BETTER SHIPS, BLUE OCEANS

Sea Shipping Emissions 2021: Netherlands Continental Shelf, 12-Mile Zone and Port Areas

Final Report

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Sea Shipping Emissions 2021: Netherlands Continental Shelf, 12-Mile Zone and Port Areas

Final Report

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GLOSSARY OF DEFINITIONS AND ABBREVIATIONS

Definitions:

Ship characteristics database	IHS-database (Lloyds Register of ships) contains vessel characteristics of over 120,000 seagoing merchant vessels larger than 100 GT operating worldwide. The information includes year of built, vessel type, vessel size, service speed, installed power of main and auxiliary engine.
Netherlands sea area	NCS and 12-mile zone

Abbreviations/Substances:

Methane (CH_4)	Gas formed from the combustion of LNG. Substance number **1011**
VOC	*V*olatile Organic Compounds. Substance number **1237**
Sulphur dioxide (SO_2)	Gas formed from the combustion of fuels that contain sulphur. Substance number **4001**
Nitrogen oxides (NO_x)	The gases nitrogen monoxide (NO) and nitrogen dioxide (NO_2). NO is predominantly formed in high temperature combustion processes and can subsequently be converted to NO_2 in the atmosphere. Substance number **4013**
Carbon Monoxide (CO)	A highly toxic colourless gas, formed from the combustion of fuel. Particularly harmful to humans. Substance number **4031**
Carbon Dioxide (CO_2)	Gas formed from the combustion of fuel. Substance number **4032**
PM	Particulates from marine diesel engines irrespective of fuel type. Substance number **6598**
PM-MDO	Particulates from marine diesel engines operated with distillate fuel oil. Substance number **6601**
PM-HFO	Particulates from marine diesel engines operated with residual fuel oil. Substance number **6602**

Abbreviations/Other:

AIS	Automatic Identification System
EMS	Emissieregistratie en Monitoring Scheepvaart (Emission inventory and Monitoring for the shipping sector)
GT	Gross Tonnage
IHS	IHS Maritime World Register of Ships
IMO	International Maritime Organization
LLI	Lloyd's List Intelligence (previously LLG and LMIU)
m	meter
MMSI	Maritime Mobile Service Identity is a unique number to call a ship. The number is added to each AIS message.
NCS	Netherlands Continental Shelf
nm	nautical mile or sea mile is 1852m
SAMSON	Safety Assessment Model for Shipping and Offshore on the North Sea
TSS	Traffic Separation Scheme

1 INTRODUCTION

1.1 Objective

This study aims to determine the emissions to air of seagoing vessels and fishing vessels for 2021. The results of both the seagoing vessels and 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 2021 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 2021.
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 2021 for the Dutch port areas and the Netherlands sea area and makes a comparison with 2020.
Chapter 7 contains the emissions results for 2021 for the fishing activities.
Chapter 8 presents conclusions and recommendations.

2 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.

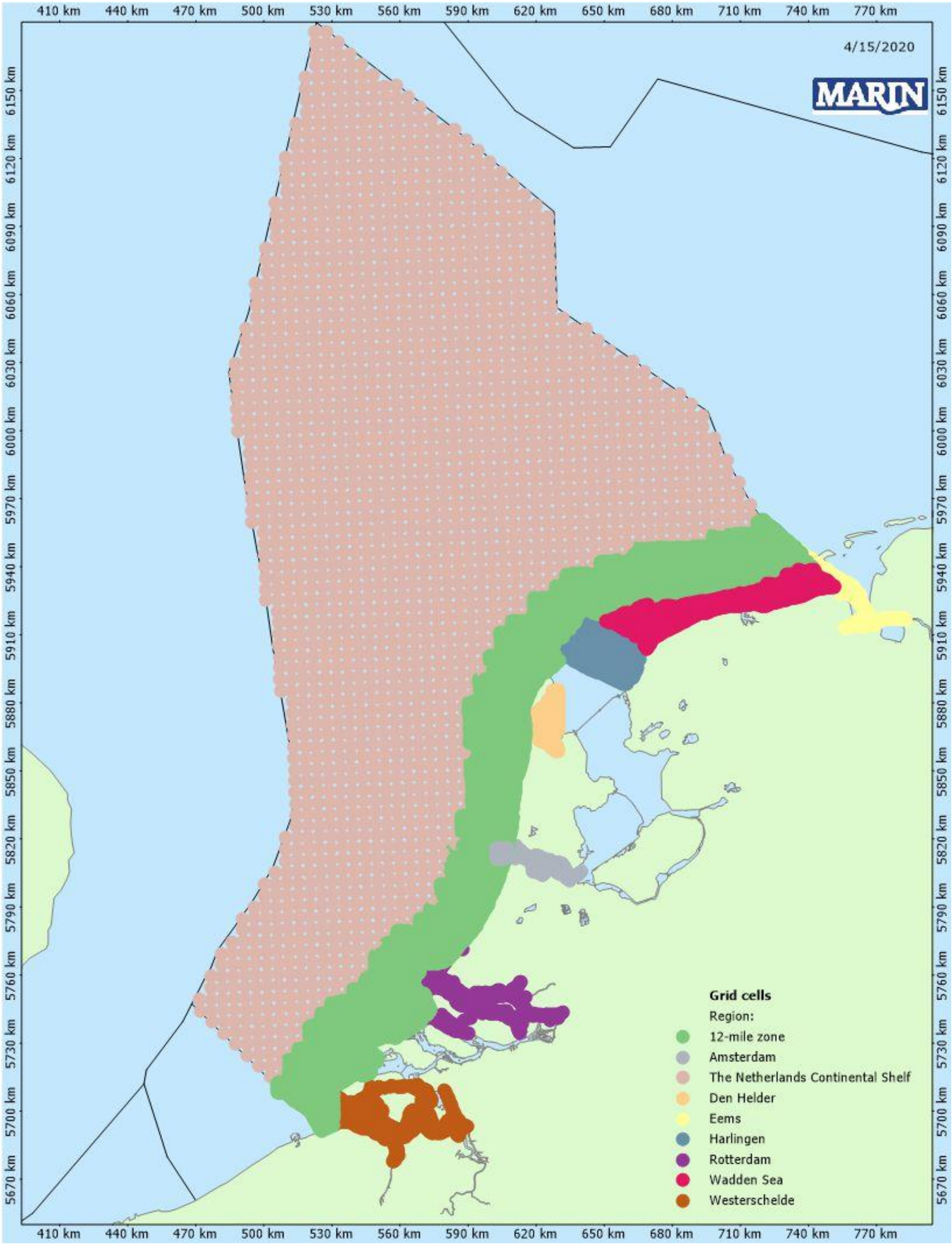

Figure 2-1 **Grid points for The Netherlands Continental Shelf, 12-mile zone, The Wadden Sea and six port areas**

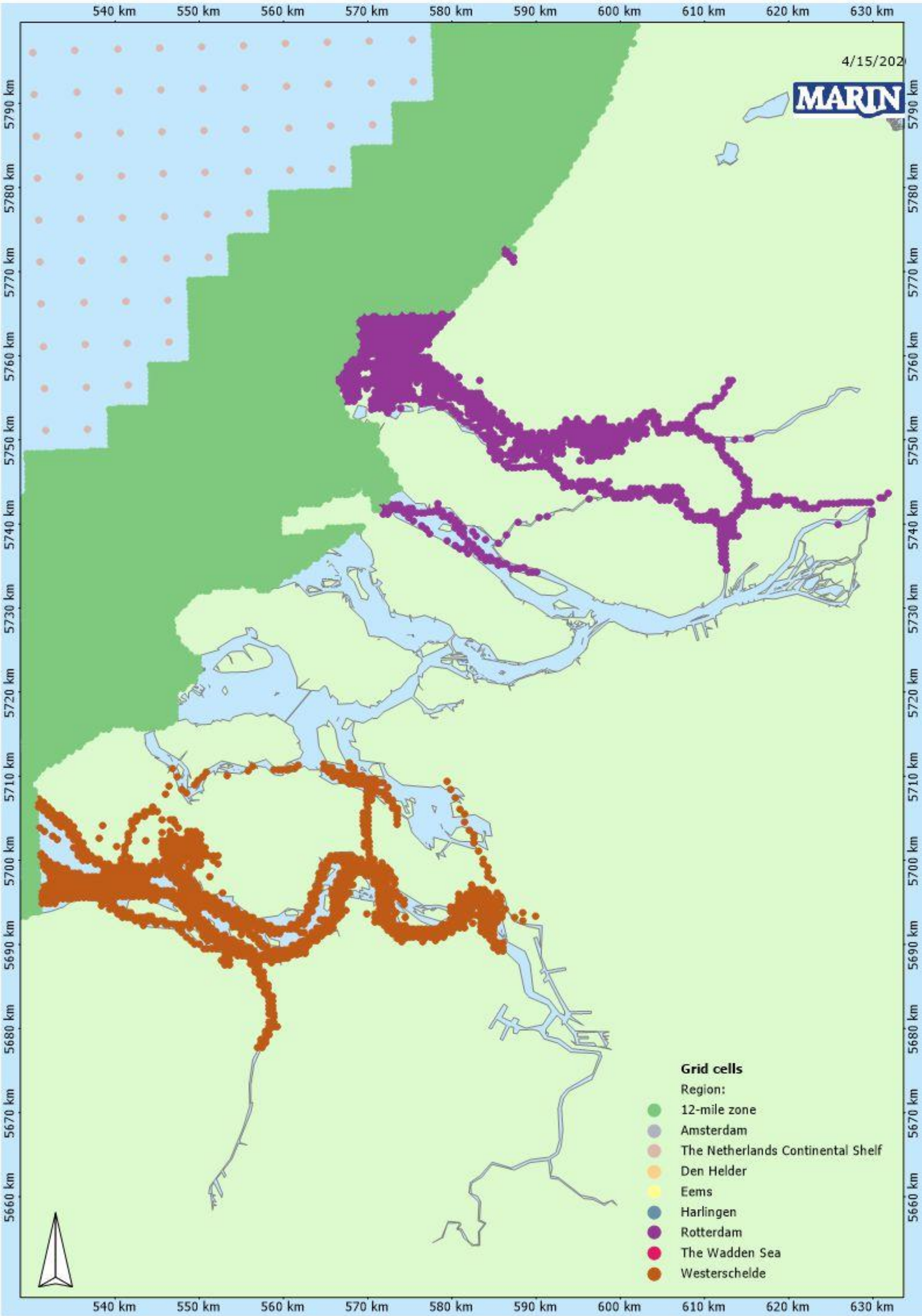

Figure 2-2 **Rotterdam and the Western Scheldt: The points indicate the centres of grid cells for which emissions are calculated**

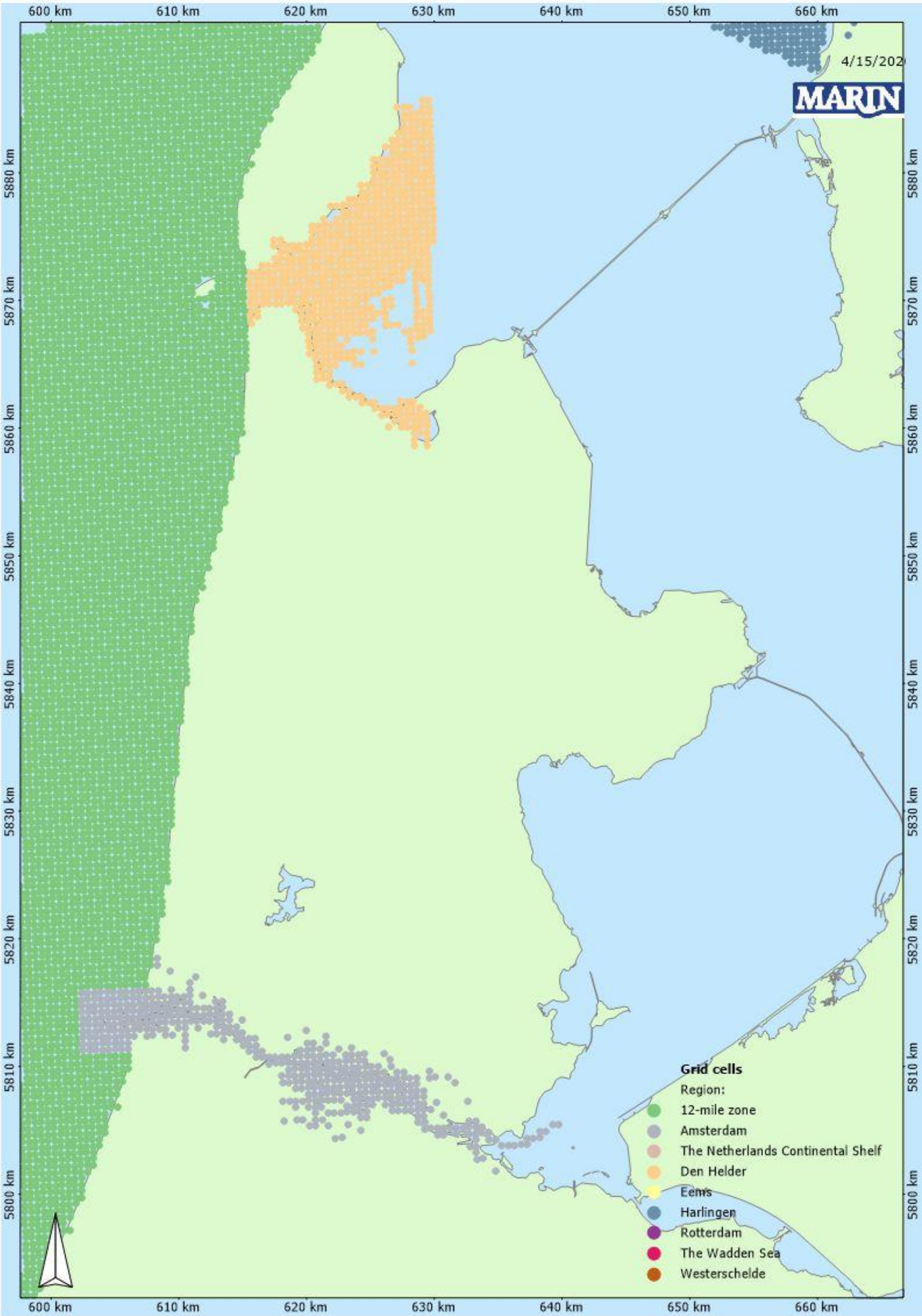

Figure 2-3 **Amsterdam and Den Helder: The points indicate the centres of grid cells for which emissions are calculated**

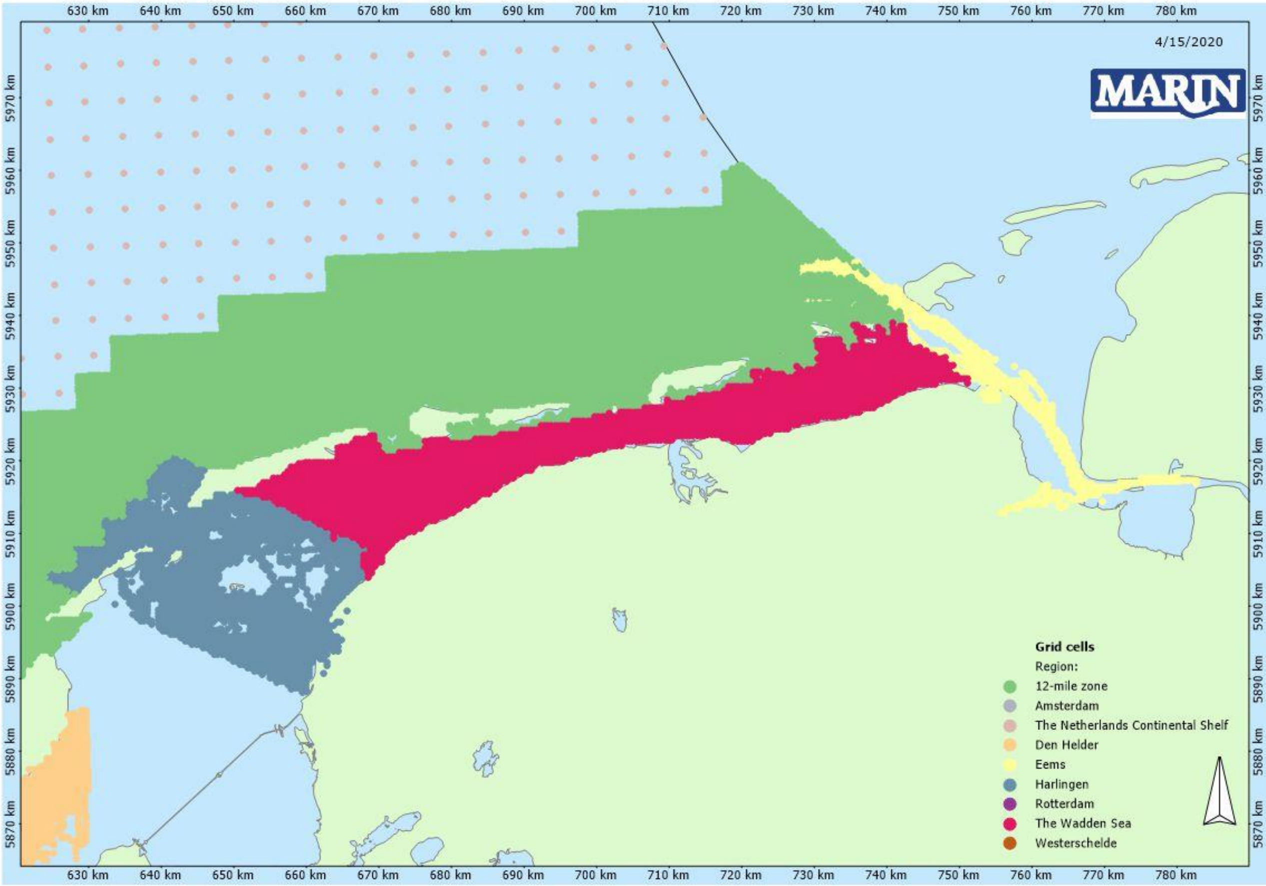

Figure 2-4 **Harlingen, the Wadden Sea and Ems: The points indicate the centres of grid cells for which emissions are calculated**

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
In this study, AIS data of 2021 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 2020 [8], 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 2021 comprised 39,159 valid MMSI numbers. Based on these MMSI-numbers, 14,376 commercial seagoing vessels could be identified (see Table 3-1). About 46% of all messages obtained, were sent by the 14,376 commercial vessels for which emission factors were calculated.

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

	Total individual valid mmsi	Total valid mmsi emission factors included	Total valid messages obtained	Total valid messages obtained emission factors included	Valid messages obtained emission factors included [%]
2017	33,612	12,952	733,405,583	328,970,302	45%
2018	36,167	12,797	865,399,825	375,120,674	43%
2019	37,970	13,238	910,441,140	386,801,288	42%
2020	37,321	13,914	946,587,638	442,001,668	47%
2021	39,159	14,376	914,653,016	418,725,035	46%

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 aid to navigation, wind turbines and oil and gas installations) or inland vessels near the port areas which are not relevant with respect to sea shipping emissions. Based on experience from earlier studies it is estimated roughly that at maximum 250 commercial seagoing 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 and in 4.2 the coverage of the AIS data.

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 127 minutes for 2021. The AIS data is practically complete, so there is no need to compensate for this.

4.2 AIS coverage

In the previous section, the number of files received from the Netherlands Coastguard describes 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.

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.

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 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.

The figure show the coverage for June 2021. This month is chosen so that the data can be compared with previous registrations. The overall coverage of AIS data of 2021 seems in most places of the same order of magnitude compared to the AIS coverage of 2020. However, fluctuations in coverage are expected due to the dependency on atmospheric conditions.

