BETTER SHIPS, BLUE OCEANS

Sea Shipping Emissions 2019: Netherlands Continental Shelf, 12-Mile Zone and Port Areas

Final Report

Report No.	:	33052-1-MO-rev.1
Date	:	9 March 2021
Version	:	1.0
		Final

Sea Shipping Emissions 2019: Netherlands Continental Shelf, 12-Mile Zone and Port Areas

Final Report

Ordered by : RIVM/Emissieregistratie
P.O. Box 1
3720 BA BILTHOVEN
The Netherlands

Gerapporteerd door : K.F. Kauffman, J. Hulskotte

Paraaf management :

Version	Date	Version description	Checked by
Rev. 0	11-02-2021	Draft	Y. Koldenhof / R. te Molder
Rev. 1	9-03-2021	Final	R. te Molder / J. Hulskotte

CONTENTS Page

TABLE OF TABLES

TABLE OF FIGURES

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 2019. 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 2019 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 2019.
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 2019 for the Dutch port areas and the Netherlands sea area and makes a comparison with 2018.
Chapter 7 contains the emissions results for 2019 for the fishing activities.
Chapter 8 presents conclusions and recommendations.

2 2019 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 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. In addition, we noticed that container cranes disturb the determination of the GPS position and therefore the AIS-message is not containing 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.

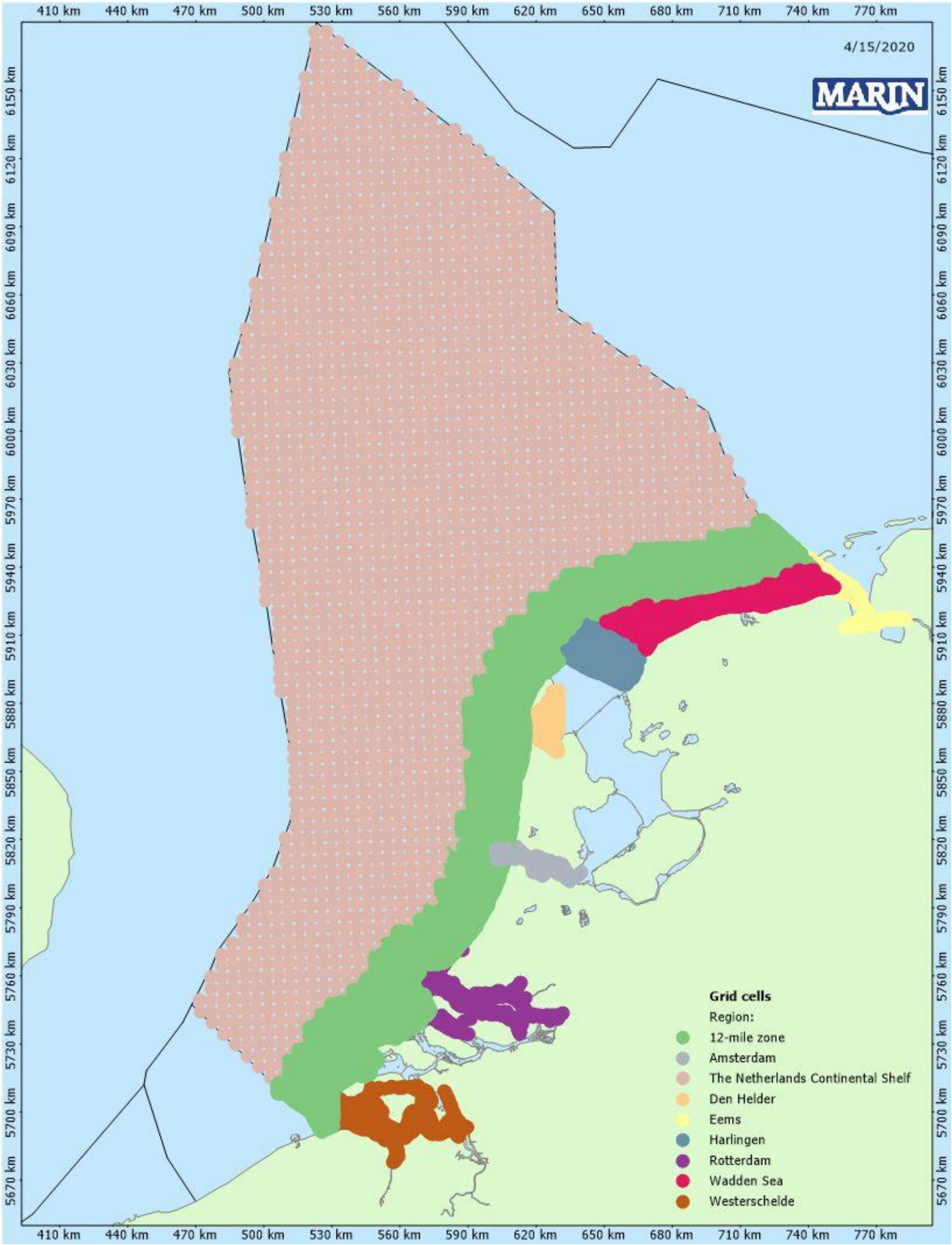

Figure 2-1 Grid points for The Netherlands Continental Shelf, 12-mile zone, The Wadden Sea and six port areas

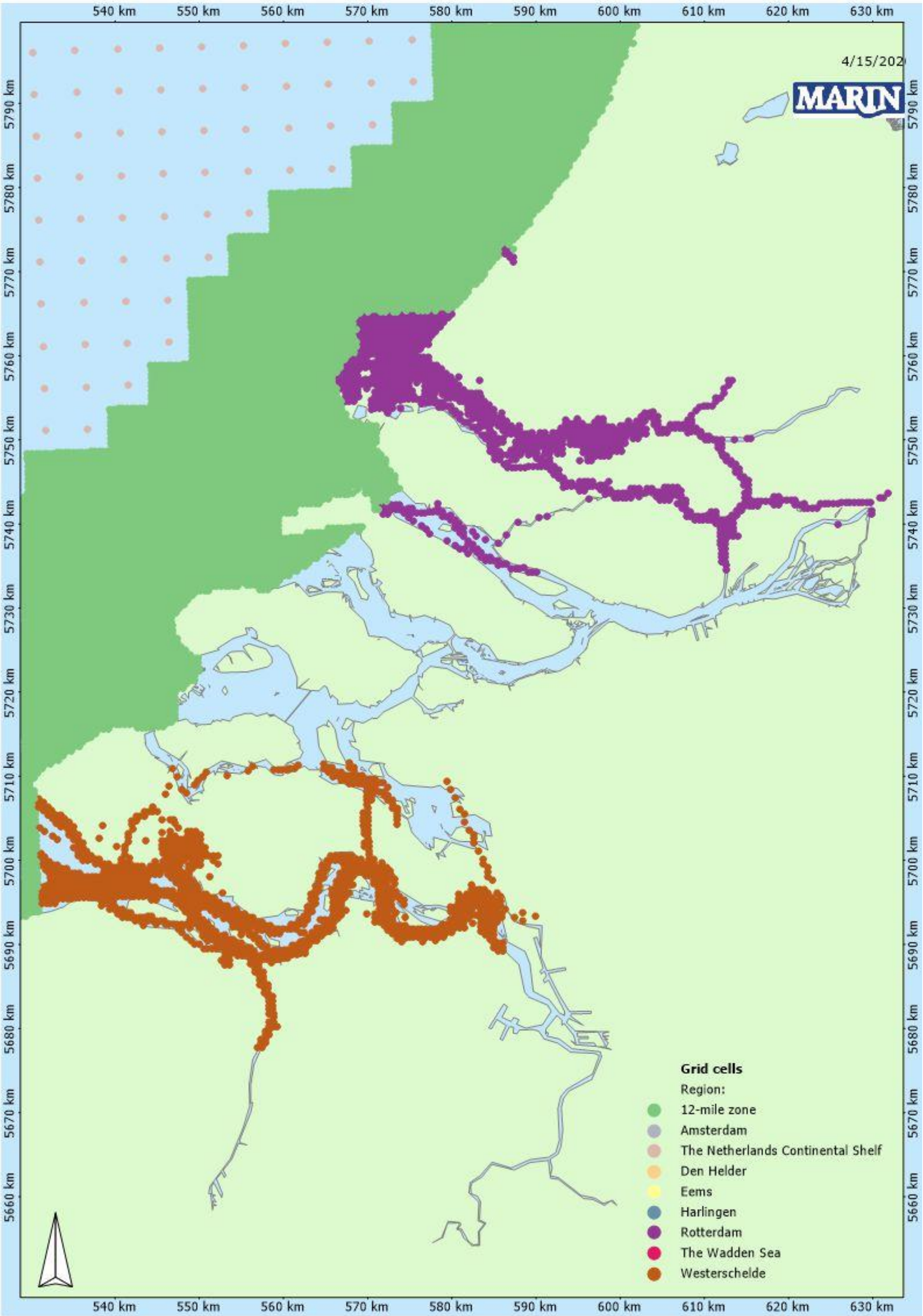

Figure 2-2 **Rotterdam and the Western Scheldt: The points indicate the centres of grid cells for which emissions are calculated**

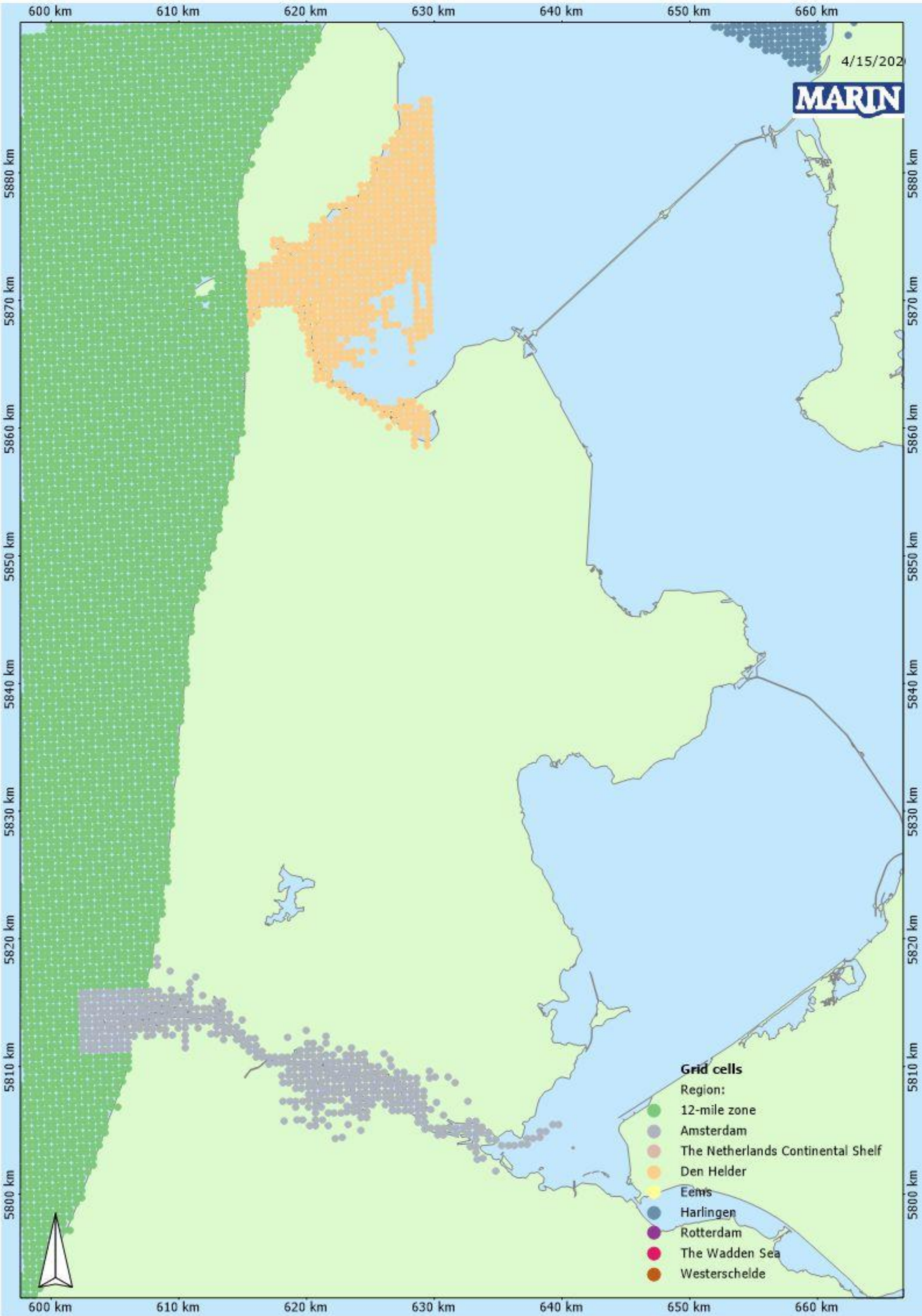

Figure 2-3 Amsterdam and Den Helder: The points indicate the centres of grid cells for which emissions are calculated

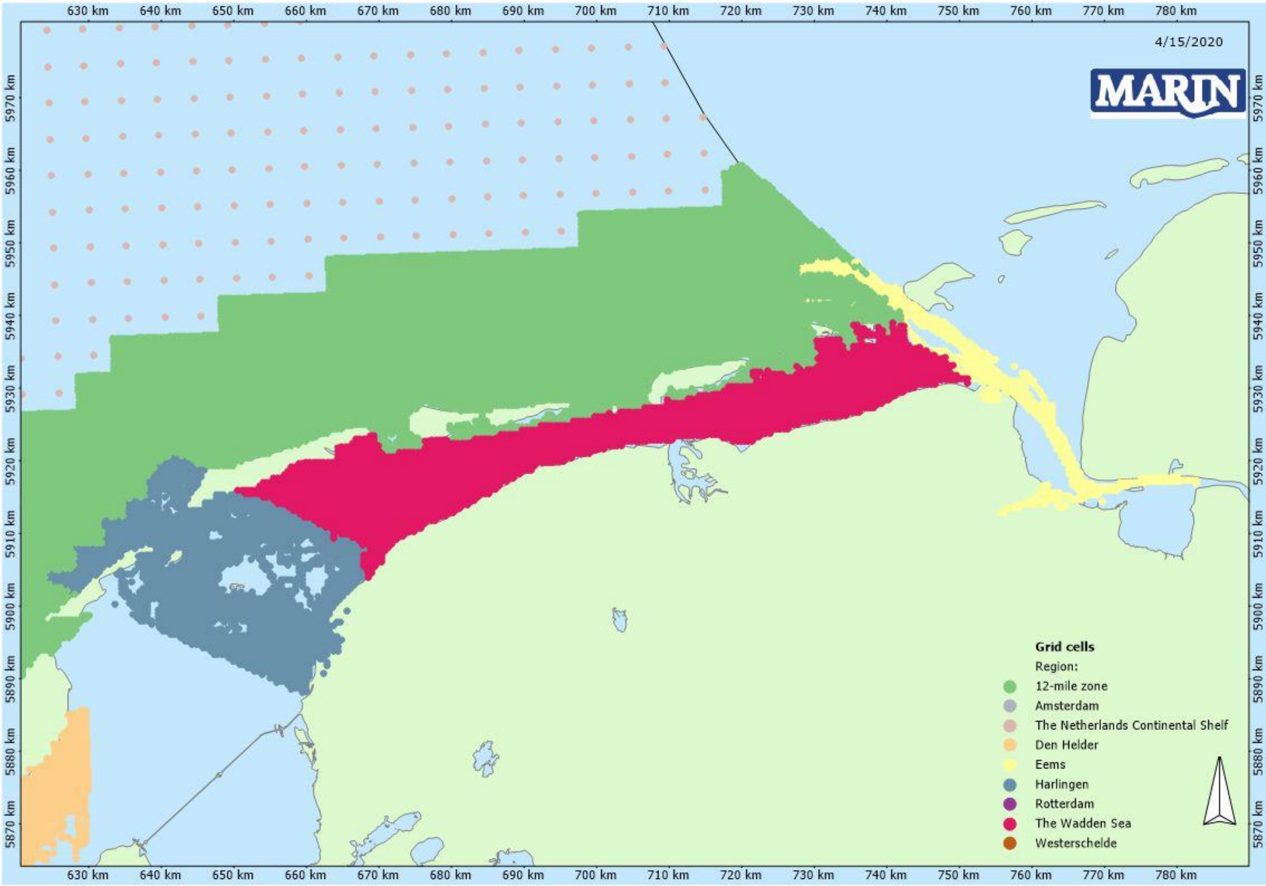

Figure 2-4 Harlingen, the Wadden Sea and Ems: The points indicate the centres of grid cells for which emissions are calculated

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. In the appendix, TNO provides more information about the current calculation method.

AIS data for 2019

In this study, AIS data of 2019 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 2018, 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 2019 comprised 37,970 valid MMSI numbers. Based on these MMSI-numbers, 13,238 commercial seagoing vessels could be identified (see Table 3-1). About 42% of all messages obtained, were sent by the 13,238 commercial vessels for which emission factors were calculated.

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

	2017		2018		2019	
Total individual valid mmsi	33,612		36,167		37,970	
mmsi with emission factors	12,952	39%	12,797	35%	13,238	35%
Total valid mmsi messages obtained	733,405,583		865,399,825		910,441,140	
Total valid mmsi messages with emission factors	328,970,302	45%	375,120,674	43%	386,801,288	42%

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 roughly that at maximum 250 commercial vessels could not be identified, representing about 2% of shipping emissions.

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

The sample frequency of the AIS runs is exactly 2 minutes. In case the gap between the signals 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 missing periods, which are larger than 10 minutes, is about 1 day. To compensate for this missing period the results are multiplied with 365/364.

4.2 Bad AIS coverage in certain areas

4.2.1 Base stations

In section 4.1, the number of files received from the Netherlands Coastguard was used to describe the completeness of the data. This does not 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.

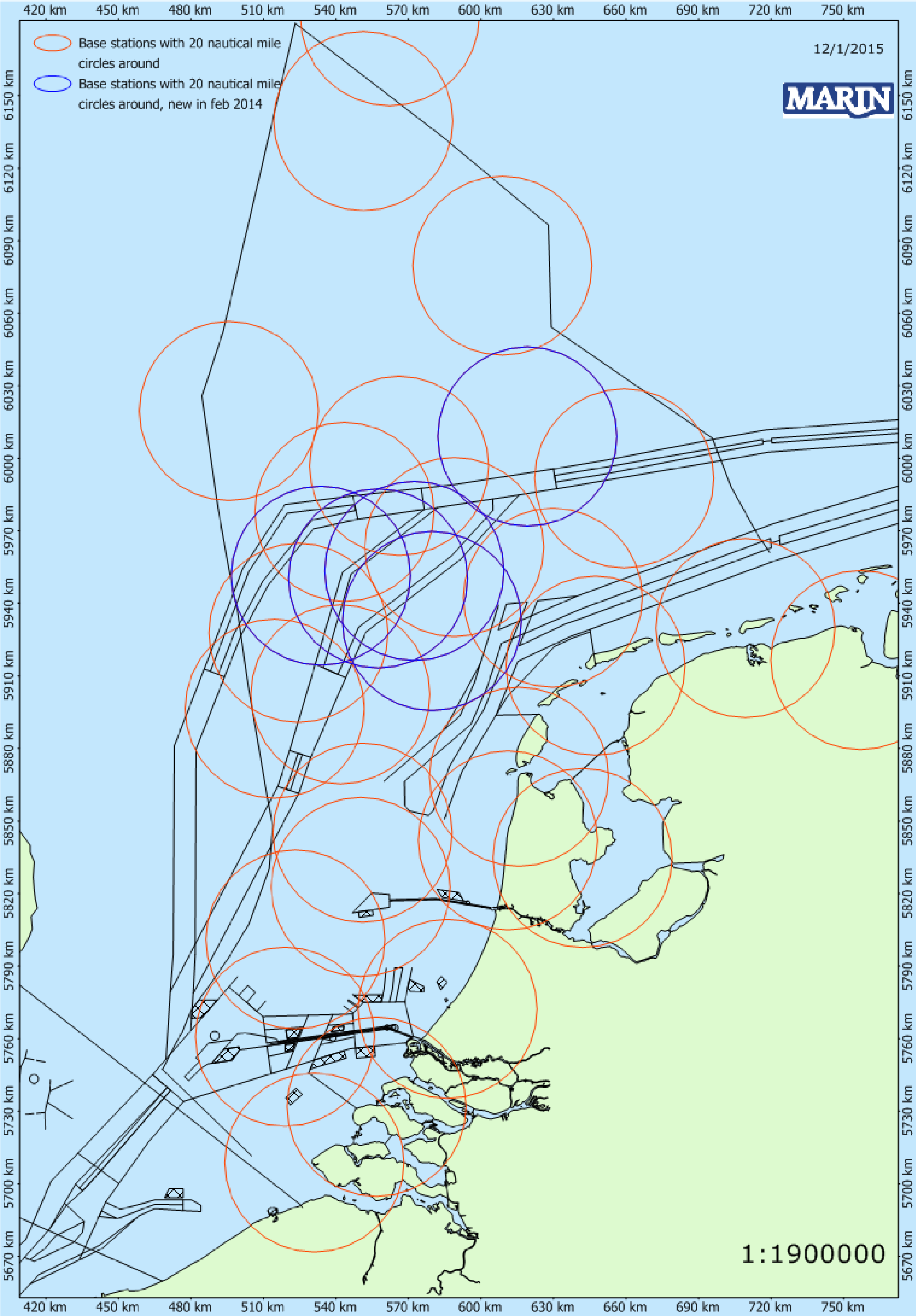

Figure 4-1 **AIS base stations in 2020 delivering data to the Netherlands Coastguard.**

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 were 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 2019. These months were chosen so that the data can be compared with last year. The overall coverage of AIS data of 2019 seems in most places of the same order of magnitude compared to the AIS coverage of 2018. However, fluctuations in coverage are expected due to the dependency on atmospheric conditions.

