SEA SHIPPING EMISSIONS 2010: NETHERLANDS CONTINENTAL SHELF, PORT AREAS AND OSPAR REGION II

Final Report

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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
Shipping database	This database contains vessel characteristics of more than 116,000 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 (Shipping Emission inventory and Monitoring)
IMO	International Maritime Organization
LLG	Lloyd's List Group (previously LMIU)
LLI	Lloyd's List Intelligence (previously LLG)
LMIU	Lloyd's Marine Intelligence Unit
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 allocations 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 makes large-scale background concentration maps of NO_x, PM, SO_2 and CO, and large-scale background deposition maps of NH_x and NO_x. Calculations are based on data from the Emission Register in the Netherlands [7]. 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 programmed 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 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 and 2009 based on AIS ([3] and [4]), and;
- the OSPAR region II for 2008 and 2009 based on the emissions at the NCS and the SAMSON traffic database ([3] and [4]).

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

MARIN also performed a study for the Netherlands Environmental Assessment Agency (PBL) to compare the emissions to air of seagoing vessels for 2009 calculated by MARIN with those calculated by the Entec method [5]. For that study, a method has been developed to estimate the emissions from foreign ports that are outside the AIS coverage. The method is based on the voyage database of Lloyd's List Intelligence (LLI) and has also been applied in this study.

1.4 Objective

This study aims to determine the emissions to air of seagoing vessels, excluding fishery, for 2010. 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 the SAMSON traffic database for the whole of the North Sea are used to determine the emissions for 2010 in the OSPAR region II area at sea and in the foreign ports. The grid size for the Dutch port areas is 500 x 500 m, for the other areas a grid size of 5000 x 5000 m has been used.

The emissions for 2010 are determined for VOC, SO_2, NO_x, CO, CO_2 and Particulate Matter (PM). A distinction will be made for ships sailing under EU-flag and non-EU flag, and for the NCP within or outside the 12-mile zone.

1.5 Report structure

Chapter 2 describes the emission databases that were delivered for 2010. Chapter 3 describes the procedure that was used for the emission calculation based on AIS data. Chapter 4 describes the completeness of the AIS data, both with respect to missing files and spots that are not fully covered by base stations. Chapter 5 summarises the emissions for 2010 for the Dutch port areas and the NCS and makes a comparison with 2009. Chapter 6 describes the procedure used for the emission calculations based on the SAMSON database. Chapter 7 summarises the 2010 emissions for OSPAR region II, both at sea and for the port areas. It also contains a comparison with 2009. Finally, Chapter 8 presents conclusions and recommendations.

2 2010 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.

This chapter contains information on the databases. It describes the basis of the traffic data, and the way to deselect fishing vessels from the different databases. Furthermore, it gives the grid size for the different areas and defines the different areas by figures.

The databases that result from this study 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.

The information can be used in studies for which a detailed spatial distribution of the emissions is necessary.

In the calculations for 2009 and 2010 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 because it is expected that the fractions PM2.5 and PM10 in the total aerosol emission differs between these fuel types. The fractions PM2.5 and PM10 are applied to the total aerosol emission when the data are read in 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 reported in:

- Emissions_2010_MARIN_NCP.mdb
- Emissions_2010_MARIN_Dutch_port_areas.mdb

As RIVM is interested in the emissions without fishing vessels, these have to be deselected before reading in the data. Information on vessel types in both databases can be found in the table EMS_type_upd_decode.

For the Western Scheldt the emissions in Belgium are not part of the database ‘Dutch Port areas’ but are included in the OSPAR region II database. In case of the Ems, however, the emissions in Germany are part of the Dutch port database. It is possible to deselect the German grid cells by using the table “cells_OK_unique_Germany”.

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 at sea 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 Belgium emissions in the Western Scheldt are not included in the database of the Dutch port areas, but in the port database of OSPAR region II);

The four port areas are illustrated in more detail in Figure 2-2 to Figure 2-5. In the outer west part of the port of Rotterdam in Figure 2-3, there are some red points on land. This is 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 implemented in the electronic chart. Also at other places there are some red points on land. In some cases this is caused by the detail of the chart, thus waterways and/or quays really exist. Also it has been observed that the determination of the GPS position is sometimes disturbed by container cranes, so that the AIS message is not fed with the correct position.

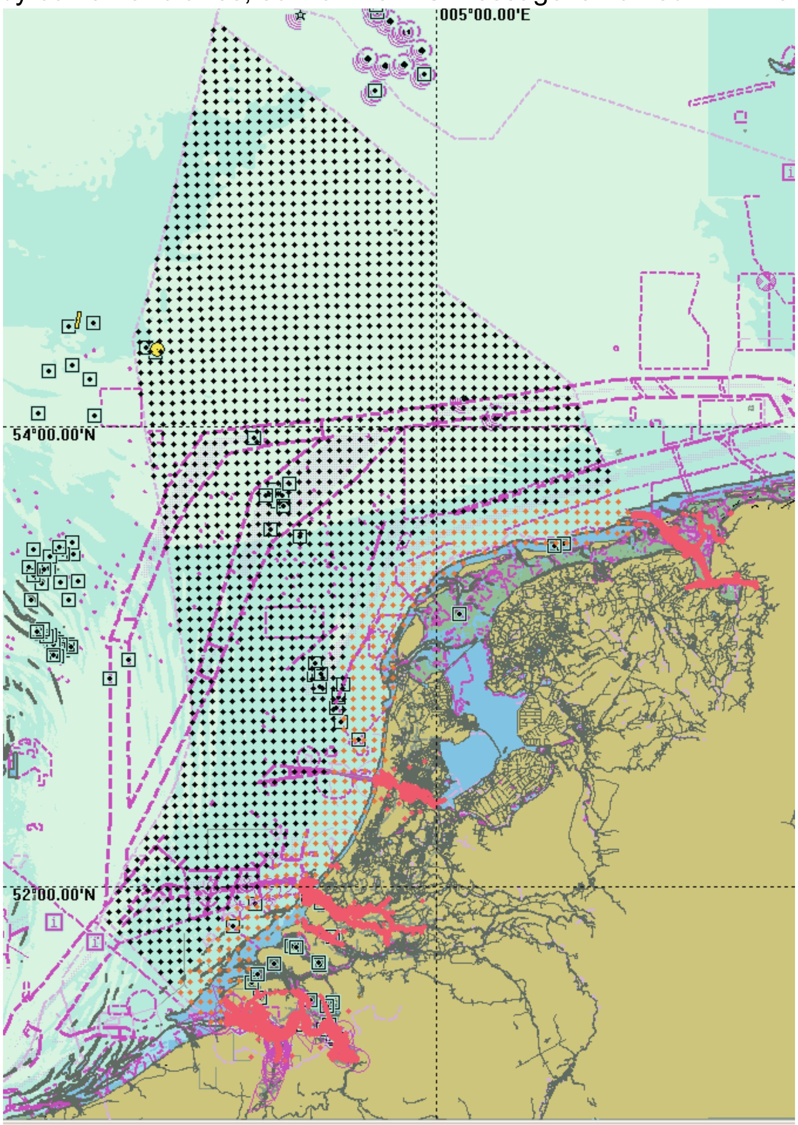

Figure 2-1 The Netherlands Continental Shelf with four port areas

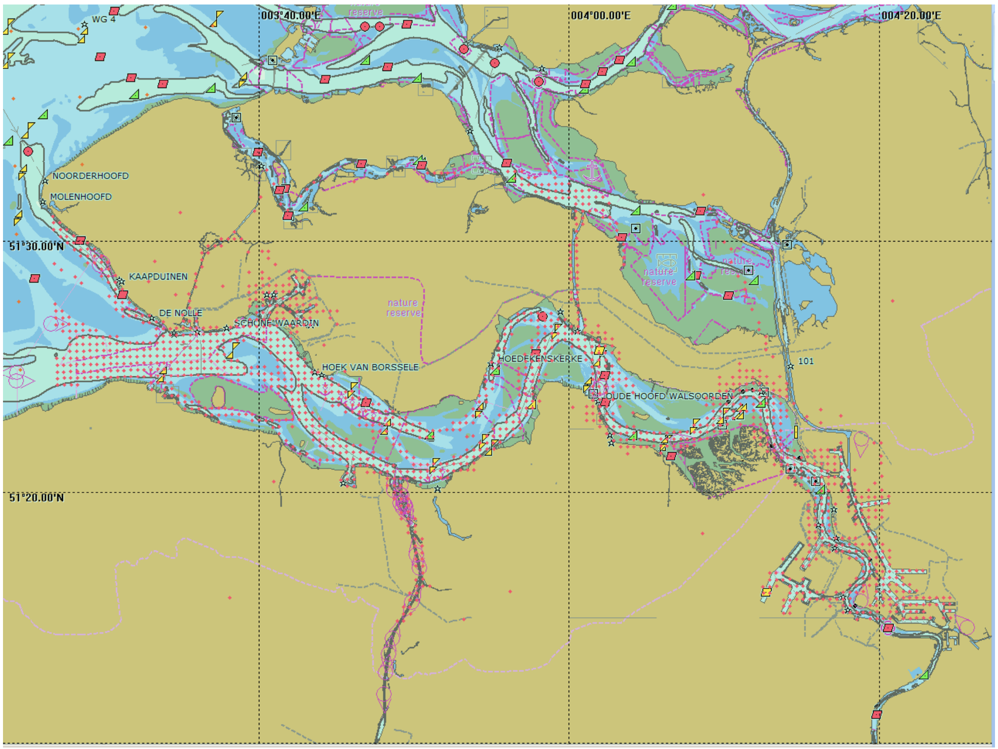

Figure 2-2 **Western Scheldt, emissions in red points have been included in databases. Note that Belgium emissions are only included in the database for the OSPAR region II port areas.**

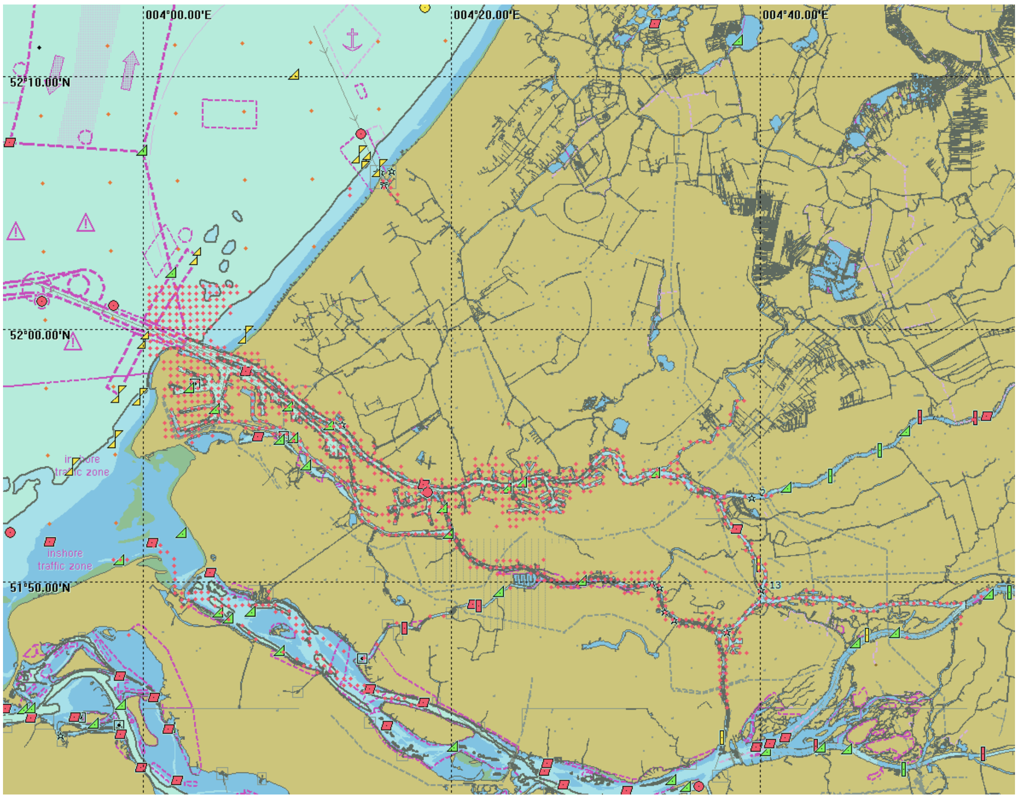

Figure 2-3 **Rotterdam, emissions in red points have been included in databases**

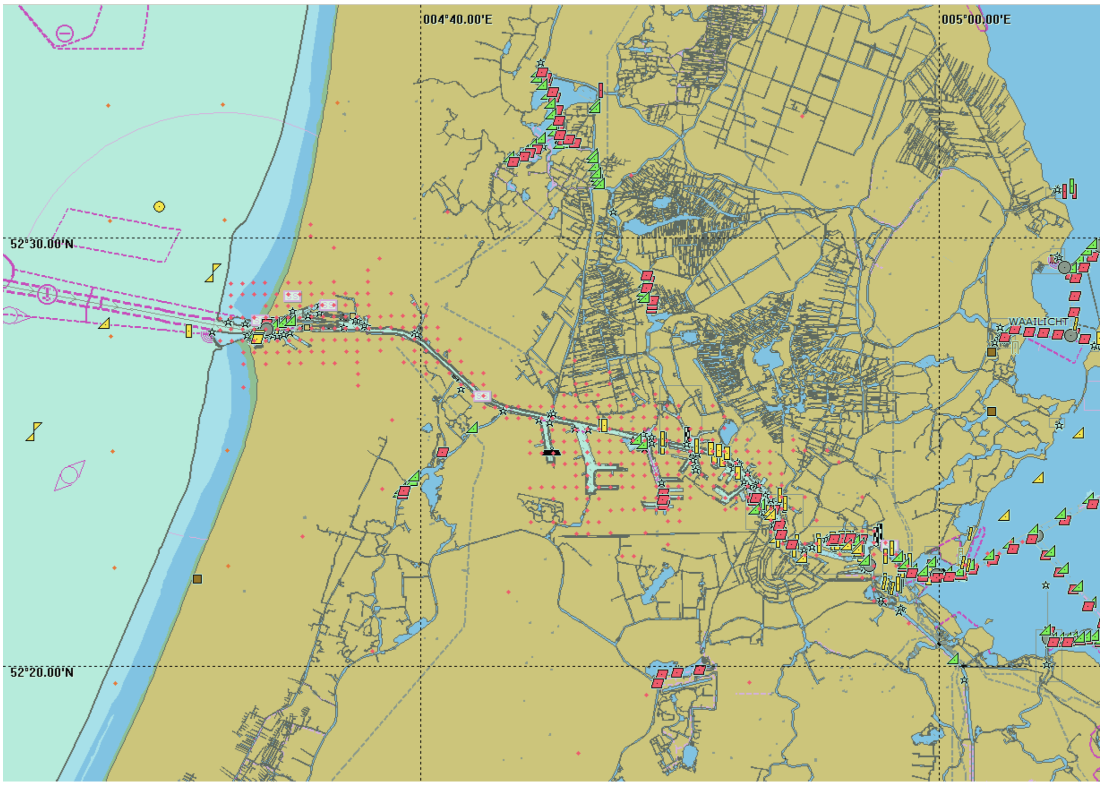

Figure 2-4 **Amsterdam, emissions in red points have been included in databases**

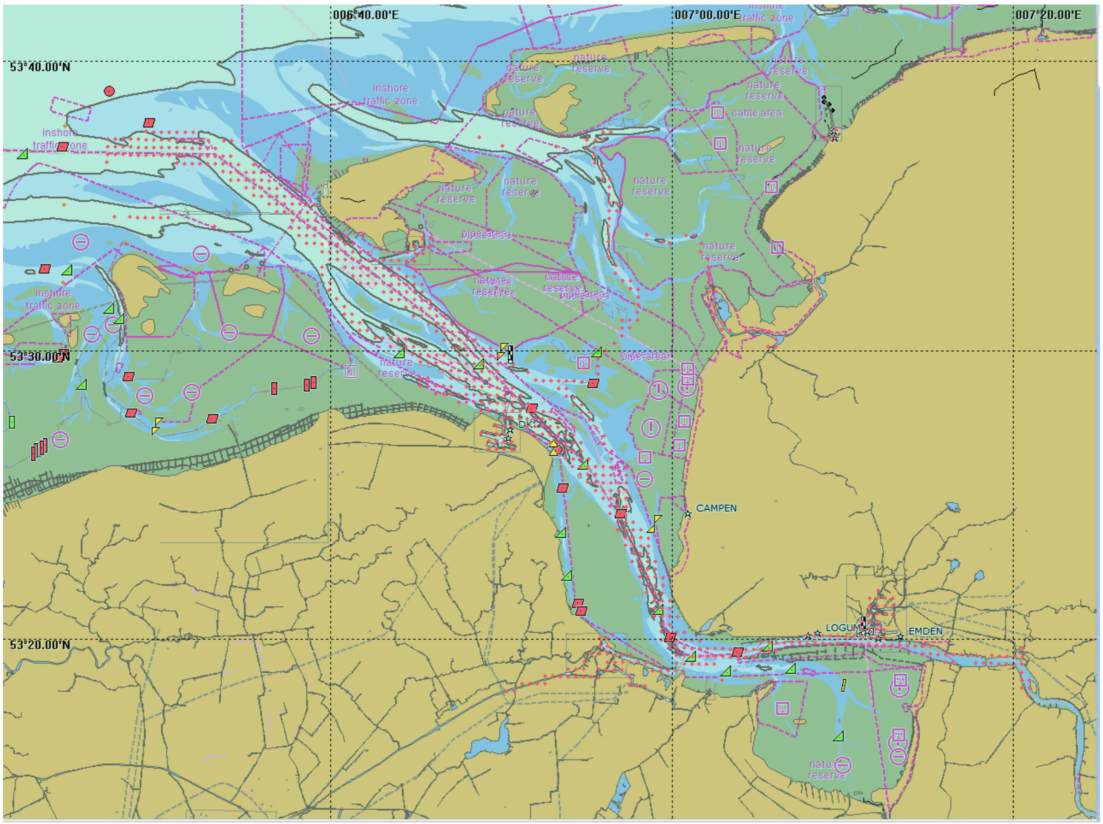

Figure 2-5 **Ems, emissions in red points have been included in databases. Note that also the German emissions are included in the database for the Dutch port areas**

2.3 OSPAR region II

2.3.1 OSPAR region II at sea

The database “Emissions_OSPAR_region_II_2010_MARIN_sea.mdb” contains the emissions in OSPAR region II at sea and is based on:

- the SAMSON traffic database of 2008;
- the emissions of ferries that are not included in the Lloyd’s List Intelligence (LLI) voyage database.

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 Intelligence voyage database.

The calculated emissions have been corrected for the changes in the traffic volumes and composition between 2008 and 2010.

This database contains a specific field “Fishing” which tells the user whether the emission is from a fishing vessel or not.

The emissions have been calculated on a 5000 x 5000 m grid. Note that this grid is chosen independently of the NCS grid for the AIS based database. The following areas have been indicated in Figure 2-6 and 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).

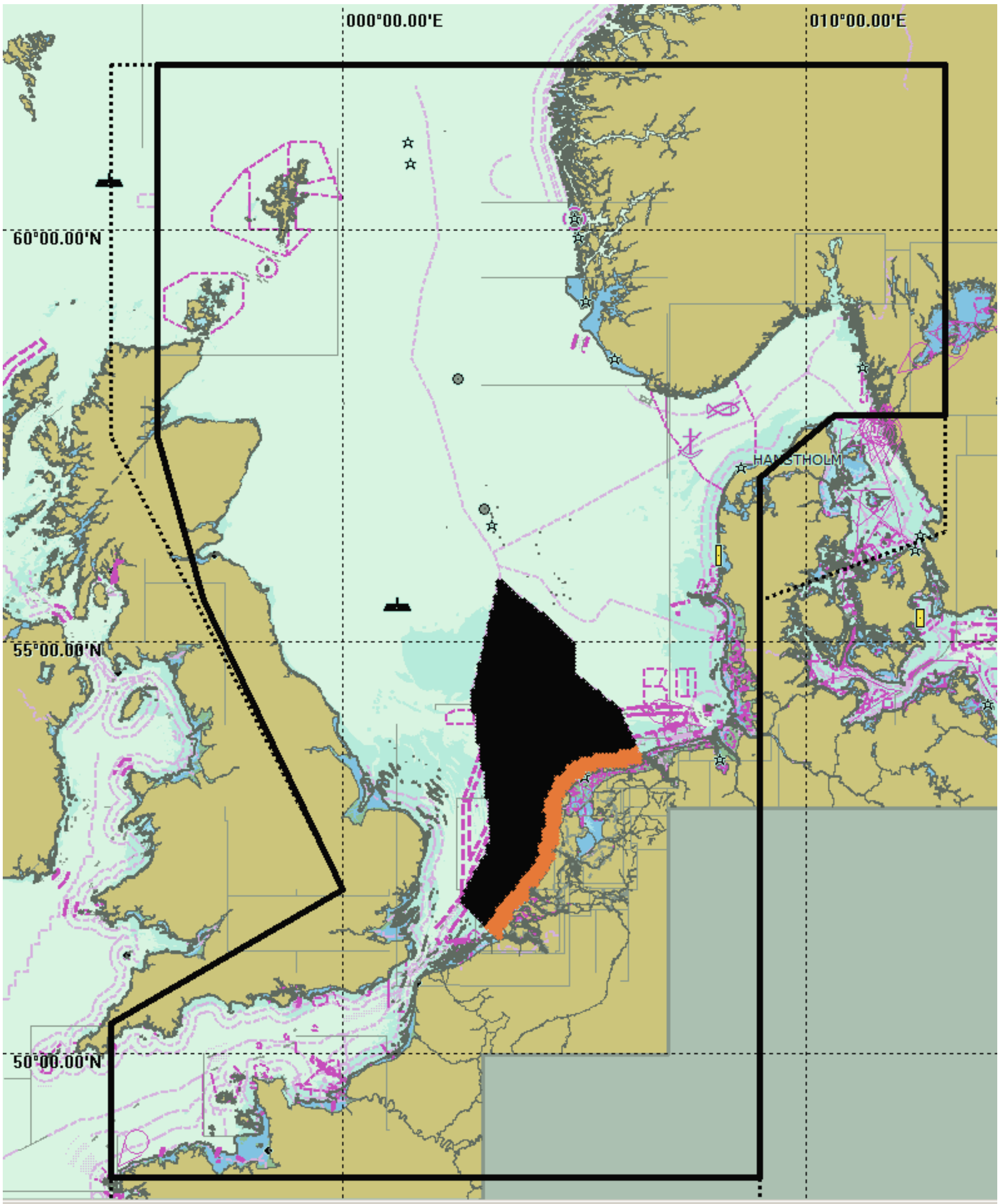

Figure 2-6 **Areas within OSPAR region II (dotted black line): North Sea according to IMO (black line), NCS outside 12-mile zone (black), NCS inside 12-mile zone (orange)**

2.3.2 OSPAR region II port emissions

The database "Emissions_OSPAR_region_II_2010_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 on a 5000 x 5000 m grid;
- AIS data of 2010 of the Belgium part of the Western Scheldt on a 500 x 500 m grid.

Note that the emissions in the German part of the Ems are not included in this database, but in the database for the Dutch port areas. Note also that, as in Section 2.2, the AIS based data contain fishing vessels as a separate ship type.

The results in port areas based on LLI have been multiplied by the sailed distance at sea based on AIS data in 2010 divided by the sailed distance at sea based on AIS data in 2008 per ship type and ship size to approximate the change in the number of port calls between 2008 and 2010.

