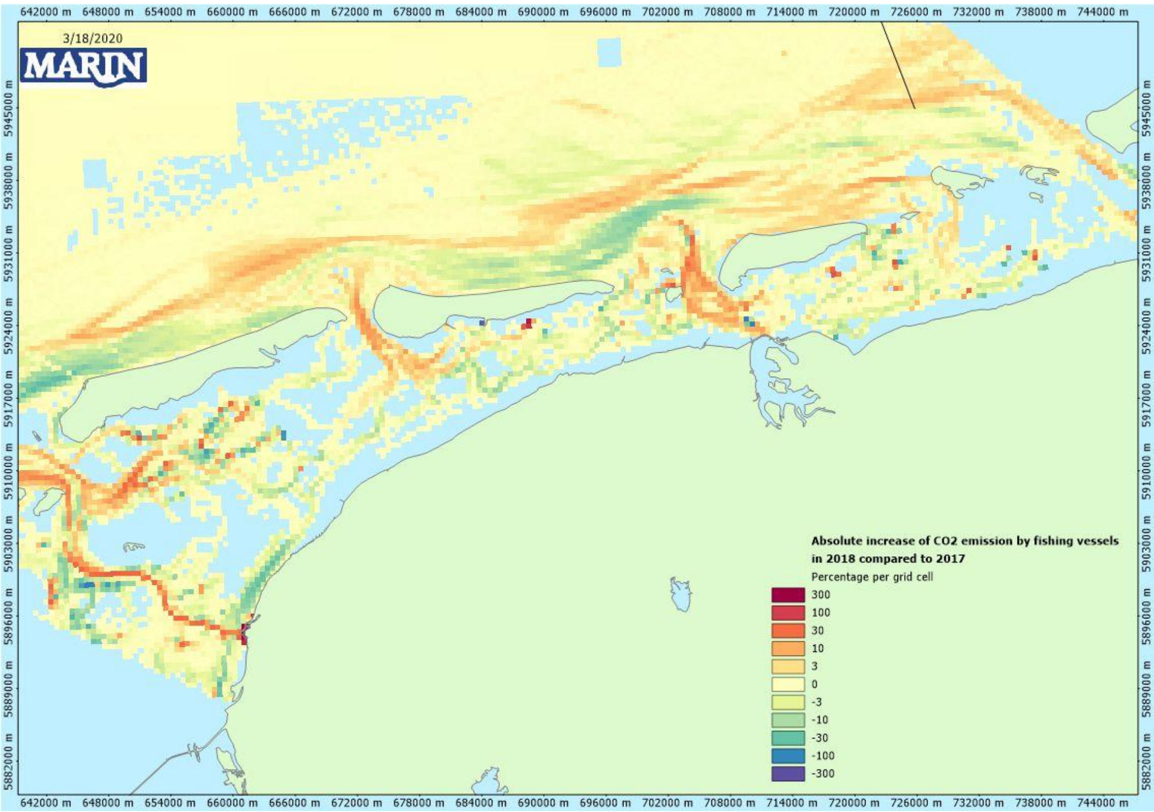

Figure 7-5 **Absolute change in CO2 emission from 2017 to 2018 in the Dutch Wadden Sea, fishing vessels including trawlers.**