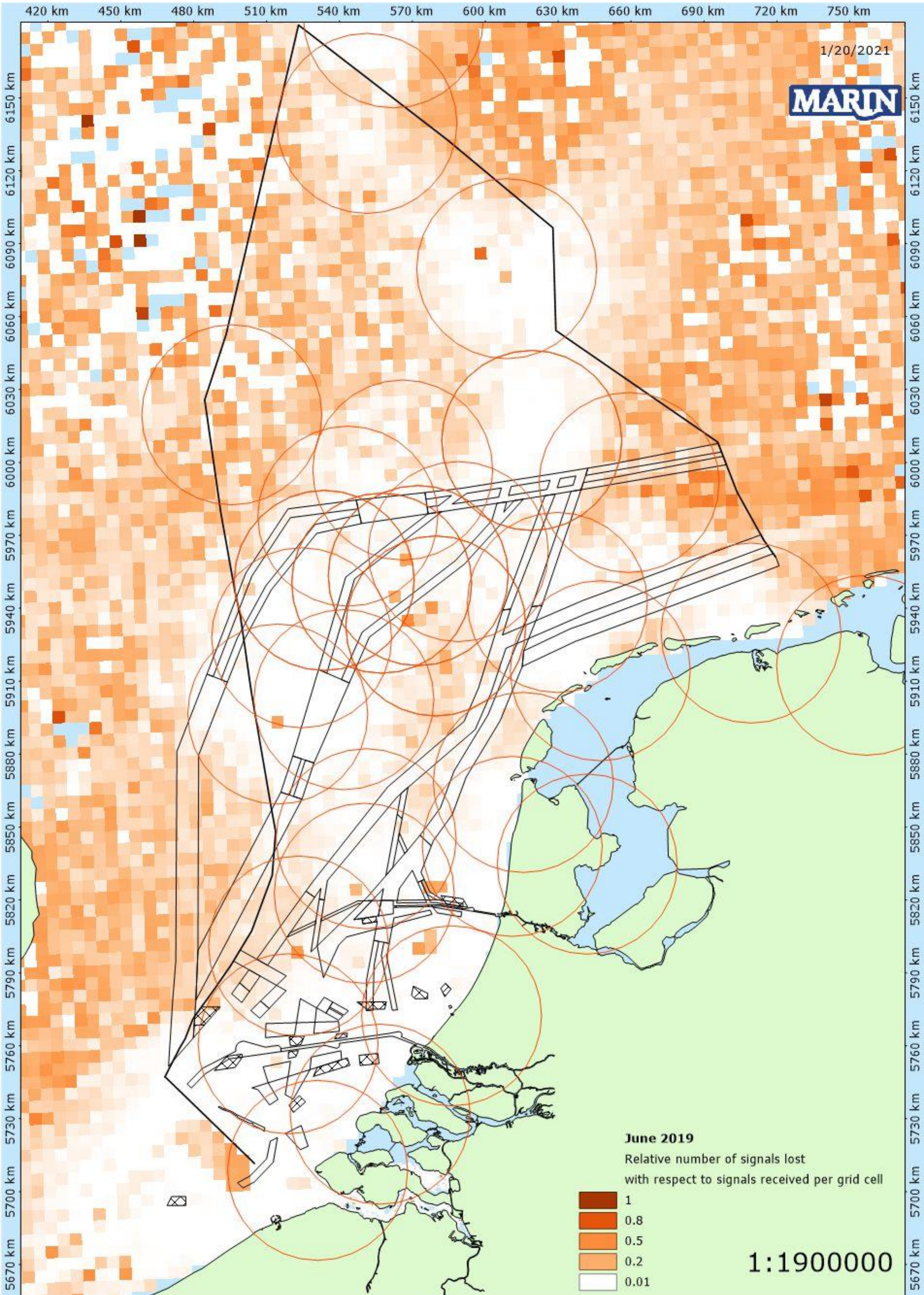

Figure 4-2 **June 2019, relative number of signals lost with respect to signals received per grid cell, circles mark the 20 nautical miles zones around the Dutch base stations**

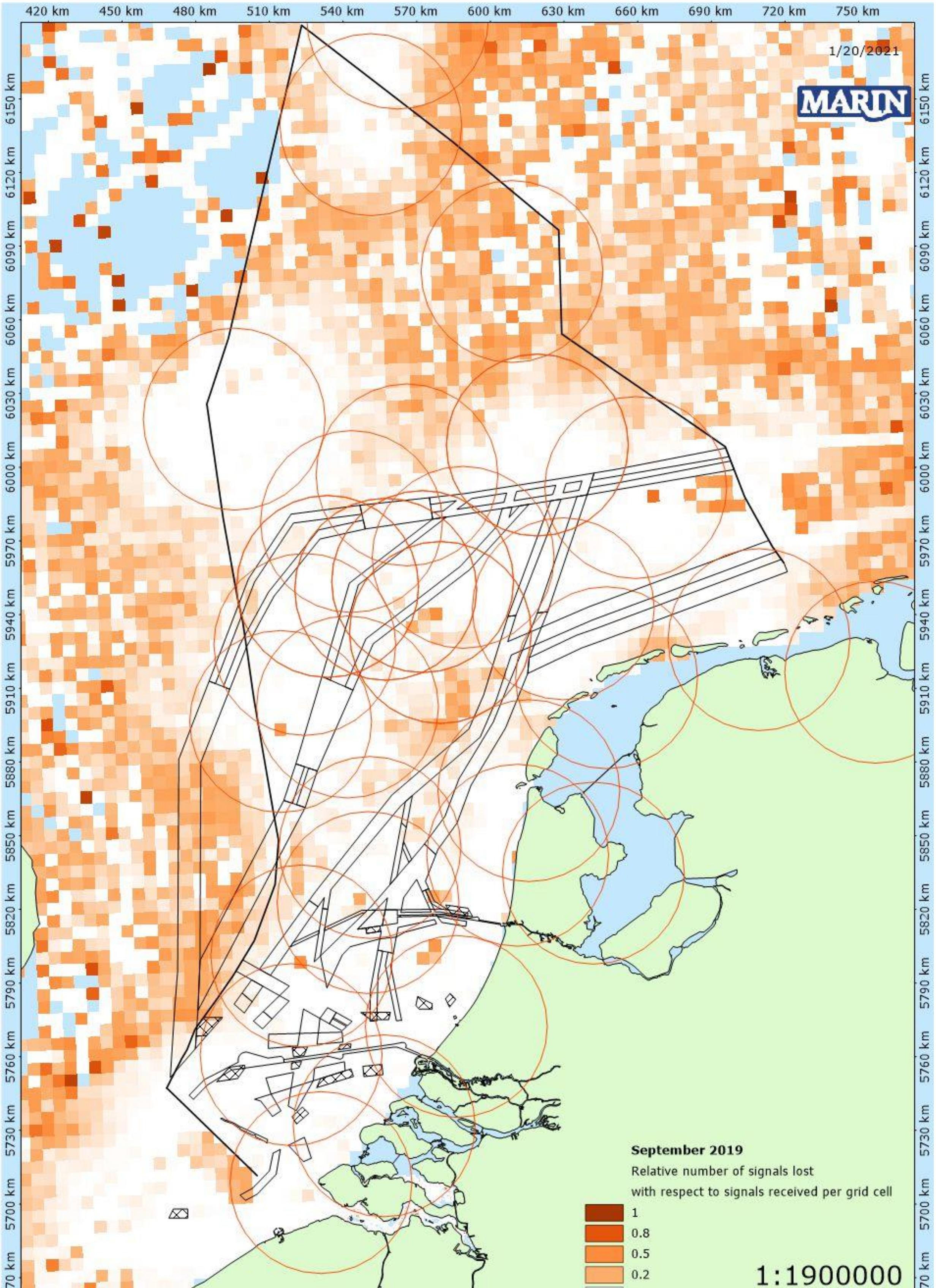

Figure 4-3 **September 2019, relative number of signals lost with respect to signals received per grid cell, circles mark the 20 nautical miles zones around the Dutch base stations**

5 ACTIVITIES OF SEAGOING VESSELS FOR 2019 AND COMPARISON WITH 2018 FOR THE DUTCH PORT AREAS AND THE NETHERLANDS SEA AREA

5.1 Introduction

This chapter presents the activities of seagoing vessels for 2019 in the Dutch port areas and in the Netherlands sea area. The activities of 2019 are compared to those of 2018. 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 [7]. 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. The table contains the number of calls and the cargo handling for the main ports in each port area.

Table 5-1 show an increase in cargo handling in the port of Amsterdam, Western Scheldt and Rotterdam. The next chapter will also show that in these ports the CO_2 emissions have increased the most compared to last year.

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	2019	2017	2018	2019
Western Scheldt	Antwerp	14,223	14,595	14,391	223,655	235,331	238,179
	Zeeland seaports (Vlissingen en Terneuzen)	Not available	-		Not available	-	-
Rotterdam	Rijn- en Maasmondgebied	29,646	29,476	29,491	467,400	468,984	469,402
Amsterdam	Noordzeekanaalgebied	7,011	7,525	-	100,800	101,800	105,000

The shipping activities of 2019 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 2018. 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 increased with 5.0% compared to 2018 and GT.nm (gross tonnage time’s nautical miles) increased with 12.3%.

For berthed ships the hours increased by 5.8% in 2018 and GT.hours increased with 3.1%.

Rotterdam
The activity tables, Table 5-4 and Table 5-5, for Rotterdam show that for the moving activities, the hours decreased with 0.5% and the GT.nm (gross tonnage time’s nautical miles) increased with 3.6% in 2019 compared to 2018.

Berthed activities, hours and GT.hours, increased with 0.4% and 6% respectively.

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 11.6% and the increase in GT.nm is 15.9%.

The hours at berth also increased. The berthed activities for Amsterdam, hours and GT.hours, increased respectively with 33.3% and 41.3%.

Ems
The activity tables, Table 5-8 and Table 5-9, for the Ems area shows that the moving activities, hours and GT.nm, decreased by respectively 11.8% and 9.2%.
The number of berthed hours and GT.hours decreased respectively by 2.6% and 19%.

Den Helder
Table 5-10 and Table 5-11, for Den Helder show that the moving activities decreased. The moving hours and GT.nm decreased respectively by 8.6% and 4.7%.

Compared to 2018, the berthed hours increased with 6.5% and the berthed GT.hours increased with 6.1%.

Harlingen
The activity tables, Table 5-12 and Table 5-13 show a clear decrease in activities in the port of Harlingen. The moving activities hours and GT.nm decreased respectively by 61.6% and 79%.

The berthed hours and GT.hours decreased respectively by 35% and 55.3%.

Overall
In comparison with the activities observed in 2018 there is overall increase of berthed and sailing ships in the port of Amsterdam, Western Scheldt and Rotterdam, while it descends in the port of Ems and Harlingen.

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

Ship type	Totals for Western Scheldt in 2019					2019 as percentage of 2018				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	6,287	263,920,170	4,818	1,618,609,953	10.2	87.50%	97.20%	82.10%	97.40%	101.40%
Chem.+ Gas tanker	73,254	856,453,156	45,307	4,858,632,689	10.6	106.00%	106.10%	106.70%	103.70%	97.20%
Bulk carrier	31,796	957,884,872	7,945	1,971,618,580	7.9	103.10%	103.40%	101.60%	100.70%	95.30%
Container ship	10,650	237,505,508	29,663	20,733,999,191	12.9	199.40%	223.30%	109.20%	106.90%	102.00%
General Dry Cargo	101,091	698,203,376	35,260	1,726,284,681	9.5	104.00%	95.20%	96.20%	96.20%	99.90%
RoRo Cargo / Vehicle	13,205	301,344,027	10,659	6,032,905,589	12.4	105.70%	109.10%	157.10%	181.40%	117.40%
Reefer	8,618	105,727,649	751	91,310,814	10.1	80.10%	75.90%	61.40%	52.50%	92.70%
Passenger	18,829	57,289,840	5,012	86,226,589	10.1	104.60%	140.80%	100.00%	108.30%	103.10%
Miscellaneous	126,116	290,721,867	21,644	473,956,542	6.6	108.80%	104.80%	94.40%	114.40%	92.40%
Tug/Supply	210,691	508,754,077	28,691	125,456,969	6.3	104.90%	89.30%	115.50%	123.70%	105.10%
Total / Average	600,537	4,277,804,542	189,750	37,719,001,597	9.6	105.80%	103.10%	105.00%	112.30%	100.70%

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 2019					2019 as percentage of 2018				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	273,660	129,229,715	41,972	170,097,897	7.9	105.80%	99.80%	103.20%	88.30%	93.70%
1,600-3,000	82,268	201,713,927	32,273	704,736,965	8.4	99.50%	103.00%	95.90%	98.90%	104.90%
3,000-5,000	66,695	262,955,017	24,432	930,177,030	9.6	128.10%	126.90%	104.50%	103.40%	109.10%
5,000-10,000	46,878	314,457,578	22,543	1,604,056,574	10.1	108.40%	104.90%	97.00%	95.30%	97.70%
10,000-30,000	96,629	1,817,261,897	35,105	7,470,365,040	10.2	99.70%	102.00%	111.60%	107.40%	96.30%
30,000-60,000	31,070	1,288,874,316	20,695	10,480,009,857	10.4	104.40%	105.60%	105.40%	105.90%	97.80%
60,000-100,000	3,200	248,789,094	7,880	7,319,608,581	11.6	79.80%	80.30%	190.60%	197.90%	105.40%
>100,000	135	14,523,000	2,550	4,415,611,411	10.2	482.10%	317.40%	54.30%	52.10%	91.00%
Total / Average	600,535	4,277,804,544	187,450	33,094,663,355	9.4	105.80%	103.10%	103.60%	101.80%	99.70%

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

Ship type	Totals for Rotterdam in 2019					2019 as percentage of 2018				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	48,274	3,444,171,383	4,663	1,721,240,036	7.3	98.30%	99.00%	108.00%	109.90%	104.30%
Chem.+ Gas tanker	87,723	1,548,115,136	23,498	2,135,432,305	7.7	105.40%	110.40%	103.30%	104.80%	100.00%
Bulk carrier	76,483	4,013,553,455	2,943	762,973,157	7.8	96.60%	93.20%	99.90%	99.50%	105.40%
Container ship	204,134	11,222,076,106	31,616	6,543,228,826	7.7	103.70%	109.70%	98.90%	103.20%	95.10%
General Dry Cargo	59,373	405,903,961	18,030	665,657,719	8.9	110.50%	102.20%	99.50%	100.50%	100.00%
RoRo Cargo / Vehicle	54,771	1,876,551,049	10,673	3,201,666,869	9.3	117.50%	121.20%	105.60%	104.30%	103.30%
Reefer	644	6,891,468	148	14,784,676	9.5	98.00%	94.10%	43.90%	42.30%	105.60%
Passenger	1,884	69,476,811	557	328,581,719	8.7	29.90%	368.50%	101.50%	128.10%	97.80%
Miscellaneous	51,446	272,522,716	20,219	474,980,363	6.8	91.00%	100.20%	88.70%	84.60%	98.60%
Tug/Supply	233,742	1,053,623,419	57,013	240,101,037	6.6	96.20%	116.20%	101.30%	106.80%	106.50%
Total / Average	818,474	23,912,885,504	169,360	16,088,646,707	7.4	100.40%	106.00%	99.50%	103.60%	101.20%

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

Ship size in GT	Totals for Rotterdam in 2019					2019 as percentage of 2018				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average Speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	230,057	93,819,092	67,574	163,305,885	7.5	88.90%	91.40%	99.70%	98.60%	117.20%
1,600-3,000	33,806	82,685,711	13,568	295,536,916	8.6	90.10%	92.50%	98.70%	99.30%	96.60%
3,000-5,000	38,209	152,200,588	18,114	617,950,426	9.0	102.20%	102.30%	78.30%	81.70%	101.10%
5,000-10,000	100,864	787,999,788	24,861	1,691,308,800	8.9	111.50%	109.30%	117.30%	114.40%	102.30%
10,000-30,000	176,579	3,260,920,915	27,220	4,053,822,845	8.3	106.80%	107.60%	99.50%	98.80%	100.00%
30,000-60,000	115,182	4,920,071,131	8,590	2,875,066,938	7.4	112.60%	111.60%	106.90%	107.50%	98.70%
60,000-100,000	66,449	5,290,984,588	5,314	2,766,614,656	6.7	93.40%	92.80%	102.00%	100.90%	98.50%
>100,000	57,328	9,324,203,691	4,118	3,625,040,241	5.6	109.60%	111.40%	109.90%	109.70%	100.00%
Total / Average	818,474	23,912,885,504	169,359	16,088,646,707	8.0	100.40%	106.00%	99.50%	103.60%	105.60%

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

Ship type	Totals for Amsterdam in 2019					2019 as percentage of 2018				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	29,553	1,237,810,405	1,685	394,429,543	6.3	158.20%	162.50%	135.50%	171.30%	108.60%
Chem.+ Gas tanker	116,977	2,361,466,172	9,750	869,888,354	5.9	163.00%	164.90%	122.70%	125.20%	96.70%
Bulk carrier	87,036	3,793,514,247	3,242	647,982,643	5.5	125.30%	125.50%	100.70%	106.20%	114.60%
Container ship	3,434	22,111,775	444	17,106,852	6.1	103.70%	73.60%	84.90%	71.70%	148.80%
General Dry Cargo	105,154	426,639,701	9,913	182,058,943	5.6	114.40%	112.20%	101.30%	94.00%	100.00%
RoRo Cargo / Vehicle	10,380	378,126,977	1,196	299,789,285	6.0	146.40%	150.20%	106.00%	112.50%	103.40%
Reefer	20,011	113,471,764	590	14,993,339	4.8	112.40%	120.10%	100.70%	112.50%	96.00%
Passenger	17,176	273,846,131	2,485	314,485,524	6.2	138.90%	100.00%	124.70%	70.50%	101.60%
Miscellaneous	53,251	647,048,289	5,101	237,047,114	5.0	228.90%	424.20%	177.00%	272.20%	94.30%
Tug/Supply	183,000	281,605,339	21,542	52,324,331	4.1	119.00%	80.30%	103.50%	107.00%	95.30%
Total / Average	625,972	9,535,640,800	55,948	3,030,105,928	5.1	133.30%	141.30%	111.60%	115.90%	99.80%

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

Ship size in GT	Totals for Amsterdam in 2019					2019 as percentage of 2018				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	172,957	67,091,760	24,576	45,242,628	5.6	127.50%	113.20%	103.50%	94.80%	107.70%
1,600-3,000	104,060	241,606,377	8,059	116,487,525	5.9	139.60%	136.80%	112.80%	106.90%	115.70%
3,000-5,000	42,891	169,181,587	4,619	103,003,341	5.9	137.90%	139.10%	137.80%	130.60%	100.00%
5,000-10,000	58,096	404,709,259	3,676	144,772,393	5.7	100.10%	98.30%	95.00%	93.20%	101.80%
10,000-30,000	119,118	2,684,385,109	7,446	857,970,108	5.3	135.10%	140.00%	113.70%	115.90%	100.00%
30,000-60,000	102,625	3,939,116,031	6,137	1,169,397,664	5.5	165.50%	160.40%	156.70%	142.50%	110.00%
60,000-100,000	25,851	1,985,023,848	1,350	536,153,181	5.3	132.40%	126.40%	93.10%	90.70%	103.90%
>100,000	378	44,526,829	87	57,079,087	5.4	114.50%	116.50%	80.60%	80.00%	108.00%
Total / Average	625,976	9,535,640,800	55,950	3,030,105,927	5.6	133.30%	141.30%	111.60%	115.90%	106.80%

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

Ship type	Totals for Ems in 2019					2019 as percentage of 2018				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	189	161,445	293	2,281,130	9.6	71.30%	3.90%	111.40%	44.00%	109.10%
Chem.+ Gas tanker	4,929	26,659,174	1,601	107,560,310	10.3	131.90%	114.50%	105.10%	104.20%	100.00%
Bulk carrier	4,126	66,077,930	765	110,445,217	9.0	103.60%	117.90%	86.20%	78.30%	96.80%
Container ship	937	13,011,391	48	4,407,131	10.7	901.00%	1076.30%	106.70%	66.00%	97.30%
General Dry Cargo	59,018	284,132,682	7,187	319,587,068	9.9	117.10%	129.00%	103.00%	104.60%	100.00%
RoRo Cargo / Vehicle	14,744	508,979,253	7,537	1,550,435,912	11.4	99.10%	102.10%	91.00%	95.40%	96.60%
Reefer	1,213	9,265,474	60	2,854,678	10.4	211.70%	530.10%	56.60%	55.20%	103.00%
Passenger	859	36,076,555	1,273	47,452,115	14.7	36.40%	11.70%	89.70%	70.60%	110.50%
Miscellaneous	22,943	31,332,993	11,944	207,769,458	6.7	103.20%	67.30%	88.50%	68.30%	95.70%
Tug/Supply	171,482	267,568,411	11,748	216,148,758	8.7	90.60%	71.30%	77.60%	81.40%	100.00%
Total / Average	280,440	1,243,265,308	42,456	2,568,941,777	9.1	97.40%	81.00%	88.20%	90.80%	99.40%