For the emissions based on LLI data, there has also been added an identification whether a certain grid cell belongs to the North Sea according to the IMO definition or to OSPAR region II.

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. First the input used for the calculations will be explained. Then the procedure for combining the input to obtain emissions will be described.

3.1 Input

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

- AIS data;
- ship characteristics database, and;
- emission factors.

3.1.1 AIS data for 2010 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 ship databases, additional characteristics about the ship can be used, allowing for calculations of emissions.

In this study, AIS data of 2010 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 (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 and message 5 contains ship static and voyage related 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 yet still has 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

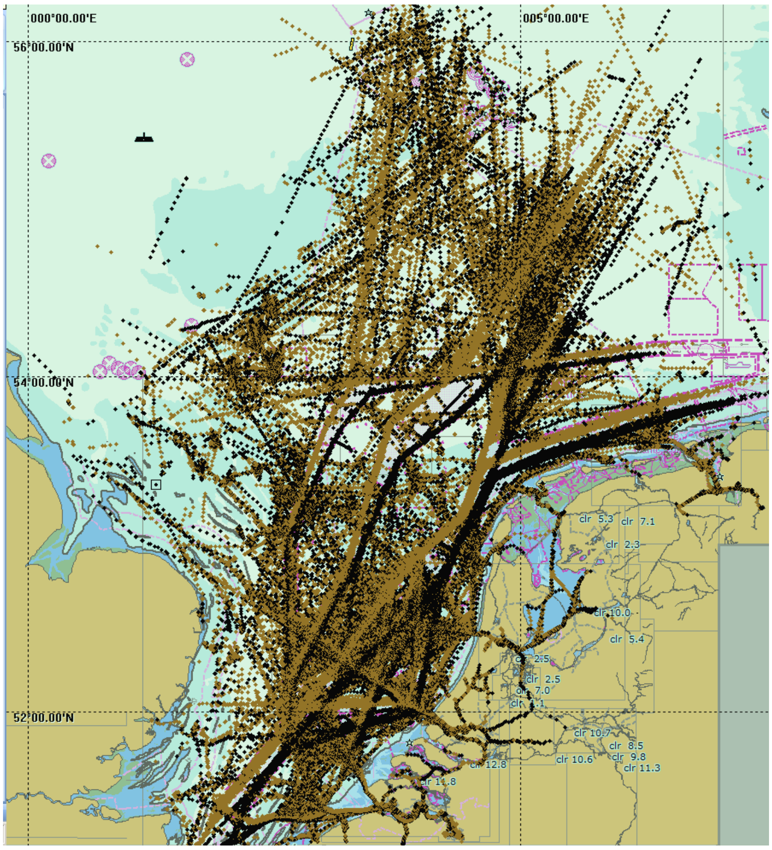

Figure 3-1 **Example of one week of AIS data of route bound traffic. Every ten minutes a dot was plotted to show the location of all vessels. A brown dot indicates westwards travelling, a black dot indicates eastwards travelling.**

3.1.2 Ship characteristics database of May 2011

The shipping database of LLI of May 2011 has been purchased. This database contains vessel characteristics of more than 116,000 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 shipping 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 basic files are the ones shown in blue in Figure 3-2 and they have been described in the previous Section.

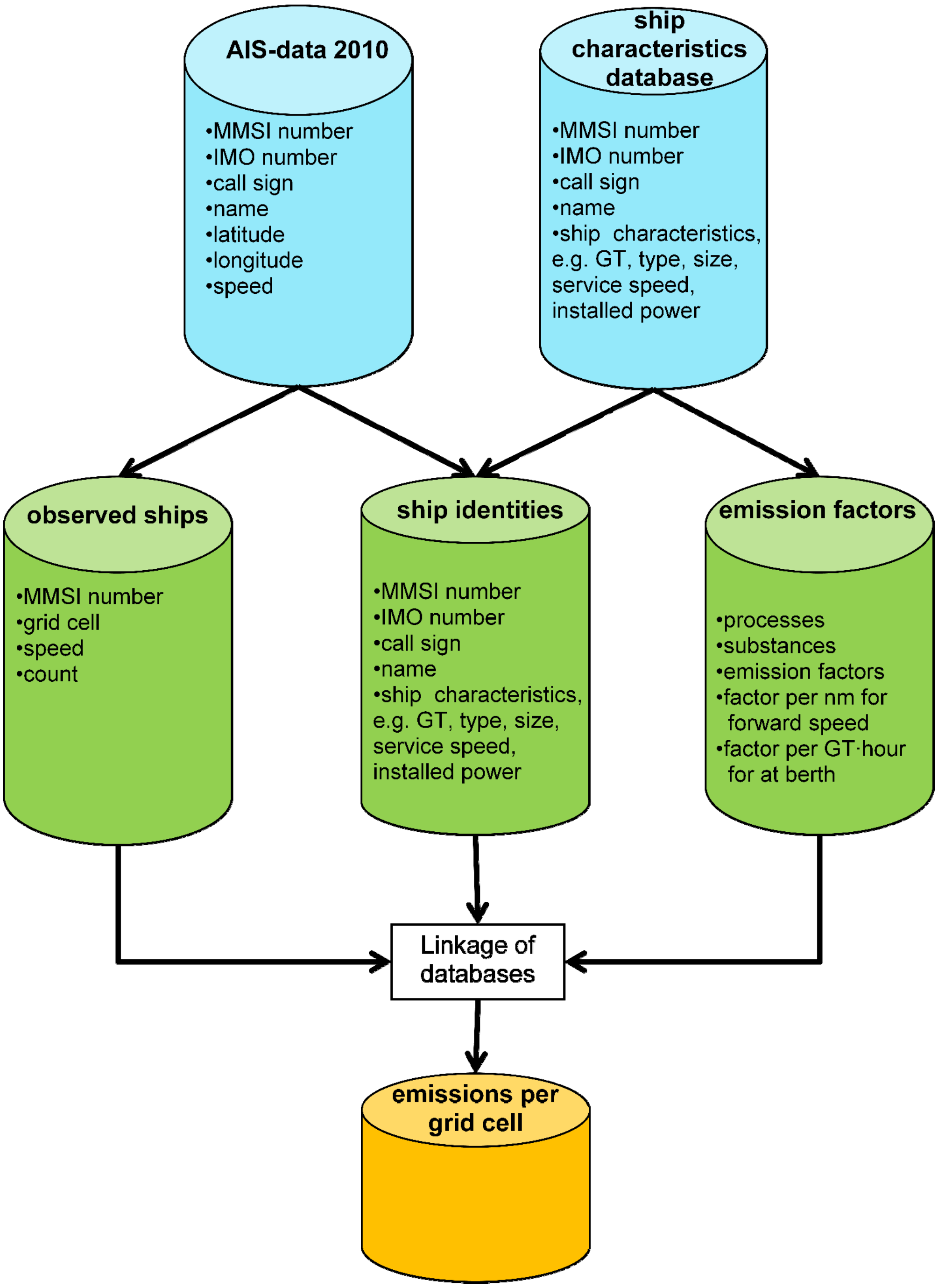

Figure 3-2 **Databases with relations (blue = input, green = intermediate, orange = output)**

3.2.1 From "AIS-data 2010" to "observed ships"

Each AIS data file contains the data of the ships in standard AIS format. That means that the file cannot be read with a text editor, but only by a program that converts the data into readable values. It is impossible to deal with all full text data. Therefore, an approach has been chosen in which every two minutes an observation is done to determine for the whole area which ships are in which grid cell with which speed. The essential parameters that have been collected during 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 of this class (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 (number of similar observations) are written to the “observed ships“ log file that has been used in the next steps. The determination 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 can be based on the observed speed.**

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

A separate step is to assess the emission factors for all ships from the ship characteristics database. TNO has determined emission factors per nautical mile for ships with forward speed and emissions per GT·hour for ships at berth for each ship contained in the database.

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 speed have been used. For this study these parameters were taken from the May 2011 shipping 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 EMS protocol and have been described in Appendix A.

In 2010 some of the factors that are used in the emission calculation have changed. The main changes are summarised below:

1. Load correction factors have been determined for a larger range of %MCR;
2. Load correction factors have been determined for specific engine types:
    a. reciprocating engines
    b. steam turbines
    c. gas turbines

    Steam turbines and gas turbines are according to the LLI database installed on 0.5% of the ships;
3. Emission factors for gas turbines and steam turbines have been changed;
4. A major change is that the sulphur content of marine fuels used for ships at berth is regulated by the European Union to a maximum of 0.1 percent. This directive entered into force at January 1, 2010 and implies that only marine gas oil with a sulphur content below 0.1 percent may be used. This gives reductions for the following substances for at berth emissions:
    a. SO_2, large reduction
    b. NO_x, small reduction for ships with engines from 2000 or later
    c. PM, large reduction

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 2009 AIS data. The following approximate emission reductions are the result of this combined effect:

- VOC 10%;
- SO_2 4%
- NO_x 2%
- CO 13%
- CO_2 0%
- Aerosols MDO 15%
- Aerosols HFO 3%

3.2.3 From “AIS-data 2010” and “ship characteristics database” to “ship identities”

Another activity is to find the corresponding ship in the shipping database for each MMSI number in the AIS data of 2010. The MMSI number which is included in each AIS message is (in most cases) a unique number for an individual ship. 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. In some cases different ships transmit the same MMSI number, which can cause problems with identification. Further, there is the default MMSI number in the AIS data, 1193046, which a number of ships may adopt, again making it impossible to couple the ship to the ship characteristics database and sometimes errors were made when typing the numbers.

All ships that are present in the AIS data of 2010 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. When at least two out of four connections delivered the same ship, the connection was used. Finally, a connection was made based on IMO numbers only.

In the remaining cases a manual view was necessary to decide which linkage was most likely. Sometimes a digit was wrong or zeros were added before or after the correct number in the AIS message. The manual view is a time consuming task, but is necessary in order to link as many MMSI numbers as possible to the correct ship. By following this approach, most MMSI numbers from the 2010 AIS data could be connected with a ship in the ship characteristics database, and, consequently, with the emission factors.

The success of coupling is given in Table 3-2. The emissions have been reported for all coupled ships. The total number of uncoupled ships for 2010 is quite large (34%). This is due to the fact that more and more small, recreational and inland ships are equipped with an AIS transponder and these ships are not included in the LLI shipping characteristics database.

Route bound ships are defined as ships with AIS type 40 and 60-99. Appendix B contains a table with AIS ship type numbers. There is a great difference between 2009 and 2010 for route bound ships, both in the number of ships and in the number of uncoupled ships. This is mainly due to the fact that inland ships have started to install AIS transponders. Starting in October 2009 AIS transponders for inland ships were subsidised by the Government. In April 2011 more than 3400 inland vessels were equipped with AIS transponders [6]. Inland ships are almost always shorter than 135 m. Only 2% of the route bound ships above 135 m could not be coupled.

Table 3-2 Number of ships in AIS and the success of coupling

	Total	Uncoupled	
	#	#	%
2010 all	19484	6531	34
2010 route bound	14467	2546	18
2009 route bound	11249	228	2
2010 route bound >135 m	7127	162	2

Because this study is about the emissions of seagoing vessels, for the sea area the emissions were calculated for all ships of which it was possible to connect the AIS data with a ship in the ship characteristics database, including fishing vessels. For the port areas, the inland ships that have been coupled had to be removed. This has been done by removing all vessels smaller than 135 m and without IMO number in the LLI database.

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 2010.

For ships with forward speed the actual speed is an important parameter for the emission at that moment. The speed from the AIS message combined with the emission factors for that ship has been used to calculate the emission.

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

4 COMPLETENESS OF AIS DATA

4.1 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 2010 contains 523,992 files, which is 99.69% of the maximum number of 525,600 files (365 days times 24 hours times 60 minutes). Therefore, in total slightly more than one day is 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 2010 a completion factor of 1.0017 has been used to correct for missing periods longer than 10 minutes, which add up to 15 hour. All emissions both in at the NCS and in the Dutch port areas have been multiplied with this factor. For 2009 it was not necessary to apply a completion factor, whereas in 2008 a factor of 1.025 has been applied to correct for missing data.

4.2 Bad AIS coverage in certain areas

4.2.1 Base stations

In the previous Section the completeness of the data has been described by the number of files received from the Netherlands Coastguard. There is, however, another type of completeness, namely, the area covered. This is illustrated in Figure 4-1, in which all base stations that deliver data to the Netherlands Coastguard are plotted. The circle with a radius of 20 nautical miles around each base station illustrates the area covered by that base station.

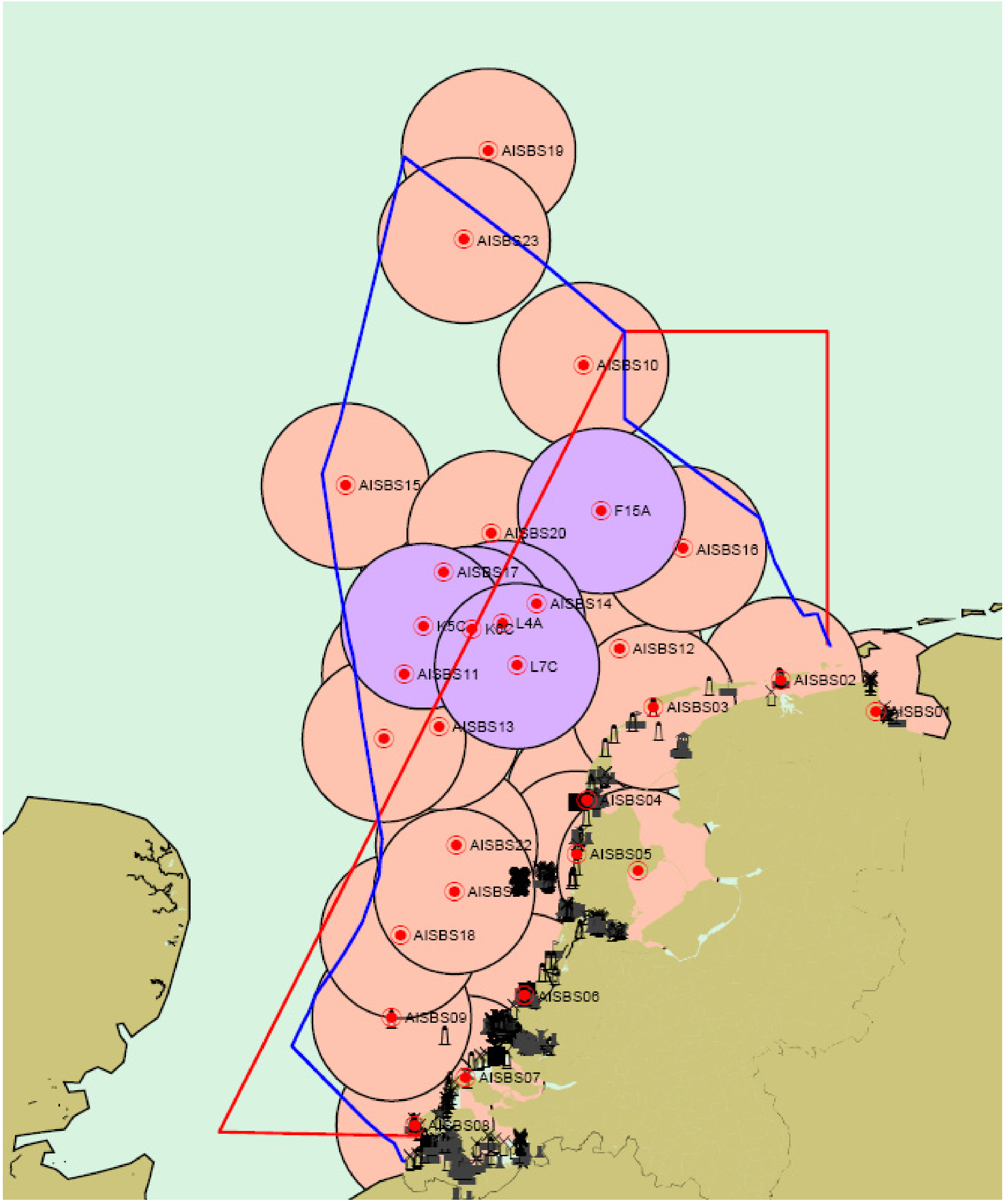

Figure 4-1 **AIS base stations delivering data to the Netherlands Coastguard, the blue line illustrates the NCS, the circles indicate the reach of the base stations, the purple circles indicate the newest base stations**

4.2.2 Known weak spots

In reality the coverage varies with the atmospheric conditions. The figure 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 spot above the Wadden on the border between the NCS and the German sector;
- 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 this last location is a shortcoming because it is a very dense shipping traffic area. MARIN has noticed this also in other projects. In 2010, the coverage has changed over time. During some periods the coverage was fine, but, unfortunately, the periods with bad coverage were longer.

4.2.3 Checks of coverage performed

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 has been 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 4-2. The areas marked red are focussed on in Figure 4-3. This figure shows the counted number of route bound ships with forward speed per day in the Western Scheldt. The lines show a drop for a day in which a certain base station has failed which normally works or the processing has gone wrong for a certain area and 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. However, the area between 4°10.00′ and 4°20.00′ only has a good coverage on days with favourable atmospheric conditions. This also follows from the high peaks on certain days which occur more often during summer time than during the winter.

In the other port areas no suspicious elements were found this year. After a comparison of the number of ships per subsection between 2010 and 2009 it was observed that in Rotterdam, the activities closer to sea have increased, while the inland activities have decreased. This has nothing to do with the coverage, but with the real activity.

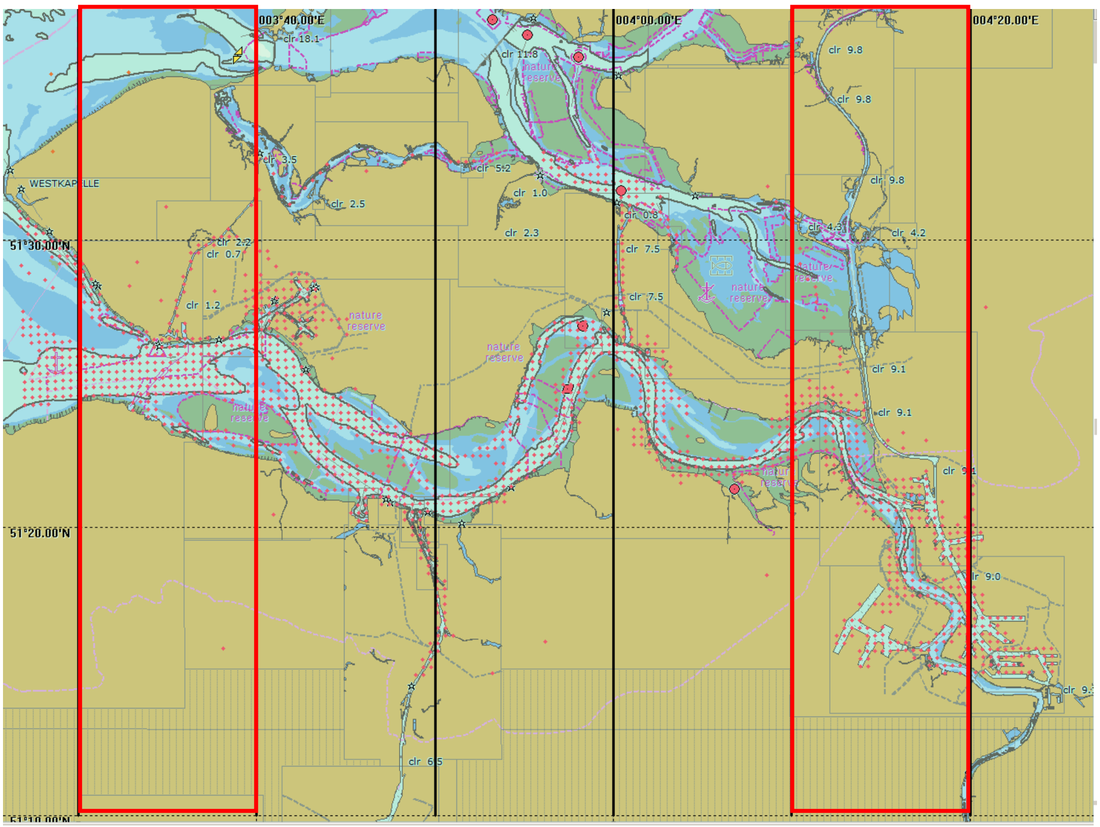

Figure 4-2 **Subdivision of the Western Scheldt area for coverage check**

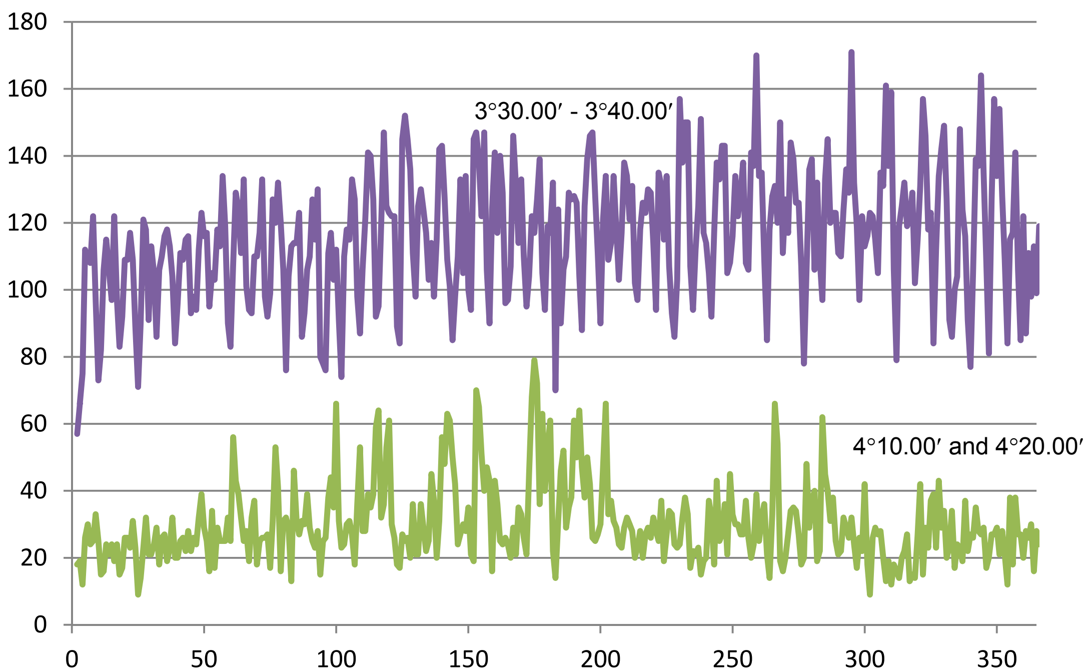

Figure 4-3 **Number of route bound vessels per day with forward speed in the Western Scheldt between 3°30.00′ and 3°40.00′, and between 4°10.00′ and 4°20.00′**

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 and a colour code was used to see great differences. Figure 4-4 is the resulting figure for the last four weeks of 2010. Great differences in the traffic lanes indicate a difference from the average number of traffic during that period. Great differences also occur at the port entrances and in anchorage areas. Great differences in an area around a base station indicate a difference in coverage of the base station. For 2010 it was observed that 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. Figure 4-5 shows the coverage over the year for this spot. It shows that the coverage is worse than average in the winter period and better than average in the summer period. Probably, the atmospheric conditions are better during the summer than the winter. Therefore, other base stations compensate for the bad/non-working base station in the summer, but not in the winter.