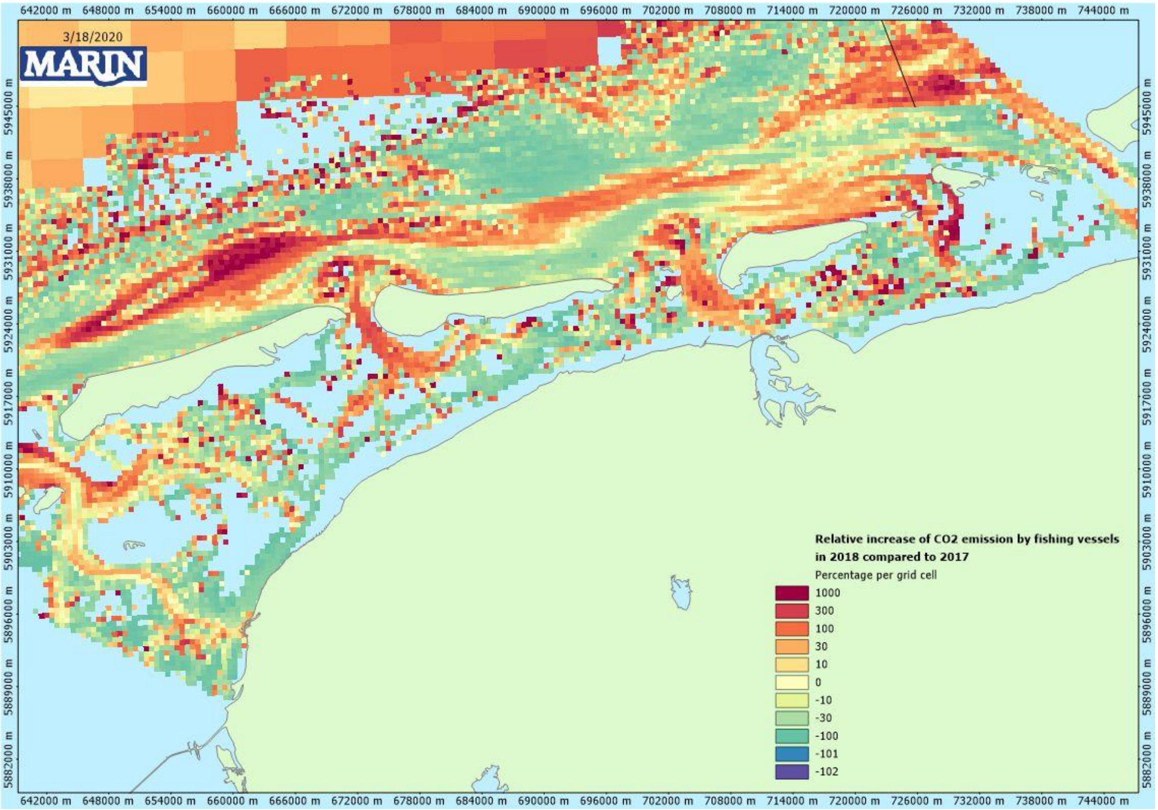

Figure 7-6 Relative change in CO_2 emission from 2017 to 2018 in the Dutch Wadden Sea, fishing vessels including trawlers.

8 SUMMARY AND CONCLUSIONS

- **Deliveries**

  The main delivery of this study is a set of databases containing gridded emissions of seagoing ships, including fishing vessels, both 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**

  In 2017 the sum of periods missing which are larger than 10 minutes was approximately 1 day. To compensate for the missing period, the results are multiplied with a small correction factor: 365/364. In 2018 there is no missing period longer than 10 minutes, so the results of that year are not compensated.

- **Activity data**

  Port areas
  In comparison with the activities observed in 2017 there is a clear increase of not moving or berthed ships, especially in the ports of Ems, Rotterdam and Amsterdam. This increase can also be seen in the average number of ships per day. For moving ships the increase of activities is much smaller or about the same. The annual reports of the port of Rotterdam and Amsterdam mention container ships in relation to the increase of transhipment. This is also derived from the AIS data.

  NCP
  No distinctive differences are observed for moving ships in the NCP. For ships at anchor there is an average increase for both hours and GT.nm of about 17%.

- **Emission results**

  Port areas
  Regarding the total emission for all port areas there is a clear increase of emissions between 2017 and 2018, especially for berthed ships (54% on average). This is in line with the a grow of activities in these ports. For sailing ships there is an increase around 10% on average.

  For the emissions of CO_2 there is an overall increase around 27%, mainly due to the increase of emissions in the port of Ems, Rotterdam and Amsterdam.

  NCP
  The increase of emissions of not moving ships is about 15% on average. The most substances show an increase, except for SO_2. There is slight decrease of emissions of sailing ships, except for the substance methane and CO.

  The average number of ships decreased slightly for moving ships, and increased for not moving ships. Overall, the total average number of ships on the North Sea is of the same order of magnitude.

- **Emission results fishery**

Port areas
For all ports together a clear increase of CO_2 emissions for berthed ships, around 14 percent. The contribution of CO_2 emissions by fishing vessels is largest in Harlingen, WesternScheldt and Amsterdam. In these ports there has been a clear increase of CO_2 emissions for berthed ships compared to 2017.

The emissions for sailing ships in ports is approximately the same.

NCP
The average increase of CO_2 emissions for moving and berthed fishing vessels is around 20%.

REFERENCES

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

[2] M.C. ter Brake & J. Hulskotte
Sea Shipping emissions 2016: Netherlands Continental Shelf and Port areas
MARIN, no: 29555-1-MSCN-rev.2, June 10, 2017

[3] ir. J. Hulskotte & dr. M.C. ter Brake
Revised calculation of emissions of fisheries on the Netherlands territory
TNO R10784, 29 June 2017

[4] D.R. Schouten & T.W.F. Hasselaar
Ship emission model validation with noon reports
MARIN, no: 30799-1-TM, 24 August 2018

[5] M.C. ter Brake, K.F. Kauffman, J. Hulskotte
Sea Shipping emissions 2017: Netherlands Continental Shelf, 12 Mile Zone and Port areas
MARIN, no: 31270-1-MSCN-rev.1, 6 May 2020

[6] Websites:

https://www.portofrotterdam.com/nl/havenbedrijf/over-het-havenbedrijf/financien/jaarverslagen

https://www.portofamsterdam.com/nl/nieuwsbericht/jaarverslag-2017-omzetgroei-2017-bij-amsterdamse-haven

https://jaarverslag2018.portofamsterdam.com/

https://www.portofantwerp.com/nl/publications/jaarverslagen

https://www.portofantwerp.com/nl/publications/statistieken

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 using ship characteristics provided by IHS Maritime World Register of Ships to The Port of Rotterdam. 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 0.

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:

$$fMCR = CRScor * (1\text{-Sea margin}) = ([(V_{actual}/V_{design})^n + c] / (1+c)) * (1\text{-Sea margin})$$

Following values are used in calculations that are reported:
Sea margin = 15%
n = 3.2 (value was 3.0 in previous reports)
c = 0.1 (value was 0.2 in previous reports)