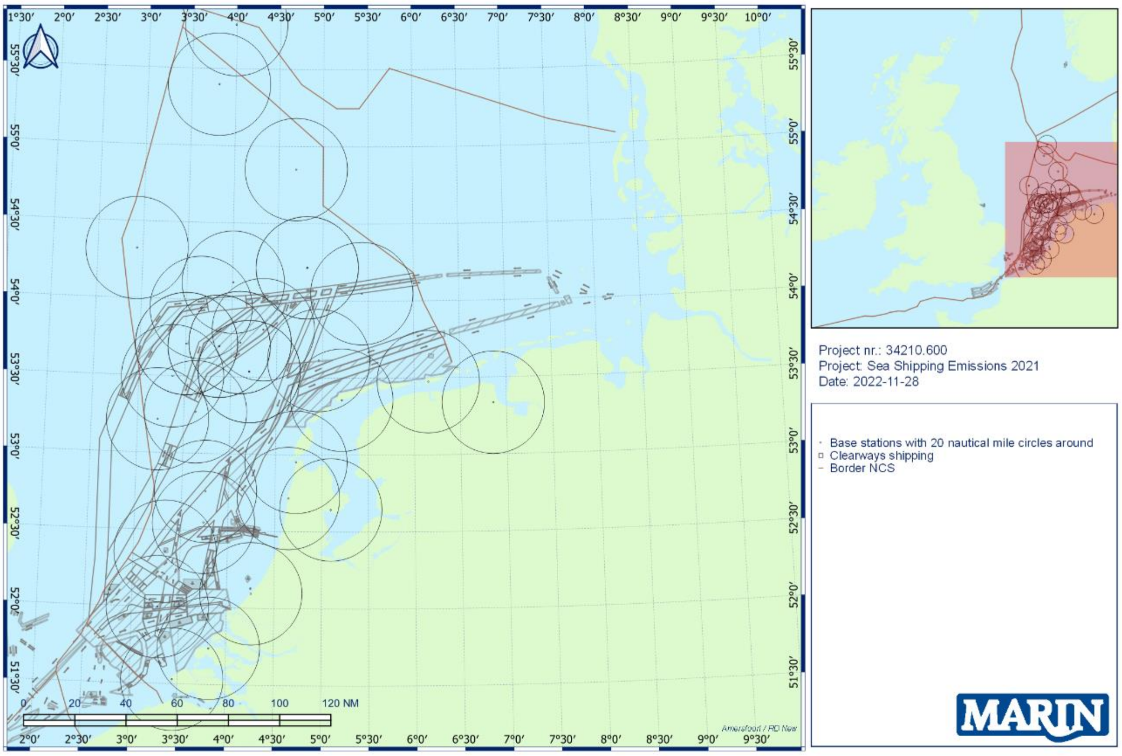

Figure 4-1 AIS base stations in 2021 delivering data to the Netherlands Coastguard.

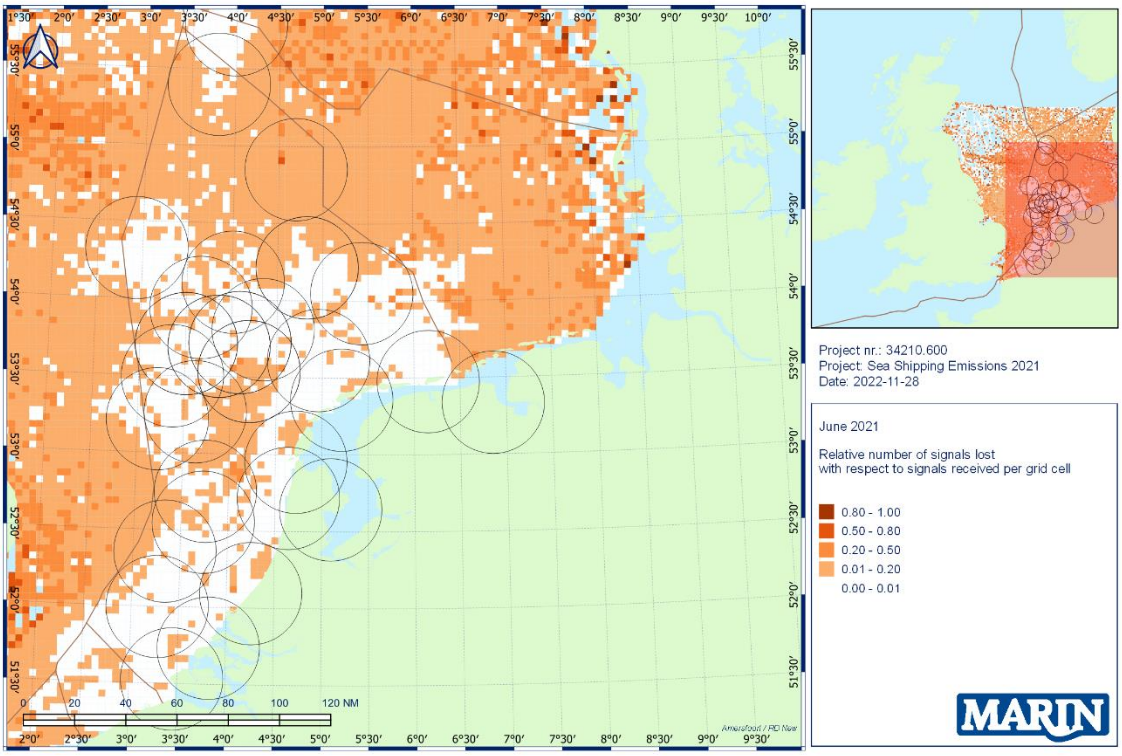

Figure 4-2 June 2021, relative number of signals lost with respect to signals received per grid cell, circles mark the 20 nautical miles zones around the Dutch base stations

5 ACTIVITIES FOR THE DUTCH PORT AREAS AND THE NETHERLANDS SEA AREA

5.1 Introduction

This chapter presents the activities of seagoing vessels for 2021 in the Dutch port areas and in the Netherlands sea area. The activities of 2021 are compared to those of 2020. 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 [9]. 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 Number of calls extracted from websites of the ports

Port area	Ports	Number of calls		Cargo handling x 1000 tons	
		2020	2021	2020	2021
Amsterdam	North Sea channel area	-	-	91,000	88,000
Eems		4,433	5,261	10,3	13,3
Harlingen		553	642	1,5	1,9
Rotterdam	Rijn- / Maasmond area	28,170	28,876	436,800	468,700
Western Scheldt	Antwerp	13,655	14,181	230,972	239,855

The shipping activities of 2021 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 2020. Take into account that some percentages can vary a lot due to the low absolute numbers or that a MMSI number is not linked to an emission factor. 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. Therefore, the (AIS-) methodology for investigating berthed ships may have to be revised.

Western Scheldt

The activity tables, Table 5-2 and Table 5-3, show that the moving hours increased with 1.0% and the GT.nm (gross tonnage time's nautical miles) decreased with 6%. For berthed ships the hours decreased by 6% and GT.hours increased with 7%. The activity numbers that could be extracted from the port websites show also an increase in the number of calls and cargo handling.

Rotterdam

The activity tables, Table 5-4 and Table 5-5, for Rotterdam show that the moving hours decreased with 36% and the GT.nm decreased with 8%. Berthed activities, hours and GT.hours, decreased with 34% and 8% respectively. The decrease in berthed and moving hours is not in line with the activity numbers that could be extracted from the port websites. They show an upward trend in number of calls and cargo handling.

Amsterdam

The activity tables, Table 5-6 and Table 5-7, for Amsterdam show that the moving hours and the GT.nm increased by 4%. The berthed hours decreased with 1% and the berthed GT.hours decreased with 7%. This is in line with the activity numbers that could be extracted from the port websites. They show a downward trend except for container shipment.

Ems

The activity tables, Table 5-8 and Table 5-9, for the Ems show that the moving hours increased with 4% and the GT.nm increased with 3%. This is in line with the activity numbers that could be extracted from the port websites. They show an increase trend despite the influence of COVID-19. The berthed hours decreased with 88% and the berthed GT.hours decreased with 89%. The decrease of berthed hours cannot be properly explained in comparison with the figures of the port itself.

Den Helder

The activity tables, Table 5-10 and Table 5-11, for Den Helder show that the moving hours increased with 15% and the GT.nm increased with 8%. The berthed hours increased with 22% and the berthed GT.hours increased with 20%.

Harlingen

The activity tables, Table 5-12 and Table 5-13, for Harlingen show that the moving hours and GT.nm increased with 13% and 30% respectively. The berthed hours decreased with 5% and the berthed GT.hours increased with 13%. This is in line with the activity numbers that could be extracted from the port websites; they show an increase in number of calls and cargo handling.

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

Ship type	Totals for Western Scheldt in 2021					2021 as percentage of 2020				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	5,688	144,277,146	3,937	1,158,632,801	10.0	86%	86%	84%	83%	98%
Chem.+ Gas tanker	72,829	800,316,531	47,248	5,507,579,400	10.5	98%	94%	113%	117%	98%
Bulk carrier	41,811	1,197,988,710	8,976	2,167,346,201	8.5	137%	137%	127%	128%	103%
Container ship	8,860	194,615,936	26,490	18,602,955,854	12.8	78%	89%	90%	93%	103%
General Dry Cargo	99,846	617,011,677	38,596	1,760,355,711	9.4	112%	97%	112%	108%	100%
RoRo Cargo / Vehicle	13,461	330,899,351	6,687	3,420,520,788	10.7	94%	103%	72%	64%	94%
Reefer	9,813	124,990,484	1,247	177,474,923	10.4	113%	116%	135%	152%	105%
Passenger	32,550	87,931,602	5,568	64,638,059	9.3	101%	94%	111%	130%	92%
Miscellaneous	242,793	426,262,525	34,894	455,097,223	8.0	94%	98%	100%	103%	111%
Tug/Supply	228,051	658,400,644	24,955	102,074,067	7.0	81%	115%	86%	64%	106%
Total / Average	755,702	4,582,694,606	198,598	33,416,675,027	9.6	94%	107%	101%	94%	102%

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 2021					2021 as percentage of 2020				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	319,277	143,229,906	40,193	164,586,081	7.6	84%	90%	94%	101%	98%
1,600-3,000	97,916	230,911,997	34,279	730,671,445	8.4	99%	97%	108%	108%	100%
3,000-5,000	76,362	299,881,810	27,332	1,000,218,787	8.7	98%	98%	106%	102%	92%
5,000-10,000	53,877	361,111,576	22,422	1,680,614,006	9.7	92%	88%	103%	106%	98%
10,000-30,000	115,202	2,207,087,918	34,722	7,655,034,604	11.0	115%	117%	106%	107%	102%
30,000-60,000	26,533	1,033,302,263	18,527	9,162,398,472	10.9	102%	101%	101%	97%	101%
60,000-100,000	3,589	286,292,108	8,605	8,135,501,355	11.7	129%	137%	113%	115%	107%
>100,000	105	16,709,909	2,024	3,673,174,708	10.3	32%	42%	85%	88%	121%
Total / Average	755,699	4,582,694,609	200,280	32,210,917,764	9.2	94%	107%	103%	103%	99%

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

Ship type	Totals for Rotterdam in 2021					2021 as percentage of 2020				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	44,340	2,937,252,231	4,274	1,964,029,833	8.9	78%	75%	90%	118%	120%
Chem.+ Gas tanker	42,050	999,515,541	13,315	1,497,906,763	8.6	36%	52%	58%	73%	112%
Bulk carrier	70,673	4,171,311,054	2,243	711,576,858	8.0	96%	118%	78%	105%	104%
Container ship	196,796	13,634,747,036	20,823	5,442,452,626	8.2	90%	116%	72%	94%	101%
General Dry Cargo	34,568	201,942,818	8,765	353,582,191	9.5	40%	35%	45%	52%	109%
RoRo Cargo / Vehicle	26,962	1,042,691,718	6,853	2,802,970,124	10.6	44%	49%	68%	85%	117%
Reefer	5	64,240	70	10,107,117	12.2	0%	1%	47%	64%	134%
Passenger	1,658	17,477,069	114	75,339,808	8.6	19%	3%	37%	72%	101%
Miscellaneous	77,886	97,692,573	17,212	313,369,748	7.7	75%	22%	61%	61%	115%
Tug/Supply	186,674	2,150,620,933	40,020	731,890,240	6.9	60%	88%	67%	240%	110%
Total / Average	681,612	25,253,315,213	113,689	13,903,225,308	8.0	66%	92%	64%	92%	109%

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

Ship size in GT	Totals for Rotterdam in 2021					2021 as percentage of 2020				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average Speed	Hours	GT.hour s	Hours	GT.nm	Average speed
100-1,600	209,080	85,632,289	47,680	114,312,417	7.2	67%	63%	62%	64%	92%
1,600-3,000	27,190	63,933,983	6,932	152,281,497	9.2	55%	53%	48%	50%	106%
3,000-5,000	16,105	62,385,919	11,155	404,791,451	10.3	30%	30%	58%	62%	114%
5,000-10,000	47,547	385,032,520	12,509	928,852,614	9.7	38%	41%	54%	58%	110%
10,000-30,000	116,516	2,056,503,537	16,545	2,577,910,145	9.3	54%	52%	66%	71%	115%
30,000-60,000	87,629	3,791,491,572	6,785	2,758,014,197	9.3	69%	71%	81%	99%	122%
60,000-100,000	79,472	6,281,065,178	5,514	3,107,869,278	7.2	106%	109%	101%	108%	116%
>100,000	75,005	12,526,459,908	3,669	3,858,537,980	6.4	114%	114%	112%	126%	121%
Total / Average	681,614	25,253,315,212	113,691	13,903,225,308	8.3	66%	92%	64%	92%	103%

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

Ship type	Totals for Amsterdam in 2021					2021 as percentage of 2020				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	21,228	908,664,102	1,016	196,634,410	5.9	65%	59%	76%	63%	98%
Chem.+ Gas tanker	97,598	1,886,760,974	7,511	657,804,693	6.1	95%	89%	92%	89%	102%
Bulk carrier	70,213	3,190,068,882	2,743	569,372,287	5.7	108%	118%	110%	116%	100%
Container ship	5,015	25,572,757	930	30,223,928	6.3	67%	33%	184%	176%	111%
General Dry Cargo	107,178	437,498,368	8,251	185,129,697	6.1	102%	105%	104%	112%	102%
RoRo Cargo / Vehicle	11,924	466,990,893	1,684	389,991,138	5.7	76%	86%	150%	159%	91%
Reefer	20,749	131,001,001	439	13,754,158	5.6	107%	117%	96%	102%	102%
Passenger	21,406	231,493,728	720	30,943,016	5.3	183%	194%	80%	185%	104%
Miscellaneous	127,089	177,971,754	10,442	101,382,665	5.7	113%	56%	138%	108%	114%
Tug/Supply	181,437	307,728,752	16,252	40,527,120	5.5	91%	71%	92%	109%	95%
Total / Average	663,837	7,763,751,211	49,988	2,215,763,112	5.8	99%	93%	104%	104%	101%

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

Ship size in GT	Totals for Amsterdam in 2021					2021 as percentage of 2020				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hour s	Hours	GT.nm	Average speed
100-1,600	221,247	88,856,476	22,056	50,586,367	5.7	111%	105%	103%	122%	98%
1,600-3,000	104,216	247,037,650	6,478	102,351,000	6.1	95%	98%	103%	110%	105%
3,000-5,000	58,843	237,377,273	5,661	137,120,083	5.8	108%	113%	106%	111%	98%
5,000-10,000	60,072	393,574,540	3,014	130,307,021	5.9	84%	85%	98%	96%	100%
10,000-30,000	97,790	2,100,712,908	5,639	659,193,906	5.6	85%	83%	91%	90%	102%
30,000-60,000	74,779	2,986,506,381	3,919	856,852,365	5.6	99%	101%	125%	129%	110%
60,000-100,000	21,204	1,708,613,462	742	278,658,154	5.2	81%	90%	85%	83%	98%
>100,000										
Total / Average	663,837	7,763,751,210	49,988	2,215,763,112	5.8	99%	93%	104%	104%	100%

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

Ship type	Totals for Ems in 2021					2021 as percentage of 2020				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	4	3,085	132	1,994,193	12.8	3%	2%	61%	92%	139%
Chem.+ Gas tanker	526	1,672,011	1,639	104,194,473	10.6	12%	7%	98%	98%	103%
Bulk carrier	404	6,543,106	683	117,173,211	10.1	12%	11%	103%	141%	110%
Container ship	160	1,166,659	40	4,484,127	12.2	2%	1%	87%	80%	120%
General Dry Cargo	9,011	30,383,355	7,691	292,096,453	10.4	17%	11%	106%	98%	105%
RoRo Cargo / Vehicle	3,456	28,980,810	6,868	1,301,910,674	11.6	30%	6%	106%	101%	96%
Reefer	84	635,306	47	2,214,137	10.3	8%	11%	90%	110%	110%
Passenger	103	7,904,317	274	34,278,789	10.7	21%	298%	111%	111%	97%
Miscellaneous	7,838	16,415,899	15,462	240,792,599	9.6	24%	38%	104%	104%	132%
Tug/Supply	7,852	32,137,177	7,646	188,045,926	10.0	6%	19%	101%	117%	105%
Total / Average	29,438	125,841,725	40,482	2,287,184,582	10.2	12%	11%	104%	103%	111%

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 2021					2021 as percentage of 2020				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	8,625	5,366,649	10,564	45,622,846	8.9	7%	15%	106%	119%	104%
1,600-3,000	12,208	29,245,971	15,642	309,276,197	9.7	29%	29%	114%	113%	104%
3,000-5,000	2,178	8,959,483	6,281	214,143,805	9.5	12%	12%	92%	90%	101%
5,000-10,000	4,757	30,630,940	3,555	273,161,851	11.0	20%	19%	83%	89%	112%
10,000-30,000	991	18,441,214	2,059	479,135,090	11.3	6%	6%	96%	102%	109%
30,000-60,000	379	19,105,008	1,076	666,693,771	12.0	6%	5%	105%	106%	118%
60,000-100,000	104	6,906,693	336	277,084,319	14.8	6%	6%	114%	113%	119%
>100,000	40	7,177,679	15	21,237,685	8.0	444%	424%	188%	158%	83%
Total / Average	29,438	125,841,725	40,482	2,287,184,582	9.9	12%	11%	104%	103%	106%

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

Ship type	Totals for Den Helder in 2021					2021 as percentage of 2020				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	130	5,380,783	6	2,955,233	10.4					
Chem.+ Gas tanker	55	351,435	1	49,993	6.9	17%	14%	8%	13%	153%
Bulk carrier	1,435	6,330,338	7	138,022	4.2					
Containership										
General Dry Cargo	2,568	12,436,854	388	12,607,045	9.4	134%	424%	128%	154%	136%
RoRo Cargo / Vehicle	6,003	92,952,190	2,426	297,619,024	7.9	97%	98%	93%	90%	108%
Reefer										
Passenger	16,551	116,060,902	1,972	199,142,826	5.5	101%	93%	143%	150%	108%
Miscellaneous	170,308	325,973,510	3,477	20,105,713	6.1	141%	138%	119%	96%	100%
Tug/Supply	133,324	150,971,142	3,190	30,471,543	5.4	106%	117%	116%	119%	87%
Total / Average	330,374	710,457,154	11,467	563,089,399	6.3	122%	120%	115%	108%	100%

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 2021					2021 as percentage of 2020				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	166,570	71,844,415	3,214	7,818,203	5.9	107%	107%	102%	78%	104%
1,600-3,000	36,711	83,547,894	1,331	23,053,565	7.4	95%	95%	84%	90%	110%
3,000-5,000	48,860	198,839,549	974	21,886,565	5.6	183%	189%	219%	241%	124%
5,000-10,000	3,386	19,288,900	73	3,335,272	7.3	162%	144%	107%	123%	126%
10,000-30,000	18,957	330,167,614	4,341	503,868,305	6.3	103%	105%	110%	107%	98%
30,000-60,000	128	5,360,476	5	2,895,195	13.5					
60,000-100,000										
>100,000										
Total / Average	330,375	710,457,154	11,467	563,089,401	6.3	122%	120%	115%	108%	100%

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

Ship type	Totals for Harlingen in 2021					2021 as percentage of 2020				
	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	1,726	6,489,386	29	847,587	7.4	326%	273%	100%	97%	101%
Bulk carrier	143	779,202	18	731,984	6.7	138%	147%	164%	264%	79%
Containership	3,069	20,600,247	629	39,026,705	9.2					
General Dry Cargo	30,218	108,071,212	1,606	35,661,770	7.9	126%	152%	108%	116%	101%
RoRo Cargo / Vehicle	35,913	98,557,658	10,441	344,628,844	10.6	90%	96%	116%	128%	102%
Reefer	2,325	10,821,335	161	6,245,297	7.9	118%	87%	143%	118%	94%
Passenger	34,826	12,906,718	1,103	3,232,207	6.3	94%	93%	97%	88%	83%
Miscellaneous	70,725	62,488,690	6,253	37,428,790	6.5	82%	83%	100%	80%	90%
Tug/Supply	48,925	28,867,819	799	2,461,825	8.0	101%	98%	163%	124%	103%
Total / Average	227,870	349,582,267	21,039	470,265,009	8.8	95%	113%	113%	130%	99%

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

Ship size in GT	Totals for Harlingen in 2021					2021 as percentage of 2020				
	Berthed		Moving			Berthed		Moving		
	Hours	GT.hours	Hours	GT.hours	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	138,029	60,067,794	8,205	28,041,832	7.3	85%	76%	100%	80%	97%
1,600-3,000	37,912	92,402,924	4,836	130,864,321	7.8	98%	97%	99%	116%	100%
3,000-5,000	27,781	105,009,519	6,318	247,914,657	7.3	121%	123%	141%	139%	92%
5,000-10,000	15,327	89,077,606	1,141	62,861,927	8.4	202%	186%	170%	176%	100%
10,000-30,000	206	2,439,704	4	321,472	7.2					
30,000-60,000										
60,000-100,000										
>100,000										
Total / Average	227,871	349,582,267	21,040	470,265,009	7.5	95%	113%	113%	130%	97%

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 2021 are compared to the activities of 2020. 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 moving hours increased with 1% and GT.nm for moving vessels increased with 2%.

