MARIN

EMISSIONS 2008: NETHERLANDS CONTINENTAL SHELF, PORT AREAS AND OSPAR REGION II

Report

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GLOSSARY OF DEFINITIONS AND ABBREVIATIONS:

NMVOC	Non-methane volatile organic compounds. Substance number **1237**.
Sulphur dioxide (SO_2)	Gas formed from the combustion of fuels that contain sulphur. Substance number **4001**.
Nitrogen oxides (NOx)	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 NO2 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**.
PM10, PM2.5	Fine particulate matter in ambient air with a diameter less than 10 or 2.5 millionths of a meter respectively. Substance number **6598**.
AIS	Automatic Identification System
CRS	Correction factor Reduce Speed
DCMR	Dienst Centraal Milieubeheer Rijnmond
EMS	Emissieregistratie en Monitoring Scheepvaart (Shipping Emission inventory and Monitoring)
IMO	International Maritime Organization
LMIU	Lloyd’s Marine Intelligence Unit
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
NCS	Netherlands Continental Shelf
SAMSON	Safety Assessment Model for Shipping and Offshore on the North Sea

1 INTRODUCTION

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 during movements.

In 2008 a pilot study [1] has been performed, commissioned by the Ministry of Transport, Public Works and Water Management, DCMR and the Netherlands Environmental Assessment Agency, (PBL), in which the ship emissions were quantified for the port of Rotterdam area. The pilot study was successful. The knowledge about the level and spatial distribution of all emissions was improved, which is used for making policy with respect to emissions.

This study, co-financed by the Ministry of Transport and the Netherlands Environmental Assessment Agency, can be considered as the follow up of the pilot study [1]. In this study, the study area is extended to the Netherlands Continental Shelf (NCS) and the port areas of the Western Scheldt, Rotterdam, Amsterdam and the Eems.
The results for the NCS are used for estimating the emission in the OSPAR Region II, a region that covers a much larger sea area. The SAMSON model is used for these calculations.

This report is the main report, containing a description of the method applied. Furthermore the calculated emissions are compared with the emissions of previous years. Also a summary report is published with the main results for the Netherlands Continental Shelf and port areas, see [5].

Notations
In all numbers the point is used as decimal separator and the comma as thousands separator.

2 OBJECTIVE

This study aims to determine the emissions, totals and spatial distribution, over the Netherlands Continental Shelf and the port areas Western Scheldt, Rotterdam, Amsterdam and the Eems from AIS data. In addition, the information contained in the AIS data for the NCS and the SAMSON model are used to determine the emissions in the OSPAR Region II area.

The emissions are determined for NMVOC, SO_2, NO_x, CO, CO_2 and fine particulates (PM10). A distinction will be made for ships sailing under EU-flag and non-EU flag and sailing within or outside the 12 miles zone.

3 OVERVIEW

In this study, AIS data from the NCS and the port areas is used. The port areas that have been analyzed are the Western Scheldt, Rotterdam, Amsterdam and the Eems, The emission results are finally analyzed using Geographic Information Systems.

The results are shown for various criteria:

- Inside and outside of the 12 mile zone
- EU and non-EU ships
- Moving and non- moving ships.