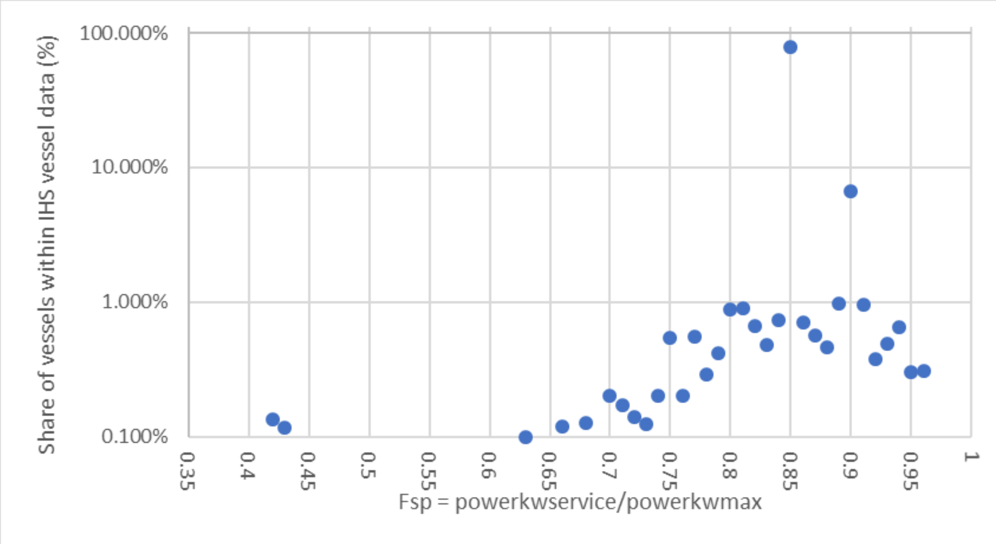

Figure A- 1 Statistics of the Sea-margin

Figure A-1 shows that of the majority of this vessels (about 80%) the power of reaching the service speed is exact 85% of the maximum rated power (Sea Margin = 15%) and for about 7% of the vessels the power of reaching the service speed is exact 90% of the maximum rated power (Sea margin = 10%). These data justify the application of 15% Sea margin within Formula 2.

Using data of sea trials MARIN (D.R. Schouten & T.W.F. Hasselaar [4]) has advised a value of 3.2 for n in Formula 2. Concerning the choice of a proper value of c no clear data were found in the literature. However it is obvious that the value of zero (used in many studies) will deliver far too low emission data in the low speed range. I a service letter concerning “low load operation” MAN diesel (Jensen and Jacobsen, 2009) show fuel usage of just below 20% of maximum usage around 55% of the service speed. The result of the parameters chosen in formula 2 confirm this number for the fuel usage around 55% of the service speed.

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-2 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.

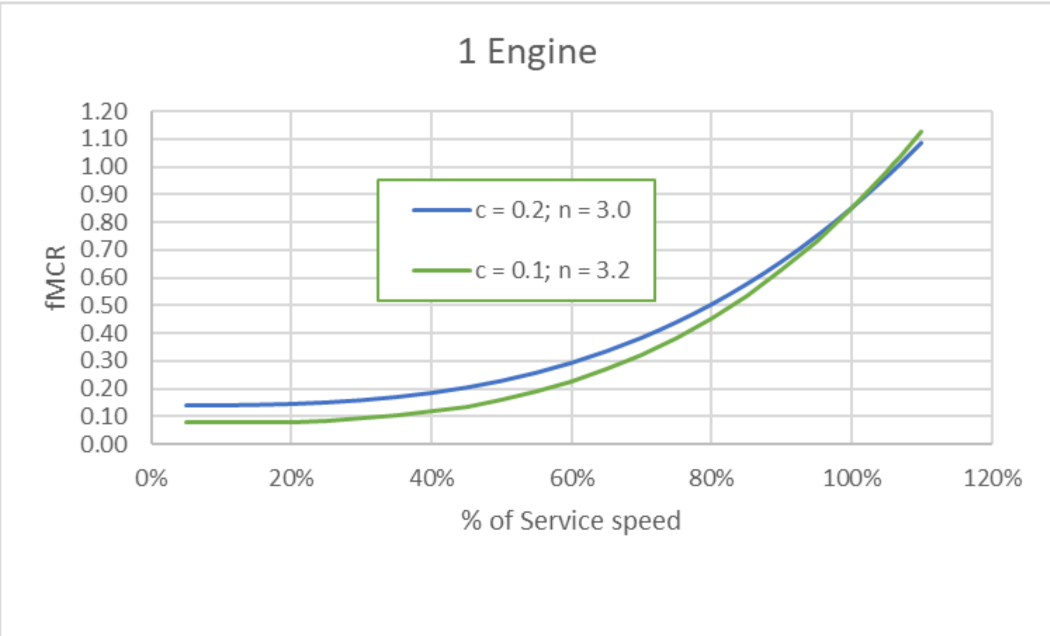

Figure A- 2 The relationship between service speed and fMCR at ships with one single propulsion engine used in emission calculations

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	76,135	445,834	5.9	735%
2	40,709	139,118	3.4	22.9%
3	1,866	10,100	5.4	1.7%
4	1,256	8,211	6.5	1.4%
5	56	265	4.7	0.04%
6	84	3,099	36.9	0.5%
8	3	149	49.8	0.02%
	120,109	606,777	5.1	100.0%

As a data source for daily fuel usage the ship characteristic database-item FUEL_CONSUMPTION of the LLI database was analysed. Daily fuel consumption is given for only about 10.000 ships. 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.