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 2019					2019 as percentage of 2018				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hour s	Hours	GT.nm	Average speed
100-1,600	149,971	46,820,832	13,364	54,935,754	11.0	90.30%	92.90%	73.60%	80.30%	105.80%
1,600-3,000	49,463	119,245,312	13,658	281,095,628	9.8	114.40%	116.40%	120.80%	112.10%	103.20%
3,000-5,000	35,816	138,204,222	7,011	256,138,185	9.3	115.40%	114.90%	95.50%	111.60%	100.00%
5,000-10,000	24,772	187,202,005	4,699	361,563,131	9.6	123.10%	121.70%	68.40%	66.00%	94.10%
10,000-30,000	11,083	198,607,870	1,892	408,053,022	10.0	68.20%	66.60%	74.90%	82.80%	102.00%
30,000-60,000	6,996	376,283,091	1,424	866,625,919	10.0	82.90%	87.10%	87.20%	89.50%	98.00%
60,000-100,000	2,130	141,596,152	390	317,569,351	12.3	199.40%	201.00%	146.10%	145.70%	98.40%
>100,000	209	35,305,827	19	22,960,786	7.2	12.20%	11.50%	55.90%	43.70%	81.80%
Total / Average	280,440	1,243,265,311	42,457	2,568,941,776	10.1	97.40%	81.00%	88.20%	90.80%	101.50%

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

Ship type	Totals for Den Helder in 2019					2019 as percentage of 2018				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker										
Chem.+ Gas tanker	215	924,451	6	223,340	5.9	565.80%	399.00%	200.00%	177.50%	72.80%
Bulk carrier										
Containership										
General Dry Cargo	284	597,738	21	278,249	8.1	202.90%	150.50%	72.40%	27.90%	80.20%
RoRo Cargo / Vehicle	5,322	82,405,258	2,325	266,557,255	5.7	100.00%	100.00%	118.90%	122.90%	75.00%
Reefer										
Passenger	10,232	101,552,060	1,230	119,959,266	6.7	102.80%	109.50%	98.60%	92.10%	84.80%
Miscellaneous	33,996	28,290,846	1,067	6,256,175	5.1	96.00%	77.90%	51.00%	9.30%	85.00%
Tug/Supply	121,438	158,830,330	2,952	29,780,606	6.0	110.20%	114.20%	98.60%	105.70%	107.10%
Total / Average	171,487	372,600,683	7,601	423,054,891	5.9	106.50%	106.10%	91.40%	95.30%	90.30%

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 2019					2019 as percentage of 2018				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	109,780	43,627,214	2,371	6,517,793	5.9	104.70%	110.00%	74.10%	88.40%	96.70%
1,600-3,000	37,453	88,301,661	1,445	21,440,012	5.2	110.70%	110.00%	111.20%	109.20%	69.30%
3,000-5,000	8,129	33,102,180	242	5,524,890	8.1	102.70%	103.60%	110.00%	111.80%	106.60%
5,000-10,000	2,781	17,669,583	51	1,895,697	5.7	257.50%	232.20%	85.00%	68.90%	74.00%
10,000-30,000	13,342	189,853,037	3,492	387,510,289	6.4	100.30%	99.00%	98.70%	94.70%	95.50%
30,000-60,000	1	47,008	1	166,208	6.2		664.10%		1299.20%	137.80%
60,000-100,000										
>100,000										
Total / Average	171,486	372,600,683	7,602	423,054,889	6.1	106.50%	106.10%	91.40%	95.30%	91.50%

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

Ship type	Totals for Harlingen in 2019					2019 as percentage of 2018				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.hours	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker										
Chem.+ Gas tanker	863	3,333,801	20	490,198	7.7	153.00%	214.40%	74.10%	118.50%	122.20%
Bulk carrier	30	70,864	5	31,860	8.3	8.00%	4.90%	18.50%	9.00%	113.70%
Containership										
General Dry Cargo	22,253	59,209,676	1,794	30,385,942	7.5	72.20%	61.50%	116.90%	92.40%	93.80%
RoRo Cargo / Vehicle										
Reefer	2,263	12,525,687	174	7,010,793	8.8	122.90%	133.10%	118.40%	119.10%	98.90%
Passenger	4,774	1,548,011	200	1,262,910	7.9	16.60%	13.10%	6.40%	3.70%	56.80%
Miscellaneous	50,803	34,954,418	5,259	43,907,097	6.8	83.30%	59.80%	70.30%	56.00%	87.20%
Tug/Supply	37,126	29,868,394	777	6,490,308	7.5	113.30%	130.00%	85.30%	248.80%	98.70%
Total / Average	118,114	141,512,586	8,234	89,618,588	7.1	65.00%	44.70%	38.40%	21.00%	73.30%

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

Ship size in GT	Totals for Harlingen in 2019					2019 as percentage of 2018				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.hours	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	87,070	42,355,160	5,671	23,388,286	7.6	77.10%	89.50%	54.60%	36.40%	82.60%
1,600-3,000	21,524	53,314,532	1,646	25,484,626	7.5	53.40%	54.60%	28.20%	16.80%	88.20%
3,000-5,000	6,007	25,228,498	275	8,607,113	7.5	53.90%	58.80%	6.10%	4.90%	85.20%
5,000-10,000	3,512	20,570,065	641	32,138,564	8.5	20.20%	16.00%	89.30%	86.60%	101.20%
10,000-30,000										
30,000-60,000										
60,000-100,000										
>100,000										
Total / Average	118,113	141,468,255	8,233	89,618,589	7.6	65.00%	44.70%	38.40%	21.00%	85.90%

5.3 Activities of seagoing vessels in the Netherlands sea area (NCS and 12-mile zone)

The shipping activities in the Netherlands sea area are presented in Table 5-14 and Table 5-15, where the activities of 2019 are compared to the activities of 2018. 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 has increased with almost 7.0%.

For ships at anchor, there is an increase for both hours (13.0%) and GT.nm (9.7%).

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 2019					2019 as percentage of 2018				
	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	122,854	7,191,608,679	72,864	40,286,371,415	9.4	107.10%	113.10%	108.70%	108.20%	98.80%
Chem.+Gas tanker	428,268	5,730,606,564	306,159	44,661,543,267	10.4	121.80%	129.40%	107.90%	110.10%	95.00%
Bulk carrier	116,672	5,330,641,376	108,330	38,447,339,763	9.8	106.60%	98.10%	104.80%	102.70%	101.70%
Container ship	68,130	2,525,190,333	197,563	135,540,041,870	12.8	90.70%	101.20%	109.40%	109.60%	98.40%
General Dry Cargo	88,652	493,327,424	398,604	17,834,944,006	10.4	120.30%	118.30%	101.90%	101.70%	98.10%
RoRo Cargo / Vehicle	4,423	206,562,918	130,683	71,228,208,755	12.9	28.20%	100.40%	107.40%	105.30%	94.10%
Reefer	2,407	16,752,538	9,191	973,135,399	12.2	76.90%	74.40%	93.60%	86.90%	101.20%
Passenger	84	1,898,999	10,729	10,219,267,230	12.2	14.10%	85.30%	100.40%	98.20%	100.00%
Miscellaneous	43,333	302,765,893	97,264	2,033,675,000	7.0	90.70%	39.60%	103.10%	84.90%	94.90%
Tug/Supply	118,408	755,124,665	142,699	3,159,462,421	7.7	136.10%	178.60%	120.50%	110.10%	96.00%
Total / Average	993,231	22,554,479,389	1,474,086	364,383,989,126	10.4	113.00%	109.70%	106.70%	106.90%	97.00%

Table 5-15 Shipping activities per ship size class for the Netherlands Continental Shelf and 12-mile zone

Ship size in GT	Totals for NCS and 12-mile zone in 2019					2019 as percentage of 2018				
	Not moving / at anchor		Moving			Not moving / at anchor		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hour s	Hours	GT.nm	Average Speed
100-1,600	72,737	42,822,564	172,770	835,311,392	7.5	149.30%	139.40%	114.90%	98.10%	88.50%
1,600-3,000	99,798	245,111,769	309,928	6,638,617,321	9.1	106.20%	107.00%	102.30%	101.90%	100.40%
3,000-5,000	141,064	568,047,659	194,208	7,747,616,954	10.3	118.10%	118.10%	105.90%	103.70%	100.90%
5,000-10,000	151,933	1,096,626,886	194,237	16,344,956,491	11.2	104.00%	100.70%	104.00%	101.10%	98.70%
10,000-30,000	291,587	5,630,276,144	298,175	70,141,728,750	11.8	120.80%	119.60%	107.50%	105.40%	97.40%
30,000-60,000	126,542	5,360,364,737	160,141	86,935,226,757	11.4	98.10%	98.40%	110.10%	107.50%	100.00%
60,000-100,000	89,141	6,684,095,039	96,155	84,036,767,269	10.7	101.00%	98.60%	101.80%	100.00%	93.50%
>100,000	20,426	2,927,134,589	48,471	91,703,764,193	11.9	171.90%	164.20%	120.30%	116.80%	99.60%
Total / Average	993,228	22,554,479,387	1,474,085	364,383,989,127	10.3	113.00%	109.70%	106.70%	106.90%	97.80%

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 Amsterdam by 33%.

For the NCS combined with the 12-miles zone the average number of ships increased slightly, for moving ships by 7% and for non-moving ships by 13%.

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

Area	In 2019			In 2019 as percentage of 2018		
	Average # ships/day		Speed	Average # ships/day		Speed
	Not moving	Moving	Knots	Not moving	Moving	Knots
Amsterdam	71	6	5	133%	112%	100%
Den Helder	20	1	6	106%	91%	90%
Ems	32	5	9	97%	88%	99%
Harlingen	13	1	7	65%	38%	73%
Rotterdam	93	19	7	100%	100%	101%
Western Scheldt	68	22	10	106%	105%	101%
NCS +12-mile zone	113	168	10	113%	107%	97%

Figure 2-1 shows the average number of ships per day from 2017 up to and including 2019. The average number of ships per day contains not moving and moving ships excluding fishing vessels. This figure also shows that the average number of ships per day for the NCS combined with the 12-mile zone and in the port of Amsterdam has increased the most.

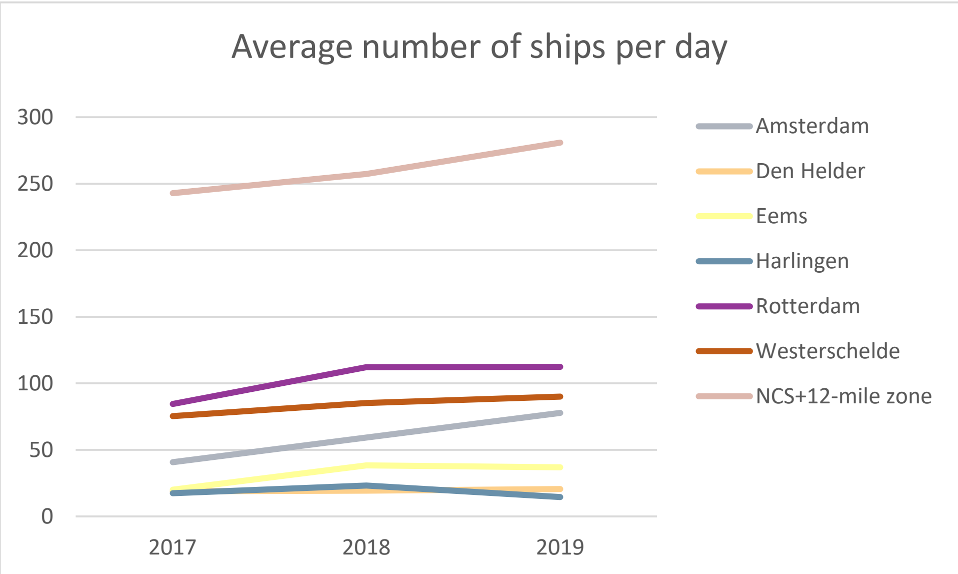

Figure 5-1 Average number of not moving and moving ships per day for 2017-2019, excluding fishing vessels.

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

6.1 Introduction

This chapter presents the results of emission calculations for 2019 for the Dutch port areas and the Netherlands sea area. To indicate the change in emissions, all values for 2019 are compared with the values of 2018.

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 2019 NO_x emissions together with the absolute and relative change compared to 2018.

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 2018. Similar to the procedure in the previous studies, the values for at berth or at anchor include all vessels with speed below 1 knots.

The substance CO_2 has the largest contribution to the total emissions in ton (98%). For all ports together, there is an overall increase of CO_2 by 7%, for ships at berth 10% and sailing ships 2%. As indicated in the previous chapter with regard to shipping activities there is a clear increase in emissions in the port of Amsterdam.

Figure 6-1 to Figure 6-3 shows the CO_2 emissions in ton in each port area from 2017 up to and including 2019. The emissions in ton contains not moving and moving ships excluding fishing vessels. There is a clear increase of CO_2 and NO_x emissions in the port of Amsterdam as well for the total of all ports together. SO_2 emissions show a decrease for all ports except for Amsterdam.

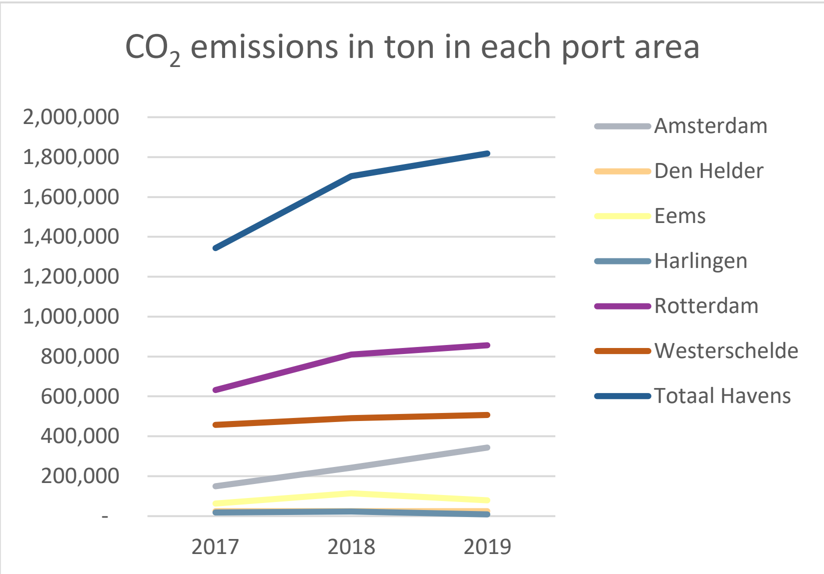

Figure 6-1 **CO_2 emissions in ton in each port area for 2017-2019, excluding fishing vessels.**

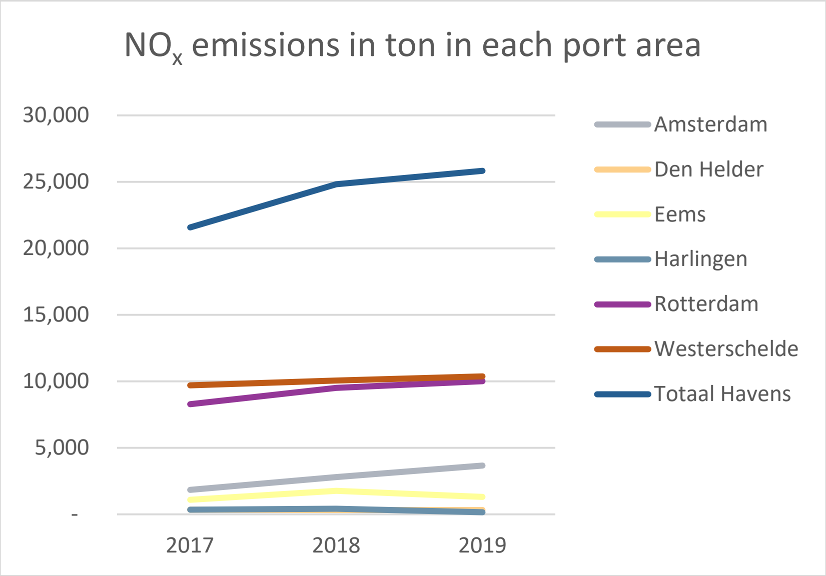

Figure 6-2 **NO_x emissions in ton in each port area for 2017-2019, excluding fishing vessels.**

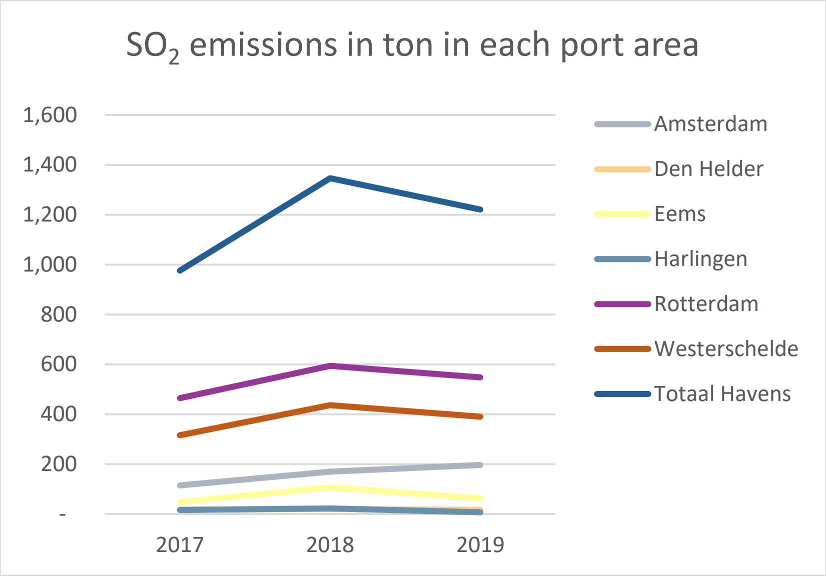

Figure 6-3 **SO_2 emissions in ton in each port area for 2017-2019, excluding fishing vessels.**

Table 6-1 Total emissions in ton in each port area for 2019, excluding fishing vessels (EMS-type 11).

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Total
1011 Methane	Berthed							
	Sailing	12	71	1	19	53		157
	Total	12	71	1	19	53		157
1237 VOC	Berthed	62	256	125	18	7	4	472
	Sailing	292	190	44	30	4	3	562
	Total	354	446	169	48	11	6	1,034
4001 SO_2	Berthed	84	372	159	29	11	4	660
	Sailing	306	176	36	34	6	3	561
	Total	390	548	196	63	17	7	1,221
4013 NO_x	Berthed	1,493	5,479	2,751	475	195	91	10,484
	Sailing	8,884	4,538	905	831	128	69	15,355
	Total	10,377	10,017	3,656	1,306	323	160	25,839
4031 CO	Berthed	101	452	213	30	12	5	811
	Sailing	534	372	82	53	20	4	1,065
	Total	635	824	295	83	32	9	1,877
4032 CO_2	Berthed	131,597	638,418	298,026	35,920	13,716	5,151	1,122,827
	Sailing	374,835	218,579	44,562	42,693	10,576	3,613	694,858
	Total	506,432	856,997	342,588	78,612	24,292	8,764	1,817,685
6601 Aerosols MDO	Berthed	30	132	61	9	3	2	236
	Sailing	41	35	10	8	2	1	97
	Total	71	167	71	17	5	3	333
6602 Aerosols HFO	Berthed	0	0	1	1	1	0	4
	Sailing	189	106	18	19	3	1	337
	Total	189	106	20	20	4	1	340

Table 6-2 Emissions in each port area for 2019 as percentage of the emissions in 2018, 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[1]	Total
1011 Methane	Berthed							
	Sailing	116%	1065%	234%	106%	125%	-	200%
	Total	116%	1065%	234%	106%	125%	-	200%
1237 VOC	Berthed	98%	108%	141%	56%	111%	74%	109%
	Sailing	106%	101%	115%	86%	82%	27%	102%
	Total	104%	105%	133%	71%	99%	41%	105%
4001 SO_2	Berthed	86%	95%	119%	46%	95%	54%	93%
	Sailing	90%	88%	102%	79%	72%	21%	88%
	Total	90%	92%	115%	59%	86%	33%	91%
4013 NO_x	Berthed	97%	109%	137%	58%	110%	73%	108%
	Sailing	104%	102%	116%	88%	85%	25%	102%
	Total	103%	106%	131%	74%	99%	40%	104%
4031 CO	Berthed	99%	108%	143%	54%	110%	67%	109%
	Sailing	106%	108%	116%	93%	105%	27%	105%
	Total	105%	108%	134%	74%	107%	40%	107%
4032 CO_2	Berthed	100%	107%	145%	53%	109%	62%	110%
	Sailing	104%	103%	117%	92%	95%	24%	102%
	Total	103%	106%	141%	69%	102%	38%	107%
6601 Aerosols MDO	Berthed	97%	109%	143%	51%	108%	74%	109%
	Sailing	102%	103%	113%	79%	87%	29%	98%
	Total	100%	107%	138%	62%	99%	46%	105%
6602 Aerosols HFO	Berthed	130%	253%	60%	142%	121%	6%	92%
	Sailing	103%	97%	116%	99%	79%	18%	100%
	Total	103%	97%	109%	101%	85%	18%	100%

[1] The decrease in emissions in Harlingen is probably less because the emission factors in this area are not properly linked to the AIS data.