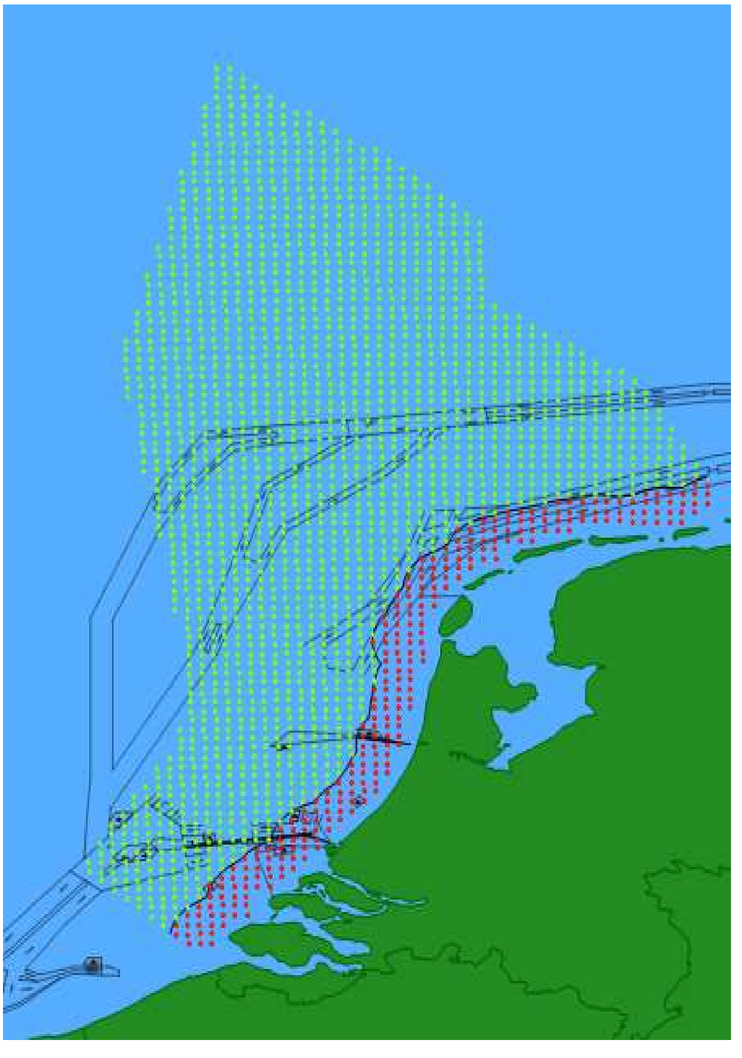

Figure 3-1 Grid over NCS showing cells within (red) and outside (green) the 12 mile zone.

Figure 3-1 shows the 5000 x 5000m grid used over the NCS. The green dots represent the grid cells outside of the 12 mile zone and the red represent those within it. The cells are only visible if they contain ships, thus areas with no dots have no ships recorded in them for this particular time period or are out of the study area in question. The black lines are the traffic separation schemes on the NCS, thus containing most ships.

3.1 Port areas

The emissions are calculated for the Netherlands Continental Shelf and four port areas, shown in Figure 3-2. The areas are presented on electronic charts, that are used for navigation. The purple lines are the traffic separations schemes and the squares are offshore platforms.

