SEA SHIPPING EMISSIONS 2011: NETHERLANDS CONTINENTAL SHELF, PORT AREAS AND OSPAR REGION II

Final Report

Report No. : 26437-1-MSCN-rev. 2
Date : July 24, 2013

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Revision no.	Status	Date	Author	Approval
0	Draft	February 15, 2013	C. van der Tak	A. Cotteleer
1	Draft	June 10, 2013	C van der Tak	A. Cotteleer
2	Final	July 24, 2013	C van der Tak	A. Cotteleer

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GLOSSARY OF DEFINITIONS AND ABBREVIATIONS

Definitions:

Voyage database Database consisting of all voyages crossing the North Sea in 2008 collected by Lloyd's List Intelligence

SAMSON Traffic database Database that contains the number of ship movements per year for each traffic link divided over ship type and size classes. It is based on the Lloyd's List Intelligence voyage database

Ship characteristics database This database contains vessel characteristics of nearly 123,000 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.

Abbreviations/Substances:

VOC *V*olatile organic carbons. 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
CRS	Correction factor Reduce Speed
EMS	Emissieregistratie en Monitoring Scheepvaart (Emission inventory and Monitoring for the shipping sector)
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.
MCR	Maximum Continuous Rating is defined as the maximum output (MW) that a generating station is capable of producing continuously under normal conditions over a year
n.a.	Not applicable
NCS	Netherlands Continental Shelf
NHR	Nationale Havenraad (National Ports Council in the Netherlands)
nm	nautical mile or sea mile is 1852m
SAMSON	Safety Assessment Model for Shipping and Offshore on the North Sea
TNO	Netherlands Organisation for Applied Scientific Research

1 INTRODUCTION

1.1 The Emission Register project

The emissions calculated in this project for the Netherlands Continental Shelf and the Dutch port areas are input to the Dutch Emission Register. Ref [1] explains the project, and the most important information has been copied into this section.

Since 1974 a number of organisations have been working closely together in the emission register project to collect and formally establish the yearly releases of pollutants to air, water and soil in the Netherlands. Goal of the project is to agree on one national data-set for emissions that meets the following criteria: transparent, complete, comparable, consistent and accurate.

Results of this project serve to underpin the national environmental policy. Furthermore, data is provided for numerous international environmental reports to the European Union and the United Nations, e.g. the National Inventory Report for the Kyoto Protocol.

The Emission Register (ER) contains data on the yearly releases of more than 350 pollutants to air, soil and water. The Emission Register project covers the whole process of collecting, processing and reporting of the emission data in the Netherlands. Emissions from individual point sources (companies or facilities) and diffuse emissions (calculated from national statistics by the so called task forces) are stored into one central database, from which all the national and international reporting is done.

The National Institute for Public Health and the Environment (RIVM) co-ordinates the Emission Register project on behalf of the Ministry of Infrastructure and Environment (I&M)

Collecting and processing national emissions for each emission source is done according to a standard protocol. Various emission experts from the participating organisations in the Task Forces calculate the national emissions from 1200 emission sources on the basis of these protocols.

The task force on transportation covers the emissions to soil, water and air from the transportation sector (aviation, shipping, rail and road transport). The following organisations are represented in this task force: RIVM, Netherlands Environmental Assessment Agency, (PBL), Statistics Netherlands (CBS) Centre for Water Management, Deltares and the Netherlands Organisation for Applied Scientific Research (TNO).

A formal agreement is drawn up by all the participating organisations. After close study, the national emissions are accepted by the project leader of the Emission Register and the data set is stored in the central database located at RIVM.

Together with national totals for each emission source, the ER website also shows maps with the emission given per community, water catchment area or on a 5 * 5 km grid cell. To allocate an emission spatially, the Emission Register has a spatial allocation available for each emission source. For example, traffic intensity (car kilometres) for the emissions from road traffic, land use (surface) for agricultural emissions and population density for the emissions from households. If an allocation per community is not available, the allocation on a 5*5 km grid is aggregated to the area of a community, taking the surface of each grid cell in that community into account.

1.2 Concentration and deposition maps for the Netherlands

Every year RIVM produces large-scale background concentration maps of NO_2, PM, SO_2 and CO, and large-scale background deposition maps of NH_x and NO_y. Calculations are based on emission data from the Emission Register in the Netherlands [7] and from the Centre for Emission Inventories and Projections [9] for the emissions from other countries. The concentration maps (GCN-maps) give a view of the large-scale component of the air quality. The deposition maps (GDN-maps) are made to support the Programmatic Approach Nitrogen (Programmatische Aanpak Stikstof (PAS)). This approach is needed because the deposition of nitrogen is a problem in the implementation of the European nature network (Natura 2000).

Next to emissions in the Dutch ports and the Netherlands Continental Shelf (NCS), emissions within the remainder of OSPAR region II are input to the concentration and deposition maps. Such a wide approach is needed, because also emissions originating far away from the Netherlands affect the air quality and nitrogen deposition in the Netherlands.

1.3 Activities of MARIN

In the past, MARIN has performed studies to quantify the emissions to air of seagoing vessels for:

- the port of Rotterdam for 2007 based on AIS [2];
- the Netherlands Continental Shelf (NCS) and the four Dutch port areas for 2008, 2009 and 2010 based on AIS ([3], [4] and [8]), and;
- the OSPAR region II for 2008, 2009 and 2010 based on the emissions at the NCS and the SAMSON traffic database ([3], [4] and [8]);
- the foreign ports for 2010 based on the number of calls in these ports ([8]).

RIVM has asked MARIN to perform the same work for 2011 as for 2008, 2009 and 2010.

1.4 Objective

This study aims to determine the emissions to air of seagoing vessels above 100 GT, excluding fishery, for 2011. The totals and the spatial distribution for the Netherlands Continental Shelf and the port areas Western Scheldt, Rotterdam, Amsterdam and the Ems are based on AIS data. In addition, the information contained in the AIS data for the NCS and in the SAMSON traffic database for the whole of the North Sea are used to determine the emissions for 2011 in the OSPAR region II area at sea and in the foreign ports. The grid size for the port area emissions based on AIS is 500 x 500 m, for the other areas a grid size of 5000 x 5000 m has been used.

The emissions for 2011 are determined for VOC, SO_2, NO_x, CO, CO_2 and Particulate Matter (PM). A distinction is made between ships sailing under EU-flag and non-EU flag and between ships sailing within or outside the 12-mile zone of the NCS.

1.5 Report structure

Chapter 2 describes the emission databases that were obtained for 2011.
Chapter 3 describes the procedure that was used for the emission calculation based on AIS data.
Chapter 4 describes the procedure used for the emission calculations based on the SAMSON database.
Chapter 5 describes the completeness of the AIS data, both with respect to missing files and with respect to spots that are not fully covered by base stations.
Chapter 6 describes the changes in the (calculation of the) emission factors.
Chapter 7 contains the level of shipping activity in the Dutch port areas and at the NCS.
Chapter 8 summarises the emissions for 2011 for the Dutch port areas and the NCS and makes a comparison with 2010.
Chapter 9 summarises the 2011 emissions for OSPAR region II, both at sea and in the port areas. It also contains a comparison with 2010.
Chapter 10 presents conclusions and recommendations.

2 2011 EMISSION DATABASES

2.1 General information

Access databases with the calculated emissions to air from sea shipping have been delivered for:

- the Netherlands Continental Shelf;
- the four Dutch port areas;
- the OSPAR region II at sea;
- the OSPAR region II port areas outside the Netherlands.

The databases contain emission information on a grid cell basis, distinguished into:

- substance;
- EMS ship type classes and ship size classes;
- moving / not moving;
- 12-mile zone / outside 12 mile-zone;
- EU / non-EU flag (only for the databases based on AIS).

Since 2009 a distinction is made between the aerosols from marine diesel engines operated with distillate fuel oil (substance 6601) and aerosols from marine diesel engines operated with residual fuel oil (substance 6602). This has been done to facilitate a potential differentiation of the fractions $PM_{2.5}$ and PM_{10} in the total aerosol emission between these fuel types. The fractions $PM_{2.5}$ and PM_{10} are applied to the total aerosol emission when the data are read into the Dutch emission register. The sum of the emission of both numbers can be compared with the 2008 data for substance number 6598.

2.2 NCS and Dutch port areas

The emissions at the Netherlands Continental Shelf (NCS) and the four Dutch port areas based on AIS data have been stored in:

- Emissions_2011_MARIN_NCP.mdb
- Emissions_2011_MARIN_Dutch_port_areas.mdb

In 2011 smaller fishing vessels (<45 m) were not obligatory equipped with an AIS transponder. Therefore, the AIS based emissions of fishing vessels are far from complete with a contribution of less than 1.5%. Other sources outside the scope of this project are used to determine the emission of fishing vessels. Despite this, the tables and figures in this report include the AIS based emissions of fishing vessels. Also the above databases contain the emissions of fishing vessels. These can easily be deselected by excluding EMS type 11. Information on vessel types can be found in Appendix B and in the database table EMS_type_upd_decode.

Concerning the Western Scheldt and the Ems, only the emissions in the Dutch part of these port areas are included in the database 'Dutch Port areas'. The AIS based emissions in the Belgian or German part are included in the OSPAR region II database.

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 port areas. The grids are chosen in such a way that they do not overlap each other.

The NCS including port areas is presented in Figure 2-1 on an electronic sea chart. The purple lines are the traffic separations schemes and the squares are offshore platforms. The different areas are indicated by plotting the centre points of the grid cells with different colours:

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

The four port areas are illustrated in more detail in Figure 2-2 to Figure 2-5.
At some places, there are red points on land. There are several reasons for this. In general, the detail of the charts presented here is such that not all existing waterways and/or quays are visible, though they do exist. Also, it has been observed that the determination of the GPS position is disturbed by container cranes, so that the AIS message is not fed with the correct position. When, for whatever reason, AIS signals are disturbed or lost, data are extrapolated and this is done before MARIN receives the data. In the case of Rotterdam, dots on land are partly caused by the fact that there has already been created an extra side channel as part of the changes for Maasvlakte II. This extra channel is not yet drawn in the electronic chart.

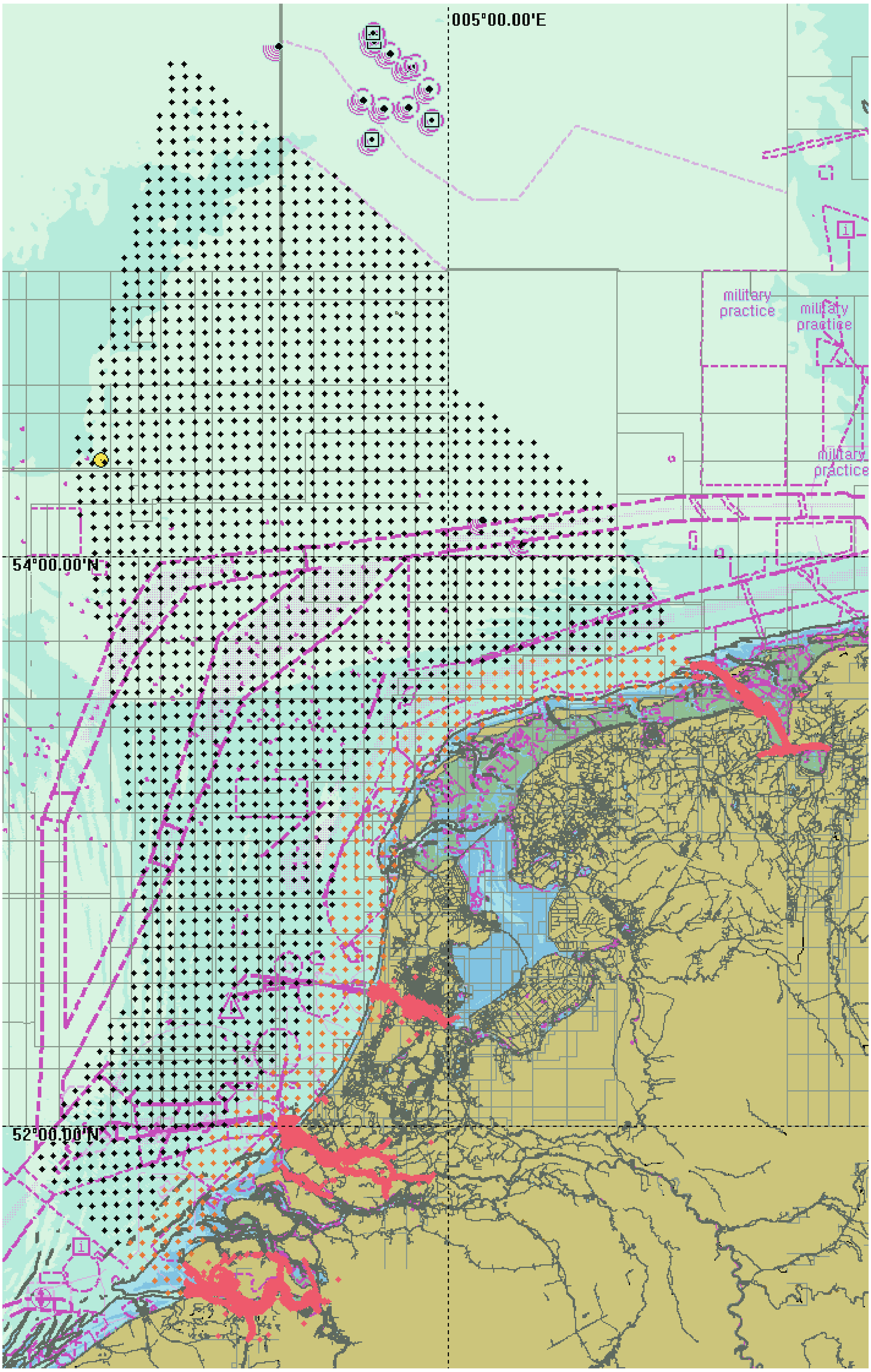

Figure 2-1 The Netherlands Continental Shelf with four port areas

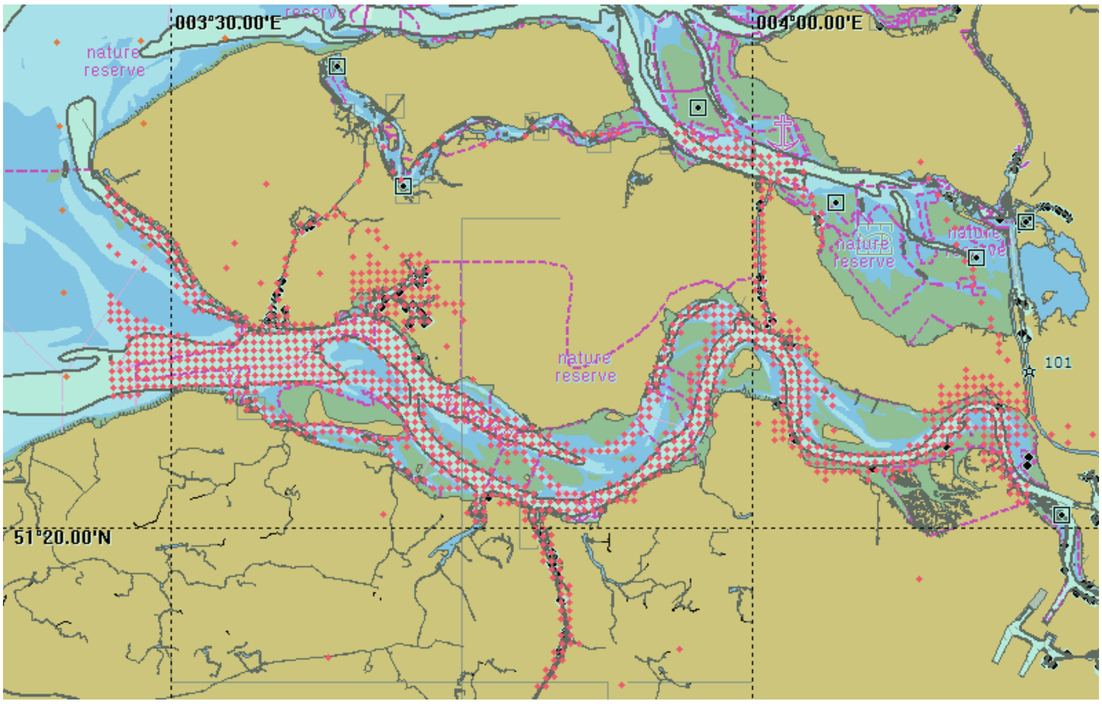

Figure 2-2 Western Scheldt: The red points indicate the locations of the emissions included in the Dutch port areas database.

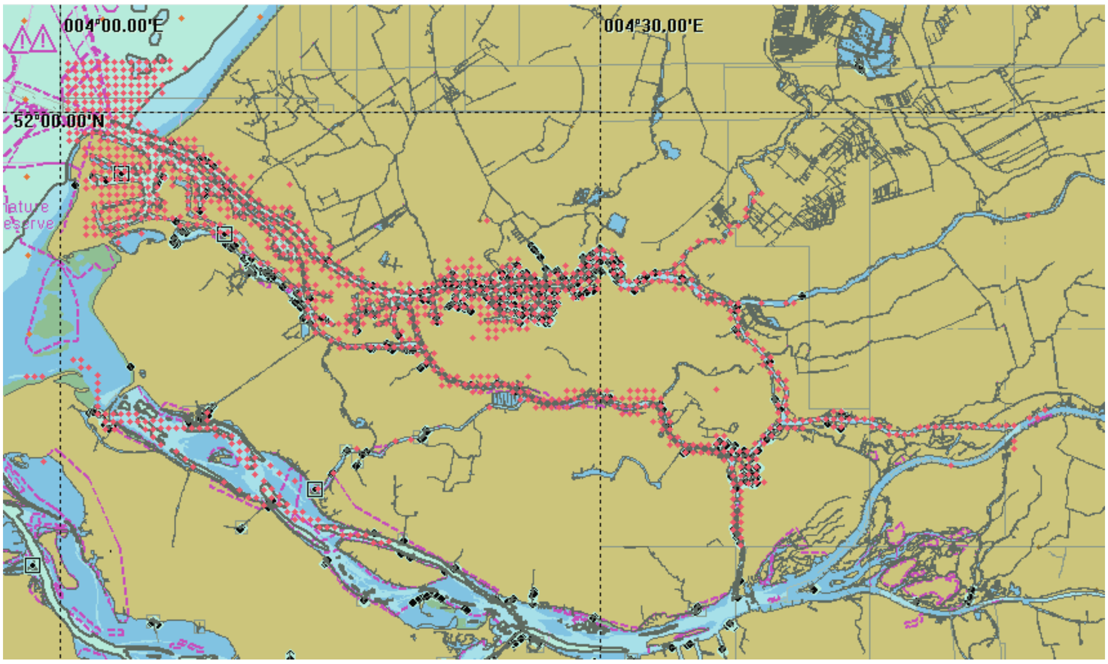

Figure 2-3 Rotterdam: The red points indicate the locations of the emissions included in the Dutch port areas database

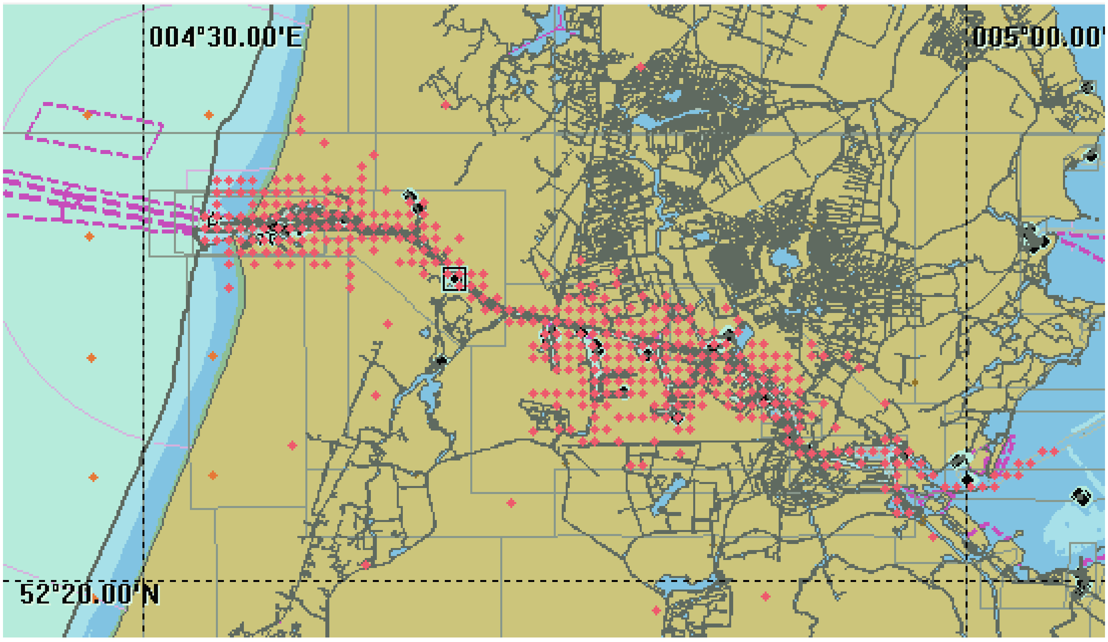

Figure 2-4 Amsterdam: The red points indicate the locations of the emissions included in the Dutch port areas database

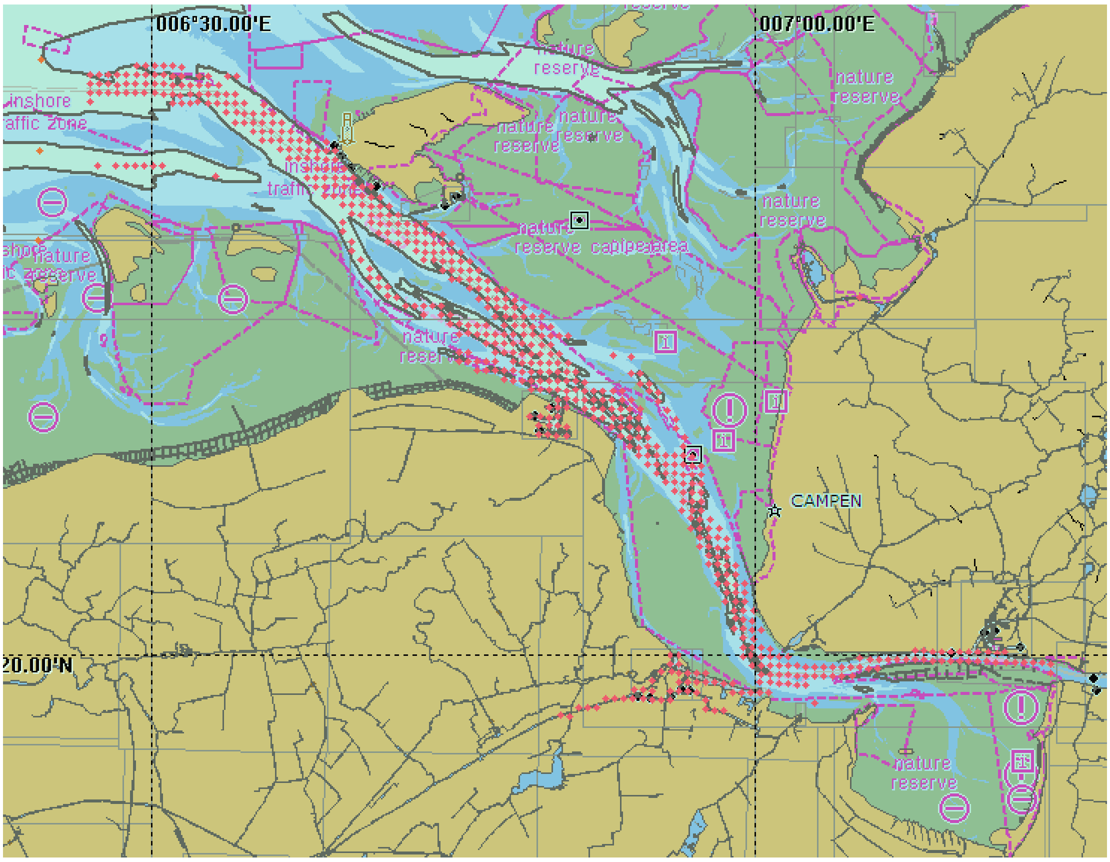

Figure 2-5 Ems: The red points indicate the locations of the emissions included in the Dutch port areas database

2.3 OSPAR region II

2.3.1 OSPAR region II at sea

The database “Emissions_OSPAR_region_II_2011_MARIN_sea.mdb” contains the emissions in OSPAR region II at sea and is based on:

- the SAMSON traffic database of 2008;
- the movements of ferries that are not included in the Lloyd’s List Intelligence (LLI) voyage database, but are collected from other sources, see 4.3.

The SAMSON traffic database contains the number of ship movements per year for each traffic link divided over ship types and ship size classes. It is based on the LLI voyage database.

The calculated emissions have been corrected for the changes in the traffic volumes and composition between 2008 and 2011.

The LLI database does only contain a small number of voyages of fishing vessels, which means that the emissions of fishing vessels are far underestimated. Despite this, the emissions of fishing vessels are included in all tables and figures of this report and also in the emission database for OSPAR region II. The respective records can be skipped by not selecting vessel type 11.

The emissions have been calculated on a 5000 x 5000 m grid. Note that this grid (based on UTM coordinates) is different from the NCS grid for the AIS based database (based on RDM coordinates), However, an optimum match was chosen. The following areas are indicated in Figure 2-6 and can be selected in the OSPAR region II database:

- the 12-mile zone of the NCS (in orange),
- the remainder of the NCS (in black),
- the North Sea as defined by IMO (with black line),
- OSPAR region II (with black dotted line).

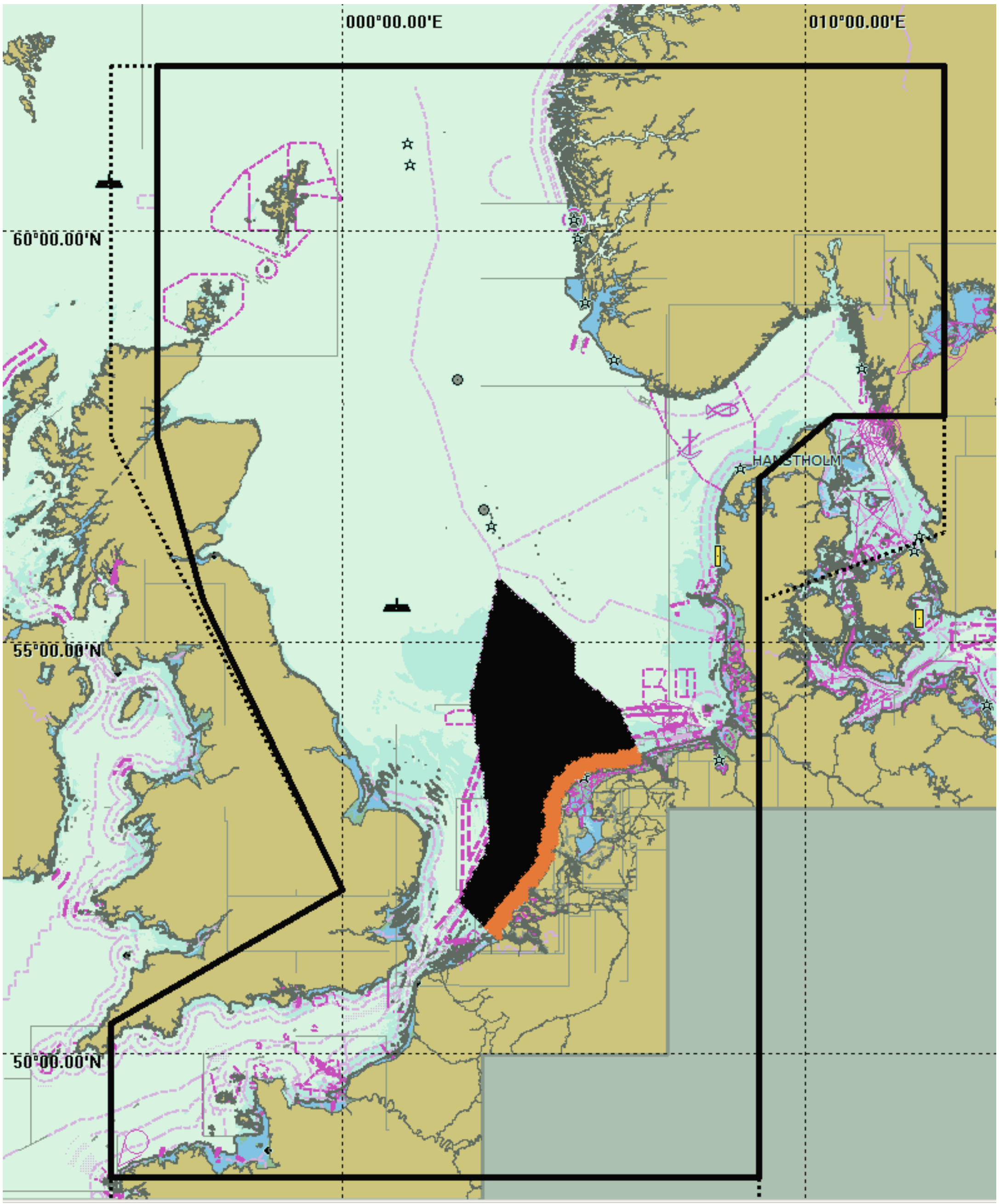

Figure 2-6 Areas within OSPAR region II (dotted black line): North Sea according to IMO (black line), NCS outside 12-mile zone (black), NCS inside 12-mile zone (orange)

2.3.2 OSPAR region II port emissions

The database "Emissions_OSPAR_region_II_2011_MARIN_ports_outside_NL.mdb" contains the emissions in port areas outside the Netherlands, based on:

- the Lloyd's List Intelligence (LLI) voyage database of 2008 for foreign ports outside the coverage of Dutch AIS base stations; .
- AIS data of 2010 for the Belgian ports leading to the Western Scheldt and the German ports leading to the Ems.

The LLI-based emissions are described with a 5000 x 5000 m grid, the AIS-based emissions with a 500 x 500 m grid. The field size_of_gridcell on the database records indicates the size of the grid cell.