6.3 Emissions in the Netherlands sea area (NCS and 12-mile zone)

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 2019 are summarised in Table 6-3. This table also contains a comparison with 2018.

The most substances show an overall increase except for SO_2. The substance CO_2 has the largest contribution to the total emissions in ton (97%). For NCS combined with the 12-miles there is a total increase of CO_2 by 4%, for ships at berth 8% and sailing ships 4%.

For the Netherlands sea area the average number of ships increased by 9%.

Figure 6-4 shows CO_2, NO_x and SO_2 emissions in ton in the Netherlands sea area from 2017 up to and including 2019. The total emissions in ton contains not moving and moving ships excluding fishing vessels. This figure confirm an upward trend of CO_2 emissions and a downward trend for SO_2. The substance NO_x show a dip for the emissions registration of 2018.

Table 6-3 Emissions of ships in ton in the Netherlands sea area for 2019 compared with 2018, excluding fishing vessels (EMS-type 11). The percentages in grey are based on very low absolute numbers, and not very reliable.

No	Substance	Emission in ton in 2019			Emission in 2019 as percentage of 2018		
		Not moving	Moving	Total	Not moving	Moving	Total
1011	Methane		718	718		137%	137%
1237	VOC	117	2295	2412	108%	106%	106%
4001	SO_2	178	2697	2875	94%	90%	90%
4013	NO_x	3478	78270	81748	108%	105%	105%
4031	CO	188	4271	4459	108%	108%	108%
4032	CO_2	216769	3353967	3570736	108%	104%	104%
6601	Aerosols MDO	88	266	354	106%	104%	105%
6602	Aerosols HFO	4	1824	1828	83%	101%	101%
Average number of ships present in the area		113	168	281	113%	107%	109%

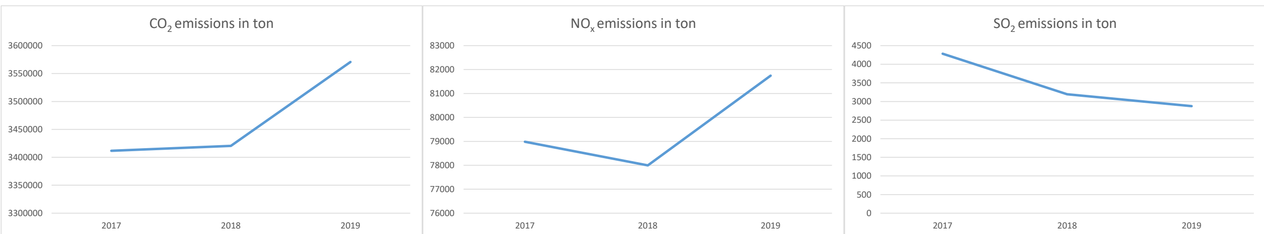

Figure 6-4 CO_2, NO_x and SO_2 emissions in ton in the Netherlands sea area for 2017-2019, excluding fishing vessels.

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 6-5 up to Figure 6-25.

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 2018 and 2019 and the third one shows the *relative* change in emission between 2018 and 2019. 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 2018 and 2019 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 6-5 up to and including Figure 6-13 show the spatial distribution of NO_x emissions in the port of Amsterdam, Western Scheldt and Rotterdam. In these ports, NOx emissions have increased.

Figure 6-16 and Figure 6-22 show the spatial distribution of NO_x emissions in the port of Ems and Harlingen. In these ports, NOx emissions have decreased.

On the NCS the absolute changes are rather small, see Figure 6-24.

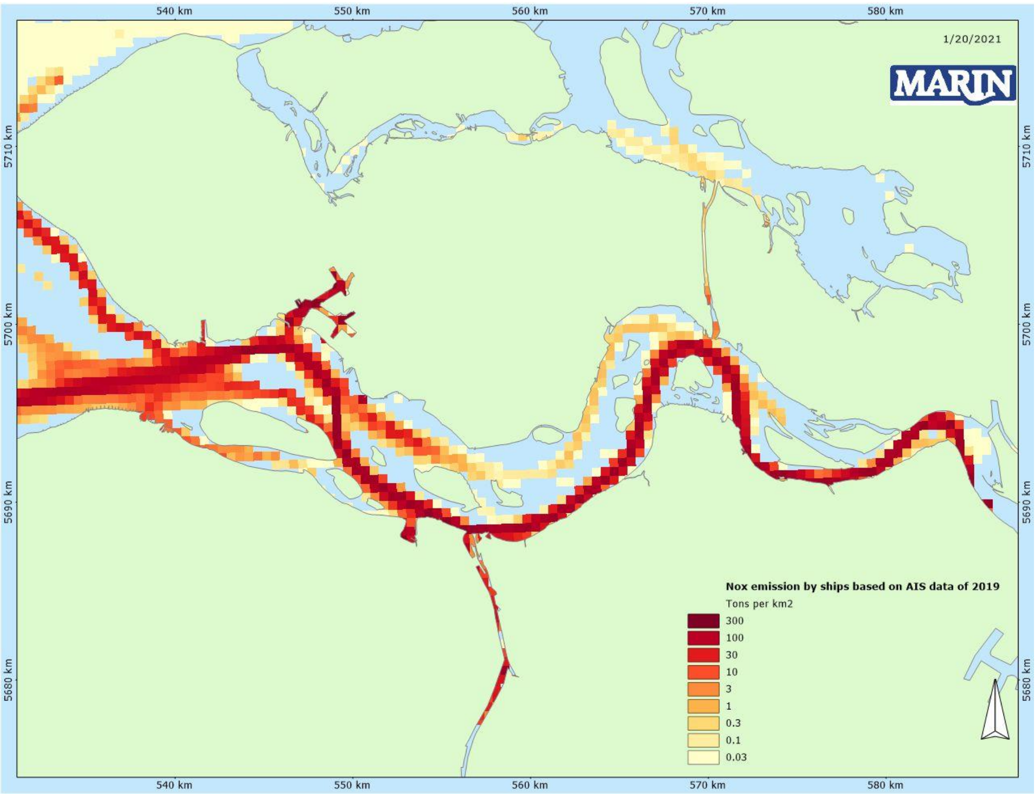

Figure 6-5 NO_x emission in 2019 in the Dutch part of the Western Scheldt by ships with AIS.

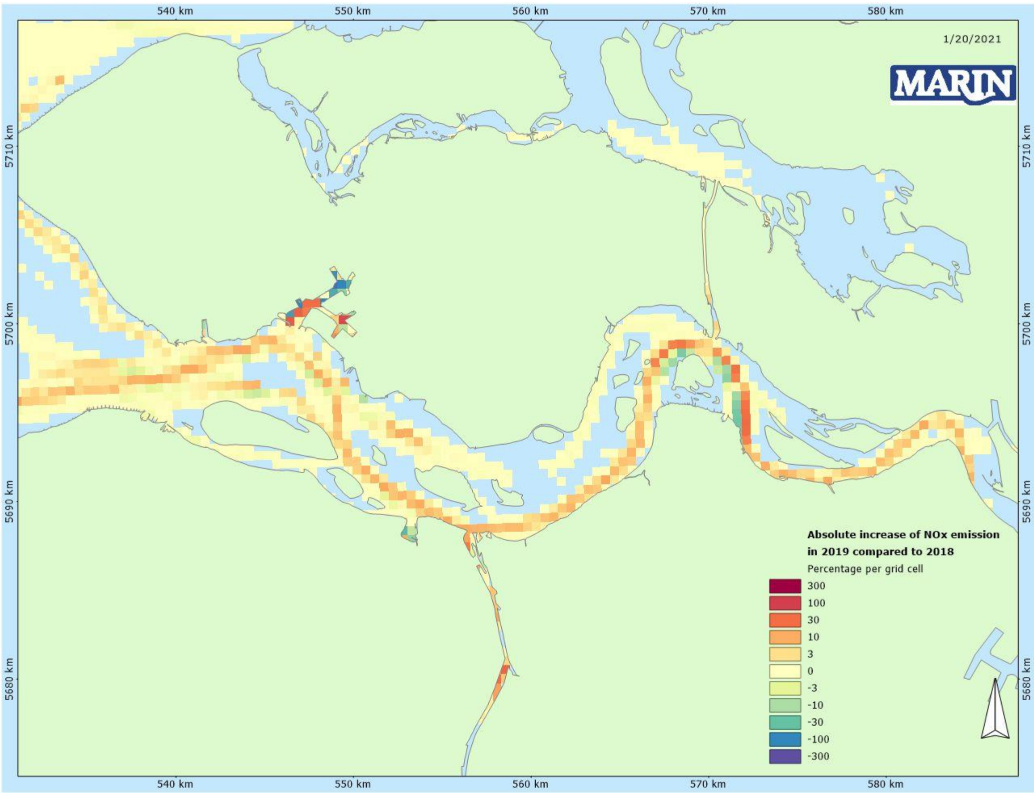

Figure 6-6 Absolute change in NO_x emission from 2018 to 2019 in the Dutch part of the Western Scheldt by ships with AIS.

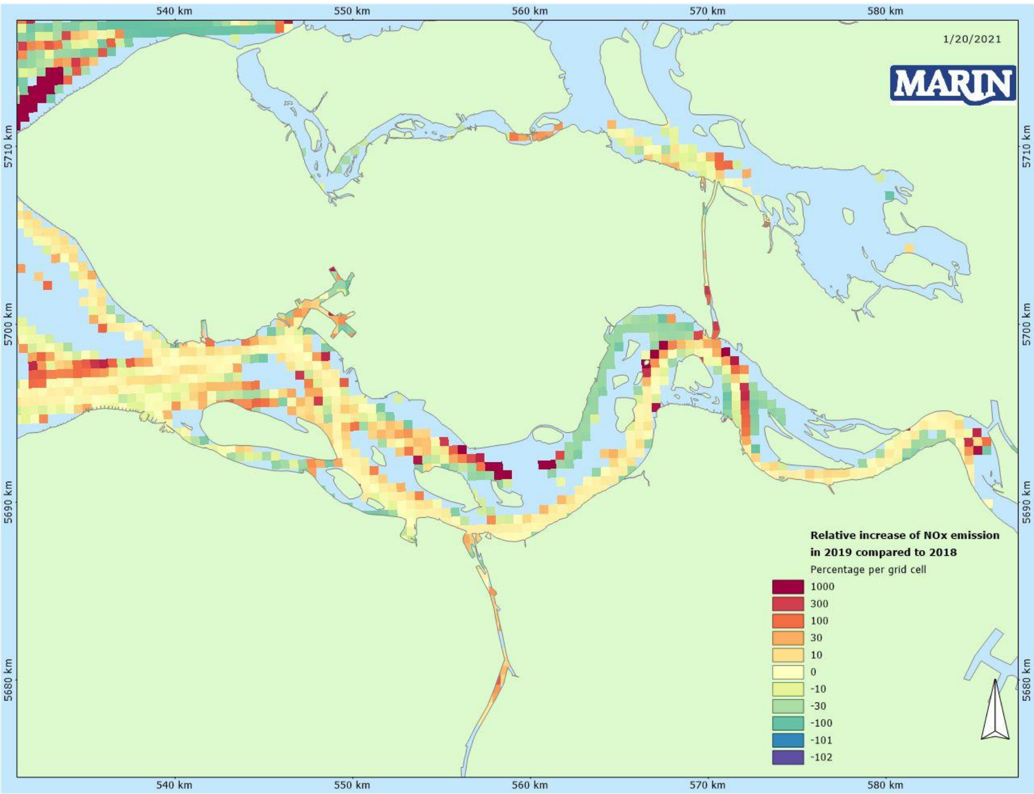

Figure 6-7 Relative change in NO_x emission from 2018 to 2019 in the Dutch part of the Western Scheldt by ships with AIS.

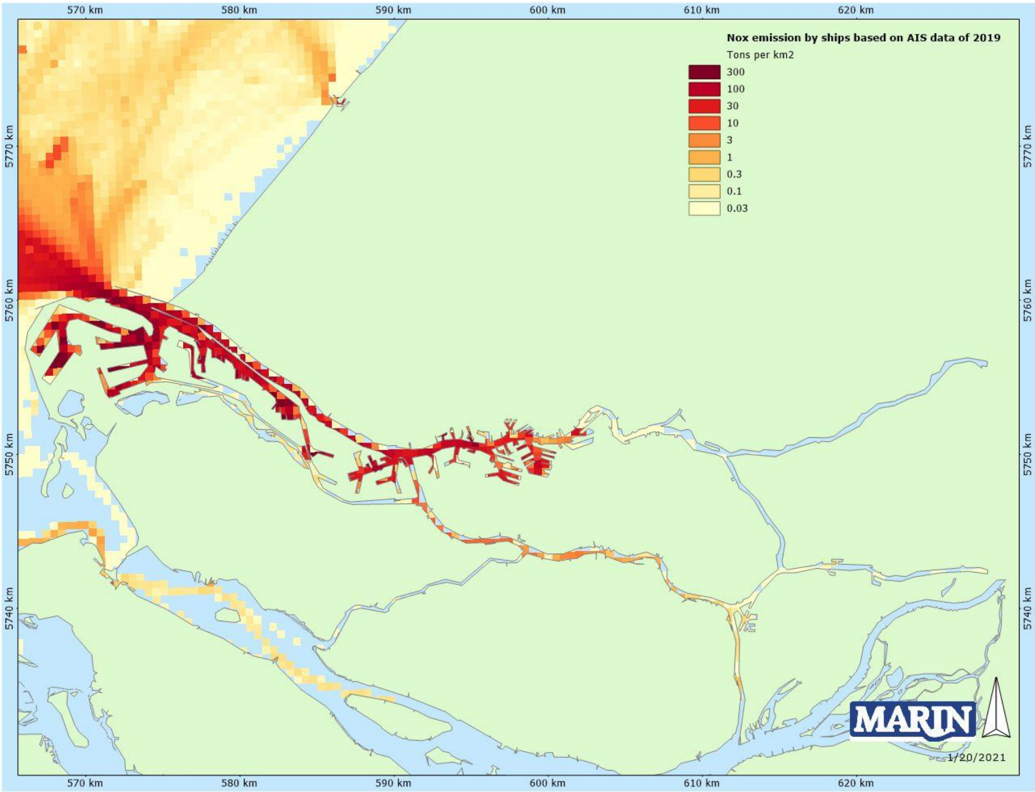

Figure 6-8 **NO_x emission in 2019 in the port area of Rotterdam by ships with AIS.**

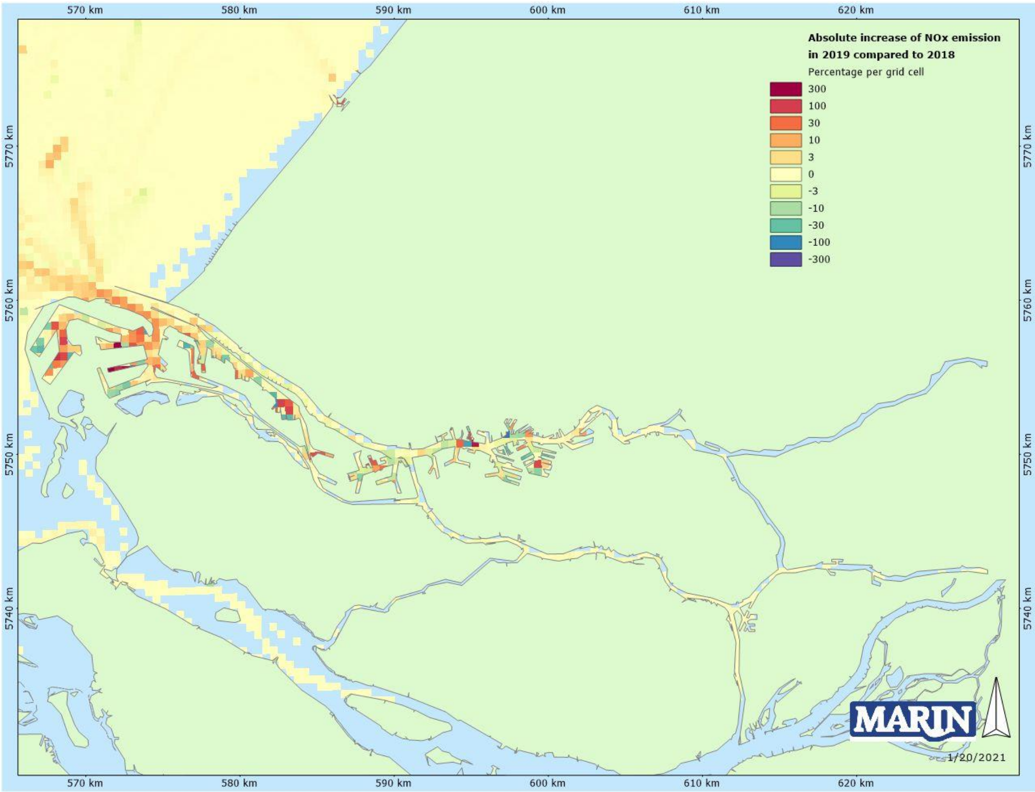

Figure 6-9 **Absolute change in NO_x emission from 2018 to 2019 in the port area of Rotterdam by ships with AIS.**

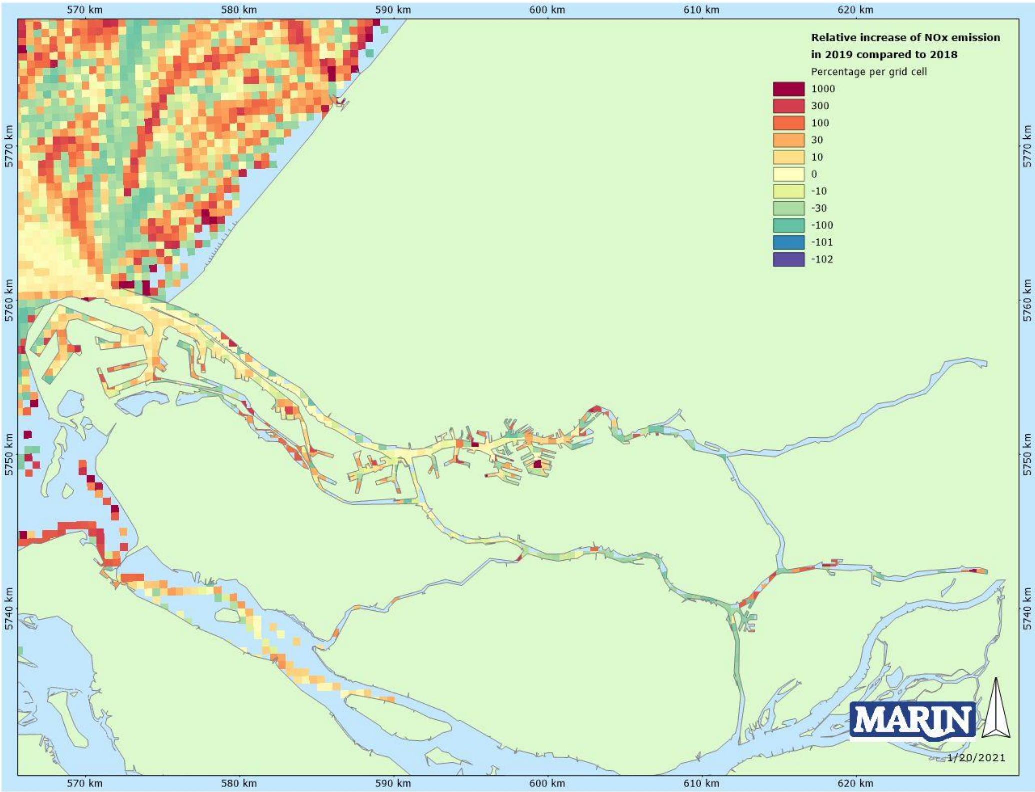

Figure 6-10 **Relative change in NO_x emission from 2018 to 2019 in the port area of Rotterdam by ships with AIS.**