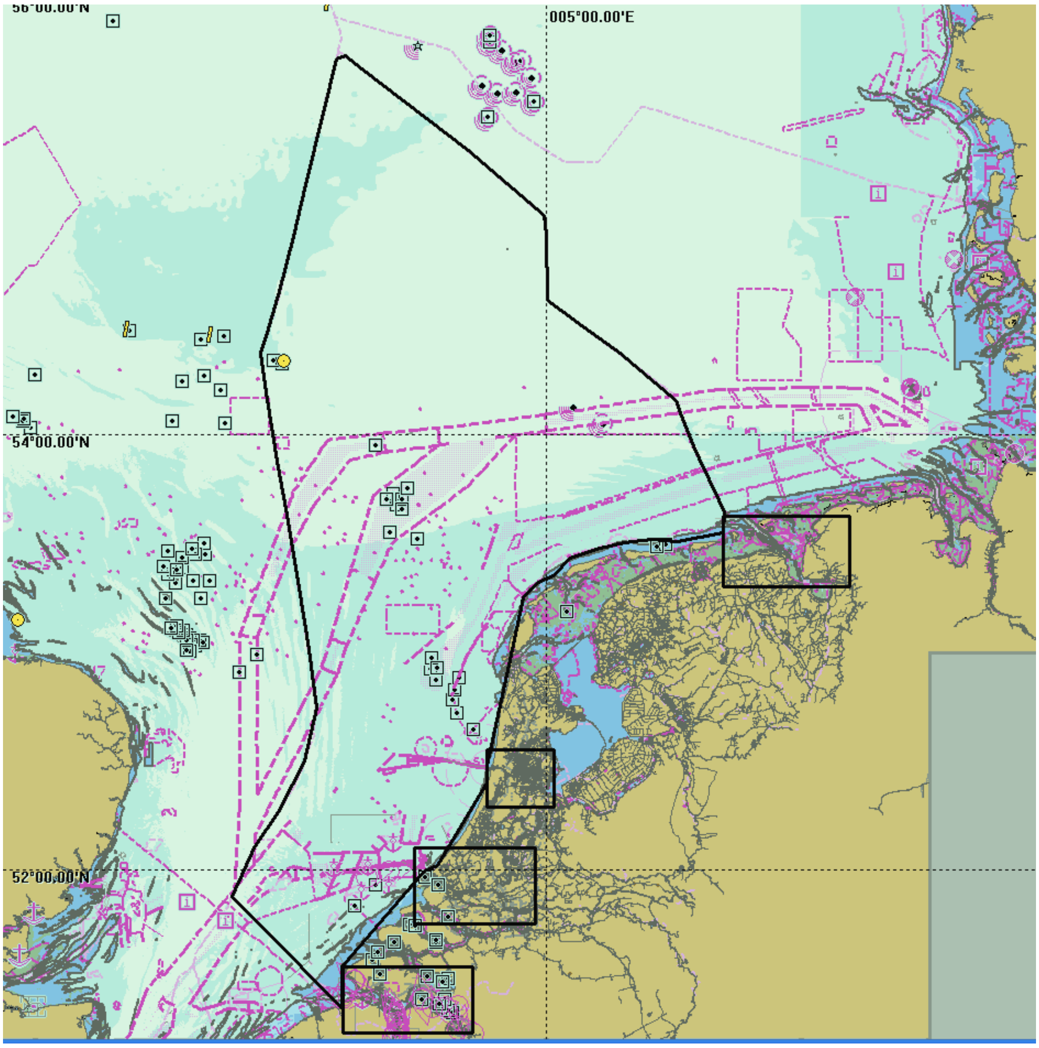

Figure 3-2 The Netherlands Continental Shelf with four port areas

The grid size that is used in the port area is 500m by 500m, thus much smaller than the grid size at sea. The port areas are defined as rectangles. All ships with AIS within these rectangles are included in the study. In order to avoid an overlap some grid cells are removed in Rotterdam, Amsterdam and the Eems because these areas are already covered by the North Sea area shown in Figure 3-2. The full extension of each of the four port areas is illustrated in Figure 3-3 to Figure 3-6.