The emissions of fishing vessels are also for this area far from complete. Nevertheless they are included in the database from which they can be deselected by excluding EMS type 11.

3 PROCEDURE FOR EMISSION CALCULATION BASED ON AIS DATA

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

3.1 Input

This section explains the input that has been used to perform the emission calculations based on AIS data:

- AIS data
- ship characteristics database

3.1.1 AIS data for 2011 at NCS and Dutch port areas

Since 2005 all merchant vessels over 300 Gross Tonnage are equipped with an Automatic Identification System (AIS). These systems transmit information about the ship, its voyage and its current position, speed and course. Static information, such as name, IMO number, ship type, size, destination and draft, is transmitted every six minutes. Dynamic information such as position, speed and course is transmitted every 2 to 10 seconds.

Although meant for improving safety at sea, dynamic AIS information offers great opportunities to gain insight into the spatial use of sea and waterways. Local traffic intensities and densities can, for example, be calculated very precisely. By linking the AIS data with a ship characteristics database, additional characteristics about the ship can be used, allowing for calculations of emissions.

In this study, AIS data of 2011 for the NCS and the port areas Western Scheldt, Rotterdam, Amsterdam and the Ems has been used to calculate the emissions in these areas. Figure 3-1 gives an example of one week of AIS data; a dot was plotted to show the location of all vessels with a ten minutes interval.

MARIN receives AIS messages of the type 1, 2, 3 and 5 from the Netherlands Coastguard. Message type 1, 2 and 3 contain information about the position of the ship. Message type 5 contains static and voyage related ship data. Information is not always complete and is occasionally entered incorrectly.

Table 3-1 shows an example of the kind of information contained in these messages.

The information on a ship’s position is the most reliable as this is automatically transmitted via the navigation equipment installed onboard. The navigational status, which specifies whether a ship is sailing, at anchor or moored, is often incorrect. This is visible, for example, when a ship has an anchoring status, but still a considerable speed. The speed thus, in most cases, gives a better indication of the ship’s real navigational status than the navigational status field which needs to be manually filled in by crew.

Table 3-1 Example of AIS data collected from various message types.

Data fields	Contents (example)	AIS message type
MMSI	235007237	1, 2, 3, 5
Call Sign	GFVM	1, 2, 3
IMO number	377438	5
ship name	HITT-STENA TRANSFER	5
ship type	60	5
Latitude	51.987485	1, 2, 3
Longitude	4.060318	1, 2, 3
Heading	110	1, 2, 3
course over ground	112	1, 2, 3
rate of turn	0	1, 2, 3
speed over ground	14.3	1, 2, 3
navigational status	0	1, 2, 3
actual draught	6.2	5
Altitude	0	
a (distance of antenna to bow)	140	5
b (distance of antenna to stern)	43	5
c (distance of antenna to portside)	8	5
d (distance of antenna to starboard)	16	5
Destination	HUMBER\HOOKOFHOLLAND	5
navSensorType	0	5
navName		5
parseTime (in seconds from 01/10/1970)	1178004614	1, 2, 3
ETA	01/05/07 07:00:00	5
posAccuracy	0	1, 2, 3
ownShip	0	
lastSysTimeOfReport	00/00/00 00:00:00	Added
Valid	0	Added
lastUtcTimeFromTarget	01/05/07 07:30:14	Added
utcTimeStamp	19	1, 2, 3

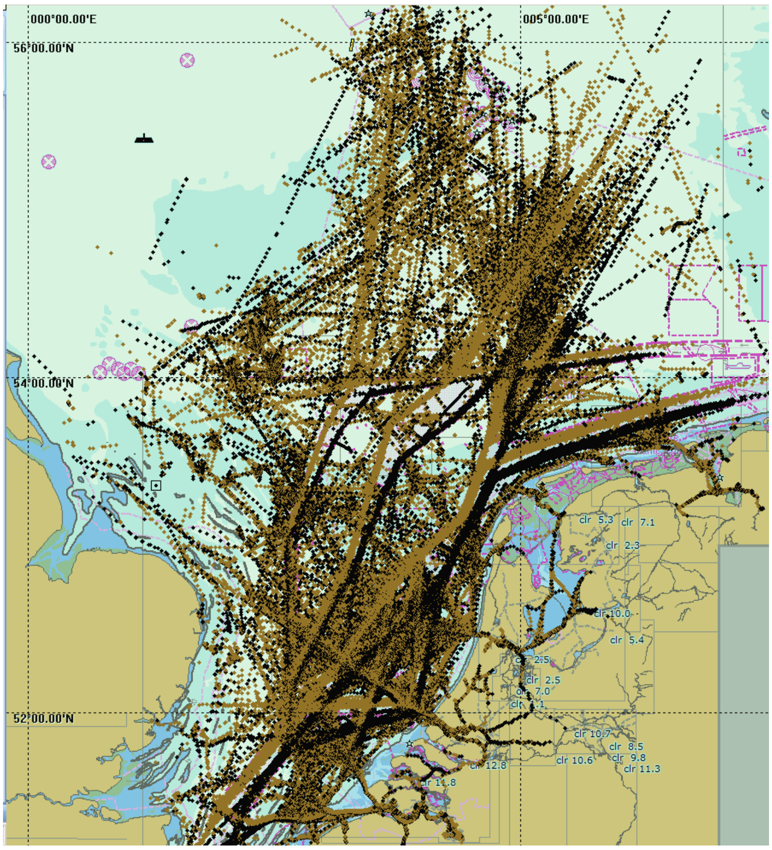

Figure 3-1 Example of one week of AIS data of route bound traffic. The location of all vessels is plotted every ten minutes. A brown dot indicates westwards travelling, a black dot indicates eastwards travelling.

3.1.2 Ship characteristics database of October 2012

The LLI ship characteristics database of October 2012 has been purchased. This database, combined with earlier issues, contains vessel characteristics of nearly 123,000 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 engines. To be able to calculate the emissions, each ship observed in the AIS data should be connected to a ship in the ship characteristics database. For this reason, a yearly update of the ship characteristics database is required.

3.2 Procedure for combining the input to obtain emissions

The AIS messages contain detailed information about the location and speed of the ships. This is the most important information for calculating the emissions to air that these ships produce at a certain time. The main problem is how to organize the tremendous amount of data flows and keep the computing time manageable. Therefore, the work has been divided into a number of separate activities, delivering intermediate results. The final emission calculation uses these intermediate databases. Figure 3-2 visualizes the databases that are mentioned in the description of the procedure in the remainder of this section. The input files, described in Section 3.1, are the ones shown in blue.

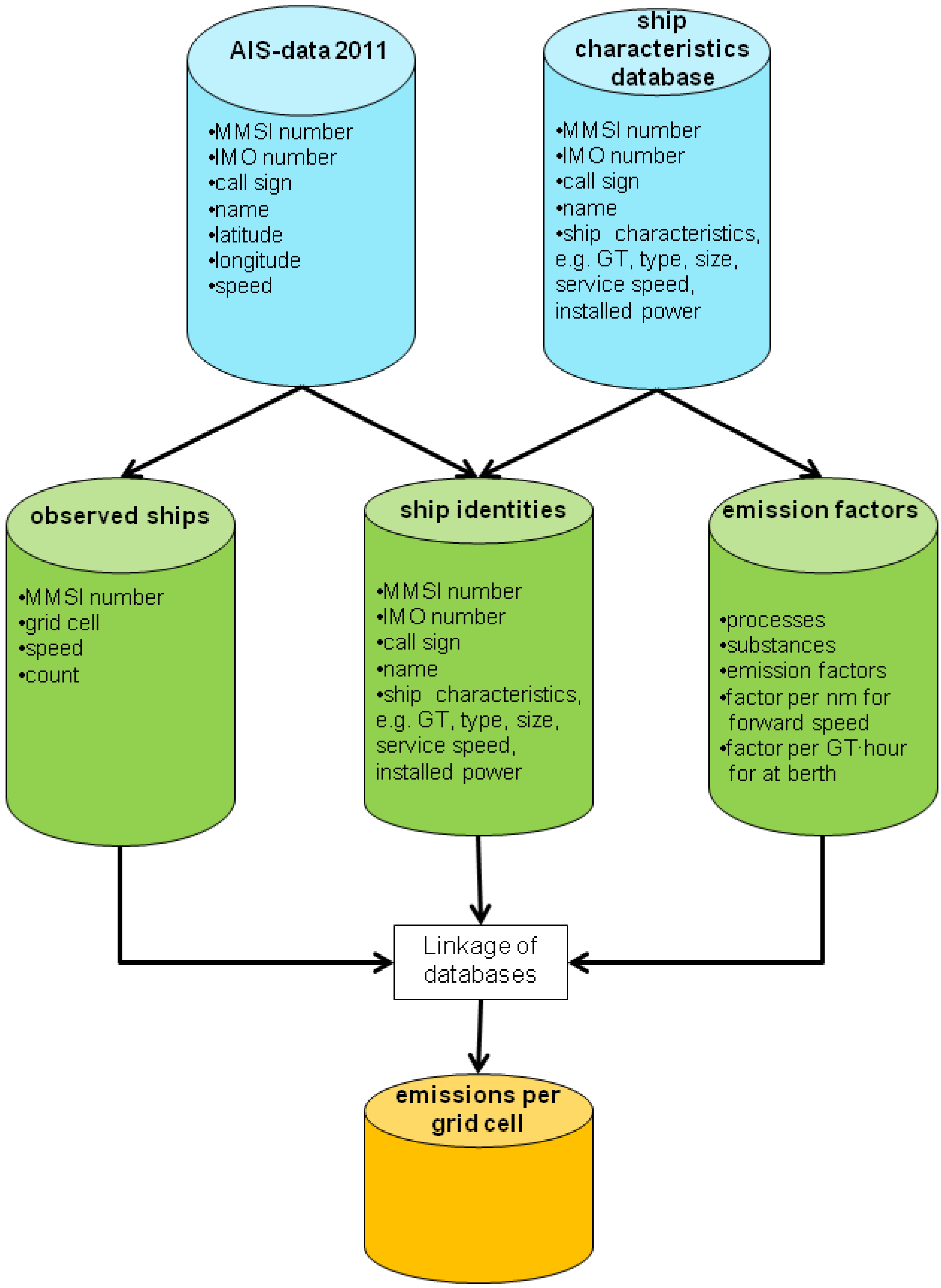

Figure 3-2 Databases with relations (blue = input, green = intermediate, orange = output)

3.2.1 From “AIS-data 2011” to “observed ships”

Each AIS data file contains the data of the ships in standard AIS format. This means that the file cannot be read with a text editor, but only by a program that converts the data into readable values. Since information is gathered every 5-10 seconds, it is impossible to deal with all full text data. Therefore, an approach has been chosen in which with a two minutes interval the number of ships per grid cell, their type and their speed is determined for the whole area. The essential parameters collected in processing the AIS data files are:

- The MMSI numbers indicating the different ships;
- The position of each ship indicating the grid cell in which the ship has been observed;
- The speed which has been converted to a speed class by cutting off to whole values. Speed class 10 means a speed between 10 and 11 knots and is processed as 10.5 knots. A speed between 0 and 1 knots is processed as 0 knots because it is assumed that this means at berth or at anchor;
- The number of observations (counts) per class with identical MMSI, grid cell, speed class.

At the end of the observation period, all observations consisting of MMSI number, grid cell and speed with corresponding counts are written to the “observed ships“ log file that will be used in the next steps. The preparation of the total “observed ships” file for the NCS (at sea) has been carried out in twelve observation periods of one month due to memory limitations. The data for each port area was obtained by one observation period of a year.

Within the subsequent calculations it has been **assumed that the emission for each ship in the next two minutes takes place in the observed grid cell and the emission is based on the observed speed.**

3.2.2 From “ship characteristics database” to “emission factors”

In a separate step emission factors are obtained for all ships from the ship characteristics database. For each ship in the database, TNO has determined emission factors per nautical mile for ships with forward speed, and emissions per GT.hour for ships at berth.

During sailing and manoeuvring, the main engine(s) is/are used to propel/manoeuvre the ship. In the emission factor calculation, the nominal engine power and the design speed have been used. For this study, these parameters were taken from the LLI October 2012 ship characteristics database. It has been assumed that a vessel uses 85% of its maximum continuous rating power (MCR) to attain the design speed, which is identical to the service speed mentioned in the ship characteristics database.

The relations and emission factors have been determined by TNO according to the method described in Appendix A.

3.2.3 From “AIS-data 2011” and “ship characteristics database” to “ship identities”

Another step is to find the corresponding ship in the ship characteristics database for each MMSI number in the AIS data of 2011.

The MMSI number which is included in each AIS message is (in most cases) a unique number for an individual ship. However, connecting ships from the AIS data to ships in the ship characteristic database is not as easy as one would expect because only 60% of the ships in the LLI ship characteristics database contain an MMSI number and this number does not always correspond with the MMSI number in the AIS data.

All ships that are present in the AIS data of 2011 have been stored in “ship identities”. The combination of MMSI number, IMO number, call sign and name, of which the first three are unique for each ship, were used to find a linkage between the ships in the AIS data and the ship characteristics database.

Because of the increasing use of AIS by vessels smaller than 300GT (not mandatory) and inland vessels, fishing vessels and pleasure craft, the task to link an MMSI number to a ship of the ship characteristic database becomes more and more difficult. It is not straightforward to decide whether an MMSI number that cannot be linked can be ignored or not. Therefore other sources have been used as well, namely:

- The data of the International Telecommunications Union (ITU);
- The website of Marine Traffic: www.marinetraffic.com.

Aids to Navigation are originally buoys or lights but nowadays also AIS transponders can help to warn the traffic, for example a transponder on a platform or an offshore windmill. It is even possible that a transponder sends information about an area that has to be avoidedThe ITU receives the data of AIS transponders of ships, coast stations and AIS Aids to Navigation[1] from the Administrations of the Member States. The ship data contains the MMSI number and a number of ship characteristics, including IMO number, ship name, gross tonnage, length and type of ship. It was expected that nearly all MMSI numbers would be present in the ITU data. As this expectation proved not to be true, the data belonging to a certain MMSI number was also looked up on the Marine Traffic website. The advantage of these two new sources is that they include all vessels, thus also inland, fishing and recreation vessels, which makes it easier to decide which MMSI numbers should be included.

The IMO number plays an important role in the linking process. The IMO number is a unique seven-digit number assigned to propelled, seagoing vessels of 100 gross tons and above. The number is assigned by Lloyd’s Register - Fairplay Ltd. on behalf of the IMO. This number is sent with the AIS message with ship static and voyage related data. If the ship has no IMO number the field has to contain a 0. Because the IMO number has to be filled in manually, many errors occur.

The first criterion for deciding which MMSI numbers should be included is whether the IMO number is always 0 or not. An IMO number that is always 0 does suggest that the ship is not a seagoing vessel above 100GT, thus does not belong to the group of relevant ships for which the emissions have to be calculated. An IMO number that is not equal to 0 is likely a relevant ship.

[1] Aids to Navigation are originally buoys or lights but nowadays also AIS transponders can help to warn the traffic, for example a transponder on a platform or on an offshore windmill. It is even possible that a transponder sends information about an area that has to be avoided

Table 3-2 shows the final result of the process to link a MMSI number to a ship in the ship characteristic database. In the first step all 21,715 unique MMSI numbers in the AIS data of 2011 are divided into a group with 12,651 MMSI numbers with a corresponding IMO number that is not always equal to 0 and a group of 10,064 MMSI numbers with a corresponding IMO number that is always 0. The other sources were used to eliminate the errors and to be as sure as possible that all seagoing ships above 100GT are linked to the correct ship of the ship characteristics database and that all MMSI numbers that are skipped are less than 100GT or are not seagoing vessels. There were 185 vessels with an IMO number that was not always equal to 0 that could not be coupled, because they were not in the ship characteristic database for different reasons; 64 inland ships, 18 pleasure crafts, 34 fishing vessels, 21 ships <100 GT and 48 for other unknown reasons. The ship characteristic database contains all merchant seagoing vessels >100GT but is not complete for other type of ships.

Table 3-2 Number of ships in AIS coupled with LLI

Different MMSI numbers in AIS data of 2011	IMO number in AIS message	Coupled		Not coupled	
		Direct	After search	Ship is not a seagoing ship > 100GT	No data found
21,715	12,651 IMO≠0	11,988	454	64 inland 18 pleasure 34 fishing 21 <100GT 48 other reason	24
	10,064 IMO=0	0	675	9067	322

The table shows that no further data was found of 24 ships out of 12,651. In 11 out of these cases the IMO number was incorrect (not 7 digits). From the second group, containing 10,064 ships with IMO always 0, 675 could be coupled with a ship in the LLI database and 9067 could not be coupled with a ship in the LLI database but were found in the other sources, 322 ships could not be identified. Probably none or only a few of these 322 ships belong to seagoing ships >100 GT. The 675 ships that could be coupled to the LLI database with seagoing vessels are considered as relevant vessels despite the fact that they have constantly sent AIS messages with IMO is 0. Generally these are small vessels (505 are in size class 1 < 1600GT) with a very small contribution to the emissions.
Overall, it can be concluded that more than 99.5% of all MMSI numbers of the relevant ships are coupled with the ship characteristic database of LLI. Such a link is necessary, because the LLI database is the only database that contains data with respect to the engine of the ship, required for the determination of the emissions.

3.2.4 From “linkage of databases” to “emissions per grid cell”

After all databases were prepared, they were linked and the emissions per grid cell were calculated based on all AIS messages every other minute.

For ships with forward speed, the actual speed is an important parameter for the emission at a certain moment. Here, the speed from the AIS message combined with the ship specific emission factors for sailing has been used to calculate the emission.

For ships at berth or at anchor the emission is based on the time at berth combined with a ship specific emission factor for at berth.

4 PROCEDURE FOR EMISSION CALCULATION BASED ON THE LLOYD'S LIST INTELLIGENCE VOYAGE DATABASE

Because AIS data outside the NCS is not available to MARIN, the emissions in OSPAR region II area have been estimated based on all voyages crossing the North Sea in 2008 collected by Lloyd's List Intelligence. This expensive voyage database has so far been purchased once every 4th or 5th year.

4.1 Procedure for at sea

The Lloyd's List Intelligence voyage database is the basis of the SAMSON traffic database, which contains the number of ship movements per year for each traffic link divided over 36 ship types and 8 size classes. The SAMSON traffic database has been used for the distribution of the traffic within OSPAR region II. The changes in traffic volume and behaviour extracted from the AIS data of 2008 and 2011 at the NCS are superimposed on the traffic distribution in the OSPAR region II, assuming that these changes at the NCS are representative for the total OSPAR region II. Figure 4-1 shows all traffic links in the 2008 traffic database.

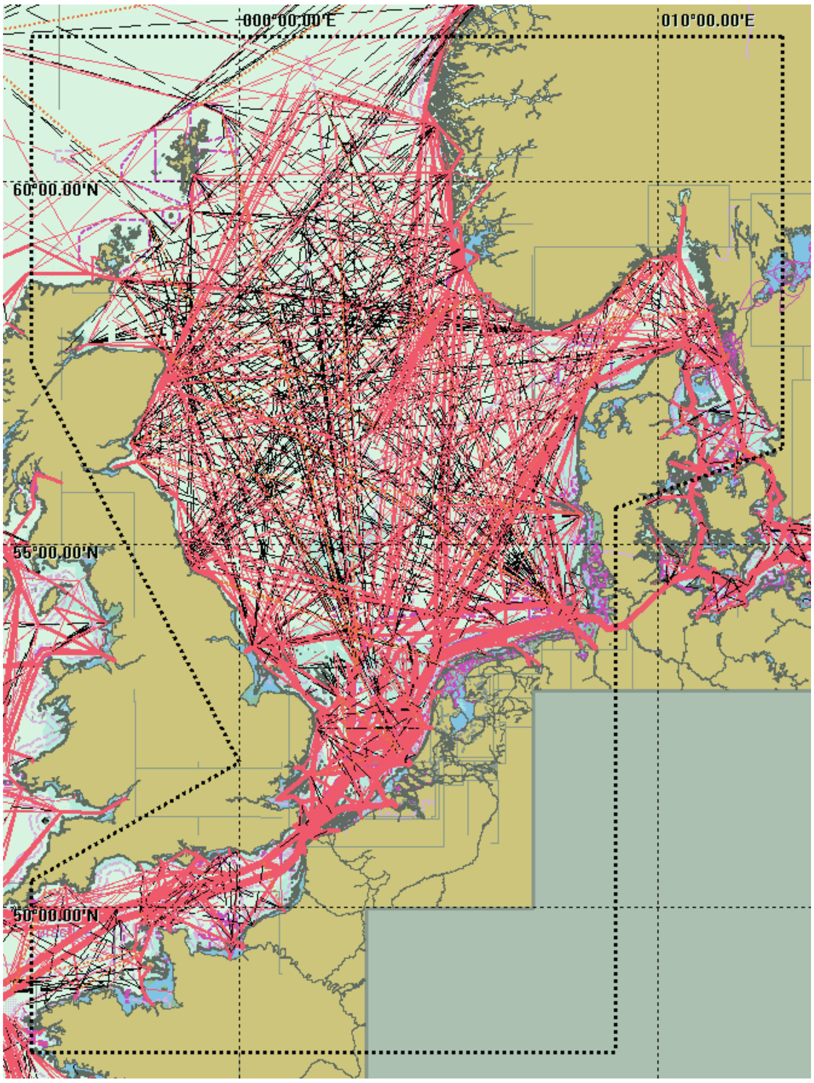

Figure 4-1 Traffic links in OSPAR region II, the width indicates the intensity of ships on the link, red links represent a higher intensity than black links

The black lines represent links with less than one movement per month. The red lines describe the traffic links with more movements. The width indicates, on a non linear scale, the number of movements per year. The traffic links in Dover Strait represent about 40,000 movements in one direction per year.

Based on analyses in the past, SAMSON uses 90% of the service speed for the average speed in knots for ship type i and size j (v_{ij}). However, the AIS analysis of [5] showed that it was approximately 87% of the service speed before the crisis and 85% in 2011, instead of the 90% assumed in SAMSON.

To account for the correct speed, the emission calculation should be based on the average number of nautical miles sailed per grid cell for each ship type and size. This is not a type of output that can be obtained directly from the SAMSON model. In short, the method for the emission calculation is as follows:

1. the average number of ships per ship type and ship size in each grid cell has to be extracted from the program. Internally, this number has been calculated by assuming an average speed of 90% of the service speed.
2. the average number of nautical miles per grid cell for each ship type and ship size has been calculated by again using this average speed of 90% of the service speed. In this calculation it is assumed that all ships sail over the centre line of the traffic link. A lateral distribution over this link, which is normally used in SAMSON has not been used for the emission calculations because that level of detail is not needed.
3. Subsequently, the number of shipping miles per ship type and size class is multiplied by the average emission per mile for the corresponding ship type and size class at the Netherlands Continental Shelf determined from the AIS data of 2011. This includes the real speed distribution of 2011 at sea.
4. A correction has to be applied because the shipping volumes in 2011, for which the emissions in OSPAR region II have to be calculated, differ from those for the year 2008, as contained in the SAMSON traffic database.

A more detailed description of the four steps taken for the emission calculations based on the SAMSON traffic database is given below.

1. The average number of ships of type i and size j in grid cell c is calculated in SAMSON with:

$$Ships_{cij} = n_{ijk} \frac{L_k}{v_{ij}}$$

   where:

   n_{ijk} the number of ship movements of type i and size j over link k per year in 2008 (here divided by the number of hours per year for the right unit);

   L_k the length of the link k within the grid cell in nautical miles;

   v_{ij} the average speed in knots of ship type i and size j.

2. The average number of nautical miles of type i and size j in grid cell c is calculated with:

$$Distance_{cij} = Ships_{cij} v_{ij}$$

3. The emission of ships type i and size j in each grid cell c of the OSPAR region II can be calculated with:

$$Emission_{cij} = Distance_{cij} \frac{Emission_{ij}^{NCS,AIS}}{D_{ij}^{NCS,AIS}}$$

where:

$Emission_{ij}^{NCP,AIS}$	total emission at the NCS for ship type i and size j, derived from AIS data
$D_{ij}^{NCP,AIS}$	total distance in nautical miles sailed by ships type i size j at the NCS, derived from AIS data

The time the ship is in a grid cell is proportional to 1/speed and the produced emission per hour is proportional to the third power of the speed. Thus the emission in each grid cell and in each other area is proportional to the second power of the speed.
The average emission per nautical mile for each ship type and ship size, as determined from the AIS data for 2011 at the NCS, contains implicitly the behaviour of the ships in 2011, so also the reduced speed.

With this approach it is assumed that the average emission per ship type and size per nautical mile at the NCS is typical of the whole OSPAR region II, thus that the speed of a ship at sea is not dependent on the geographical location.

4. A correction must be applied because the year 2011 for which the emissions in OSPAR region II have to be calculated differs from the year 2008 in the SAMSON traffic database. This correction is essential, because the traffic volume changes over the years. To account for this, the ratio between the number of miles travelled in 2011 and 2008 was determined from the AIS data, and this was done for each combination of ship type class i and ship size class j.

$$F_{ij}^{traffic} = \frac{nm_{ij}^{2011,AIS}}{nm_{ij}^{2008,AIS}}$$

This factor was applied to the whole OSPAR region II. By doing this, it is assumed that the impact on the traffic volume at the NCS is representative of the whole OSPAR region II. Separate correction factors per ship type and size are applied to account for different changes in traffic volume and composition.

4.2 Procedure for port areas outside AIS coverage

4.2.1 At berth

To assess the emissions at berth in port areas outside AIS coverage, a method has been developed that is not based on the SAMSON traffic database, but directly on the 2008 voyage database of Lloyd's List Intelligence. The time and gross tonnage of the ships at berth have been obtained from this database. A shortcoming is that only the day of arrival and departure are given. This means that the berth time can only be assessed in whole days. For 0 days, a berth time of 12 hours has been assumed and for all other cases the berth time in days is multiplied by 24 hours. All port times longer than 15 days were excluded.

The hours at berth per ship type and ship size were multiplied by the average emissions per hour at berth derived from the AIS data for the four Dutch port areas. The average emissions were taken per ship type class i and size class j.

$$Emission_{cij}^{berth} = hours_{cij}^{berth}\left(\frac{Emission_{ij}^{berth,AIS}}{hours_{ij}^{berth,AIS}}\right)$$

The emissions calculated in this way were then multiplied by the ratio between the number of miles travelled in 2011 and 2008 at the NCS ($F_{ij}^{traffic}$) to account for changes in traffic volume between 2008 and 2011. It is assumed that this ratio is representative for the changes in at berth time as well.

4.2.2 Moving

The emissions of moving ships in port areas without AIS coverage have been calculated from the sailing distance in the port area. The nautical miles per ship type and size have been estimated from the 2008 voyage database of Lloyd's List Intelligence.

This database has been used to develop the SAMSON traffic database of 2008, which models the traffic at sea, but not in the port areas. The SAMSON traffic database starts at a point at sea just outside the approach channel to a port area. Several ports may use the same approach channel and may therefore be modelled by the same point at sea. The LLI voyage database has a geographical position attached to all important ports. To determine the sailing distance within a port area, a straight line has been assumed between the geographical position of the LLI voyage database and the starting point at sea from the SAMSON traffic database. The emissions are calculated for the grid cells that are crossed by the straight line. The distance of the straight line in the grid cell is taken into account. Figure 4-2 shows the port areas of Hamburg and Bremen. The red lines are the links of the SAMSON traffic database. The black dots are the grid cells centres for which emission of moving ships have been calculated.

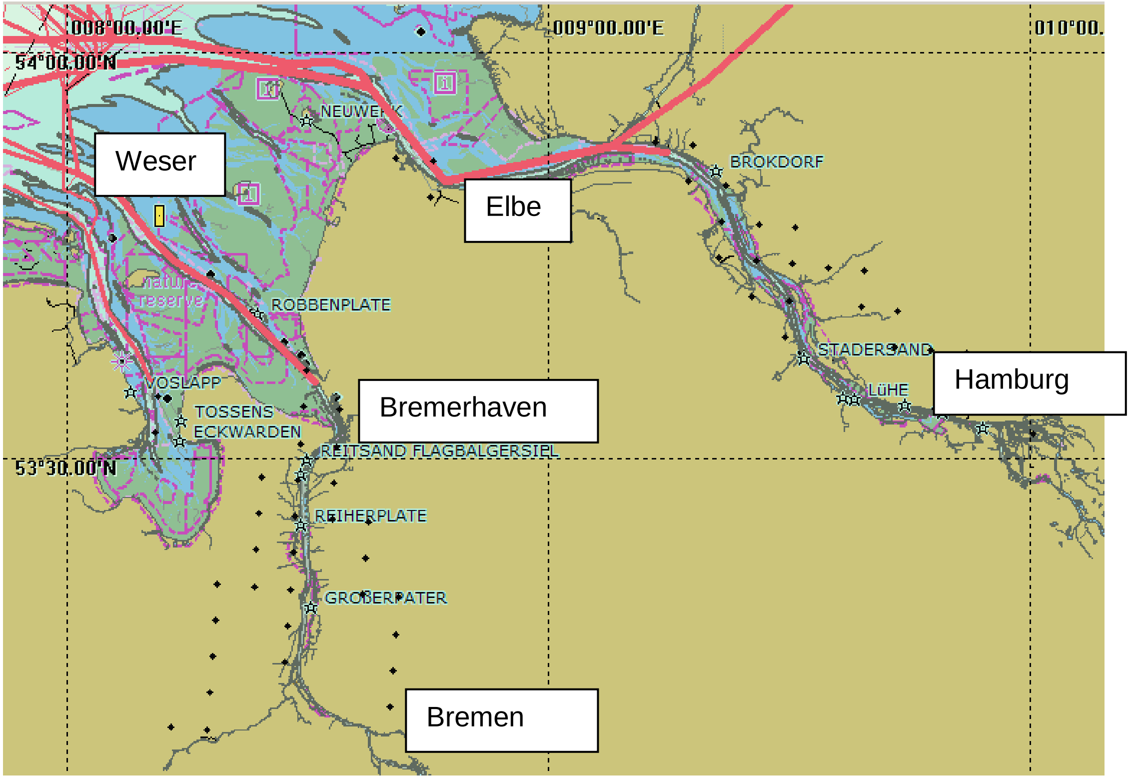

Figure 4-2 Elbe and Weser area: Grid cells for which emissions of moving ships have been calculated are shown by black dots. Links of SAMSON traffic database are shown by red lines.