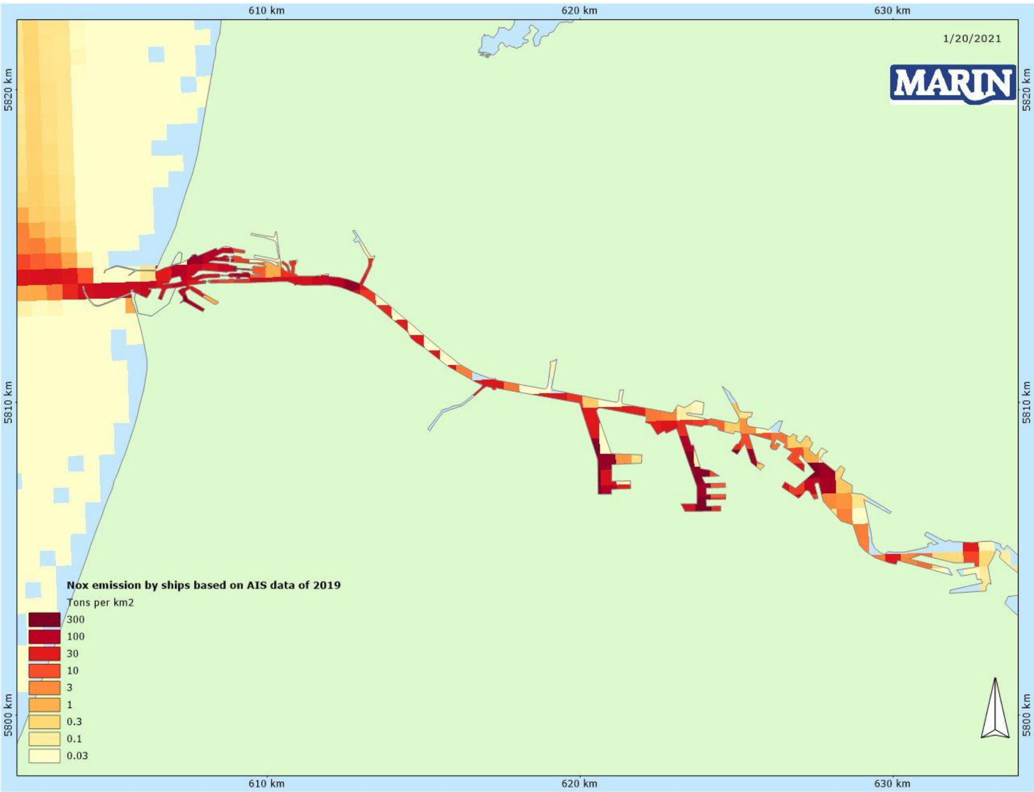

Figure 6-11 **NO_x emission in 2019 in the port area of Amsterdam by ships with AIS.**

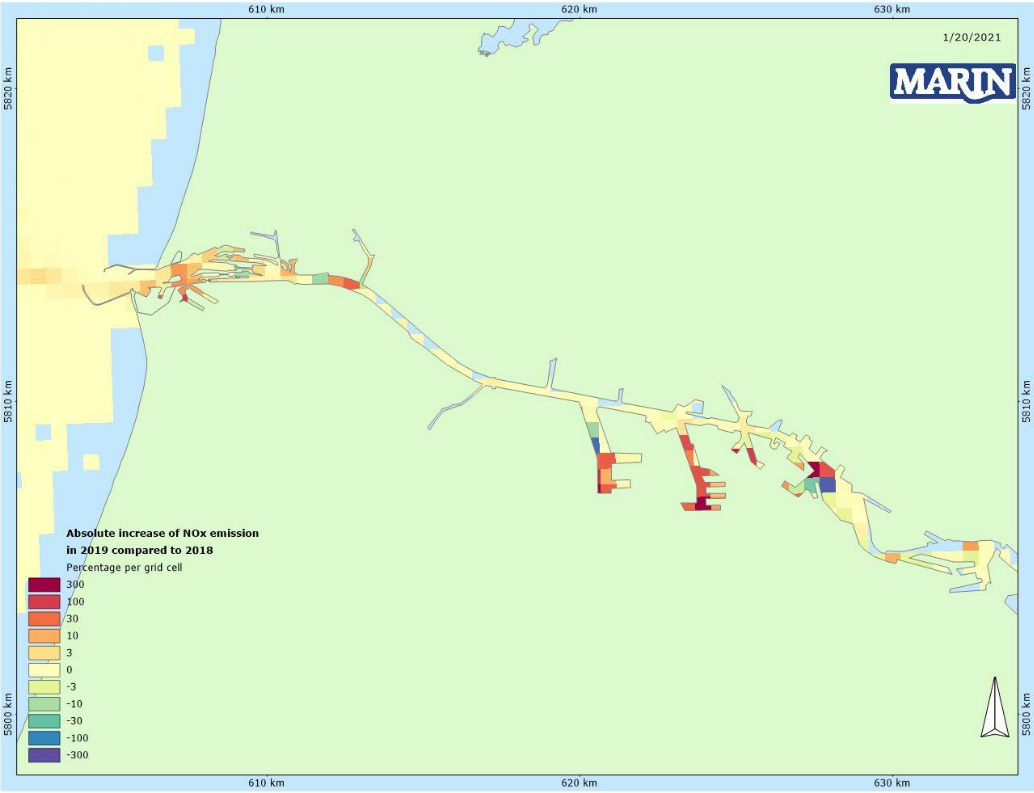

Figure 6-12 **Absolute change in NO_x emission from 2018 to 2019 in the port area of Amsterdam by ships with AIS.**

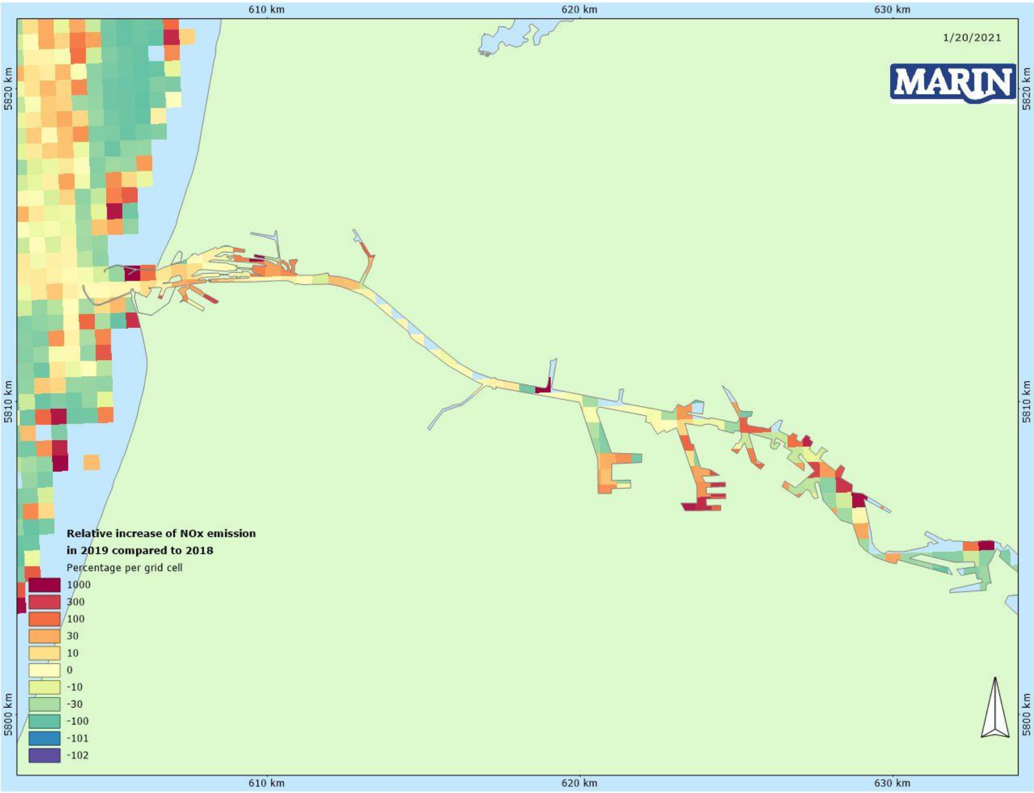

Figure 6-13 **Relative change in NO_x emission from 2018 to 2019 in the port area of Amsterdam by ships with AIS.**

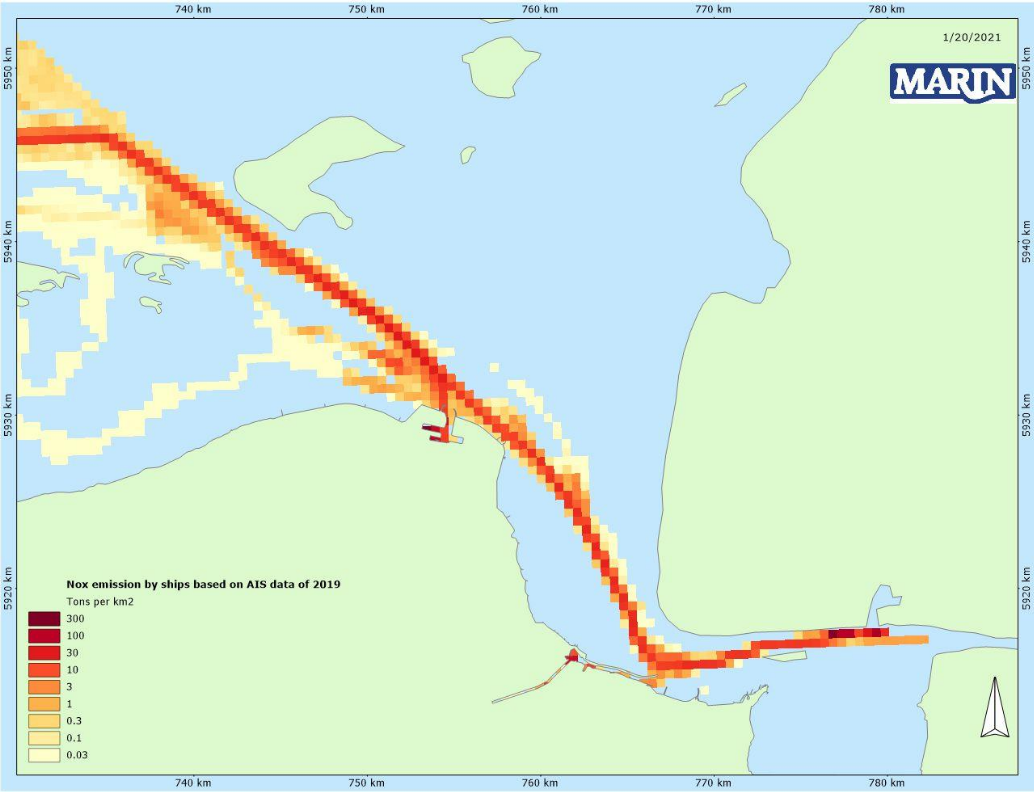

Figure 6-14 **NO_x emission in 2019 in the Ems area by ships with AIS.**

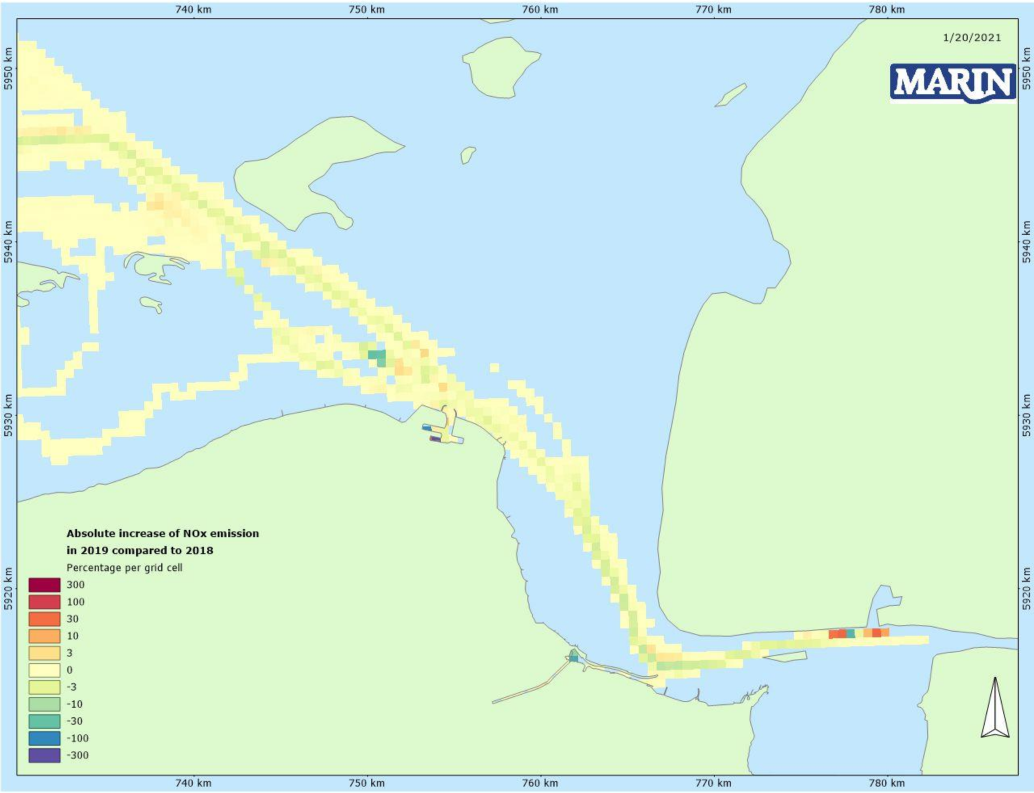

Figure 6-15 **Absolute change in NO_x emission from 2018 to 2019 in the Ems area by ships with AIS.**

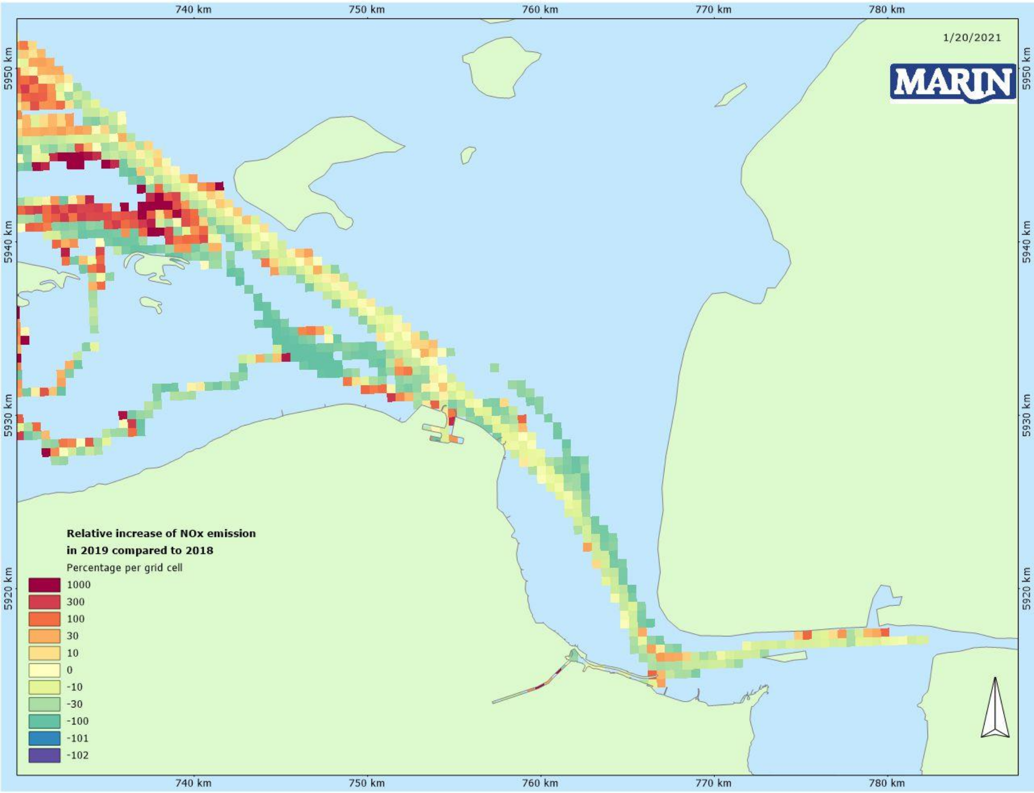

Figure 6-16 **Relative change in NO_x emission from 2018 to 2019 in the Ems area by ships with AIS.**

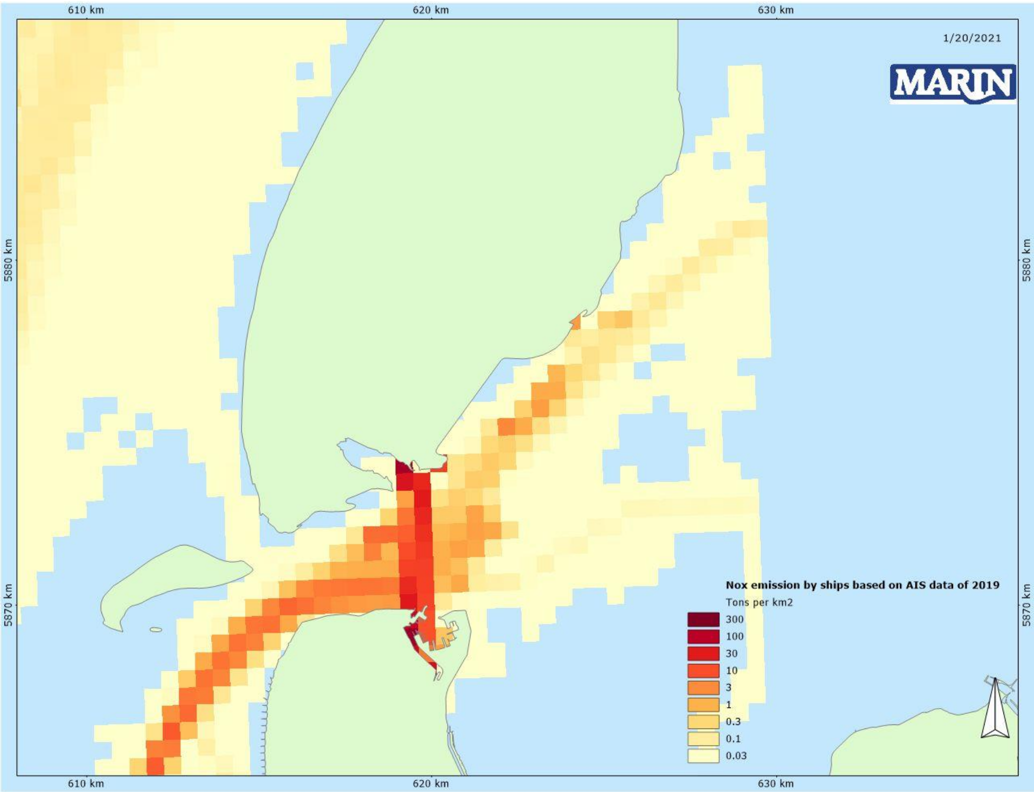

Figure 6-17 **NO_x emission in 2019 in the port area of Den Helder by ships with AIS.**

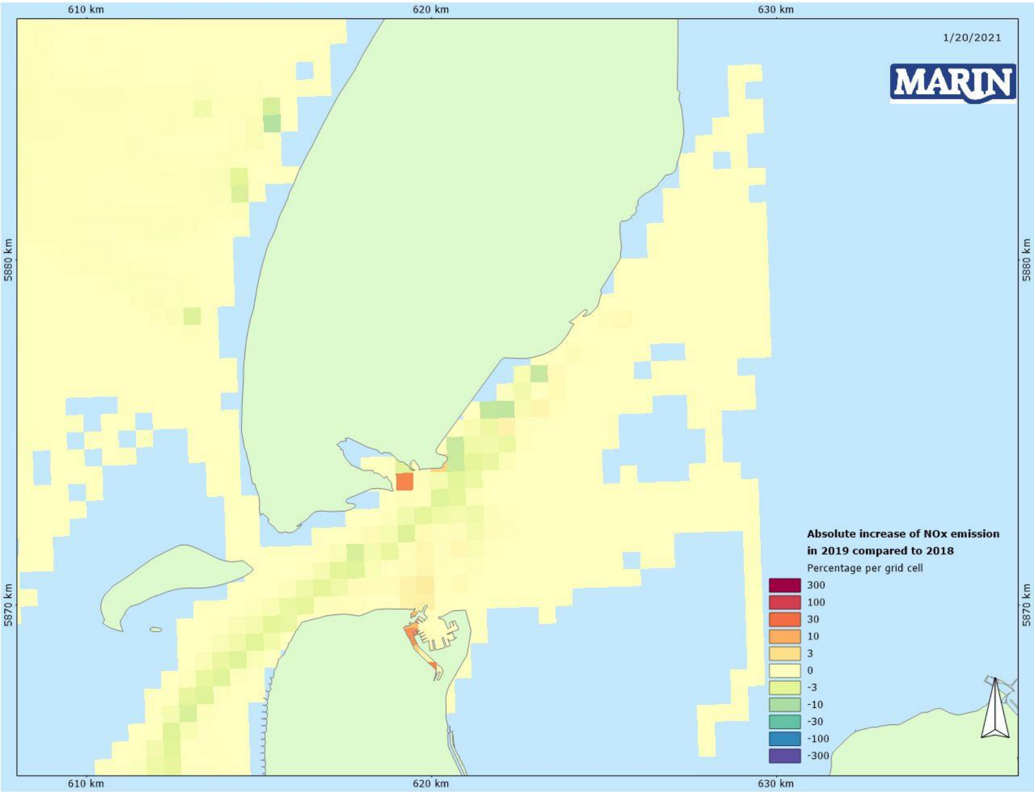

Figure 6-18 **Absolute change in NO_x emission from 2018 to 2019 in the port area of Den Helder by ships with AIS.**