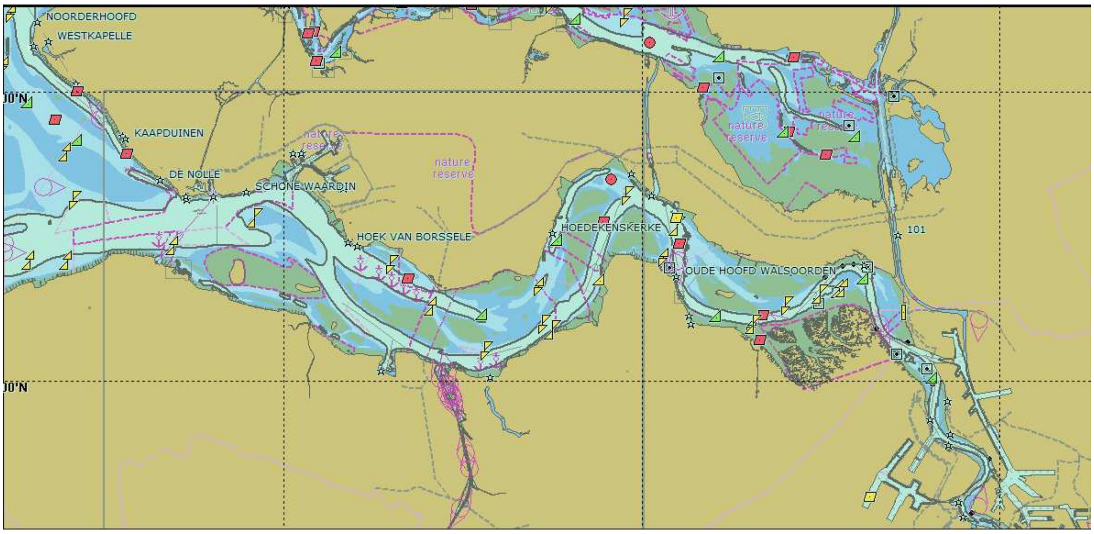

Figure 3-3 Western Scheldt

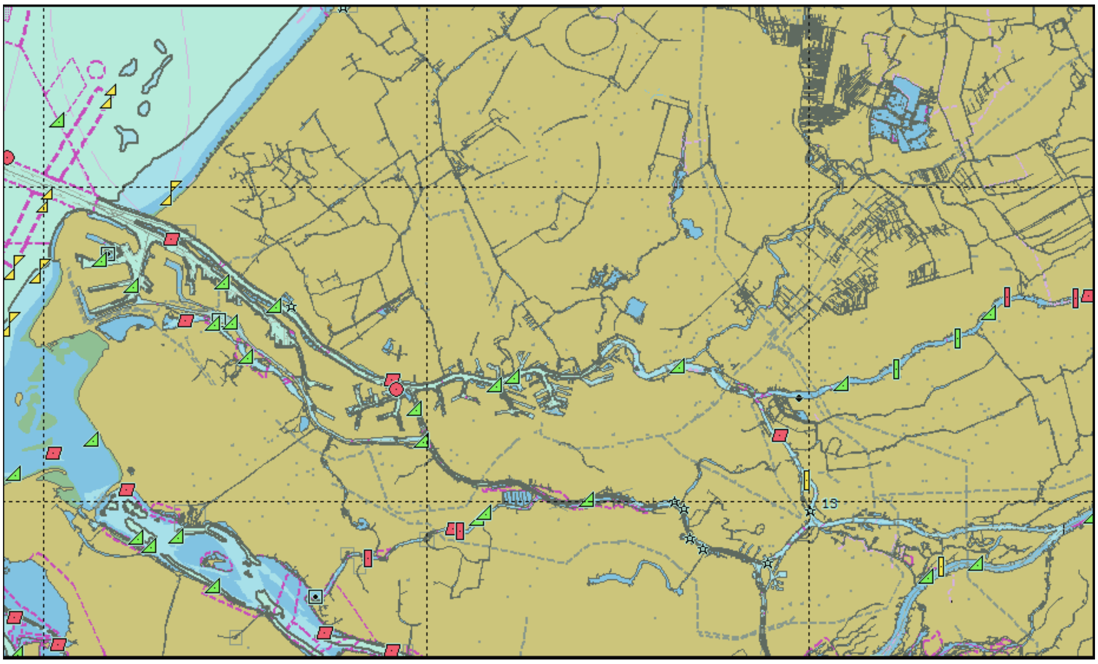

Figure 3-4 Rotterdam

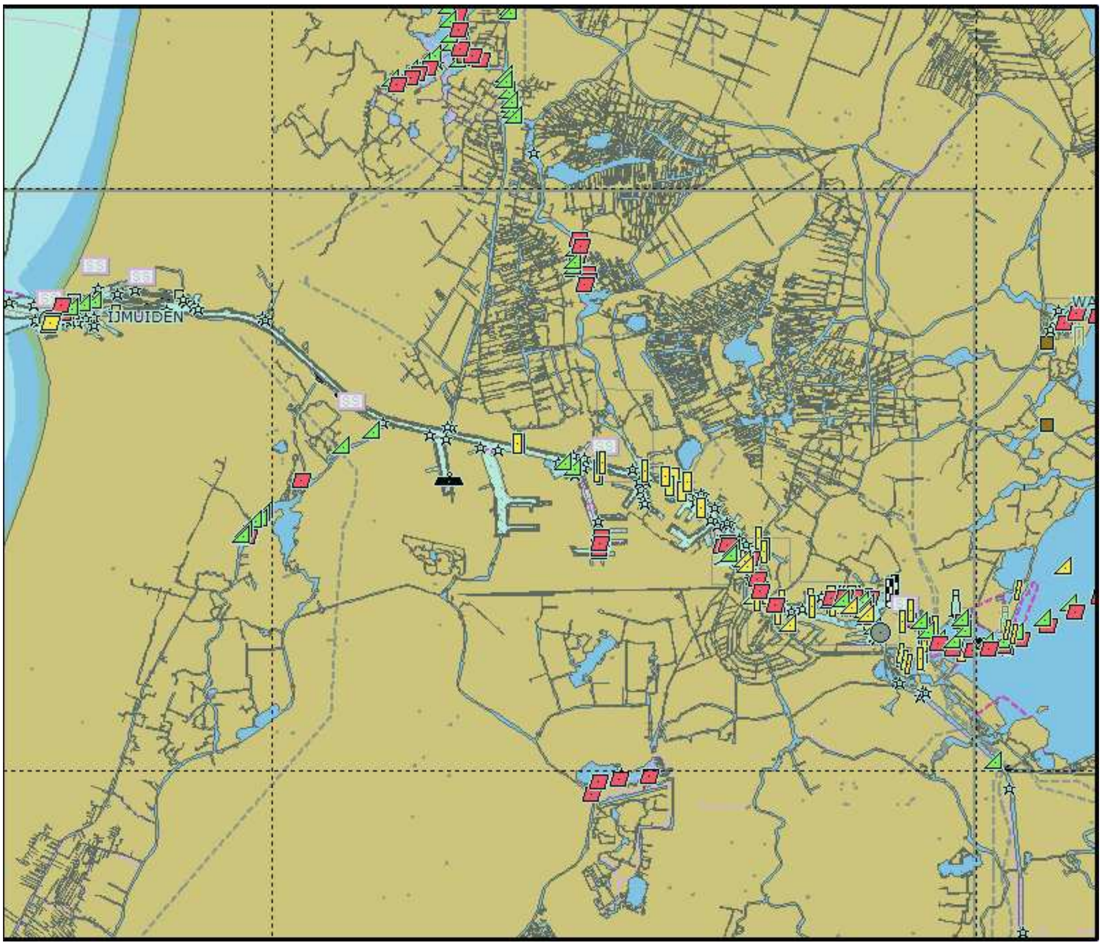

Figure 3-5 Amsterdam

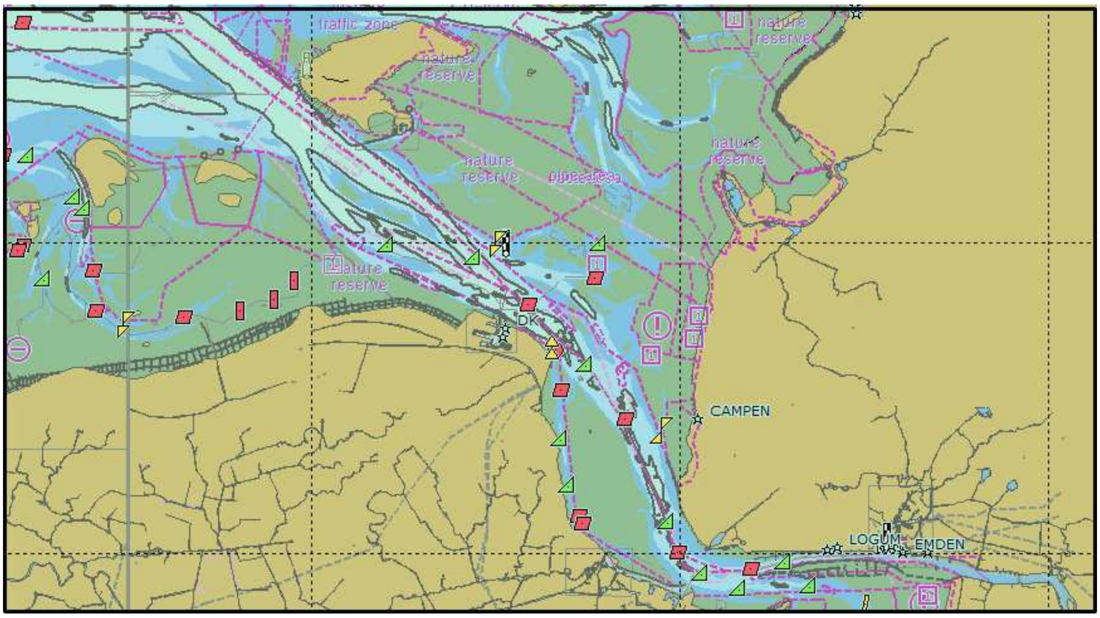

Figure 3-6 Eems

4 AIS

4.1 AIS DATA

A number of AIS messages are sent out at certain time intervals and these contain various data. Each AIS message contains an MMSI number, which is (in most cases) a unique number for an individual ship. However, there are cases where different ships may use the same MMSI number, which can cause problems with identification. Further, there is the default MMSI number, 1193046, which a number of ships may adopt, again making it impossible to couple the ship with ship characteristics.

MARIN receives AIS messages of the type 1, 2, 3 and 5 from the Netherlands Coastguard. From these messages, various information is acquired. Information is not always complete and is occasionally entered incorrectly. Table 4-1 shows an example of the kind of information contained in these messages.

Table 4-1 AIS data collected from various message types.

Data fields	Contents	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
navigation 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

The information on a ship's position is the most reliable as this is automatically given out via the navigation equipment installed onboard. The navigation 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, yet still a considerable speed. The speed thus, in most cases, gives a better indication of the ship's real navigation status than the navigation status field which needs to be manually filled in by crew.

4.2 Methodology

The AIS messages contain detailed information about the location and speed of the ships. This is the most important information for calculating the emissions they produce at that time. The main problem is how to organize the tremendous amount of data flows and keep the computing time manageable. The work is divided into a number of separate activities, delivering intermediate results. The final emission calculation uses these intermediate databases.
Figure 4-1 contains the databases that are mentioned in the description of the methodology.