The nautical miles per ship type i and ship size j were multiplied by the average emissions per nautical mile derived from the AIS data for the four Dutch port areas. Also the average emissions were taken per ship type class i and size class j.

$$Emission_{cij}^{moving} = nm_{cij}^{moving}\left(\frac{Emission_{ij}^{moving,AIS}}{nm_{ij}^{moving,AIS}}\right)$$

The emissions calculated in this way were then multiplied by the ratio between the number of miles travelled in 2011 and 2008 at the NCS ($F_{ij}^{traffic}$) to account for changes in traffic volume between 2008 and 2011. It is assumed that the ratio determined for the NCS also applies to sailing in the harbours.

The whole traffic database with the links from sea to the port is presented in Figure 4-3.

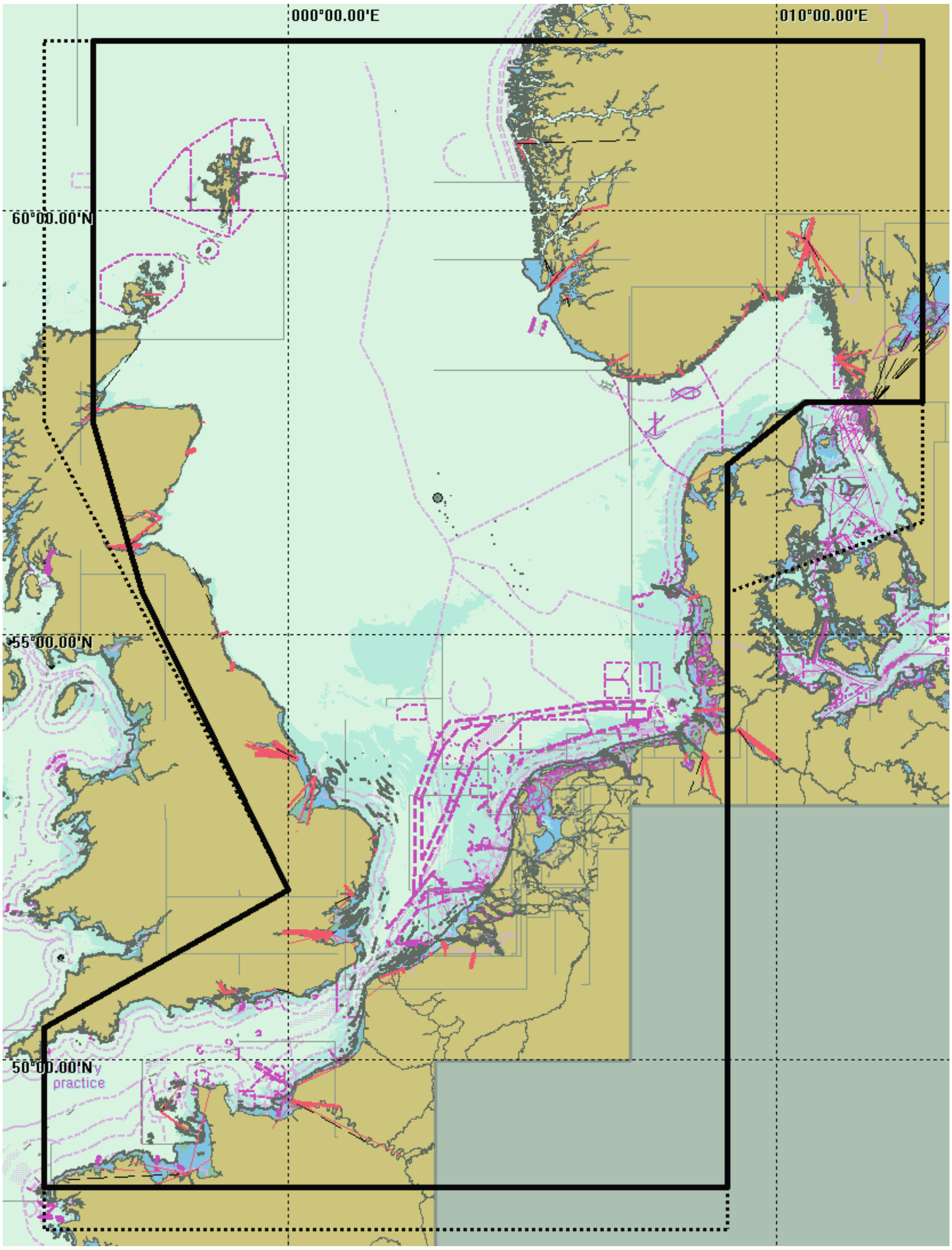

Figure 4-3 Links of the traffic database from sea to port, Dutch ports excluded

4.3 Procedure for missing ferry voyages

The Lloyd's List Intelligence voyage database for 2008 contains only the ferries that cross once a day at most. Therefore, an additional database has been composed with the emissions of the other ferries.

The last time that these additional ferry movements have been investigated was for the European research project MarNIS. All ferry lines were scrutinised whether or not, they were included in the 2004 voyage database of Lloyd's. This work has not been repeated now; the same additional ferry voyages as compiled for the database of 2004 were used. Based on the origin and destination, the most probable route over sea is determined and the ferry movements are assigned to this route. The result is a traffic database for these ferry lines, given in Figure 4-4. Most added ferry movements are between England and France in the English Channel and between Denmark, Sweden and Germany. Local ferries between an island and the coast such as they operate for example in Norway are not included. The ferry traffic database has the same elements as the traffic database for all other traffic. Therefore the same approach as described in Section 4.1 is followed to determine the emissions for this group.

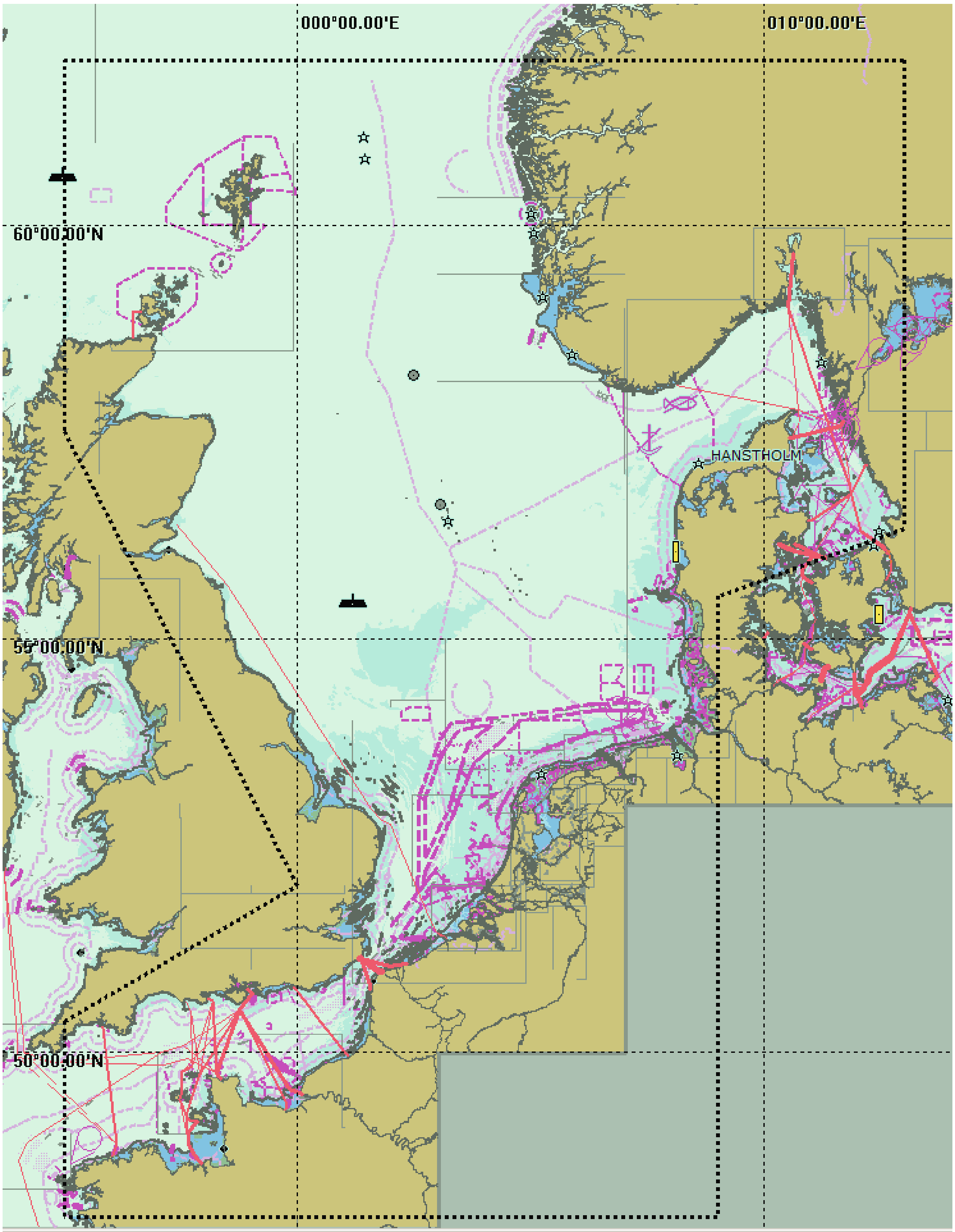

Figure 4-4 The ferry lines that are added to the traffic database are shown by red lines. The width of these lines is an indication for the number of movements

5 COMPLETENESS OF AIS DATA

5.1 Missing AIS minute files

Each AIS data file contains the AIS messages of all ships received in exactly one minute. The total collection of the AIS data of 2011 contains 522,240 files, which is 99.36% of the maximum number of 525,600 files (365 days times 24 hours times 60 minutes). Therefore, in total almost two and a half day are missing due to failures in the process. However, in case the gap is less than 10 minutes, this has no effect on the results because each ship is kept in the system until no AIS message has been received during 10 minutes. This approach has been followed to prevent incompleteness for larger distances from the coast where the reception of AIS messages by the base station decreases. For 2011 a completion factor of 1.0055 has been used to correct for missing periods longer than 10 minutes. These periods add up to 48 hours in total. All emissions, both at the NCS and in the Dutch port areas have been multiplied with this factor.

5.2 Bad AIS coverage in certain areas

5.2.1 Base stations

In the previous section the number of files received from the Netherlands Coastguard was used to describe the completeness of the data. There is, however, another type of completeness, namely, the area covered. This is illustrated in Figure 5-1, 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.

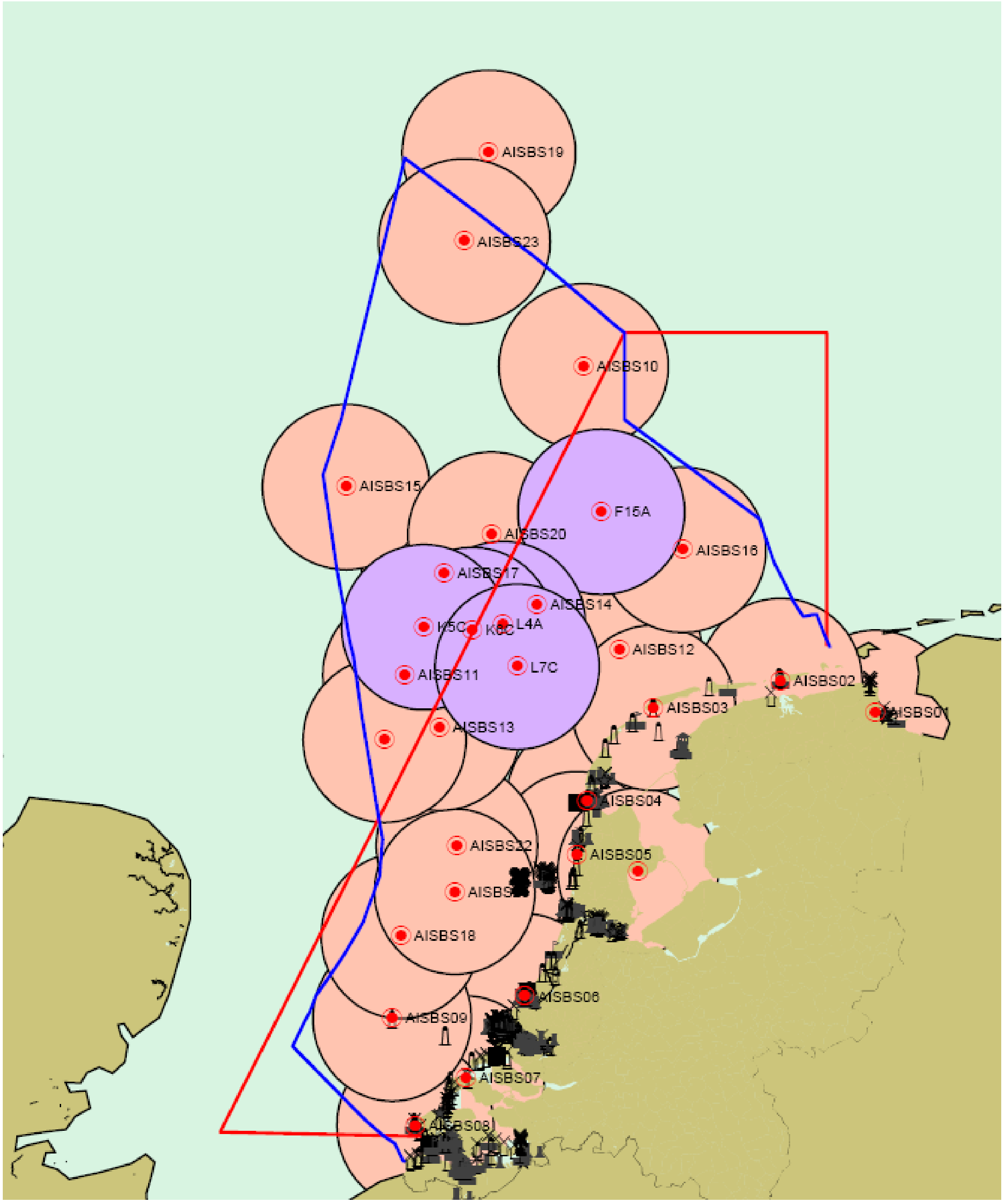

Figure 5-1 AIS base stations delivering data to the Netherlands Coastguard, the blue line illustrates the NCS, the circles indicate the reach of the base stations, the purple circles indicate the newest base stations. The red line is the Flight Information Region controlled by the Netherlands Coastguard.

5.2.2 Known weak spots

In reality, the coverage varies with the atmospheric conditions. Figure 5-1 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 at the NCS 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 area North-West of Texel;
- the Western Scheldt close to the border with Belgium, and

- the spot close to the border with the United Kingdom Continental Shelf, southwest of Rotterdam.

Especially the last location is a shortcoming because it is a very dense shipping traffic area. MARIN has noticed this also in other projects.

The area above the Wadden on the border of the NCS and the German sector was a known weak spot, but not any longer in 2011;

5.2.3 Coverage in port areas

It is possible that certain areas are not covered by AIS base stations during some time. Although it is impossible to carry out a complete check on this, some checks on coverage have been performed.

For the Dutch port areas, plots have been made containing the number of ships counted daily during the year. An area related subdivision was made to be able to trace coverage problems in part of the port areas. The direction of the subdivision depends on the port lay-out:

- each 10 geographical minutes in eastern direction (just over 6 nautical miles) for the Western Scheldt, Rotterdam and Amsterdam;
- each 5 geographical minutes in northern direction (5 nautical miles) for the Ems.

As an example, the subdivision of the Western Scheldt is shown in Figure 5-2. The areas marked red are focussed on in Figure 5-3. This figure shows the counted number of route bound ships with forward speed per day in the Western Scheldt. The lines will show a drop if a certain base station has failed which normally works, or if the processing has gone wrong for a certain area. The lines will show a peak in case of very intensive shipping activities.

For the area between 3°30.00′ and 3°40.00′, the band width remains approximately equal over the year, which means that the coverage doesn't change. The area between 4°10.00′ and 4°20.00′ shows relatively large fluctuations, predominantly in upward direction. The average level is too low compared to the level between 3°30.00′ and 3°40.00′ because most ships in the Western Scheldt sail to and from the port of Antwerp. The higher levels at certain days can be explained by atmospheric conditions that favour the receipt of the AIS signal. The AIS data for the Western Scheldt are corrected for this bad coverage (see Section 5.2.5).

In the other port areas no suspicious behaviour was found.

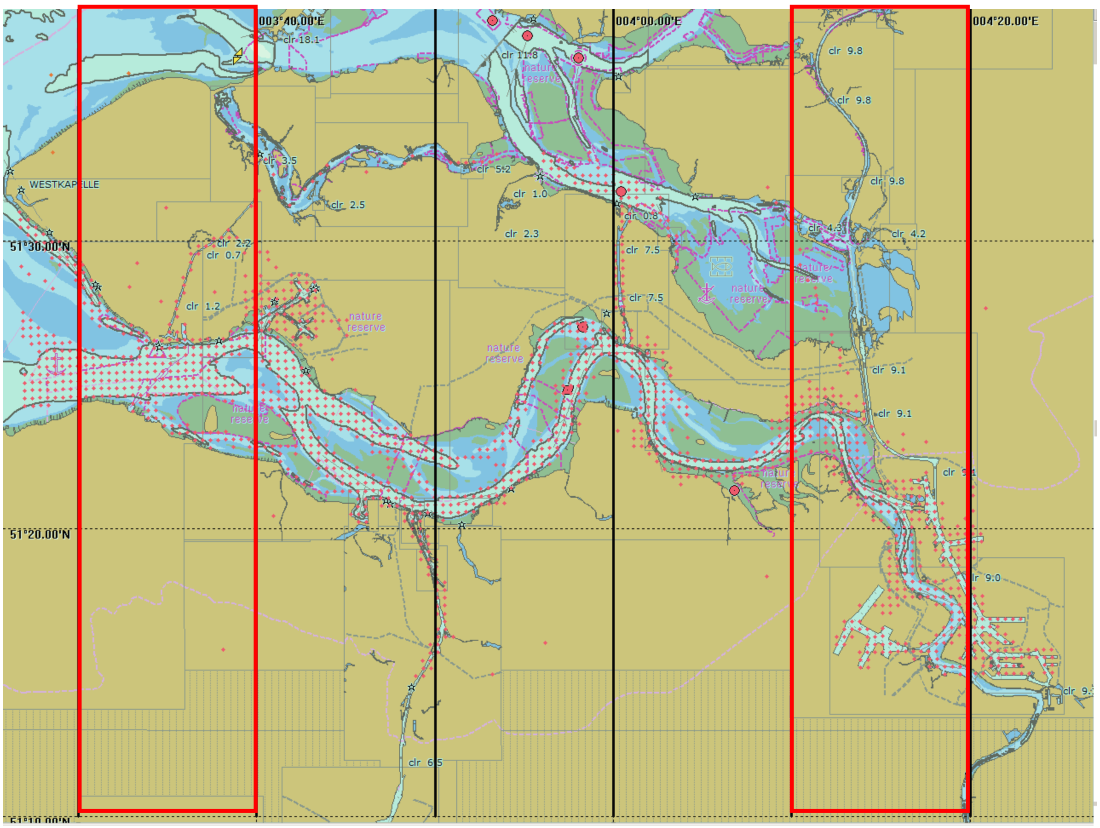

Figure 5-2 **Subdivision of the Western Scheldt area for coverage check**

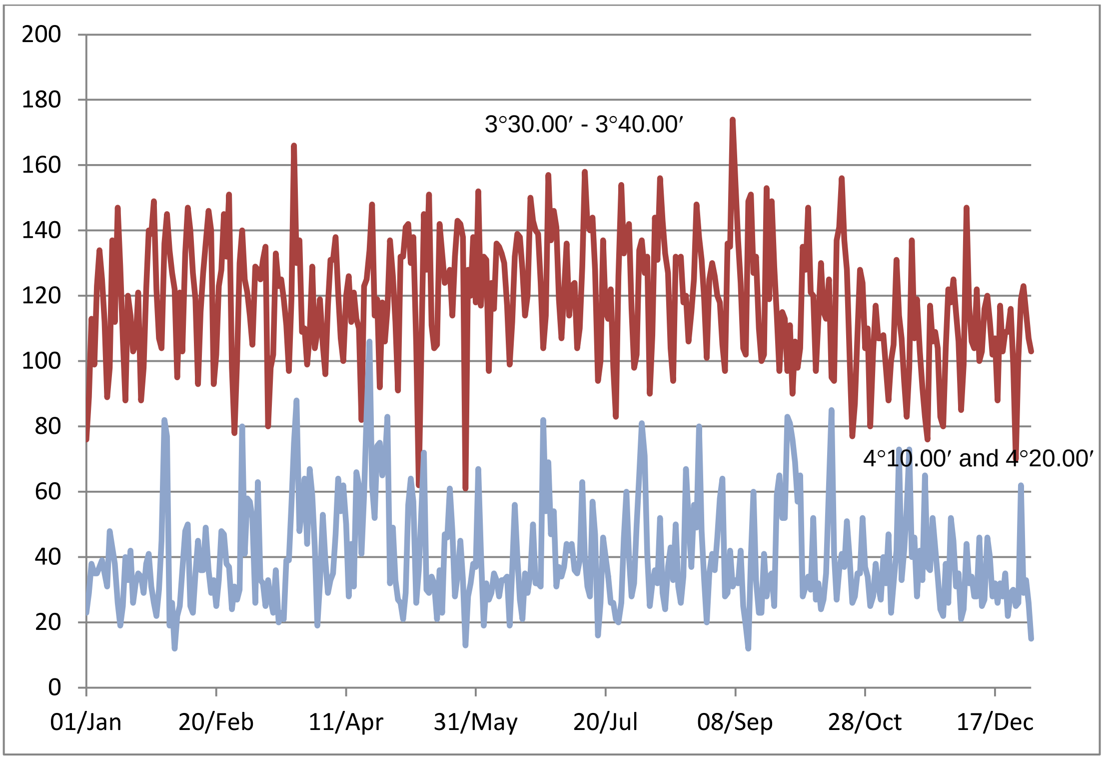

Figure 5-3 **Number of route bound vessels per day with forward speed in the Western Scheldt between 3°30.00′ and 3°40.00′, and between 4°10.00′ and 4°20.00′**

5.2.4 Coverage at the NCS

For the NCS, a new method has been developed to identify the weak spots in the collection of the AIS data by indicating 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 5-4 shows in each cell of 5x5km the average number of ships per day that has lost AIS contact with the Dutch AIS base stations in 2011.

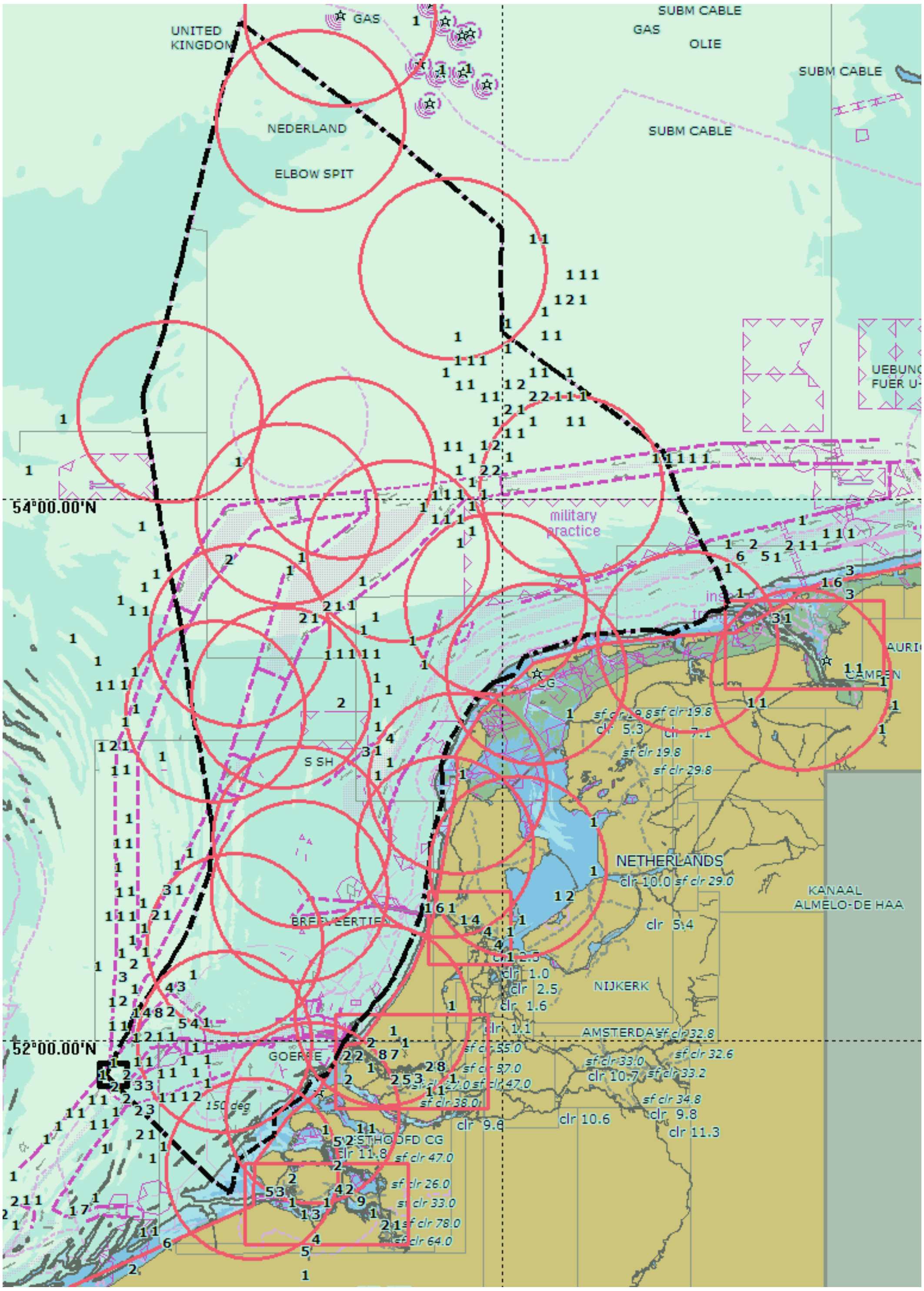

Figure 5-4 Numbers mark locations where ships lose AIS contact with Dutch base stations, red circles mark the 20 nautical miles zones around the Dutch base stations

The red circles mark the 20 nautical miles around each Dutch base station. It can be seen that most contacts are lost on the border, or outside the coverage of a base station, except for the base station at the Euro port platform, which lies in the traffic separation scheme towards the port of Rotterdam.
Sometimes the receipt of AIS messages is recovered after some time, which is the case in the center area of the NCS. However, on most locations near the border of the NCS it means that the ship has left the system until its next journey over the NCS. Thus, the figure shows more or less the locations where ships are removed from the system. The ideal situation would be when the ships that leave the system are located outside the NCS, which is the case on the west side of the NCS and on the traffic lanes near the Wadden. The figure shows that AIS messages are missing in the most southwestern point of the NCS and on the route to Skagerrak in the northeastern part of the NCS. Most ships in the dense traffic lane above the Wadden leave the system when they are already in the German sector.

Figure 5-4 contains the base stations in operation in 2011 with their reach of 20 nautical miles. The area outside the circles is not fully covered. Figure 5-4 shows that the new base stations on the offshore platforms F15A and L7C (see purple circles in Figure 5-1) are really necessary to cover the route to Skagerrak and improve the area west of the Texel TSS.

The same check as in [8] has been performed in which the sea area has been divided into a grid of 5 geographical minutes in direction north (5 nautical miles) and 10 minutes in direction east (roughly 6 nautical miles). The average number of ships per cell for each of the thirteen four-week periods was calculated. For each period the difference with the average number was calculated per grid cell. Large differences in the traffic lanes indicate a difference from the average number of ships during that period. Large differences also occur at the port entrances and in anchorage areas. Large differences in an area around a base station indicate a difference in coverage of the base station.

In 2011 the spot close to the border with the United Kingdom Continental Shelf, SW of Rotterdam had varying coverage over the four-week periods indicating that the base station in that area was not working well. This also occurred in 2010. Figure 5-5 shows the coverage over the year for this spot (the black square in Figure 5-4). Coverage is worse than average in the last three four-week periods and better than average in the first part of the year. Probably, the AIS base station on the Euro platform has not functioned well during the last three months of 2011. This is unfortunate, because the base station seemed to work well in the 4-week period 1 through 10, after MARIN in November 2010 reported to the Netherlands Coastguard that the AIS coverage was weak and measures were taken.

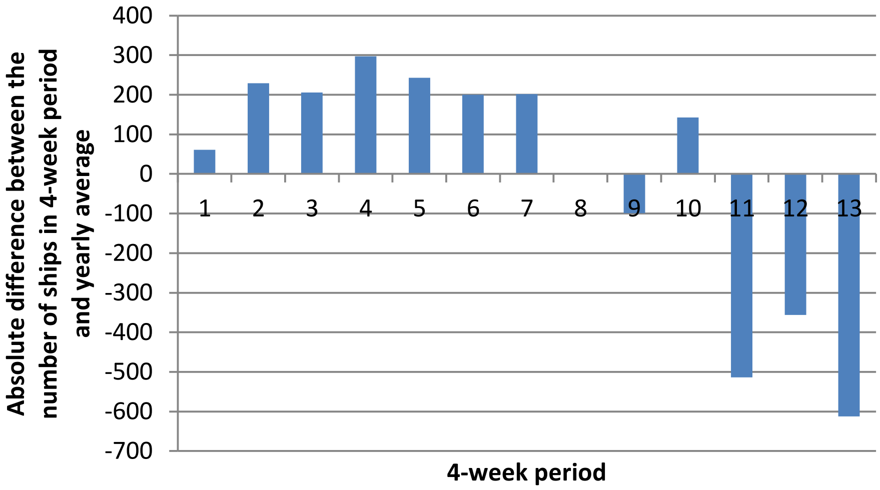

Figure 5-5 **4-weekly fluctuation in the number of observed ships in 2011 for the grid cell with a latitude between 51°50.00′ and 51°55.00′, and a longitude between 2°30.00′ and 2°40.00′**

5.2.5 Correction for bad AIS coverage in Western Scheldt

Moving ships close to the Belgian border and in Belgium

The AIS data of the Western Scheldt is received by the two most southern AIS base station of the Netherlands as shown in Figure 5-1. As explained in Section 5.2.1, AIS base stations cover a circular area with a radius of 20 nautical miles. When the atmospheric conditions are favourable, a larger area is covered. The stretch of the Western Scheldt that lies closest to the Belgian border and the stretch in Belgium including the port of Antwerp lie outside the standard coverage area of the two base stations mentioned. This means that AIS messages can be received from this area, but there is no continuous full coverage.