For ships at anchor, there is an increase for hours by 3% and for GT hours by 26%.

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 2021					2021 as percentage of 2020				
	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	159,928	9,579,041,654	76,062	42,909,896,619	9.7	110%	114%	104%	104%	104%
Chem.+Gas tanker	467,363	5,934,281,529	310,829	44,959,052,582	10.7	101%	89%	100%	98%	100%
Bulk carrier	131,527	7,507,885,565	108,268	40,998,210,227	10.1	166%	211%	101%	109%	101%
Container ship	99,263	7,294,018,041	195,559	128,637,725,677	12.5	107%	208%	100%	98%	99%
General Dry Cargo	64,178	337,878,813	415,832	18,816,792,263	10.5	64%	61%	103%	104%	102%
RoRo Cargo / Vehicle	17,520	278,721,376	119,537	69,361,466,967	12.7	73%	48%	102%	107%	103%
Reefer	2,893	24,199,270	8,968	1,030,841,903	11.2	99%	108%	95%	89%	95%
Passenger	5,111	394,611,053	5,139	3,251,549,006	10.4	40%	37%	113%	121%	114%
Miscellaneous	50,158	287,724,340	118,645	2,676,140,531	8.6	104%	52%	110%	98%	119%
Tug/Supply	128,143	717,878,330	135,755	3,073,673,547	7.3	100%	86%	94%	88%	91%
Total / Average	1,126,084	32,356,239,971	1,494,594	355,715,349,322	10.5	103%	126%	101%	102%	101%

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 2021					2021 as percentage of 2020				
	Not moving / at anchor		Moving			Not moving / at anchor		Moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average Speed
100-1,600	66,170	43,173,459	152,291	745,101,276	7.1	104%	124%	91%	99%	98%
1,600-3,000	100,293	245,183,650	311,739	6,709,572,141	8.9	102%	101%	101%	103%	103%
3,000-5,000	165,849	664,938,119	230,988	8,875,664,064	10.1	103%	101%	112%	112%	101%
5,000-10,000	157,296	1,118,397,268	197,391	16,376,087,435	11.0	90%	90%	99%	100%	104%
10,000-30,000	292,151	5,473,131,956	289,588	67,357,574,328	12.1	85%	79%	98%	101%	105%
30,000-60,000	146,479	6,603,616,164	155,381	83,494,441,988	11.4	117%	122%	99%	99%	102%
60,000-100,000	157,111	11,982,802,015	107,140	90,789,874,074	11.7	157%	163%	115%	116%	108%
>100,000	38,645	6,224,864,763	42,930	81,363,994,228	11.7	149%	163%	92%	92%	101%
Total / Average	1,126,085	32,356,239,974	1,494,593	355,715,349,321	10.3	103%	126%	101%	102%	103%

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. For the port areas, except for Den Helder, most remarkable is the decrease of berthed ships.

For the NCS combined with the 12-miles zone the average number of not moving and moving ships increased by 3% and 1% respectively.

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

Area	In 2021			In 2021 as percentage of 2020		
	Average # ships/day		Speed	Average # ships/day		Speed
	Not moving	Moving	Knots	Not moving	Moving	Knots
Amsterdam	76	6	6	99%	104%	101%
Den Helder	38	1	6	122%	115%	100%
Ems	3	5	10	12%	104%	111%
Harlingen	26	2	9	95%	113%	99%
Rotterdam	78	13	8	66%	64%	109%
Western Scheldt	86	23	10	94%	101%	102%
NCS +12-mile zone	128	170	10	103%	101%	101%

Figure 5-1 shows the average number of ships per day from 2017 up to 2021. The average number of ships per day contains not moving and moving ships excluding fishing vessels. The NCS combined with the 12-miles zone shows a slight increase over time.

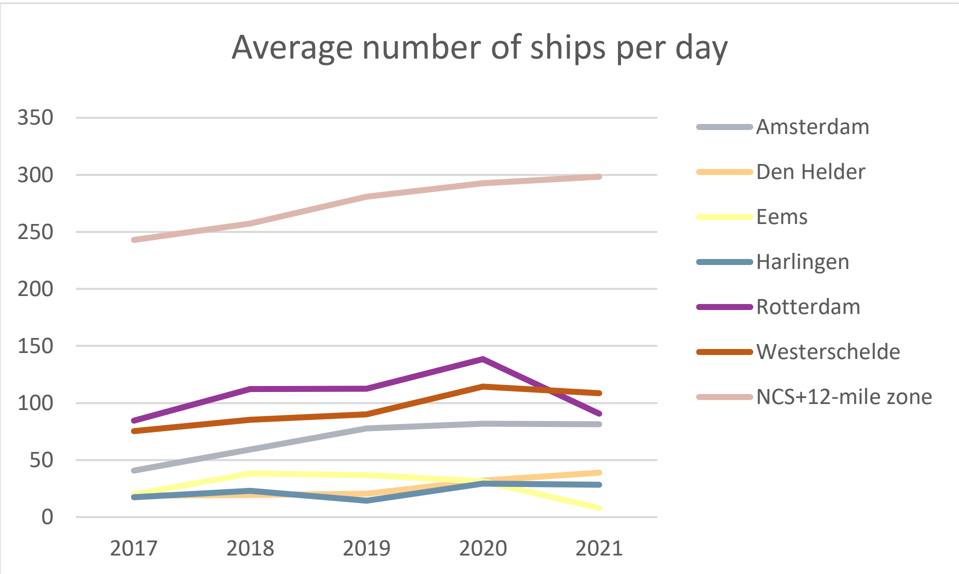

Figure 5-1 Average number of not moving and moving ships per day for 2017-2021, excluding fishing vessels.

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

6.1 Introduction

This chapter presents the results of emission calculations for 2021 for the Dutch port areas and the Netherlands sea area. To indicate the change in emissions, all values for 2021 are compared with the values of 2020.

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 0 presents the spatial distribution of the 2021 NO_x emissions together with the absolute and relative change compared to 2020.

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 2020. The percentages in grey are based on very low absolute numbers and not very reliable. 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 decrease of CO_2 by 16%. Ships at berth have a total decrease of CO_2 by 21% and sailing ships decrease by 7%. The decrease in CO_2 emissions for ships at berth is mainly caused by not moving / anchored ships in the port of Rotterdam since this port has a significant influence in an absolute sense.

Figure 6-1 to Figure 6-3 show respectively CO_2, NO_x and SO_2 emissions in ton in each port area from 2017 up to 2021. The emissions in ton contains not moving and moving ships excluding fishing vessels. For all ports together CO_2, NO_x and SO_2 emissions decreased.

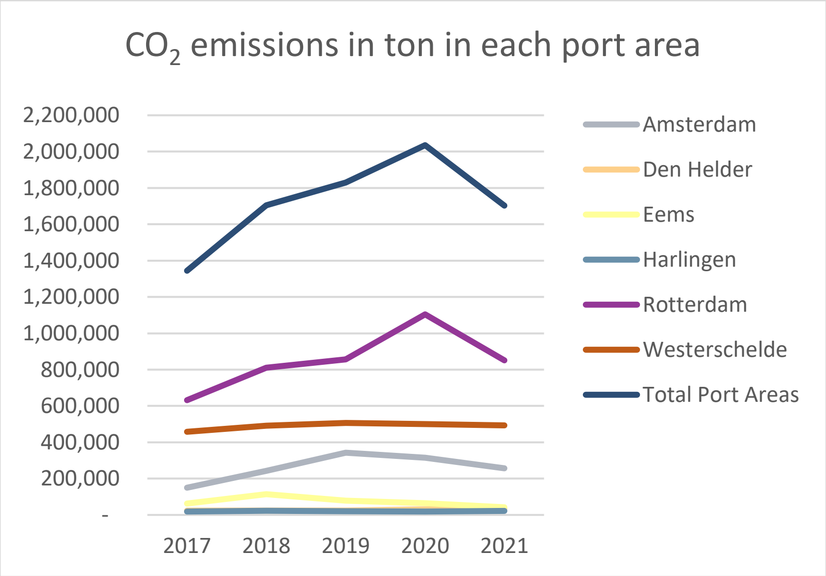

Figure 6-1 **CO_2 emissions in ton in each port area for 2017-2021, excluding fishing vessels.**

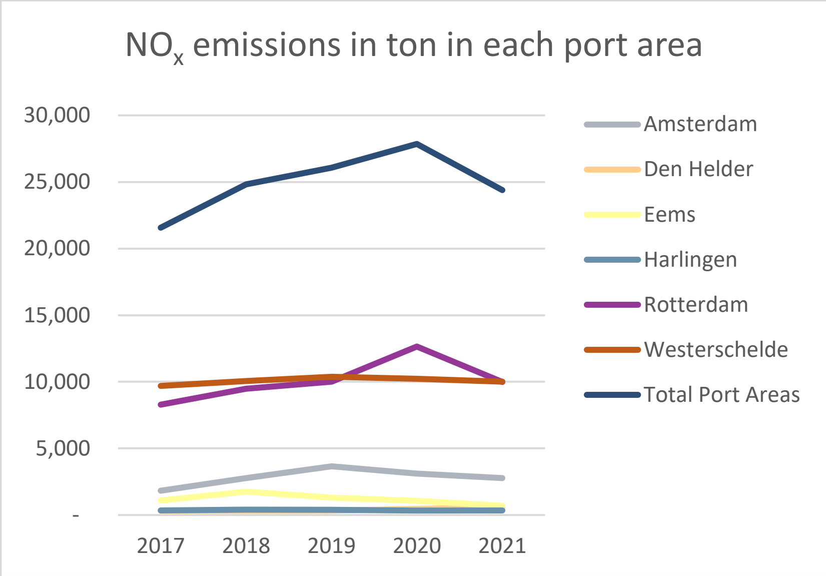

Figure 6-2 **NO_x emissions in ton in each port area for 2017-2021, excluding fishing vessels.**

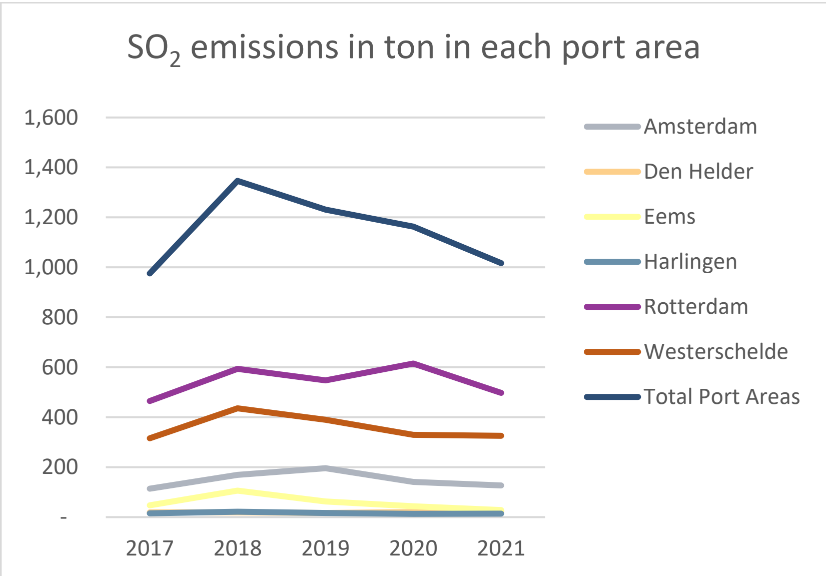

Figure 6-3 **SO_2 emissions in ton in each port area for 2017-2021, excluding fishing vessels.**

Table 6-1 Total emissions in ton in each port area for 2021, excluding fishing vessels (EMS-type 11)

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Total
1011 Methane	Berthed							
	Sailing	19	38	1	18	12	31	119
	Total	19	38	1	18	12	31	119
1237 VOC	Berthed	65	294	96	2	15	6	477
	Sailing	269	127	30	22	6	7	462
	Total	334	421	126	24	21	13	939
4001 SO_2	Berthed	74	389	104	2	18	7	595
	Sailing	252	107	22	26	6	7	422
	Total	326	497	126	28	25	14	1017
4013 NO_x	Berthed	1615	6767	2133	47	404	147	11113
	Sailing	8406	3223	650	649	155	190	13273
	Total	10021	9990	2784	696	559	337	24386
4031 CO	Berthed	102	518	161	3	23	8	814
	Sailing	507	265	57	51	15	23	918
	Total	609	782	218	54	38	31	1732
4032 CO_2	Berthed	128108	693187	225040	3590	26697	9605	1086227
	Sailing	365064	157592	32283	38635	9919	12453	615946
	Total	493172	850780	257323	42225	36616	22058	1702173
6601 Aerosols MDO	Berthed	32	151	46	1	5	3	239
	Sailing	40	23	7	7	2	4	83
	Total	72	174	54	8	7	7	321
6602 Aerosols HFO	Berthed	0	1	1	0	2	0	4
	Sailing	179	76	12	17	4	2	289
	Total	179	77	13	17	6	2	293

Table 6-2 Emissions in each port area for 2021 as percentage of the emissions in 2020, excluding fishing vessels (EMS-type 11).

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Total
1011 Methane	Berthed							
	Sailing	147%	58%	130%	93%	99%	662%	104%
	Total	147%	58%	130%	93%	99%	662%	104%
1237 VOC	Berthed	98%	79%	83%	13%	119%	102%	81%
	Sailing	97%	72%	100%	90%	120%	91%	88%
	Total	97%	77%	86%	62%	119%	96%	85%
4001 SO_2	Berthed	97%	83%	87%	13%	118%	104%	84%
	Sailing	100%	75%	103%	106%	120%	109%	93%
	Total	99%	81%	90%	65%	118%	107%	87%
4013 NO_x	Berthed	99%	82%	86%	13%	119%	102%	84%
	Sailing	98%	74%	101%	94%	118%	100%	91%
	Total	98%	79%	89%	65%	119%	101%	88%
4031 CO	Berthed	96%	79%	81%	13%	119%	103%	81%
	Sailing	100%	77%	103%	109%	115%	175%	94%
	Total	99%	79%	86%	77%	118%	147%	87%
4032 CO_2	Berthed	94%	78%	79%	13%	119%	105%	79%
	Sailing	100%	75%	103%	105%	118%	124%	93%
	Total	99%	77%	82%	65%	119%	115%	84%
6601 Aerosols MDO	Berthed	100%	80%	83%	12%	113%	104%	82%
	Sailing	100%	67%	103%	103%	107%	99%	89%
	Total	100%	78%	85%	57%	111%	101%	83%
6602 Aerosols HFO	Berthed	38%	113%	64%	18%	133%	46%	82%
	Sailing	99%	76%	102%	100%	138%	144%	93%
	Total	99%	77%	99%	98%	137%	142%	92%

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 2021 are summarised in Table 6-3. This table also contains a comparison with 2020. The percentages in grey are based on very low absolute numbers and not very reliable.

VOC and NO_x show an overall decrease by 2% for moving and not moving vessels. CO_2 has the largest contribution to the total emissions in ton (98%). For NCS combined with the 12-miles zone there is a total increase of CO_2 emission by 2%. This is due to 7% increase for ships at anchor and 2% increase for sailing ships. For the Netherlands sea area the average number of ships increased by 2%.

Figure 6-4 shows CO_2, NO_x and SO_2 emissions in ton in the Netherlands sea area from 2017 up to 2021. The total emissions in ton contains not moving and moving ships excluding fishing vessels.

Table 6-3 Emissions of ships in ton in the Netherlands sea area for 2021 compared with 2020, excluding fishing vessels (EMS-type 11).

No	Substance	Emission in ton in 2021			Emission in 2021 as percentage of 2020		
		Not moving	Moving	Total	Not moving	Moving	Total
1011	Methane		958	958		94%	94%
1237	VOC	143	2144	2287	104%	98%	98%
4001	SO_2	192	2214	2406	107%	102%	102%
4013	NO_x	4250	73675	77924	104%	98%	98%
4031	CO	247	4276	4522	110%	102%	103%
4032	CO_2	276560	3283223	3559783	107%	102%	102%
6601	Aerosols MDO	108	264	372	106%	101%	103%
6602	Aerosols HFO	7	1701	1707	133%	102%	102%
Average number of ships present in the area		128	170	298	103%	101%	102%

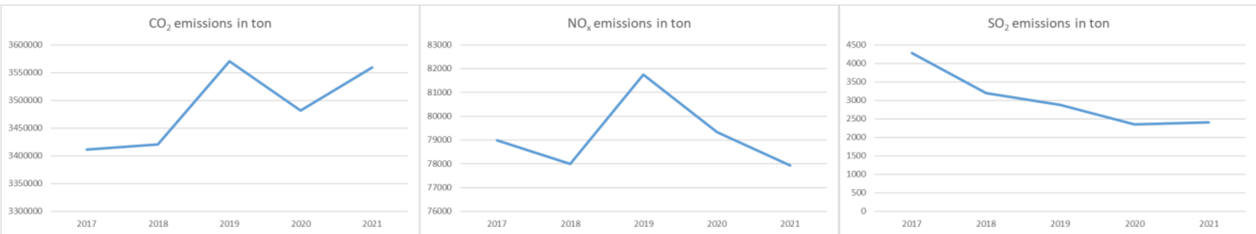

Figure 6-4 CO_2, NO_x and SO_2 emissions in ton in the Netherlands sea area for 2017-2021, excluding fishing vessels.

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 2020 and 2021 and the third one shows the *relative* change in emission between 2020 and 2021. 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 2020 and 2021 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.