-0.2	-0.5	-0.9	-4.9	-3.5	-0.3	-3.2	-9.6	0.5	-5.5	1.2	0.4	1.2	-2.5	-2.3	-1.7	-3.1	-2.6	-1.8	-0.9	-1.2	-2.6	-2.2	-1.8	-3.4
-0.5	-0.8	-2.5	-1.4	-1.2	-0.6	-5.7	0.8	-4.2	4.9	0.1	-6.1	0.2	-2.2	-3.5	-1.2	-4.2	-3.4	-1.1	-1.4	-2.6	-2.1	-2.3	-2.8	-6.2
-0.7	-1.1	-1.4	0.8	2.6	-4.9	5.1	-0.8	-2.5	-10.1	8.2	6.0	1.6	-1.6	-3.4	-2.7	-3.9	-2.6	-1.5	-1.7	-2.4	-1.9	-3.5	-4.4	-6.4
-0.4	-1.2	-0.8	-1.7	-0.4	-1.6	0.5	-3.8	-6.5	-8.3	3.0	-0.6	3.5	-5.8	-7.0	-2.5	-3.3	-2.8	-1.8	-2.7	-1.7	-3.8	-5.5	-8.8	-6.9
-1.0	-0.2	-0.6	-1.2	-1.1	-0.4	-3.5	1.4	-2.8	-10.5	7.8	0.2	-3.9	-6.6	-6.7	-0.8	-3.2	-3.8	-3.2	-3.1	-3.1	-5.5	-6.6	-9.2	-7.7
-0.4	-0.4	1.2	1.1	-2.5	-1.2	-7.0	-9.5	2.9	-7.1	2.0	-6.5	-6.8	-6.8	-4.0	-0.9	-3.7	-5.5	-4.8	-3.6	-5.5	-6.8	-11.8	-11.8	-3.0
-0.2	-0.4	-0.8	-2.7	-0.9	-4.4	-2.5	-1.5	-6.3	-1.6	-1.8	-12.9	-5.9	0.9	-2.6	-1.3	-6.7	-7.5	-4.7	-3.5	-9.3	-9.4	-14.3	-8.1	-2.0
-0.2	-0.6	-0.6	1.2	-6.8	2.2	-2.0	2.2	-9.3	-4.3	-10.7	-3.5	1.5	1.8	-4.2	-2.2	-10.6	-6.5	-5.4	-9.9	-8.9	-17.8	-13.6	-4.6	-1.1
-0.6	-0.9	-0.8	-4.2	-3.8	-8.4	6.3	-7.5	-10.0	-9.7	-4.0	0.2	-2.5	0.9	-10.8	-3.5	1.5	0.2	-6.5	-13.2	-12.3	-17.4	-7.1	-2.1	-0.9
-0.5	-0.5	-0.6	-3.0	-0.1	-2.4	-3.6	-1.5	2.5	-1.1	4.6	0.5	-0.2	0.5	-7.7	1.5	3.5	4.7	-13.9	-11.2	-18.7	-15.0	-4.4	-0.9	-0.3
-0.3	-0.8	-1.4	-1.8	-1.2	-8.1	-16.2	-6.8	-8.4	9.8	-4.8	-1.8	0.5	7.0	-5.8	-9.3	-5.2	-5.2	-10.6	-16.5	-19.5	-7.6	-3.2	-0.8	-1.2
-0.2	-1.0	-0.9	-2.8	-3.0	-15.7	-9.0	2.8	7.7	0.8	2.6	-7.7	0.5	-7.5	-10.5	7.0	-6.9	2.4	-13.0	-26.8	-18.9	-6.8	-2.1	-2.5	-0.8
-0.3	-0.9	-2.5	-7.2	-6.7	-14.5	-0.1	-0.2	14.8	7.3	2.6	8.9	-3.8	1.8	4.6	-10.5	-28.1	-1.7	-18.6	-29.0	-11.2	-5.6	-1.2	-0.5	-0.8
-0.6	-1.8	-3.8	-7.1	-2.2	-5.2	0.6	-2.3	15.5	9.2	4.7	-0.5	-0.2	-9.3	0.5	-17.5	0.7	-1.2	1.8	-23.5	-7.8	-2.5	-0.8	-1.0	-0.8
-1.4	-5.5	-6.6	-4.1	-6.2	-7.5	-2.5	8.1	18.2	10.8	8.8	-2.1	-3.5	-3.1	-14.1	-27.3	11.9	-5.5	-16.1	-8.5	-4.5	-2.5	-1.9	-1.0	-1.4
-2.3	-1.5	-5.4	-4.0	-3.4	-2.5	-4.7	7.8	12.0	-0.1	15.0	4.2	0.5	-14.3	-5.4	-0.8	1.0	-31.2	-18.9	-8.4	-2.2	-1.5	-1.3	-3.1	-1.6
-7.2	-10.5	-4.6	-1.8	-3.6	-8.3	1.7	3.2	6.2	-1.3	15.1	-1.9	-10.4	-5.1	-31.3	10.6	-11.7	-28.6	-8.8	-5.3	-1.1	-0.8	-0.8	-1.4	-3.4
-6.5	-5.1	-2.2	-3.9	-0.5	-7.4	1.4	6.1	-3.0	-4.5	-1.5	-1.0	5.6	0.8	-0.8	-3.0	-26.9	-26.9	-6.2	-1.2	-0.8	-0.9	-1.5	-2.0	-1.0
1.1	3.4	-0.3	2.8	7.2	-2.5	-0.2	-9.5	-6.3	-3.5	-2.8	-3.6	-17.4	-9.8	-19.3	-5.0	-40.2	0.8	-3.7	-0.2		-0.3	-1.9	-1.8	-0.8
-0.6	-3.7	-1.4	-0.9	-1.2	-6.8	-6.5	-0.9	-0.1	1.8	0.4	-2.0	-21.2	-12.2	-17.8	-24.5	5.2	-5.0	-1.7	-0.5	-1.8	-0.8	-1.5	-3.9	-1.5
0.4	1.5	-3.5	-5.5	-2.0	-10.2	-9.2	-5.0	0.0	-0.5	6.5	-4.3	1.2	-7.8	-28.7	-31.7	-5.1	3.5	-5.4	2.6	-3.8	-0.4	-16.7	-8.2	-6.0
-8.9	-2.8	-10.6	3.0	2.6	-6.3	1.0	-5.4	-1.5	0.2	-11.0	-30.9	-5.5	-16.5	-33.9	-9.5	0.0	1.8	-2.1	12.5	-9.3	-8.7	-5.6	-9.5	-4.1
0.3	9.5	8.7	6.0	-7.8	0.0	0.8	-4.3	0.5	3.8	-18.5	10.1	-34.8	-16.4	-27.5	13.8	-8.8	-0.6	-9.2	-0.9	0.4	2.5	-4.1	-1.9	-0.2
10.9	-9.9	-3.6	5.5	-14.6	-11.6	4.5	-8.7	-8.8	-10.4	-16.8	-0.9	-22.4	-38.3	-21.3	3.8	-6.7	-5.5	-7.8	5.4	4.8	-1.8	1.6	-0.8	-1.1
-7.4	-12.3	-4.0	-1.9	-9.5	-2.4	5.4	-4.5	-19.7	7.4	0.5	2.3	-5.7	-14.0	-13.4	13.0	-4.6	-3.6	-2.9	-9.8	0.6	-4.9	2.9	-18.8	-26.6
-7.2	3.2	-2.1	-12.2	-1.7	-5.5	-6.5	-5.1	-17.8	-4.8	-8.0	20.8	-12.5	-23.5	-4.5	-18.1	-6.0	-2.6	1.8	1.1	4.9	-3.2	25.7	83.5	48.9
-2.0	-7.7	-4.3	-12.6	-11.0	-3.0	-19.1	-16.5	-1.3	-19.3	6.2	0.0	0.2	-19.8	-9.5	2.5	1.8	9.2	-10.8	-15.7	41.8	41.2	37.9	0.2	6.7
-6.6	-7.2	-5.5	2.4	-0.2	-1.8	-4.9	-2.8	-6.9	-43.9	-0.7	-1.4	-16.5	6.9	-16.5	19.5	-29.2	2.3	47.7	41.7	45.0	-17.2	5.5	-3.9	24.2
-8.0	-9.8	-21.1	-5.0	-1.2	-1.4	-14.5	12.2	-0.5	-1.1	-0.1	-1.8	2.6	18.2	-14.8	11.5	17.5	63.0	2.5	-3.3	-4.9	-3.2	-2.7	-1.0	-0.5
-8.2	-16.8	-7.8	9.4	-2.3	-5.7	-16.1	-1.5	-3.2	0.3	-3.8	-3.0	-31.5	6.8	73.7	40.2	-0.5	-8.5	-2.1	-2.2	-1.5				
-38.2	-31.6	7.9	0.1	-2.9	-17.5	19.5	-0.6	3.8	6.5	1.3	-2.2	42.2	26.4	7.2	-6.7	-1.6								
-87.6	-44.8	-6.8	-1.5	1.4	-28.3	17.0	5.0	3.9	3.4	-4.8	-2.7	40.8	10.6	10.7	-5.8									
-1.4	-31.1	-97.4	-11.2	8.1	8.9	-2.1	7.5	0.9	-2.0	-4.2	-15.8	44.4	-3.8	-0.2										
-7.8	-4.5	-3.5	-0.7	-0.3	-3.8	2.8	-6.3	-3.2	-6.5	10.1	-13.4	-0.5	-0.5											
-5.0	-7.1	2.2	2.2	1.7	-23.2	-2.6	-3.1	-3.2	-38.4	-28.8	48.4	-3.2	-0.7											
-12.2	-12.4	-3.5	-5.6	-7.2	19.7	-0.9	-8.5	-22.9	-30.5	45.0	1.2	-12.8	-1.0											
-23.8	-21.9	-18.2	-7.8	-33.7	11.6	-4.5	-11.9	17.1	-8.1	-0.9	-7.3	-16.9												
-18.0	-22.9	-18.2	-2.6	13.2	-10.2	11.8	-8.0	-21.2	14.3	38.5	-3.8	-15.9	-0.1											
-27.8	-17.3	-13.8	-24.1	4.4	-23.2	-7.0	-4.8	-8.7	20.4	32.2	-2.8	-8.0												
-32.7	-31.8	-29.3	11.2	1.2	11.4	-33.4	-2.2	1.7	-26.9	-11.0	-12.7	-4.8												
-74.2	-43.7	-27.3	6.5	7.5	-14.1	-1.3	38.8	-12.9	214.5	284.5	-184.3	-5.6												
-18.0	-48.1	-31.8	-18.2	27.2	-19.9	23.8	-41.3	-20.4	-18.2	-1.4	11.0	-27.7												
-15.4	0.6	-9.8	-39.9	-23.9	-12.5	49.3	32.7	-9.1	9.2	-6.8	22.2	-0.2												
-9.5	-15.1	-12.3	11.0	-26.2	60.8	-10.2	11.1	4.2	-17.6	-42.0	-1.9													
-49.1	15.2	-49.2	17.0	38.8	-69.6	-32.5	-280.5	-40.2	-321.4	-427.8	-0.6													
-62.9	-103.8	-67.8	52.6	18.5	-1.5	5.2	-588.0	-201.2	-45.8	-11.3														
-81.5	-164.6	-99.0	-47.9	-64.5	-81.9	-2.2	-90.8	-41.8	-17.8	-1.1														
-122.6	-161.9	-274.2	-1.7	-88.7	-57.0	-9.7	-53.3	-62.2	-12.8															
-202.8	-166.8	-147.7	-3.6	8.3	90.8	-36.2	1.9	0.1																
-89.9	-59.1	-7.1	29.1	3.3	-11.5	-4.7	-0.5																	
-73.5	-39.5	13.3	19.8	85.9	-8.8	0.5																		
-6.5	-38.1	-5.4	-5.4	-26.5	36.2																			
12.2	-22.6	-36.0	-10.6	-25.1	2.8																			

Figure 4-4 **Absolute difference between the number of route bound ships that are moving per grid cell in the last four-week period of 2010 and the yearly average. Grid cells are marked red for a positive difference and green for a negative difference. The black rectangle marks the location with bad coverage SW of Rotterdam**

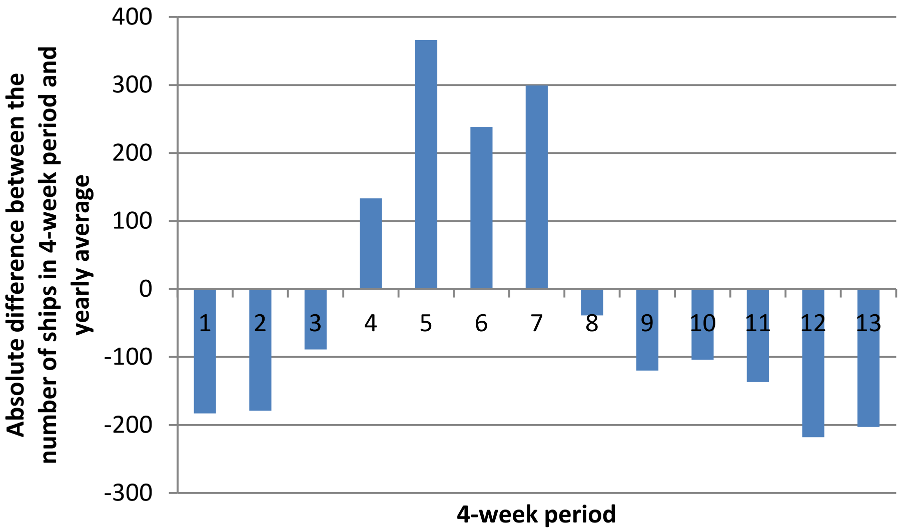

Figure 4-5 **2010 absolute difference in number of observed ships for the grid cell with a latitude between 51°50.00′ and 51°55.00′, and a longitude between 2°30.00′ and 2°40.00′**

4.2.4 Compensation for bad AIS coverage in Western Scheldt

The AIS data of the Western Scheldt is received by the two most southern AIS base station of the Netherlands as shown in Figure 4-1. As explained in Section 4.2.1, 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 have sometimes been received for this area, but there is no full coverage.

The emissions for ships at berth in Antwerp have been calculated based on the method that has been developed for port areas outside the Netherlands (see Section 6.2.1).

The emissions for moving ships on the Western Scheldt close to the Belgian border and in Belgium have been increased by a factor to compensate for the bad AIS coverage. A comparison was made between the number of voyages towards and from Antwerp, determined from the LLI voyage database and from AIS. For this comparison the number of ships in the AIS data of 2010 crossing the lines shown in Figure 4-6 were counted. It was concluded that line 2 still had 100% AIS coverage and that the coverage decreased towards line 7. Also, it was 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.

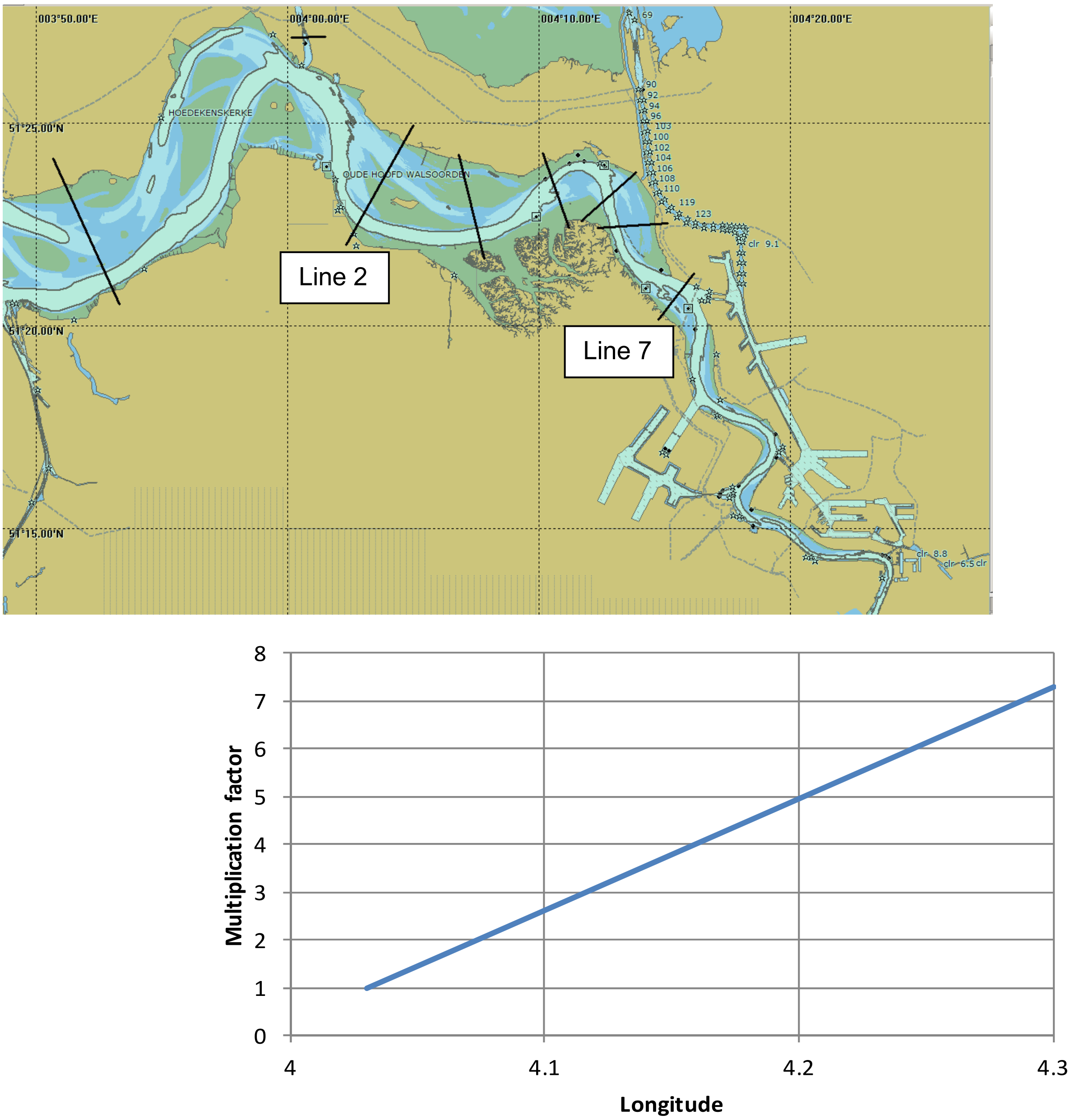

Figure 4-6 **Crossing lines used to check coverage of AIS data in the Western Scheldt and average multiplication factor. The decimal numbers of the Longitude indicate minutes**

A location-based linear regression was used to compensate 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 4-6.

4.3 Influence on the reported emissions

In the coming years, an increase in calculated emissions is expected by 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 shipping characteristics database already account for 7 to 10% of the emissions at the NCS. In the future, also inland ships will probably be compelled to be equipped with an AIS transponder or a similar system. However, a system with inland base stations for AIS data collection of inland ships has not been set up yet.

Improvement of the coverage of AIS or the extension of the user group of AIS 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 coverage and the changes the AIS user group also in the future to prevent drawing wrong conclusions. This year the correction for the bad coverage in the Western Scheldt has resulted in an increase in reported emissions.

5 EMISSIONS FOR 2010 AND COMPARISON WITH 2009 FOR THE DUTCH PORT AREAS AND THE NCS

5.1 Introduction

This chapter presents the results of the emission calculations and the most important changes in shipping characteristics for 2010 in the Dutch port areas and at the Netherlands Continental Shelf. To see how the emissions evolve over the years, all values for 2010 are also presented as percentages of the 2009 values. Values are presented as calculated are and not rounded off.

The emissions for the port areas are given in Section 5.2 and for the NCS in Section 5.3. Section 5.4 contains an overview of the number of ships in both areas. Section 5.5 presents the 2010 spatial distribution of CO_2 emissions for ports and NCS as well as the difference between 2010 and 2009.

5.2 Emissions in port areas

Table 5-1 contains the emissions for the four Dutch port areas, calculated for ships berthed and for journeys within the port area. The latter are divided into those resulting from main and those resulting from auxiliary engines. Table 5-2 contains the same emissions expressed as a percentage of the corresponding emissions in 2009. Note that values for at berth include all vessels with zero speed, so also the vessels at anchor.

Emission values for the Western Scheldt in Table 5-1 are corrected for the bad AIS coverage (see 4.2.4) and emissions in Belgium have not been taken into account. Table 5-2 gives percentages based on:

- the uncorrected AIS data with Belgian emissions included, and;
- corrected data for 2010, but uncorrected data for 2009 without Belgian emissions.

Table 5-2 shows the changes in emission between 2009 and 2010. The largest differences are due to changes in emission factors and load correction factors. These changes have been summarised in Section 3.2.2.

The emission changes of CO_2 are only due to changed traffic. The percentages in Table 5-2 show:

- in Rotterdam a 4 to 9 % increase in sailing emissions and 7% decrease in emissions of ships at berth, resulting in an overall decrease in emission of 4%;
- in Amsterdam for the second year in row a decrease over 10% of berthed and sailing emissions together;
- in the Western Scheldt 4% increase in sailing, 8% increase in at berth (including emissions in Belgium and without correction for insufficient AIS coverage;
- in the Ems area an increase of 3% for sailing and a decrease of 13% for at berth. Last year there was a large increase due to ships at berth, so there is a slight change towards the situation in 2008.