The emissions for moving ships on the Western Scheldt close to the Belgian border and in Belgium are scaled up to compensate for the bad AIS coverage. To determine the scale factor, a comparison was made between the number of voyages towards and from Antwerp, determined from the LLI voyage database and from AIS. The number of ships in the AIS data of 2011 crossing the lines shown in Figure 5-6 were counted. It was concluded that line 2 still had 100% AIS coverage and that the coverage decreased towards line 7. It was also noticed that larger ships had a better coverage than smaller ships. Their AIS transponders are often placed higher, so more within the reach of the base station.

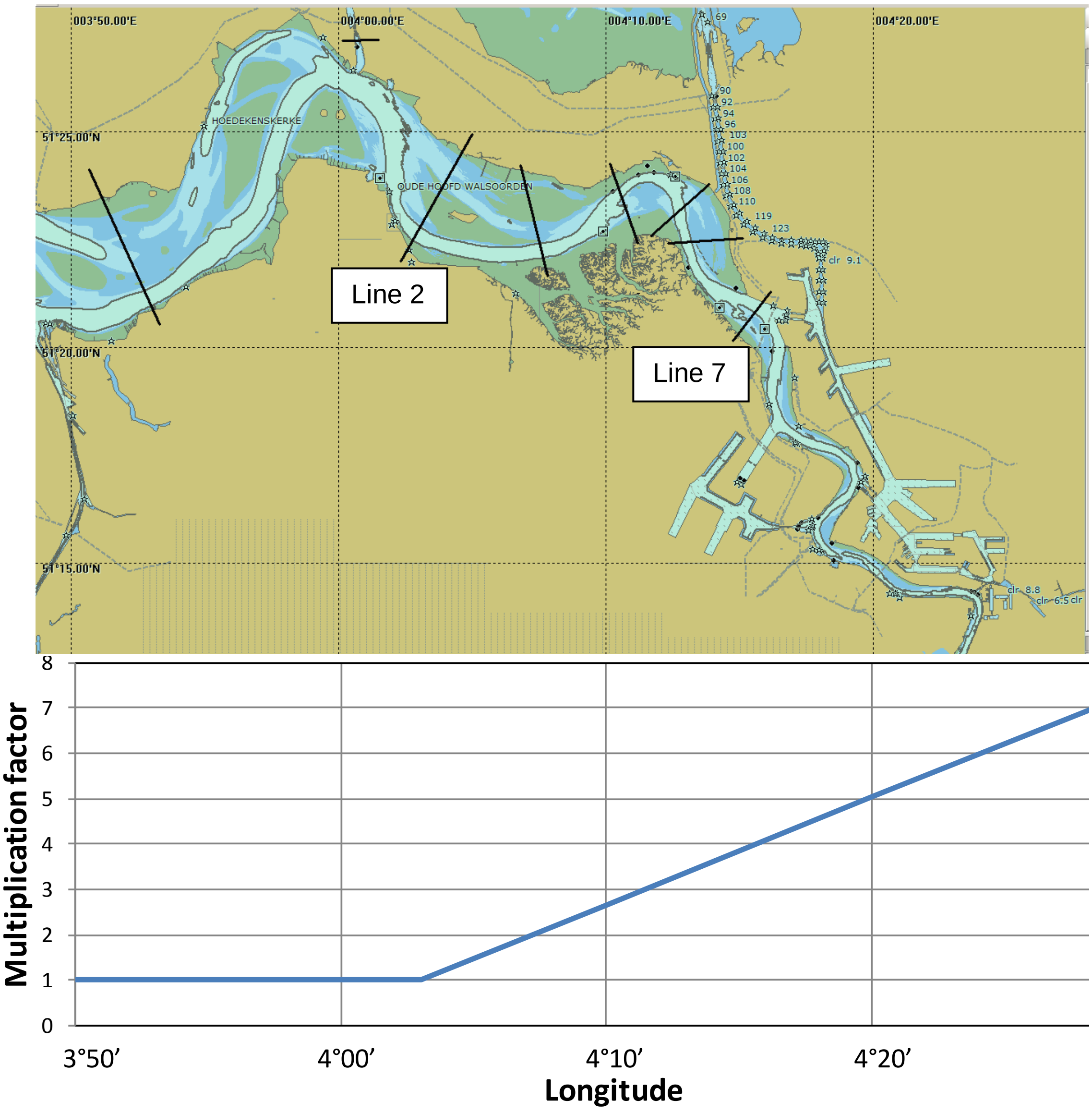

Figure 5-6 Crossing lines used to check coverage of AIS data in the Western Scheldt and average multiplication factor

A location-based linear regression was used to correct for the decreased AIS coverage from line 2 into Belgium. For each ship type and size class a specific factor was determined. The average multiplication factor over the ship type and size classes is visualized in Figure 5-6.

Ships berthed in Antwerp

As a start, the same correction factor as applied for sailing ships was applied for berthed ships in Belgium. However, a check with the GT.hours calculated by the method for ports outside AIS coverage (see Chapter 9.2 and results in Appendix C) showed that the total GT.hours berthed in Antwerp was still far underestimated. As the berthed ships will have a significant share in the total emissions, a second correction was necessary to end up with a realistic level for the emissions in the port of Antwerp when berthed. This second correction factor is the total GT.hours at berth based on the publications of the port of Antwerp divided by the total GT.hours for the Belgian ports calculated from the corrected AIS data. This is elaborated below.

Table 5-1 contains the data collected for the determination of the extra correction factor for the hours and GT.hours at berth in the port of Antwerp. They apply to the same area for which AIS data are available. To determine the correction factor for Antwerp, GT.hours are compared with each other. Table 5-1 also contains data for Rotterdam. In Rotterdam the largest ships stay in the western part of the port, which is very well covered by AIS base stations. This information is also used to estimate the GT.hours for Antwerp.

Table 5-1 Data for the correction factor for berthed in the Belgian ports leading to the Western Scheldt

Port	Source				Average time at berth per call [h]
	AIS	Data 2011 of websites of ports			
	Million GT.hours for EMS type 1-8	# Calls	Sum GT of ships calling [in 1000 ton]	Average GT of ships calling [in ton]	
Rotterdam	18,815	29,720	657,186	22,113	28.6
Antwerp	3,576	15,240	316,428	20,763	11.3

The column AIS presents the GT.hours, for Antwerp already including the general correction factor for ships sailing on the Western Scheldt. Only the EMS types 1-8 are included in this number, because these are the most relevant ships, responsible for nearly all emissions and only these ship types are included in the number of calls to a port. The next three columns contain data direct from the websites of the port of Antwerp and the port of Rotterdam. The last column contains the calculated average time at berth per call. This follows from the GT.hours from AIS divided by the number of calls and by the average GT of the ships calling. The result is 28.6 hours for Rotterdam and 11.3 hours for Antwerp. An average time at berth of only 11.3 hours is not realistic.

The most obvious correction factor is 28.6/11.3, but this might be wrong since the average time at berth for a small vessel is shorter than for a large vessel. The berth time for a ship of 2000 GT is approximately 15 hours and for a ship of 100,000GT approximately 45 hours; a factor 50 in GT and a factor 3 in port time per GT. Therefore, it is important to notice that the average calling ship in Rotterdam is 22,113 GT and in Antwerp 20,763 GT, which is only slightly lower. To incorporate this effect of ship size, a regression line is determined for the port times of Rotterdam based on the GT.hours found for the 8 ship size classes. The result of this regression is that the average berth time for a ship of 20,763 GT is 0.98 times the average berth time of a ship of 22,113 GT. This means that the extra correction factor required for the ships berthed in Antwerp amounts to 0.98 x 28.6/11.3 = 2.48. This factor is used to upgrade the GT.hours berthed for the Belgian ports leading to the Western Scheldt. A final check by calculating the upgrade factors for each size class separately has been performed to be sure that the same factor is suitable for ships of all size classes. This check was satisfying, thus this factor has not to be adapted for different size classes.

The scale factors used for the determination of the emissions in Belgian ports leading to the Western Scheldt are large, which means that the accuracy in this area is considerably less than in other areas covered by AIS. However, certainly with respect to the spatial distribution, this approach is better than following the approach for the port areas outside AIS coverage (see Section 4.2), because then only one location per port is used.

5.3 Influence of future developments on the reported emissions

Improvement of the coverage of AIS or the extension of the user group can result in a growth of the reported emissions that cannot be assigned to changes in emissions of ships. Therefore, it is important to check the changes in coverage and AIS user group also in the future to prevent wrong conclusions.

In the coming years, an increase in calculated emissions can be expected due to the stepwise mandatory introduction of AIS transponders on fishing vessels, also those under 300 Gross Tonnage. Finally, in June 2014 all fishing vessels larger than 15 m are compelled to be equipped with an AIS transponder. Currently, the fishing vessels with AIS that could be connected with the LLI ship characteristics database only account for 10% of the total number of fishing vessels. In case the 10% coupled is representative for all fishing vessels, they are responsible for 6 to 9% of all emissions at the NCS. In reality this will be significantly less because the present 10% represent the larger fishing vessels with higher emissions. In the future, also inland ships will probably be compelled to be equipped with an AIS transponder or a similar system. A system with inland base stations for AIS data collection of inland ships is being set up.

6 CHANGES IN EMISSION FACTORS

6.1 Introduction

This chapter describes two changes in the emission factors that have impact on the calculated emissions. The first one is the result of new insight in the description of ships with multiple engines in the ship characteristic database. This influences the emission of sailing ships. The impact for the NCS is described in Section 6.2 by comparing the emissions with the new emission factors for multiple engines with the emission factors calculated by using the old method for the AIS data of 2011. The second change in emission factors is due to minor changes in assumptions and changes in policy. The resulting expected changes in emissions are given in Section 6.3. Finally, Section 6.4 of this chapter describes some possible future changes.

6.2 Changes due to multiple main engine use

Until this year it was assumed that the field with installed power in the ship characteristics database of LLI contains the total installed power. However, in most cases, this field contains the power of only one main engine and another field in the database contains the number of engines in the ship. Most ships have only one main engine but roughly 20% of the ships have multiple engines, especially passenger/RoRo ships and work vessels. This means that the emissions of ships with multiple engines were under estimated in the past. Only the emissions of the main engine are affected by the recalculation.

The method that was developed to calculate emissions from multiple engine ships is described in Appendix A. In order to determine the impact of this improved method on the emissions, the 2011 emissions were calculated with both the old and the new emission factors. Table 5-1 gives the result for all substances. The increase in total emissions is approximately 8%, except for aerosols from MDO. Table 6-2 shows for NOx the increase per ship type. The reason for the very high increase for passenger vessels is that they are often equipped with multiple engines. To a lesser degree, this applies to RoRo, miscellaneous and tug/supply vessels.

Table 6-1 Emissions of ships in ton at the NCS for 2011; new method with multiple engines compared with old method

Nr	Substance	Emission in ton in 2011 multiple engines				Emission in 2011 as percentage of 2011 with emission factors for one engine			
		not moving	Moving		Total	not moving	Moving		Total
			Auxiliary Engine	Main Engine			Auxiliary Engine	Main Engine	
1237	VOC	79	208	2,091	2,379	100.00%	100.00%	109.52%	108.27%
4001	SO_2	705	2,085	20,597	23,388	100.00%	100.00%	108.40%	107.32%
4013	NO_x	2,371	7,054	80,060	89,485	100.00%	100.00%	107.18%	106.38%
4031	CO	480	1,346	13,046	14,872	100.00%	100.00%	110.38%	108.99%
4032	CO_2	138,281	411,676	3,357,659	3,907,616	100.00%	100.00%	108.46%	107.18%
6601	Aerosols MDO	123	346	73	543	100.00%	100.00%	111.35%	101.40%
6602	Aerosols HFO	0	0	3,534	3,534			108.25%	108.25%
6598	Aerosols MDO+HFO	123	346	3,608	4,077	100.00%	100.00%	108.31%	107.28%
Ships		95.39	184.11		279.49	100.00%	100.00%		100.00%

Table 6-2 Emissions of NOx in ton at the NCS for 2011; new method with multiple engines compared with the old method

Ship type		Emission in ton in 2011 multiple engines				Emission in 2011 as percentage of 2011 with emission factors for one engine			
EMS type	name	not moving	Moving		Total	not moving	Moving		Total
			Auxiliary Engine	Main Engine			Auxiliary Engine	Main Engine	
1	Oil tanker	416	406	6,906	7,728	100.00%	100.00%	104.91%	104.37%
2	Chem.+Gas tanker	845	1,078	10,024	11,946	100.00%	100.00%	102.12%	101.78%
3	Bulk carrier	239	473	6,799	7,512	100.00%	100.00%	101.17%	101.05%
4	Container ship	387	2,184	30,020	32,591	100.00%	100.00%	100.29%	100.26%
5	General Dry Cargo	182	941	7,235	8,359	100.00%	100.00%	101.54%	101.33%
6	RoRo Cargo / Vehicle	22	930	11,475	12,427	100.00%	100.00%	123.82%	121.60%
7	Reefer	34	149	1,447	1,630	100.00%	100.00%	100.16%	100.14%
8	Passenger	0	226	3,057	3,283	100.00%	100.00%	268.07%	240.25%
9	Miscellaneous	118	250	1,546	1,915	100.00%	100.00%	119.73%	115.35%
10	Tug/Supply	97	188	1,222	1,507	100.00%	100.00%	116.41%	112.91%
11	Fishing	31	226	315	572	100.00%	100.00%	101.23%	100.67%
12	Non Merchant	0	2	14	16	100.00%	100.00%	115.81%	113.82%
Total		2,371	7,054	80,060	89,485	100.00%	100.00%	107.18%	106.38%

Table 6-3 shows the use of multiple engines for different years of construction. The table shows that the use of multiple engines is fairly common and fluctuates around 20%, except for the last period that shows a lower use. However, this period is too short to draw conclusions, also because the crisis has influenced the building of new ships Therefore, it can be concluded that the same set of multipliers can be applied to all previous emission calculations.

Table 6-3 Use of multiple engines through the years

Year of built engine	Number of main engines						Number of ships
	1	2	3	4	≥5	multiple	
<1974	84.8%	13.7%	0.4%	1.0%	0.1%	15.2%	18706
1974-1979	79.8%	19.0%	0.4%	0.7%	0.1%	20.2%	14874
1980-1084	78.9%	19.0%	0.6%	1.3%	0.2%	21.1%	13799
1985-1989	82.8%	15.4%	0.6%	1.0%	0.1%	17.2%	12763
1990-1994	79.6%	18.4%	0.6%	1.3%	0.3%	20.4%	10297
1995-1999	76.0%	20.8%	0.7%	2.2%	0.3%	24.0%	11236
2000-2010	76.1%	20.7%	1.0%	1.9%	0.3%	23.9%	35880
2011-2012	88.2%	9.5%	0.6%	1.2%	0.5%	11.8%	5201

The emissions for the new multiple engine approach divided by those of the old “one engine” approach deliver the factors that can be applied to the emission databases of earlier years. These multipliers for emissions of the main engine were determined for each substance, EMS ship type and size class and for both the port and the sea area.

The emissions of the year under investigation are always compared to the emissions of the previous year to indicate the changes. This is also done in this report, but with the emissions of 2010 scaled with the multipliers described before. In this way, changes due to the new method are ruled out and only those changes are visible that can be attributed to ship activity.

6.3 Changes due to policy and improved knowledge

Full implementation of the SECA according to the MARPOL Annex VI in 2011 is assumed as the supplementary reduction on the sulphur content already entered into force per July 2010. Therefore, the sulphur percentage is set on 1.0% in heavy fuel oil and on 0.5 % in marine diesel oil. PM-reduction is associated with sulphur reduction because a certain fraction of oxidised sulphur emits as sulphuric acid, which easily condenses to sulphuric acid particles (PM) in exhaust gases. Based on the sulphur reductions additional PM reductions were estimated assuming a linear relationship between sulphur and PM.

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.

This year, correction factors for CO_2 en SO_2 were added for reciprocating diesel engines. 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.
Furthermore the load correction factors are determined in the range of 85% to 100% of the maximum continuous rating power

Appendix A contains a complete description of the determination of all emission factors.

The combined effect of the changed load correction factors and emission factors on emissions of the main engine for moving ships has been checked by using the new factors with the 2010 AIS data. The following approximate changes are found:

- VOC: 0%
- SO_2: -30%
- NO_x: 0%
- CO: 0%
- CO_2: +2%
- Aerosols MDO: 0%
- Aerosols HFO: -20%

The model for the emission at berth is unchanged and uses the same emission factors as in 2010. .

6.4 Possible future developments

If budget and data are available, the following subjects could be considered:

- Improvement of the emission factors. The calculation of the emission factors assumes that all vessels sail at their design draught and that this speed is attained at 85% of the MCR. This gives a certain overestimation of the calculated emissions. A possible solution may be the calculation of the ship resistance as the basis for the power calculation;
- The weather conditions (current, waves, wind) could be taken into account in the calculation of the resistance;
- Improvement of the ship characteristics database;
- Use of AIS data of Den Helder, the Wadden etc. to calculate the emissions for a larger area in the Netherlands.

Other possible improvements are:

- By studying the publications and reports that have become available recently, an update of emission factors is possible that may lead to more accurate results;
- The power and fuel use of auxiliary engines is based on lots of assumptions caused by lack of data;
- Update of the amounts of fuel used at sea/in port areas;
- Incorporate use of shore power for some specific locations/ships, decreasing at berth emissions;
- Work vessels and reefers also use their engines for other purposes, such as: dredging, towing, lifting, cooling (and fishing). Assumptions are made about the percentages of the total power that is required for sailing. These assumptions can be verified. Furthermore, it can be investigated whether the “working” mode

for which other emission factors should be used can be determined from the data;

- Do not calculate emissions for ships that are at berth for a long time, because they are probably laid up;
- Correct the emissions for regions with low AIS coverage.

7 ACTIVITIES OF SEAGOING VESSELS FOR 2011 AND COMPARISON WITH 2010 FOR THE DUTCH PORT AREAS AND THE NCS

7.1 Introduction

This chapter presents the activities of seagoing vessels for 2011 in the Dutch port areas and at the Netherlands Continental Shelf. The activities of 2011 are compared to those of 2010. Values are presented as calculated and are not rounded off. Section 7.2 describes the activities in the port areas, Section 7.3 the activity at the NCS and Section 7.4 the number of ships in these areas.

7.2 Activities of seagoing vessels in the Dutch port areas

Shipping activities in the four Dutch port areas are determined to calculate the emissions in these areas. The activities extracted from AIS are important explaining parameters for the total emissions. The other parameter is the emission factor, which has been discussed in Section 6.3.

Until now the statistics published by the National Ports Council (Nationale Havenraad, NHR) were used. Because the NHR does not exist anymore since December 1st 2011, the numbers presented in Table 7-1 are extracted from the websites of the ports. First the values of 2011 are shown and then the percentages with respect to 2010. The table contains the number of calls and total GT for the main ports in each port area. From the ports to the Western Scheldt only the summarised GT data for Antwerp was available. Table 7-1 shows increases in the number of calls for the Western Scheldt and increases in GT for the Western Scheldt and Rotterdam.

Table 7-1 Number of calls extracted from websites of the ports

Port area	Ports	Number of calls		GT (in 1000 ton)	
		2011	2011/2010	2011	2011/2010
Western Scheldt	Antwerp	15,240	103.1%	316,428	109.0%
	Vlissingen, Terneuzen	6,263	102.4%		
Rotterdam	Rijn- en Maasmondgebied	29,720	99.7%	657,186	107.3%
Amsterdam	Noordzeekanaalgebied	7,266	93.0%	94,315*	99.3%
Ems	Delfzijl/Eemshaven	3,743	97.7%	3134	92.7%

* not GT but cargo handling in tons

Because emissions (strongly) depend on ship type and size, it is useful to present the changes of these parameters here. This helps to get insight in the reason of the observed changes in emission from 2010 to 2011. In addition, it gives insight in which ship types and ship sizes in the port areas produce the highest emissions.

The emission explaining variables are:

- hours: number of hours that ships are in the area;
- GT.hours: sum of (GT of the ship times the number of hours);
- GT.nm: sum of (GT of the ship times the nautical miles travelled in the area).

The emission explaining variables are presented in a table per ship type and a table per ship size class. The results are presented for each port area separately in Table 7-2 through Table 7-9.

Table 7-2 and Table 7-3 for the Western Scheldt confirm the increased number of calls by the increase in at berth hours and GT.hours of ships at berth. The growth is about 10%, which is in line with Table 7-1.

Table 7-4 and Table 7-5 for Rotterdam show that the number of hours berthed have decreased while all other explaining variables have increased with 4 to 5.6%. This reduction can be caused by reduction of the extra waiting time for cargo due to improved economic circumstances. The fact that the explaining variables multiplied with GT show more growth than without, conforms with the growth of the calls and GT in Table 7-1. The average size of the ships at berth increases, which means that the emissions increase. Table 7-5 shows a significant growth in the largest ship size class; above 100,000GT.

Table 7-6 andTable 7-7 for Amsterdam indicate that the number of hours berthed has increased with around 10% while the hours moving has increased slightly with 1.5%. This is not in line with the numbers of Table 7-1 and the reason for this is unclear. The average GT increases which corresponds with Table 7-1.

Table 7-8 and Table 7-9 for the Ems no longer contain the activities in the German port Emden. The activities for 2010 without Emden were recalculated. Because the absolute values for the explaining variables are much lower, the percentages between 2011 and 2010 fluctuate more than in the other areas. The tables show a growth in all variables, varying from 4 to 13%. That does not correspond with Table 7-1. The reason is that the port of Emden is not included in Table 7-1. A large share of the “RoRo cargo / Vehicle“ ships, thus the ships with the largest contribution and the highest growth, visit Emden and are not covered by Table 7-1.

The development in the number of calls and total GT presented in Table 7-1 is not always in line with the explaining variables presented in table 6-2 through 6-9, because there is no fixed relationship between these items. Sailing time depends on the quays visited in the port areas and the time on the quay is influenced by the type and size of the ship and economic pressure.

Therefore general growth factors from Table 7-1 cannot be used to estimate the emission explaining variables for 2011 out the data of 2010, certainly not when a spatial distribution is required also.

Table 7-2 Ship characteristics per EMS type for the Dutch part of the Western Scheldt

Ship type	Totals for Western Scheldt in 2011					2011 as percentage of 2010				
	Berthed		Moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	5,679	147,002,530	6,455	1,448,861,116	10.78	121.2%	87.5%	144.5%	103.9%	99.7%
Chem.+Gas tanker	37,144	393,414,099	45,172	3,762,097,597	10.79	99.8%	107.3%	116.3%	120.0%	97.3%
Bulk carrier	19,463	603,088,832	8,810	2,160,149,543	9.18	121.7%	136.6%	116.1%	121.4%	100.7%
Container ship	6,615	54,694,098	34,024	15,366,494,730	12.61	129.0%	81.6%	111.0%	114.6%	99.1%
General Dry Cargo	69,651	469,105,783	45,983	2,368,051,928	10.35	98.4%	92.8%	108.0%	106.0%	98.8%
RoRo Cargo / Vehicle	16,881	234,738,364	13,643	5,967,287,087	12.03	88.2%	87.6%	107.6%	110.8%	98.4%
Reefer	9,470	75,299,042	3,077	470,046,376	12.73	110.4%	112.5%	111.6%	111.1%	99.0%
Passenger	11,815	14,400,329	5,502	220,456,379	12.70	208.8%	209.7%	201.9%	155.0%	95.6%
Miscellaneous	115,437	342,954,882	27,953	608,453,982	7.37	114.8%	138.5%	77.6%	46.0%	102.7%
Tug/Supply	78,816	32,347,118	14,126	32,769,455	6.40	163.1%	151.1%	205.3%	146.9%	89.6%
Fishing	2,974	6,168,790	304	1,410,181	7.67	174.6%	67.2%	718.9%	89.2%	81.7%
Non Merchant	1,532	1,902,369	92	457,097	5.40	114.6%	103.5%	126.4%	115.7%	69.5%
Total	**375,477**	**2,375,116,236**	**205,142**	**32,406,535,471**	**11.56**	**117.7%**	**109.4%**	**110.7%**	**110.8%**	**100.6%**

Table 7-3 Ship characteristics per EMS ships size classes for the Dutch part of the Western Scheldt

Ship size in GT	Totals for Western Scheldt in 2011					2011 as percentage of 2010				
	Berthed		Moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	169,257	100,862,680	35,011	231,430,298	8.65	142.3%	124.4%	149.3%	132.9%	101.6%
1,600-3,000	58,748	137,753,040	45,341	971,099,979	9.13	104.0%	104.8%	109.7%	108.8%	100.1%
3,000-5,000	40,306	160,972,816	30,364	1,224,668,417	10.30	101.3%	104.7%	111.9%	112.9%	100.2%
5,000-10,000	37,819	256,513,713	26,190	2,129,013,693	11.31	104.1%	99.9%	110.5%	111.6%	99.8%
10,000-30,000	50,349	805,083,957	37,767	8,301,460,965	11.61	97.3%	92.8%	87.2%	98.1%	104.5%
30,000-60,000	15,944	649,645,454	22,606	11,507,676,123	11.77	114.5%	120.5%	113.0%	112.6%	99.3%
60,000-100,000	2,577	209,857,695	6,579	6,029,080,174	12.08	144.8%	160.7%	121.3%	120.8%	98.3%
>100,000	478	54,426,881	1,285	2,012,105,822	11.69	651.7%	514.7%	133.8%	132.7%	95.6%
Total	**375,477**	**2,375,116,236**	**205,142**	**32,406,535,471**	**11.56**	**117.7%**	**109.4%**	**110.7%**	**110.8%**	**100.6%**

Table 7-4 Ship characteristics per EMS type for the Rotterdam port area

Ship type	Totals for Rotterdam in 2011					2011 as percentage of 2010				
	berthed		moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	56,943	3,990,054,953	5,929	1,835,137,477	6.05	91.5%	98.7%	99.9%	98.9%	100.1%
Chem.+Gas tanker	107,928	1,369,607,985	22,889	1,746,159,292	7.96	82.4%	81.7%	99.3%	101.9%	99.8%
Bulk carrier	88,149	5,310,597,049	4,155	1,115,258,973	5.86	112.0%	118.1%	108.6%	111.9%	100.4%
Container ship	177,903	6,134,106,883	33,002	5,718,313,311	7.09	96.2%	106.5%	102.2%	111.7%	98.2%
General Dry Cargo	114,445	592,412,240	24,964	772,419,478	8.58	93.7%	88.9%	95.7%	95.7%	101.1%
RoRo Cargo / Vehicle	28,240	690,789,562	7,310	1,684,072,507	9.48	75.6%	89.1%	83.3%	101.2%	101.4%
Reefer	3,230	27,237,114	1,068	89,921,942	9.08	65.7%	66.9%	128.7%	124.7%	95.7%
Passenger	13,816	700,292,722	1,832	1,016,838,042	10.25	87.7%	98.4%	96.7%	105.5%	98.4%
Miscellaneous	95,750	1,177,493,829	15,716	427,835,457	5.66	111.4%	119.4%	124.2%	95.6%	83.3%
Tug/Supply	181,652	89,479,249	44,849	106,144,506	5.94	105.7%	101.7%	110.8%	109.5%	98.6%
Fishing	16,040	4,897,463	360	566,018	4.52	123.0%	109.7%	305.7%	278.3%	77.9%
Non Merchant	501	230,935	145	670,197	8.26	219.8%	82.4%	180.3%	118.7%	107.4%
Total	**884,596**	**20,087,199,985**	**162,219**	**14,513,337,200**	**7.29**	**97.4%**	**104.4%**	**104.0%**	**105.6%**	**98.6%**

Table 7-5 Ship characteristics per EMS ships size class for the Rotterdam port area

Ship size in GT	Totals for Rotterdam in 2011					2011 as percentage of 2010				
	Berthed		Moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average Speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	235,605	104,764,256	57,998	171,131,267	6.56	113.8%	115.3%	114.7%	103.8%	96.5%
1,600-3,000	81,427	199,312,149	20,379	445,620,726	8.93	90.1%	90.3%	95.2%	96.2%	100.1%
3,000-5,000	74,718	295,653,241	15,693	549,174,563	8.64	99.5%	98.4%	93.9%	93.5%	100.0%
5,000-10,000	130,306	966,824,272	27,333	1,745,207,319	8.63	89.0%	88.5%	103.4%	100.7%	98.9%
10,000-30,000	155,844	3,127,304,822	22,960	3,859,861,366	8.52	77.6%	77.8%	87.5%	90.5%	102.4%
30,000-60,000	90,110	3,865,072,734	9,407	2,932,515,510	7.25	113.9%	109.3%	131.1%	120.4%	95.6%
60,000-100,000	80,515	6,472,445,074	6,238	3,108,194,592	6.49	103.6%	103.7%	107.3%	108.8%	102.8%
>100,000	36,069	5,055,823,436	2,211	1,701,631,857	5.45	115.0%	135.0%	134.4%	137.9%	101.2%
Total	**884,596**	**20,087,199,985**	**162,219**	**14,513,337,200**	**7.29**	**97.4%**	**104.4%**	**104.0%**	**105.6%**	**98.6%**