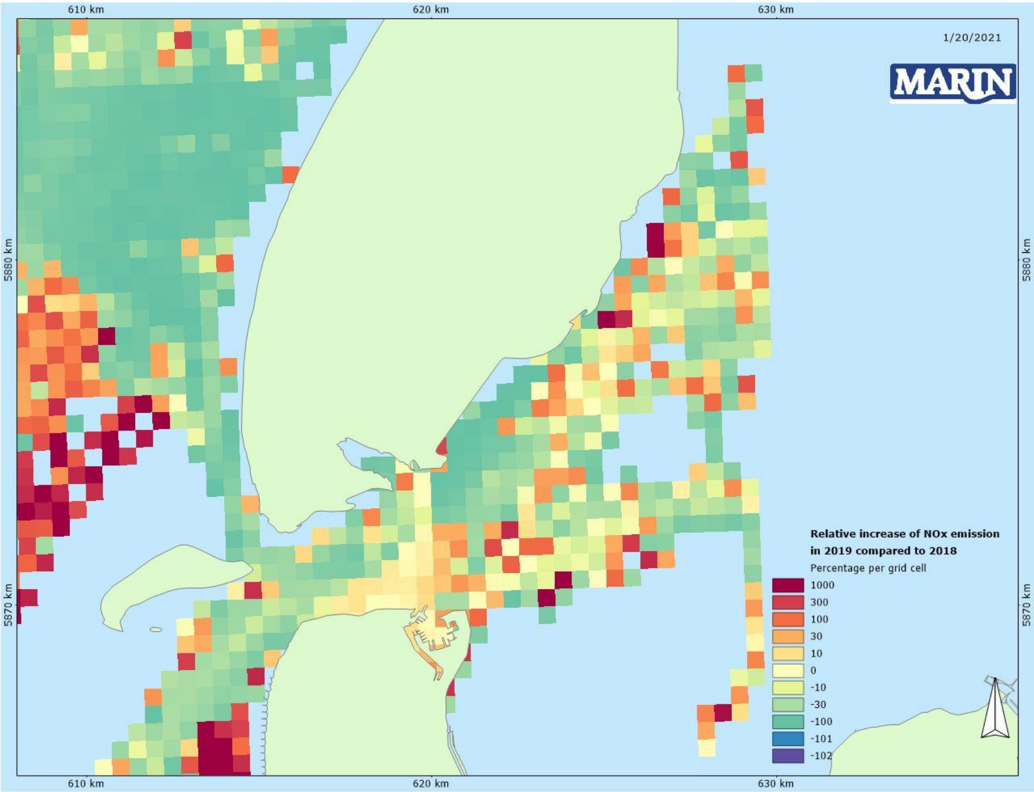

Figure 6-19 **Relative change in NO_x emission from 2018 to 2019 in the port area of Den Helder by ships with AIS.**

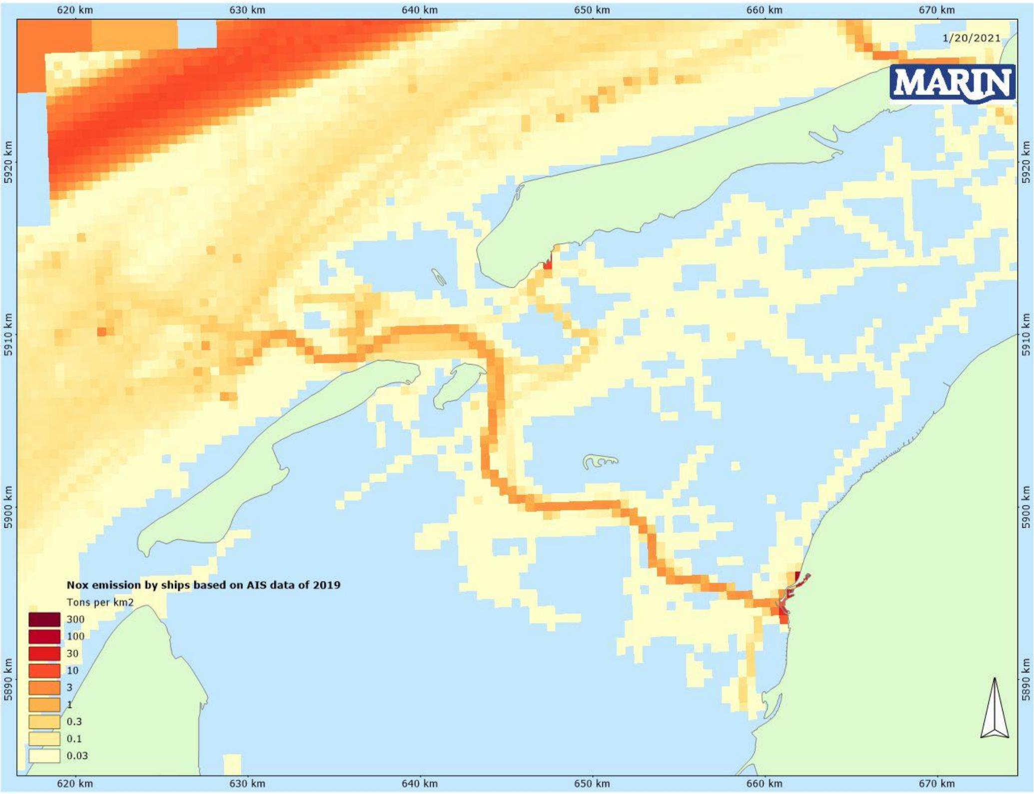

Figure 6-20 **NO_x emission in 2019 in the port area of Harlingen by ships with AIS.**

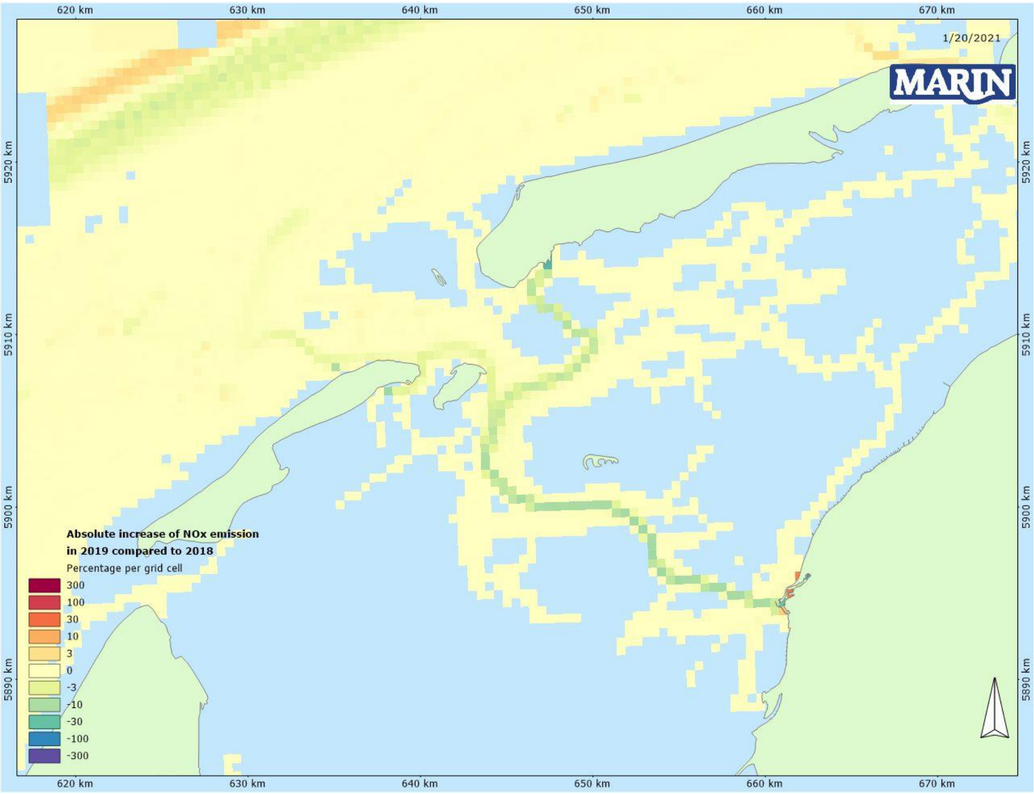

Figure 6-21 **Absolute change in NO_x emission from 2018 to 2019 in the port area of Harlingen by ships with AIS.**

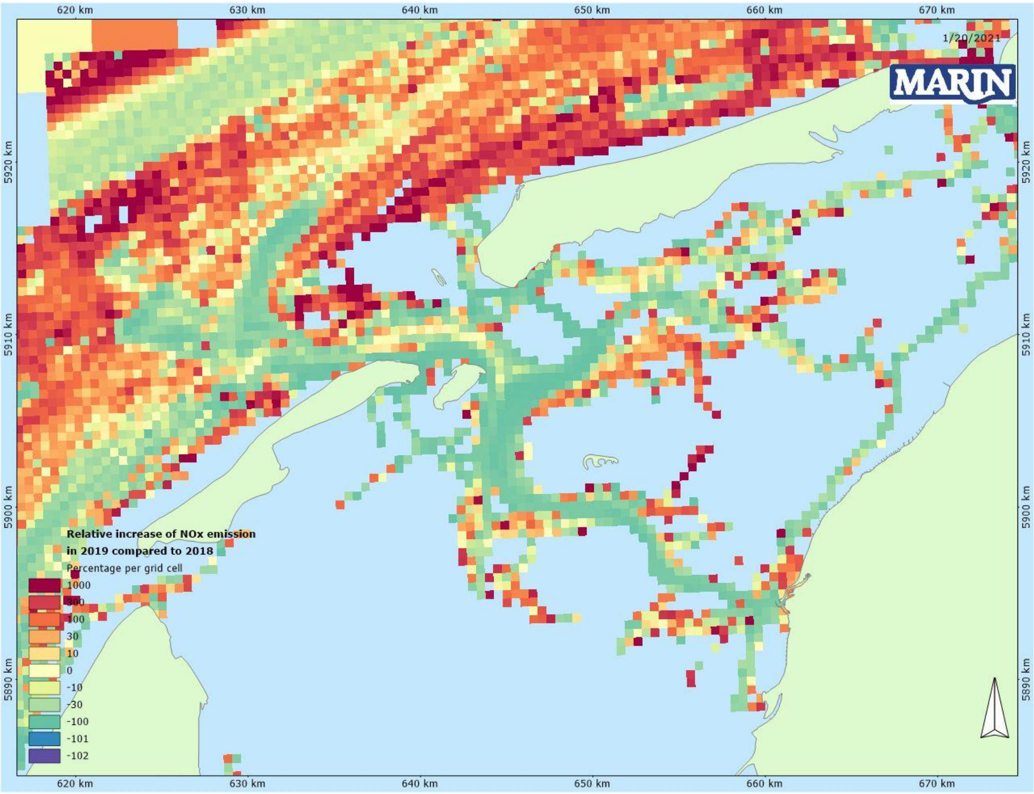

Figure 6-22 **Relative change in NO_x emission from 2018 to 2019 in the port area of Harlingen by ships with AIS.**

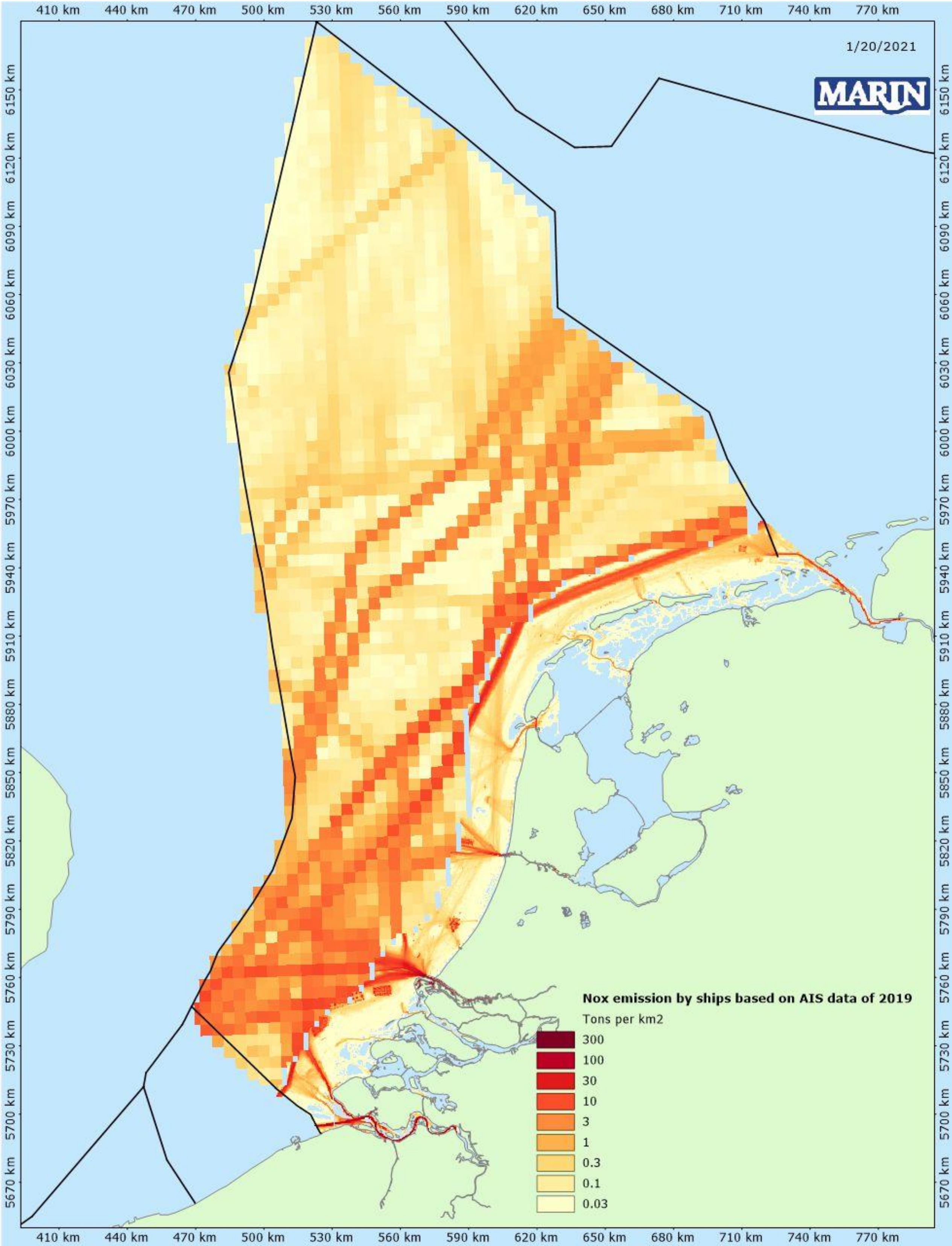

Figure 6-23 NO_x emission in 2019 in the NCS, the 12-mile zone and the Dutch port areas by ships with AIS.

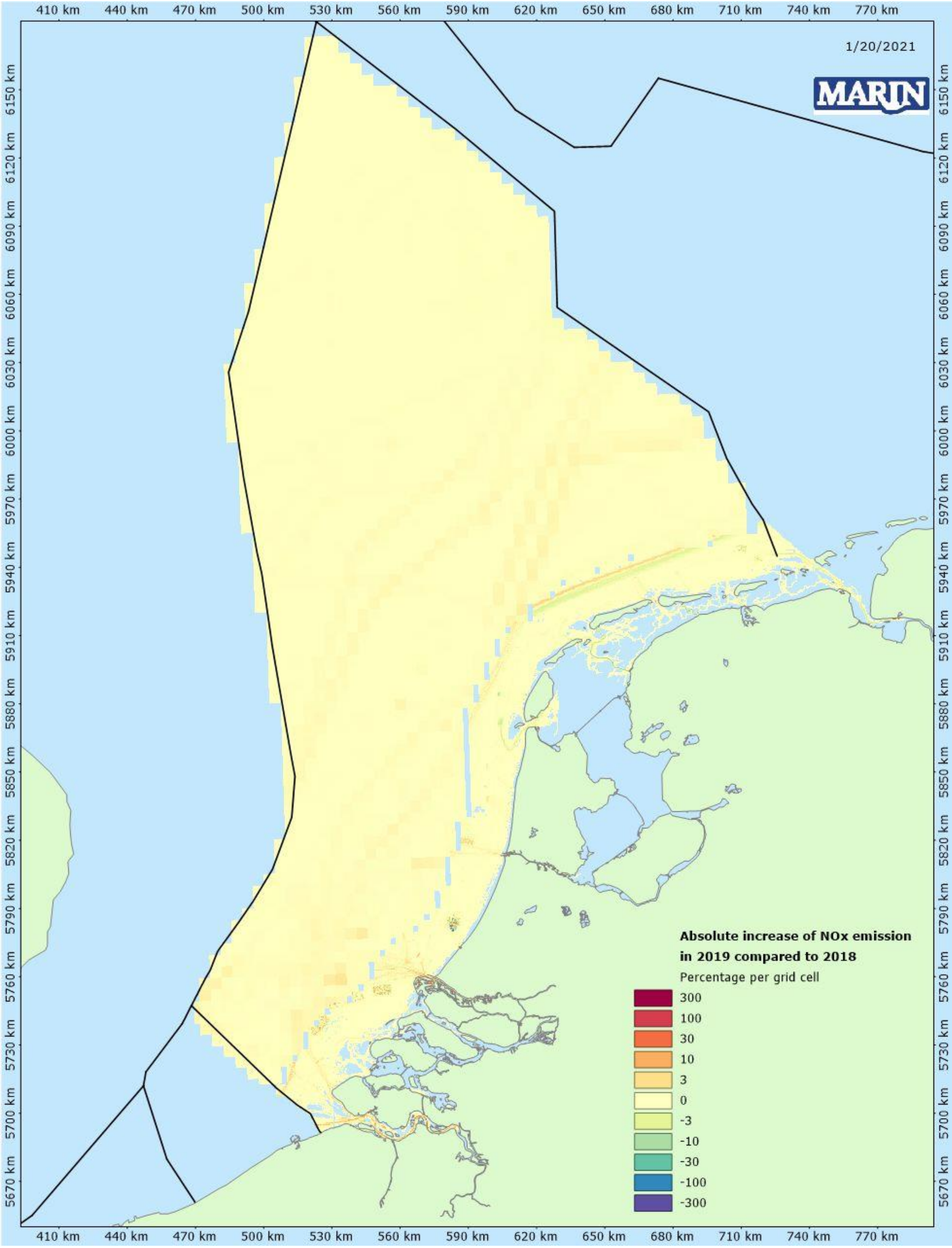

Figure 6-24 **Absolute change in NO_x emission from 2018 to 2019 in the NCS, the 12-mile zone and in the Dutch port areas by ships with AIS.**

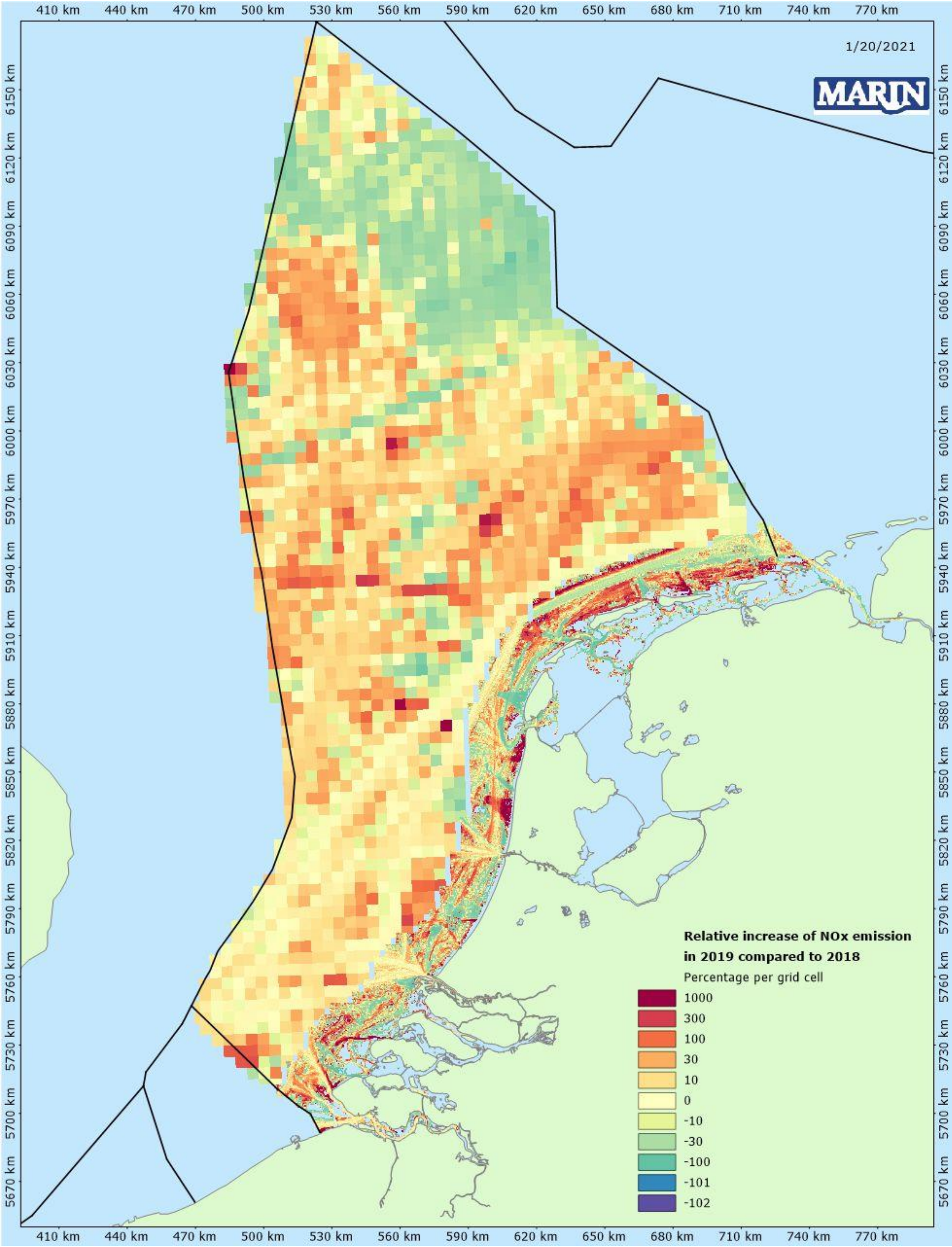

Figure 6-25 Relative change in NO_x emission from 2018 to 2019 in the NCS, the 12-mile zone and in the Dutch port areas by ships with AIS.