Table 5-1 Total emissions in ton in each port area for 2010 based on AIS data

Substance	Source	Western Scheldt*	Rotter-dam	Amster-dam	Ems**	Total*
1237 VOC	Berthed	31	237	55	19	342
	Sailing: Main engine	219	134	23	18	394
	Sailing: Auxiliary engines	32	27	5	4	67
	Total	***282***	***398***	***82***	***41***	***802***
4001 SO_2	Berthed	55	451	98	45	650
	Sailing: Main engine	2,584	1,310	172	209	4,276
	Sailing: Auxiliary engines	428	379	54	34	895
	Total	***3,067***	***2,141***	***325***	***288***	***5,820***
4013 NO_x	Berthed	722	5,179	1,204	466	7,572
	Sailing: Main engine	7,494	3,690	516	582	12,282
	Sailing: Auxiliary engines	1,093	902	152	109	2,257
	Total	***9,309***	***9,772***	***1,872***	***1,158***	***22,110***
4031 CO	Berthed	142	1,091	250	94	1,576
	Sailing: Main engine	1,423	989	162	107	2,681
	Sailing: Auxiliary engines	195	171	27	20	413
	Total	***1,760***	***2,251***	***439***	***221***	***4,671***
4032 CO_2	Berthed	62,690	554,377	121,293	36,662	775,023
	Sailing: Main engine	290,704	151,133	20,747	25,843	488,427
	Sailing: Auxiliary engines	58,175	50,415	8,020	5,858	122,467
	Total	***411,569***	***755,926***	***150,060***	***68,363***	***1,385,918***
6601 Aerosols MDO	Berthed	16	123	28	11	178
	Sailing: Main engine	9	9	2	4	24
	Sailing: Auxiliary engines	51	46	6	4	107
	Total	***76***	***178***	***37***	***19***	***309***
6602 Aerosols HFO	Berthed	n.a.	n.a.	n.a.	n.a.	n.a.
	Sailing: Main engine	406	203	26	26	662
	Sailing: Auxiliary engines	n.a.	n.a.	n.a.	n.a.	n.a.
	Total	***406***	***203***	***26***	***26***	***662***
6598 Aerosols MDO+HFO	Berthed	16	123	28	11	178
	Sailing: Main engine	415	212	29	30	686
	Sailing: Auxiliary engines	51	46	6	4	107
	Total	***483***	***380***	***63***	***45***	***971***

* corrected for the bad AIS coverage and emissions in Belgium have not been taken into account

** including emissions in German part of the Ems

Table 5-2 Emissions in each port area for 2010 as percentage of the emissions in 2009

Substance	Source	Western Scheldt*	Western Scheldt**	Rotter-dam	Amster-dam	Ems ***	Total*
1237 VOC	Berthed	103.6%	103.3%	92.5%	87.4%	87.5%	92.2%
	Sailing: Main engine	96.8%	112.5%	95.4%	84.3%	80.9%	102.4%
	Sailing: Auxiliary engines	88.2%	104.7%	95.2%	77.5%	88.2%	97.5%
	Total	***96.7%***	***110.5%***	***93.6%***	***85.9%***	***84.6%***	***97.4%***
4001 SO_2	Berthed	19.8%	19.9%	16.0%	16.0%	19.3%	16.5%
	Sailing: Main engine	101.2%	118.6%	100.8%	86.7%	100.7%	110.0%
	Sailing: Auxiliary engines	93.5%	109.4%	96.7%	76.8%	92.0%	100.5%
	Total	***89.4%***	***107.7%***	***47.5%***	***36.6%***	***60.3%***	***66.8%***
4013 NO_x	Berthed	99.9%	100.0%	89.8%	86.7%	88.3%	90.1%
	Sailing: Main engine	103.2%	119.8%	102.0%	87.2%	100.4%	111.2%
	Sailing: Auxiliary engines	102.5%	122.0%	106.2%	89.2%	97.8%	111.3%
	Total	***102.7%***	***118.3%***	***95.5%***	***87.0%***	***94.9%***	***102.9%***
4031 CO	Berthed	103.4%	103.3%	93.9%	90.0%	89.8%	93.8%
	Sailing: Main engine	99.9%	115.1%	99.6%	88.1%	84.8%	105.6%
	Sailing: Auxiliary engines	97.8%	115.9%	105.0%	83.8%	91.4%	107.2%
	Total	***100.1%***	***114.1%***	***97.2%***	***88.9%***	***87.4%***	***101.4%***
4032 CO_2	Berthed	108.1%	108.7%	93.1%	87.4%	87.4%	92.9%
	Sailing: Main engine	104.4%	122.4%	103.5%	90.9%	103.9%	113.2%
	Sailing: Auxiliary engines	104.4%	124.0%	108.9%	90.5%	102.7%	113.7%
	Total	***105.2%***	***120.3%***	***95.9%***	***88.1%***	***94.3%***	***100.9%***
6601 Aerosols MDO	Berthed	49.2%	49.2%	37.0%	37.5%	49.4%	38.5%
	Sailing: Main engine	74.5%	87.4%	74.0%	84.1%	81.6%	80.8%
	Sailing: Auxiliary engines	87.5%	102.0%	91.6%	72.3%	90.0%	94.6%
	Total	***70.7%***	***81.8%***	***45.0%***	***42.6%***	***60.2%***	***51.1%***
6602 Aerosols HFO	Berthed	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Sailing: Main engine	103.1%	119.9%	103.1%	84.9%	100.0%	111.6%
	Sailing: Auxiliary engines	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Total	***103.1%***	***119.9%***	***103.1%***	***84.9%***	***100.0%***	***111.6%***
6598 Aerosols MDO+HFO	Berthed	49.2%	49.2%	37.0%	37.5%	49.4%	38.5%
	Sailing: Main engine	102.3%	118.9%	101.4%	84.8%	97.4%	110.1%
	Sailing: Auxiliary engines	87.5%	102.0%	91.6%	72.3%	90.0%	94.6%
	Total	***95.6%***	***111.7%***	***64.3%***	***53.8%***	***78.5%***	***81.1%***

* not corrected for bad coverage of AIS data and including emissions in Belgium
** 2010 corrected, 2009 not corrected for bad coverage of AIS data, both Dutch emissions only
*** including emissions in German part of the Ems

The changes in emission presented in Table 5-2 are the combined effects of changes in:
- the number and location of the visits in that port;
- ship type, ship size, main and auxiliary engine;
- the speed used;
- emission factors.

Therefore, it is difficult to explain each trend separately.

However, more insight can be gained and results made more plausible when other independent sources show the same trends. Therefore, a comparison has been made with the amount of traffic in the different port areas based on the statistics published by the National Ports Council (Nationale Havenraad, NHR).

The numbers of the NHR are presented in Table 5-3. Again, first the values of 2010 are shown and then the percentage with respect to the values in 2009. The table contains the number of calls for each port area. Only for Antwerp summarised GT data were available from the website of the port. The percentages in Table 5-3 show increases in the number of calls in all port areas with the largest increase in the Western Scheldt. For all port areas the number of calls increased, whereas the emissions decreased in all port areas except in the Western Scheldt. In the Western Scheldt the increase in port calls is also higher than the increase in emissions.

Table 5-3 Number of calls from Nationale Havenraad and from www.PortOfAntwerp.com

Port area	Ports	Number of calls		GT (in 1000 ton)	
		2010	2010/2009	2010	2010/2009
Western Scheldt	Antwerp	14,783	106.2%	290,387	109.1%
	Vlissingen, Terneuzen	5,505	111.3%		
Rotterdam	Rijn- en Maasmondgebied	32,725	103.8%		
Amsterdam	Noordzeekanaalgebied	7,813	102.0%		
Ems	Delfzijl/Eemshaven	1,888	101.9%		

Because emissions also (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 2009 to 2010. 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 in Table 5-4 through Table 5-11.

Table 5-4 and Table 5-5 for the Western Scheldt confirm the increased number of calls by the increase in at berth hours and GT.hours of ships at berth. Hours and GT.nm of sailing ships have increased even more, but this is mainly caused by the correction for bad AIS coverage applied to sailing in the Western Scheldt.

Table 5-6 and Table 5-7 for Rotterdam show that the overall number of hours that ships were in the area decreased. The number of calls, however, increased. This can be explained by an increase in activity for moving ships in 2010 closer to sea, and at the same time a decrease further inland. This was already mentioned in Section 4.2.3. The shorter number of hours at berth also results in lower emissions.

Table 5-8 and Table 5-9 for Amsterdam show that the number of hours increases slightly, which corresponds to the slight increase of the number of port calls in Table 5-3. However, there is a decrease in the number of GT.hours and GT.nm and in average speed. This explains part of the emission reduction.

Table 5-10 and Table 5-11 for the Ems show that there is a decrease of approximately 15% of at berth hours and only a very slight decrease of hours for moving ships. Table 5-3 showed a slight increase in the number of port calls. A reduction in the number of at berth hours might be the result of fewer ships that were laid up. Last year a very large increase was observed in ships that were a long time at berth at the same position. The decrease in the hours for moving ships can be the result of the higher average speed in 2010. The GT.nm and the average speed increased with 12% and 5% respectively, resulting in higher emissions for sailing.

Table 5-4 Ship characteristics per EMS type for the Dutch part of the Western Scheldt

Ship type	Totals for Western Scheldt in 2010*					2010 as percentage of 2009**				
	Berthed		Moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	4,687	168,034,154	4,467	1,395,079,183	10.82	100.0%	111.0%	107.6%	126.1%	102.8%
Chem.+Gas tanker	37,231	366,604,869	38,842	3,134,366,834	11.09	127.0%	121.7%	134.1%	131.1%	100.2%
Bulk carrier	15,991	441,547,413	7,591	1,780,016,037	9.12	98.5%	96.2%	124.1%	120.5%	98.5%
Container ship	5,127	67,050,297	30,660	13,404,836,073	12.72	231.5%	233.8%	116.6%	121.7%	98.5%
General Dry Cargo	70,765	505,364,133	42,584	2,234,879,310	10.47	98.7%	111.5%	125.5%	122.8%	99.8%
RoRo Cargo / Vehicle	19,133	267,895,136	12,685	5,387,997,240	12.23	117.6%	108.2%	112.2%	119.5%	100.4%
Reefer	8,577	66,950,674	2,756	423,058,033	12.86	90.7%	100.7%	109.8%	116.0%	99.1%
Passenger	5,658	6,868,373	2,725	142,215,809	13.29	47.3%	35.6%	52.7%	195.8%	113.6%
Miscellaneous	100,561	247,603,290	36,004	1,323,988,646	7.17	109.5%	94.8%	148.2%	203.1%	86.6%
Tug/Supply	48,328	21,404,649	6,882	22,300,063	7.14	97.5%	85.5%	113.0%	134.1%	105.0%
Fishing	1,703	9,186,364	42	1,581,496	9.38	30.3%	33.9%	51.7%	44.6%	105.4%
Non Merchant	1,336	1,838,169	73	394,923	7.77	135.4%	295.5%	68.8%	52.1%	83.4%
Total	**319,096**	**2,170,347,520**	**185,309**	**29,250,713,647**	**11.49**	**103.0%**	**106.3%**	**124.4%**	**124.9%**	**97.8%**

* 2010 corrected for the bad AIS coverage
** 2009 not corrected for the bad AIS coverage

Table 5-5 Ship characteristics per EMS ships size classes for the Dutch part of the Western Scheldt

Ship size in GT	Totals for Western Scheldt in 2010*					2010 as percentage of 2009**				
	Berthed		Moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	118,947	81,063,443	23,443	174,153,910	8.51	102.6%	102.5%	94.4%	91.5%	94.1%
1,600-3,000	56,504	131,386,443	41,333	892,706,920	9.12	76.6%	77.3%	123.7%	125.1%	99.4%
3,000-5,000	39,804	153,690,296	27,140	1,084,554,363	10.27	128.2%	127.4%	144.3%	143.2%	99.2%
5,000-10,000	36,326	256,695,683	23,710	1,908,427,767	11.33	132.3%	139.8%	119.2%	116.7%	97.2%
10,000-30,000	51,741	867,314,826	43,294	8,461,379,614	11.12	111.7%	106.0%	139.9%	121.9%	93.7%
30,000-60,000	13,921	539,060,689	20,006	10,220,086,738	11.85	104.4%	103.9%	124.6%	124.6%	99.7%
60,000-100,000	1,779	130,562,109	5,423	4,992,897,900	12.29	87.3%	89.0%	128.2%	131.2%	100.5%
>100,000	73	10,574,031	960	1,516,506,437	12.24	301.7%	300.6%	117.8%	128.6%	98.1%
Total	**319,096**	**2,170,347,520**	**185,309**	**29,250,713,647**	**11.49**	**103.0%**	**106.3%**	**124.4%**	**124.9%**	**97.8%**

* 2010 corrected for the bad AIS coverage
** 2009 not corrected for the bad AIS coverage

Table 5-6 Ship characteristics per EMS type for the Rotterdam port area

Ship type	Totals for Rotterdam in 2010					2010 as percentage of 2009				
	berthed		moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	62,222	4,041,290,241	5,934	1,855,825,707	6.04	84.5%	90.5%	100.4%	101.3%	101.9%
Chem.+Gas tanker	130,927	1,676,219,300	23,055	1,714,089,499	7.97	83.5%	88.6%	101.0%	106.0%	101.3%
Bulk carrier	78,710	4,496,044,318	3,825	996,407,746	5.84	125.5%	136.5%	118.7%	123.5%	99.2%
Container ship	184,862	5,757,330,616	32,301	5,118,981,636	7.21	99.7%	108.0%	106.9%	107.7%	101.8%
General Dry Cargo	122,167	666,331,228	26,074	807,533,463	8.49	68.5%	81.4%	90.8%	95.6%	99.6%
RoRo Cargo / Vehicle	37,362	775,123,136	8,781	1,664,807,425	9.36	89.1%	93.3%	102.7%	113.6%	100.3%
Reefer	4,920	40,717,188	830	72,099,089	9.49	74.4%	70.1%	89.6%	91.1%	100.3%
Passenger	15,754	711,599,588	1,896	964,270,862	10.41	80.5%	92.5%	90.4%	101.9%	96.7%
Miscellaneous	85,967	985,999,744	12,652	447,656,570	6.79	81.9%	74.9%	72.1%	76.5%	97.1%
Tug/Supply	171,823	88,001,678	40,464	96,911,546	6.02	90.1%	71.4%	92.9%	99.7%	99.1%
Fishing	13,038	4,464,886	118	203,351	5.80	81.9%	38.4%	82.0%	21.2%	90.9%
Non Merchant	228	280,349	80	564,784	7.69	17.1%	33.0%	50.0%	38.1%	92.9%
Total	**907,980**	**19,243,402,272**	**156,010**	**13,739,351,679**	**7.39**	**87.5%**	**101.7%**	**95.2%**	**105.4%**	**100.7%**

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

Ship size in GT	Totals for Rotterdam in 2010					2010 as percentage of 2009				
	berthed		moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	207,003	90,886,100	50,572	164,875,088	6.80	83.4%	74.9%	89.5%	88.3%	97.6%
1,600-3,000	90,348	220,684,009	21,408	462,985,918	8.92	68.1%	69.5%	91.5%	92.6%	100.8%
3,000-5,000	75,089	300,589,165	16,718	587,535,081	8.64	72.8%	72.4%	90.3%	92.6%	102.8%
5,000-10,000	146,464	1,092,432,144	26,427	1,733,432,116	8.73	89.0%	89.0%	100.6%	105.4%	102.9%
10,000-30,000	200,927	4,018,013,748	26,250	4,263,190,017	8.32	97.3%	98.3%	104.3%	105.9%	98.5%
30,000-60,000	79,088	3,536,270,202	7,174	2,435,996,504	7.58	90.6%	90.3%	96.9%	94.7%	100.4%
60,000-100,000	77,700	6,240,170,098	5,815	2,857,047,814	6.31	111.4%	115.6%	114.7%	118.6%	105.2%
>100,000	31,362	3,744,356,806	1,645	1,234,289,141	5.38	121.1%	109.2%	109.3%	116.4%	103.4%
Total	**907,980**	**19,243,402,272**	**156,010**	**13,739,351,679**	**7.39**	**87.5%**	**101.7%**	**95.2%**	**105.4%**	**100.7%**

Table 5-8 Ship characteristics per EMS type for the Amsterdam port area

Ship type	Totals for Amsterdam in 2010					2010 as percentage of 2009				
	berthed		moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	14,770	486,022,036	1,707	230,394,188	5.06	77.7%	81.8%	96.8%	92.7%	99.2%
Chem.+Gas tanker	41,975	750,914,657	6,099	476,071,570	5.56	75.7%	81.5%	91.6%	90.1%	100.3%
Bulk carrier	55,176	2,515,308,525	3,032	625,795,147	4.97	112.6%	116.9%	100.8%	95.8%	94.5%
Container ship	3,498	82,928,882	247	29,161,967	5.49	82.6%	53.4%	34.1%	19.7%	100.3%
General Dry Cargo	86,985	285,463,584	8,104	143,448,271	6.37	89.2%	95.9%	97.2%	91.6%	95.6%
RoRo Cargo / Vehicle	11,479	284,575,061	2,011	249,632,586	5.79	52.3%	62.1%	102.7%	92.4%	100.0%
Reefer	15,550	65,008,850	465	10,732,793	4.91	87.5%	82.4%	77.9%	72.2%	99.7%
Passenger	5,296	174,978,370	1,115	262,223,912	6.02	156.2%	134.7%	109.8%	102.6%	99.6%
Miscellaneous	39,471	182,538,322	3,502	78,305,805	4.61	115.7%	116.7%	116.7%	104.1%	90.6%
Tug/Supply	131,971	72,954,853	18,350	37,323,097	5.24	124.6%	132.1%	107.6%	110.0%	97.1%
Fishing	24,531	90,156,831	440	7,222,340	4.39	126.5%	118.0%	98.6%	97.0%	104.2%
Non Merchant	10,258	4,501,710	285	822,887	6.06	96.4%	78.5%	157.4%	123.6%	88.0%
Total	**440,961**	**4,995,351,681**	**45,357**	**2,151,134,564**	**5.38**	**100.6%**	**98.3%**	**101.4%**	**89.9%**	**97.6%**

Table 5-9 Ship characteristics per EMS ships size classes for the Amsterdam port area

Ship size in GT	Totals for Amsterdam in 2010					2010 as percentage of 2009				
	berthed		moving			berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	176,829	95,045,953	21,848	58,105,424	5.79	118.4%	107.8%	109.3%	105.7%	99.0%
1,600-3,000	76,273	180,681,712	6,566	101,994,323	6.45	96.9%	98.7%	106.4%	102.8%	95.9%
3,000-5,000	33,641	131,572,147	2,685	64,641,392	5.98	97.7%	96.9%	94.6%	92.5%	96.9%
5,000-10,000	36,219	261,689,706	4,287	192,400,232	5.98	81.9%	81.4%	90.3%	89.0%	99.1%
10,000-30,000	59,681	1,245,581,000	5,554	586,253,600	5.40	78.3%	83.3%	87.7%	86.4%	98.7%
30,000-60,000	41,840	1,702,005,891	3,371	723,829,194	5.32	103.0%	104.1%	99.3%	98.7%	99.0%
60,000-100,000	16,307	1,361,597,402	1,039	420,887,500	4.94	109.9%	111.4%	82.4%	78.4%	93.0%
>100,000	171	17,177,872	7	3,022,899	4.22	1561.5%	1527.1%	122.6%	83.7%	69.9%
Total	**440,961**	**4,995,351,681**	**45,357**	**2,151,134,564**	**5.38**	**100.6%**	**98.3%**	**101.4%**	**89.9%**	**97.6%**

Table 5-10 Ship characteristics per EMS type for the Ems area including Germany

Ship type	Totals for Ems in 2010					2010 as percentage of 2009				
	berthed		Moving			Berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
Oil tanker	471	1,931,796	327	7,177,474	9.63	73.7%	128.9%	95.7%	121.2%	102.4%
Chem.+Gas tanker	6,428	33,443,220	2,202	106,612,639	10.36	145.0%	145.1%	124.0%	117.3%	98.9%
Bulk carrier	4,911	69,142,130	744	66,584,304	9.36	79.9%	74.1%	100.0%	85.3%	102.6%
Container ship	36,522	537,518,989	316	26,007,894	7.33	52.4%	79.5%	39.0%	60.0%	150.2%
General Dry Cargo	89,913	336,021,609	9,243	312,144,196	9.77	69.5%	74.5%	98.5%	105.0%	102.4%
RoRo Cargo / Vehicle	39,319	604,143,352	8,341	1,322,736,485	12.36	77.6%	98.7%	98.7%	120.8%	100.3%
Reefer	2,293	5,404,477	199	5,927,578	10.55	61.0%	41.8%	98.7%	95.0%	103.0%
Passenger	25,776	103,253,615	3,818	91,744,981	9.71	103.8%	99.1%	98.8%	147.5%	89.8%
Miscellaneous	44,736	71,273,462	10,575	235,565,069	7.26	102.3%	125.9%	90.2%	84.3%	102.2%
Tug/Supply	106,500	69,273,902	7,297	34,551,665	7.86	127.5%	215.8%	120.2%	222.7%	114.3%
Fishing	1,717	1,188,433	176	629,870	7.44	29.5%	46.0%	37.0%	45.7%	91.0%
Non Merchant	942	3,291,973	34	351,033	10.76	176.6%	1426.9%	32.8%	161.2%	199.0%
Total	**359,528**	**1,835,886,959**	**43,273**	**2,210,033,190**	**10.65**	**85.0%**	**88.9%**	**98.5%**	**111.9%**	**105.0%**

Table 5-11 Ship characteristics per EMS ships size classes for the Ems area including Germany

Ship size in GT	Totals for Ems in 2010					2010 as percentage of 2009				
	berthed		moving			Berthed		moving		
	Hours	GT.hours	Hours	GT.nm	Average speed	Hours	GT.hours	Hours	GT.nm	Average speed
100-1,600	158,718	62,794,783	15,796	71,645,034	8.92	98.3%	73.6%	99.0%	96.4%	103.7%
1,600-3,000	73,600	167,664,358	12,586	257,555,499	9.71	82.2%	79.7%	106.3%	107.0%	101.3%
3,000-5,000	40,519	160,991,369	3,183	120,280,873	9.76	65.6%	66.8%	55.3%	60.8%	118.7%
5,000-10,000	49,488	365,291,676	8,875	556,763,541	9.67	75.9%	72.3%	118.7%	120.3%	103.0%
10,000-30,000	24,849	492,146,920	1,377	314,928,248	11.33	77.4%	84.1%	72.6%	84.7%	105.9%
30,000-60,000	10,792	459,296,718	1,208	701,354,236	12.17	89.8%	137.4%	132.2%	131.5%	101.0%
60,000-100,000	1,275	93,885,989	214	158,780,693	11.68	186.8%	208.9%	198.8%	200.6%	101.0%
>100,000	287	33,815,146	34	28,725,066	6.93	58.8%	56.8%	216.2%	188.9%	87.6%
Total	**359,528**	**1,835,886,959**	**43,273**	**2,210,033,190**	**10.65**	**85.0%**	**88.9%**	**98.5%**	**111.9%**	**105.0%**

5.3 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 under 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 2010 are summarised in Table 5-12. This table also contains a comparison to 2009. The number of ships has not changed significantly. However, the emissions of all substances decreased, with strong reductions for VOC and CO and moderate reductions for the other substances. As explained in Section 3.2.2, this is the result of changed load correction and emission factors. Only the emission of CO_2 is not influenced by these changed factors and it is therefore almost equal to 2009.

This conclusion is supported by Table 5-13 and Table 5-14 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.

The number of ships is almost identical to 2009. There are only minor shifts between the ship type and size classes. There is an almost negligible decrease in non-moving ships and increase in moving ships. Also the average speed is almost identical to the average speed in 2009.

The emissions of ships at anchor are very limited, approximately 4% of the total emissions at the NCS, while 36% of all ships in the NCS are at anchor.