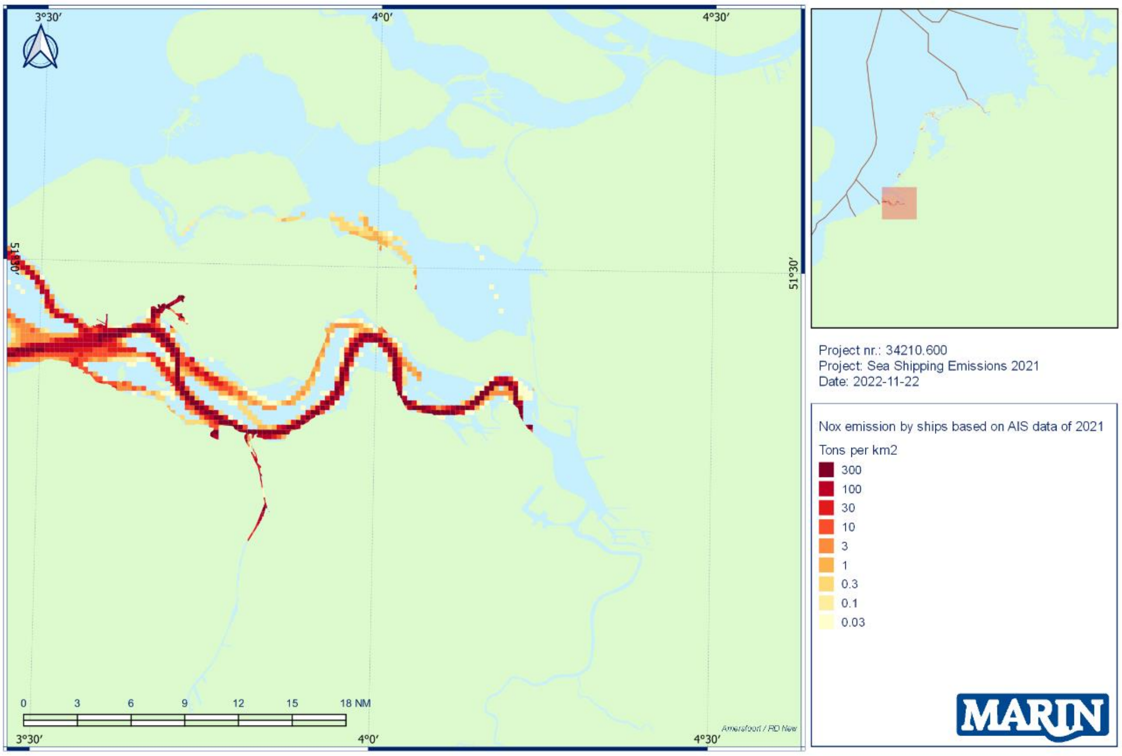

Figure 6-5 NO$_x$ emission in 2021 in the Dutch part of the Western Scheldt by ships with AIS.

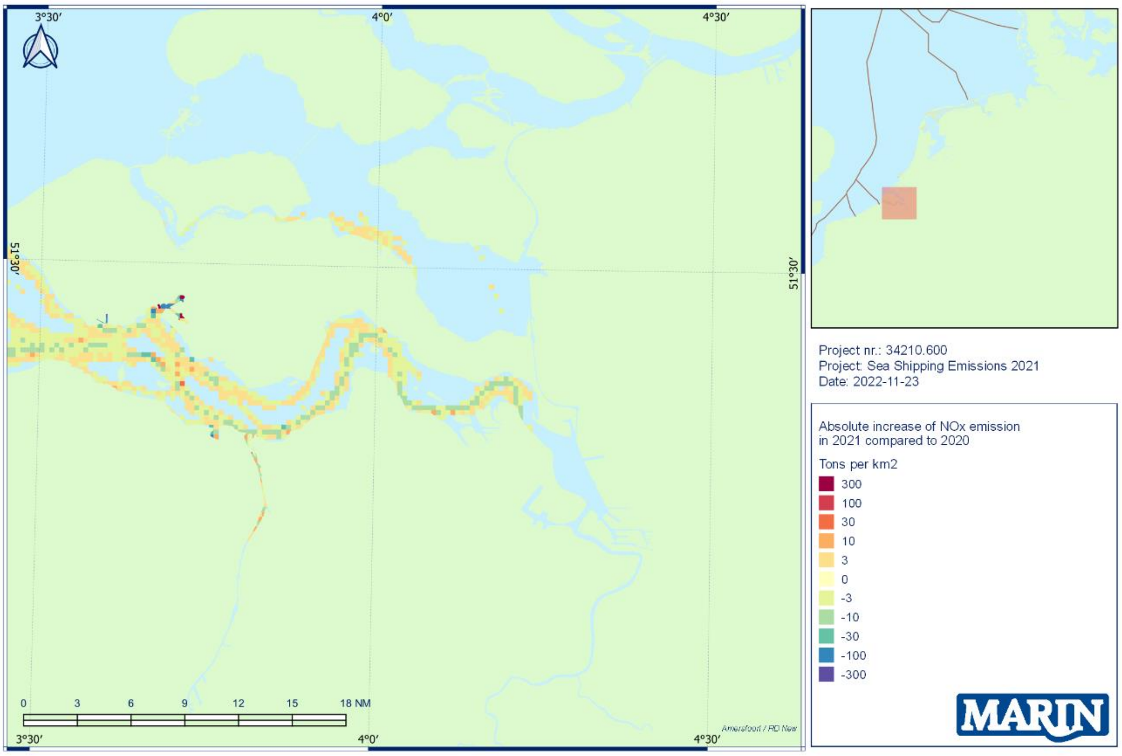

Figure 6-6 Absolute change in NO$_x$ emission from 2020 to 2021 in the Dutch part of the Western Scheldt by ships with AIS.

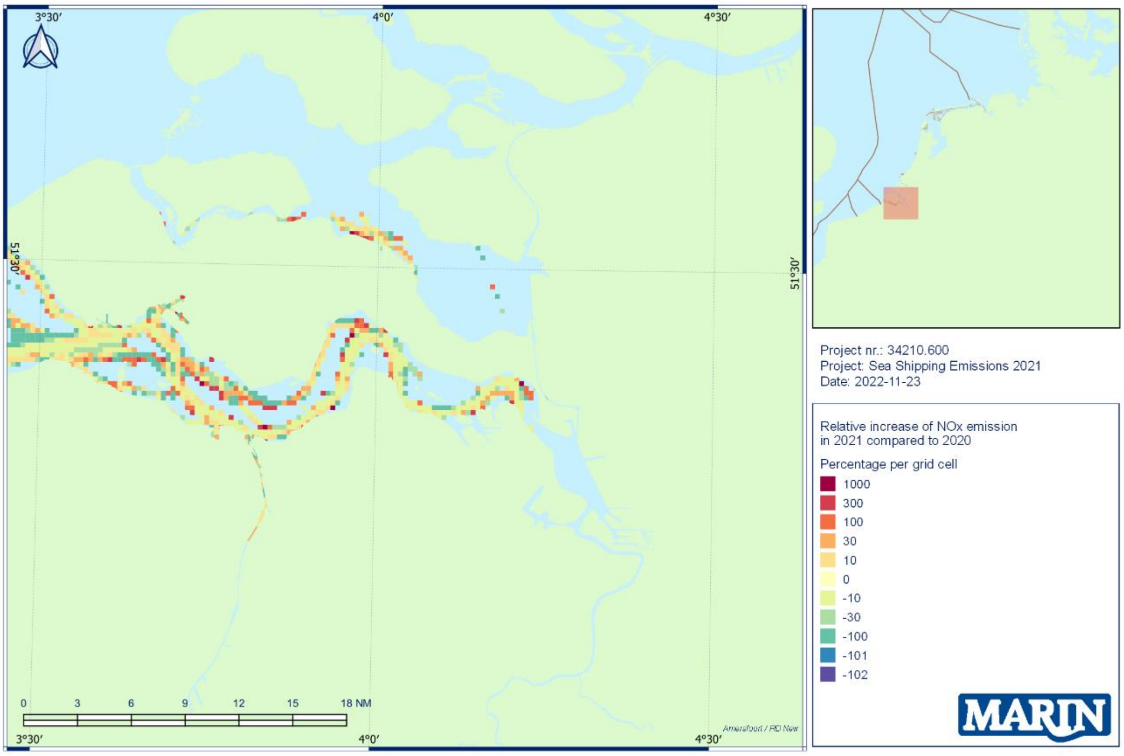

Figure 6-7 **Relative change in NO_x emission from 2020 to 2021 in the Dutch part of the Western Scheldt by ships with AIS.**

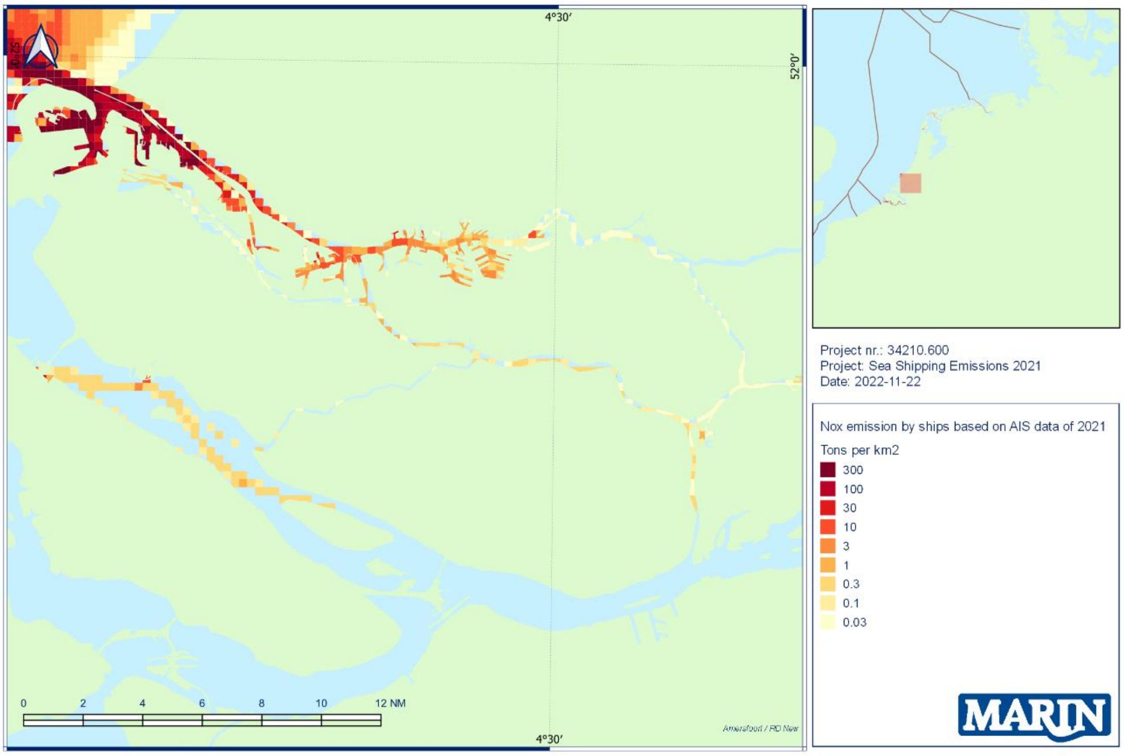

Figure 6-8 **NO_x emission in 2021 in the port area of Rotterdam by ships with AIS.**

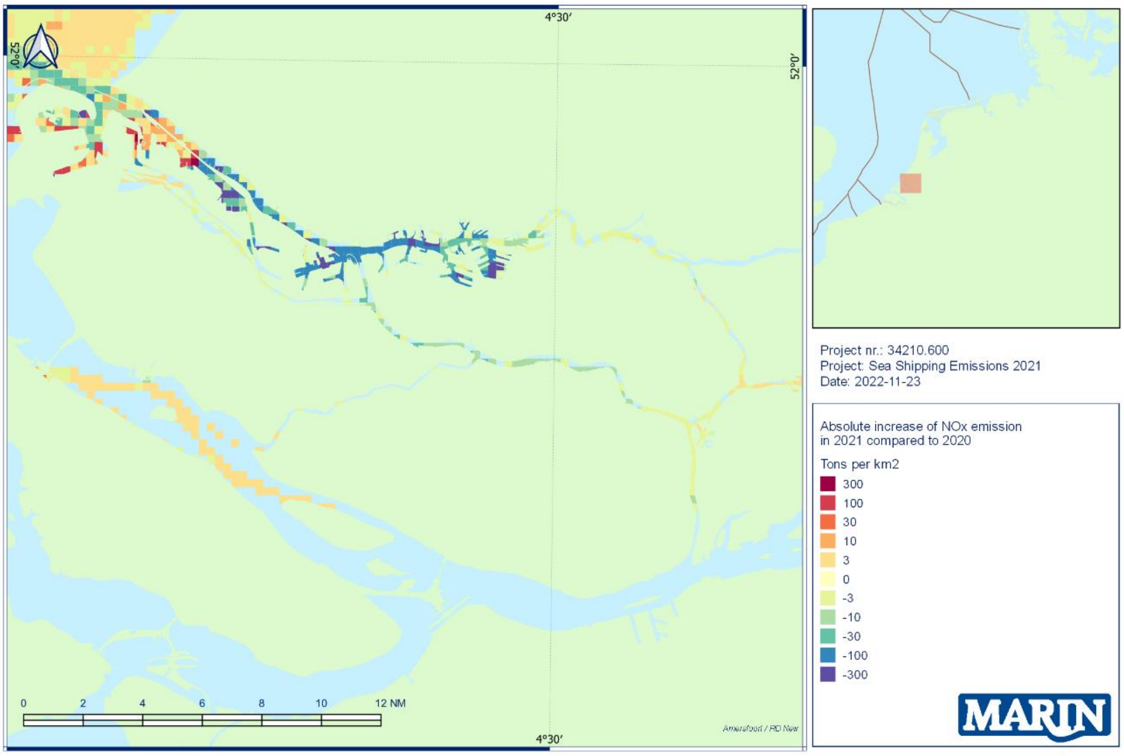

Figure 6-9 Absolute change in NO_x emission from 2020 to 2021 in the port area of Rotterdam by ships with AIS.

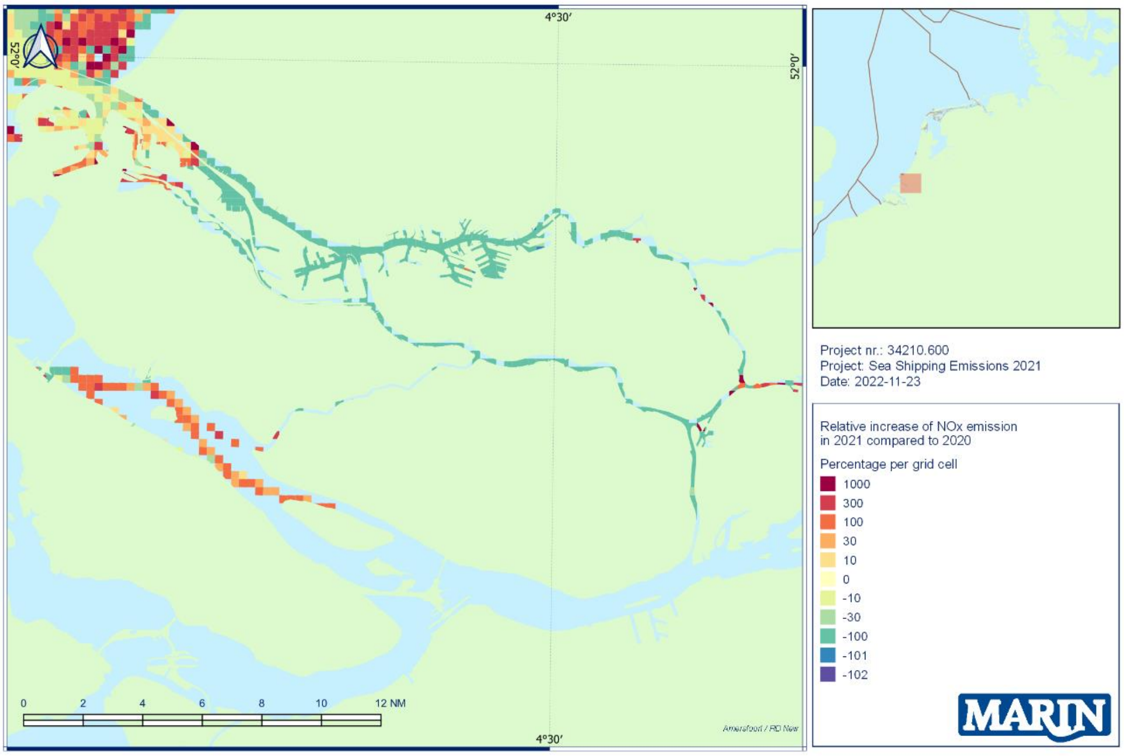

Figure 6-10 Relative change in NO_x emission from 2020 to 2021 in the port area of Rotterdam by ships with AIS.

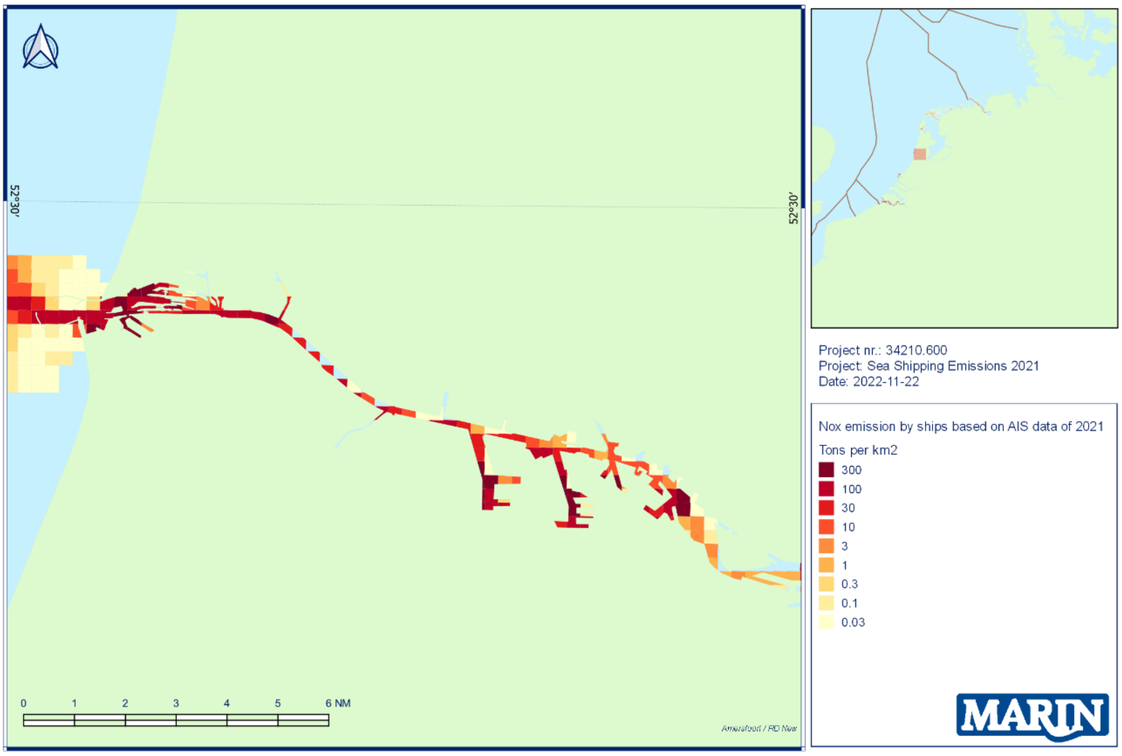

Figure 6-11 NO$_x$ emission in 2021 in the port area of Amsterdam by ships with AIS.