Table 7-6 Ship characteristics per EMS type for the Amsterdam port area

Ship type	Totals for Amsterdam in 2011					2011 as percentage of 2010				
	Berthed		moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	19,805	706,571,678	1,997	291,816,812	5.01	134.1%	145.4%	117.0%	126.7%	99.1%
Chem.+Gas tanker	38,044	656,349,261	5,790	446,437,616	5.56	90.6%	87.4%	94.9%	93.8%	100.0%
Bulk carrier	59,326	2,918,944,061	2,820	624,220,330	4.82	107.5%	116.0%	93.0%	99.7%	96.9%
Container ship	1,729	30,609,748	106	9,302,609	5.45	49.4%	36.9%	42.9%	31.9%	99.2%
General Dry Cargo	98,406	360,371,297	8,538	168,210,317	6.22	113.1%	126.2%	105.4%	117.3%	97.7%
RoRo Cargo / Vehicle	10,861	289,399,355	2,040	254,103,397	5.86	94.6%	101.7%	101.4%	101.8%	101.2%
Reefer	15,976	75,447,063	452	10,857,148	4.95	102.7%	116.1%	97.1%	101.2%	100.8%
Passenger	3,783	141,588,677	1,178	306,201,060	6.02	71.4%	80.9%	105.7%	116.8%	100.0%
Miscellaneous	43,009	201,912,694	3,029	58,718,173	4.94	109.0%	110.6%	86.5%	75.0%	107.3%
Tug/Supply	139,218	76,453,867	19,231	35,178,886	5.25	105.5%	104.8%	104.8%	94.3%	100.2%
Fishing	33,571	83,532,062	438	6,353,224	4.39	136.9%	92.7%	99.5%	88.0%	100.0%
Non Merchant	15,316	8,343,311	414	1,161,422	5.29	149.3%	185.3%	145.2%	141.1%	87.2%
Total	**479,044**	**5,549,523,075**	**46,033**	**2,212,560,993**	**5.35**	**108.6%**	**111.1%**	**101.5%**	**102.9%**	**99.4%**

Table 7-7 Ship characteristics per EMS ships size classes for the Amsterdam port area

Ship size in GT	Totals for Amsterdam in 2011					2011 as percentage of 2010				
	Berthed		Moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	190,147	95,257,883	22,270	52,507,296	5.61	107.5%	100.2%	101.9%	90.4%	96.9%
1,600-3,000	87,517	203,928,285	6,579	100,167,845	6.32	114.7%	112.9%	100.2%	98.2%	97.9%
3,000-5,000	38,150	151,192,486	3,158	76,872,707	6.03	113.4%	114.9%	117.6%	118.9%	100.9%
5,000-10,000	41,516	296,479,315	4,169	185,153,975	5.97	114.6%	113.3%	97.3%	96.2%	99.9%
10,000-30,000	55,395	1,172,139,892	5,110	554,027,784	5.50	92.8%	94.1%	92.0%	94.5%	101.9%
30,000-60,000	45,324	1,885,892,247	3,560	769,237,014	5.26	108.3%	110.8%	105.6%	106.3%	99.0%
60,000-100,000	20,893	1,734,273,145	1,126	438,329,838	4.80	128.1%	127.4%	108.4%	104.1%	97.1%
>100,000	101	10,359,822	60	36,264,535	5.87	59.2%	60.3%	846.4%	1199.7%	139.1%
Total	**479,044**	**5,549,523,075**	**46,033**	**2,212,560,993**	**5.35**	**108.6%**	**111.1%**	**101.5%**	**102.9%**	**99.4%**

Table 7-8 Ship characteristics per EMS type for the Ems area

Ship type	Totals for Ems in 2011					2011 as percentage of 2010				
	Berthed		Moving			Berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	392	900,257	532	7,244,809	9.53	142.4%	95.3%	169.2%	103.1%	94.4%
Chem.+Gas tanker	3,185	14,177,387	1,794	102,284,729	10.93	71.3%	79.8%	86.3%	98.4%	98.0%
Bulk carrier	3,373	53,794,372	642	71,076,731	9.98	85.8%	90.5%	90.3%	107.6%	103.7%
Container ship	601	2,309,710	91	9,418,610	11.86	6.5%	3.0%	41.5%	40.8%	97.6%
General Dry Cargo	61,907	242,417,367	9,392	318,321,315	9.97	122.6%	116.2%	108.7%	104.6%	99.2%
RoRo Cargo / Vehicle	18,931	529,202,962	7,990	1,558,129,054	12.54	95.0%	122.2%	109.7%	119.4%	99.0%
Reefer	1,948	4,833,122	196	6,182,101	10.76	84.9%	89.4%	98.5%	104.3%	101.9%
Passenger	1,235	30,811,511	2,409	61,260,630	11.34	45.9%	43.7%	84.9%	71.7%	105.3%
Miscellaneous	32,867	79,320,673	13,844	276,343,167	7.08	149.4%	141.9%	143.0%	119.0%	95.2%
Tug/Supply	83,920	41,763,470	7,752	31,263,088	7.93	118.4%	126.5%	121.0%	94.3%	95.4%
Fishing	1,954	2,451,660	237	1,220,790	8.14	315.5%	280.9%	155.1%	204.9%	105.6%
Non Merchant	278	76,528	38	114,360	7.27	244.6%	327.1%	125.8%	34.1%	57.5%
Total	**210,590**	**1,002,059,019**	**44,920**	**2,442,859,384**	**10.94**	**112.7%**	**104.0%**	**116.5%**	**112.8%**	**98.9%**

Table 7-9 Ship characteristics per EMS ships size classes for the Ems area

Ship size in GT	Totals for Ems in 2011					2011 as percentage of 2010				
	Berthed		moving			Berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	100,402	38,554,579	17,625	77,317,637	9.30	118.7%	119.8%	130.1%	115.8%	99.0%
1,600-3,000	50,487	115,901,110	12,085	258,419,113	9.87	142.3%	145.9%	112.1%	109.5%	95.9%
3,000-5,000	24,629	97,874,704	6,658	241,016,623	8.30	121.5%	121.0%	222.1%	206.2%	82.4%
5,000-10,000	19,569	126,927,809	5,337	426,798,188	10.63	57.8%	53.3%	62.2%	77.8%	106.5%
10,000-30,000	5,598	104,653,027	1,535	367,824,072	12.00	120.9%	109.3%	124.0%	117.9%	97.9%
30,000-60,000	8,601	423,544,321	1,441	892,306,898	12.21	128.7%	131.6%	121.8%	127.5%	99.1%
60,000-100,000	1,074	66,582,241	222	164,152,448	11.78	97.1%	81.3%	106.9%	103.9%	98.3%
>100,000	229	28,021,227	16	15,024,405	7.55	80.9%	84.1%	53.4%	54.2%	100.9%
Total	**210,590**	**1,002,059,019**	**44,920**	**2,442,859,384**	**10.94**	**112.7%**	**104.0%**	**116.5%**	**112.8%**	**98.9%**

7.3 Activities of seagoing vessels at the NCS

The shipping activities at the NCS are presented in Table 7-10 and Table 7-11. 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 number of ships at anchor has decreased slightly in 2011, this development being stronger for larger ships. It results in a 4.1% decrease overall in GT.hours at anchor. The number of hours moving increases with 8.8% and the GT.nm increases with 13.2%. This larger growth in GT than in numbers is a development which goes on for as much as thirty years. The increase in numbers is partly realistic, reflecting the recovery of the world economy, and partly artificial, reflecting the fact that more vessels are equipped with an AIS transponder and could be connected with the ship characteristics database. Going into more detail, Table 7-10 shows considerable growths for bulk carriers, container ships and the ship types “tug/supply”, “fishing” and “non merchant”. The growth in the last three ship types is mainly due to the fact that more of these ships are equipped with an AIS transponder. For small tug/supply and non-merchant vessels this is voluntary, but for some fishing vessels this is mandatory.

The average number of fishing vessels at the NCS in 2011 amounts to 6.84 (= (50142+9773)/(24*365)). In reality this number is 69 fishing vessels. This means that only 10% of the fishing vessels was equipped with an AIS transponder. The contribution of fishing vessels in the emission explanation variables is therefore negligible.

For moving ships, the average speed in 2011 is 2% less than the average speed in 2010.

Table 7-10 Ship characteristics per EMS type for the Netherlands Continental Shelf

Ship type	Totals for NCS in 2011					2011 as percentage of 2010				
	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	131,827	5,847,310,635	84,397	41,520,108,834	11.00	79.9%	70.3%	100.1%	96.7%	101.3%
Chem.+Gas tanker	313,516	3,930,883,384	274,242	31,754,413,570	11.55	95.2%	94.8%	106.6%	104.8%	99.0%
Bulk carrier	61,781	3,002,429,879	93,478	34,091,815,289	10.87	197.4%	271.8%	119.5%	128.8%	93.2%
Container ship	59,938	1,688,466,415	200,060	114,458,348,210	15.19	77.8%	96.1%	115.6%	120.2%	92.1%
General Dry Cargo	107,271	448,879,250	458,371	18,124,808,776	10.84	122.4%	142.0%	106.5%	103.7%	97.3%
RoRo Cargo / Vehicle	3,948	160,569,852	119,637	54,250,810,987	15.90	56.5%	84.4%	107.4%	120.4%	99.7%
Reefer	6,444	44,811,217	20,930	2,515,801,587	15.15	157.4%	171.5%	81.4%	76.7%	95.4%
Passenger	32	611,654	22,078	16,546,659,429	17.49	6.1%	3.9%	102.9%	115.0%	99.4%
Miscellaneous	54,641	539,009,798	124,212	3,710,296,426	6.80	80.0%	107.6%	94.7%	80.0%	103.7%
Tug/Supply	86,272	139,085,163	162,126	1,310,611,985	6.58	119.9%	124.6%	119.3%	104.7%	92.5%
Fishing	9,773	3,703,291	50,142	267,691,615	7.48	150.9%	102.3%	159.7%	110.1%	87.0%
Non Merchant	141	43,458	3,088	27,528,269	11.73	87.7%	105.6%	128.9%	120.0%	99.4%
Total	**835,584**	**15,805,803,996**	**1,612,760**	**318,578,894,979**	**13.18**	**98.4%**	**95.9%**	**108.8%**	**113.2%**	**98.0%**

Table 7-11 Ship characteristics per ship size class for the Netherlands Continental Shelf

Ship size in GT	Totals for NCS in 2011					2011 as percentage of 2010				
	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	98,264	67,822,625	281,159	1,420,288,933	6.69	129.9%	123.0%	115.5%	97.7%	93.5%
1,600-3,000	115,302	280,643,091	372,112	8,078,315,199	9.11	100.7%	103.8%	109.3%	107.4%	96.8%
3,000-5,000	112,816	449,289,267	210,902	8,908,009,928	10.60	116.7%	118.2%	109.9%	109.1%	98.4%
5,000-10,000	127,150	934,394,866	214,148	19,364,269,415	12.49	88.9%	87.9%	104.0%	105.2%	101.6%
10,000-30,000	227,732	4,425,813,136	287,915	73,426,550,192	13.14	84.3%	85.0%	95.2%	96.5%	100.7%
30,000-60,000	90,727	4,063,767,061	146,085	88,058,405,866	13.89	95.2%	89.9%	118.3%	113.6%	98.3%
60,000-100,000	52,033	3,877,962,828	81,339	84,233,298,250	13.62	132.4%	140.8%	128.4%	118.8%	92.8%
>100,000	11,560	1,706,111,123	19,100	35,089,757,195	13.67	80.3%	76.3%	167.1%	164.9%	97.8%
Total	**835,584**	**15,805,803,996**	**1,612,760**	**318,578,894,979**	**13.18**	**98.4%**	**95.9%**	**108.8%**	**113.2%**	**98.0%**

7.4 Overview of ships in the port areas and at the NCS

The average number of ships in the port areas and at sea is given in Table 7-12 and graphically depicted in Figure 7-1. Large differences between ports in the ratio of not moving ships over moving ships are observed. This is explained by the length of the route to the berth: the longer the route, the smaller the ratio. Amsterdam and Ems with short routes show high ratios. For the Western Scheldt a small ratio is observed due to long sailing distances but also because most ships berth outside the area. Table 7-12 shows in addition that the average speed is quite different between the port areas, with an average of 5.35 knots for Amsterdam and 11.56 knots in the Western Scheldt.

Remark: The percentages for the average number of ships in 2011 compared with 2010 are the same as found earlier in Table 7-2 through Table 7-9 under the column "Hours".

The average GT of the ships is given in Table 7-13. The average GT of a ship in Rotterdam is more than 4 times higher than that of a ship in the Ems. Further, the average GT of not moving (thus mostly berthed) ships is larger than that of moving ships, which is caused by a longer time needed for cargo handling. An exception is the Western Scheldt, because the larger ships here are calling for Antwerp, whereas these tables only cover the Dutch part of the Western Scheldt. The average GT in Rotterdam has increased with 6.3% compared to 2010, while the average GT in the Ems shows a decrease of 6.8%.

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

Table 7-12 Average number of ships in distinguished areas

Area	in 2011				in 2011 as % percentage of 2010			
	average ships			Speed	average ships			speed
	not moving	Moving	total	Knots	not moving	moving	Total	knots
Western Scheldt	42.86	23.42	66.28	11.56	117.7%	110.7%	115.1%	100.6%
Rotterdam	100.98	18.52	119.50	7.29	97.4%	104.0%	98.4%	98.6%
Amsterdam	54.69	5.25	59.94	5.35	108.6%	101.5%	108.0%	99.4%
Ems	24.04	5.13	29.17	10.94	112.7%	116.5%	113.3%	98.9%
NCS	95.39	184.11	279.49	13.18	98.4%	108.8%	105.0%	98.0%

Table 7-13 Average GT of ships in distinguished areas

Area	in 2011			In 2011 as percentage of 2010		
	average GT of ships			average GT of ships		
	not moving	Moving	Total	not moving	Moving	Total
Western Scheldt	6,326	13,670	8,921	93.0%	99.5%	95.4%
Rotterdam	22,708	12,271	21,090	107.1%	103.0%	106.3%
Amsterdam	11,585	8,982	11,356	102.3%	102.0%	102.4%
Ems	4,758	4,973	4,796	92.3%	97.9%	93.2%
NCS	18,916	14,988	16,329	97.4%	106.2%	101.8%

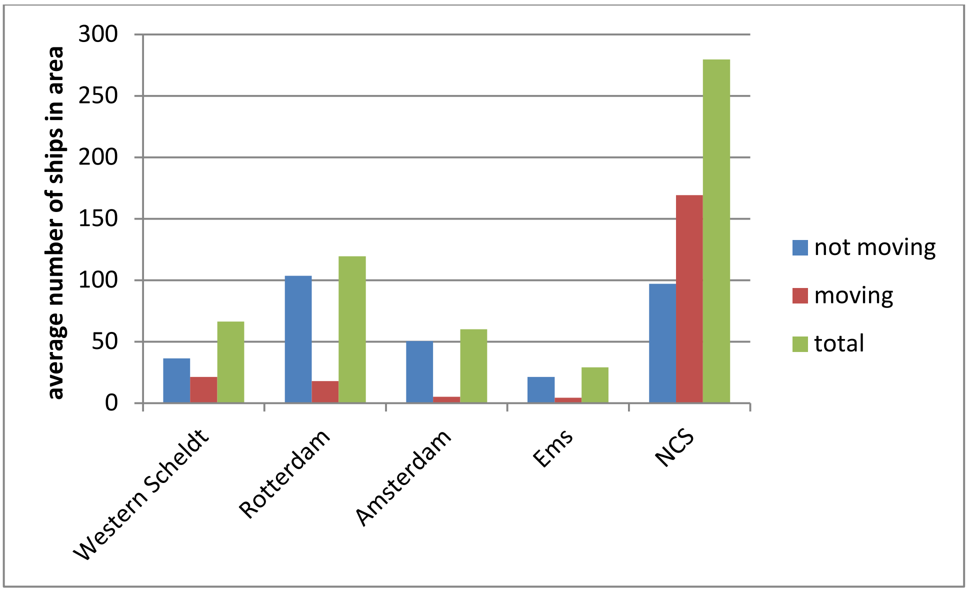

Figure 7-1 Average number of ships in distinguished areas

8 EMISSIONS FOR THE DUTCH PORT AREAS AND THE NCS

8.1 Introduction

This chapter presents the results of the emission calculations for 2011 for the Dutch port areas and at the Netherlands Continental Shelf. To see how the emissions evolve over the years, all values for 2011 are also presented as percentages of the 2010 values. Both 2010 and 2011 have been calculated with the multiple engines methodology. Values are presented as calculated and are not rounded off.

The emissions for the port areas are given in Section 8.2 and for the NCS in Section 8.3. Section 8.4 presents the spatial distribution of the 2011 NO_x emissions for ports and NCS. Also the change in these emissions compared to 2010 is presented.

8.2 Emissions in port areas

Table 8-1 contains the emissions for the four Dutch port areas, calculated for ships berthed and sailing within the port area. The latter are divided into those resulting from main engines and those resulting from auxiliary engines. Table 8-2 contains the same emissions expressed as a percentage of the corresponding emissions in 2010. Note that values for at berth include all vessels with zero speed, so also the vessels at anchor.

The difference in the behaviour of the shipping activities in the four areas becomes clear when the ratios “berthed” over “sailing” are compared with each other. For NO_x the emissions for berthed and sailing are nearly equal in Rotterdam, while for the Western Scheldt the emissions for sailing are more than 12 times higher. Rotterdam is a real port area while the Western Scheldt is mainly a waterway. The ratios for Amsterdam and the Ems are between these extremes. The character of the area has effect on the change in emissions.

Table 8-2 shows the changes in emission between 2010 and 2011. The largest differences occur for SO_2 and aerosols during sailing, due to the assumption that the SECA according to the IMO is fully implemented.

The emissions for VOC, CO, CO_2 show the same trend. Relatively large increases in the area Western Scheldt and smaller increases in Amsterdam and Ems. The emissions in Rotterdam for these substances have remained almost unchanged.

The emission changes of NO_x are only caused by changed traffic. The percentages in Table 8-2 show:

- Western Scheldt: +7.6% for sailing (main engine), +3.6% for sailing (auxiliary engine) and +4.9% for at berth, resulting in an overall increase of 7%;
- Rotterdam: -1% for sailing (main engine), -9.8% for sailing (auxiliary engine) and -1.4% for at berth, resulting in an overall decrease of -2%. At berth emissions decrease while the GT.hours increase by 4.4% (see Table 7-4). This is caused by a relative large growth in GT.hours for bulk carriers and container ships with relatively low emissions per GT.hour (see Table A- 13 in Appendix);
- Amsterdam: -2.6% for sailing (main engine); -6% for sailing (auxiliary engine) and +9.1% for at berth, resulting in an overall increase of 4.4%.

- o Ems: +1.2% for sailing (main engine), +0.7% for sailing (auxiliary engines) and +9.1% for at berth, resulting in an overall increase of 3.2%.

The overall picture is that the NO_x emission increases in three out of four port areas; only in Rotterdam there is a decrease of 2%. Summarized over all port areas there is an increase of 2.7%.

Table 8-1 Total emissions in ton in each port area for 2011 based on AIS data

Substance	Source	Western Scheldt	Rotter-dam	Amster-dam	Ems	Total
1237 VOC	Berthed	33	218	59	12	322
	Sailing: Main engine	245	150	25	22	441
	Sailing: Auxiliary engines	34	24	4	3	66
	Total	***311***	***392***	***88***	***37***	***829***
4001 SO_2	Berthed	60	441	109	27	637
	Sailing: Main engine	2,077	1,061	146	164	3,448
	Sailing: Auxiliary engines	327	262	37	22	648
	Total	***2,463***	***1,765***	***292***	***212***	***4,733***
4013 NO_x	Berthed	757	4,697	1,314	295	7,063
	Sailing: Main engine	8,373	4,044	571	678	13,666
	Sailing: Auxiliary engines	1,132	814	143	100	2,190
	Total	***10,262***	***9,555***	***2,028***	***1,074***	***22,919***
4031 CO	Berthed	153	1,036	276	60	1,524
	Sailing: Main engine	1,642	1,115	181	134	3,072
	Sailing: Auxiliary engines	214	162	27	18	422
	Total	***2,009***	***2,313***	***483***	***212***	***5,018***
4032 CO_2	Berthed	66,384	534,124	133,760	21,532	755,799
	Sailing: Main engine	343,247	179,906	25,887	31,148	580,189
	Sailing: Auxiliary engines	64,897	49,354	8,058	5,612	127,921
	Total	***474,528***	***763,384***	***167,705***	***58,292***	***1,463,910***
6601 Aerosols MDO	Berthed	17	114	30	6	167
	Sailing: Main engine	13	11	3	5	32
	Sailing: Auxiliary engines	55	44	6	4	109
	Total	***84***	***168***	***39***	***16***	***308***
6602 Aerosols HFO	Berthed	0	0	0	0	0
	Sailing: Main engine	360	181	24	24	588
	Sailing: Auxiliary engines	0	0	0	0	0
	Total	***360***	***181***	***24***	***24***	***588***
6598 Aerosols MDO+HFO	Berthed	17	114	30	6	167
	Sailing: Main engine	372	192	27	29	620
	Sailing: Auxiliary engines	55	44	6	4	109
	Total	***444***	***349***	***63***	***40***	***896***

Table 8-2 Emissions in each port area for 2011 as percentage of the emissions in 2010

Substance	Source	Western Scheldt*	Rotter-dam	Amster-dam	Ems	Total*
1237 VOC	Berthed	104.9%	98.2%	108.1%	106.7%	100.9%
	Sailing: Main engine	106.6%	101.1%	92.7%	105.5%	103.7%
	Sailing: Auxiliary engines	106.4%	91.0%	94.9%	102.8%	99.2%
	Total	***106.4%***	***98.8%***	***102.6%***	***105.7%***	***102.2%***
4001 SO_2	Berthed	107.9%	101.8%	110.7%	107.3%	104.0%
	Sailing: Main engine	76.9%	71.8%	72.9%	68.6%	74.6%
	Sailing: Auxiliary engines	76.4%	69.2%	68.7%	70.3%	72.7%
	Total	***77.4%***	***77.0%***	***82.8%***	***72.1%***	***77.3%***
4013 NO_x	Berthed	104.9%	98.6%	109.1%	109.1%	101.5%
	Sailing: Main engine	107.6%	99.0%	97.4%	101.2%	104.2%
	Sailing: Auxiliary engines	103.6%	90.2%	94.0%	100.7%	97.4%
	Total	***107.0%***	***98.0%***	***104.4%***	***103.2%***	***102.7%***
4031 CO	Berthed	107.7%	100.1%	110.5%	109.4%	102.9%
	Sailing: Main engine	109.7%	101.9%	93.8%	106.1%	105.6%
	Sailing: Auxiliary engines	109.9%	94.6%	98.6%	101.5%	102.4%
	Total	***109.6%***	***100.5%***	***103.0%***	***106.6%***	***104.5%***
4032 CO_2	Berthed	105.9%	98.8%	110.3%	106.4%	101.4%
	Sailing: Main engine	112.7%	105.3%	106.1%	104.6%	109.5%
	Sailing: Auxiliary engines	111.6%	97.9%	100.5%	104.9%	104.9%
	Total	***111.5%***	***100.2%***	***109.1%***	***105.3%***	***104.8%***
6601 Aerosols MDO	Berthed	104.2%	99.4%	108.8%	106.1%	101.7%
	Sailing: Main engine	121.9%	103.6%	101.1%	112.9%	111.6%
	Sailing: Auxiliary engines	107.7%	95.8%	97.7%	104.2%	101.9%
	Total	***108.8%***	***98.7%***	***106.3%***	***107.8%***	***102.7%***
6602 Aerosols HFO	Berthed					
	Sailing: Main engine	85.4%	80.7%	80.7%	79.7%	83.5%
	Sailing: Auxiliary engines					
	Total	***85.4%***	***80.7%***	***80.7%***	***79.7%***	***83.5%***
6598 Aerosols MDO+HFO	Berthed	104.2%	99.4%	108.8%	106.1%	101.7%
	Sailing: Main engine	86.3%	81.7%	82.4%	84.2%	84.6%
	Sailing: Auxiliary engines	107.7%	95.8%	97.7%	104.2%	101.9%
	Total	***89.1%***	***88.5%***	***94.9%***	***89.0%***	***89.2%***

8.3 Emissions at the NCS

The emissions at the NCS are calculated for moving and non-moving ships. Ships are counted as non-moving when the speed is less than 1 knot. 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 2011 are summarised in Table 8-3. This table also contains a comparison with 2010. The average number of moving ships has changed significantly with an increase of nearly 8.8%.

The emissions of CO and CO_2 follow this increase with respectively 9% and 7%. There is less increase for VOC with 4%, Aerosols MDO with 3% and NO_x with 2%. The SO_2 emissions decrease with 27% and the Aerosols by HFO with 18%, which is again due to the assumption that the SECA according to the IMO is fully implemented.

The emissions presented in Table 8-3 are the result of the activities shown in Table 7-10 and Table 7-11, which contain information distinguished 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.

Of the most relevant ship types, the bulk carriers and container ships show the largest growth. There are considerable fluctuations in the number of non-moving ships but their effect on the emissions is limited because the share of the emissions of non-moving in the total emission is less than 4% of the total emissions at the NCS, while 34% of all ships at the NCS are at anchor.

Changes in the NO_x emissions are described because the emission factors for NO_x are not. The +8.8% moving ships at the NCS cause +2.1% NO_x emission for the main engine and +7.5% NOx emission by the auxiliary engine. The reason that the increase in main engine emission is much less is the reduction of the average speed with 2%, resulting in roughly -6% emissions per ship at sea, which corresponds reasonable with +8.8%-6%.

Summarized for the port areas and the NCS, it can be concluded that it remains difficult to explain changes in emissions based on changes in total number of ships, hours, GT.hours or GT.nm. The reason is that underlying changes in the traffic composition and used speed are not described by these totals. Therefore the best results for emissions in an area can be achieved by dealing with the real traffic.

Table 8-3 Emissions of ships in ton at the NCS for 2011 compared with 2010

Nr	Substance	Emission in ton in 2011				Emission in 2011 as percentage of 2010			
		not moving auxiliary engine	Moving		Total	not moving	Moving		Total
			Auxiliary Engine	Main Engine			Auxiliary Engine	Main Engine	
1237	VOC	79	208	2,091	2,379	92.8%	112.7%	103.4%	103.8%
4001	SO_2	705	2,085	20,597	23,388	63.9%	78.3%	73.2%	73.3%
4013	NO_x	2,371	7,054	80,060	89,485	88.9%	107.5%	102.1%	102.1%
4031	CO	480	1,346	13,046	14,872	94.4%	114.8%	108.9%	108.9%
4032	CO_2	138,281	411,676	3,357,659	3,907,616	95.6%	116.3%	106.7%	107.1%
6601	Aerosols MDO	123	346	73	543	88.4%	109.8%	101.4%	103.0%
6602	Aerosols HFO	0	0	3,534	3,534			82.4%	82.4%
6598	Aerosols MDO+HFO	123	346	3,608	4,077	88.4%	109.8%	82.7%	84.6%
Ships		95.39	184.11		279.49	98.4%	108.8%		105.0%

8.4 Spatial distribution of the emissions

Because of the strong relation between location of the emissions and the shipping routes, all substances show more or less the same spatial distribution. Therefore, only the spatial distribution of NO_X is presented for the four Dutch port areas and the NCS in Figure 8-1 to Figure 8-10.

Two figures are composed for each area: The first one represents the total emission (emissions of auxiliary and main engine of moving and non moving ships together) expressed as NO_x in kton/km^2. The second one shows the change in emission between 2010 and 2011. Also the emissions in the cells of adjacent areas are plotted.
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 difference. This is necessary because at the NCS differences are more smoothed due to the use of larger grid cells, they are 25 km^2 instead of 0.25 km^2 as used in the port areas.