Table 5-12 Emissions of ships in ton at the NCS for 2010 compared with 2009

Nr	Substance	Emission in ton in 2010				Emission in 2010 as percentage of 2009			
		not moving auxiliary engine	Moving		Total	not moving	Moving		Total
			Auxiliary Engine	Main Engine			Auxiliary Engine	Main Engine	
1237	VOC	85	185	1,840	2,110	91.65%	79.34%	88.56%	87.79%
4001	SO_2	1,104	2,662	26,011	29,777	88.67%	87.91%	96.41%	95.27%
4013	NO_x	2,666	6,561	73,266	82,492	95.21%	95.26%	98.02%	97.70%
4031	CO	509	1,172	10,780	12,461	94.90%	89.84%	86.04%	86.71%
4032	CO_2	144,601	354,111	2,906,541	3,405,253	95.37%	96.83%	99.96%	99.42%
6601	Aerosols MDO	139	315	64	519	87.96%	81.94%	81.59%	83.42%
6602	Aerosols HFO	n.a.	n.a.	3,989	3,989	n.a.	n.a.	97.04%	97.04%
6598	Aerosols MDO+HFO	139	315	4,054	4,508	87.96%	81.94%	96.75%	95.25%
Ships		96.64	168.78		265.42	99.82%	100.14%		100.02%

Table 5-13 Ship characteristics per EMS type for the Netherlands Continental Shelf

Ship type	Totals for NCS in 2010					2010 as percentage of 2009				
	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	165,023	8,313,144,939	84,293	42,940,660,523	10.86	99.7%	100.5%	99.0%	99.9%	99.9%
Chem.+Gas tanker	329,420	4,148,204,940	257,227	30,302,574,550	11.67	100.4%	100.1%	100.3%	100.0%	99.9%
Bulk carrier	31,299	1,104,479,640	78,248	26,478,307,765	11.67	100.2%	100.0%	100.0%	100.3%	99.9%
Container ship	77,024	1,756,675,206	172,996	95,253,981,416	16.49	98.8%	99.6%	99.2%	99.9%	100.0%
General Dry Cargo	87,624	316,058,160	430,307	17,472,047,321	11.14	99.1%	97.9%	99.8%	100.4%	100.1%
RoRo Cargo / Vehicle	6,988	190,292,286	111,377	45,040,244,156	15.95	107.3%	101.2%	100.5%	101.2%	100.1%
Reefer	4,095	26,135,196	25,711	3,278,487,383	15.89	100.2%	100.1%	100.7%	100.9%	99.9%
Passenger	522	15,644,946	21,464	14,392,015,314	17.59	943.8%	768.5%	101.2%	101.1%	98.6%
Miscellaneous	68,283	500,980,133	131,230	4,636,072,137	6.56	100.1%	100.4%	100.7%	99.9%	99.8%
Tug/Supply	71,932	111,663,501	135,927	1,251,196,426	7.12	102.2%	102.1%	102.7%	101.4%	99.4%
Fishing	6,474	3,619,865	31,389	243,096,650	8.60	114.4%	107.9%	125.4%	104.9%	96.5%
Non Merchant	161	41,145	2,395	22,933,260	11.80	9.1%	7.0%	40.5%	85.0%	138.3%
Total	**848,844**	**16,486,939,958**	**1,482,566**	**281,311,616,900**	**13.44**	**100.1%**	**100.3%**	**100.4%**	**100.3%**	**99.9%**

Table 5-14 Ship characteristics per ship size class for the Netherlands Continental Shelf

Ship size in GT	Totals for NCS in 2010					2010 as percentage of 2009				
	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	75,625	55,130,995	243,525	1,454,445,746	7.16	102.1%	104.0%	103.2%	101.5%	100.1%
1,600-3,000	114,445	270,331,978	340,438	7,521,305,021	9.41	99.6%	99.9%	99.3%	99.0%	99.6%
3,000-5,000	96,674	380,187,591	191,969	8,168,599,874	10.77	100.4%	100.4%	100.9%	100.9%	100.0%
5,000-10,000	143,095	1,063,570,286	205,948	18,413,860,353	12.30	99.7%	99.7%	99.7%	99.7%	100.0%
10,000-30,000	270,048	5,205,688,147	302,445	76,071,119,154	13.05	99.5%	99.8%	99.9%	100.2%	100.0%
30,000-60,000	95,263	4,521,166,898	123,457	77,514,836,146	14.13	100.9%	101.2%	99.8%	100.0%	100.0%
60,000-100,000	39,291	2,755,007,734	63,356	70,884,793,346	14.68	100.2%	100.2%	100.4%	100.4%	99.9%
>100,000	14,403	2,235,856,329	11,429	21,282,657,261	13.98	100.1%	100.1%	102.0%	101.4%	99.7%
Total	**848,844**	**16,486,939,958**	**1,482,566**	**281,311,616,900**	**13.44**	**100.1%**	**100.3%**	**100.4%**	**100.3%**	**99.9%**

5.4 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 5-15 and graphically in Figure 5-1. The average GT of the ships is given in Table 5-16. The tables show great differences between ports in the average size of the ships and in the ratio between not moving ships and moving ships. This ratio is large in Amsterdam and the Ems, which means that a relatively large number of ships are not moving, thus berthed in these areas. This ratio decreases by an increased length of the route from sea to the berth. This sailing route for example is long in the area of the Western Scheldt and in addition, the at berth emissions in Antwerp are not part of the Dutch port emissions. Also the average speed is quite different among the port areas with an average of 5.38 knots for Amsterdam and 11.49 knots in the Western Scheldt.

The percentages for the average number of ships in 2010 compared with 2009 are the same as found earlier in Table 5-4 through Table 5-11 under the column ”Hours”.

The table with the average GT shows the difference in the average size of the ships in the different port areas. The average GT of a ship in Rotterdam is more than 3.5 times higher compared to an average ship in the Ems. Further, the average GT of not moving (thus mostly berthed) ships is larger than for moving ships, which is caused by a relatively 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 increased with more than 10% compared to 2009, while the average GT in Amsterdam shows a slight decrease.

From these figures it can be concluded that due to the great 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 5-15 Average number of ships in distinguished areas

Area	in 2010				in 2010 as % percentage of 2009			
	average ships			speed	average ships			speed
	not moving	moving	total	knots	not moving	moving	Total	knots
Western Scheldt	36.43	21.15	57.58	11.49	103.0%	124.4%	109.9%	97.8%
Rotterdam	103.65	17.81	121.46	7.39	87.5%	95.2%	88.5%	100.7%
Amsterdam	50.34	5.18	55.52	5.38	100.6%	101.4%	100.7%	97.6%
Ems	41.04	4.94	45.98	10.65	85.0%	98.5%	86.2%	105.0%
NCS	96.64	168.78	265.52	13.44	100.1%	100.4%	100.3%	100.0%

Table 5-16 Average GT of ships in distinguished areas

Area	in 2010			In 2010 as percentage of 2009		
	average GT of ships			average GT of ships		
	not moving	moving	total	not moving	moving	total
Western Scheldt	6,802	13,740	9,351	103.3%	102.7%	106.3%
Rotterdam	21,194	11,910	19,832	116.3%	110.0%	115.2%
Amsterdam	11,328	8,810	11,093	97.7%	90.9%	97.2%
Ems	5,106	4,798	5,073	104.6%	108.2%	104.8%
NCS	19,423	14,113	16,046	100.2%	99.9%	100.0%

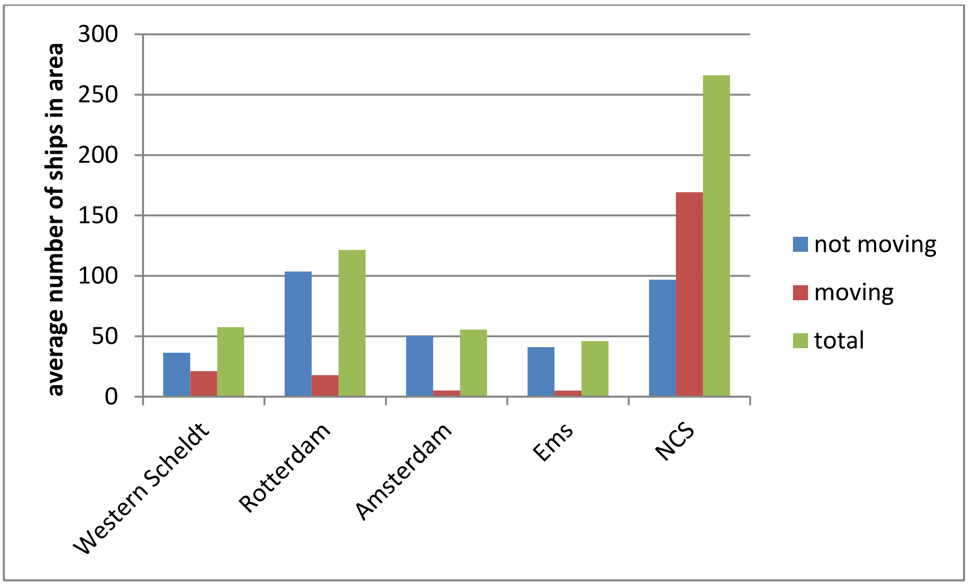

Figure 5-1 Average number of ships in distinguished areas

5.5 Spatial distribution of the emissions

All substances show more or less the same spatial distribution because there is a strong relation between the location of the emissions and the shipping routes. Therefore, only the spatial distribution of CO_2 is presented for the four Dutch port areas and the NCS in Figure 5-2 to Figure 5-12. Two figures are composed for each port area and three for the NCS.

The first figure for each area represents the total emission (emissions of auxiliary and main engine of moving and not moving ships together) expressed as CO_2 in kton/km^2. To make a comparison between areas easier the same colour table has been used for all areas.

The second figure shows the change in emission between 2009 and 2010. For all port areas the same colour table has been used, 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 5-11 uses the same scale as applied in the 2009 report [4], Figure 5-12 uses a smaller scale, because of the minimal differences between the 2009 and 2010 emissions.

The figures that compare the emission of 2010 with 2009 for the port areas visualize the conclusions in Section 5.2 about the changes in shipping activities: an increase in the Western Scheldt, Ems and the port area of Rotterdam, and a decrease in the port area of Amsterdam. Figure 5-5 for Rotterdam shows a further move of the activities from the more inland berths to the berths in Europort and Maasvlakte. Figure 5-3 shows the increase of moving vessels in the Western Scheldt close to the Belgian border due to the correction for insufficient AIS coverage.

Figure 5-12 for the NCS shows fewer emission in the shipping lanes and in most anchorage areas. The anchorage areas are marked by the shaded areas.

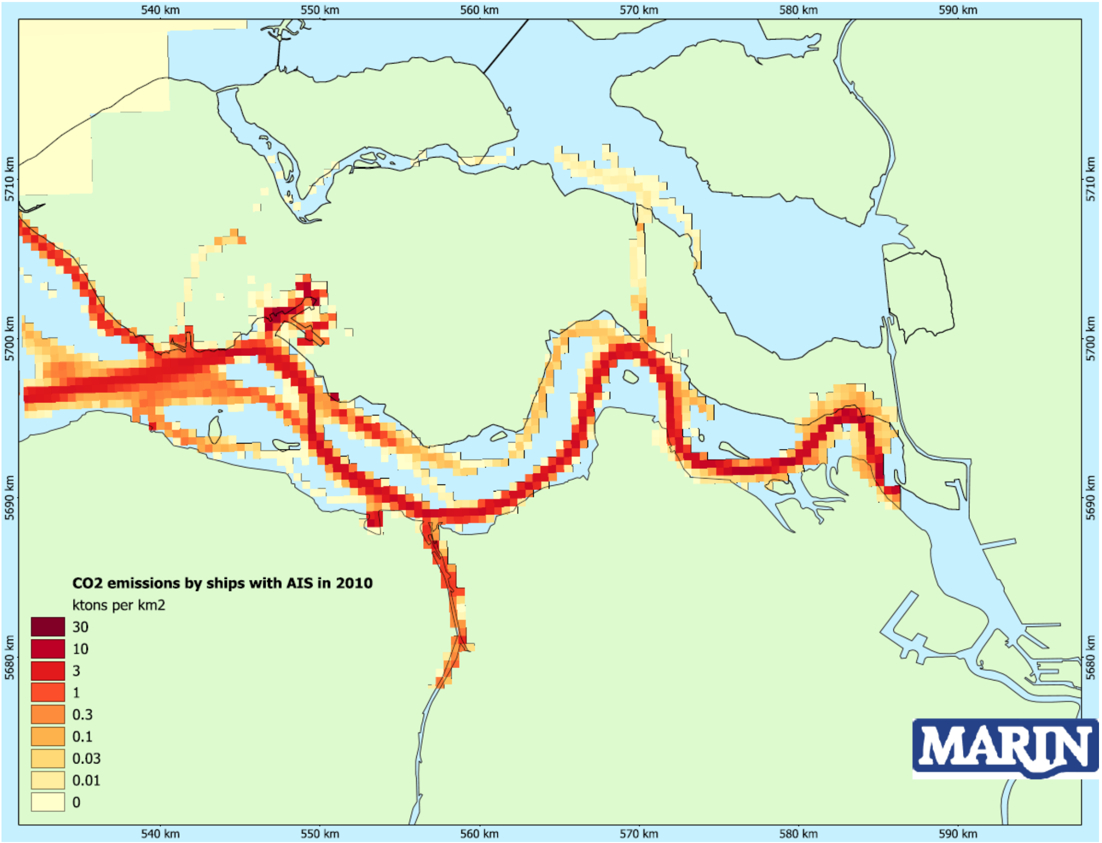

Figure 5-2 **CO_2 emission in the Dutch part of the Western Scheldt by ships with AIS in 2010, corrected for bad AIS coverage**

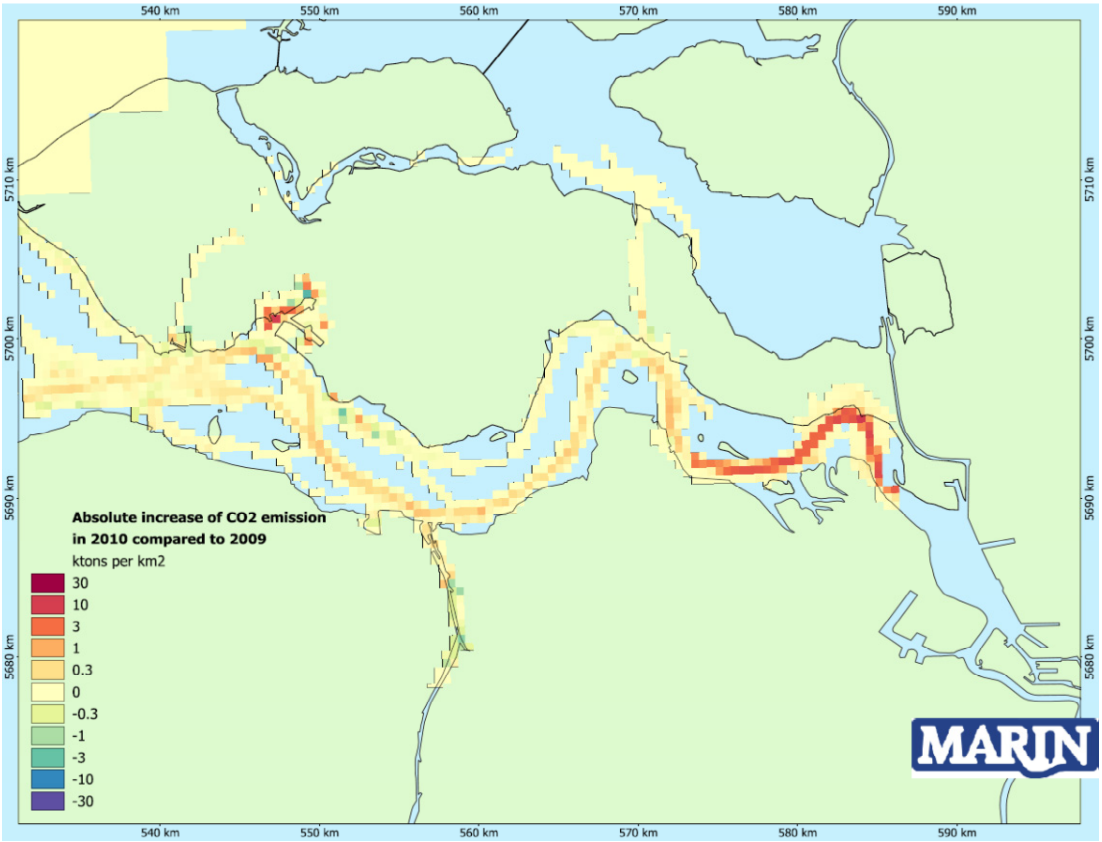

Figure 5-3 **CO_2 emission in the Dutch part of the Western Scheldt by ships with AIS. Emission in 2010 – emission in 2009. The 2010 emissions are corrected for bad AIS coverage.**

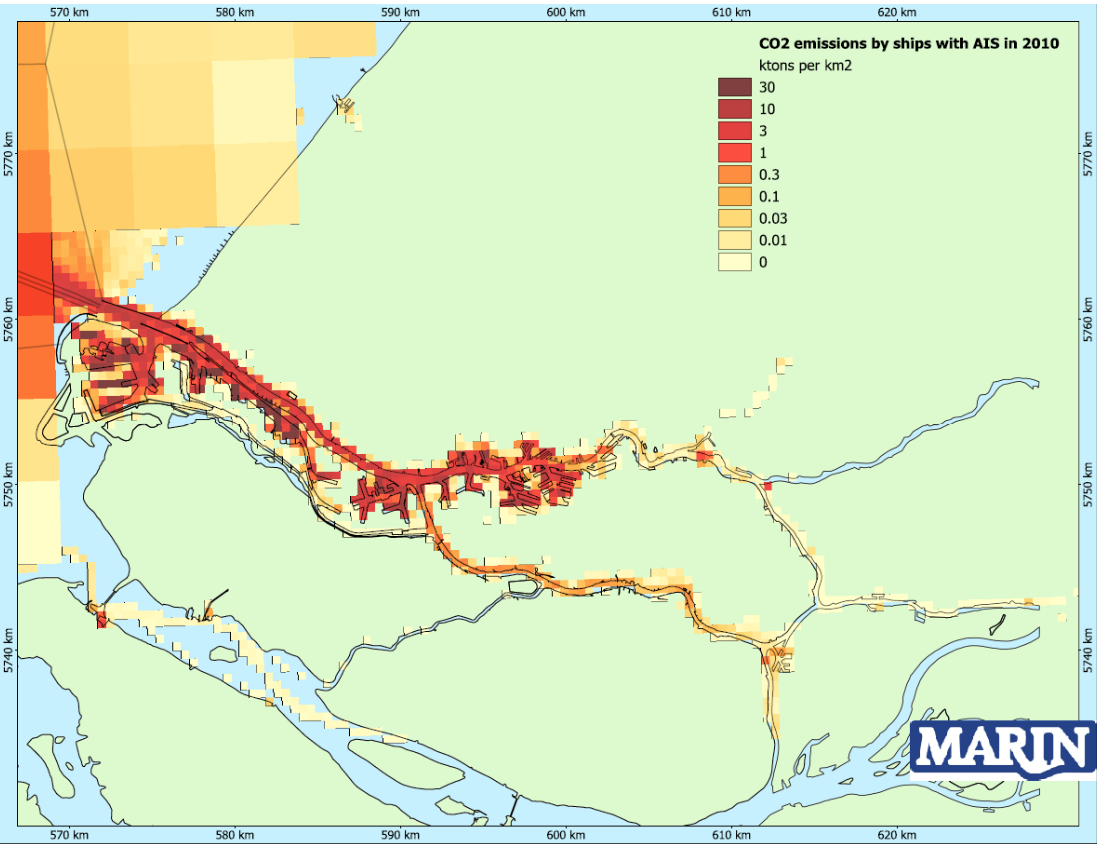

Figure 5-4 **CO_2 emission in the port area of Rotterdam by ships with AIS in 2010**

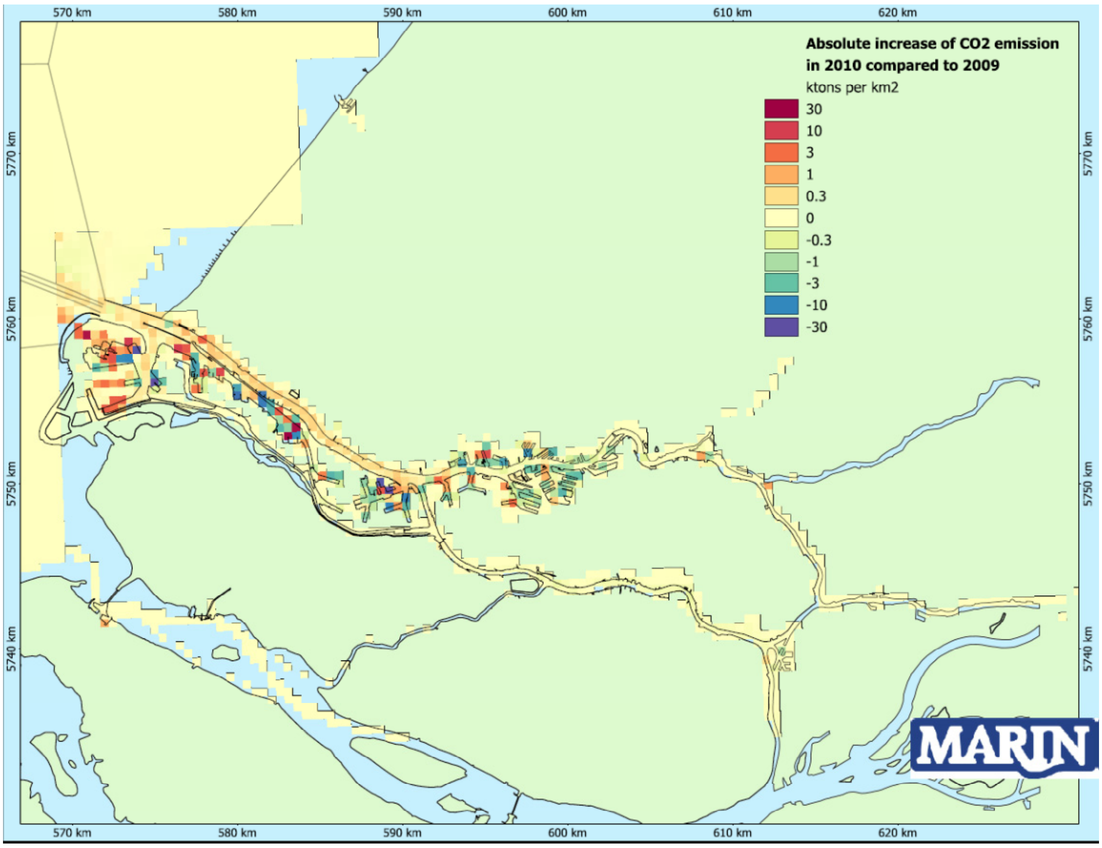

Figure 5-5 **CO2 emission in the port area of Rotterdam by ships with AIS. Emission in 2010 – emission in 2009**