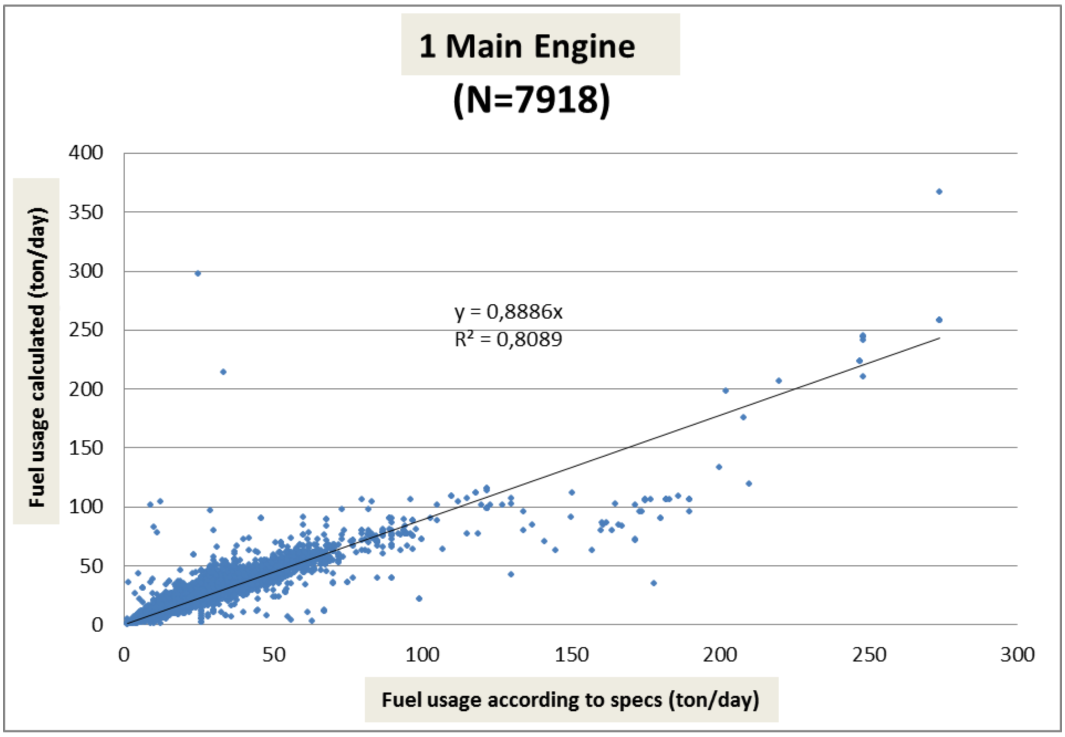

Figure A- 3 Calculated daily fuel usage of one engine ships compared with specifications

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.

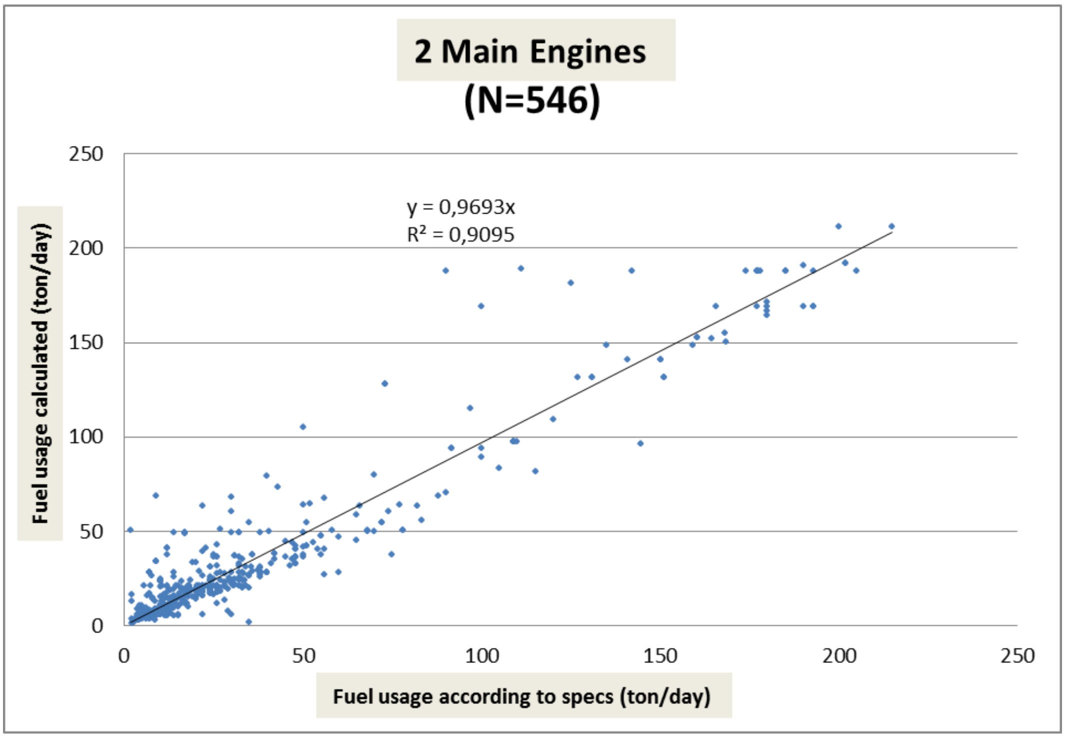

Figure A- 4 Calculated daily fuel usage of two engine ships compared with specifications

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.