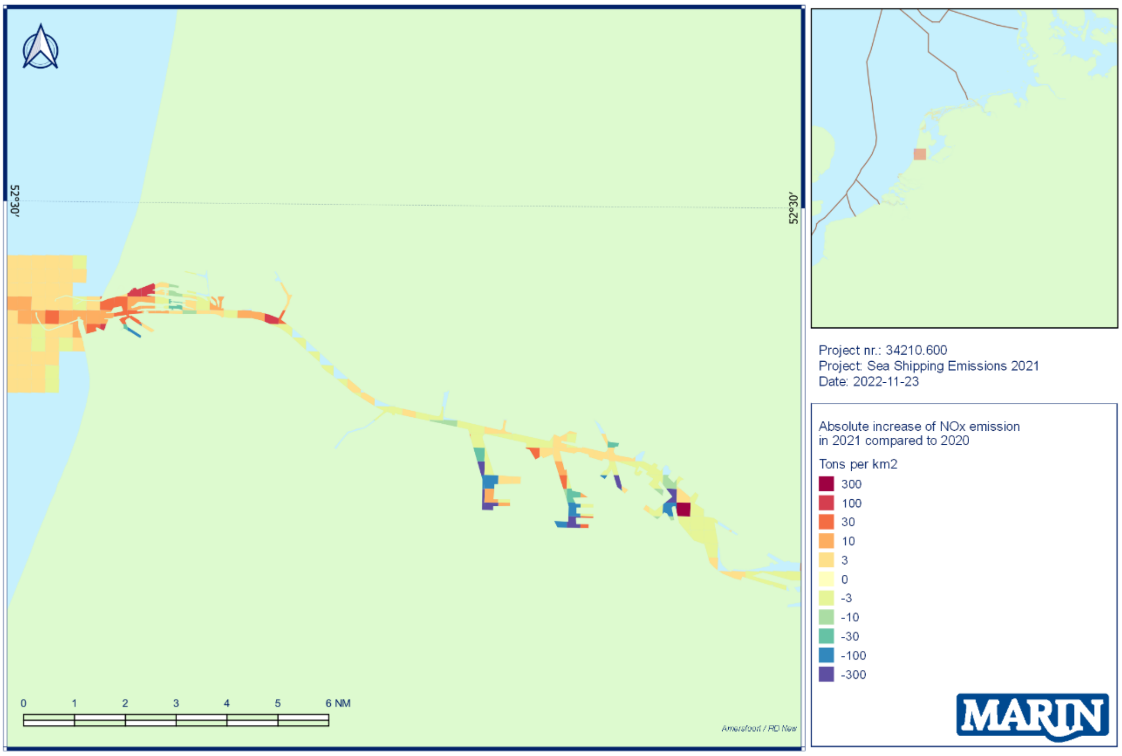

Figure 6-12 Absolute change in NO$_x$ emission from 2020 to 2021 in the port area of Amsterdam by ships with AIS.

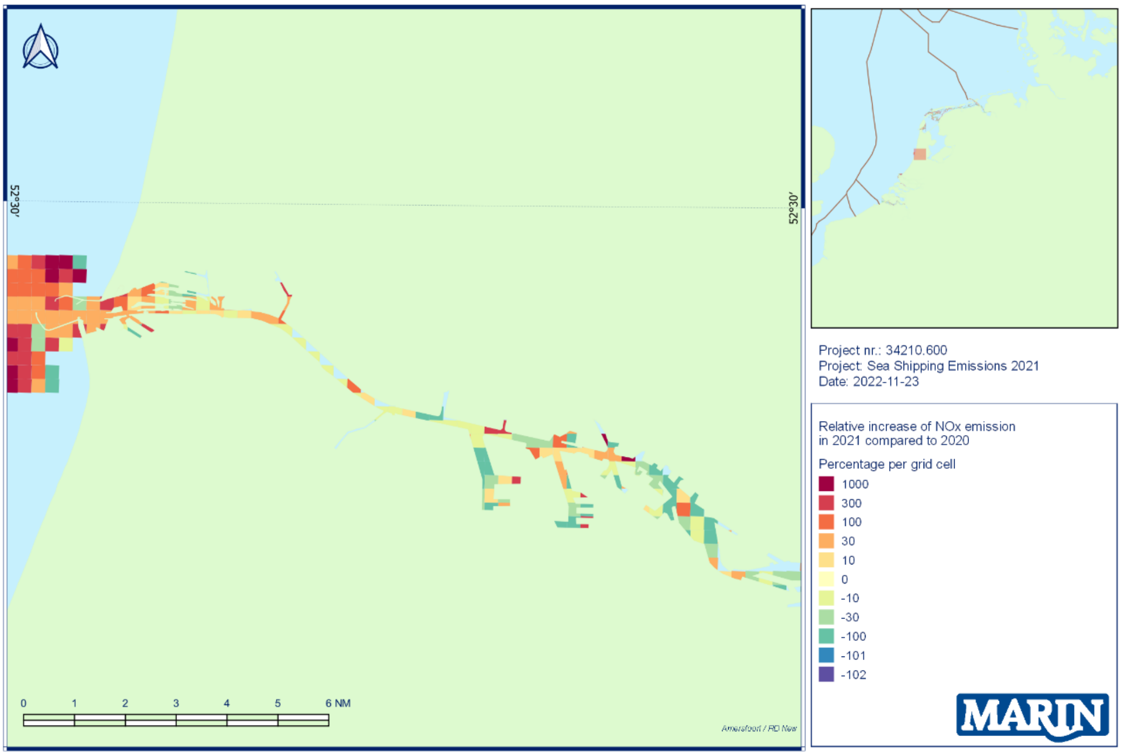

Figure 6-13 Relative change in NO_x emission from 2020 to 2021 in the port area of Amsterdam by ships with AIS.

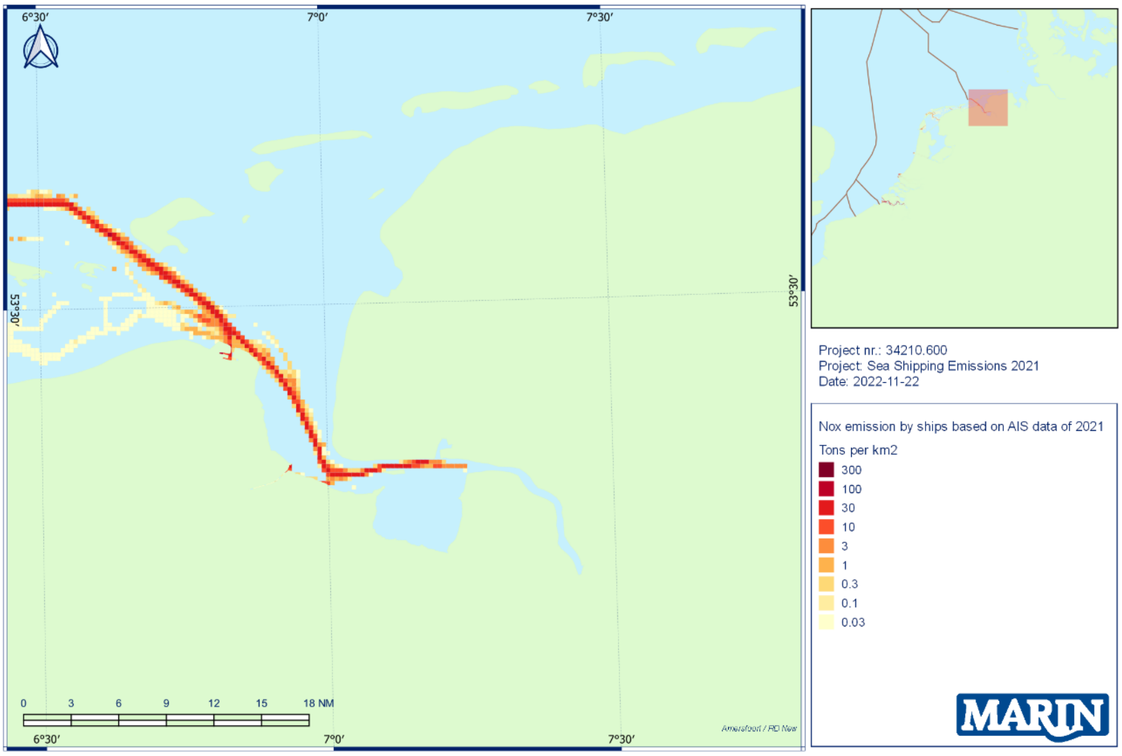

Figure 6-14 NO_x emission in 2021 in the Ems area by ships with AIS.

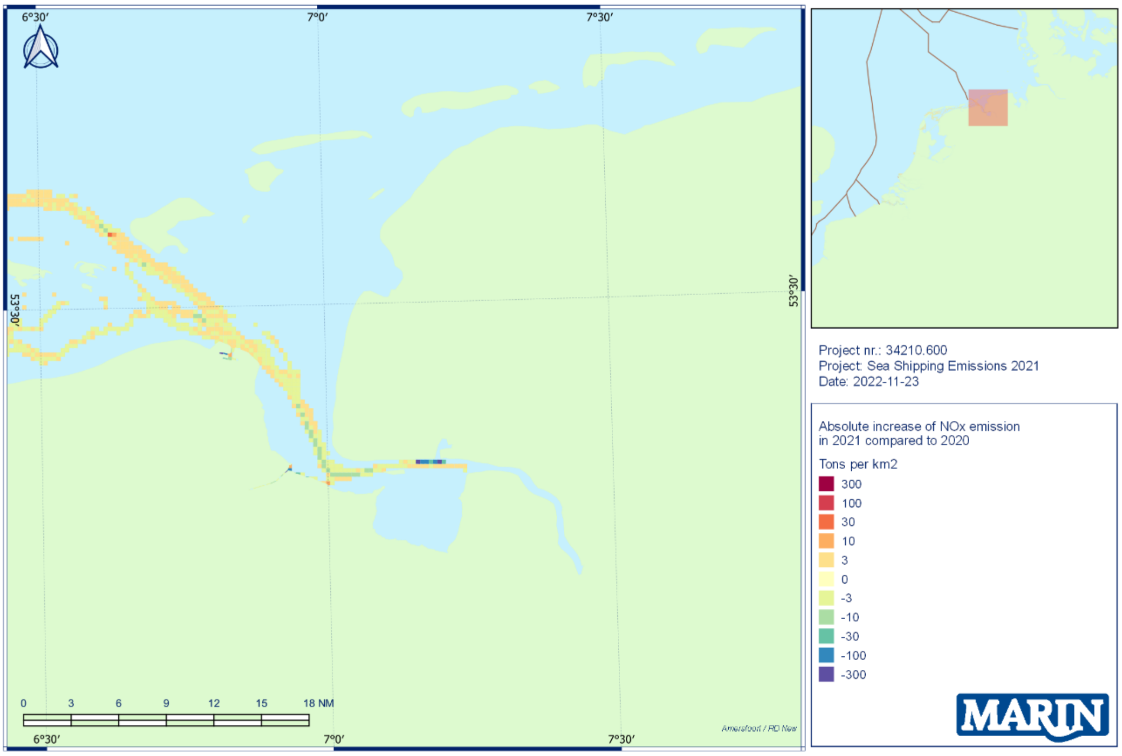

Figure 6-15 Absolute change in NO_x emission from 2020 to 2021 in the Ems area by ships with AIS.

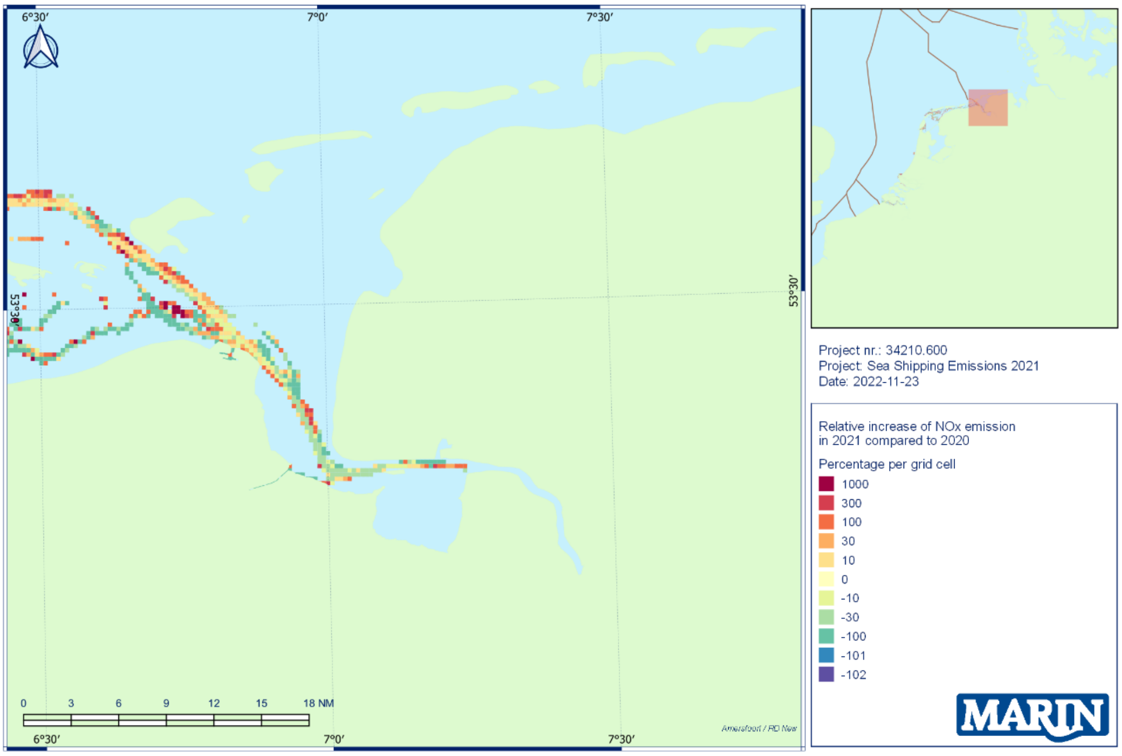

Figure 6-16 Relative change in NO_x emission from 2020 to 2021 in the Ems area by ships with AIS.

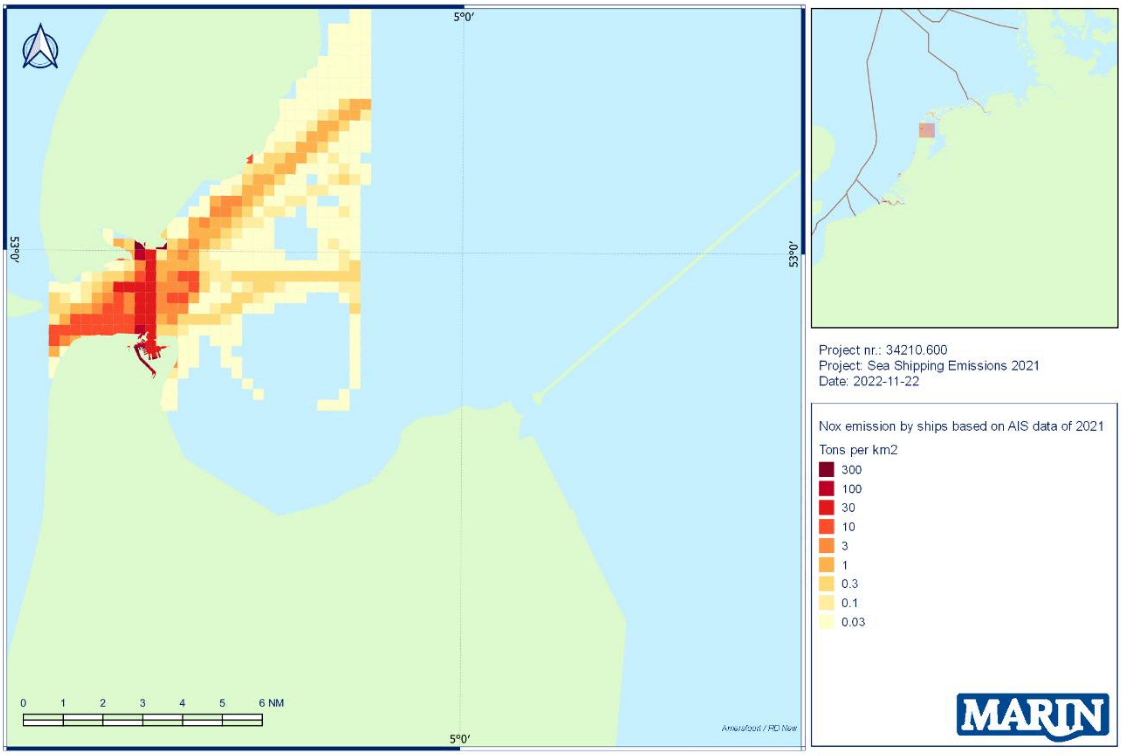

Figure 6-17 NO$_x$ emission in 2021 in the port area of Den Helder by ships with AIS.

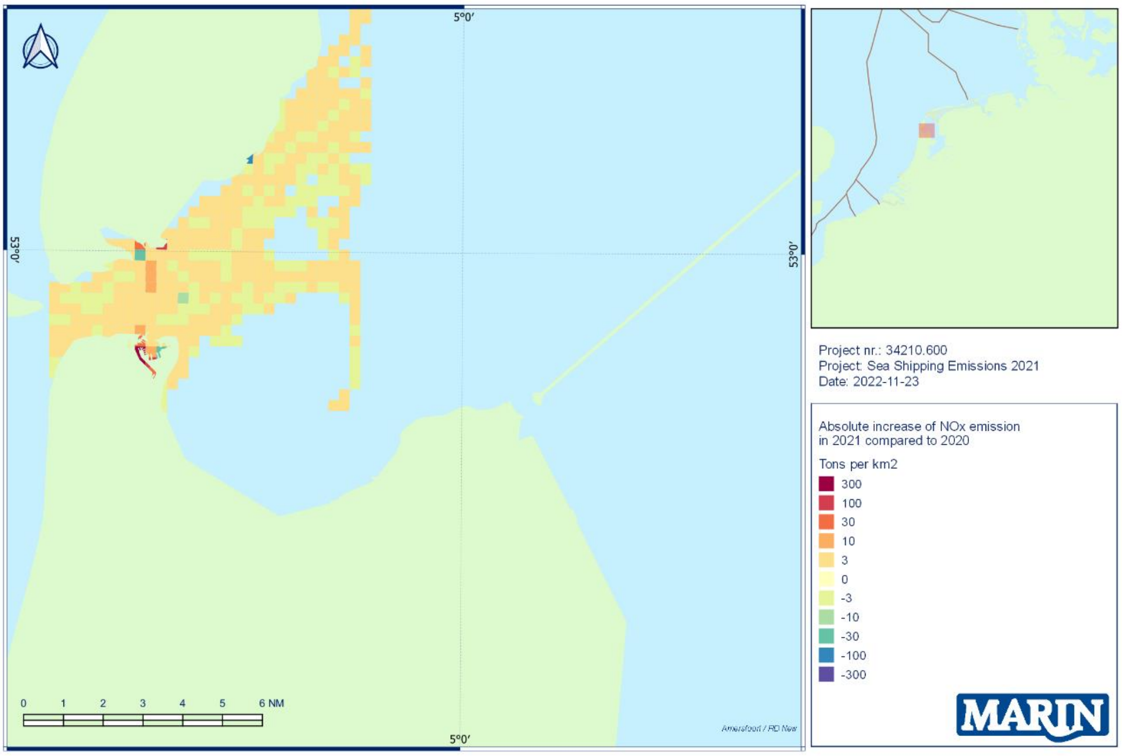

Figure 6-18 Absolute change in NO$_x$ emission from 2020 to 2021 in the port area of Den Helder by ships with AIS.