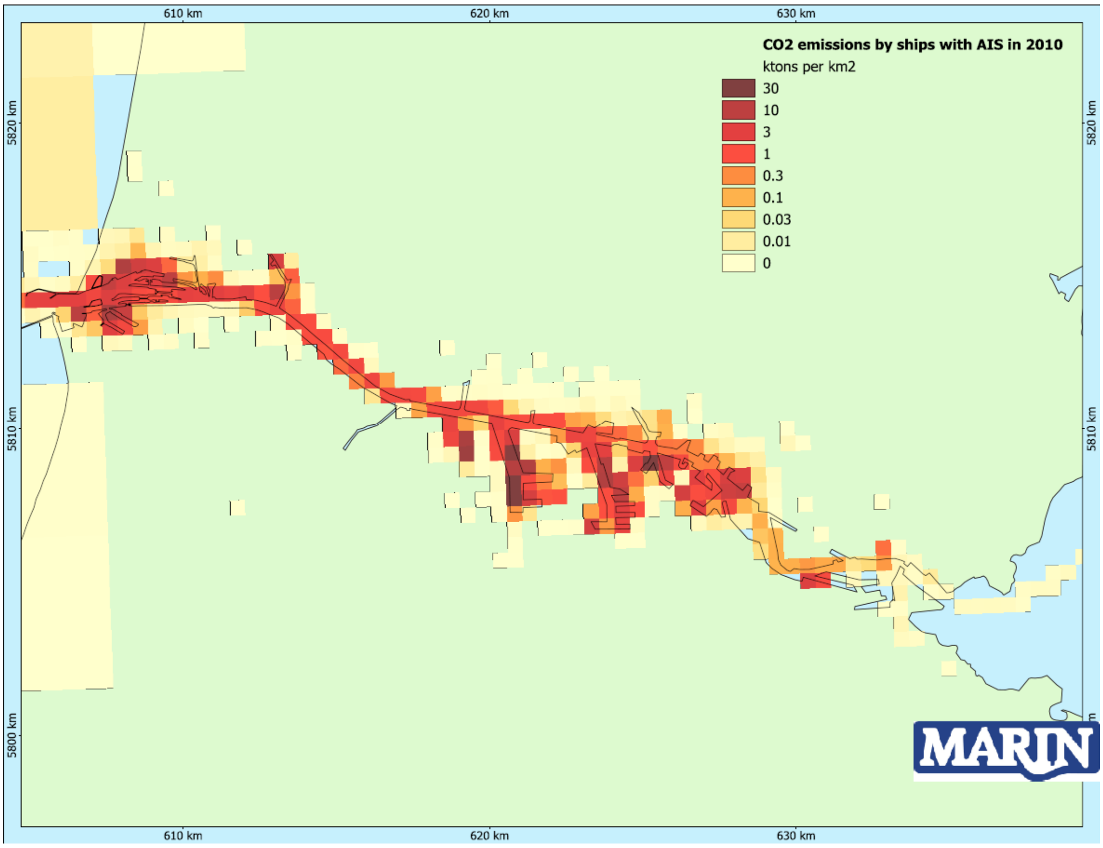

Figure 5-6 CO_2 emission in the port area of Amsterdam by ships with AIS in 2010

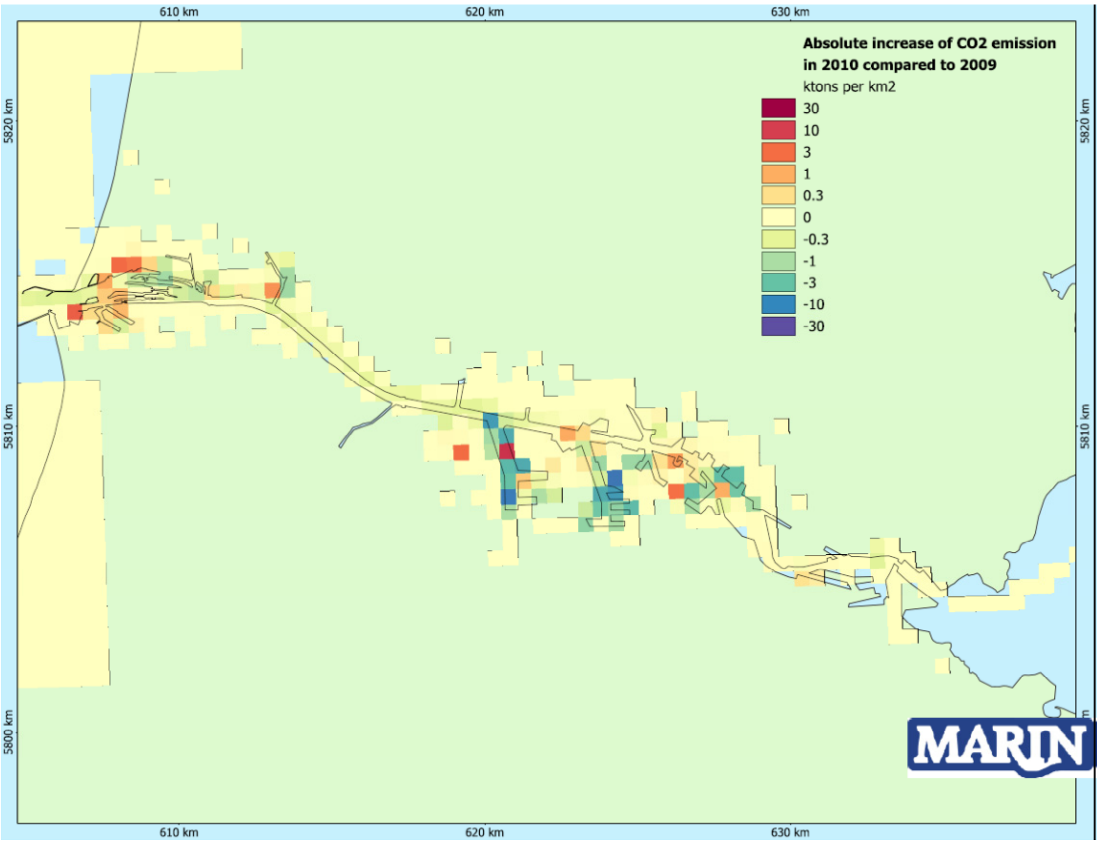

Figure 5-7 CO_2 emission in the port area of Amsterdam by ships with AIS. Emission in 2010 - emission in 2009

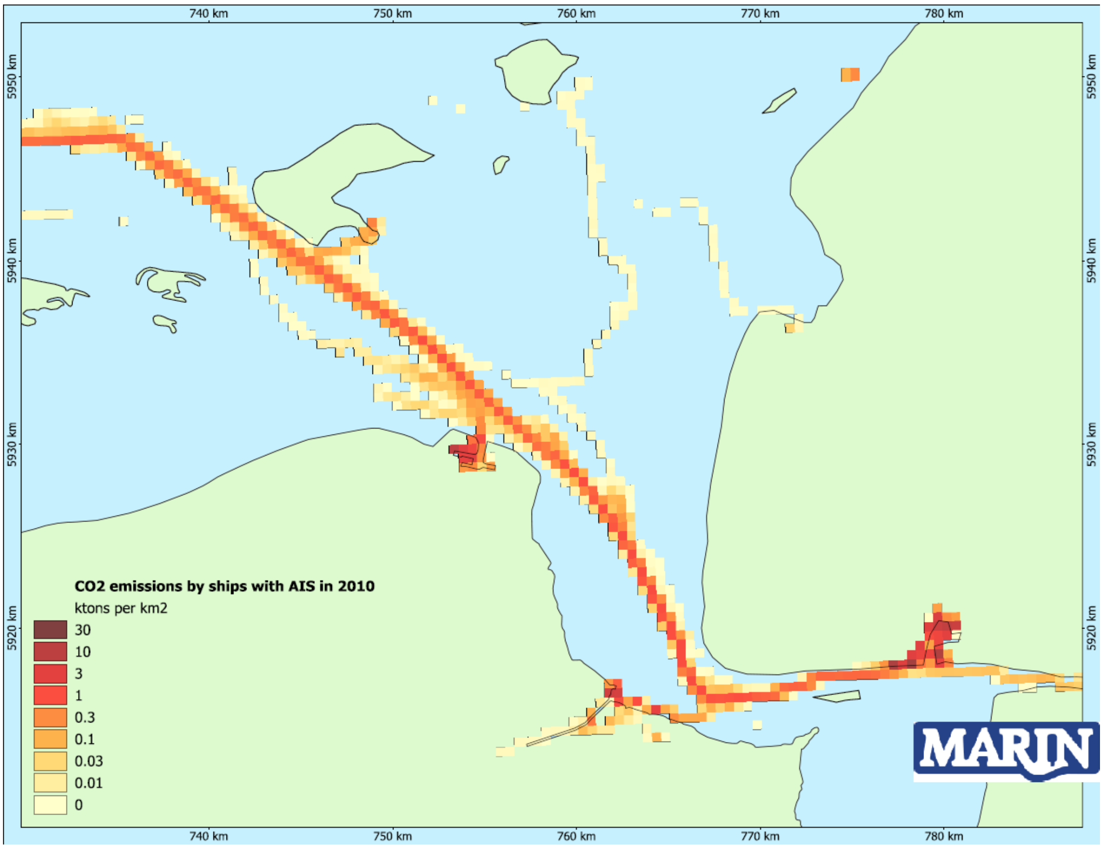

Figure 5-8 **CO_2 emission in the Ems area by ships with AIS in 2010**

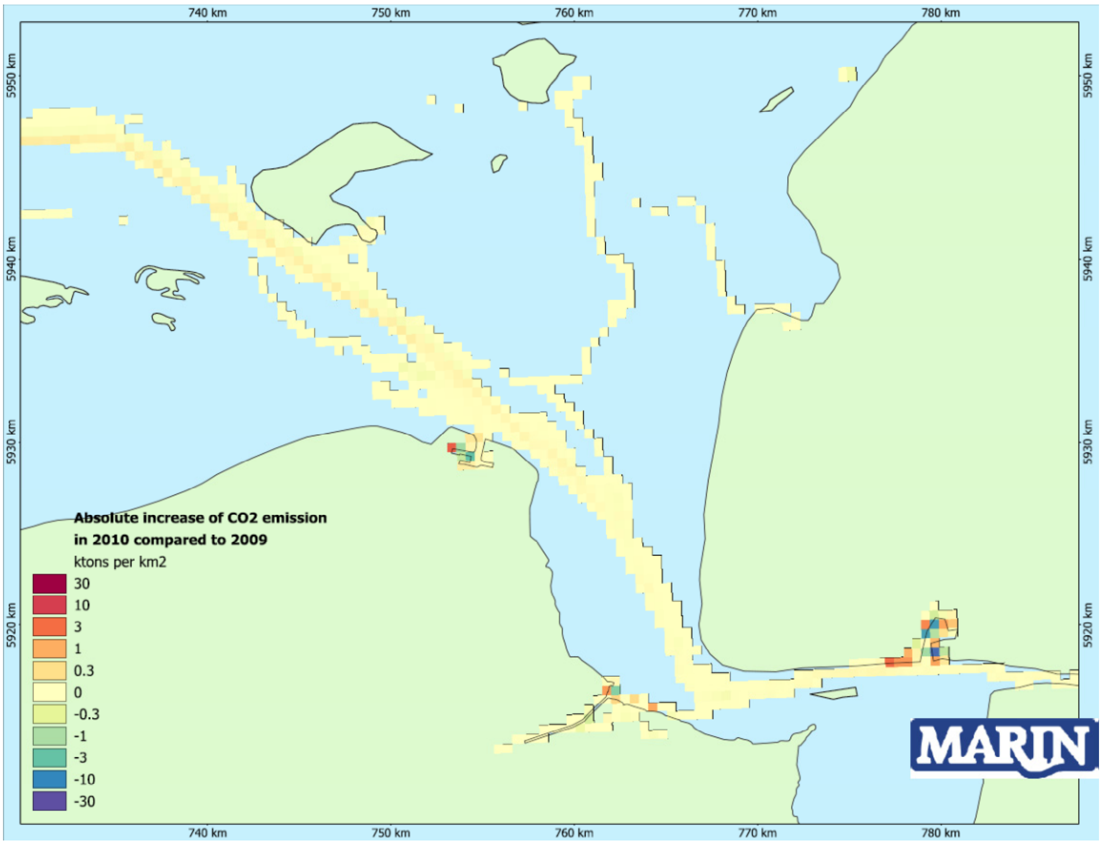

Figure 5-9 **CO_2 emission in the Ems area by ships with AIS in 2010. Emission in 2010 – emission in 2009**

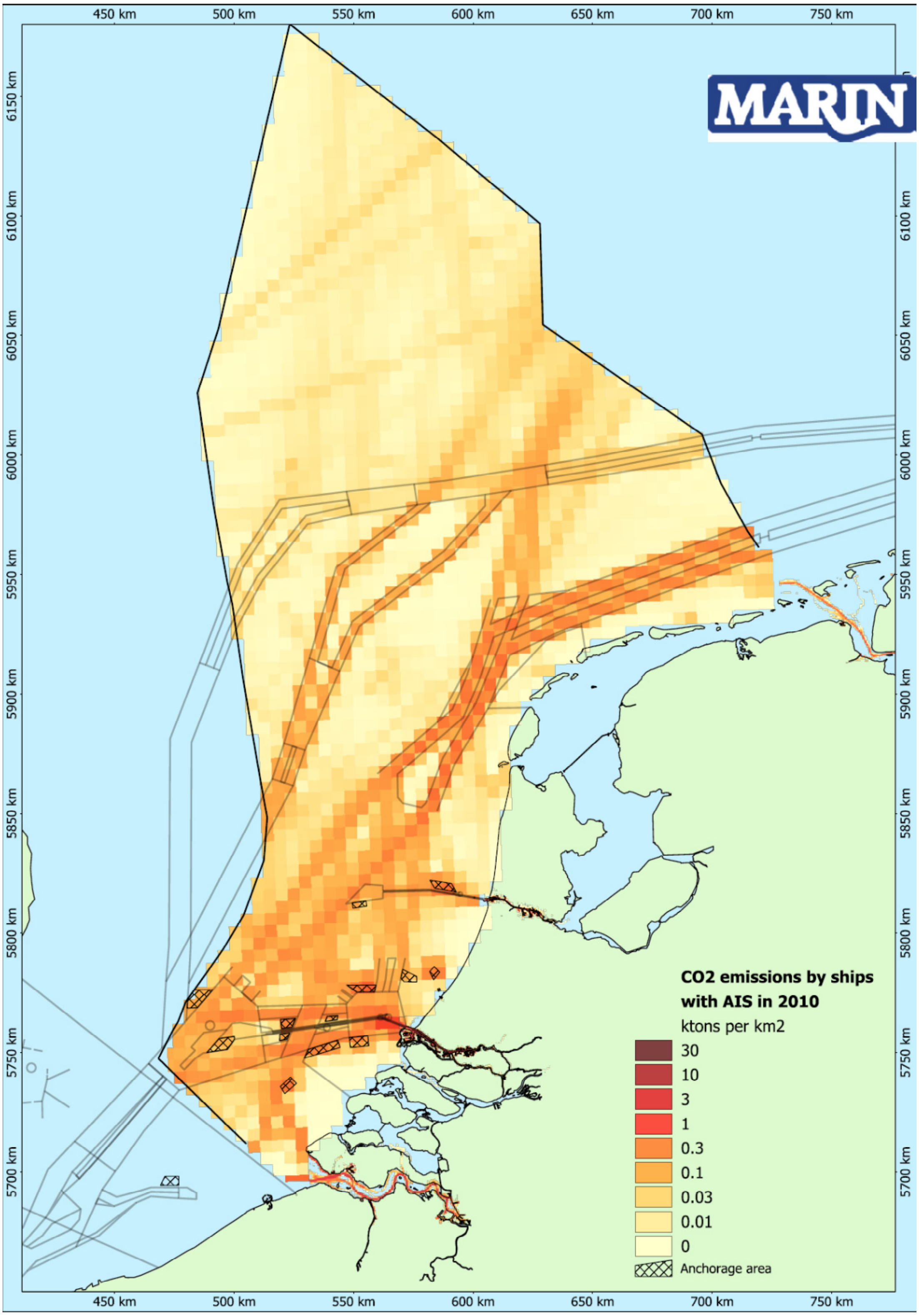

Figure 5-10 **CO_2 emission at the NCS including Dutch port areas by ships with AIS in 2010**

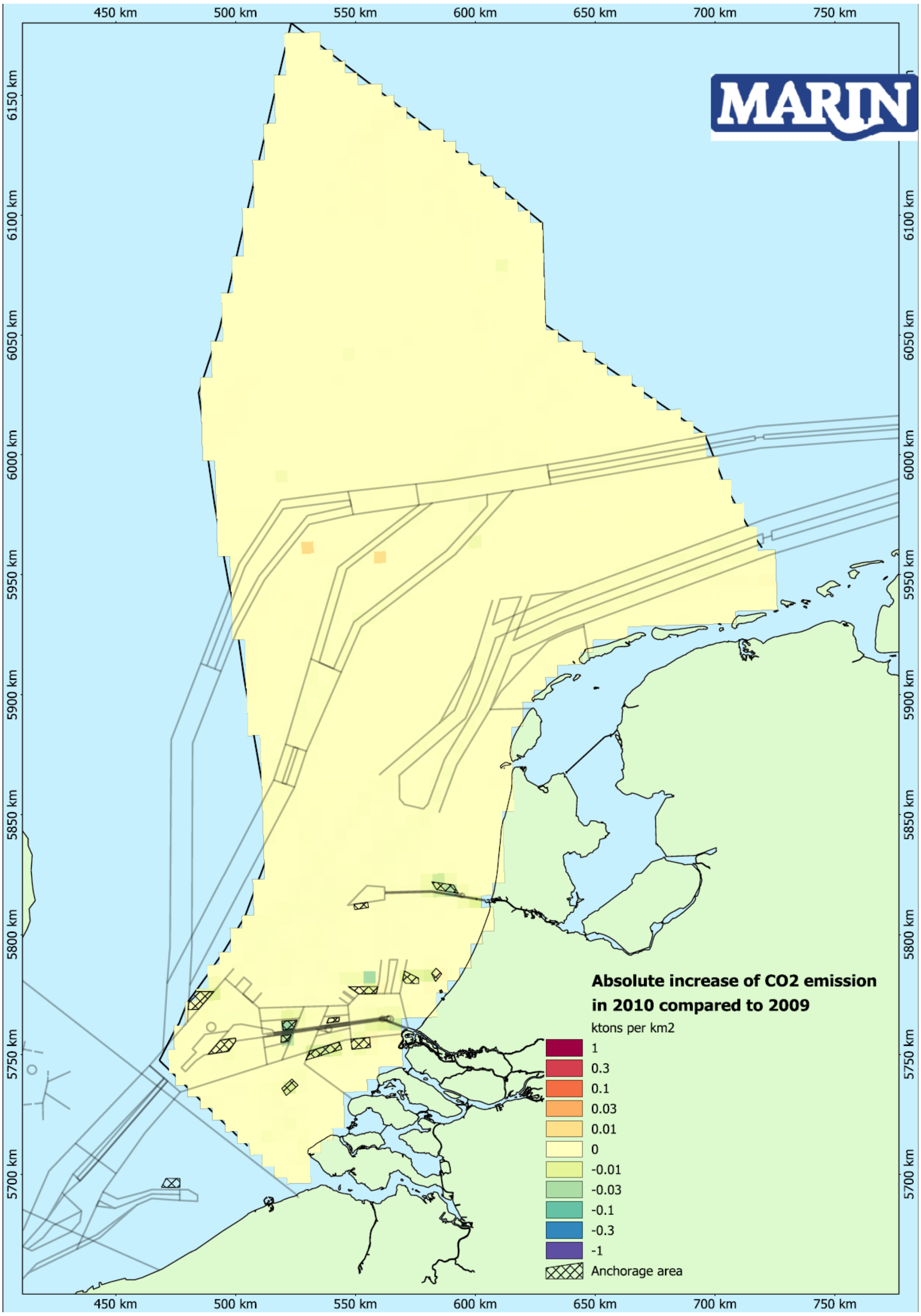

Figure 5-11 CO_2 emission at the NCS by ships with AIS in 2010 with similar scale as in 2009 report. Emission in 2010 – emission in 2009

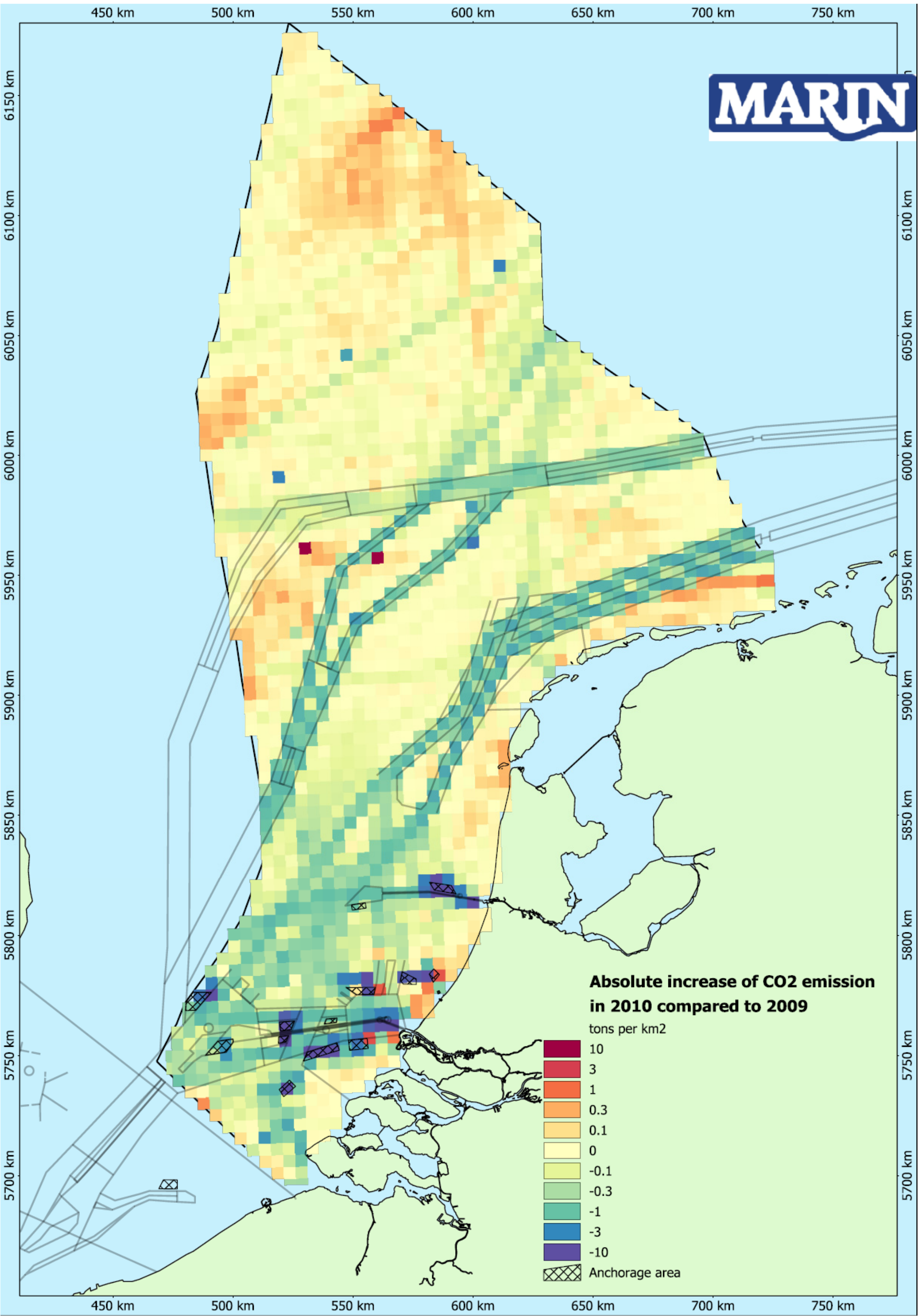

Figure 5-12 **CO_2 emission at the NCS by ships with AIS in 2010 with smaller scale than in 2009 report. Note that the legend is in tons instead of in ktons. Emission in 2010 – emission in 2009**

6 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.

6.1 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 ship type and 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 2010 at the NCS are superimposed on the traffic distribution in the OSPAR region II, assuming that these changes at the NCS are also representative for the total OSPAR region II. Figure 6-1 shows all traffic links in the 2008 traffic database.