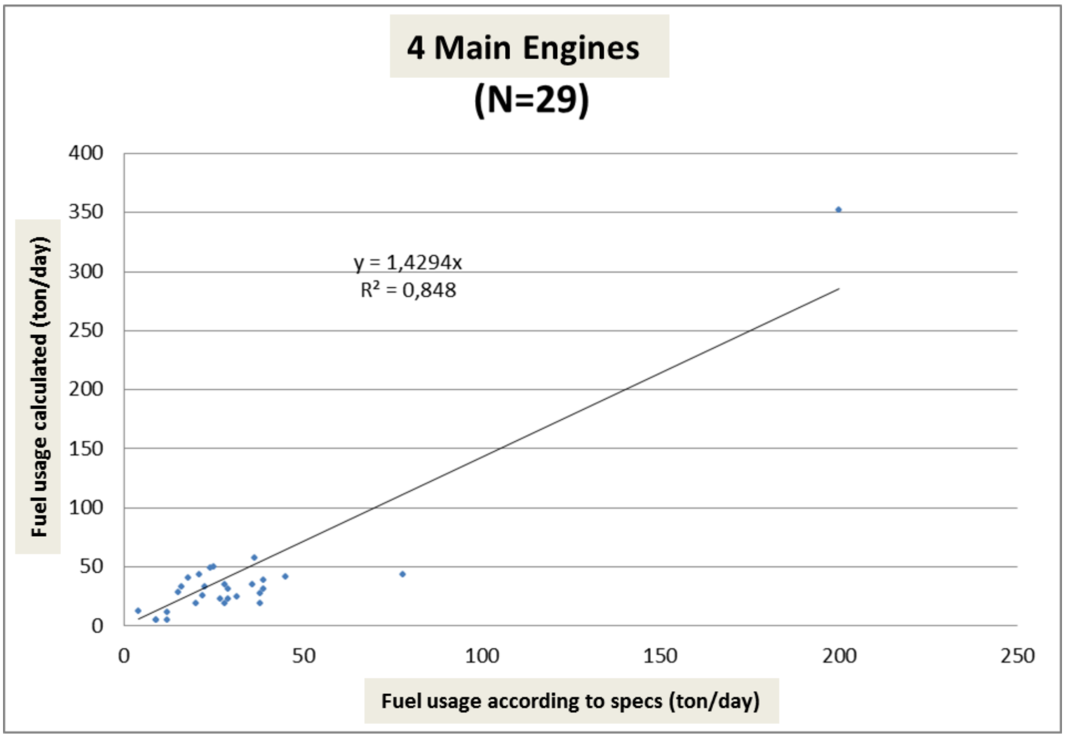

Figure A- 5 Calculated daily fuel usage of four engine ships compared with specifications

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).

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 in the 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).
Linear relations exist between SFOC and SO2 and CO2 depending on fuel quality. SFOC values as such are not used in emission calculations.

Effect of sulphur in calculation of PM-emission factors
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].

Partial implementation of the SECA according to the MARPOL Annex VI in 2016 has been assumed. Combined surveillance results of EU competent authorities are shared on a website of EMSA. The results are presented in Table A-3.

Table A- 3 Percentage of fuel samples from ships oils services systems with a sulphur content beyond legal limits

Region	2015	2016	2017	2018	2019
North sea regions	5.34	6.1	7.23	5.72	3.25
Baltic sea	2	3.8	3.46	3.1	2.13
Calculated average S% North sea regions	0.15	0.15	0.17	0.15	0.13

Source: https://portal.emsa.europa.eu/web/thetis-eu/compliance

The calculated average S% in North sea regions is calculated by assuming 0.1 %S for compliant fuel samples and 1% S for non-compliant fuel samples. This results in an estimated sulphur percentage of 0.15% for all areas. It can be concluded that compliance of sulphur legislation is very high since 2015. Surveillance by competent authorities seems to be important as numbers of non-compliance show considerable fluctuation over the years and structural differences between areas.

A sulphur% of 0.15% of HFO and MDO was assumed in all areas in 2018 (see table A-3). According to [12] the contribution of PM from sulphur was calculated as 8% of SO2 (calculated from S%): 0.08 * 0.15 * 20 = 0.24 g/kg fuel. For instance having a SFOC value of 210 g/kWh results in PM from sulphur alone in 210/1000 * 0.24 = 0.067 g/kWh. The PM emission factors in the tables below (table A3 – A10) are the result of the addition part of PM from sulphur and the part produced by the engines.

Table A- 4 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[6]	PM-HFO Other[7]	SO_2 NCP	SO_2 Other	VOC	CO	CO_2	SFOC
1900 – 1973	16	0,45	0,45	0.63	0.63	0.6	0.75	666	210
1974 – 1979	18	0,45	0,45	0.60	0.60	0.6	0.75	635	200
1980 – 1984	19	0,45	0,45	0.57	0.57	0.6	0.75	603	190
1985 – 1989	20	0,44	0,44	0.54	0.54	0.6	0.63	571	180
1990 – 1994	18	0,44	0,44	0.53	0.53	0.5	0.5	555	175
1995 – 1999	15	0,34	0,34	0.51	0.51	0.4	0.5	539	170
2000 – 2010	~rpm[8]	0,34	0,34	0.50	0.50	0.3	0.5	533	168
2011 – 2018		0,24	0,24	0.50	0.50	0.3	0.5	524	165

Table A- 5 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	0,35	0,35	0.63	0.63	0.6	0.75	666	210
1974 - 1979	18	0,35	0,35	0.60	0.60	0.6	0.75	635	200
1980 - 1984	19	0,35	0,35	0.57	0.57	0.6	0.75	603	190
1985 – 1989	20	0,34	0,34	0.54	0.54	0.6	0.63	571	180
1990 – 1994	18	0,34	0,34	0.53	0.53	0.5	0.5	555	175
1995 – 1999	15	0,24	0,24	0.51	0.51	0.4	0.5	539	170
2000 – 2010	~rpm[1]	0,24	0,24	0.50	0.50	0.3	0.5	533	168
2011 – 2018		0,24	0,24	0.50	0.50	0.3	0.5	523	165