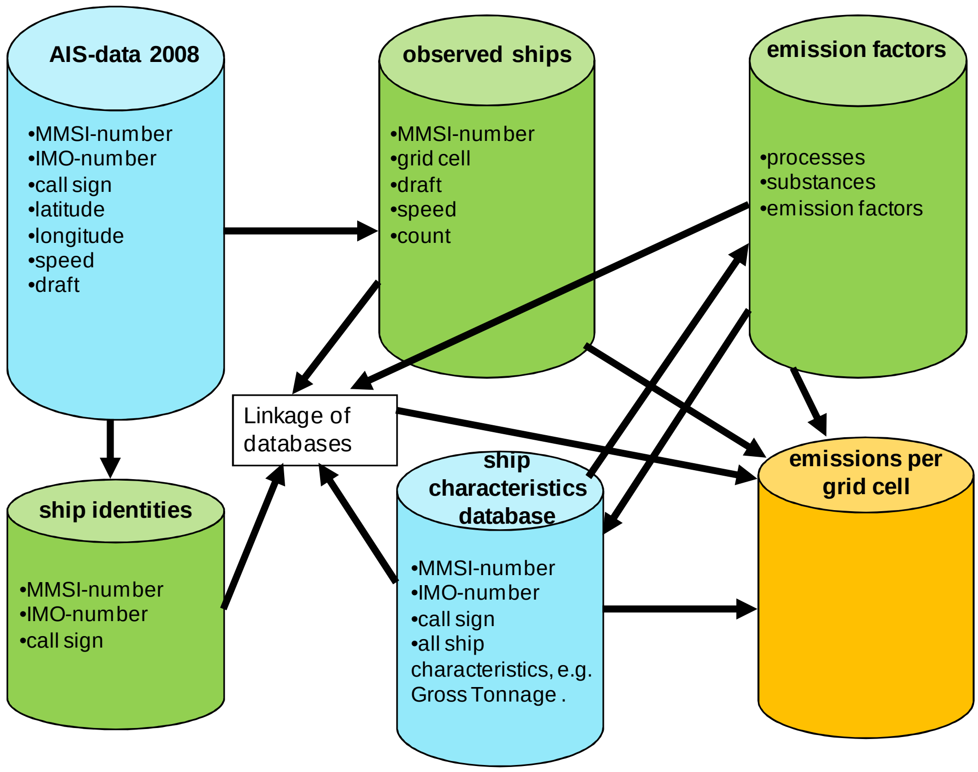

Figure 4-1 Databases with relations (blue = input, green = intermediate, orange = output)

The basic files are:

- All AIS data files collected in 2008
- Shipping database of April 2009 from LMIU (the ship characteristics database).

Each AIS data file contains the AIS messages of all ships received in exactly one minute. The total collection of the AIS data of 2008 contains 510,123 files, this is 96.8% of the maximum number of 527,040 (366 days times 24 hours times 60 minutes) files. Thus 3.2% of the files are missing due to failures in the process. In case the failure is less than 20 minutes, it has no effect on the results because each ship is kept in the system until no AIS message is received during 20 minutes. This approach is followed to prevent incompleteness for larger distances from the coast where the reception of AIS messages by the base station decreases.

Each 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 is chosen in which each two minutes an observation is done to determine which ships are in the area.

- The “which ship” is indicated by the unique MMSI number.
- The “where” is indicated by the grid cell in which the ship is observed.
- The speed is converted to a speed class by cutting off to whole values. Thus speed class 10 means a speed between 10 and 11 knots.
- The navigation status and the draught of the ship in classes of 1 meter are added for future use.

The combination of these items forms the key of the observation. For all ships in the area, it is checked whether the key already exists or not. If so, the number of occurrences for that key is increased by 1, otherwise a new key is added with an initial observation count of 1. At the end of the observation period, all keys with corresponding occurrences are written to the “observed ships“ log file that is used in the next steps. The determination of the total “observed ships” file is carried out in steps of two months as observation period for the North Sea due to memory limitations. For the NCS this process, 6 runs of two months, delivers nearly 19 million records for the whole year 2008. These records are stored in “observed ships”.
Within the further calculations it is **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.**

A separate step is to assess the emission factors for all 106,000 ships, operating worldwide. Within this project the shipping database of LMIU of April 2009 is purchased that contains all characteristics, such as year of built, type, size, main and auxiliary engine for this purpose. TNO has determined the emission factors per nautical mile for each ship based on these characteristics.

Another activity is to find for each MMSI number the corresponding ship in the shipping database. This is not that easy because only 60% of the ships in the shipping database contain an MMSI-number and this number does not always correspond with the MMSI number in the AIS data. For this task all ships that are present in the AIS data of 2008 are extracted from the database and stored in “ship identities”. The combination of

MMSI number, IMO-number and call sign is stored. These three items, unique for one ship, were used to find a linkage with the shipping database. When at least two of the three linkages delivered the same ship, there was no doubt. In the remaining cases a manual view was necessary to decide which linkage was most likely. Often a digit was wrong or zeros were added before or after the correct number in the AIS message. This is a time consuming task but is necessary in order to link the data to the correct ship as much as possible. By following this approach, nearly all MMSI numbers could be coupled with a ship in the shipping database, thus with the emission factors. Of all 22,353 ships in “ship identities”, 298 could not be coupled, thus 1.3 %.

4.3 Correction factor for missing AIS data

The AIS data consists of an enormous number of data files. Each file contains the AIS-messages of one minute. The dataset of 2008 contains 510,123 files spreads over 357 days. When considering the emissions for a year with 365 days (thus not 2008), this means a coverage of 97.8% (357/365) with respect to the number of days and 97.1% (510,123/(365x24x60)) with respect to the number of files. Because some smaller failures have no effect the emissions are upgraded with 2.5%, being a value between the outer limits of 2.2% and 2.9%.