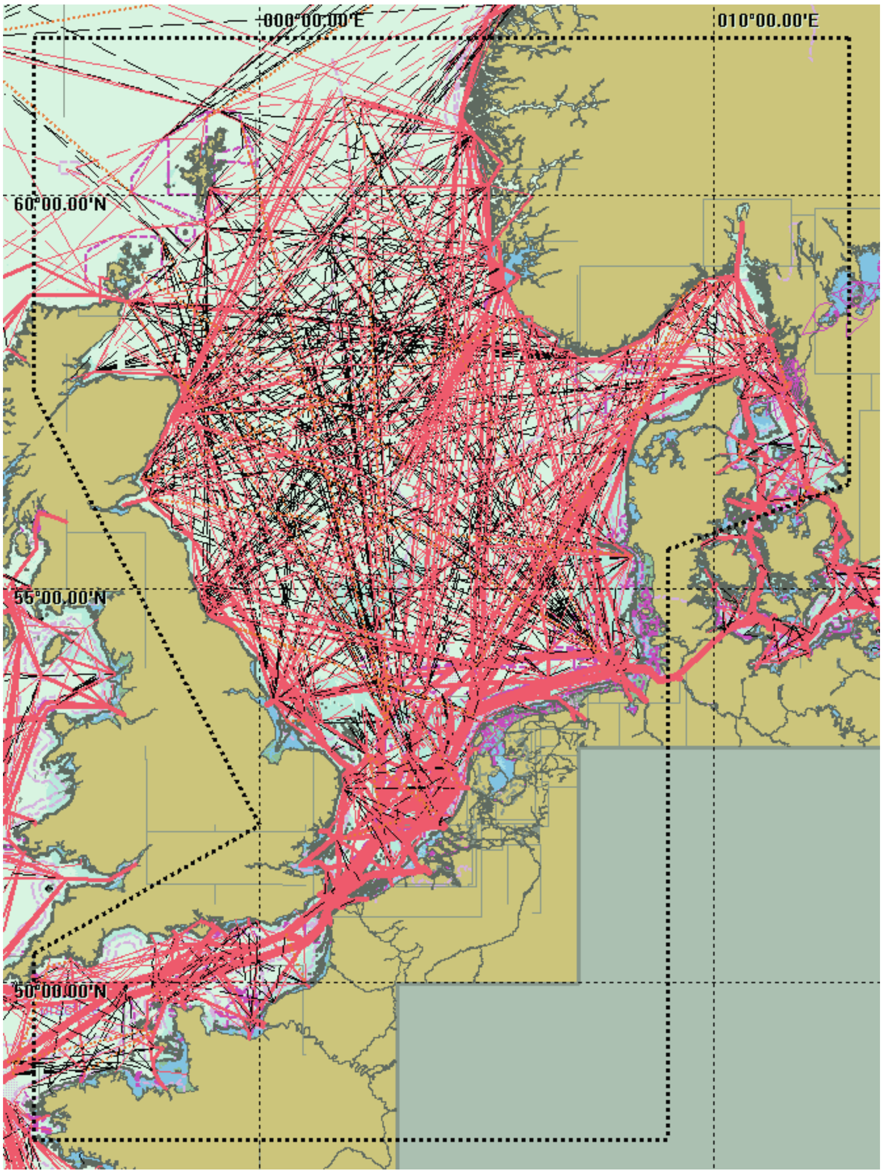

Figure 6-1 Traffic links in OSPAR region II, the width indicates the intensity of ships on the link, red links represent a higher intensity than black links

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.

The SAMSON traffic database contains the number of ship movements per year for each traffic link divided over 36 ship types and 8 ship size classes.

Based on analyses in the past, SAMSON uses 90% of the service speed for v_{ij}, the average speed in knots for ship type i and size j. However, the AIS analysis of [5] showed that it was approximately 87% of the service speed before the crisis and 85% in 2010, 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. 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 2010. This includes the real speed distribution of 2010 at sea.
4. A correction has to be applied because the shipping volumes in 2010, 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 2010 at the NCS, contains implicitly the behaviour of the ships in 2010, 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 2010 for which the emissions in OSPAR region II have to be calculated differs from the year 2008 of the SAMSON traffic database. This correction is essential, because it has been observed that the traffic volume in 2010 was lower than in 2008, because of the crisis that started in the last months of 2008 for the transport over sea and continued afterwards. The number of calls in most ports was lowered. To account for this, the ratio between the number of miles travelled in 2010 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.

$$F_{ij}^{traffic} = \frac{nm_{ij}^{2010,AIS}}{nm_{ij}^{2008,AIS}}$$

This factor is then 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. A correction factor per individual ship type and size accounts for different impacts of the crisis on tankers, container ships etc. And for different impacts for larger ships than for smaller ships.

6.2 Procedure for port areas outside AIS coverage

6.2.1 At berth

To assess the emissions at berth in the foreign port areas, 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 have been 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 at berth hours per ship type and ship size were multiplied by the average emissions per at berth hour 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 2010 and 2008 at the NCS ($F_{ij}^{traffic}$) to account for changes in traffic volume between 2008 and 2010. It is assumed that this ratio is representative for the changes in at berth time as well.

6.2.2 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 6-2 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 have been calculated.

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 2010 and 2008 at the NCS ($F_{ij}^{traffic}$) to account for changes in traffic volume between 2008 and 2010. It is assumed that the ratio determined for the NCS also applies to sailing in the harbours.

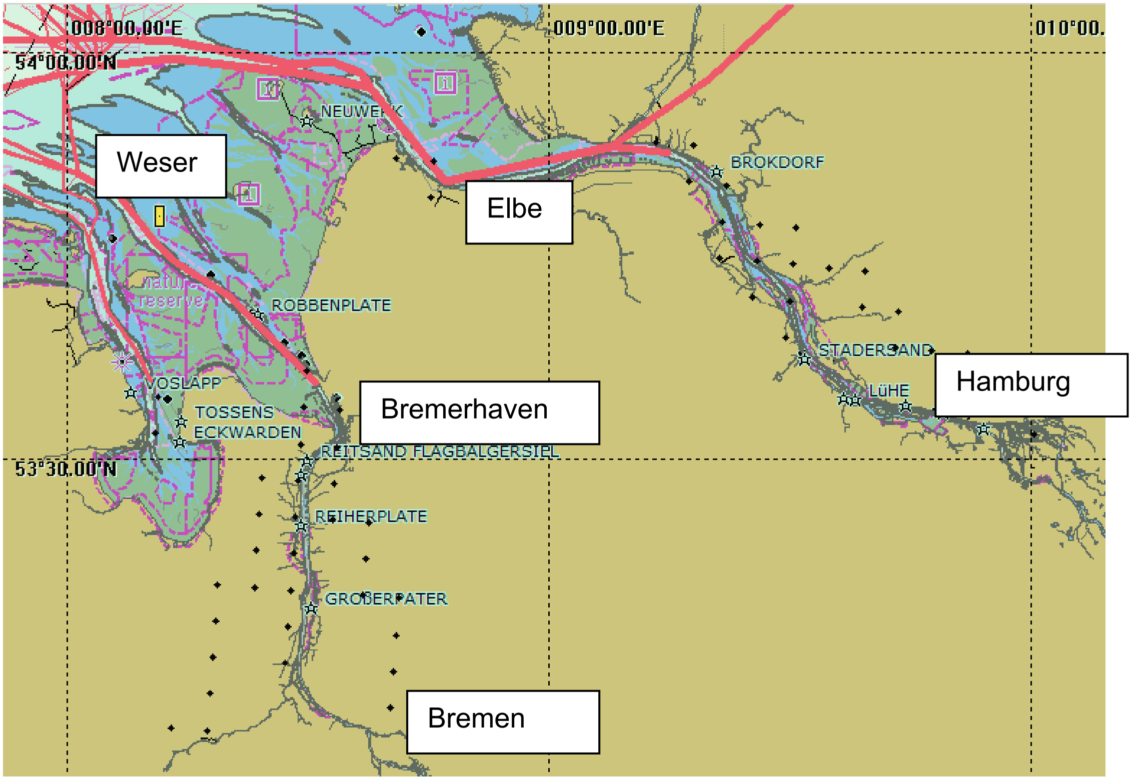

Figure 6-2 **Elbe and Weser area: Grid cells for which emissions of moving ships have been calculated are shown by black dots. Links of SAMSON traffic database are shown by red lines.**

6.3 Procedure for added ferries

The Lloyd's List Intelligence voyage database for 2008 contains only the ferries that cross at the most once a day. 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. The traffic database composed for these ferry lines is given in Figure 6-3. 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 Norwegian are not included.

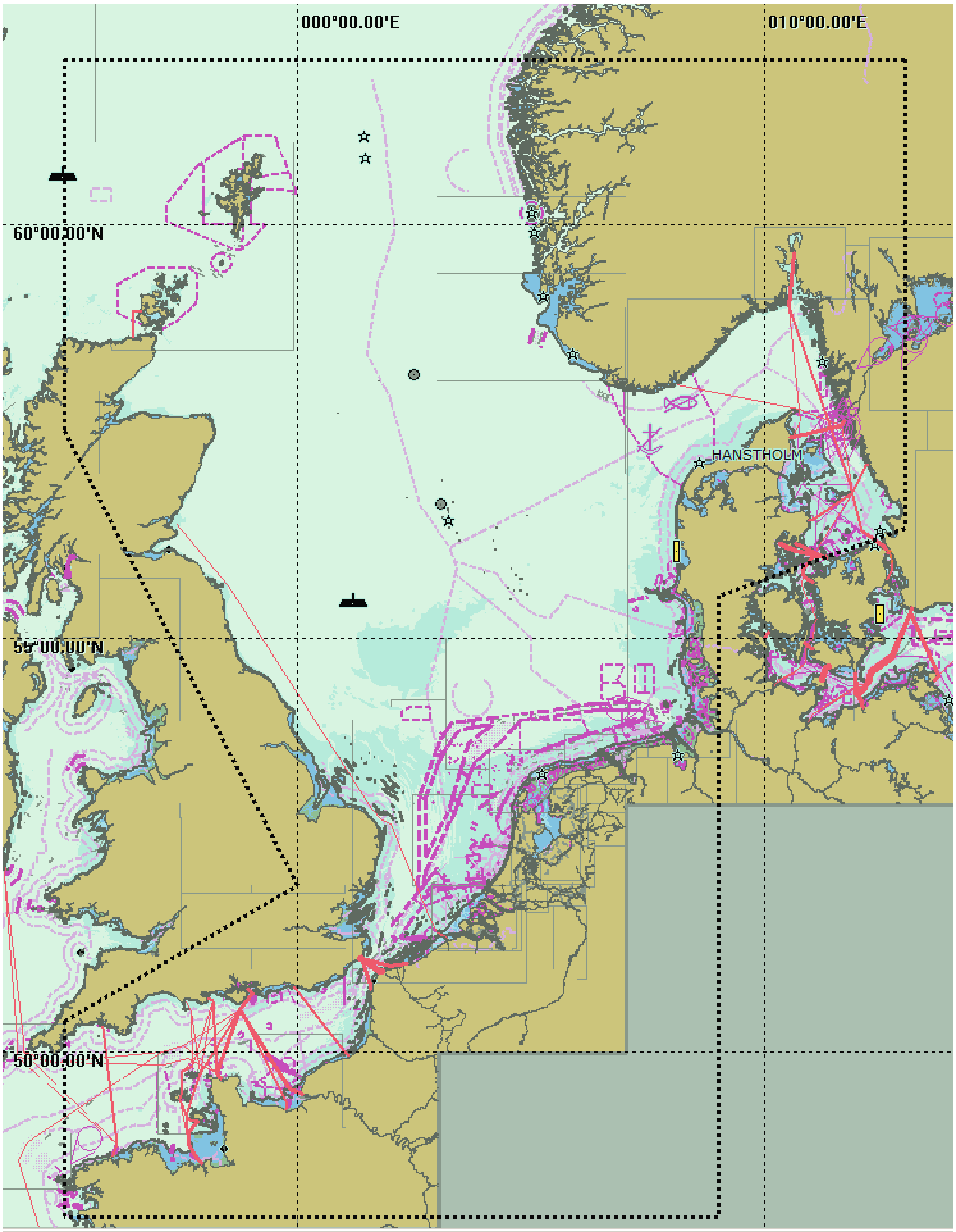

Figure 6-3 **The ferry lines that are added to the traffic database are shown by red lines. The width of these lines is an indication for the number of movements**

7 EMISSIONS FOR 2010 AND COMPARISON WITH 2009 IN PORT AREAS AND AT SEA FOR OSPAR REGION II

7.1 OSPAR region II at sea

The emissions for the total OSPAR region II are summarised in Table 7-1. The average number of ships at sea in the OSPAR region II amounts to 915.8. 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 2010 and after applying the correction factor for the traffic volume in 2010.

The emissions for most substances are lower than those for 2009 and for VOC and CO the reductions are significant. As explained in Section 3.2.2, this is the result of changed load correction and emission factors. Only the values for CO_2 are not influenced by changed factors and they show a slight increase.

Table 7-1 Emissions of ships in OSPAR region II at sea for 2010, based on SAMSON

Nr	Substance	Emission in ton in 2010			Emission in 2010 as percentage of 2009		
		moving		Total	moving		Total
		Auxiliary Engine	Main Engine		Auxiliary Engine	Main Engine	
1237	VOC	998	9,907	10,905	80.8%	90.0%	89.1%
4001	SO_2	14,478	140,737	155,214	90.0%	98.1%	97.3%
4013	NO_x	35,580	395,215	430,795	97.5%	99.5%	99.3%
4031	CO	6,354	57,097	63,451	91.9%	87.1%	87.6%
4032	CO_2	1,921,852	15,789,546	17,711,397	99.1%	101.9%	101.6%
6601	Aerosols MDO	1,715	373	2,088	83.9%	83.2%	83.7%
6602	Aerosols HFO	n.a.	23,006	23,006	n.a.	105.8%	105.8%
6598	Aerosols MDO+HFO	1,715	23,379	25,094	83.9%	105.3%	103.5%
Average number of ships in area		915.83			102.8%		

Table 7-2 contains the emissions for 2010 at the NCS based on the SAMSON database. The emissions at the NCS amount to approximately 19% of the emissions in the OSPAR region II, whereas the number of ships at the NCS is only 17% (=158.76/915.83). This is because an average ship at the NCS is larger than an average ship in OSPAR region II.

Table 7-2 Emissions of ships at the NCS at sea for 2010, based on SAMSON

Nr	Substance	Emission in ton in 2010			Emission in 2010 as percentage of 2009		
		moving		Total	moving		Total
		Auxiliary Engine	Main Engine		Auxiliary Engine	Main Engine	
1237	VOC	181	1,865	2,046	79.3%	88.8%	87.9%
4001	SO_2	2,664	26,650	29,314	88.3%	96.7%	95.8%
4013	NO_x	6,478	75,192	81,671	95.5%	98.1%	97.9%
4031	CO	1,160	10,873	12,034	90.2%	86.1%	86.5%
4032	CO_2	351,085	2,978,174	3,329,259	97.2%	100.3%	99.9%
6601	Aerosols MDO	315	63	378	82.2%	81.1%	82.0%
6602	Aerosols HFO	n.a.	4,358	4,358	n.a.	103.6%	103.6%
6598	Aerosols MDO+HFO	315	4,421	4,736	82.2%	103.2%	101.4%
Average number of ships in area		158.76			100.3%		

In Table 7-3 the calculated emission from SAMSON is compared with the emission determined from the AIS data. The emissions based on both methods 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 for each ship type and size calculated from the AIS data has been used within the calculation of the emissions from 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 are below 3% except for Aerosols HFO; the emission of this substance is 9% higher for the SAMSON method compared to the AIS method. The emission of Aerosols HFO has decreased according to AIS, but increased according to SAMSON.

The average number of ships at the NCS based on AIS corresponds quite well with the number 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.

Table 7-3 Emissions of ships at the NCS at sea for 2010, based on SAMSON and AIS

Nr	Substance	Emission in ton in 2010			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	181	1,865	2,046	98.1%	101.3%	101.0%
4001	SO_2	2,664	26,650	29,314	100.1%	102.5%	102.2%
4013	NO_x	6,478	75,192	81,671	98.7%	102.6%	102.3%
4031	CO	1,160	10,873	12,034	99.0%	100.9%	100.7%
4032	CO_2	351,085	2,978,174	3,329,259	99.1%	102.5%	102.1%
6601	Aerosols MDO	315	63	378	99.9%	97.4%	99.4%
6602	Aerosols HFO	n.a.	4,358	4,358	n.a.	109.2%	109.2%
6598	Aerosols MDO+HFO	315	4,421	4,736	99.9%	109.1%	108.4%
Average number of ships in area		158.76			93.8%		

7.2 OSPAR region II total emissions

Table 7-4 shows the emission for the total OSPAR region II both at sea and in the port areas. The following emission data has been used to come to this table:

- At sea without fishing vessels, based on SAMSON data
- Added ferries, based on SAMSON data
- Dutch port areas based on AIS data
- Foreign port areas based on LLI data

The emission of added ferries is approximately 3% of the total emission at sea including ferries.

Appendix C gives the at berth emission for all ports in OSPAR region II with CO_2 emission over 10,000 ton.

Table 7-4 Total emission of ships in ton per year in the OSPAR region II for 2010

nr	Substance	at sea, including added ferries	Moving in port area *	at berth *	Total
1237	VOC	11,245	874	1,197	13,316
4001	SO_2	160,074	9,722	2,440	172,236
4013	NOx	441,653	27,040	26,525	495,217
4031	CO	65,174	5,913	5,591	76,678
4032	CO_2	18,252,401	1,155,104	2,725,403	22,132,908
6601	Aerosols MDO	2,116	263	632	3,011
6602	Aerosols HFO	23,545	1,276	n.a.	24,821
6598	Aerosols MDO+HFO	25,661	1,539	632	27,832

* For 2010 the Western Scheldt is corrected for the bad AIS coverage and emissions in Belgium have not been taken into account

Table 7-5 gives the comparison with 2009. The at berth emission for SO_2 and aerosols has reduced significantly as a consequence of the EU-obligation for ships at berth to use fuels with a sulphur content less than 0.1 % as off January 1, 2010. The emissions for moving ships both at sea and in port areas show changes mainly due to changed emission factors and load correction factors as described in Section 3.2.2.

Table 7-5 Total emission of ships in the OSPAR region II for 2010, expressed as a percentage of the 2009 emission

nr	Substance	at sea, including added ferries	Moving in port area* **	at berth* **	Total
1237	VOC	88.7%	93.3%	97.9%	89.8%
4001	SO_2	97.0%	97.9%	18.2%	91.5%
4013	NOx	99.0%	101.1%	95.8%	99.0%
4031	CO	87.1%	97.4%	99.3%	88.6%
4032	CO_2	101.2%	103.4%	98.4%	101.0%
6601	Aerosols MDO	83.1%	87.4%	42.9%	69.7%
6602	Aerosols HFO	105.0%	97.4%	n.a.	104.6%
6598	Aerosols MDO+HFO	102.8%	95.5%	42.9%	99.2%

* For 2010 the Western Scheldt is corrected for the bad AIS coverage and emissions in Belgium have not been taken into account

** For 2009 the Western Scheldt is not corrected for the bad AIS coverage and emissions in Belgium have been taken into account

Figure 7-1 contains the spatial distribution of the CO_2 emission in OSPAR region II. It contains the same data as Table 7-4. By comparing the emission at the NCS in Figure 7-1 which is based on the SAMSON traffic database with the emission at the NCS in Figure 5-10 which is 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.

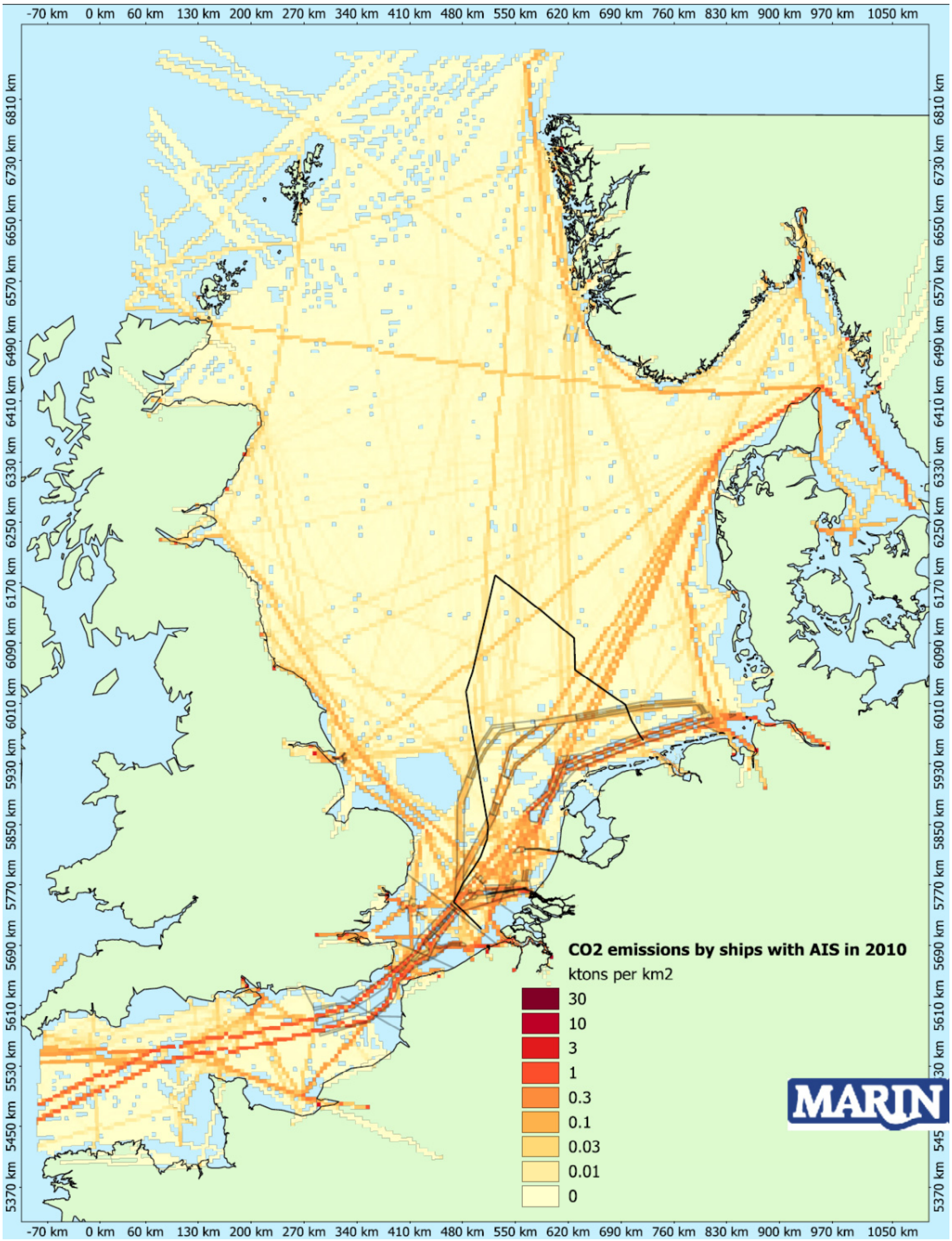

Figure 7-1 **CO_2 emission in OSPAR Region II at sea and in port areas by route bound ships**

8 CONCLUSIONS AND RECOMMENDATIONS

The main delivery of this study is a set of databases containing the emissions per grid cell distinguished into substance, EMS ship type class, ship size class, moving / not moving, EU / non-EU flag and inside/outside 12-mile zone. These databases can be used in studies for which a detailed spatial distribution of the emissions is required. Fishing vessels can be identified in the databases and easily deselected when the information is not needed.

The conclusions and recommendations given here 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.

8.1 Conclusions and findings

The general conclusions are:

- AIS data is an excellent source for the determination of the spatial distribution of emissions by ships in the Netherlands Continental Shelf and 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, adapting the emissions factors;

- The grid size of 5000 x 5000 m for the Netherlands Continental Shelf and OSPAR region II and 500 x 500 m for the Dutch port areas could be handled;

- The average number of ships at the NCS based on AIS corresponds quite well with the number 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.

- The emissions in the OSPAR region II including port areas could be estimated from the SAMSON traffic database of 2008, corrected for the change in traffic volume between 2008 and 2010, and the average emission per nautical mile at the NCS. The traffic correction factor and emission per nautical mile were derived from the AIS data of 2008 and 2010 for the NCS, assuming that they apply for the total OSPAR region II.

- In this study as well as in other studies, it was observed that the AIS coverage is weak in the shipping lane southwest of Rotterdam, close to the border with the United Kingdom Continental Shelf. This weak spot has been discussed with the Netherlands Coastguard and improvements have been made. At the end of 2010 full coverage was realised. Hopefully this situation will continue, and the 2011 emission calculation can be performed with a better quality AIS dataset.