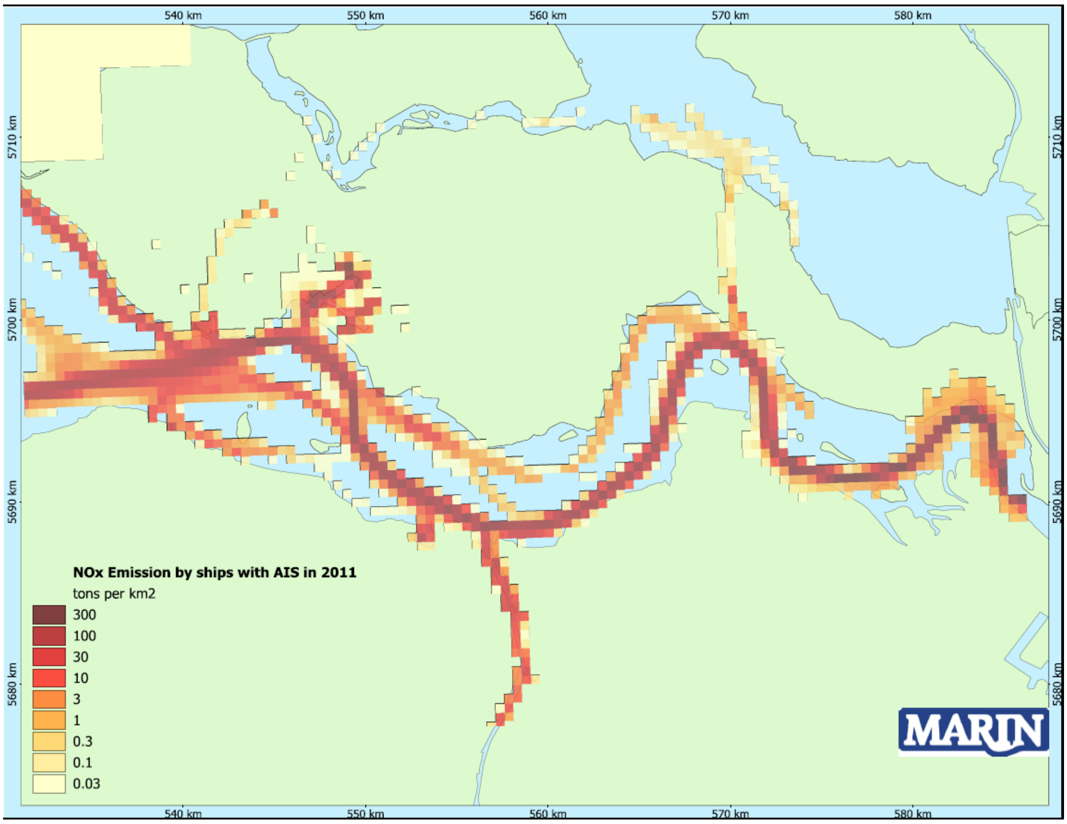

Figure 8-1 NO_x emission in 2011 in the Dutch part of the Western Scheldt by ships with AIS. The emissions have been corrected for bad AIS coverage

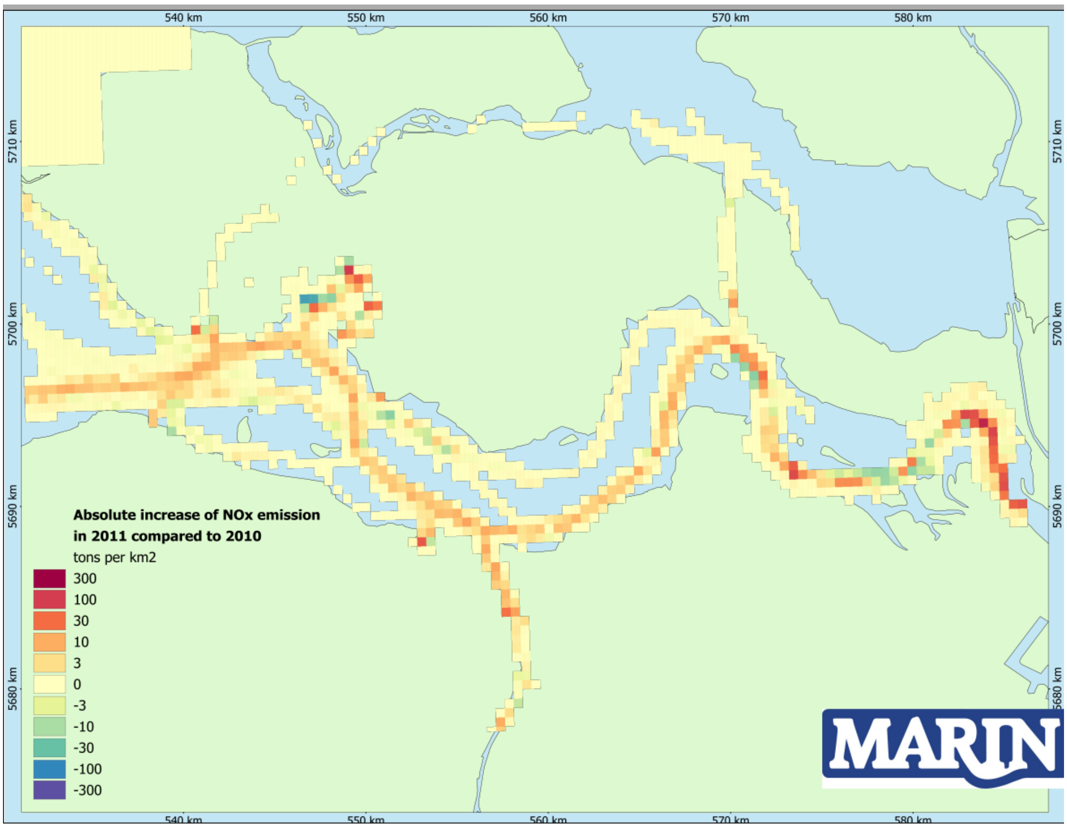

Figure 8-2 Change in NO_x emission from 2010 to 2011 in the Dutch part of the Western Scheldt by ships with AIS.

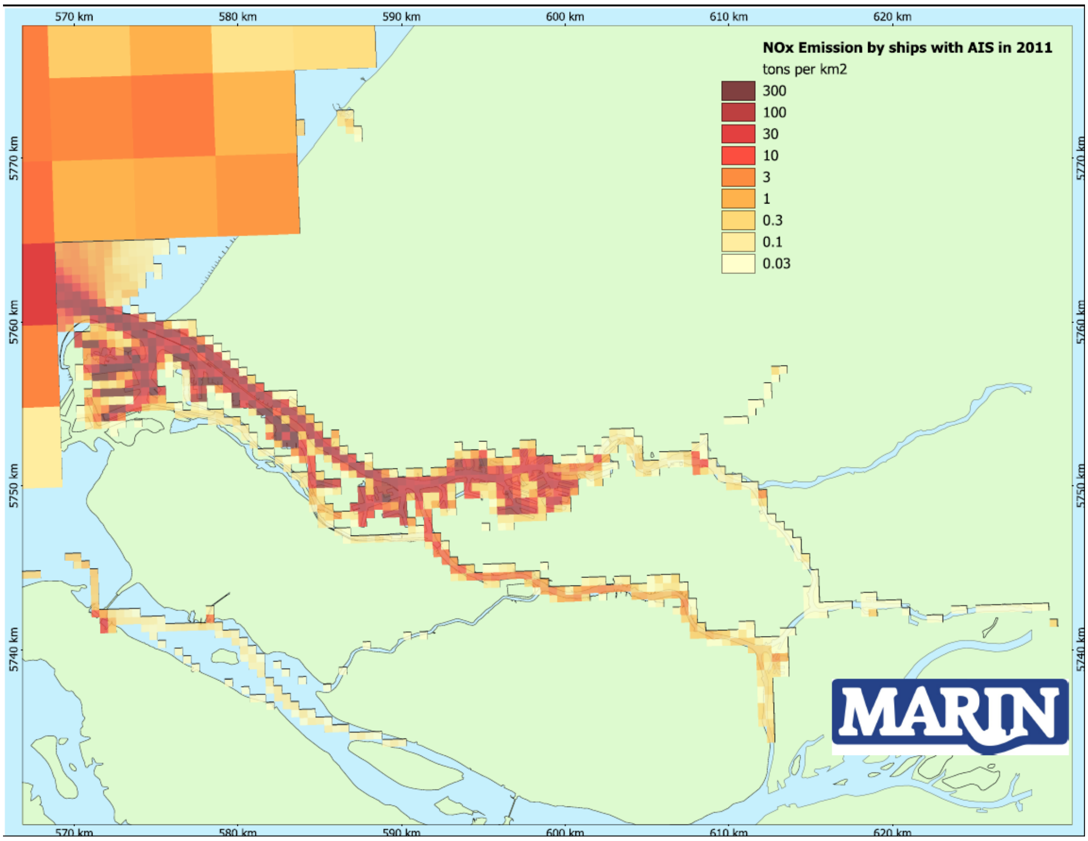

Figure 8-3 **NO_x emission in 2011 in the port area of Rotterdam by ships with AIS**

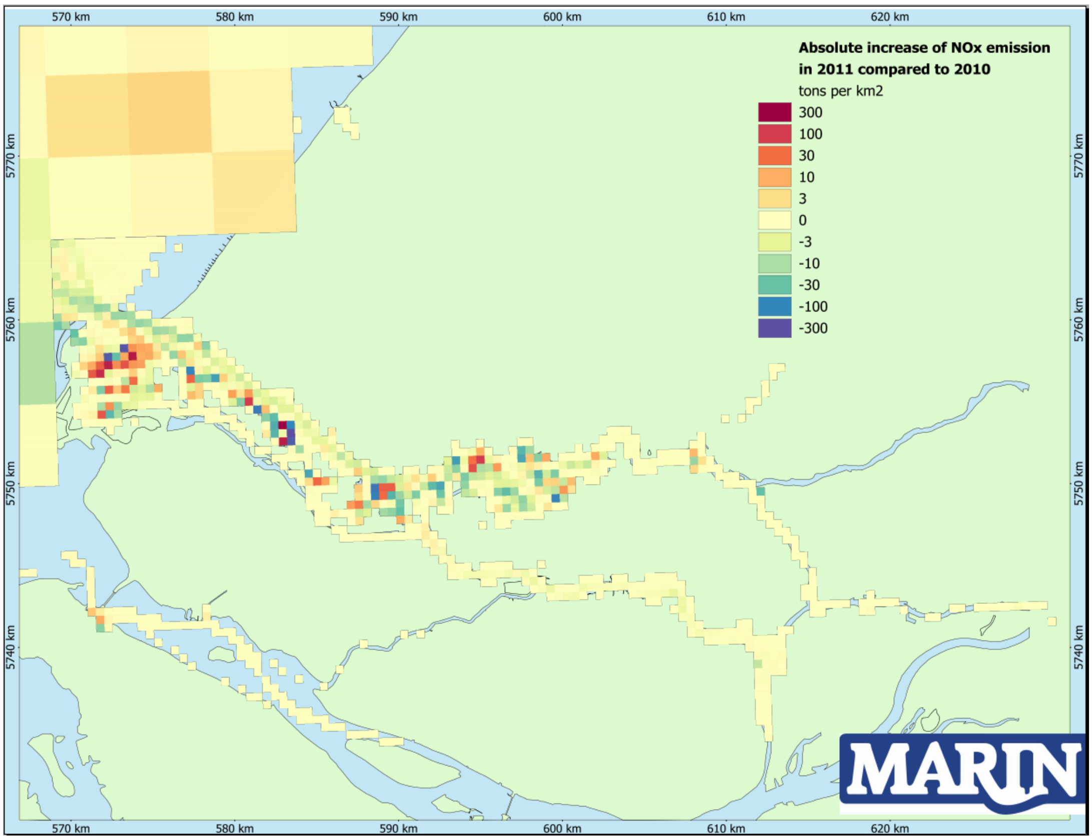

Figure 8-4 **Change in NO_x emission from 2010 to 2011 in the port area of Rotterdam by ships with AIS.**

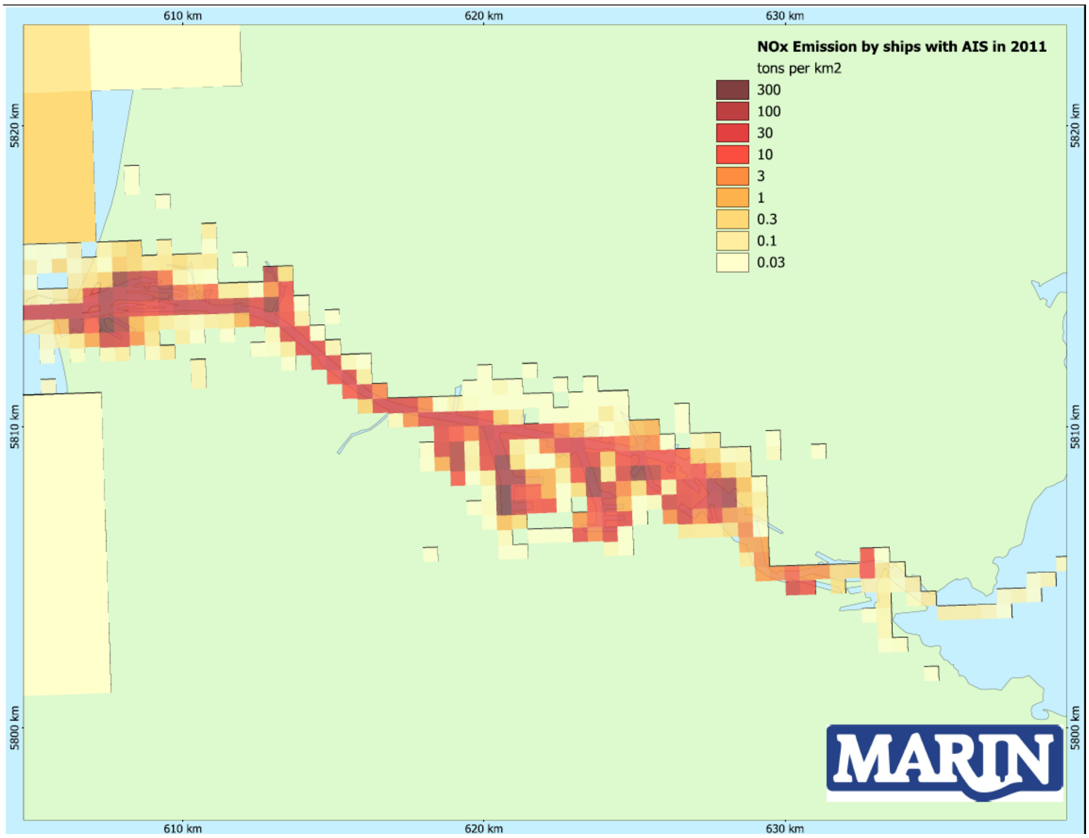

Figure 8-5 **NO_x emission in 2011 in the port area of Amsterdam by ships with AIS**

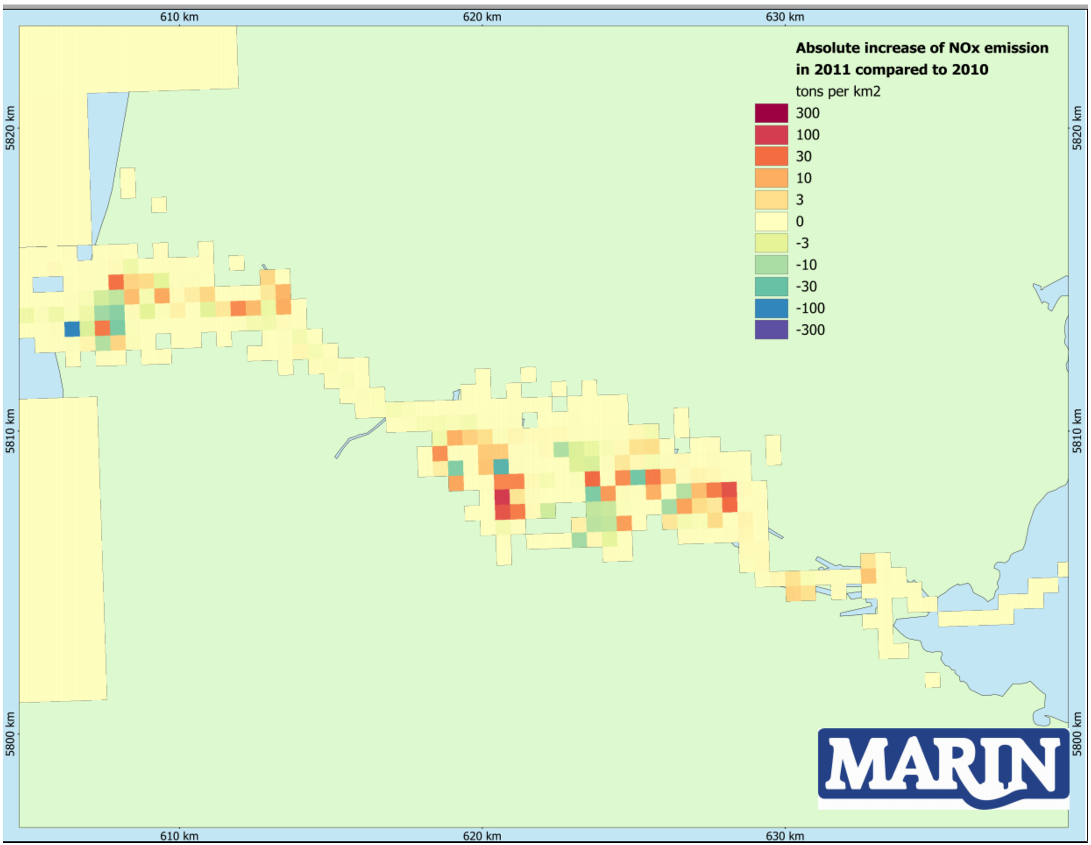

Figure 8-6 **Change in NOx emission from 2010 to 2011 in the port area of Amsterdam by ships with AIS**

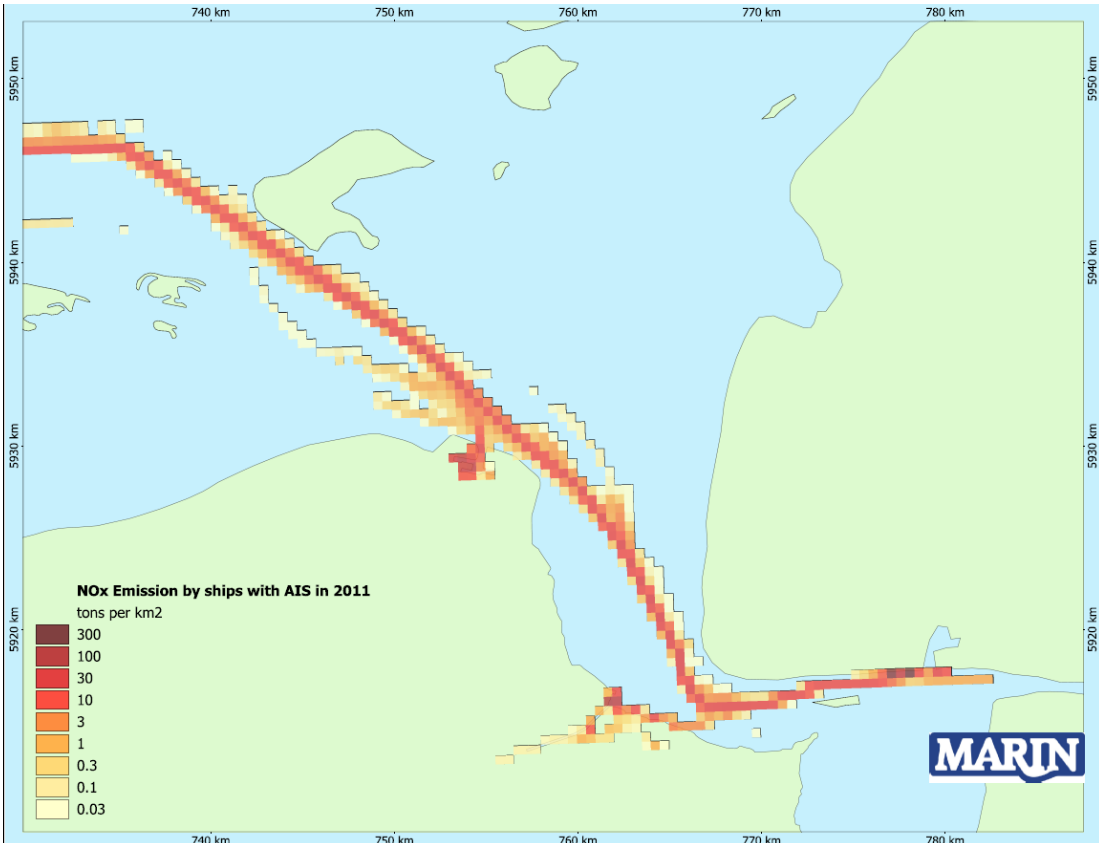

Figure 8-7 NO$_x$ emission in 2011 in the Ems area by ships with AIS

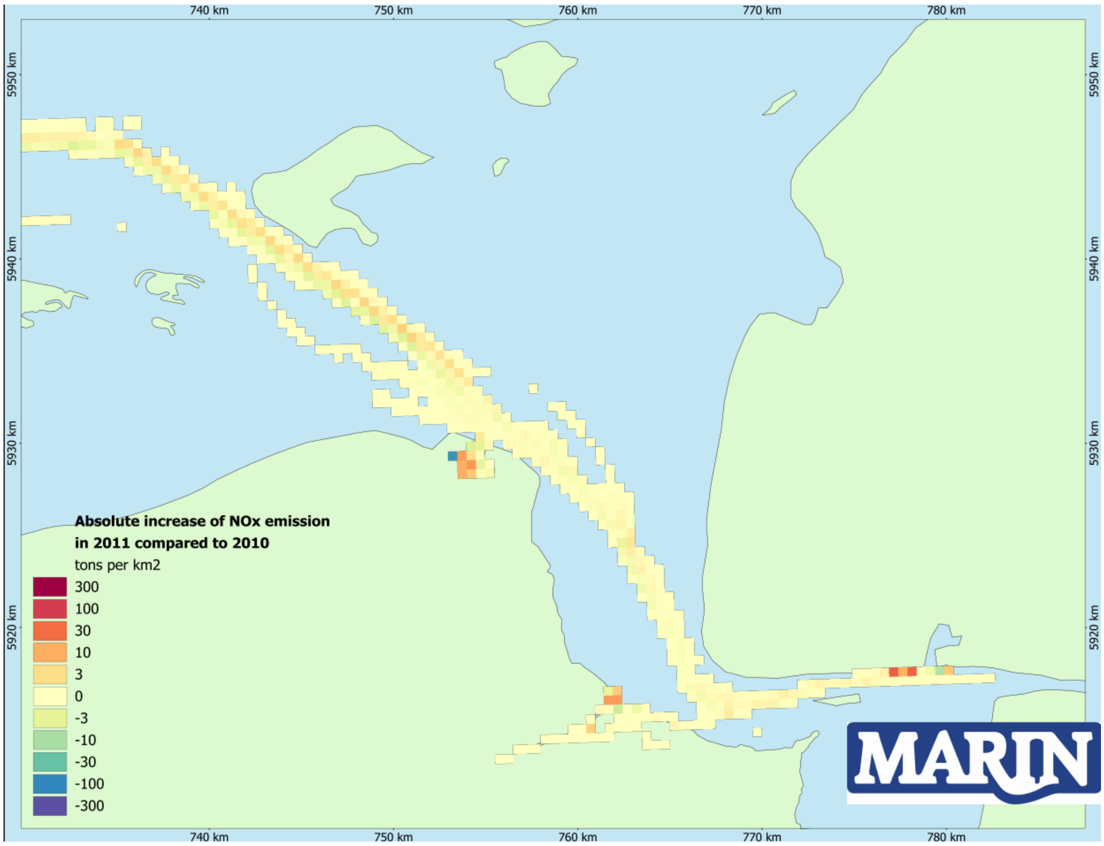

Figure 8-8 Change in NOx emission from 2010 to 2011 in the Ems area by ships with AIS in 2011

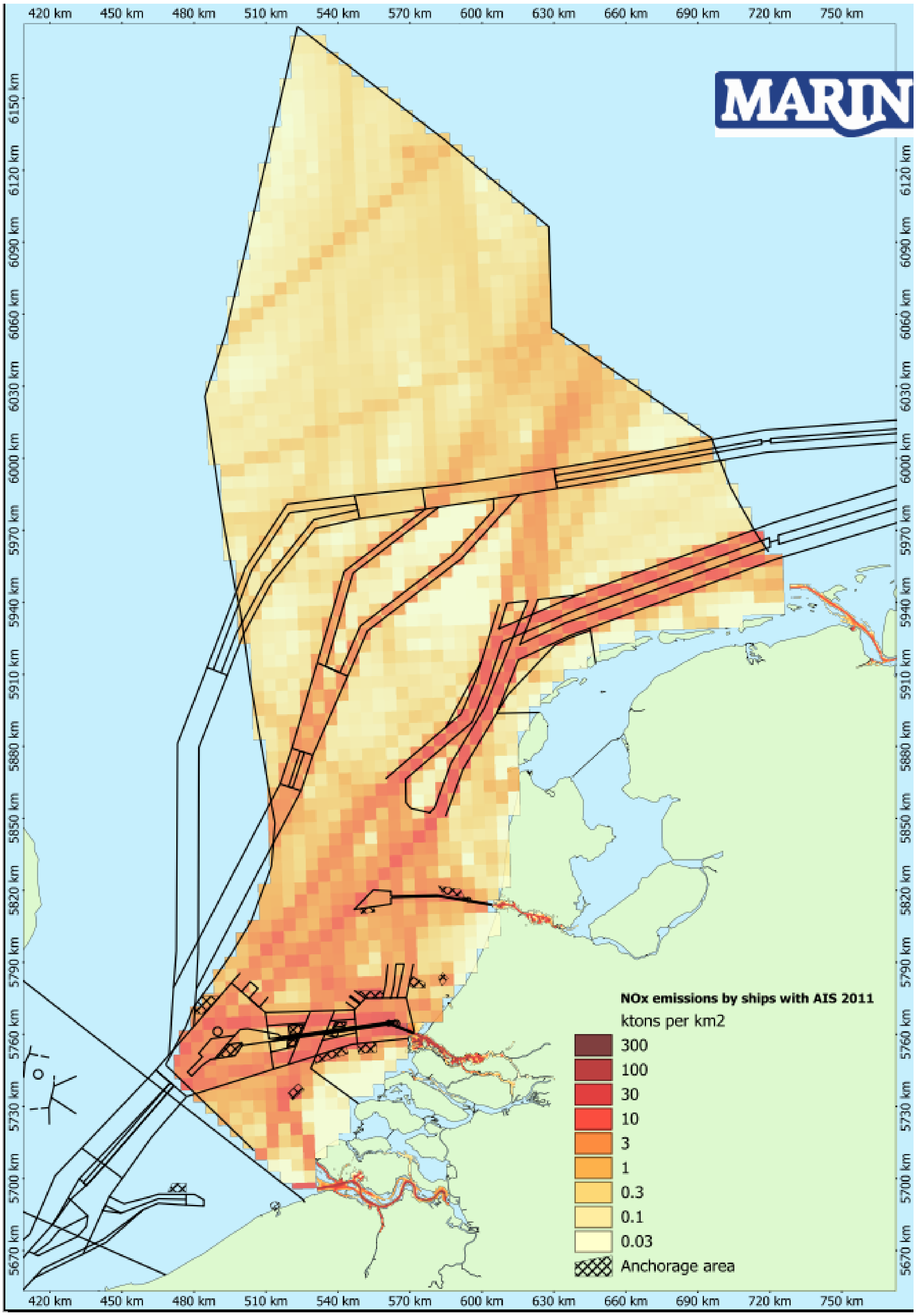

Figure 8-9 NO_x emission in 2011 at the NCS and in the Dutch port areas by ships with AIS

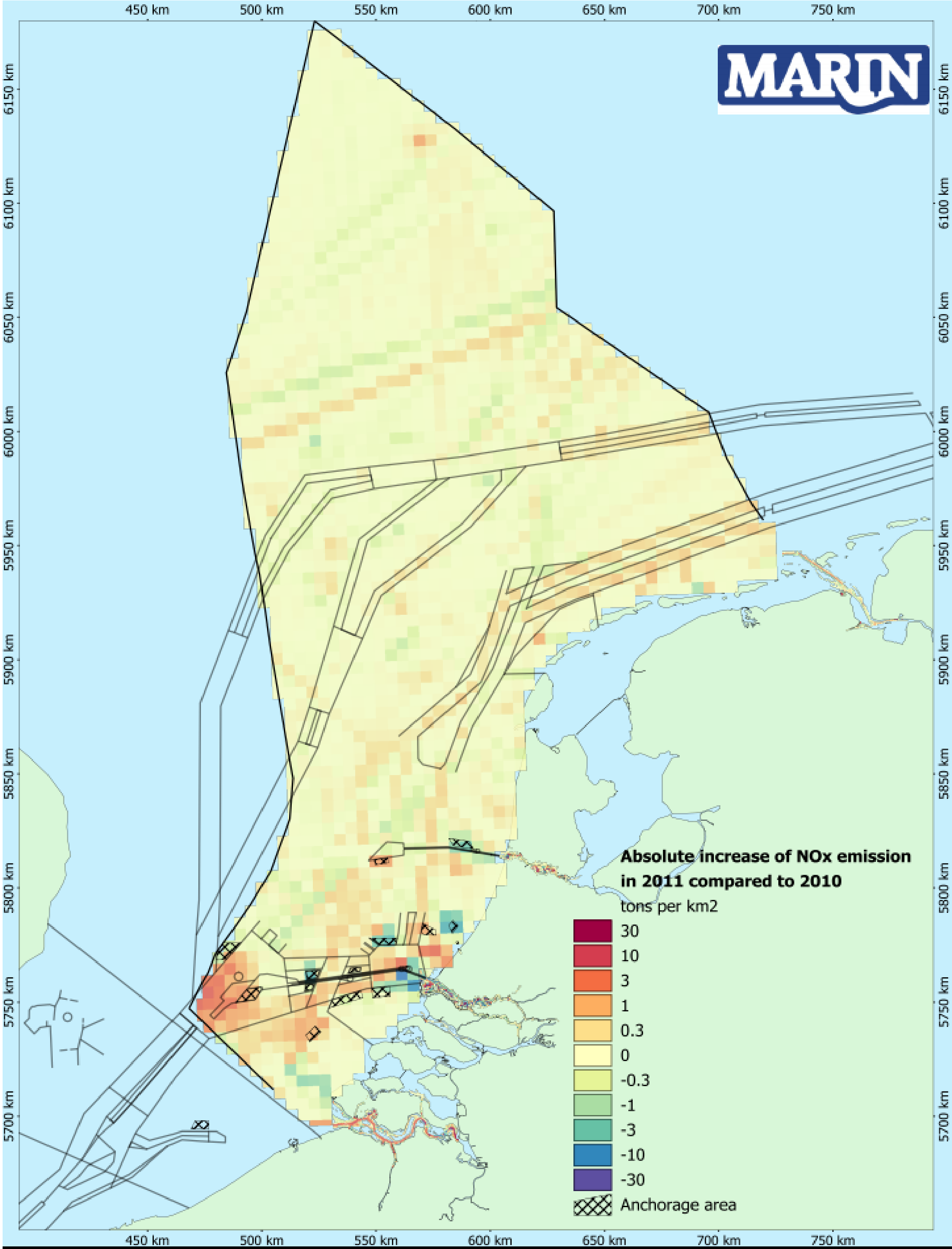

Figure 8-10 Change in NO_x emission from 2010 to 2011 at the NCS and in the Dutch port areas by ships with AIS in 2011

9 EMISSIONS IN OSPAR REGION II

9.1 Emissions at sea

The emissions for the total OSPAR region II without the added ferries are summarised in Table 9-1. The average number of ships at sea in the OSPAR region II amounts to 965.4. This is the number calculated with SAMSON after applying the correction for the difference between the assumed speed in SAMSON and the real speed as found in the AIS data of 2011 and after applying the correction factor for the traffic volume in 2011.

On average there are 5.4% more ships in the area than in 2010. The emissions of CO, CO_2 and Aerosols MDO increase with approximately the same percentage. The emission of NO_x increases with nearly 1% and VOC with 2%, thus a little less than the increase in the number of ships. The largest changes are the 28% decrease of the emission of SO_2 and the 24% decrease in the emissions of Aerosols HFO, which is the result of the reduced sulphur content of the fuel.