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 2019 for the fishing activities in the Dutch port areas, the Wadden Sea and the Netherlands sea area. Its method is explained by TNO in reference [3] and in 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. Table 7-2 presents the trend in percentages compared with the results of 2018. Table 7-3 gives the total emissions of fishing vessels for the 12 miles zone and the NCP and Table 7-4 presents the trend in percentages compared with 2018. Figure 7-1 up to and including Figure 7-6 present 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 absolute contribution of CO_2 emissions by fishing vessels is largest in Harlingen, Amsterdam and the WesternScheldt.

Compared to the previous year there is a clear increase of CO_2 emissions in the port of Amsterdam, for berthed and sailing ships together 22%. In all other ports, the total emissions of fishing vessels has decreased compared to 2018. For all ports together, there is a decrease of CO_2 emissions by 5 percent.

For the NCP and the 12-miles zone, the CO_2 emissions by fishing vessels decreased 10 percent.

Table 7-1 Total emissions in ton in each port area for 2019, fishing vessels including trawlers.

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Wadden	Total
1237 VOC	Berthed	4	2	5	0	3	6	0	21
	Sailing	1	0	1	1	1	5	1	10
	Total	5	2	6	1	4	11	2	31
4001 SO_2	Berthed	4	3	6	0	3	6	0	22
	Sailing	1	0	1	1	1	5	1	10
	Total	5	3	7	1	4	11	1	33
4013 NO_x	Berthed	95	56	134	10	62	142	5	505
	Sailing	24	3	19	16	27	114	27	230
	Total	120	59	153	26	90	256	32	735
4031 CO	Berthed	5	3	6	0	3	7	0	25
	Sailing	1	0	1	1	1	6	2	12
	Total	6	3	8	1	4	13	2	37
4032 CO_2	Berthed	6,420	4,023	7,877	737	4,427	10,080	353	33,918
	Sailing	1,586	229	1,126	1,129	1,941	7,743	1,945	15,700
	Total	8,007	4,252	9,003	1,867	6,368	17,824	2,298	49,618
6598 Aerosols MDO/HFO	Berthed	3	2	2	0	2	5	0	14
	Sailing	1	0	0	1	1	3	1	7
	Total	4	2	2	1	3	8	1	21

Table 7-2 Emissions in each port area for 2019 as percentage of the emissions in 2018, 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	93%	100%	120%	71%	111%	86%	69%	98%
	Sailing	77%	68%	99%	103%	71%	89%	110%	88%
	Total	89%	97%	116%	88%	95%	87%	100%	94%
4001 SO_2	Berthed	92%	101%	111%	78%	113%	86%	65%	97%
	Sailing	80%	65%	93%	103%	72%	89%	106%	88%
	Total	90%	98%	108%	91%	96%	87%	97%	94%
4013 NO_x	Berthed	93%	103%	119%	75%	112%	86%	64%	99%
	Sailing	81%	67%	100%	103%	72%	91%	105%	89%
	Total	90%	100%	116%	90%	96%	88%	96%	96%
4031 CO	Berthed	93%	100%	119%	73%	112%	85%	67%	98%
	Sailing	78%	67%	97%	105%	71%	88%	108%	88%
	Total	90%	97%	115%	90%	96%	86%	99%	94%
4032 CO_2	Berthed	94%	102%	125%	78%	113%	86%	68%	99%
	Sailing	82%	70%	102%	103%	72%	87%	107%	88%
	Total	91%	99%	122%	91%	97%	87%	98%	95%
6598 Aerosols MDO/HFO	Berthed	94%	99%	157%	72%	114%	83%	73%	97%
	Sailing	80%	80%	112%	104%	73%	79%	113%	84%
	Total	91%	97%	149%	89%	98%	81%	104%	92%

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	2	0	3
	Sailing	19	47	65
	Total	21	47	68
4001 SO_2	Berthed	3	0	3
	Sailing	19	48	67
	Total	22	48	70
4013 NO_x	Berthed	61	10	71
	Sailing	436	1,095	1,531
	Total	497	1,105	1,603
4031 CO	Berthed	3	0	3
	Sailing	23	56	79
	Total	26	56	82
4032 CO_2	Berthed	3,532	670	4,202
	Sailing	30,099	72,276	102,375
	Total	33,630	72,947	106,577
6598 Aerosols MDO/HFO	Berthed	1	0	1
	Sailing	14	31	45
	Total	14	31	46

Table 7-4 Emissions in 12 miles and NCP for 2019 as percentage of the emissions in 2018, 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	86%	64%	82%
	Sailing	96%	88%	90%
	Total	95%	88%	90%
4001 SO_2	Berthed	73%	61%	71%
	Sailing	95%	85%	88%
	Total	92%	85%	87%
4013 NO_x	Berthed	83%	63%	79%
	Sailing	97%	89%	91%
	Total	95%	88%	90%
4031 CO	Berthed	84%	64%	80%
	Sailing	96%	86%	88%
	Total	94%	85%	88%
4032 CO_2	Berthed	82%	69%	79%
	Sailing	97%	89%	91%
	Total	95%	88%	90%
6598 Aerosols MDO/HFO	Berthed	100%	88%	96%
	Sailing	97%	91%	93%
	Total	97%	91%	93%

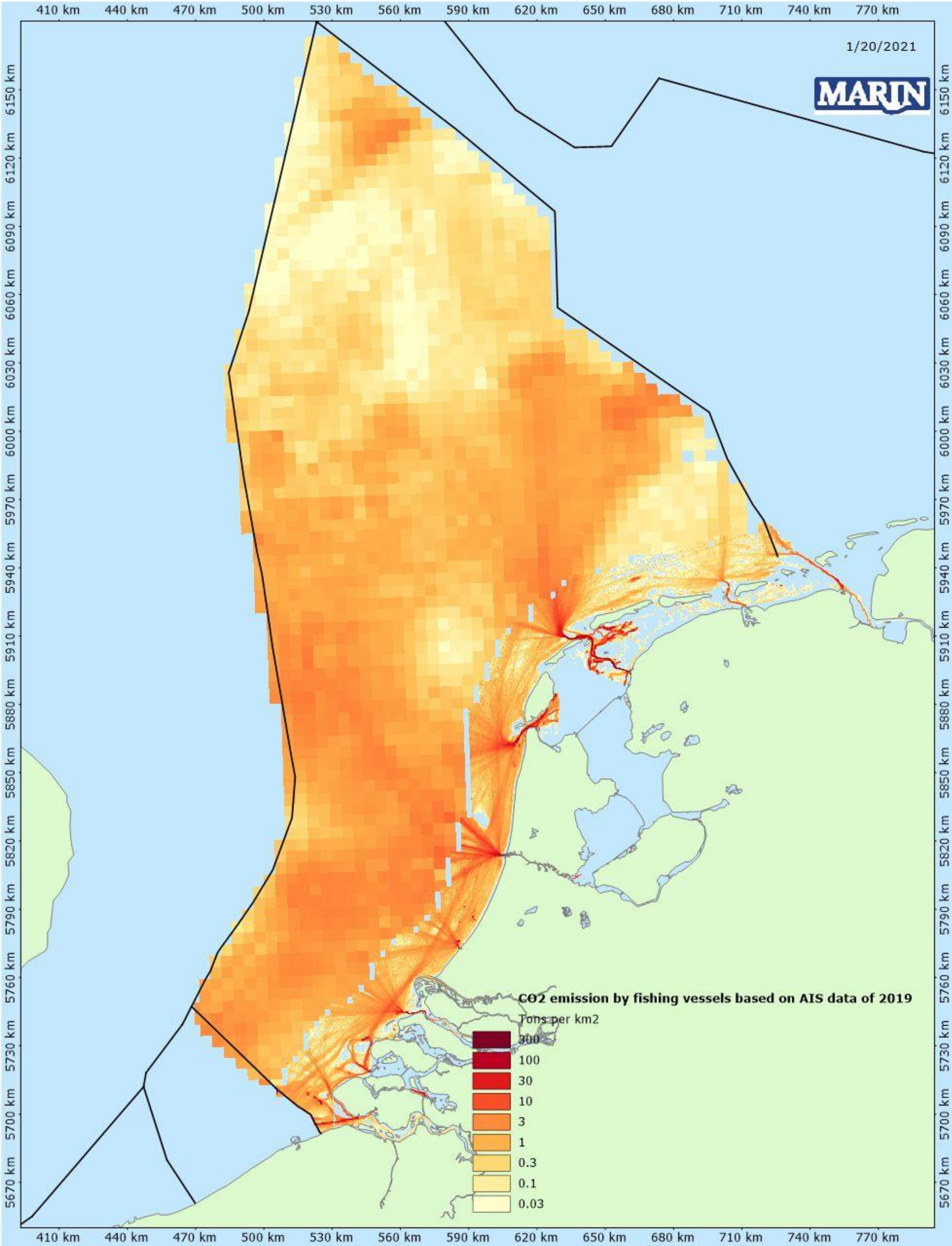

Figure 7-1 **CO_2 emission observed in the NCS, fishing vessels including trawlers, based on AIS data of 2019**

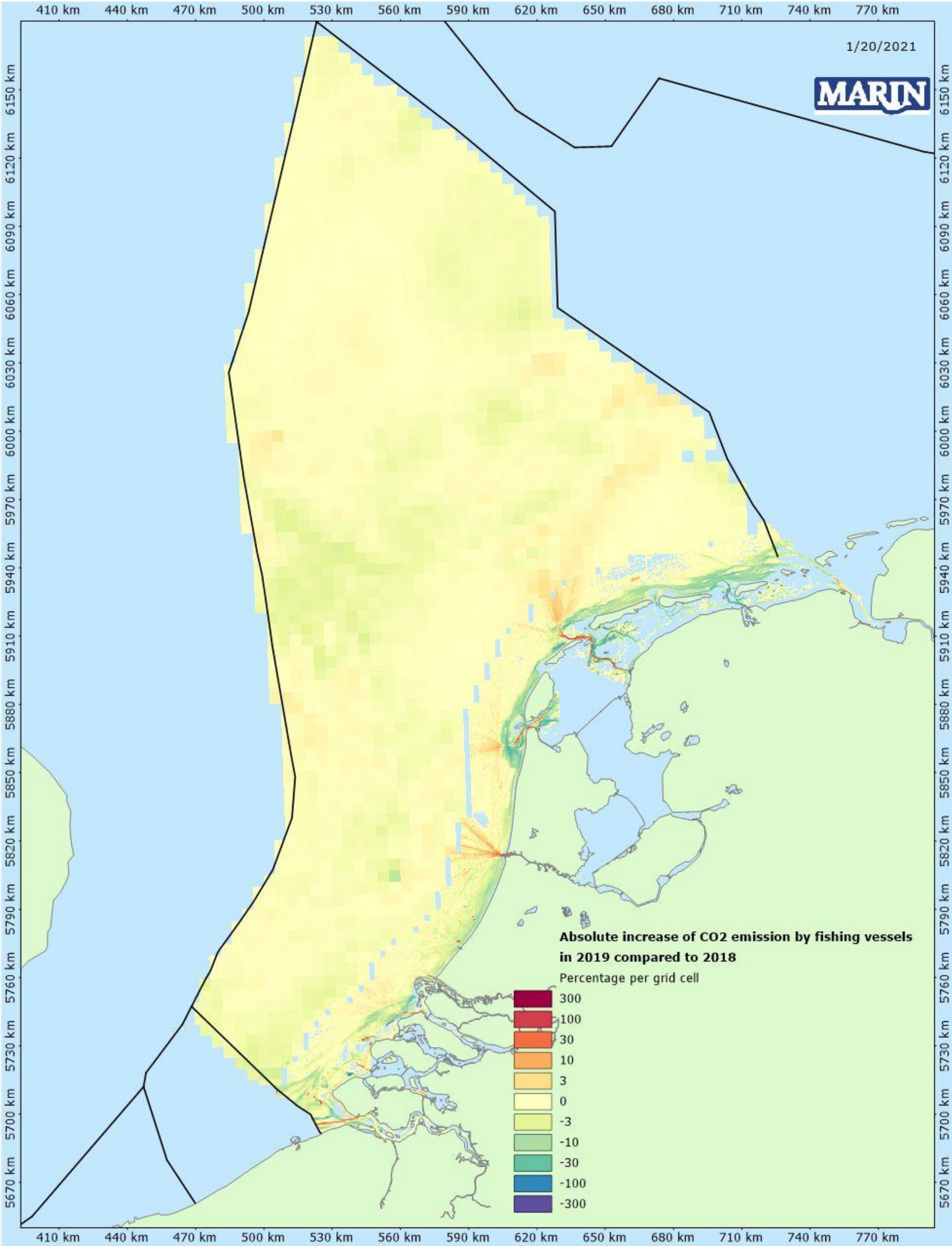

Figure 7-2 **Absolute change in CO_2 emission from 2018 to 2019 observed in the NCS, fishing vessels including trawlers.**

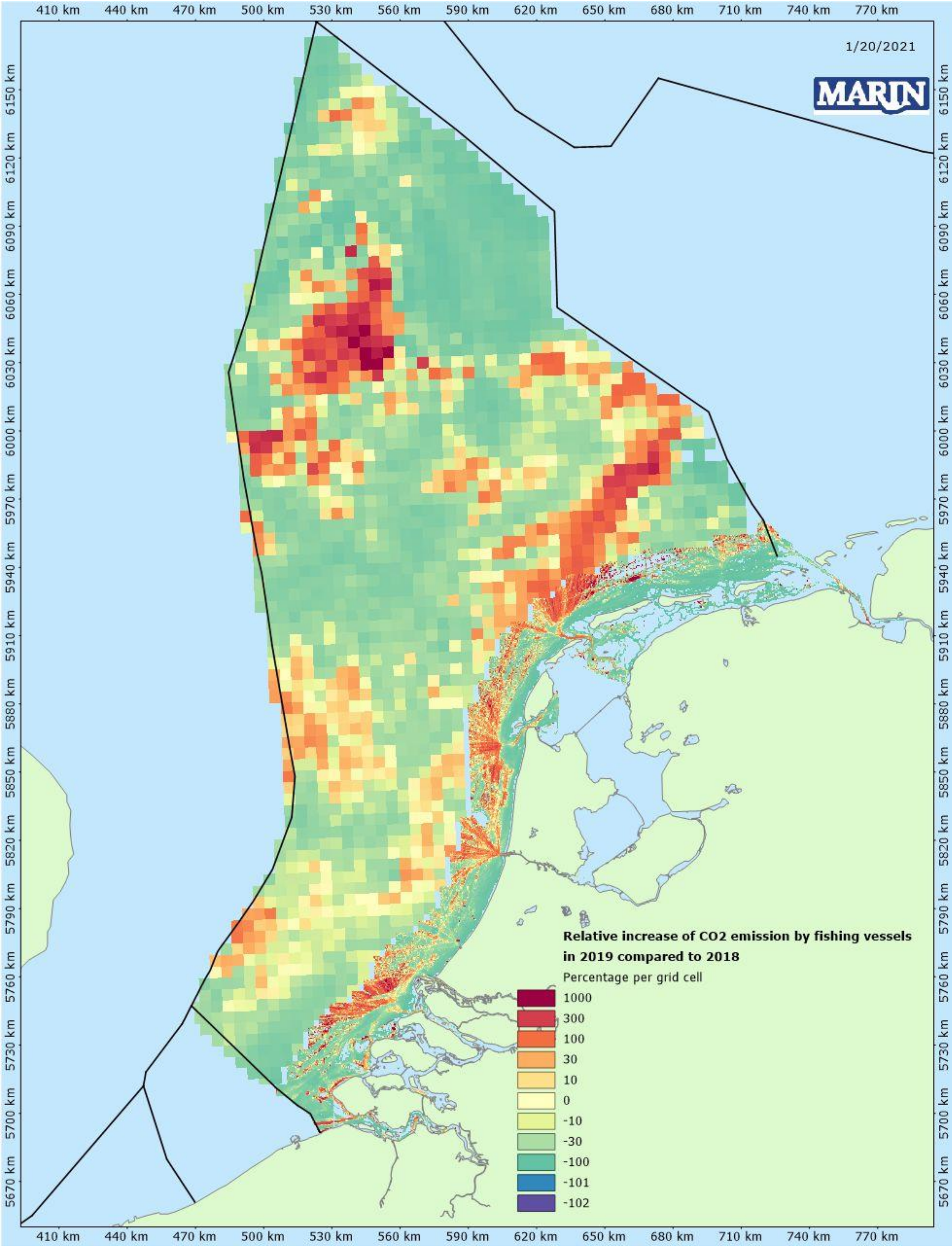

Figure 7-3 Relative change in CO2 emission from 2018 to 2019 observed in the NCS, fishing vessels including trawlers.

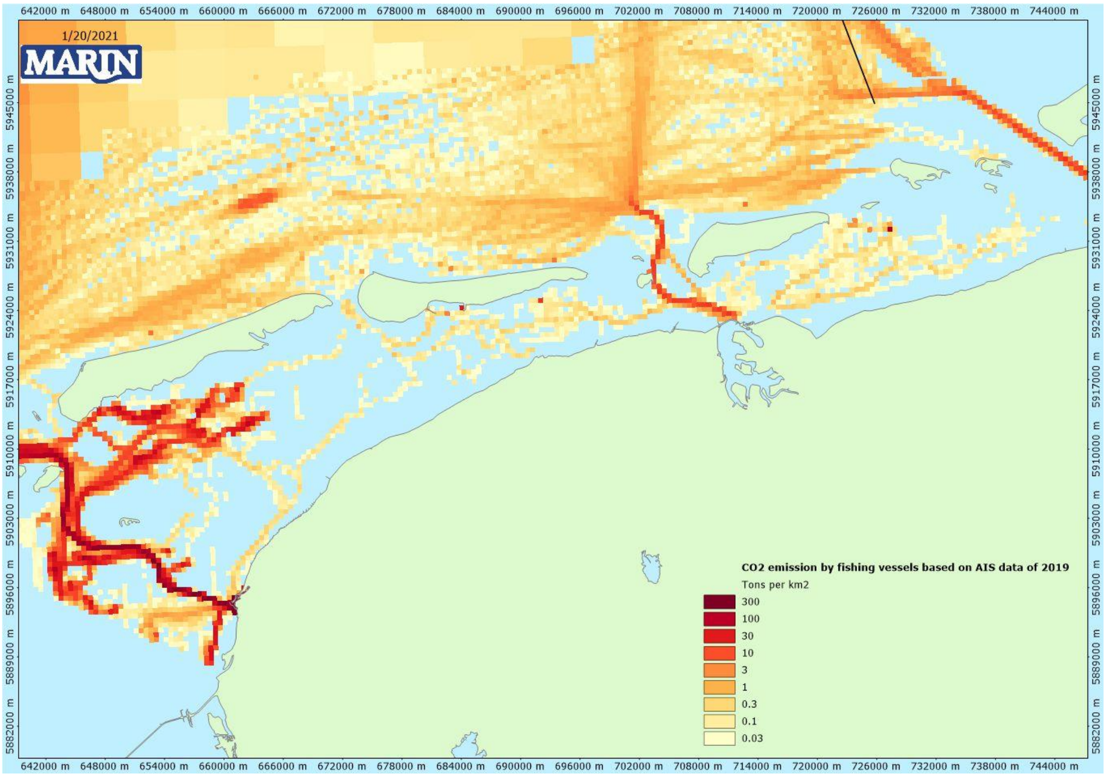

Figure 7-4 **CO_2 emission observed in the Dutch Wadden Sea, fishing vessels including trawlers, based on AIS data of 2019**