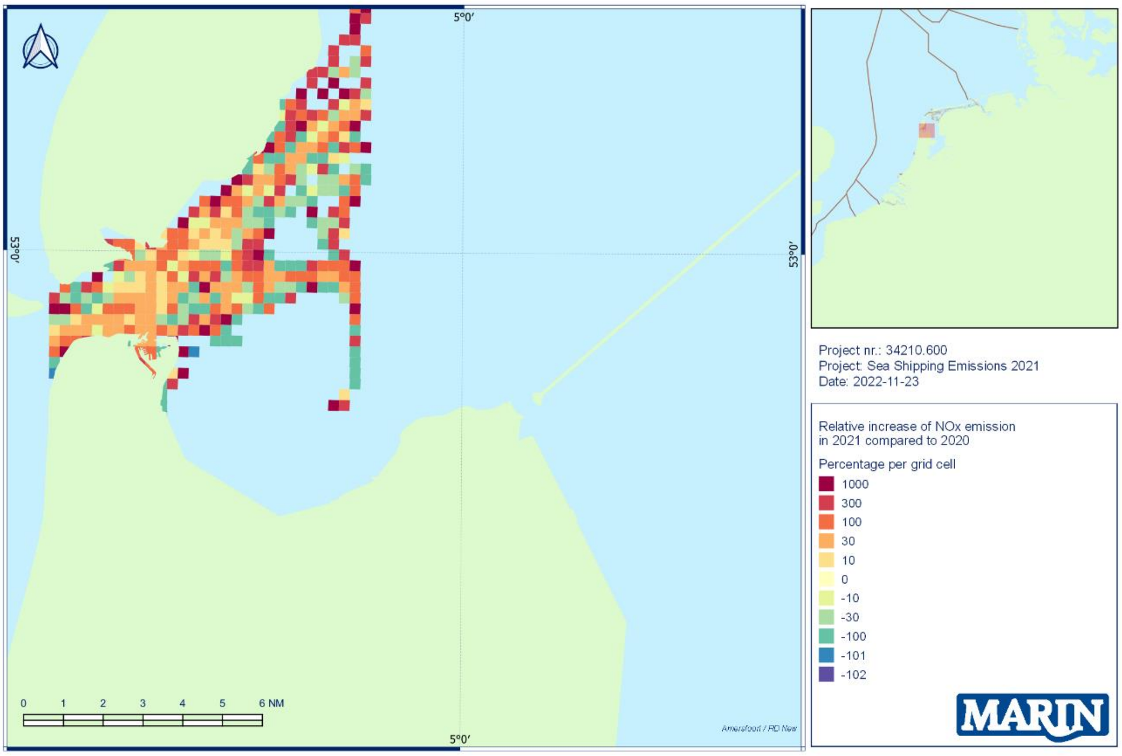

Figure 6-19 **Relative change in NO_x emission from 2020 to 2021 in the port area of Den Helder by ships with AIS.**

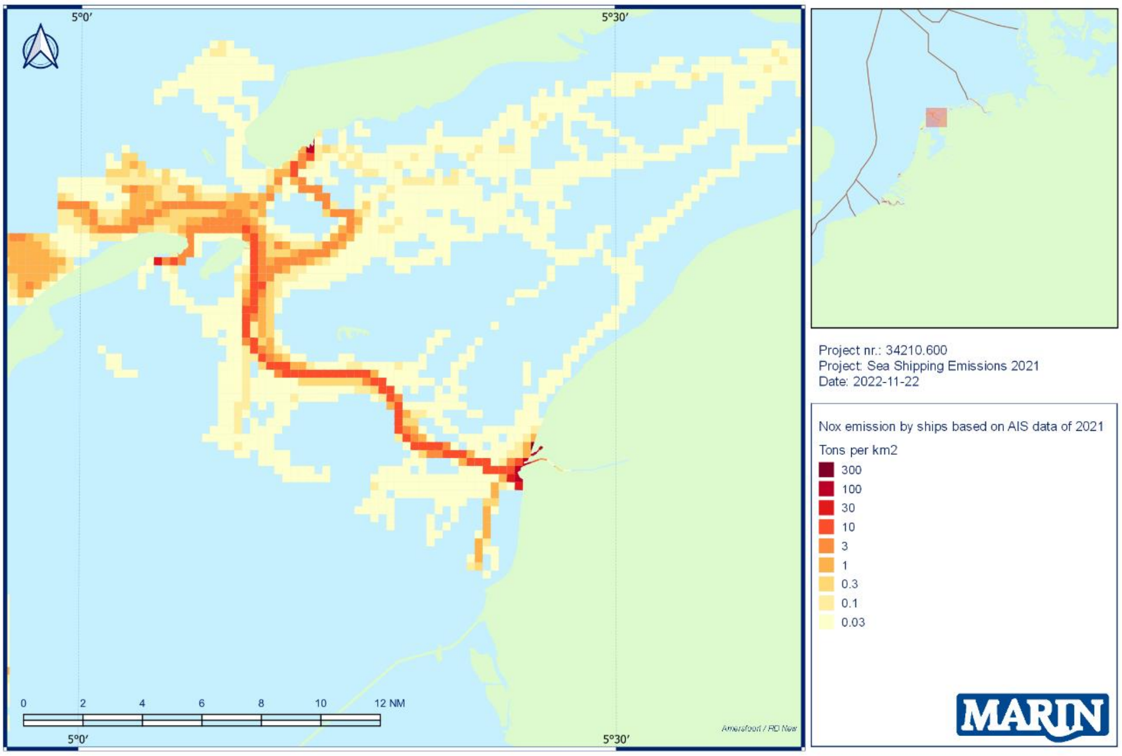

Figure 6-20 **NO_x emission in 2021 in the port area of Harlingen by ships with AIS.**

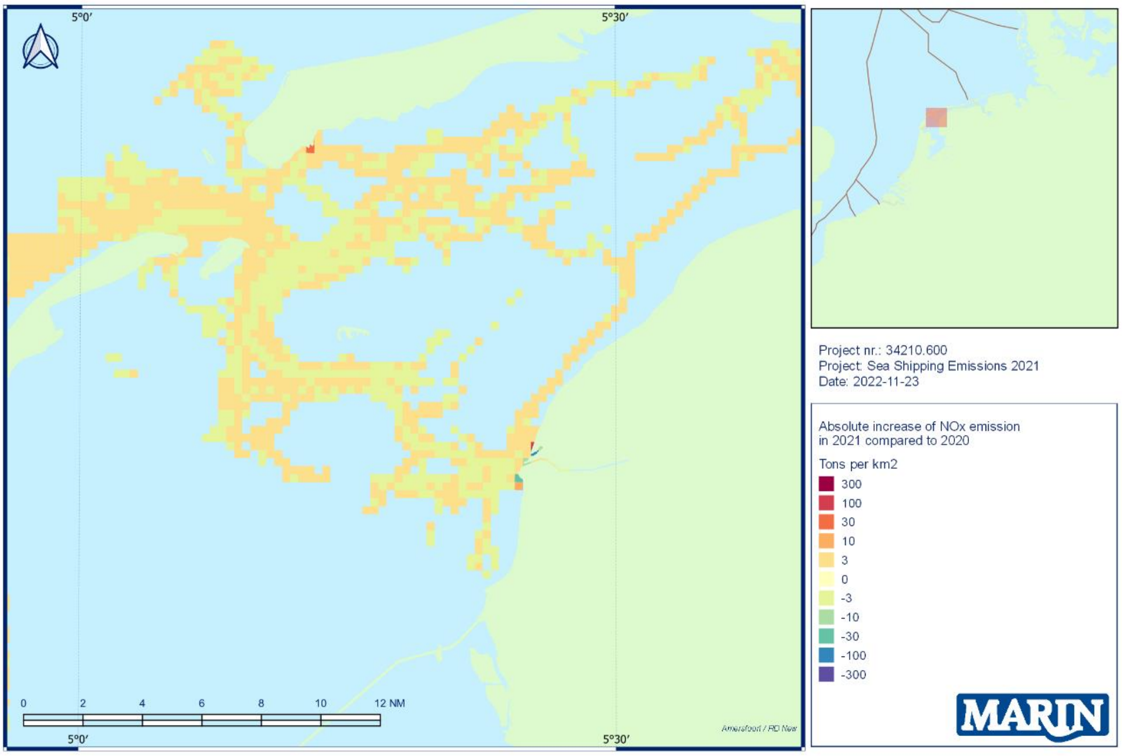

Figure 6-21 Absolute change in NO_x emission from 2020 to 2021 in the port area of Harlingen by ships with AIS.

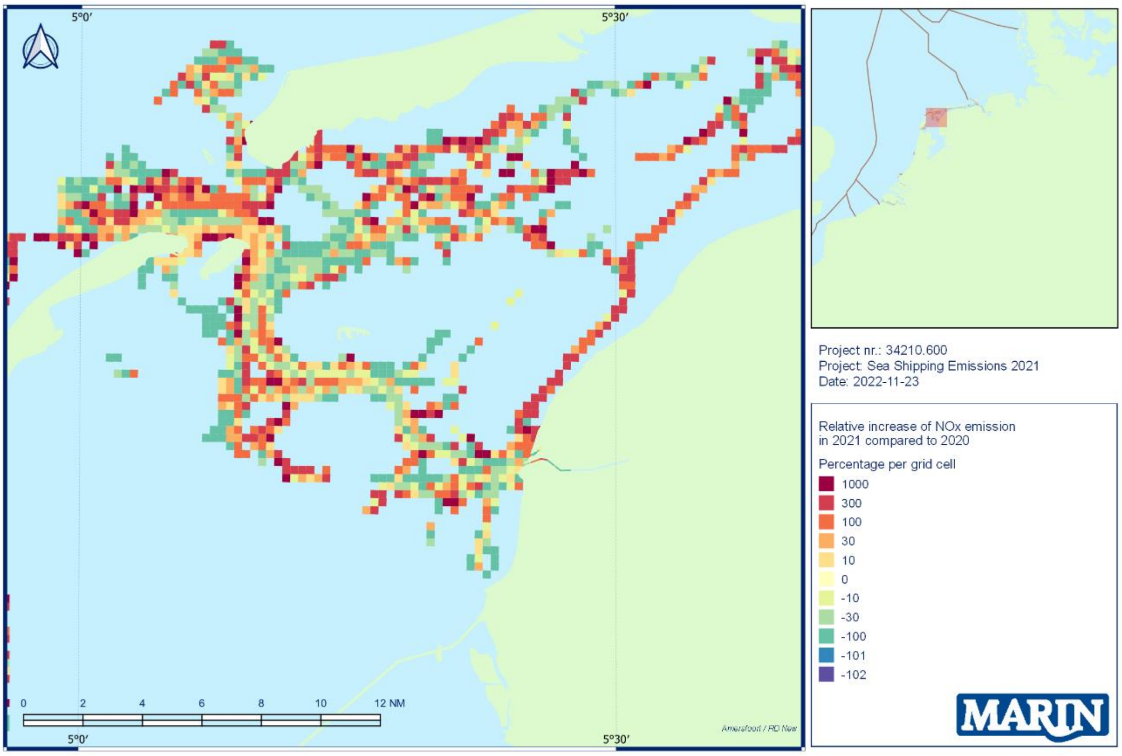

Figure 6-22 Relative change in NO_x emission from 2020 to 2021 in the port area of Harlingen by ships with AIS.

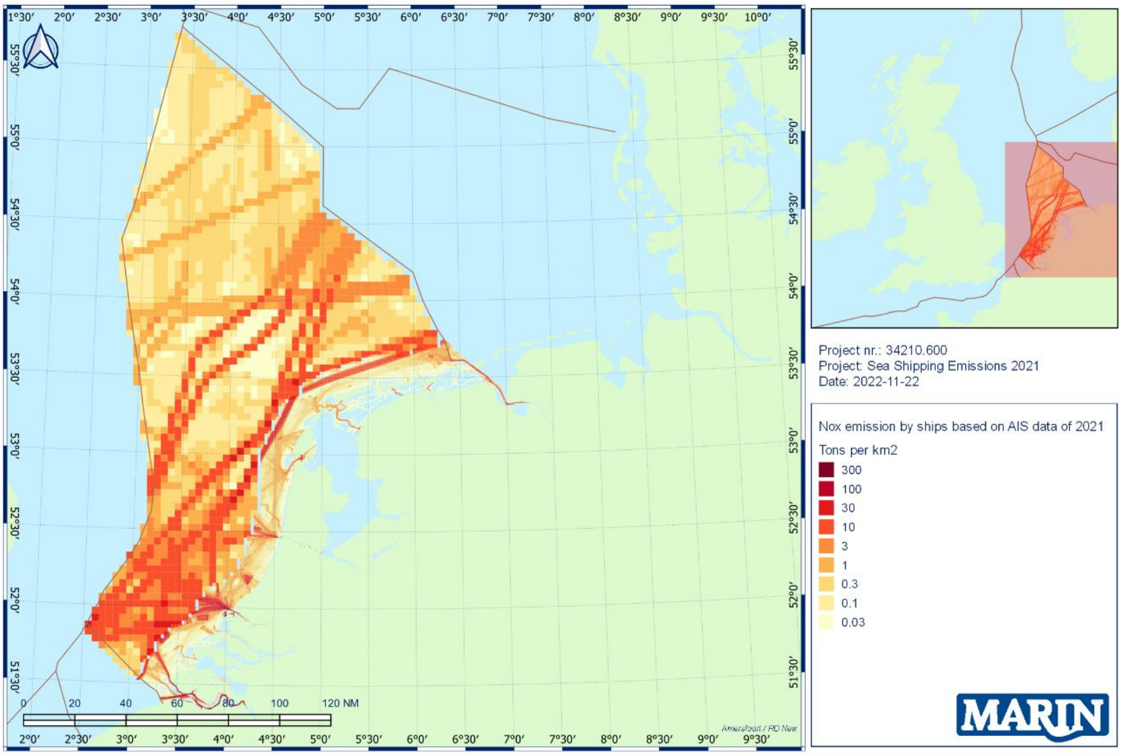

Figure 6-23 **NO_x emission in 2021 in the NCS, the 12-mile zone and the Dutch port areas by ships with AIS.**

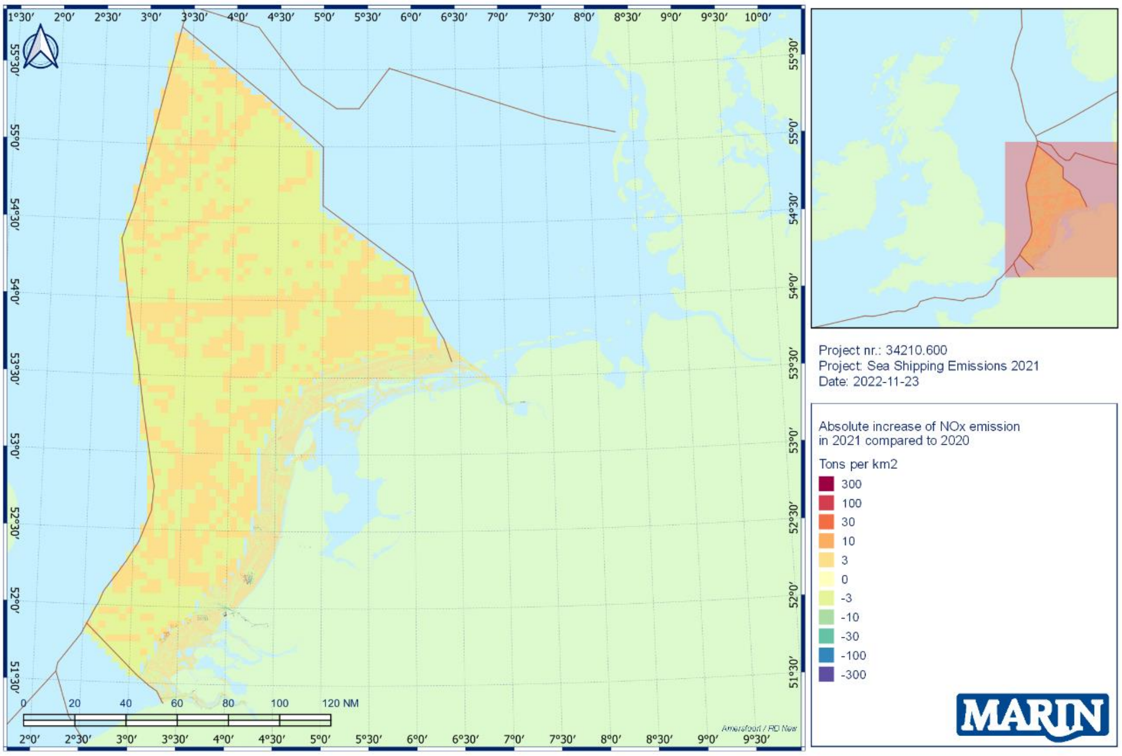

Figure 6-24 **Absolute change in NO_x emission from 2020 to 2021 in the NCS, the 12-mile zone and in the Dutch port areas by ships with AIS.**

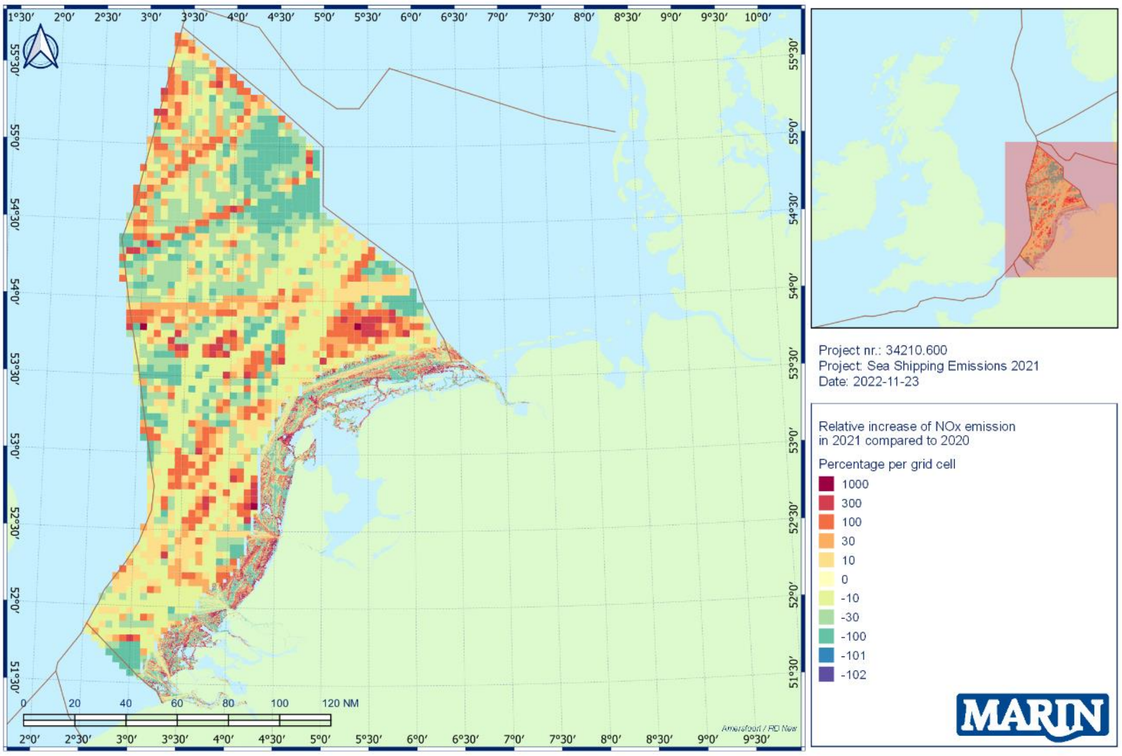

Figure 6-25 Relative change in NO_x emission from 2020 to 2021 in the NCS, the 12-mile zone and in the Dutch port areas by ships with AIS.

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 2021 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 2020. 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 2020. The percentages in grey are based on very low absolute numbers and not very reliable.
Figure 7-1 up to 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, WesternScheldt and Amsterdam. Compared to the previous year there is a clear increase of CO_2 emissions in the port of WesternScheldt, for berthed and sailing ships together 14%. In Amsterdam and Harlingen there is a small decrease of CO_2 emissions. For all ports together the CO_2 emissions have been decreased by 2%.

For the NCP and the 12-miles zone, the CO_2 emissions by fishing vessels increased by 18 percent, mainly caused by an increase of moving ships by 20%.