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

Table A- 6 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	0,65	0,65	0.68	0.68	0.6	0.75	714	225
1974 – 1979	14	0,65	0,65	0.65	0.65	0.6	0.75	682	215
1980 – 1984	15	0,65	0,65	0.62	0.62	0.6	0.75	651	205
1985 – 1989	16	0,65	0,65	0.59	0.59	0.6	0.63	619	195
1990 – 1994	14	0,65	0,65	0.57	0.57	0.5	0.5	603	190
1995 – 1999	11	0,54	0,54	0.56	0.56	0.4	0.5	587	185
2000 – 2010	~rpm[1] 9[2]	0,54	0,54	0.55	0.55	0.3	0.5	581	183
2011 - 2018	~rpm 7[2]	0,54	0,54	0.54	0.54	0.3	0.5	571	180

[2] applied on auxiliary engines only

Table A- 7 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	0,35	0,35	0.68	0.68	0.6	0.75	714	225
1974 - 1979	14	0,35	0,35	0.65	0.65	0.6	0.75	682	215
1980 - 1984	15	0,35	0,35	0.62	0.62	0.6	0.75	650	205
1985 - 1989	16	0,35	0,35	0.59	0.59	0.6	0.63	619	195
1990 - 1994	14	0,30	0,30	0.57	0.57	0.5	0.5	603	190
1995 - 1999	11	0,24	0,24	0.56	0.56	0.4	0.5	587	185
2000 - 2010	~rpm[1] 9[2]	0,24	0,24	0.55	0.55	0.3	0.5	581	183
2011 - 2018	~rpm[1] 7[2]	0,24	0,24	0.54	0.54	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- 8 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 – 2018 (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 factors for Tier I engines (0.87) and Tier II engines (0.93) are based on IAPP-certificate engine data obtained in a project for the Port of London Authority [24].

Table A- 9 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	0.09	0.09	0.93	0.93	0.1	0.32	984	310

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

Table A- 10 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	0.323	0.323	0.92	0.92		0.1	0.15	971	306
MDO	2.0	0.320	0.320	0.87	0.87		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- 11 Emission factors and specific fuel oil consumption (SFOC) of engines operated on LNG, (g/kWh)

Engine type	NO_X	PM	SO_2	CH4	CO	CO_2	SFOC
MS-DF	2.0	0.02	0.003	6.90	1.9	450	162
SP-GDI	12.5	0.02	0.003	0.15	0.2	475	171

The methane (CH4) emission factor of MS-DF (medium speed dual fuel engines) was adapted according to [22]. Other emission factors were based on preliminary estimations by TNO.

A1.5 Fuel allocation

Fuel allocation has been based on IHS-data primarily and secondly some assumptions have been applied. Table A-11 shows allocation of fuel to main and auxiliary engines depending on the indication of the IHS vessel data. Sulphur legislation introduced in 2015 may have resulted in the usage of less HFO than indicated in table A-11. As a consequence PM emission factors are possibly little to high. Sulphur emissions are calculated according to the best estimate prevalent sulphur content of fuels (table A-3).

Table A- 12 Fuel allocation to main engines (Fuel ME) and auxiliary engines dependent on IHS fuel indication

Enginetype	Number of vessels	Average ME (kW)	IHS: FuelType1First	IHS: FuelType2Second	Fuel_ME_	Fuel_AE
Slow-speed engines	29619	13515	Distillate Fuel	Residual Fuel	HFO	MDO
	3738	1348	Distillate Fuel	Not Applicable	MDO	MDO
	354	3176	Residual Fuel	Not Applicable	HFO	MDO
	192	28170	LNG	Distillate Fuel	LNG	MDO
	53	955	Distillate Fuel	Yes, But Type Not Known	MDO	MDO
	15	5432	Distillate Fuel	Unknown	MDO	MDO
	9	14868	LNG	Not Applicable	LNG	MDO
	9	9498	Methanol	Distillate Fuel	MDO	MDO
	4	42766	Distillate Fuel	LNG	LNG	MDO
	3	1100	Distillate Fuel	Distillate Fuel	MDO	MDO
	3	2280	Residual Fuel	Unknown	HFO	MDO
	2	1618	Residual Fuel	Distillate Fuel	HFO	MDO
	2	9350	Gas Boil Off	Distillate Fuel	LNG	MDO
	1	2795	Yes, But Type Not Known	Residual Fuel	HFO	MDO
	1	970	Residual Fuel	Yes, But Type Not Known	HFO	MDO