Table 9-1 Emissions at sea in OSPAR region II for 2011, based on SAMSON

Nr	Substance	Emission in ton in 2011			Emission in 2011 as percentage of 2010		
		Moving		Total	moving		Total
		Auxiliary Engine	Main Engine		Auxiliary Engine	Main Engine	
1237	VOC	1,091	11,168	12,260	109.3%	101.4%	102.0%
4001	SO_2	11,070	111,148	122,218	76.5%	72.1%	72.4%
4013	NO_x	37,232	429,566	466,798	104.6%	100.5%	100.8%
4031	CO	7,111	68,424	75,535	111.9%	106.5%	107.0%
4032	CO_2	2,178,117	18,221,461	20,399,577	113.3%	105.2%	106.0%
6601	Aerosols MDO	1,829	415	2,244	106.7%	99.3%	105.2%
6602	Aerosols HFO	0	19,002	19,002		76.0%	76.0%
6598	Aerosols MDO+HFO	1,829	19,417	21,246	106.7%	76.4%	78.3%
Average number of ships in area		965.36			105.4%		

Table 9-2 contains the emissions at sea for the total OSPAR region II based on the database with the added ferry movements. The table shows that the emissions of ferries are relatively high. The added ferries represent 2.4% of the ships at sea and 5 to 6% of the emissions.

Table 9-2 Emissions of added ferries in OSPAR region II

Nr	Substance	Emission in ton in 2011			Emission of ferries as percentage of all ships in 2011		
		Moving		Total	moving		Total
		Auxiliary Engine	Main Engine		Auxiliary Engine	Main Engine	
1237	VOC	42	735	778	3.7%	6.2%	6.0%
4001	SO_2	274	6,763	7,038	2.4%	5.7%	5.4%
4013	NO_x	1,197	22,724	23,922	3.1%	5.0%	4.9%
4031	CO	220	4,228	4,449	3.0%	5.8%	5.6%
4032	CO_2	64,257	1,091,436	1,155,692	2.9%	5.7%	5.4%
6601	Aerosols MDO	48	12	61	2.6%	2.9%	2.6%
6602	Aerosols HFO	0	1,196	1,196		5.9%	5.9%
6598	Aerosols MDO+HFO	19	1,127,096	1,193,135	0.0%	5.6%	5.4%
Average number of ships in area		18.62			2.4%		

9.2 Comparison of the emissions at the NCS based on AIS and SAMSON

Table 9-3 contains the emissions for 2011 at the NCS based on the SAMSON database. The emissions at the NCS amount to approximately 18.6% of the emissions in the OSPAR region II, whereas the number of ships at the NCS is only 17.6% (=169.57/965.36). This is because an average ship at the NCS is larger than an average ship in OSPAR region II.

Table 9-3 Emissions at sea at the NCS for 2011, based on SAMSON

Nr	Substance	Emission in ton in 2011			Emission in 2011 as percentage of 2010		
		Moving		Total	moving		Total
		Auxiliary Engine	Main Engine		Auxiliary Engine	Main Engine	
1237	VOC	200	2,097	2,297	110.4%	102.6%	103.2%
4001	SO_2	2,041	20,833	22,873	76.6%	72.2%	72.6%
4013	NO_x	6,826	81,355	88,182	105.4%	101.1%	101.4%
4031	CO	1,305	12,986	14,291	112.4%	108.0%	108.4%
4032	CO_2	399,996	3,395,709	3,795,705	113.9%	105.2%	106.1%
6601	Aerosols MDO	337	70	407	106.9%	100.2%	105.7%
6602	Aerosols HFO	0	3,578	3,578		76.4%	76.4%
6598	Aerosols MDO+HFO	337	3,647	3,984	106.9%	76.8%	78.6%
Average number of ships in area		169.57			106.8%		

In Table 9-4 the NCS emissions based on SAMSON are compared with those based on AIS data. The results of both procedures correspond very well, which means that the SAMSON method is useful. However, the two methods are not completely independent because the average emission per nautical mile derived from the AIS data is used in the calculation of the emissions using the SAMSON database. Thus, the nice fit of the results means that the SAMSON traffic database fits well with the reality described by the AIS data. The differences in emissions between both methods are less than +1.2% with the exception of Aerosols MDO for which the emission based on SAMSON is 3.1% lower.

The average number of ships at the NCS based on SAMSON is 7.9% lower. The reason is that with AIS pilot tenders, tugs, service vessels and dredgers are registered that are not included in the route-bound database of SAMSON. If only the EMS ship types 1-8 are considered, the average number of ships at the NCS based on SAMSON amounts 158.3 while this is 159.5 based on AIS; these numbers are much closer to each other.

Table 9-4 Emissions of ships at the NCS at sea for 2011, based on SAMSON and AIS

Nr	Substance	Emission in ton in 2011 based on SAMSON			Emission based on SAMSON as percentage of emission based on AIS		
		Moving		Total	Moving		Total
		Auxiliary Engine	Main Engine		Auxiliary Engine	Main Engine	
1237	VOC	200	2,097	2,297	96.1%	100.3%	99.9%
4001	SO_2	2,041	20,833	22,873	97.9%	101.1%	100.8%
4013	NO_x	6,826	81,355	88,182	96.8%	101.6%	101.2%
4031	CO	1,305	12,986	14,291	96.9%	99.5%	99.3%
4032	CO_2	399,996	3,395,709	3,795,705	97.2%	101.1%	100.7%
6601	Aerosols MDO	337	70	407	97.2%	95.1%	96.9%
6602	Aerosols HFO	0	3,578	3,578		101.2%	101.2%
6598	Aerosols MDO+HFO	337	3,647	3,984	97.2%	101.1%	100.8%
Average number of ships in area		169.57			92.1%		

9.3 Emissions at sea and in port areas

Table 9-5 shows the emissions for the total OSPAR region II both at sea and in the port areas. These are based on the following data:

- At sea and added ferries: SAMSON
- Dutch port areas and foreign ports leading to the Western Scheldt and Ems: AIS data;
- Other foreign ports: LLI data .

The emissions of the added ferries amount to 5 - 6% of the total emissions at sea.

Appendix C gives the emissions at berth for all ports in OSPAR region II with CO_2 emission over 10,000 ton based on the GT.hours. The database for foreign ports contains the emissions for sailing and at berth for all foreign ports without restriction on CO_2 emission.

Table 9-5 Total emission of ships in the OSPAR region II for 2011 (in ton)

nr	Substance	at sea, including added ferries	Moving in port area	at berth	Total	fraction of emissions by fishing on the total
1237	VOC	13,037	1,078	1,172	15,287	0.35%
4001	SO_2	129,255	8,608	2,530	140,393	0.19%
4013	NO_X	490,720	32,698	26,012	549,430	0.23%
4031	CO	79,984	7,504	5,645	93,132	0.35%
4032	CO_2	21,555,270	1,487,187	2,721,008	25,763,465	0.25%
6601	Aerosols MDO	2,305	303	624	3,232	0.68%
6602	Aerosols HFO	20,199	1,229	0	21,427	0.13%
6598	Aerosols MDO+HFO	22,503	1,532	624	24,659	0.20%

Table 9-6 Total emission of ships in the OSPAR region II for 2011, expressed as a percentage of the 2010 emission

nr	Substance	at sea, including added ferries	Moving in port area	at berth	Total
1237	VOC	101.3%	111.9%	97.5%	101.7%
4001	SO_2	72.0%	79.9%	103.3%	72.8%
4013	NO_X	100.6%	110.7%	97.5%	101.0%
4031	CO	106.3%	114.8%	100.5%	106.6%
4032	CO_2	105.4%	116.3%	99.6%	105.3%
6601	Aerosols MDO	105.8%	111.8%	98.3%	104.8%
6602	Aerosols HFO	76.5%	86.3%		77.0%
6598	Aerosols MDO+HFO	78.8%	90.4%	98.3%	79.8%

Table 9-6 gives the comparison with 2010. The last column presents the relative contribution by fishing vessels. These fishing vessels are coded with EMS type 11 and can be deselected or replaced by emissions known from other sources, because data for this vessel type are far from complete.

The emissions of CO, CO_2 and Aerosol MDO have increased with approximately 6%. For VOC the increase is 2% and for NO_X 1%. The emission of SO_2 and Aerosols HFO have decreased with 27% and 23% respectively, due to the assumed reduction of the fuel sulphur content.

Figure 9-1 contains the spatial distribution of the NO_x emission in OSPAR region II. Comparing the emission at the NCS in Figure 9-1 (based on the SAMSON traffic database) with the emission at the NCS in Figure 8-9 (based on AIS data), one sees that the emissions based on the SAMSON traffic database are more concentrated on the traffic lanes. This is because in the extrapolation it was assumed that all ships sail over the centre line of each shipping route. Furthermore, the emissions based on AIS contain more ships sailing outside the main routes, such as supply vessels and other work vessels.

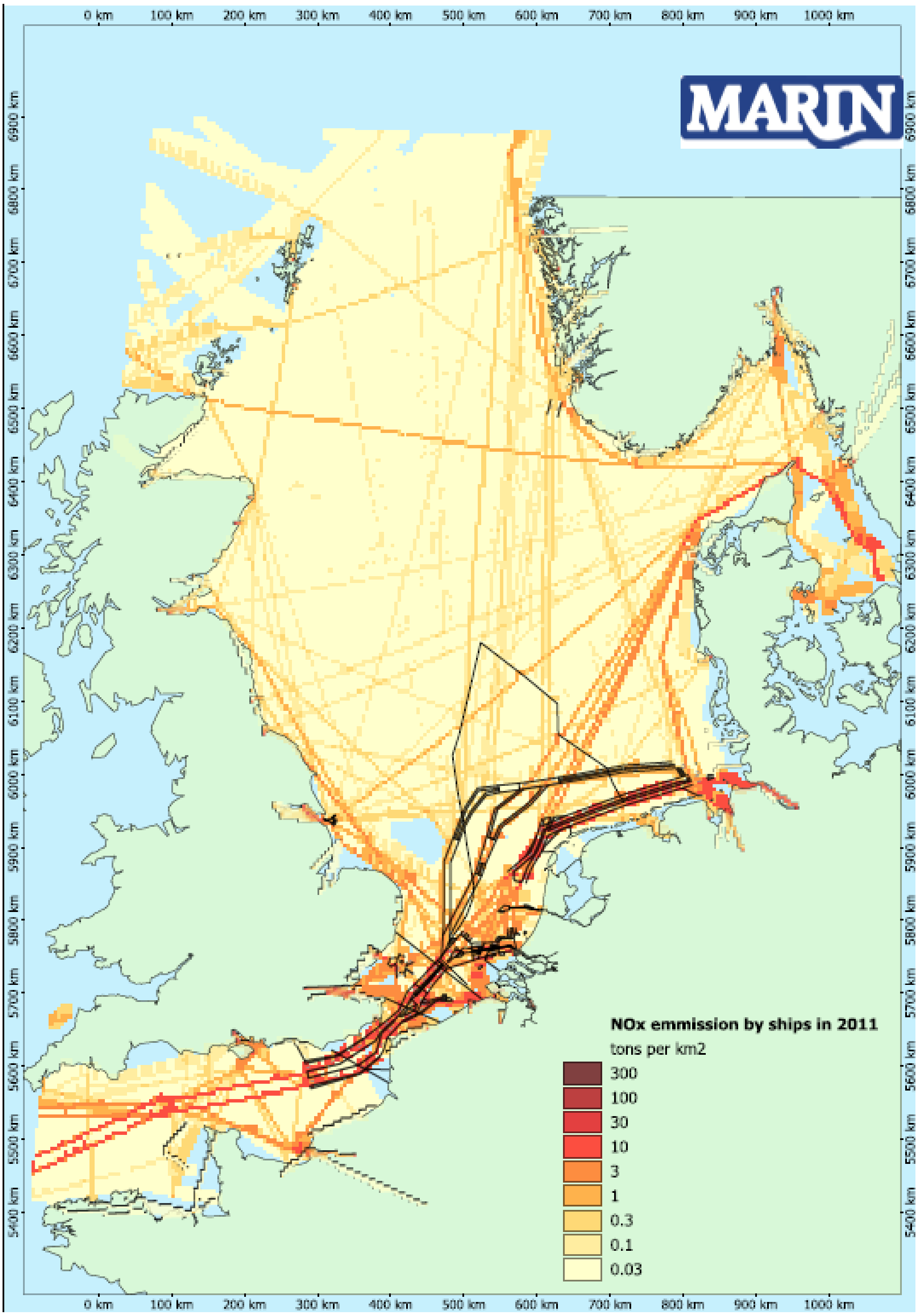

Figure 9-1 NO_x emission in OSPAR Region II at sea and in port areas by route bound ships

10 CONCLUSIONS AND RECOMMENDATIONS

The main delivery of this study is a set of databases containing gridded sea shipping emissions for at sea and in ports and for a number of substances. These emissions are distinguished into ship type and size. Where applicable the emissions are also distinguished into moving / not moving, EU / non-EU flag and inside/outside 12-miles zone. These databases can be used in studies for which a detailed spatial distribution of the emissions is required. The emissions by fishing vessels are far from complete. They can be identified in the databases and easily deselected when the information is not needed.

The conclusions and recommendations given below are based on both the calculated totals for (1) the NCS, (2) the Dutch port areas and (3) OSPAR region II including port areas, and on the findings during the execution of the study.

10.1 Conclusions and findings

The general conclusions are:

- AIS data is an excellent source for the determination of the spatial distribution of emissions by ships at the Netherlands Continental Shelf and in the Dutch port areas;

- The calculation based on AIS delivers the effect of all changes by:
  - an economic crisis, leading to less traffic and lower speeds;
  - new transport flows;
  - changes in use of ship types and ship sizes;
  - new ships with other emission factors;
  - measures, influencing the emissions factors;

- The average number of ships at the NCS based on AIS (184.1) is larger than the 169.6 ships based on SAMSON. With AIS more ships are observed, which is mainly due to the pilot tenders, tugs, service vessels and dredgers that are not included in the route-bound database of SAMSON. In case only the EMS ship types 1-8 are considered, the number of ships at the NCS based on SAMSON amounts 158.3 while this is 159.5 based on AIS; these numbers are nearly identical;

- Previous studies showed, that AIS coverage was weak in the shipping lane southwest of Rotterdam, close to the border with the United Kingdom Continental Shelf. This was reported in November 2010 to the Netherlands Coastguard after which measures were taken. In 2011 coverage was good up to September. However, the base station on the Euro platform has not functioned quite well during the last three months of 2011. This again was reported to the Netherlands Coastguard;

- The connection between MMSI numbers and ships in the ship characteristic database has been improved by using two additional sources, being the International Telecommunications Unit and the website of Marine Traffic. This has made it possible to identify and classify more than 99.5% of the relevant ships, i.e the ships for which the emissions have to be determined;

- The determination of emission factors has been improved for ships with multiple engines. To correct the emissions of previous years, correction factors were derived for each substance, EMS ship type and size class for both the port areas and at sea;

The conclusions with respect to the 2011 developments in shipping traffic and emissions are:

- In general, shipping traffic increased by 8.8% at the NCS. Part of this growth can be attributed to the recovery of the world economy. However, as 8.8% seems to be rather high, it is expected that a part of the increase is caused by an improvement in the quality and completeness of the AIS data;

- The combined effect of the change in sulphur content of marine fuels and changed load correction factors on emissions of the main engine for moving ships has been checked by using the new factors with the 2010 AIS data. The following approximate emission changes are the result of this combined effect:
    - VOC 0%
    - SO_2 -30%
    - NO_x 0%
    - CO 0%
    - CO_2 +2%
    - Aerosols MDO 0%
    - Aerosols HFO -20%

- The largest differences in port emissions between 2010 and 2011 are due to the previously mentioned changes in sulphur content, emission factors and load correction factors.

10.2 Recommendations

The group of AIS users is increasing over the years. Examples are the mandatory use by all fishing vessels above 15 m from June 2014 and the voluntary use by recreational vessels. For vessels that can be connected to the ship characteristics database this will cause a growth in the reported emissions that cannot be assigned to real changes in emissions of ships. This remains a point of attention in the future to prevent drawing wrong conclusions.

It is recommended to continue the emission calculations on a yearly basis. A longer sequence will give more insight in trends.

To perform the calculations well, the latest ship characteristics database (costs about GBP 4,000) has to be purchased. Otherwise ships built in the most recent year are missing, which means they cannot be dealt with correctly. Emission factors for the new database have to be determined by TNO.

The SAMSON database is based on the LLI database, containing all voyages crossing the European waters. This database costs approximately €30,000 for one year of data. Because of this, a new traffic database in SAMSON is only created every fourth or fifth

year. Changes in the traffic patterns in the intermediate years, for example caused by changes in the Traffic Separation Schemes or offshore wind farms, are implemented by rerouting the voyages of the last voyage database. Changes in traffic intensity can be implemented by deriving a correction factor from the AIS data.
It is recommended to keep an update frequency of once in every four years.

AIS data can be analysed to see whether it is possible to derive the uninterrupted time at berth. In this way, an adjusted emission factor can be used for ships that are laid up. At this moment, the emission factor for at berth is largely based on emissions from loading/unloading activities. This analysis will have a considerable impact on the amount of data to be collected and processed.

It is recommended to check the AIS coverage every time before the emissions are reported. This study and the ones carried out before have shown that variations do occur and have significant impact on the emissions calculated. In 2013, MARIN starts with an in depth investigation of the coverage of AIS. The purpose of this investigation is to quantify the spatial distribution of the quality and completeness of the AIS data. This can help in the future to apply correction factors for the emissions where necessary.

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APPENDIX A: EMISSION FACTORS

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A1 SAILING AND MANOEUVRING

A1.1 Main Engines

During sailing and manoeuvring, the main engine(s) are used to propel/manoeuvre the ship. Their emission factors per ship, in g per kWh, were determined by TNO according to the EMS protocols [1, 2]. An English language report [5] is available, which covers the emission calculations in accordance with the EMS protocols. In the emission factor calculation, the nominal engine power and speed are used. For this study these parameters were taken from the LLI database of October 2012. In the case that only one single main engine is present, it is assumed that a vessel requires 85% of its maximum continuous rating power (MCR) to attain the design speed (its service speed). When multiple main engines are present some more assumptions have to be made in order to calculate the required power of the main engines. This is described in the next paragraph A1.2.

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

Formula 1:

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

where:

EF’	Actual emission factor expressed as kg per nautical mile
EF	Basic engine emission factor expressed as kg per KWh (Table A- 3/Table A- 9)
CEF	Correction factors of basic engine emission factors (Table A- 10/Table A- 12)
P	Engine power [Watts]
*f*MCR	Actual fraction of the MCR
V	Actual vessel speed [knots]

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

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

Formula 2:

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

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

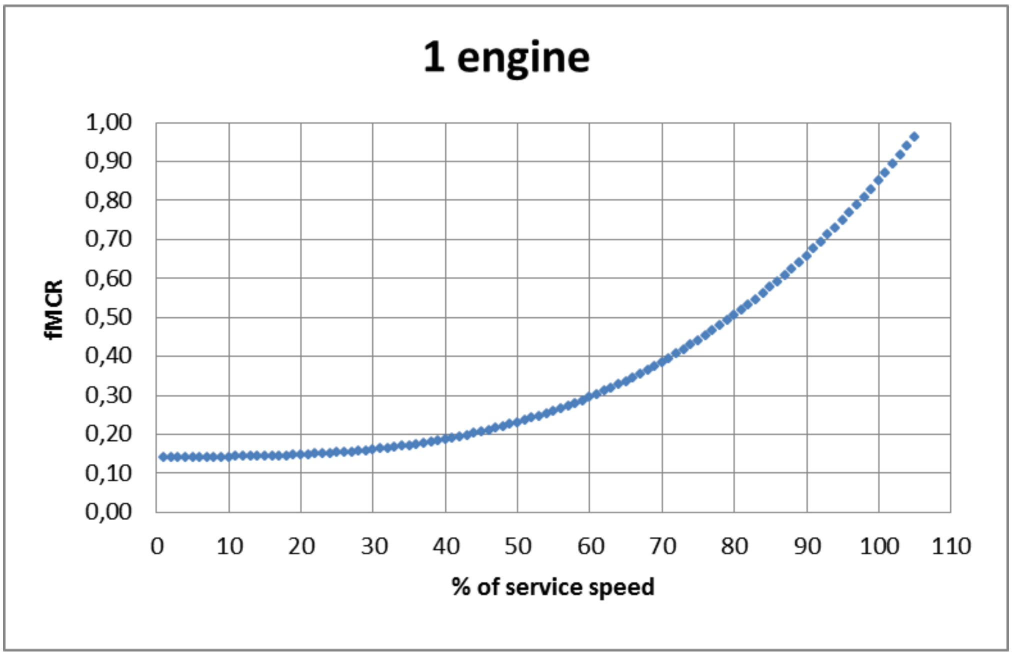

Figure A- 1 The relationship between service speed and fMCR at ships with one single propulsion engine used in emission calculations

A1.2 Multiple propulsion engines

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

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 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	97797	452,767	4.6	78.7%
2	22125	83,889	3.8	14.6%
3	820	4,684	5.7	0.8%
4	1746	25,717	14.7	4.5%
5	82	1,617	19.7	0.3%
6	146	4,719	32.3	0.8%
7	3	99	33.2	0.0%
8	29	1,268	43.7	0.2%
9	6	261	43.5	0.0%
10	1	3	3.0	0.0%
12	1	15	15.3	0.0%
	122,756	575,040	4.7	100.0%

As a data source for daily fuel usage of ships, the ship characteristic database-item FUEL_CONSUMPTION of the LLI database was analysed. Daily fuel consumption is given for only about 10.000 ships out of 122.000. By far most of these 10.000 ships are ships with a single main engine. In order to perform a check on the emission calculation, a check on the fuel consumption serves as a very good proxy. When fuel consumption is modelled properly, emission calculation probably will give results with comparable accuracy.

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

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

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

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

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

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

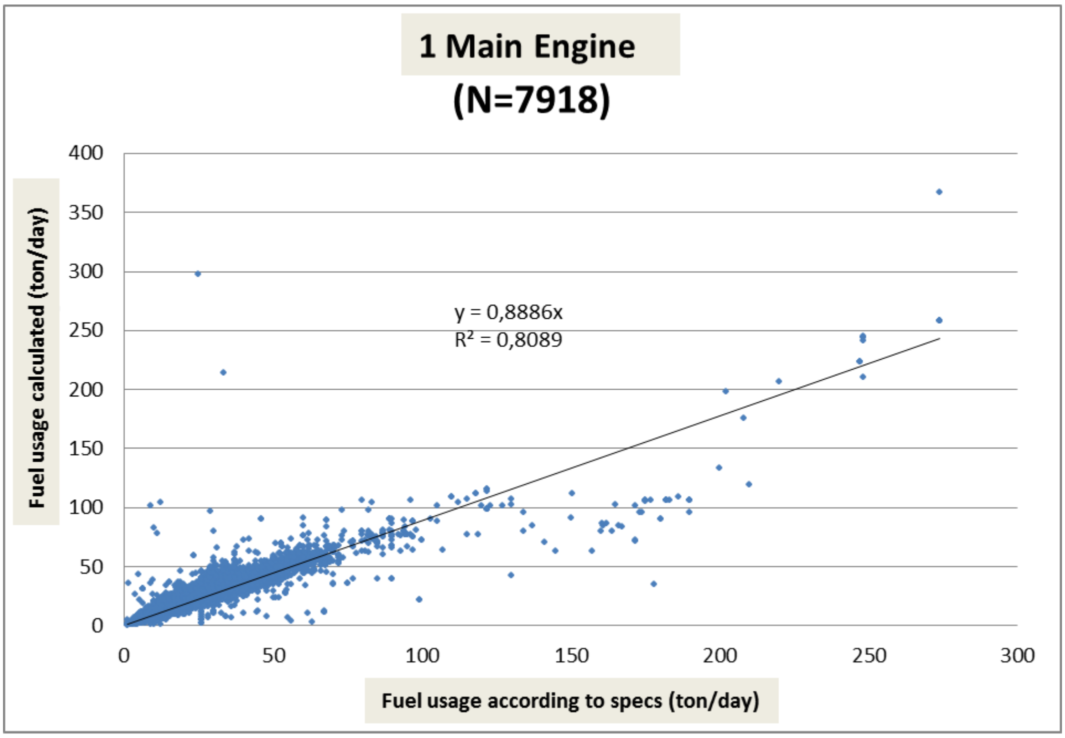

Figure A- 2 Calculated daily fuel usage of one engine ships compared with specifications

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

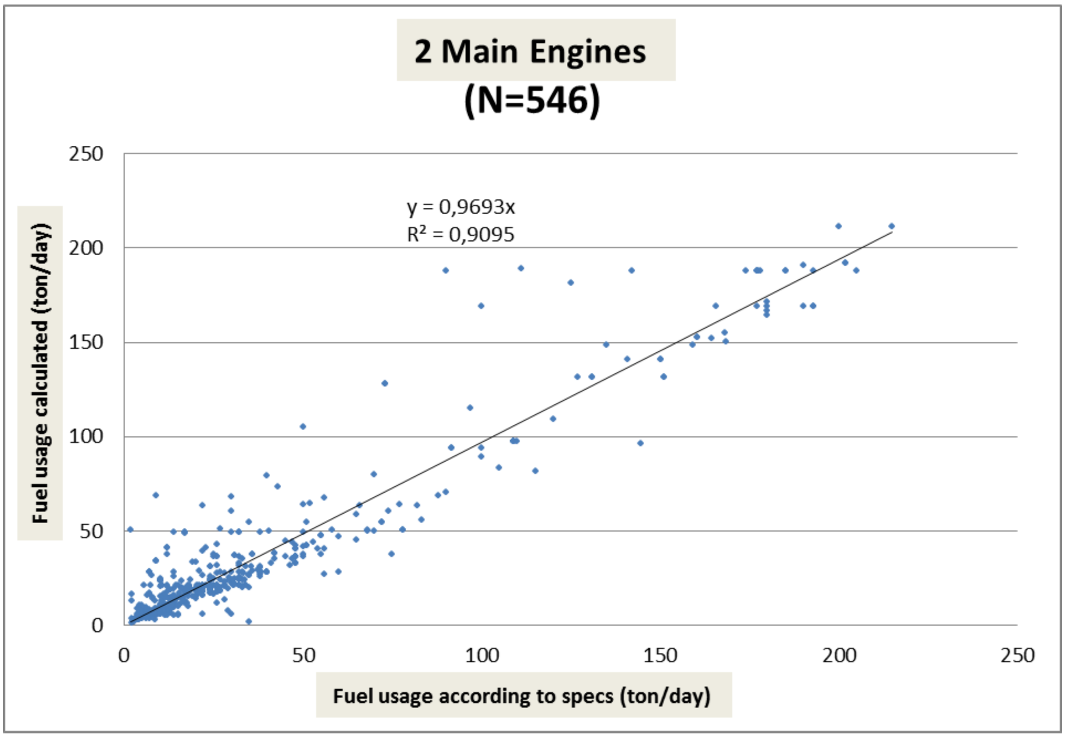

Figure A- 3 Calculated daily fuel usage of two engine ships compared with specifications

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

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

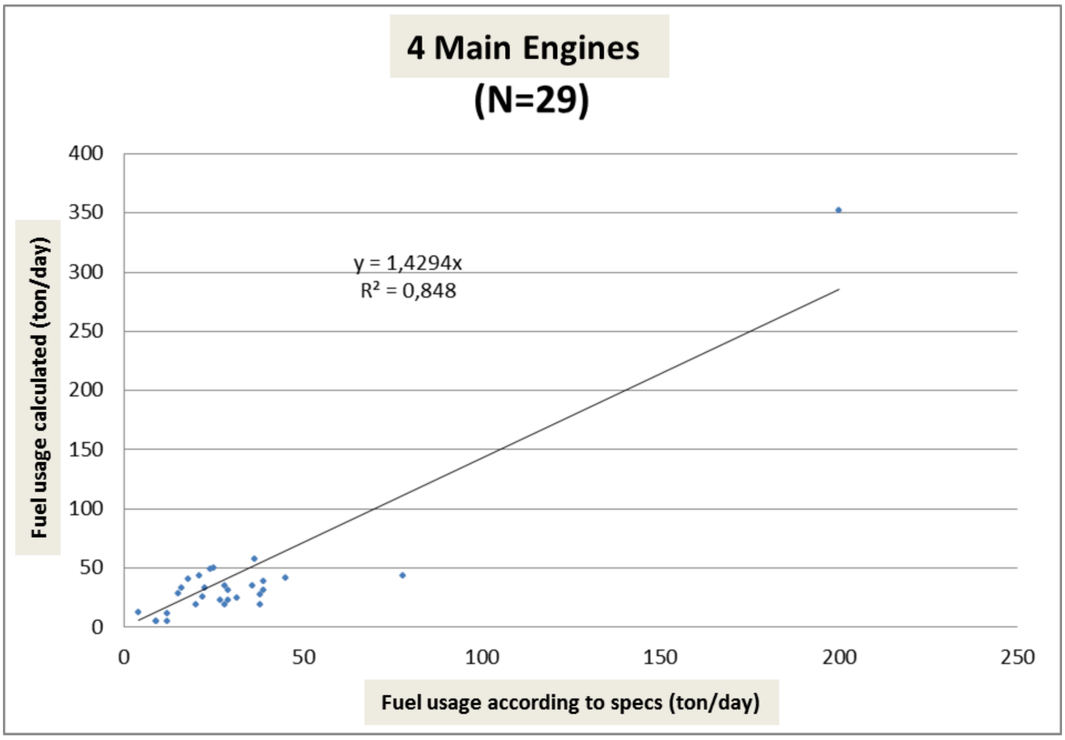

Figure A- 4 Calculated daily fuel usage of four engine ships compared with specifications

It can be argued that energy consumption of four engine ships seems to be overestimated by the assumptions that are applied but with such a small dataset it is hard to determine whether the assumptions on ships with four main engines are correct or not. Even if there is an overestimation this will probably not lead to big differences in total emissions, since the contribution of four engine ships in total installed power is below 5% (Table A- 1).