- Improvement of the coverage of AIS or the extension of the group of AIS-users (mandatory use by fishing vessels above 15 m and voluntary use by recreational vessels) can cause a growth in the reported emissions that cannot be assigned to changes in emissions of ships. Therefore, this remains a point of attention in the future to prevent drawing wrong conclusions.

The conclusions with respect to the 2010 developments in shipping traffic and emissions are:

- At the NCS, the shipping traffic in 2010 is very similar to the shipping traffic in 2009. Despite this, the emission of all substances except CO2 is slightly or significantly reduced as a result of changed emission factors.

- Some emission factors have been changed. The main difference is caused by an EU directive. 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 leads to approximate reductions for at berth emissions of:
  - 80% for SO_2,
  - 10% for NO_x,
  - 60% for Aerosols.

- 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 2009 AIS data. The following approximate emission reductions are the result of this combined effect:
  - VOC 10%;
  - SO2 4%
  - NOx 2%
  - CO 13%
  - CO2 0%
  - Aerosols MDO 15%
  - Aerosols HFO 3%

The largest differences in port emissions between 2009 and 2010 are due to the previously mentioned changes in emission factors and load correction factors. Below the emission changes of CO_2 are given because they are only due to changed traffic.

- in Rotterdam a 4 to 9 % increase in sailing activities, and 7% decrease in emissions from at berth, resulting in an overall decrease in emissions;
- in Amsterdam for the second year in row a decrease over 10%;
- in the Western Scheldt 4% increase in sailing, 8% increase in at berth, however, the reported emissions of sailing ships increased with over 15% due to the correction for bad AIS coverage;
- in the Ems area an increase of 3% for sailing and a decrease of 13% for at berth. Last year there was a large increase due to ships at berth, so there was a slight change towards the situation in 2008.

- Part of the Western Scheldt falls outside the region with complete AIS coverage. For moving vessels, a correction has been applied for this low AIS coverage. This is the largest component of the increase of emissions compared to 2009.
- The emissions of ships at anchor are very limited, approximately 4% of the total emissions at the NCS, while 36% of all ships in the NCS are at anchor.

8.2 Recommendations

It is recommended to continue with a yearly determination of the emissions. A longer sequence will give more insight into the trends.

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

The SAMSON database has been composed from all voyages crossing the European waters. The voyage database collected by LLG, with port to port voyages, costs approximately €30,000 for one year data. Next, the SAMSON traffic database has to be composed of these voyages. Because this is rather expensive, a new traffic database in SAMSON is only created every fourth or fifth year. This traffic database in SAMSON is used during a number of years. Changes in the traffic patterns by for example, changes in the Traffic Separation Schemes and the offshore wind farms are implemented by rerouting the voyages of the last voyage database.
It is recommended to keep an update frequency of once every four years. A yearly update of the emission in the OSPAR region II can be done based on an older SAMSON traffic database.

It is recommended to investigate whether it is possible to derive the uninterrupted time at berth from the AIS data, so that for ships that are laid up, an adjusted emission factor can be used. The standard emission factor for at berth, consist for a considerable percentage of the emission from loading/unloading activities. However, this will have a considerable impact on the amount of data to be collected from the AIS. At this moment the uninterrupted time berthed is not collected and an extra parameter can lead to memory problems. Thus in case time at berth is required, this problem has to be solved.

It is recommended to check the AIS coverage every time before the emissions are reported.

Part of the Western Scheldt falls outside the region with complete AIS coverage. The correction method applied for moving vessels differs from that for vessels at berth in Antwerp. It is recommended to investigate whether the approach for moving vessels can also be applied for ships at berth in Antwerp.

The emissions in the German part of the Ems have been reported in the Dutch port database. It is recommended to move this information to the port database for OSPAR region II.

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APPENDIX A: EMISSION FACTORS

A. EMISSION FACTORS

A1.1 Sailing and Manoeuvring

A1.1.1 Main Engines

During sailing and manoeuvring, the main engine(s) is/are used to propel/manoeuvre the ship. Their emission factors per ship, in g per kWh, were determined by TNO according to the EMS protocol [1, 2]. Recently an English language report [5] was published, which covered the emission calculations in accordance with the EMS protocol. In the emission factor calculation, the nominal engine power and the speed are used. For this study these parameters were taken from the May 2011 shipping database. It is assumed that a vessel requires 85% of its maximum continuous rating power (MCR) to attain the design speed (its service speed). The following formula is used to calculate the emission factor per nautical mile.

Formula 1:

$$EF' = EF \cdot \frac{P \cdot \%MCR}{V}$$

where:

EF' the emission factor expressed as kg per nautical mile
EF the emission factor expressed as kg per KWh
P the engine power [Watts]
%MCR the percentage of the MCR
V is the vessel speed [knots]

However, 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:

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

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.

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 protocol. The correction factors were extended by distinction of different engine types. In order to get more accurate calculations three engine groups were defined: reciprocating engines, steam turbines and gas turbines.

The correction factors used are shown in Table A-1 to Table A-3. The list was extended by some values provided in the documentation of the EXTREMIS model [4].
The correction factors at MCR over 85% are equally assumed to be 1.

Table A-1 Load correction factors for reciprocating engines

Power % of MCR	PM	CO	VOC	NO_X
10	1.63	5.22	4.46	1.34
15	1.32	3.51	2.74	1.17
20	1.19	2.66	2.02	1.10
25	1.12	2.14	1.65	1.06
30	1.08	1.80	1.42	1.04
35	1.05	1.56	1.27	1.03
40	1.03	1.38	1.16	1.02
45	1.01	1.23	1.09	1.01
50	1.01	1.12	1.03	1.00
55	1.00	1.06	1.00	1.00
60	1.00	1.00	0.98	0.99
65	0.99	0.94	0.95	0.99
70	0.99	0.88	0.92	0.98
75	0.98	0.82	0.89	0.98
80	0.98	0.76	0.87	0.97
85	0.97	0.70	0.84	0.97

Since steam turbines are predominantly used by LNG-carriers two types of fuel 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 from steam turbines was taken from the EXTREMIS model [4].

Table A-2 Load correction factors for steam turbines

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

Table A-3 Load correction factors for gas turbines

Power % of MCR	PM	CO	VOC	NO_X	SO_2	CO_2
10	0.79	48.81	36.67	0.21	1.26	1.26
15	0.83	39.58	28.64	0.31	1.17	1.17
20	0.89	26.65	17.41	0.45	1.04	1.04
25	0.93	18.8	10.58	0.53	0.96	0.96
30	0.97	10.02	2.96	0.63	0.87	0.87
35	0.96	9.12	2.8	0.65	0.88	0.88
40	0.94	8.22	2.64	0.68	0.89	0.89
45	0.92	7.32	2.48	0.7	0.91	0.91
50	0.90	6.42	2.32	0.73	0.92	0.92
55	0.88	5.52	2.16	0.75	0.93	0.93
60	0.86	4.62	2.00	0.78	0.94	0.94
65	0.84	3.72	1.84	0.8	0.95	0.95
70	0.83	2.82	1.68	0.83	0.96	0.96
75	0.81	1.92	1.52	0.85	0.97	0.97
80	0.79	1.02	1.36	0.87	0.98	0.98
85	0.89	1.01	1.18	0.94	0.99	0.99

A1.1.2 Auxiliary Engines and Equipment

Apart 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, was used in this study [3]. For those ships included in the *Register of Ships,* the auxiliary power of each individual ship was multiplied by the percentage given in Table A- 16. For the other ships, the percentage from Table A- 16 was multiplied by the main power of each individual ship.

A1.2 Berthed

When a ship is berthed, the main engines are stopped. The auxiliary engines and equipment will be kept in service to provide (electrical) power to the ship's systems, onboard cargo handling systems and accommodations. The emission factors for this berthed condition are also based on the EMS protocol. However, instead of a fixed berth time per ship type, the AIS data is used to get an accurate value for the length of time that a vessel is berthed.

A1.3 Connection between Emission Factors and Ship Data within the LLI 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:

- Engine year of build (grouped in classes)
- Engine type (slow speed or medium/high speed)
- Engine maximum revolutions per minute (RPM), from 2000 year of build
- Type of fuel used (Heavy Fuel Oil of 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 from the LLI Database containing data for 116,479 individual ships. In this way, emission factors can be derived for almost any seagoing ship sailing the high seas.

A1.3.1 Engine Emission Factors

Table A-1 to Table A-10 show the engine emission factors [1], [2] per engine type and fuel type expressed in grams per unit of mechanical energy delivered by ship engines (g/kWh). Full implementation of the SECA according to the IMO in 2008 has been assumed. Therefore, the sulphur percentage in heavy fuel oil is set on 1.5% and the sulphur percentage in marine diesel oil is assumed to be 0.8%.

Table A-4 Emission factors 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
1900 – 1973	16	1.0	6.3	0.6	3.0	666
1974 – 1979	18	1.0	6.0	0.6	3.0	634
1980 – 1984	19	1.0	5.7	0.6	3.0	602
1985 – 1989	20	1.0	5.4	0.6	2.5	571
1990 – 1994	18	1.0	5.3	0.5	2.0	555
1995 – 1999	15	0.8	5.1	0.4	2.0	539
2000 – 2015	~rpm[1]	0.8	5.0	0.3	2.0	533

Table A-5 Emission factors 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
1900 - 1973	16	0.5	3.4	0.6	3.0	661
1974 - 1979	18	0.5	3.2	0.6	3.0	630
1980 - 1984	19	0.5	3.0	0.6	3.0	598
1985 – 1989	20	0.5	2.9	0.6	2.5	567
1990 – 1994	18	0.4	2.8	0.5	2.0	551
1995 – 1999	15	0.3	2.7	0.4	2.0	535
2000 – 2015	~rpm[1]	0.3	2.7	0.3	2.0	529

[1] Dependant on revolutions per minute (Table A-10)

Table A-6 Emission factors 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
1900 – 1973	12	0.8	6.8	0.6	3.0	713
1974 – 1979	14	0.8	6.5	0.6	3.0	682
1980 – 1984	15	0.8	6.2	0.6	3.0	650
1985 – 1989	16	0.8	5.9	0.6	2.5	618
1990 – 1994	14	0.8	5.7	0.5	2.0	602
1995 – 1999	11	0.7	5.6	0.4	2.0	586
2000 – 2010	~rpm 10[1]	0.7	5.5	0.3	2.0	580
2011 - 2015	~rpm 8.2[1]					

[1] applied on auxiliary engines only

Table A-7 Emission factors 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
1900 - 1973	12	0.5	3.6	0.6	3.0	709
1974 - 1979	14	0.5	3.4	0.6	3.0	677
1980 - 1984	15	0.5	3.3	0.6	3.0	646
1985 - 1989	16	0.5	3.1	0.6	2.5	614
1990 - 1994	14	0.4	3.0	0.5	2.0	598
1995 - 1999	11	0.3	3.0	0.4	2.0	583
2000 - 2010	~rpm 9[1]	0.3	2.9	0.3	2.0	576
2011 - 2015	~rpm 7.2[1]					

[1] applied on auxiliary engines only

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

Table A-8 Emission factors of gas turbines (TB) operated on marine diesel oil (MDO), (g/kWh)

Fuel	NO_X	PM	SO_2	VOC	CO	CO_2
MDO	5.7	0.146	3.97	0.1	0.32	922

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

Table A-9 Emission factors 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
HFO	2.0	0.59	7.1	0.10	0.15	970
BOG	1.94	0.0	0.0	0.045	0.06	688
Operational average	1.96	0.21	2.52	0.065	0.091	789

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 year round by Shell [7].

Table A-10 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

A1.3.2 Year of Build of Main Engines

For 74,871 ships, the ship engine year of build was directly taken from the field "ENGINE_DOB" from the LLI Database. In 36,018 cases, the ship engine year of build was assumed to be equal to the ship year of build. For 5,590 cases, the ship engine year build was assumed to be the average of the ship type and/or a ship's size.

Table A-11 Method of assessment of engines year of build

Method of assessment	Number	Share
Directly taken from "ENGINE_DOB	74,871	64.2%
Directly taken from "BUILD"	36,018	30.9%
Average of ship type and/or Size	5,590	4.8%
Total	**116,479**	**100.0%**

The uncertainty in a ship engine year of build probably is not a major factor in all over uncertainty in ship emission factors.
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-12 gives a complete overview of all engine types, which were observed in the LLI 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 hundred 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 out in the database it was assumed that these ships operate diesel engines. Considering the overwhelming number of diesel engines, the attributes 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 future more diesel engines will be introduced in LNG ships mainly because of the improved thermal engine efficiency of diesel engines.

Table A-12 Engine types in the LLI-database

ENGINE_TYPE	ENGINE_TYPE_DECODE	Number	Engine type attributed
STM	Steam	518	ST
STT	Steam Turbine	3	ST
No data	No data	42,128	DSL
DSE	Diesel Electric	224	DSL
DSL	Diesel	73,502	DSL
ELC	Electric	19	DSL
GST	Gas Turbine	85	TB
		116,479	

A1.3.3 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 LLI Database. A good approximation of RPM was derived from most frequent occurring RPM in the “ENGINE_DESIGNATION” records for 21% of ships.

A rougher approximation was derived from the average engine RPM per ship type and/or ship size. The fact that bigger ships mostly operate slow speed engines as their main engine was taken into account. It is expected that an RPM value derived by this method still results in a reasonable approximation.

Table A-13 Assessment method of ships diesel engines RPM

Method of assessment	Number	Share
Directly taken from “RPM”	49,272	42%
Most frequent occurring RPM derived from “ENGINE_DESIGNATION”	24,563	21%
Average of ship type and/or size	42,644	37%
Total	**116,479**	**100%**

A1.3.4 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 LLI 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, when “BHP” was not available “POWER_KW” was taken as the second best choice. For most ships for which power was not indicated in the LLI Database, engine power was estimated by linear regression (power functions) per ship type against a ship’s gross tonnage (GT). The remainder of ship engine power was estimated by averages per ship type and ship size class.

Table A- 14 Assessment method of main engine power

Method of assessment (kW)	Number	Share Number	Share Power
Directly via BHP * 0.746	86,223	74%	89,6%
Directly via POWER_KW	1,727	1%	2,5%
Via linear regression	25,187	22%	7,6%
Average of ship type and/or size	3,342	3%	0,3%
	116,479	**100%**	**100%**

Parameters for the applied regression functions are given in Table A-15. The resulting fitting functions which were created by means of the least squares approach, taking the mathematical form of:

Power = Coefficient x Gross ^{Power}
Wherein:
Power = Calculated ships main engine power (kW)
Coefficient= Function parameter assessed by linear regression
Gross = Volume of the ship measured in Gross ton (GT)
Power = Function parameter assessed by linear regression

Considering the R^2-coefficients, it can be seen that 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-coefficients indicate rather weak relationships between ship power and ship GT.

Table A-15 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

A1.3.5 Power and Fuel of Auxiliary Engines

In a minority of records within the LLI Database, details are provided for the power of installed auxiliary engines. Furthermore, information about auxiliary engines provided by the LLI Database 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-16 Parameters used for calculation of auxiliary engine power in case of lack of data

Method of assessment	Number	Share %
Directly from LLI-database	28,348	24%
Derived from main engine power based on ratios within IMO-report	87,372	75%
10% of main engine power	759	1%
	116,479	**100%**

For just 24% of ships, a value of ship auxiliary engine power could be derived from the LLI 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]).

A1.3.6 Type of Fuel Used in Main Engines

Obtaining a confirmation of the fuel type used by the main engines from the LLI Database 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 economical 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-17 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

A1.4 Emissions of Ships at Berth

The procedure for the calculation of emissions from ships at berth is derived from the EMS protocol with some minor modifications. The methodology was recently published in an article in the journal 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 dependent 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 tonnes. This amount of fuel was specified for different fuel types, and the engine or boiler in which this fuel is used in accordance with the specification given in the EMS-protocol [2].

Table A-18 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-19 specifies total fuel use over fuel types for the EMS 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-19 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-20 gives figures about allocation of fuel amount over engine types and apparatus during berth.

Table A-20 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-21 to Table A-23, the emission factors used for emissions at berth are presented.

Table A-21 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[1]	0.8	1.6	11
2011 – 2015	39[1]	0.8	1.6	11

[1] MGO/ULMF

Table A-22 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[2]	1.0	1.8	12
2011 – 2015	60.0[2]	1.0	1.8	12

[2]MGO/ULMF

Table A-23 Emission factors 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-24 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.

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APPENDIX B: AIS SHIP TYPES

AIS Ship Types

Type No.	Route bound(R) / Non Route Bound (N)	Omschrijving
0	N	undefined
1	N	reserved for future use
2	N	WIG[2]
20	N	WIG (All ships of this type)
21	N	WIG (Carrying DG, HS, or MP IMO hazard or pollutant category A)
22	N	WIG (Carrying DG, HS, or MP IMO hazard or pollutant category B)
23	N	WIG (Carrying DG, HS, or MP IMO hazard or pollutant category C)
24	N	WIG (Carrying DG, HS, or MP IMO hazard or pollutant category D)
25 - 28	N	WIG (reserved for future use)
29	N	WIG (No additional information)
30	N	Vessel (Fishing)
31	N	Vessel (Towing)
32	N	Vessel (Towing and length of the tow exceeds 200 m or breadth exceeds 25 m)
33	N	Vessel (Engaged in dredging or underwater operations)
34	N	Vessel (Engaged in diving operations)
35	N	Vessel (Engaged in military operations)
36	N	Vessel (Sailing)
37	N	Vessel (Pleasure Craft)
38	N	Vessel (reserved for future use)
39	N	Vessel (reserved for future use)
4	N	HSC[3]
40	R	HSC (All ships of this type)
41	R	HSC (Carrying DG, HS, or MP IMO hazard or pollutant category A)
42	R	HSC (Carrying DG, HS, or MP IMO hazard or pollutant category B)
43	R	HSC (Carrying DG, HS, or MP IMO hazard or pollutant category C)
44	R	HSC (Carrying DG, HS, or MP IMO hazard or pollutant category D)
45 - 48	R	HSC (reserved for future use)
49	R	HSC (No additional information)
50	N	Special craft (Pilot vessel)
51	N	Special craft (Search and rescue vessels)
52	N	Special craft (Tugs)
54	N	Special craft (Vessels with anti-pollution facilities or equipment)
55	N	Special craft (Law enforcement vessels)
56	N	Special craft (Spare for assignments to local vessels)
57	N	Special craft (Spare for assignments to local vessels)
58	N	Special craft (Medical transports)
59	N	Special craft (Ships according to RR Resolution No. 18)
6	R	Passenger ships
60	R	Passenger ships (All ships of this type)

[2] Wing-In-Ground craft
[3] High Speed Craft

Type No.	Route bound(R) / Non Route Bound (N)	Omschrijving
61	R	Passenger ships (Carrying DG, HS, or MP IMO hazard or pollutant category A)
62	R	Passenger ships (Carrying DG, HS, or MP IMO hazard or pollutant category B)
63	R	Passenger ships (Carrying DG, HS, or MP IMO hazard or pollutant category C)
64	R	Passenger ships (Carrying DG, HS, or MP IMO hazard or pollutant category D)
65 - 68	R	Passenger ships (reserved for future use)
69	R	Passenger ships (No additional information)
7	R	Cargo ships
70	R	Cargo ships (All ships of this type)
71	R	Cargo ships (Carrying DG, HS, or MP IMO hazard or pollutant category A)
72	R	Cargo ships (Carrying DG, HS, or MP IMO hazard or pollutant category B)
73	R	Cargo ships (Carrying DG, HS, or MP IMO hazard or pollutant category C)
74	R	Cargo ships (Carrying DG, HS, or MP IMO hazard or pollutant category D)
75 - 78	R	Cargo ships (reserved for future use)
79	R	Cargo ships (No additional information)
8	R	Tanker(s)
80	R	Tanker(s) (All ships of this type)
81	R	Tanker(s) (Carrying DG, HS, or MP IMO hazard or pollutant category A)
82	R	Tanker(s) (Carrying DG, HS, or MP IMO hazard or pollutant category B)
83	R	Tanker(s) (Carrying DG, HS, or MP IMO hazard or pollutant category C)
84	R	Tanker(s) (Carrying DG, HS, or MP IMO hazard or pollutant category D)
85 - 88	R	Tanker(s) (reserved for future use)
89	R	Tanker(s) (No additional information)
90	R	Other types of ship (All ships of this type)
91	R	Other types of ship (Carrying DG, HS, or MP IMO hazard or pollutant category A)
92	R	Other types of ship (Carrying DG, HS, or MP IMO hazard or pollutant category B)
93	R	Other types of ship (Carrying DG, HS, or MP IMO hazard or pollutant category C)
94	R	Other types of ship (Carrying DG, HS, or MP IMO hazard or pollutant category D)
95 - 98	R	Other types of ship (reserved for future use)
99	R	Other types of ship (No additional information)

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

Emission in ton for 2010 by sea ships at berth for all OSPAR region II port areas (based on LLI voyage database)

Port	VOC	SO_2	NO_x	CO	CO_2	Aerosols MDO+HFO
Rotterdam	283	510	5,770	1,260	720,223	142
Antwerp	128	276	2,751	581	290,497	69
Hamburg	66	170	1,423	311	157,895	38
Amsterdam	58	95	1,132	251	149,000	28
Le Havre	54	116	1,112	247	138,393	29
Bremerhaven	47	125	1,075	229	100,492	27
Zeebrugge	46	108	1,070	224	96,256	26
Gothenburg	33	61	692	149	79,654	17
Mongstad	26	38	510	113	71,691	12
Immingham	27	51	585	125	64,724	14
Fawley	21	30	400	90	57,550	10
Southampton	25	67	586	127	54,433	14
Tees	19	33	411	88	47,238	10
Wilhelmshaven	18	27	356	78	47,225	8
Felixstowe	19	58	400	91	46,052	11
Dunkirk	18	36	384	83	43,739	9
Aberdeen(GBR)	24	50	739	143	40,231	12
Flushing	20	37	458	90	39,239	10
Ghent	15	29	319	68	33,431	8
London	14	27	325	65	28,242	7
Sullom Voe	10	15	205	45	27,099	5
Brofjorden	9	13	168	38	24,755	4
Montrose	10	14	214	42	23,951	4
Rouen	11	21	236	49	23,297	6
Hound Point	8	13	175	38	22,980	4
Oslo	10	27	253	55	22,553	6
Bergen	13	27	353	70	22,219	7
Sture	8	12	160	35	21,177	4
Tilbury	10	25	224	47	19,784	6
Terneuzen	7	11	139	31	19,146	4
Slagen	6	9	121	27	17,382	3
Hull	8	20	202	42	17,356	5
Harwich	9	21	214	45	16,770	5
Coryton	6	8	110	25	16,605	3
Ymuiden	9	19	250	47	15,369	5
Portsmouth	8	17	205	40	14,185	5
Port Jerome	5	6	83	19	13,049	2
Tyne	7	16	170	35	12,896	4
Esbjerg	8	15	208	40	12,828	4
Bremen	7	14	155	31	12,806	4
Grangemouth	4	6	74	17	11,116	2
Emden	6	13	135	27	10,799	3
Hook of Holland	5	13	128	28	10,630	3
North Killingholme	6	13	140	28	10,508	3
Scapa Flow	4	6	79	17	10,444	2
Other	106	200	2,476	495	208,382	56
Total	1,260	2,519	27,373	5,828	2,944,291	659