Table 7-1 Total emissions in ton in each port area for 2021, fishing vessels including trawlers

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Wadden	Total
1237 VOC	Berthed	5	2	5	0	2	7	0	22
	Sailing	2	0	1	1	2	5	2	12
	Total	7	2	6	1	4	12	2	34
4001 SO_2	Berthed	5	2	6	0	3	7	0	23
	Sailing	2	0	1	1	2	5	2	12
	Total	7	2	7	1	5	12	2	36
4013 NO_x	Berthed	126	48	143	1	58	151	8	535
	Sailing	38	3	19	23	44	118	35	279
	Total	164	51	162	24	102	269	43	814
4031 CO	Berthed	6	2	7	0	3	8	0	27
	Sailing	2	0	1	1	2	6	2	15
	Total	8	3	8	1	5	14	2	42
4032 CO_2	Berthed	8,534	3,547	8,880	55	4,128	10,807	538	36,489
	Sailing	2,512	207	1,159	1,652	3,047	8,315	2,470	19,362
	Total	11,046	3,754	10,039	1,706	7,175	19,122	3,008	55,850
6598 Aerosols MDO/HFO	Berthed	4	1	2	0	2	5	0	15
	Sailing	1	0	0	1	1	4	1	9
	Total	5	2	3	1	3	9	2	24

Table 7-2 Emissions in each port area for 2021 as percentage of the emissions in 2020, fishing vessels including trawlers

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Den Helder	Harlingen	Wadden	Total
1237 VOC	Berthed	111%	71%	95%	6%	101%	91%	92%	93%
	Sailing	110%	63%	82%	137%	126%	101%	111%	107%
	Total	111%	71%	93%	83%	110%	95%	107%	97%
4001 SO_2	Berthed	111%	72%	94%	6%	106%	93%	101%	94%
	Sailing	123%	64%	81%	137%	127%	103%	111%	109%
	Total	114%	71%	93%	79%	114%	97%	109%	98%
4013 NO_x	Berthed	111%	70%	94%	6%	105%	93%	100%	93%
	Sailing	119%	63%	83%	138%	126%	102%	111%	108%
	Total	113%	70%	93%	80%	113%	97%	109%	98%
4031 CO	Berthed	111%	71%	96%	6%	103%	91%	95%	93%
	Sailing	115%	65%	81%	138%	125%	102%	111%	107%
	Total	112%	70%	93%	83%	111%	96%	108%	98%
4032 CO_2	Berthed	111%	72%	94%	6%	105%	93%	101%	94%
	Sailing	123%	64%	81%	137%	127%	103%	111%	109%
	Total	114%	72%	93%	79%	114%	97%	109%	98%
6598 Aerosols MDO/HFO	Berthed	111%	76%	94%	6%	100%	91%	100%	93%
	Sailing	119%	62%	86%	138%	131%	101%	113%	110%
	Total	113%	75%	93%	82%	111%	95%	110%	98%

Table 7-3 Total emissions in ton in the 12 mile zone and the NCP for 2021, fishing vessels including trawlers

Substance	Source	12 Miles	NCP	Total
1237 VOC	Berthed	4	1	4
	Sailing	22	81	102
	Total	26	81	107
4001 SO_2	Berthed	4	1	4
	Sailing	23	83	106
	Total	26	84	110
4013 NO_x	Berthed	95	19	114
	Sailing	515	1,921	2,436
	Total	610	1,940	2,550
4031 CO	Berthed	4	1	5
	Sailing	27	99	126
	Total	31	99	131
4032 CO_2	Berthed	5,297	1,147	6,444
	Sailing	35,594	129,779	165,373
	Total	40,890	130,926	171,817
6598 Aerosols MDO/HFO	Berthed	1	0	1
	Sailing	15	56	71
	Total	16	56	73

Table 7-4 Emissions in 12 miles and NCP for 2021 as percentage of the emissions in 2020, fishing vessels including trawlers

Substance	Source	12 Miles	NCP	Total
1237 VOC	Berthed	92%	118%	95%
	Sailing	96%	125%	118%
	Total	95%	125%	116%
4001 SO_2	Berthed	83%	115%	87%
	Sailing	99%	126%	119%
	Total	96%	126%	118%
4013 NO_x	Berthed	88%	120%	92%
	Sailing	99%	125%	119%
	Total	97%	125%	117%
4031 CO	Berthed	83%	116%	87%
	Sailing	98%	123%	117%
	Total	95%	123%	115%
4032 CO_2	Berthed	83%	115%	88%
	Sailing	99%	127%	120%
	Total	96%	127%	118%
6598 Aerosols MDO/HFO	Berthed	113%	113%	113%
	Sailing	96%	132%	122%
	Total	96%	132%	122%

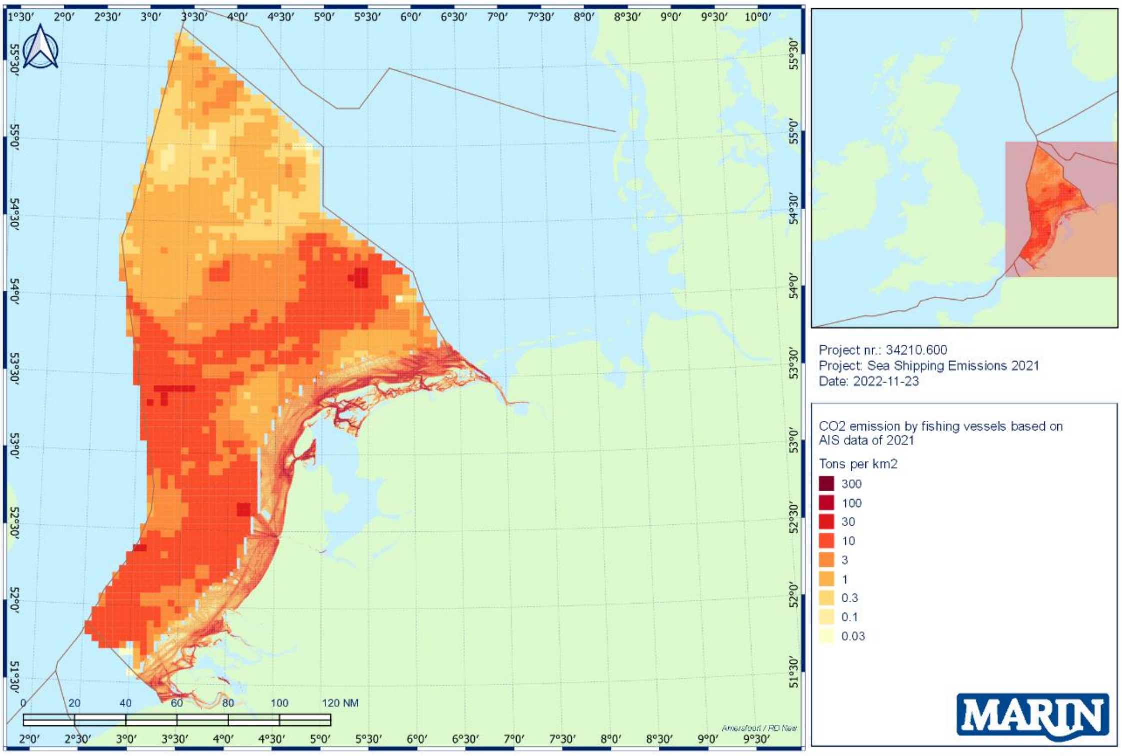

Figure 7-1 CO_2 emission observed in the NCS, fishing vessels including trawlers, based on AIS data of 2021

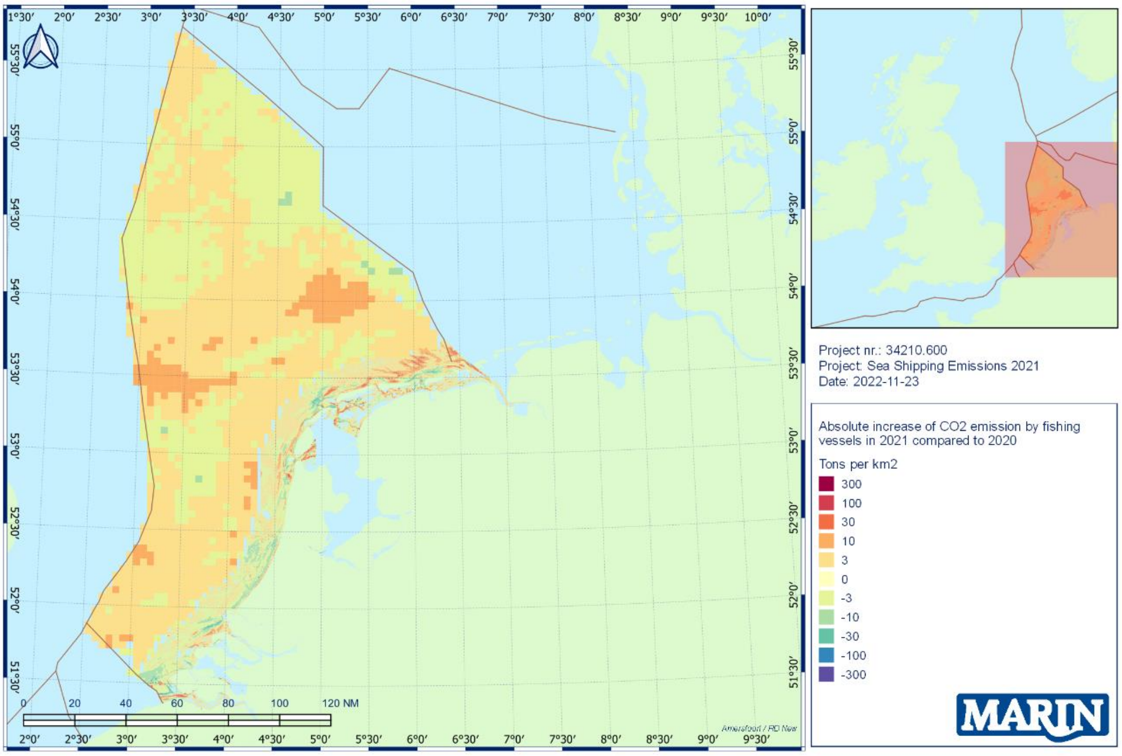

Figure 7-2 Absolute change in CO2 emission from 2020 to 2021 observed in the NCS, fishing vessels including trawlers.

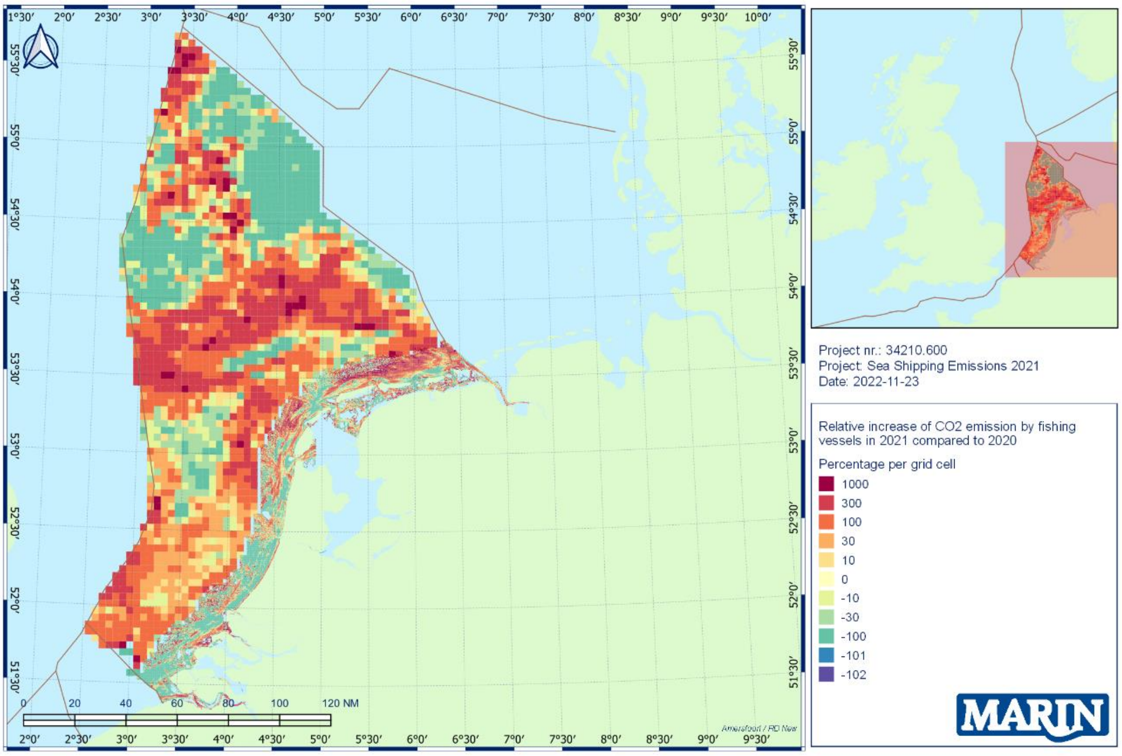

Figure 7-3 **Relative change in CO2 emission from 2020 to 2021 observed in the NCS, fishing vessels including trawlers.**

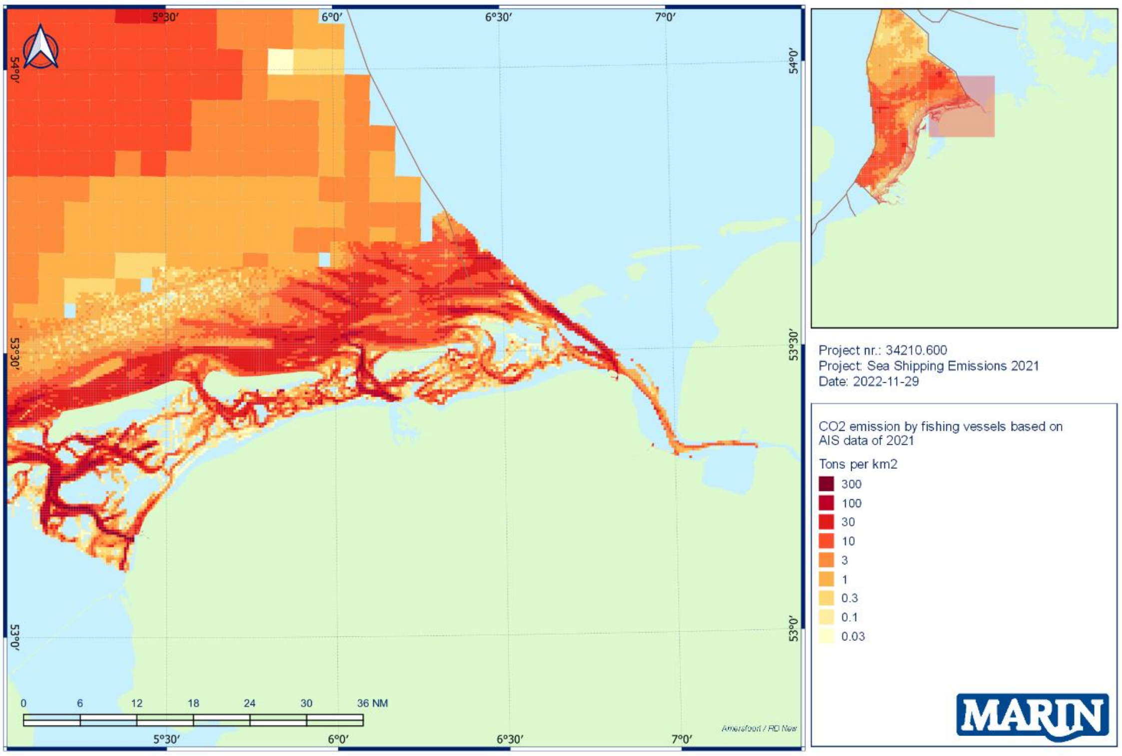

Figure 7-4 **CO_2 emission observed in the Dutch Wadden Sea, fishing vessels including trawlers, based on AIS data of 2021**

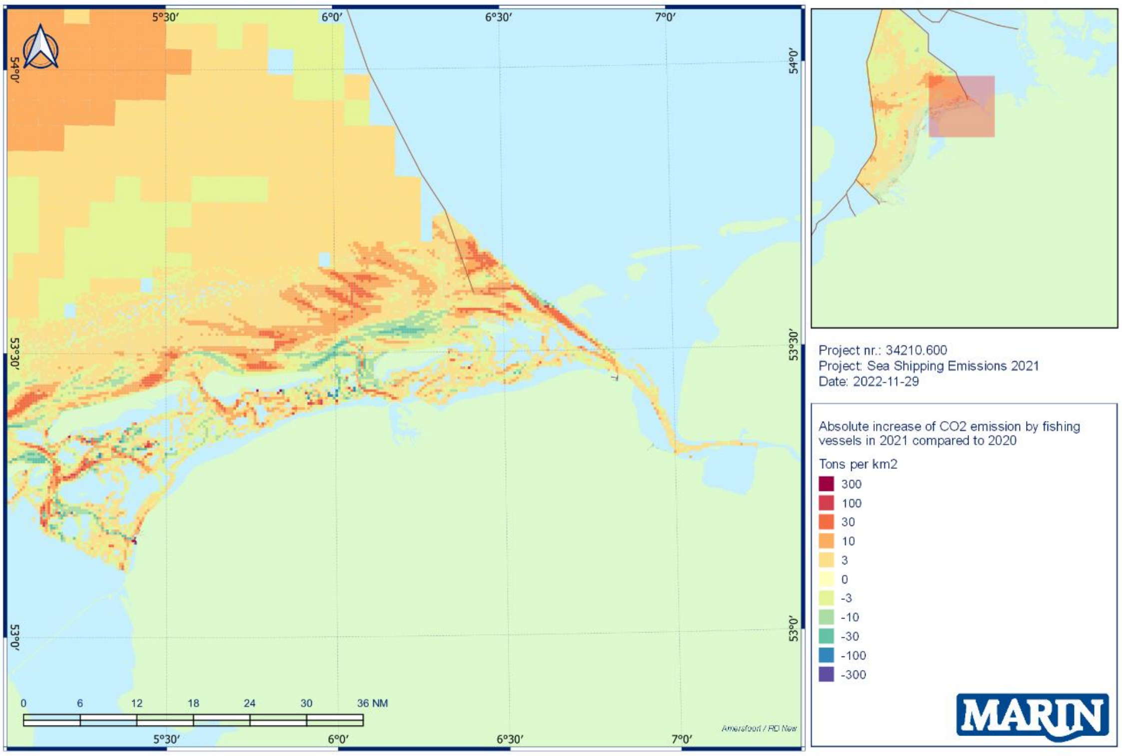

Figure 7-5 **Absolute change in CO2 emission from 2020 to 2021 in the Dutch Wadden Sea, fishing vessels including trawlers.**

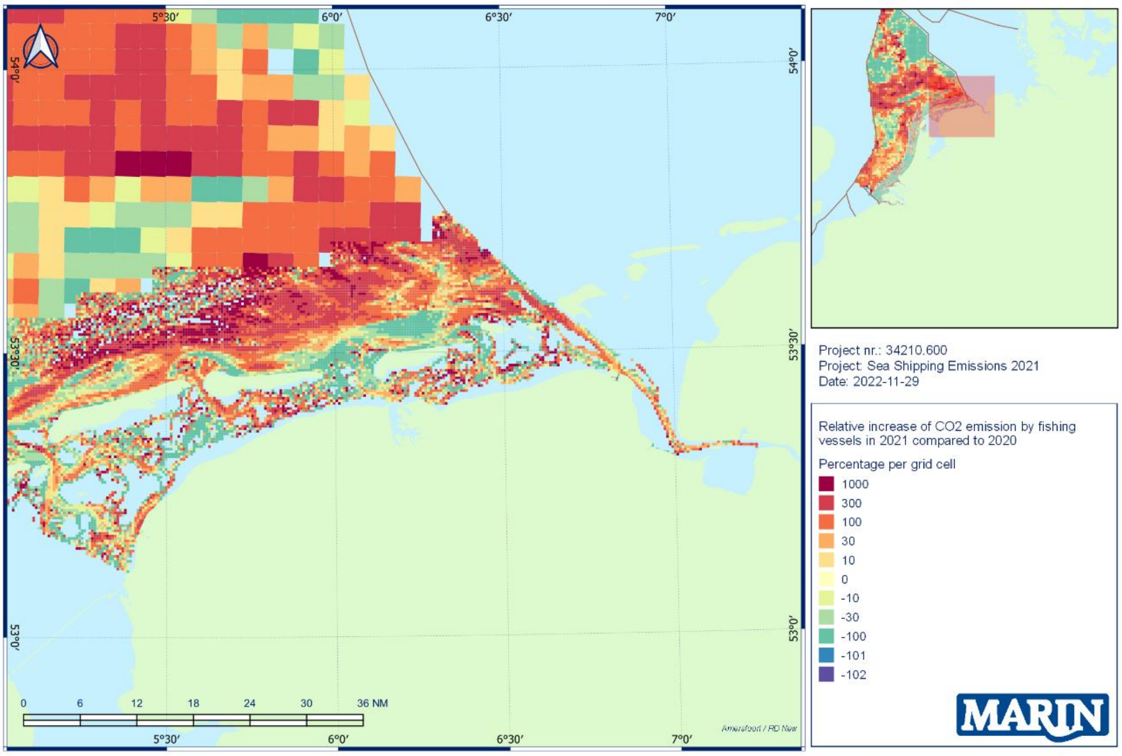

Figure 7-6 **Relative change in CO2 emission from 2020 to 2021 in the Dutch Wadden Sea, fishing vessels including trawlers.**

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 127 minutes for 2021. The AIS data is practically complete, so there is no need to compensate for this.