5 EMISSION FACTORS

5.1 Sailing and Manoeuvring

5.1.1 Main Engines

During sailing and manoeuvring, the main engine(s) are used to propel/manoeuvre the ship. Their emission factors per ship, in g per kWh, were determined by TNO according to the EMS protocols [2, 3]. Recently an English language report [6] was published, which covered the emission calculations in accordance with the EMS protocols. In the emission factor calculation, the nominal engine power and the speed are used. For this study these parameters were taken from the April 2009 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 protocols. The correction factors used are shown in Table 5-1. The correction factors for an MCR over 50% are equal to1.

Table 5-1 Correction factors

Power % of MCR	PM	CO	VOS	NOx
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

5.1.2 Auxiliary Engines and Equipment

Aside from the main engines, most vessels have auxiliary engines and equipment that provide (electrical) power to the ship's systems. There is very little information available on the use of auxiliary engines. Perhaps the best estimate to date has been made in the *Updated 2000 Study on Greenhouse Gas Emissions from Ships* report (Buhaug et al., 2008, [4]), 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 [4]. For those ships included in the *Register of Ships,* the auxiliary power of each individual ship was multiplied with the percentage given in Table 14. For the other ships, the percentage from Table 14 was multiplied with the main power of each individual ship.

5.2 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.

5.3 Connection between Emission Factors and Ship Data within the LMIU 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 [2], the following engine and fuel characteristics are required:

- Engines year of build (grouped in classes)
- Engine type (slow speed or medium/high speed)
- Engines maximum revolutions per minute (RPM), from 2000 year of build
- Type of fuel used (Heavy Fuel Oil 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 LMIU Database, containing data for 106,043 individual ships. In this way, emission factors can be derived for almost any seagoing ship, sailing the world's seas.

5.3.1 Engine Emission Factors

Tables 5-2 to 5-8 show the engine emission factors per engine type and fuel type expressed in grams per unit of mechanical energy delivered by ships engines (g/kWh). Full implementation of the SECA according to the 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 5-2 Emission factors applied on slow speed engines (SP) operated on heavy fuel oil (HFO), (g/kWh)

Year of build	NOx	PM	SO2	HC	CO	CO2
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 - 2010	~rpm[1]	0.8	5.0	0.3	2.0	533

Table 5-3 Emission factors applied on slow speed engines (SP) operated on marine diesel oil (MDO), (g/kWh)

Year of build	NOx	PM	SO2	HC	CO	CO2
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 - 2010	~rpm	0.3	2.7	0.3	2.0	529

Table 5-4 Emission factors applied on medium/high speed engines (MS) operated on Heavy fuel oil (HFO), (g/kWh)

[1] Dependant on revolutions per minute

Year of build	NOx	PM	SO 2	HC	CO	CO2
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

[1] applied on auxiliary engines only

Table 5-5 Emission factors applied on medium/high speed engines (MS) operated on marine diesel oil (MDO), (g/kWh)

Year of build	NOx	PM	SO2	HC	CO	CO2
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

[1] applied on auxiliary engines only

Table 5-6 Emission factors of gas turbines (TB) operated on marine diesel oil (MDO), (g/kWh)

Fuel	NOx	PM	SO2	HC	CO	CO2
MDO	4.96	0.155	4.96	0.031	0.341	976

Table 5-7 Emission factors of steam turbines (ST) operated on heavy fuel oil(HFO) and marine diesel oil (MDO), (g/kWh)

Fuel	NOx	PM	SO2	HC	CO	CO2
HFO	0.78	0.59	7.1	0.047	0.12	745
MDO	1.65	0.49	3.76	0.047	0.12	740

Table 5-8 Emission factors of NOx dependant on engines RPM

RPM range	IMO-norm (g/kWh)	Emission factor NOx (g/kWh)
< 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

5.3.2 Year of Build of Main Engines

For 72,554 ships, the ship engine year of build was directly taken from the field "ENGINE_DOB" from the LMIU Database. For 47,475 ships, this date is assumed to be very certain (value “A” in the field “DOB_QUALIFIER”). In 28,093 cases, the ship engine year of build was assumed to be equal to the ship year of build. For 5,395 cases, the ship engine year build was assumed to be the average of the ship type and/or a ship’s size.