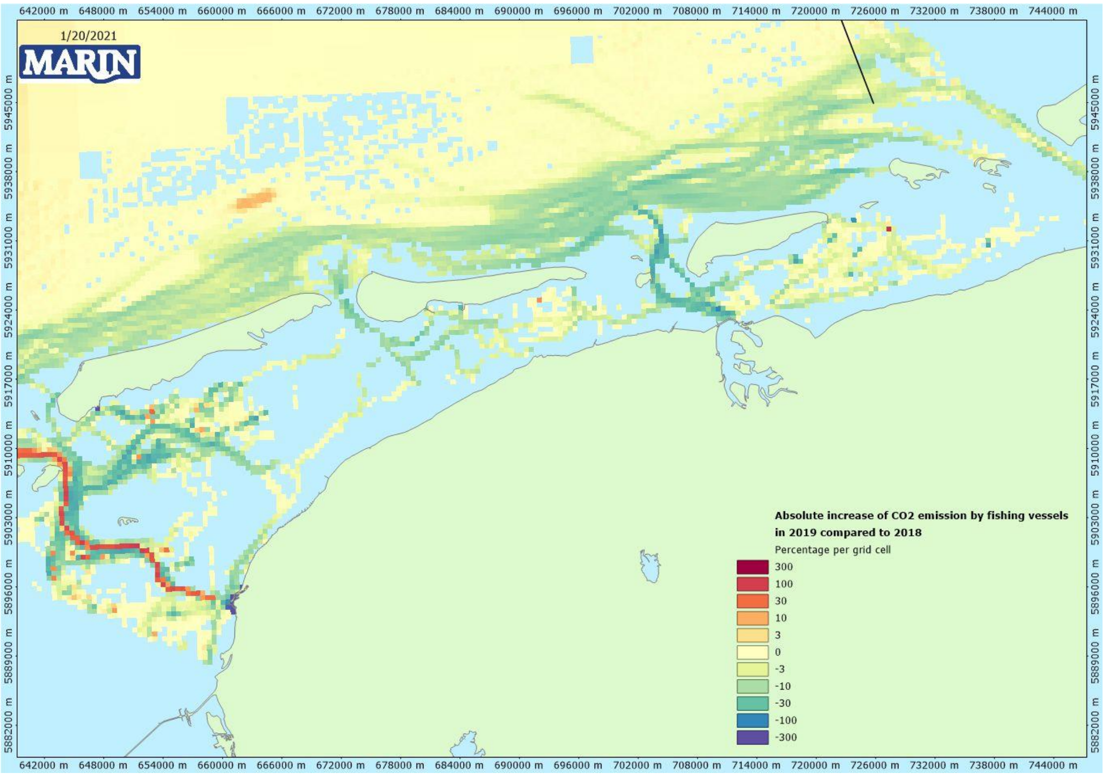

Figure 7-5 **Absolute change in CO2 emission from 2018 to 2019 in the Dutch Wadden Sea, fishing vessels including trawlers.**

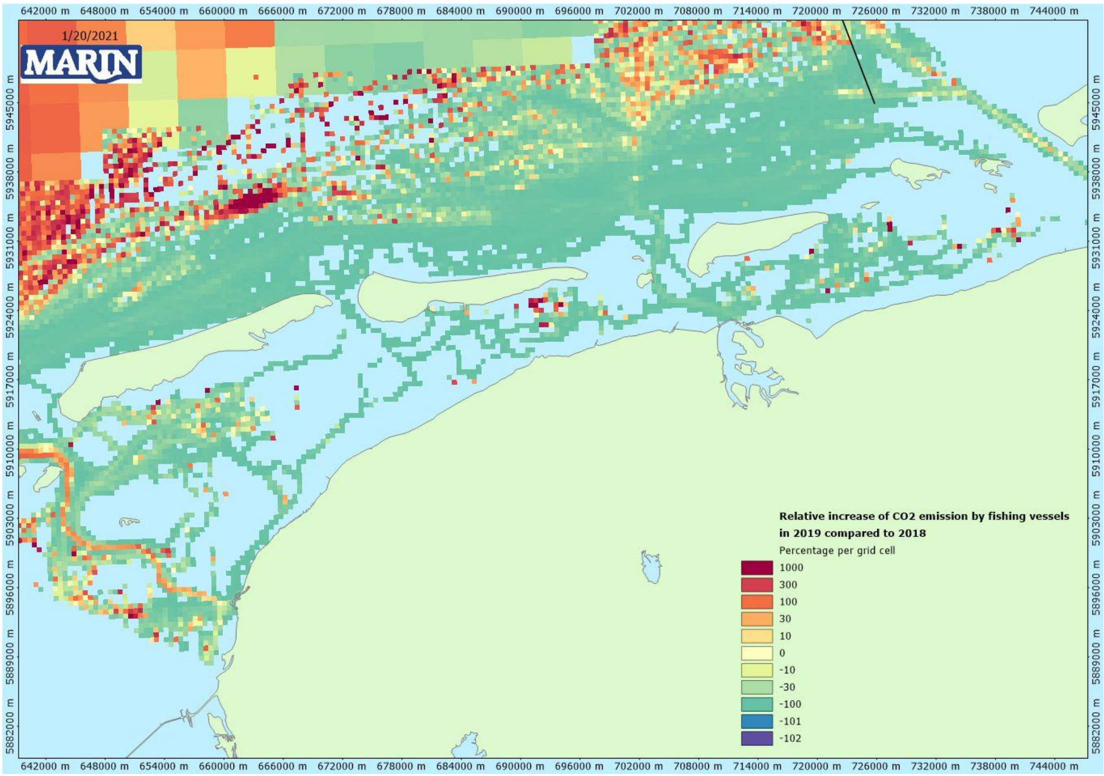

Figure 7-6 **Relative change in CO_2 emission from 2018 to 2019 in the Dutch Wadden Sea, fishing vessels including trawlers.**

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**
  The sum of missing periods, which are larger than 10 minutes, is about 1 day. To compensate for this missing period the results were multiplied with 365/364.

- **Activity data**

  Port areas
  In comparison with the activities observed in 2018 there is a clear increase of berthed and sailing ships in the port of Amsterdam, Western Scheldt and Rotterdam, while it descends in the port of Ems and Harlingen. This can also be seen in the average number of ships per day.

  NCP and the 12-miles
  The average of the total hours and GT.nm for moving vessels in the NCP has increased with almost 7.0%. For ships at anchor, there is an increase for both hours (13.0%) and GT.nm (9.7%).

- **Emission results**

  Port areas
  The substance CO_2 has the largest contribution to the total emissions in ton (98%). For all ports together, there is an overall increase of CO_2 by 7%, for ships at berth 10% and sailing ships 2%. There is a clear increase in emissions (e.g. CO_2 and NO_x) in the port of Amsterdam, Western Scheldt and Rotterdam. This is in line with the grow of activities in these ports, based from both AIS data and their annual reports. SO_2 emissions show a decrease for all ports except for Amsterdam.

  NCP and the 12-miles
  The substance CO_2 has the largest contribution to the total emissions in ton (97%). For NCP combined with the 12-miles there is a total increase of CO_2 by 4%, for ships at berth 8% and sailing ships 4%. The most substances show an overall increase except for SO_2. The substance NO_x show a dip for the emissions registration of 2018.

  For the Netherlands sea area the average number of ships increased by 9%.

- **Emission results fishery**

  Port areas
  Compared to the previous year there is a clear increase of CO_2 emissions in the port of Amsterdam, for berthed and sailing ships together 22%. In all other ports, the total emissions of fishing vessels has decreased compared to 2018. For all ports together, there is a decrease of CO_2 emissions by 5%.

  NCP and the 12-miles
  For the NCP and the 12-miles zone, the total decrease of CO_2 emissions by fishing vessels is 10%.

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 2019

[6] K.F. Kauffman, J. Hulskotte
Sea Shipping emissions 2018: Netherlands Continental Shelf, 12 Mile Zone and Port areas
MARIN, no: 32410-1-MSCN-rev.2, June 2020

[7] Websites:

https://www.portofrotterdam.com

https://jaarverslag.portofamsterdam.com

https://www.portofantwerp.com

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)

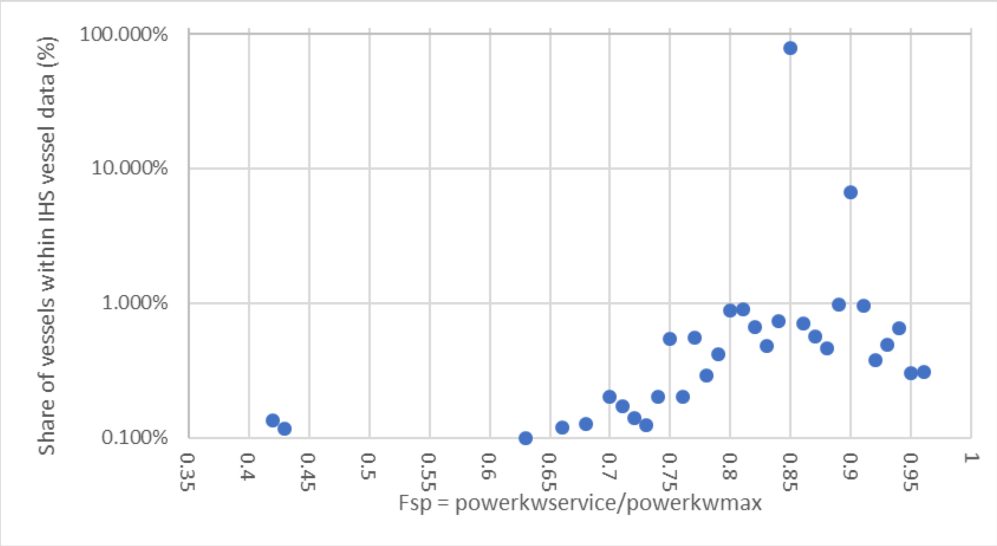

Figure A- 1 Statistics of the Sea-margin

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.

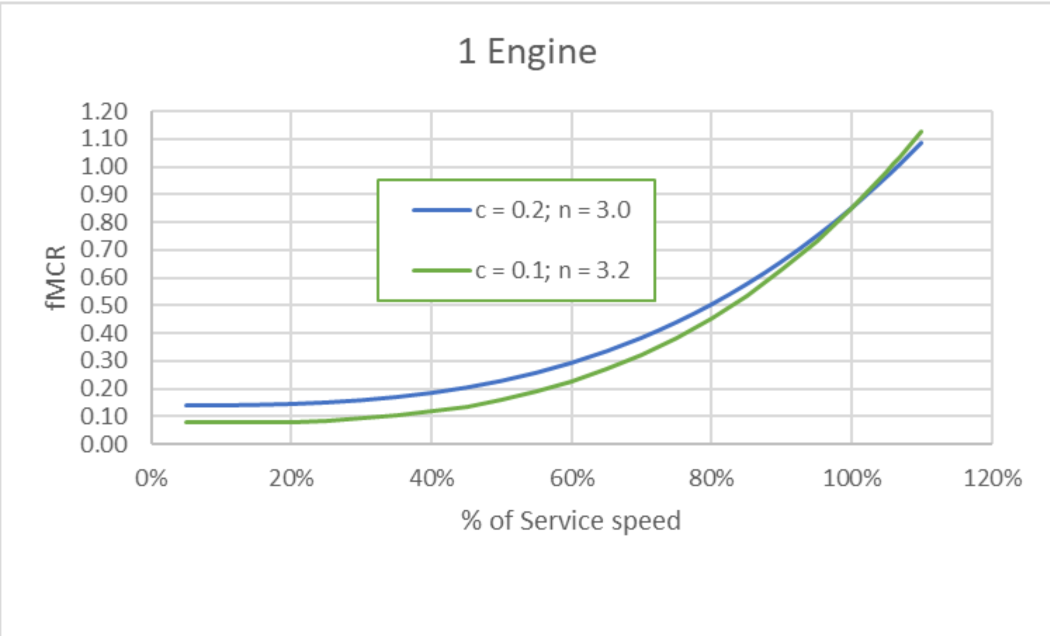

Figure A- 2 The relationship between service speed and fMCR at ships with one single propulsion engine used in emission calculations

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.

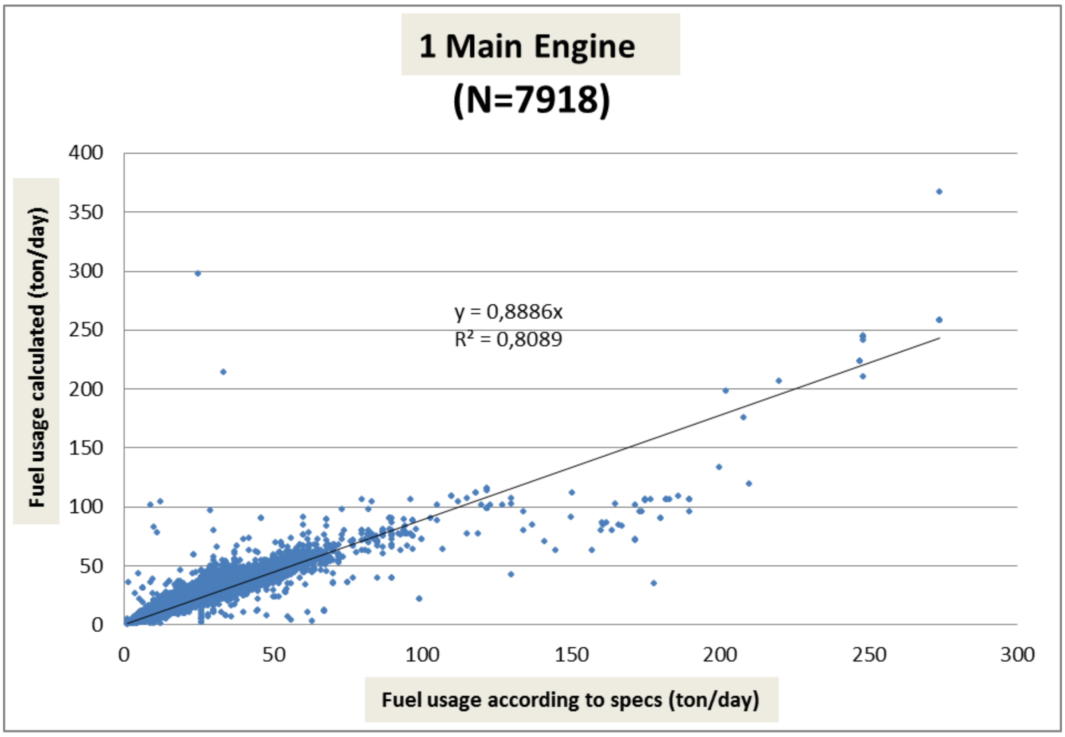

Figure A- 3 Calculated daily fuel usage of one-engine ships compared with specifications

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.

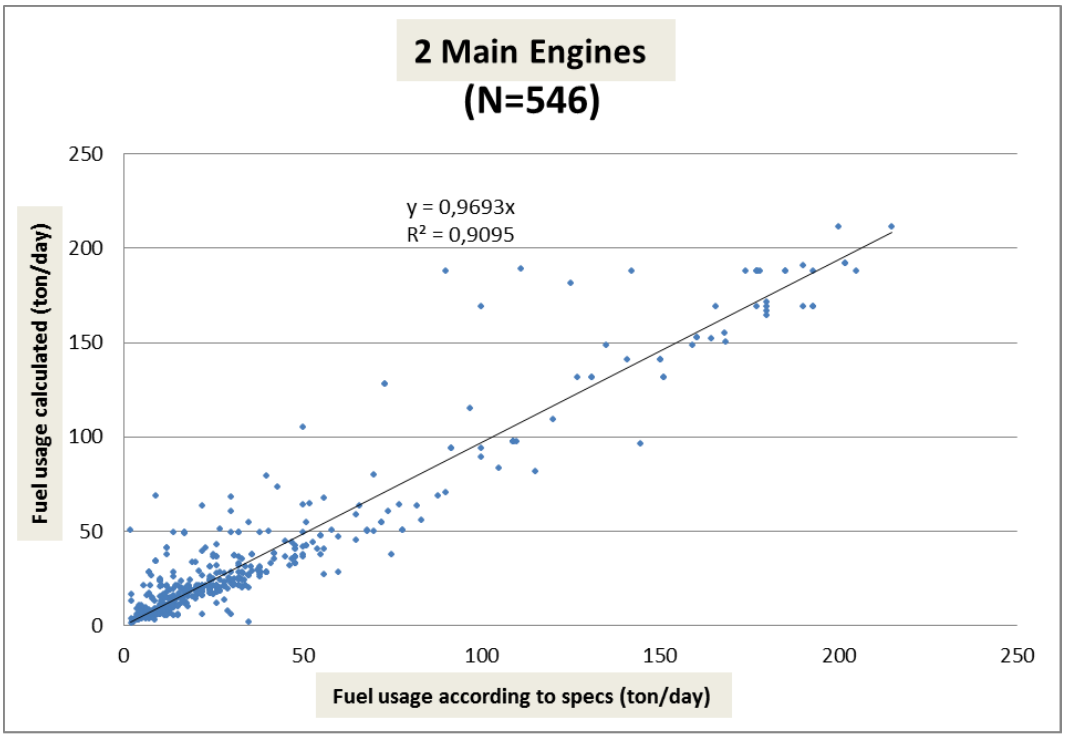

Figure A- 4 Calculated daily fuel usage of two engine ships compared with specifications

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.

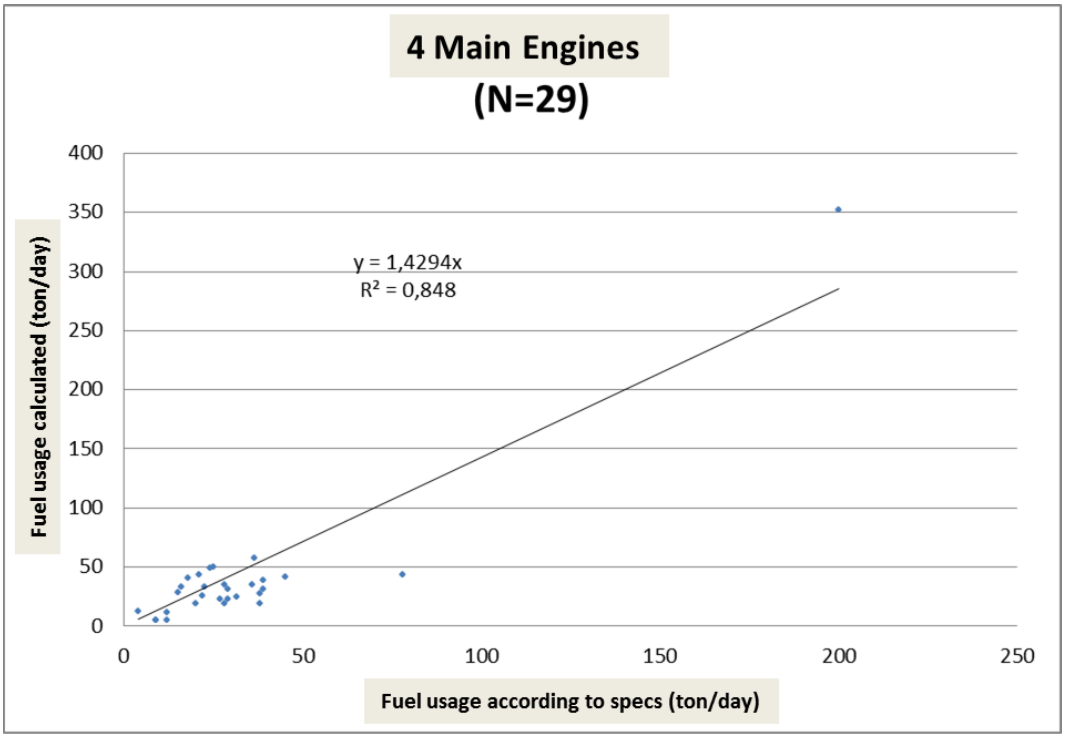

Figure A- 5 Calculated daily fuel usage of four engine ships compared with specifications

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 0.13% 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 0.13% 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 * 0.13 * 20 = 0.208 g/kg fuel. For instance having a SFOC value of 210 g/kWh results in PM from sulphur alone in 210/1000 * 0.208 = 0.044 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[2]	PM-HFO Other[3]	SO_2 NCP	SO_2 Other	VOC	CO	CO_2	SFOC
1900 – 1973	16	0,44	0,44	0.63	0.63	0.6	0.75	666	210
1974 – 1979	18	0,44	0,44	0.60	0.60	0.6	0.75	635	200
1980 – 1984	19	0,44	0,44	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[4]	0,34	0,34	0.50	0.50	0.3	0.5	533	168
2011 – 2018		0,23	0,23	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	0,34	0,34	0.63	0.63	0.6	0.75	666	210
1974 - 1979	18	0,34	0,34	0.60	0.60	0.6	0.75	635	200
1980 - 1984	19	0,34	0,34	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		0,23	0,23	0.50	0.50	0.3	0.5	523	165

2 NCP: Dutch Continental Shelf

[3] Other areas: Include harbours areas

[4] 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	0,64	0,64	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	0,34	0,34	0.62	0.62	0.6	0.75	650	205
1985 - 1989	16	0,34	0,34	0.59	0.59	0.6	0.63	619	195
1990 - 1994	14	0,29	0,29	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	0.08	0.08	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	0.314	0.314	0.92	0.92		0.1	0.15	971	306
MDO	2.0	0.311	0.31	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	0.01	0.003	6.90	1.9	450	162
SP-GDI	12.5	0.01	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 a little too 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 and SO_2 are assumed 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 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	2,6	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 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