- **Activity data**
  Compared to 2020 there is a clear decrease of berthed hours in the Dutch port areas except for the port of Den Helder. Moving activities increased except for the port of Rotterdam. For the NCS combined with 12-miles the average berthed and moving hours increased by 3% and 1% respectively. This can also be seen in the average number of ships per day.

- **Emission results**
  The substance CO_2 has the largest contribution to the total emissions in ton (98%). For all ports together, there is an overall decrease of CO_2 by 16%. Ships at berth have a total decrease of CO_2 by 21% ,and the emission of sailing ships decreased by 7%. The decrease in CO_2 emissions is mainly caused by Rotterdam since this port has a significant influence in an absolute sense. For all ports together NO_x emissions increased and SO_2 emissions decreased compared to 2020.

  For NCS combined with the 12-miles zone there is a total increase of CO_2 by 2%, this is due to 7% increase for ships at anchor and 2% increase for sailing ships. NO_x emissions decreased since the previous registration and SO_2 remains approximately at the same level. For the Netherlands sea area the average number of ships increased by 2%.

- **Emission results fishery**
  The absolute contribution of CO_2 emissions by fishing vessels is largest in Harlingen, WesternScheldt and Amsterdam. Compared to the previous year there is a clear increase of CO_2 emissions in the port of WesternScheldt, for berthed and sailing ships together 14%. In Amsterdam and Harlingen there is a small decrease of CO_2 emissions. For all ports together the CO_2 emissions have been decreased by 2%.

  For the NCP and the 12-miles zone, the CO_2 emissions by fishing vessels increased by 18 percent, mainly caused by an increase of moving ships by 20%.

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APPENDIX A: EMISSION FACTORS

Written by Jan Hulskotte & René Koch 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 report covering the emission calculations in accordance with the EMS protocols is also available [5]. 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-4/Table A-11).
CEF Correction factors of basic engine emission factors (Table A-14/Table A-16).
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).

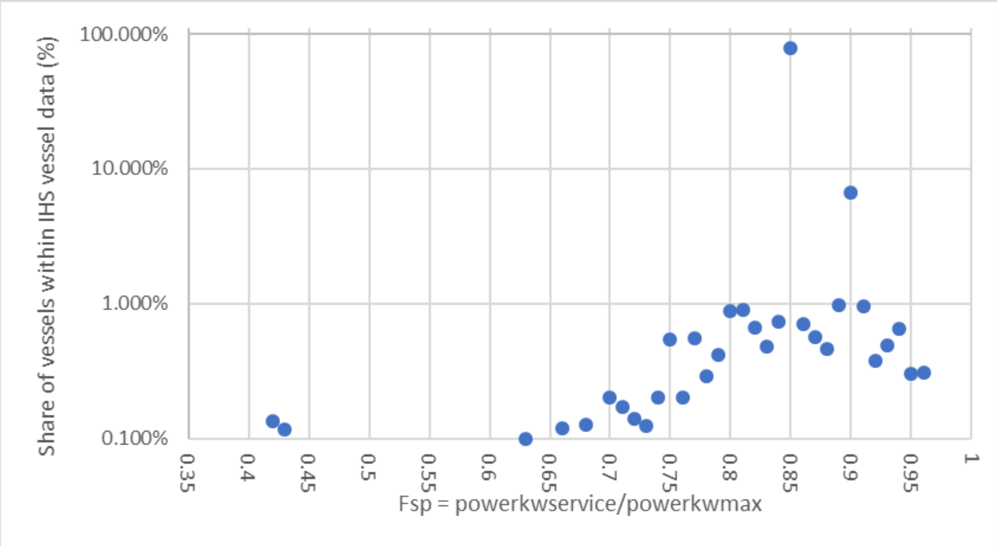

Figure A- 1 Statistics of the Sea-margin.

Figure A-1 shows that of the majority of the IHS 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. In a MAN 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.

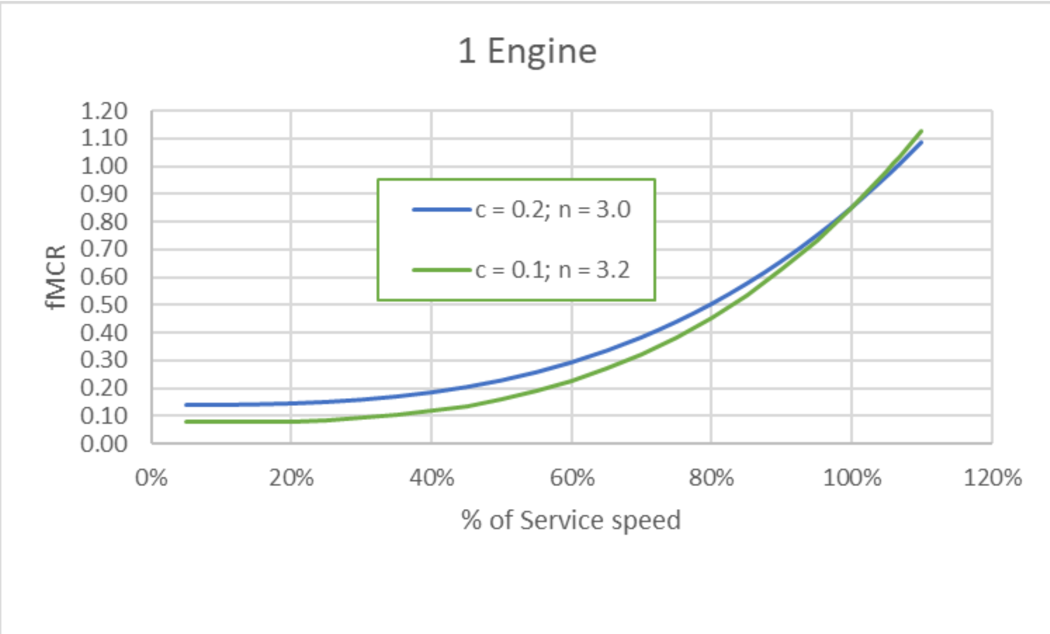

Figure A- 2 The relationship between service speed and fMCR at ships with one single propulsion engine used in emission calculations.

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 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 consumption 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-4 to A-7.

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.

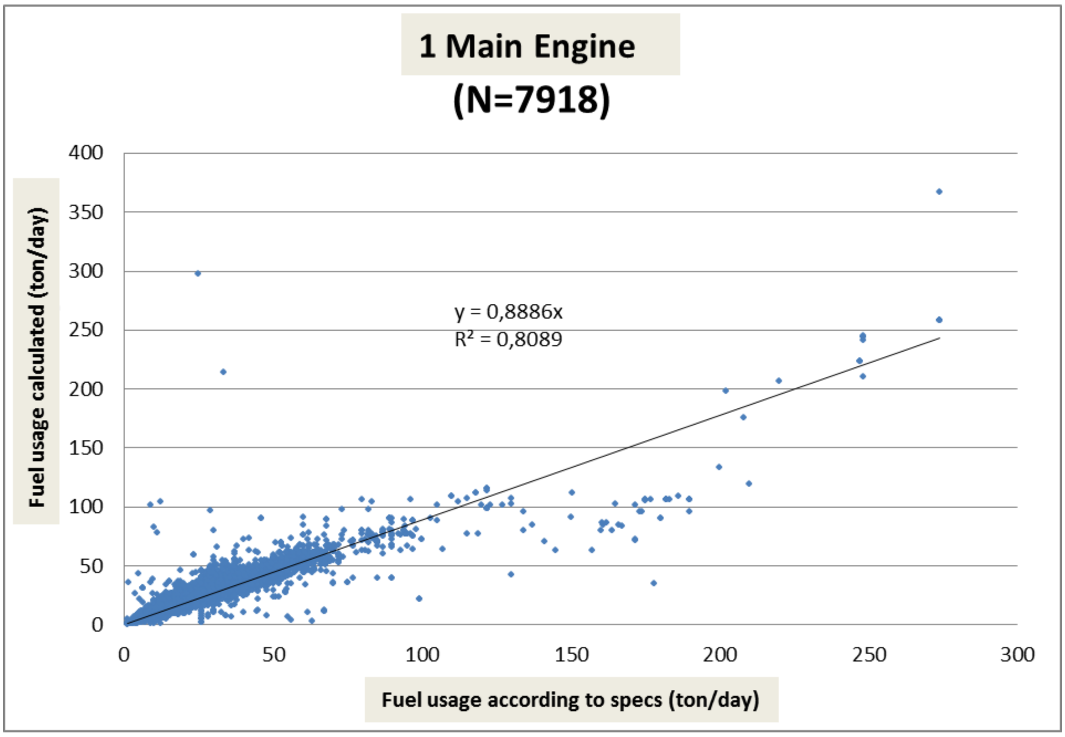

Figure A- 3 Calculated daily fuel usage of one-engine ships compared with specifications.

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.

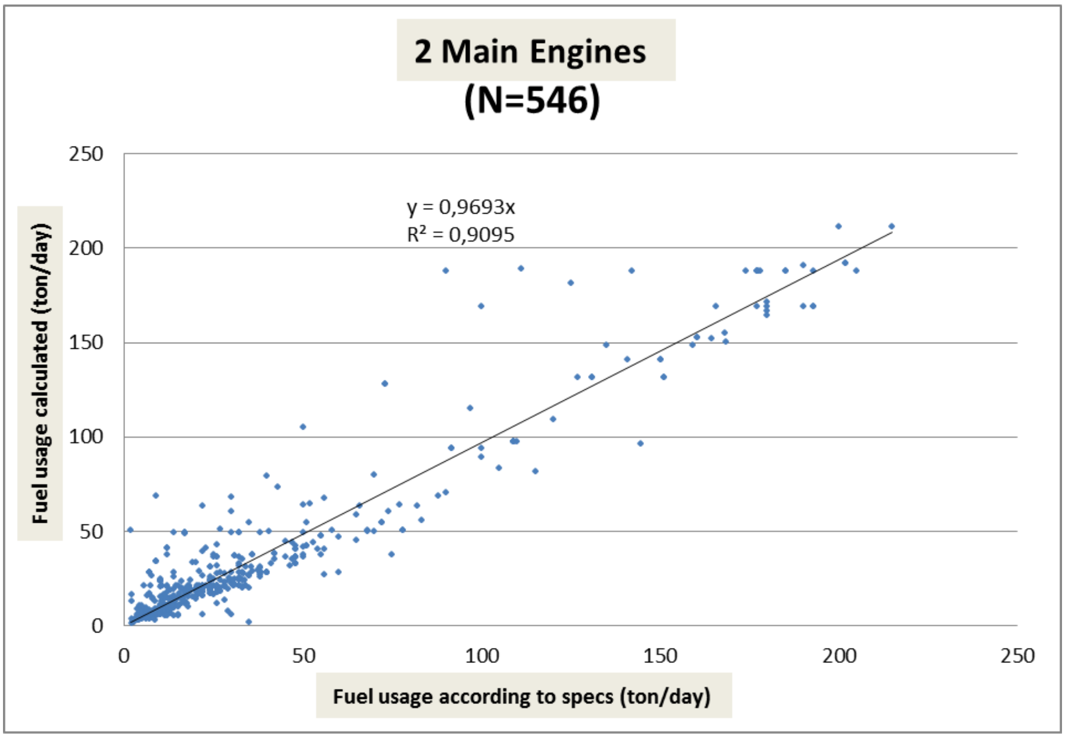

Figure A- 4 Calculated daily fuel usage of two engine ships compared with specifications.

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-5 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.

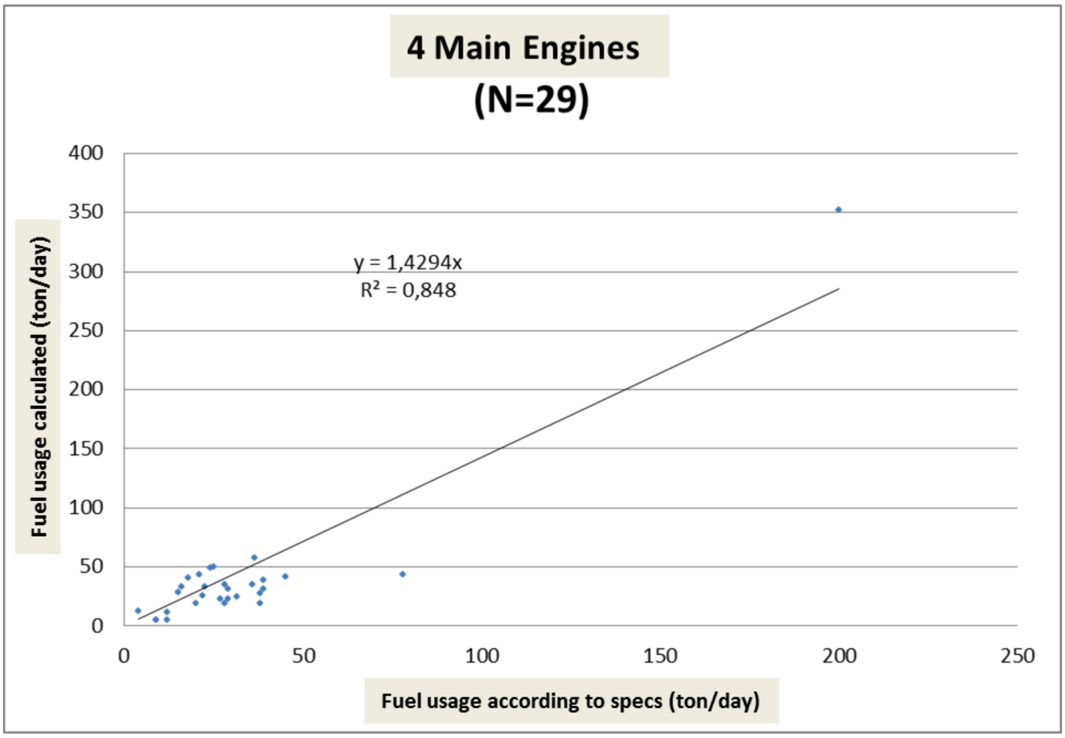

Figure A- 5 Calculated daily fuel usage of four engine ships compared with specifications.

It can be argued that energy consumption of four engined 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 engined 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-4/Table A-11)
CEF Correction factors of basic engine emission factors (Table A14/Table A-16)
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 limited 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-4 to Table A-11 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 SO_2 and CO_2 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	2020	2021
North sea regions	5.34	6.1	7.23	5.72	3.25	1.60	1.49
Baltic sea	2	3.8	3.46	3.1	2.13	0.59	0.57
Calculated average S% North sea regions	0.15	0.15	0.17	0.15	0.13	0.114	0.113

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 0.113% for all areas. It can be concluded that compliance of sulphur legislation is slowly improving 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 0.113% of HFO and MDO was assumed in all areas in 2021 (see table A-3). According to [12] the contribution of PM from sulphur was calculated as 8% of SO_2 (calculated from S%): 0.08 * 0.113 * 20 = 0.1808 g/kg fuel. For instance having a SFOC value of 210 g/kWh results in PM from sulphur alone in 210/1000 * 0.1808 = 0.038 g/kWh. The PM emission factors in the tables below (table A4 – A11) 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[1]	PM-HFO Other[2]	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		0.34	0.34	0.50	0.50	0.3	0.5	533	168
2011 –	~rpm[3]	0.23	0.23	0.49	0.49	0.3	0.5	524	165
Tier III		0.23	0.23	0.45	0.45	0.05	0.7	481	151

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

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		0.24	0.24	0.50	0.50	0.3	0.5	533	168
2011 –	~rpm[4]	0.23	0.23	0.49	0.49	0.3	0.5	524	165
Tier III		0.15	0.15	0.44	0.44	0.05	0.7	478	151

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[4] 9[5]	0.54	0.54	0.55	0.55	0.3	0.5	581	183
2011 -	~rpm[4] 7[5]	0.54	0.54	0.53	0.53	0.3	0.5	571	180
TIER III	~rpm[4] 2.2[5]	0,38	0,38	0.49	0.49	0.05	0.7	524	165

[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[4] 9[5]	0.24	0.24	0.55	0.55	0.3	0.5	581	183
2011 -	~rpm[4] 7[5]	0.24	0.24	0.53	0.53	0.3	0.5	571	180
TIER III	~rpm[4] 2.1[5]	0,18	0,18	0.48	0.48	0.05	0.7	520	164

[2] applied on auxiliary engines only

[4] Dependant on revolutions per minute (Table A-8).

[5] applied on auxiliary engines only.

Emission factors of CO were reduced by a factor of 4 according to [16]. Emission factors of PM and SO_2 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 x $n^{-0.2}$	0.87 x 45 x $n^{-0.2}$
	> 2000 RPM	9.8	0.87 x 9.8
2011 – 2022 (Tier II)	< 130 RPM	14.4	0.93 x 14.4
	Between 130 and 2000 RPM	44 x $n^{-0.23}$	0.93 x 44 x $n^{-0.23}$
	> 2000 RPM	7.7	0.93 x 7.7
(Tier III)	< 130 RPM	3.4	0.95 x 3.4
	Between 130 and 2000 RPM	9 x $n^{-0.2}$	0.95 x 9 x $n^{-0.2}$
	> 2000 RPM	2.0	0.95 x 2.0

The reduction factors for Tier I engines (0.87), Tier II engines (0.93) and Tier III engines (0.95) 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, (g/kWh).

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
SP (TIER III)	3.4	0.02	0.003	0.15	0.2	475	
ST	1.94	0.01	0.004	0.05	0.06	687.8	

The methane (CH_4) 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-12 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-12. 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 the auxiliary engines are also presented in the same table A-13.

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-14 to Table A-16. 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	Tier III			
10	1.2	1.21	1.34	1.74	6	1.63	4.46	5.22
15	1.15	1.18	1.17	1.52	3	1.32	2.74	3.51
20	1.1	1.15	1.1	1.36	1.75	1.19	2.02	2.66
25	1.07	1.13	1.06	1.3	1.45	1.12	1.65	2.14
30	1.06	1.11	1.04	1.32	1.45	1.08	1.42	1.8
35	1.05	1.09	1.03	1.34	1.45	1.05	1.27	1.56
40	1.045	1.07	1.02	1.34	1.45	1.03	1.16	1.38
45	1.035	1.05	1.01	1.32	1.45	1.01	1.09	1.23
50	1.03	1.04	1.00	1.3	1.45	1.01	1.03	1.12
55	1.025	1.03	1.00	1.27	1.45	1.00	1.00	1.06
60	1.015	1.02	0.99	1.23	1.4	1.00	0.98	1.00
65	1.01	1.01	0.99	1.13	1.25	0.99	0.95	0.94
70	1.00	1.01	0.98	1.01	1	0.99	0.92	0.88
75	1.00	1.00	0.98	0.95	0.85	0.98	0.89	0.82
80	1.01	1.00	0.97	0.95	0.85	0.98	0.87	0.76
85	1.02	1.00	0.97	0.95	0.85	0.97	0.84	0.7
90	1.03	1.01	0.97	0.95	0.85	0.97	0.85	0.7
95	1.04	1.02	0.97	0.95	0.85	0.97	0.86	0.7
100	1.05	1.02	0.97	0.95	0.85	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.
A further differentiation in NOx correction factors for new vessels is introduced for TIER III engines. This is because the North Sea and the Baltic Sea have become NECA areas ("Nitrogen Oxide Emission Control Area") as of the 1st of January 2021. See for further information publication [25].

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 the 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- 18).

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-19 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 at berth (%).

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-20 to Table A- 22, 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 – 2022	43	0.8	1.6	2,75
TIER III	12,81	0,91	0,3	1,50

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	SO_2	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
2015-2022	0.2	7	0.3	0.2	0.4	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 EU fishing fleet register or the FIGIS database managed by FAO.
As fuel, marine diesel with a sulphur content of 0.1% was assumed.

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