Medium-speed engines	16917	2700	Distillate Fuel	Not Applicable	MDO	MDO
	8087	7404	Distillate Fuel	Residual Fuel	HFO	MDO
	668	4034	Residual Fuel	Not Applicable	HFO	MDO
	312	27182	LNG	Distillate Fuel	LNG	MDO
	187	1292	Distillate Fuel	Yes, But Type Not Known	MDO	MDO
	39	3378	Distillate Fuel	Unknown	MDO	MDO
	37	5526	LNG	Not Applicable	LNG	MDO
	35	2981	Distillate Fuel	Distillate Fuel	MDO	MDO
	7	1964	Coal	Not Applicable	HFO	MDO
	6	9731	Residual Fuel	Yes, But Type Not Known	HFO	MDO
	5	6472	Yes, But Type Not Known	Residual Fuel	HFO	MDO
	3	6557	Residual Fuel	Distillate Fuel	HFO	MDO
	2	3430	Residual Fuel	Unknown	HFO	MDO
	1	24000	Methanol	Distillate Fuel	MDO	MDO
Gasturbines	23	59326	Distillate Fuel	Residual Fuel	HFO	MDO
	9	25381	Distillate Fuel	Not Applicable	MDO	MDO
	2	18389	Residual Fuel	Not Applicable	HFO	MDO
	1	44000	LNG	Distillate Fuel	LNG	MDO
	1	13000	Distillate Fuel	Unknown	MDO	MDO
Steamturbines	289	25026	Distillate Fuel	Residual Fuel	HFO	MDO
	51	29469	Residual Fuel	Not Applicable	HFO	MDO
	27	27545	Gas Boil Off	Distillate Fuel	LNG	MDO
	8	19100	LNG	Distillate Fuel	LNG	MDO
	8	57299	Nuclear	Not Applicable	none	MDO
	3	47653	Nuclear	Distillate Fuel	none	MDO
	1	2589	Yes, But Type Not Known	Not Applicable	HFO	MDO

Because there are no specific emission factors for methanol available methanol is treated as marine diesel oil in the calculations.

In cases where no specific fuel type was indicated in the IHS-data it was assumed that HFO is applied in main engines in case main engine power is more than 3000 kW. In case main engine power is less than 3000 kW MDO was assumed when [Power] - 0.8*[RPM] was lower or equal to 1000 and HFO in case same formula results in a number more than 1000.

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-12.

Table A- 13 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
SP	LNG	MDO	MDO	MDO
SP	LNG	HFO	HFO	MDO
ST	LNG	MDO	MDO	MDO
ST	LNG	HFO	HFO	MDO

A1.6 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- 14 Correction factors for reciprocating diesel engines

Power % of MCR	CO_2, SO_2	CO_2, SO_2	NOx		PM-HFO/ PM-MDO	VOC, CH4	CO
	SP	MS	Tier 0 or I	Tier II			
10	1.2	1.21	1.34	1,74	1.63	4.46	5.22
15	1.15	1.18	1.17	1,52	1.32	2.74	3.51
20	1.1	1.15	1.1	1,36	1.19	2.02	2.66
25	1.07	1.13	1.06	1,3	1.12	1.65	2.14
30	1.06	1.11	1.04	1,32	1.08	1.42	1.8
35	1.05	1.09	1.03	1,34	1.05	1.27	1.56
40	1.045	1.07	1.02	1,34	1.03	1.16	1.38
45	1.035	1.05	1.01	1,32	1.01	1.09	1.23
50	1.03	1.04	1.00	1,3	1.01	1.03	1.12
55	1.025	1.03	1.00	1,27	1.00	1.00	1.06
60	1.015	1.02	0.99	1,23	1.00	0.98	1.00
65	1.01	1.01	0.99	1,13	0.99	0.95	0.94
70	1.00	1.01	0.98	1,01	0.99	0.92	0.88
75	1.00	1.00	0.98	0,95	0.98	0.89	0.82
80	1.01	1.00	0.97	0,95	0.98	0.87	0.76
85	1.02	1.00	0.97	0,95	0.97	0.84	0.7
90	1.03	1.01	0.97	0,95	0.97	0.85	0.7
95	1.04	1.02	0.97	0,95	0.97	0.86	0.7
100	1.05	1.02	0.97	0,95	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.

A differentiation in NOx correction factors between Tier 0 or I versus Tier II engines was considered to be necessary because of a publication [23]. The Tier II correction factors were estimated by TNO. As a consequence NOx emissions of vessels with Tier II engines are in the same range of higher than Tier I engine vessels. This is caused by the circumstance that vessels use most energy in lower power ranges between 30 and 50 percent of MCR and even lower power ranges in some harbour areas. The correction factors can be replaced when sufficient measurement data become available.

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- 15 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- 16 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- 17 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- 18 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- 19 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- 20 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	3,25
1974 – 1979	65	1.5	2.8	3,5
1980 – 1984	73	1.6	2.9	3,75
1985 – 1989	82	1.8	3.1	3,25
1990 – 1994	74	1.3	2.6	2,75
1995 – 1999	59	0.8	2.2	2,75
2000 – 2010	50	0.8	1.6	2,75
2011 – 2016	43	0.8	1.6	2,75

At berth usage of medium speed engines was assumed.

Table A- 21 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- 22 Emission factors of all engines and apparatus, (g/kg fuel)

Fuel	SO_2	CO_2
MGO/ULMF	3	3173

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 0) 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- 23 Emission factors and specific fuel consumption applied on fishing vessels, (g/kWh)

Engine year of build From – To	VOC	NOx	CO	PM	SO2	SFOC
1959-1973	1.2	10.8	1.1	0.6	0.47	235
1975-1979	0.8	10.6	0.9	0.6	0.46	230
1980-1984	0.7	10.4	0.8	0.6	0.45	225
1985-1989	0.6	10.1	0.65	0.5	0.44	220
1990-1994	0.5	10.1	0.55	0.4	0.44	220
1995-2001	0.4	9.4	0.45	0.3	0.41	205
2002-2007	0.3	9.2	0.4	0.3	0.4	200
2008-2014	0.2	7	0.35	0.2	0.4	200
2015-2018	0.2	7	0.3	0.2	0.39	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 fuel marine diesel with a sulphur content of 0.1% was assumed.