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

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

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

Ship type	Engines Present → / Engines Operational ↓	2	3	4	5	6	7	8	9	10	12
Oil tanker	2	0.75	0.85								
	4			0.75	0.75	0.75					
Chem.+ Gas tanker	2	0.75	0.85								
	4			0.75	0.75						
Bulk carrier	2	0.75	0.85								
	4			0.75							
Container ship	2	0.75	0.85								
	4			0.75		0.75					
	6								0.75		
General Dry Cargo	2	0.75	0.85								
	4			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									
	4			0.75							
Passenger	2	0.75	0.85								
	4			0.75	0.75	0.75	0.75	0.75			
	6								0.75	0.75	
Miscellaneous	2	0.5	0.85	0.75	0.75	0.75	0.75	0.75	0.75		0.75
Tug/Supply	2	0.5	0.85	0.75	0.75	0.75	0.75				
Fishing	2	0.5	0.85	0.75		0.75			0.75		
Non Merchant	2	0.5	0.85	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-1/-7)
CEF Correction factors of basic engine emission factors (table-A-8/-10)
NoEA Number of active engines (engines that actually are working on a certain moment)
P Engine power of one single engine [Watts]
*f*MCR Actual fraction the MCR of active engines
V Actual vessel speed [knots]

Formula 4:

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

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

Formula 5:

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

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

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

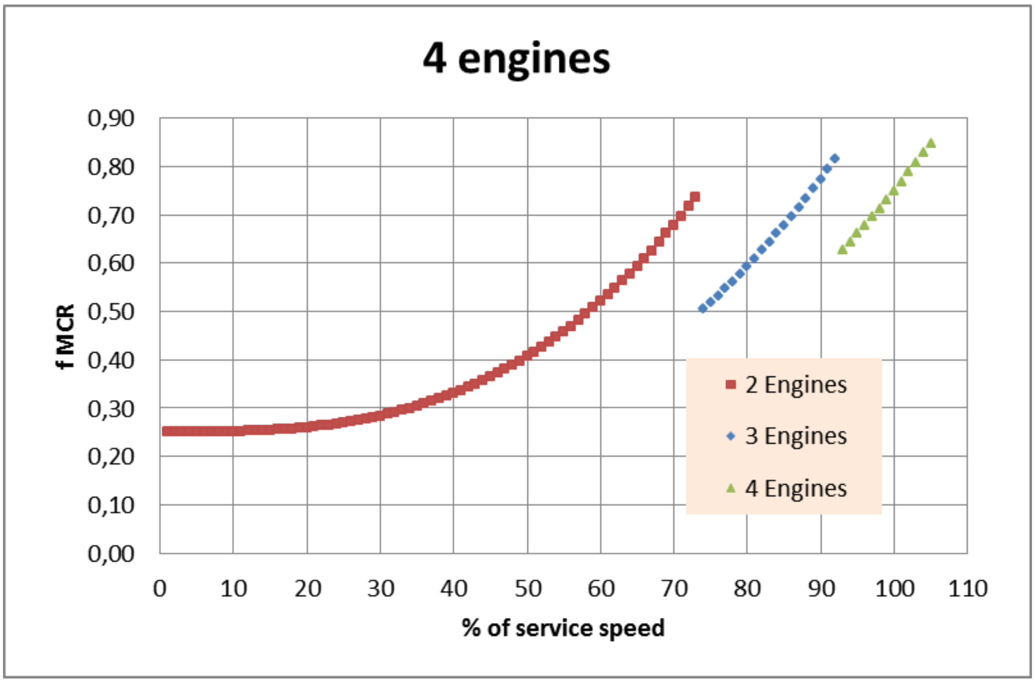

Figure A- 5 The relationship between service speed and fMCR at ships with four propulsion engines as used in emission calculations (formula 4 and 5)

A1.3 Auxiliary Engines and Equipment

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

A1.4 Engine Emission Factor

Table A- **3** to Table A- **9** 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). Full implementation of the SECA according to the MARPOL Annex VI in 2011 has been assumed because the supplementary reduction on the sulphur content already was obliged per July 2010. As a consequence, the sulphur percentage in heavy fuel oil is set on 1.0% and the sulphur percentage in marine diesel oil is assumed to be 0.5%. Linear relations exist between SFOC and SO2 and CO2 depending on fuel quality. SFOC values as such are not used in emission calculations.
PM-reduction is associated with sulphur reduction because a certain fraction of oxidised sulphur is emitted as sulphuric acid which easily condenses to sulphuric acid particles (PM) in exhaust gases. Based on the sulphur reductions additional PM reductions were estimated applying a linear relationship between sulphur and PM as demonstrated in [12].

Table A- 3 Emission factors and specific fuel oil consumption (SFOC) applied on slow speed engines (SP) operated on heavy fuel oil (HFO), (g/kWh)

Year of build	NO_x	PM	SO_2	VOC	CO	CO_2	SFOC
1900 – 1973	16	0.8	4.2	0.6	3	666	210
1974 – 1979	18	0.8	4	0.6	3	635	200
1980 – 1984	19	0.8	3.8	0.6	3	603	190
1985 – 1989	20	0.8	3.6	0.6	2.5	571	180
1990 – 1994	18	0.8	3.5	0.5	2	555	175
1995 – 1999	15	0.6	3.4	0.4	2	539	170
2000 – 2010	~rpm[2]	0.6	3.36	0.3	2	533	168
2011 – 2015		0.6	3.3	0.3	2	524	165

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

Year of build	NO_x	PM	SO_2	VOC	CO	CO_2	SFOC
1900 - 1973	16	0.5	2.1	0.6	3	666	210
1974 - 1979	18	0.5	2	0.6	3	635	200
1980 - 1984	19	0.5	1.9	0.6	3	603	190
1985 – 1989	20	0.5	1.8	0.6	2.5	571	180
1990 – 1994	18	0.4	1.75	0.5	2	555	175
1995 – 1999	15	0.3	1.7	0.4	2	539	170
2000 – 2010	~rpm[1]	0.3	1.68	0.3	2	533	168
2011 – 2015		0.3	1.65	0.3	2	523	165

[2] Dependant on revolutions per minute (Table A-7)

Table A- 5 Emission factors and specific fuel oil consumption (SFOC) applied on medium/high speed engines (MS) operated on Heavy fuel oil (HFO), (g/kWh)

Year of build	NO_x	PM	SO_2	VOC	CO	CO_2	SFOC
1900 – 1973	12	0.7	4.5	0.6	3	714	225
1974 – 1979	14	0.7	4.3	0.6	3	682	215
1980 – 1984	15	0.7	4.1	0.6	3	651	205
1985 – 1989	16	0.7	3.9	0.6	2.5	619	195
1990 – 1994	14	0.7	3.8	0.5	2	603	190
1995 – 1999	11	0.65	3.7	0.4	2	587	185
2000 – 2010	~rpm[1] 9[2]	0.65	3.66	0.3	2	581	183
2011 - 2015	~rpm 7[2]	0.65	3.6	0.3	2	571	180

[2] applied on auxiliary engines only

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

Year of build	NO_X	PM	SO_2	VOC	CO	CO_2	SFOC
1900 - 1973	12	0.5	2.25	0.6	3	714	225
1974 - 1979	14	0.5	2.15	0.6	3	682	215
1980 - 1984	15	0.5	2.05	0.6	3	650	205
1985 - 1989	16	0.5	1.95	0.6	2.5	619	195
1990 - 1994	14	0.4	1.9	0.5	2	603	190
1995 - 1999	11	0.3	1.85	0.4	2	587	185
2000 - 2010	~rpm[1] 9[2]	0.3	1.83	0.3	2	581	183
2011 - 2015	~rpm[1] 7[2]	0.3	1.8	0.3	2	571	180

[2] applied on auxiliary engines only

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

Table A- 7 Emission factors and specific fuel oil consumption (SFOC) of gas turbines (TB) operated on marine diesel oil (MDO), (g/kWh)

Fuel	NO_X	PM	SO_2	VOC	CO	CO_2	SFOC
MDO	5.7	0.146	3.1	0.1	0.32	984	310

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

Table A- 8 Emission factors and specific fuel oil consumption (SFOC) of steam turbines (ST) operated on heavy fuel oil (HFO) and boil-off gas (BOG), (g/kWh)

Fuel	NO_X	PM	SO_2	VOC	CO	CO_2	SFOC
HFO	2.0	0.59	6.1	0.10	0.15	971	306
BOG	1.94	0.0	0.0	0.045	0.06	688	270
Operational average	1.96	0.21	1.94	0.065	0.091	783	

The operational average emission factor of steam turbines, which was applied in calculations, was estimated by assuming that on average 64% of energy consumed by LNG ships is boil off gas. The value of 64% was estimated by the share of CO_2 emissions of 56% for 21 LNG ships measured one year round by Shell [7].

Table A- 9 Emission factors of NO_X dependant on engines RPM

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

A1.5 Correction factors of engine Emission Factors

At speeds around the design speed, the emissions are directly proportional to the engine’s energy consumption. However, in light load conditions, the engine runs less efficiently. This phenomenon leads to a relative increase in emissions compared to the normal operating conditions. Depending on the engine load, correction factors specified per substance can be adopted according to the EMS protocols. The correction factors were extended by distinction of different engine types in order to get more accurate calculations. Three engine groups were discerned: reciprocating engines, steam turbines and gas turbines.
The correction factors used are shown in Table A- **10** to Table A- **12** The list was extended by some values provided in the documentation of the EXTREMIS model [4].

Table A- 10 Correction factors for reciprocating diesel engines

Power % of MCR	CO_2, SO_2 SP	CO_2, SO_2 MS	NO_X	PM	VOC	CO
10	1.2	1.21	1.34	1.63	4.46	5.22
15	1.15	1.18	1.17	1.32	2.74	3.51
20	1.1	1.15	1.1	1.19	2.02	2.66
25	1.07	1.13	1.06	1.12	1.65	2.14
30	1.06	1.11	1.04	1.08	1.42	1.8
35	1.05	1.09	1.03	1.05	1.27	1.56
40	1.045	1.07	1.02	1.03	1.16	1.38
45	1.035	1.05	1.01	1.01	1.09	1.23
50	1.03	1.04	1.00	1.01	1.03	1.12
55	1.025	1.03	1.00	1.00	1.00	1.06
60	1.015	1.02	0.99	1.00	0.98	1.00
65	1.01	1.01	0.99	0.99	0.95	0.94
70	1.00	1.01	0.98	0.99	0.92	0.88
75	1.00	1.00	0.98	0.98	0.89	0.82
80	1.01	1.00	0.97	0.98	0.87	0.76
85	1.02	1.00	0.97	0.97	0.84	0.7
90	1.03	1.01	0.97	0.97	0.85	0.7
95	1.04	1.02	0.97	0.97	0.86	0.7
100	1.05	1.02	0.97	0.97	0.87	0.7

The correction factors for CO_2 en SO_2 are assumed to be equal. These newly added factors for CO_2 en SO_2 were derived from two recent publications [10] and [11] by taking interpolated values. A distinction was made for Slow-speed engines (referred as SP) and Medium and high-speed engines (referred as MS). Although correction factors for other substances may differ by engine type also, a numerical distinction was not possible so far.

Since steam turbines are predominantly used by LNG-carriers two types of fuels were assumed to be consumed: Boil-off Gas (BOG) and HFO. It was assumed that at lower engine loads (below 30%) engines are mainly operated by HFO. This is expressed in the correction factors for SO_2 and CO_2. On higher loads (above 30%) the average fuel mixture between BOG and HFO is assumed. The source of the correction factors of steam turbines was taken from the EXTREMIS model [4].

Table A- 11 Correction factors for steam turbines

Power % of MCR	CO_2	SO_2	NO_X	PM	VOC	CO
10	1.4	3.04	0.3	3	5.44	11.65
15	1.4	3.04	0.34	2.8	5.11	10.83
20	1.4	3.04	0.37	2.8	4.72	9.96
25	1.4	3.04	0.41	2.8	4.39	9.09
30	1.2	2.02	0.44	1.5	4.00	8.26
35	1.00	1.00	0.47	1.00	3.61	7.39
40	1.00	1.00	0.51	1.00	3.28	6.57
45	1.00	1.00	0.54	1.00	2.89	5.7
50	1.00	1.00	0.57	1.00	2.56	4.83
55	1.00	1.00	0.61	1.00	2.17	4
60	1.00	1.00	0.64	1.00	1.83	3.13
65	1.00	1.00	0.68	1.00	1.44	2.26
70	1.00	1.00	0.76	1.00	1.33	1.96
75	1.00	1.00	0.84	1.00	1.22	1.65
80	1.00	1.00	0.92	1.00	1.11	1.30
85	1.00	1.00	1.00	1.00	1.00	1.00
90	1.00	1.00	1.00	1.00	1.00	1.00
95	1.00	1.00	1.00	1.00	1.00	1.00
100	1.00	1.00	1.00	1.00	1.00	1.00

Correction factors for gas turbines were estimated with data from the ICAO Aircraft Engine Emissions Databank [7]. The emission behaviour of the GE CF6-6D (marine derivative: GE LM2500) and the Allison 501 (AN 501) was taken as representative for the two most occurring gas turbines in marine applications. CEF values in low power ranges have been changed for the 2011 calculation because an adapted interpolation scheme has been applied.

Table A- 12 Correction factors for gas turbines

Power % of MCR	CO_2, SO_2	NO_X	PM	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. This amount of fuel was specified for different fuel types, and the engine or boiler in which this fuel is used in accordance to the specification given in the EMS-protocol [2].

Table A- 13 Fuel rate of ships at berth, (kg/1000 GT.hour)

Ship type	Fuel rate
Bulk carrier	2.4
Container ship	5
General Cargo	5.4
Passenger	6.9
RoRo Cargo	6.9
Oil Tanker	19.3
Other Tanker	17.5
Fishing	9.2
Reefer	24.6
Other	9.2
Tug/Supply	9.2

Table A- 14 specifies total fuel use over fuel types in dependence of ship types.

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 may be used in harbours. The specification of fuel types at berth is adapted according to this new regulation.

Table A- 14 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- 15 gives figures about allocation of fuel amount over engine types and apparatus during berth.

Table A- 15 Allocation of fuels usage in engine types and apparatus per ship type (%)

Ship type	Main Engine (SP)	Main Engine (MS)	Power (MS)	Boiler
Bulk carrier	0	0	64	36
Container ship	0	0	46	54
General Cargo	0	0	67	33
Passenger	0	18	49	32
RoRo Cargo	0	18	49	32
Oil Tanker	12	6	19	63
Other Tanker	0	12	15	73
Fishing	25	0	74	1
Reefer	18	0	61	21
Other	25	0	74	1
Tug/Supply	25	0	74	1

In following tables, Table A- 16 to Table A- 18, the emission factors used for emissions at berth are presented.

Table A- 16 Emission factors of medium/high speed engines (MS) at berth, (g/kg fuel)

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

Table A- 17 Emission factors of slow speed engines (SP) at berth, (g/kg fuel)

Year of build	NO_X	PM	VOC	CO
Fuel	all	MGO/ULMF	all	all
1900 – 1973	76	1.6	2.9	14
1974 – 1979	90	1.7	3.0	15
1980 – 1984	100	1.8	3.2	16
1985 - 1989	111	2.0	3.3	14
1990 - 1994	103	1.5	2.9	11
1995 - 1999	88	1.0	2.4	12
2000 - 2010	71.4	1.0	1.8	12
2011 – 2015	60.0	1.0	1.8	12

Table A- 18 Emission factors of boilers of boilers at berth, (g/kg fuel)

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

Table A- 19 Emission factors of all engines and apparatus, (g/kg fuel)

Fuel	SO_2	CO_2
MGO/ULMF	4	3150

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

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

In order to select the appropriate emission factors of an individual ship (or to calculate the emission factor per mile sailed) it is necessary to know the characteristics of the ship, as well as its engines and fuel use.
To select engine emission factors (EF) according to the EMS-protocol [1], the following engine and fuel characteristics are required:

- Engines year of build (grouped in classes)
- Engine type (slow speed or medium/high speed)
- Engines maximum revolutions per minute (RPM), from 2000 year of build
- Type of fuel used (Heavy Fuel Oil or Marine Diesel Oil)

In the next section the procedure which has been used to complete the necessary data for the calculation of emission factors will be described for each individual ship.

The main engine power and design speed of a ship are also needed to calculate the actual emission factor. These data were elaborated upon from an extract of the ship characteristics database containing data for 122,756 individual ships. In this way, emission factors can be derived for almost any seagoing ship sailing the high seas.

A3.1 Year of Build of Main Engines

For 76,817 ships, the ship engine year of build was directly taken from the field “ENGINE_DOB” from the ship characteristics database. In 40,307 cases, the ship engine year of build was assumed to be equal to the ship year of build. For 5,632 cases, the ship engine year build was assumed to be the average of the ship type and/or a ship’s size.

Table A- 20 Method of assessment of engines year of build

Method of assessment	Number	Share
Directly taken from “ENGINE_DOB	76,817	62.6%
Directly taken from “BUILD”	40,307	32.8%
Average of ship type and/or Size	5,632	4.6%
Total	**122,756**	**100.0%**

The uncertainty in a ship engine year of build probably is not a major factor in overall uncertainty in ships emission factors.

A3.2 RPM of Diesel Engines

Diesel engines were classified in two classes: slow speed engines (SP) and medium to high speed engines (MS). Diesel engines with a maximum RPM of less than 500 were classified as slow speed (SP) engines, whereas all other diesel engines were classified as MS.
For 42% of ships, the maximum RPM was provided by the ship characteristics database. A good approximation of RPM was derived from most frequent occurring RPM in the “ENGINE_DESIGNATION” records for 18% of ships.
A rougher approximation was derived from the average engine RPM per ship type and/or ships size. Because bigger ships mostly operate slow speed engines it is

expected that an average RPM value derived from ships size still will result in a reasonable approximation especially when also the ship type is taken into account.

Table A- 21 Assessment method of ships diesel engines RPM

Method of assessment	Number	Share
Directly taken from "RPM"	52,030	42%
Most frequent occurring RPM derived from "ENGINE_DESIGNATION"	21,638	18%
Average of ship type and/or size	49,088	40%
Total	**122,756**	**100%**

A3.3 Engine types

Most ships are currently equipped with diesel engines. Engine speed or revolutions per minute (RPM) from diesel engines is an important property with respect to the emission characteristics as expressed by emission factors. **Table A- 22** gives a complete overview of all engine types, which were observed in the ship characteristics database. Diesel-electric propulsion is found increasingly in tugs, as this configuration is more efficient with a continuous fluctuation of power demand. Besides ships with diesel engines, there are a few hundreds of ships in service that are propelled by steam (engine or turbines). Also gas turbines are still used in non-military ships. The number of ships with gas turbines may rise in the near future as the thermal efficiency of gas turbines has been enhanced considerably and because some of the engines' flexibility may be attractive in some sectors (like cruise or passenger transport). In military battle ships, gas turbines are common practice. For all ships for which the field "ENGINE_TYPE" was not filled in the database it was assumed that these ships operate diesel engines. Considering the overwhelming number of diesel engines, the allocation of engine types will not introduce major errors in the assessment of emission factors.

Steam propulsion is rather common in LNG-ships because these engines are considered to be very safe and fluctuations in gas boil-off can more easily be absorbed by boilers independent of actual power demand. Recently, by-passes for these problems have been found and in the future more diesel engines will be introduced in LNG ships mainly because of the improved thermal engine efficiency of diesel engines.

A better assignment of engine types was achieved by combining information in the ship characteristics database. Considering the values in ENGINE_DESIGNATION it was decided that for some engines where ENGINE_TYPE was coded as "DSL" in fact the code had to be "GST". In the same manner for some engines where no data were given in ENGINE_TYPE it was decided that these engines were most probably steam turbines ("ST").
The distinction between "MS" and "SP" of diesel engines is based on RPM values as explained in paragraph A3.2.

Table A- 22 Engine types in the ship characteristics database

ENGINE_TYPE	ENGINE_TYPE_DECODE	Number	Engine type			
			MS	SP	ST	TB
STM	Steam	519			518	1
STT	Steam Turbine	3			3	
No data	No data	45,507	41,666	3,677	164	
DSE	Diesel Electric	248	222	26		
DSL	Diesel	76,375	36,482	39,882		11
ELC	Electric	19	18	1		
GST	Gas Turbine	85				85

A3.4 Power of Main Engines

Emission factors of ships are directly proportional to a ship's main engine power. Special attention was paid to the proper assessment of a ship's engine power. The ship characteristics database contains the power data of the main engines in most cases. However, it was found that internal inconsistency can exist sometimes between the data field "brake horse power" (BHP) and the data field "POWER_KW". After considering the data, it was deduced that the field "BHP" most probably gives the correct value for the ship main engine power. However, in a little more than 100 cases prevalence was given to the value of "POWER_KW" over "BHP". When the value of "BHP" was not available the value of "POWER_KW" was taken. In the case of no data for both fields, engine power was estimated by linear regression (power functions) per ship type against a ship's gross tonnage (GT), or averages per ship type and ship size class.

Table A- 23 Assessment method of main engine power

Method of assessment (kW)	Number	Share Number	Share Power
Directly via BHP * 0.746*)	87,727	71%	85.0%
Directly via POWER_KW	2,936	2%	4.7%
Via linear regression	28,764	23%	10.3%
Average of ship type and/or size	3,329	3%	0.01%
	122,756	**100%**	**100%**

*) 1 BHP (brake horse power) = 0.746 KW (kilowatt)

Parameters for the applied regression functions are given in Table A- 24. The resulting fitting functions which were created by means of the least squares approach, taking the mathematical from of:

$$\text{Power} = \text{Coefficient} \times \text{Gross}^n$$

Wherein:
Power : Calculated ships main engine power (kW)
Coefficient : Function parameter assessed by linear regression
Gross : Volume of the ship measured in Gross tonnage (GT)
n : Function parameter assessed by linear regression

Considering the R^2-coëfficiënts, it can be seen that the relationship between power and ship GT is rather strong for most ship types. However, for very heterogeneous ship types such as “Tug/Supply” and “Other”, moderate R^2-coëfficiënts indicate rather weak relationships between ship power and ship GT.

Table A- 24 Parameters used for calculation of main engine power in case of lack of data

Ship type	Coefficient	Power	R^2	N
Bulk carrier	17.4	0.6	0.79	7709
Container ship	1.04	0.97	0.93	4962
General Cargo	4.52	0.75	0.74	14844
Passenger	38.3	0.5	0.61	4286
RoRo Cargo	7.01	0.7	0.86	2898
Oil Tanker	9.05	0.66	0.91	7368
Other Tanker	14.4	0.63	0.9	5734
Fishing	15.7	0.64	0.68	9600
Reefer	2.19	0.9	0.89	1394
Tug/Supply	44	0.47	0.48	7506
Other	71.4	0.46	0.43	14969

It was discovered that ships that are equipped with multiple main engines in far most cases the value of BHP in the LLI-database contains the power of the individual engine. In the calculation scheme as presented in paragraph A1.2 this observation is applied.

A3.5 Power of Auxiliary Engines

Details on the power of installed auxiliary engines are only available in a minority of records within the ship characteristics database Furthermore, the information given about auxiliary engines is not always clear-cut. In some cases, the number of total auxiliary power is given together with the number of engines and in a few cases the number of engines is given together with individual power of one engine.

Table A- 25 Parameters used for calculation of auxiliary engine power in case of lack of data

Method of assessment	Number	Share %
Directly from ship characteristics database	29,133	23,7%
Derived from main engine power based on ratios within IMO-report	92,859	75,6%
10% of main engine power	764	0,7%
	122,756	100%

For just 24% of ships, a value of ship auxiliary engine power could be derived from the ship characteristics database. The completeness of data is rather poor in this situation. In order to cope with this situation, the best estimate available was taken as reported in the Buhaug et al. 2008 study [3]).

A3.6 Type of Fuel Used in Main Engines

Obtaining a confirmation from the ships characteristics database of the fuel type used by the main engines is rather complicated. Earlier versions of the database contained information about the type of fuel tanks (heated or not) that are present on a ship. This data is lacking in the current available database and in order to compensate, an algorithm was derived. Generally, it is assumed that large ships are guided by economic considerations and as such they use heavy fuel oil. Following Lloyds [3] we assumed that all ships with an engine power greater than 3.000 kW use heavy fuel oil. Also, ships with engines with more than 1.000 kW may use heavy fuel oil, especially when the engine speed is less than 2.500 RPM. As such, a limitation that the engine power minus 0.8 x RPM must be greater than 1000 was introduced. According to this formula a ship with 3,000 kW and 2,500 RPM will use MDO.

Table A- 26 Conditions for application of fuel types in dependence of Power and RPM at diesel engines

Power main engine and RPM	Fuel
Power <= 3000 kW : Power – 0.8 x RPM <= 1000	MDO
Power <= 3000 kW : Power – 0.8 x RPM > 1000	HFO
> 3000 kW all RPM	HFO

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APPENDIX B: SHIP TYPES

SAMSON SHIP TYPES TO EMS SHIP TYPES

SAMSON_shiptypes_to_EMS_shiptypes				
Samson type	**Ship**	**Main type**	**Main_ship_type _nr**	**EMS_type_upd**
1	OBO	OBO	1	3
2	OBO DH	OBO	1	3
3	CHEM IMO 1	Chemical	2	2
4	CHEM IMO 1 DH	Chemical	2	2
5	CHEM IMO 2	Chemical	2	2
6	CHEM IMO 2 DH	Chemical	2	2
7	CHEM IMO 3	Chemical	2	2
8	CHEM IMO 3 DH	Chemical	2	2
9	CHEM	Chemical	2	2
10	CHEM DH	Chemical	2	2
11	CHEM WWR	Chemical	2	2
12	CHEM WWR DH	Chemical	2	2
13	Oil crude oil	Oil	3	1
14	Oil crude oil DH	Oil	3	1
15	Oil product	Oil	3	1
16	Oil product DH	Oil	3	1
17	Oil remaining	Oil	3	1
18	Oil remaining DH	Oil	3	1
19	LNG	LNG	4	2
20	LPG refrigered	LPG	4	2
21	LPG semi pressured	LPG	4	2
22	LPG pressured	LPG	4	2
23	LPG remaining	LPG	4	2
24	BULKERS	Bulker	5	3
25	UNITISED container	Container	6	4
26	UNITISED roro	RoRo	7	6
27	UNITISED vehicle	RoRo	7	6
28	GDC dry cargo	GDC	8	5
29	GDC dry c./contain.	GDC	8	5
30	GDC reefer	GDC	9	7
31	Passenger	Pass/Ferry	10	8
32	Passenger Ro/Ro	Pass/Ferry	10	8
33	Ferries conventional	Pass/Ferry	10	8
34	Ferries HSF	Pass/Ferry	10	8
35	Miscellaneous	Miscellaneous	11	9
36	Tug/salvage	Tug/Supply	12	10
37	Fishing	Fishing	14	11
38	Supply	Tug/Supply	13	10
40	Non merchant	Non merchant	15	12
41	Offshore platform	AIS transponder on Offshore platform	16	In ports type 9 At sea not included

EMS_type_upd_decode	
EMS_type_upd	**EMS_type_upd_decode**
0	Unknown
1	Oil tanker
2	Chemical/LNG/LPG tanker
3	Bulk carrier
4	Container ship
5	General Dry Cargo
6	RoRo Cargo / Vehicle
7	Reefer
8	Passenger
9	Miscellaneous
10	Tug/Supply
11	Fishing
12	Non Merchant

APPENDIX C: EMISSIONS IN PORT AREAS BY SEA SHIPS AT BERTH

Emission in ton for 2011 by sea ships at berth for all OSPAR region II port areas (based on LLI voyage database). The table contains only the ports with more than 10,000 ton CO2 emission.

Port	VOC	SO_2	NO_x	CO	CO_2	Aerosols MDO+ HFO	Million GT.hours
Rotterdam	270	521	5,467	1,232	703,129	138	23,775
Antwerp	135	306	2,868	623	317,008	73	13,949
Hamburg	74	197	1,556	352	181,400	42	9,846
Amsterdam	61	104	1,188	270	159,981	30	4,642
Le Havre	56	126	1,139	259	144,783	30	5,559
Bremerhaven	56	157	1,284	281	125,826	33	6,724
Zeebrugge	53	127	1,203	258	115,106	29	4,959
Gothenburg	35	66	719	158	85,410	18	2,401
Immingham	29	56	610	133	69,076	15	2,771
Mongstad	24	36	469	107	68,556	12	1,183
Southampton	29	80	669	149	64,078	17	3,311
Aberdeen(GBR)	38	77	1,100	229	61,764	20	2,132
Fawley	21	31	407	93	59,776	10	1,024
Felixstowe	23	72	479	112	57,017	14	3,523
Dunkirk	20	43	431	96	49,935	11	2,838
Tees	20	36	433	95	49,856	10	1,647
Wilhelmshaven	18	28	363	82	49,367	9	1,038
Flushing	18	36	420	85	38,270	10	1,418
Ghent	15	31	320	69	32,605	8	1,787
Bergen	18	40	512	108	32,396	10	1,194
London	14	27	320	65	28,424	7	1,032
Oslo	12	33	298	68	27,752	7	1,231
Sullom Voe	10	15	204	45	27,442	5	452
Brofjorden	10	14	179	41	26,947	4	462
Rouen	11	22	243	52	24,838	6	1,124
Tilbury	10	27	236	50	21,493	6	1,307
Hound Point	8	12	156	35	20,982	4	345
Sture	8	11	154	34	20,794	4	343
Terneuzen	8	12	141	32	19,818	4	516
Slagen	7	10	127	29	18,709	3	319
Coryton	6	8	110	25	16,994	3	293
Ymuiden	9	19	232	45	15,310	5	1,136
Port Jerome	5	7	86	20	13,902	2	245
Hull	7	16	156	33	13,436	4	659
Harwich	6	16	161	35	13,089	4	570
Tyne	7	16	165	34	12,934	4	698
Emden	7	15	156	32	12,793	4	587
Esbjerg	8	15	207	40	12,768	4	502
Bremen	6	14	148	30	12,695	3	810
Grangemouth	4	6	77	18	11,869	2	260
Portsmouth	6	14	160	31	11,506	3	390
North Killingholme	6	14	142	29	11,026	3	507
Scapa Flow	4	6	74	17	10,003	2	182
Other	110	219	2,579	533	225,409	58	8,513
	1,299	2,738	28,148	6,163	3,096,273	685	118,206