REFERENCES OF APPENDIX A

[1] J. Hulskotte (TMO-MEP), E. Bolt (RWS-AVV), D. Broekhuizen (RWS-AVV)
EMS-protocol Emissies door verbrandingsmotoren van varende en manoeuvrerende zeeschepen op het Nederlands grondgebied
Versie 1, 22 november 2003

[2] J. Hulskotte (TMO-MEP), E. Bolt (RWS-AVV), D. Broekhuizen (RWS-AVV)
EMS-protocol Verbrandingsemissies door stilliggende zeeschepen in havens
Versie 2, 22 november 2003

[3] Buhaug, Ø., Corbett, J. J., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, D. S., Lee, D., Lindstad, H., Mjelde, A., Pålsson, C., Wanquing, W., Winebrake, J. J., Yoshida, K.
Updated Study on Greenhouse Gas Emissions from Ships: Phase I Report, International Maritime Organization (IMO) London, UK, 1 September, 2008

[4] F. Chiffi, Schrooten E., De Vlieger I., EX-TREMIS - Exploring non road Transport Emissions in Europe – Final Report, IPTS - Institute for Prospective Technological Studies. DG-JRC, 2007

[5] H. Denier van der Gon, J. Hulskotte, Methodologies for estimating shipping emissions in the Netherlands; A documentation of currently used emission factors and related activity data, PBL report 500099012, ISSN: 1875-2322 (print) ISSN: 1875-2314 (on line), April 2010

[6] UK Civil Aviation Authority, ICAO Engine Emissions Databank, updated December 2010

[7] I. Grose and J. Flaherty, LNG Carrier Benchmarking, LNG15 2007, Shell Global Solutions International BV, 2007

[8] Hulskotte J.H.J, H.A.C. Denier van der Gon, Emissions From Seagoing Ships At Berth Derived From An On-Board Survey, Atmospheric Environment, Doi: 10.1016/j.atmosenv.2009.10.018, 2009

[9] Cooper D., Representative emission factors for use in “Quantification of emissions from ships associated with ship movements between port in the European Community” (ENV.C.1/ETU/2001/0090), 2002

[10] Jalkanen J.-P.,Johansson L., Kukkonen J., Brink A., Kalli J., Stipa T., Extension of an assessment model of ship traffic exhaust emissions for particulate matter and carbon monoxide, Atmos.Chem.Phys.,12,2641-2659, 2012

[11] MAN Diesel&Turbo, SFOC Optimisation Methods For MAN B&W Two-stroke IMO Tier II Engines, document 5510-0099-00ppr, Augustus 2012

[12] Hulskotte J.H.J., Voorstel voor aanpassing van $PM_{2,5}$ en PM_{10}-fracties van emissies van de zeescheepvaart, TNO-060-UT-2011-02190, 20 december 2011

[13] J.H.J.Hulskotte, E. Bolt, D. Broekhuizen, EMS-protocol Emissies door Verbrandingsmotoren van Zeeschepen op het Nederlands Continentaal Plat, versie 2, 22 November 2003

[14] J.H.J Hulskotte, B. Wester, A.M. Snijder, V. Matthias, International survey of fuel consumption of seagoing ships at berth, TNO 2013 R10472, 18 December 2013

[15] J.H.J., Hulskotte, V. Matthias, Survey of fuel consumption of seagoing tankers at berth in Rotterdam, TNO 2013 R11287, 27 August 2013

[16] Smith, T. W. P., Jalkanen, J. P., Anderson, B. A., Raucci, C., Traut, M., Ettinger, S., Nelissen, D., Lee, D. S., Ng, S., Agrawal, A., Winebrake, J. J., Hoen, M., Chesworth, S., Pandey, A., *Third IMO GHG Study 2014*; International Maritime Organization (IMO) London, UK, June 2014

[17] Johan Mellqvist, Vladimir Conde, Jörg Beecken and Johan Ekholm, Results from airborne Sulphur compliance monitoring in the central and border of the SECA, Chalmers University of Technology in commission of MiljØ- of FØdevarenministerie

[18] Hulskotte J.H.J, Brake ter M.C., Revised calculation of emissions of fisheries on the Netherlands territory, TNO report TNO 2017 R10784, 29 June 2017

[19] Mike Turenhout, Katell Hamon, Hans van Oostenbrugge, Arie Mol en Arie Klok Emissie Nederlandse Visserij, Indicatoren brandstofverbruik voor broeikasgasemissieberekening, Wageningen Economic Research, NOTA 2016-122, Wageningen November 2016

[20] D.R. Schouten & T.W.F. Hasselaar, Ship emission model validation with noon reports, MARIN, no: 30799-1-TM, 24 August 2018

[21] Jensen M.C., Jacobsen S.B., Service Letter SL09-511/MTS, MAN Diesel, May 2009

[22] Stenersen, D., Thonstadt O., HG and NO_x emissions from gas fuelled engines, Mapping, verification, reduction technologies, SINTEF Ocean AS Maritim, Report OC2017 F108, version 3.0, 13-06-2017

[23] Chih-Wen Cheng, Jian Hua & Daw-Shang Hwang (2018). Nitrogen oxide emission calculation for post-Panamax container ships by using engine operation power probability as weighting factor: A slow-steaming case, Journal of the Air & Waste Management Association, 68:6, 588-597, DOI: 10.1080/10962247.2017.1413440

[24] Tim Williamson, Jan Hulskotte, Richard German, Kirsten May, Port of London Emissions Inventory 2016, Customer Port of London Authority and Transport for London, 2017