Table 5-9 Method of assessment of engines year of build

Method of assessment	Number	Share
Directly taken from “ENGINE_DOB	72,554	68.4%
Directly taken from “BUILD”	28,093	26.5%
Average of ship type and/or Size	5,395	5.1%
Total	**106,042**	**100%**

The uncertainty in a ship engine year of build probably is not a major factor in all over uncertainty in ships 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 5-10 gives a complete overview of all engine types, which were observed in the LMIU Database. Diesel-electric propulsion is found increasingly in tugs, as this configuration is more efficient with a continuous fluctuation of power demand. Besides ships with diesel engines, there are a few hundreds of ships in service that are propelled by steam (engine or turbines). Also, gas turbines are still used in non-military ships. The number of ships with gas turbines may rise in the near future as the thermal efficiency of gas turbines has been enhanced considerably and because some of the engines’ flexibility may be attractive in some sectors (like cruise or passenger transport). In military battle ships, gas turbines are common practice. For all ships, for which the field “ENGINE_TYPE” was not filled in the database, it was assumed that these ships operate diesel engines. Considering the overwhelming number of diesel engines, the 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 the future, more diesel engines will be introduced in LNG ships mainly because of the improved thermal engine efficiency of diesel engines.

Table 5-10 Engine types in the LMIU-database

ENGINE_TYPE	ENGINE_TYPE_DECODE	Number	Engine type attributed
STM	Steam	515	ST
STT	Steam Turbine	3	ST
No data	No data	37,454	DSL
DSE	Diesel Electric	173	DSL
DSL	Diesel	67,794	DSL
ELC	Electric	19	DSL
GST	Gas Turbine	85	TB
		106,042	

5.3.3 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, while all other diesel engines were classified as MS.

For 41% of ships, the maximum RPM was provided by the LMIU Database. A good approximation of RPM was derived from most frequent occurring RPM in the "ENGINE_DESIGNATION" records.

A rougher approximation was derived from the average engine RPM per ship type and/or ships 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 may still result in a reasonable approximation.

Table 5-11 Assessment method of ships diesel engines RPM

Method of assessment	Number	Share
Directly taken from "RPM"	43,751	41%
Most frequent occurring RPM derived from "ENGINE_DESIGNATION"	19,316	18%
Average of ship type and/or Size	42,976	41%
Total	**106,042**	**100%**

5.3.4 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 LMIU 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 LMIU 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 5-12 Assessment method of main engine power

Method of assessment (kW)	Number	Share Number	Share Power
Directly via BHP * 0.746	80,793	76%	92%
Directly via POWER_KW	1,077	1%	1%
Via linear regression	21,229	20%	7%
Average of ship type and/or Size	2,926	3%	0%
	106,025	**100%**	**100%**

Parameters for the applied regression functions are given in Table 5-13. The resulting fitting functions which were created by means of the least squares approach, taking the mathematical from 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-coëfficiënts, it can be seen that relationship between power and ships GT is rather strong for most ship types. However, for very heterogeneous ship types such as “Tug/Supply” and “Other”, moderate R^2-coëfficiënts indicate rather weak relationships between ship power and ships GT.

Table 5-13 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

5.3.5 Power and Fuel of Auxiliary Engines

Only in a minority of records within the LMIU Database, details are provided for the power of installed auxiliary engines. Furthermore, this provided information 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 5-14 Parameters used for calculation of main engine power in case of lack of data

Method of assessment	Number	Share %
Directly from LMIU-database	24,925	24%
Derived from main engine power based on ratios within IMO-report	81,076	76%
10% of main engine power	42	0%
	106,043	100%

For just 24% of ships, a value of ship auxiliary engine power could be derived from the LMIU Database. The completeness of this 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[4]).

5.3.6 Type of Fuel Used in Main Engines

Obtaining a confirmation of the fuel type used by the main engines from the LMIU 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 was lacking in the current available database and in order to compensate a new 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 [4] 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 than1000, was introduced. According to this formula a ship with 3,000 kW and 2,500 RPM will use MDO.

Table 5-15 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

5.4 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 [7]. 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 have been considered as ships at berth. Since the year of build of each ship was known, emission factors per amount of fuel dependant on the classification of year of build were applied. The amount of fuel used was calculated from the length of time at berth, ship type and volume in gross tonnes. This amount of fuel was specified for different fuel types, and the engine or boiler in which this fuel is used in accordance to the specification given in the EMS-protocol.

Table 5-16 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 5-17 specifies Total fuel use over fuel types in dependence of ship types.

Table 5-17 Specification of fuel types of ships at berth per ship type (%)

Ship type	HFO	MDO	MGO/ULMF
Bulk carrier	69	31	0
Container ship	59	41	0
General Cargo	33	67	0
Passenger	25	21	55
RoRo Cargo	25	21	55
Oil Tanker	97	2	1
Other Tanker	84	6	10
Fishing	25	69	6
Reefer	90	10	0
Other	25	69	6
Tug/Supply	25	69	6

Table 5-18 gives figures about allocation of fuel amount over engine types and apparatus during berth.

Table 5-18 Allocation of fuels 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 5-19 to Table 5-22, the emission factors used for emissions at berth are presented.

Table 5-19 Emission factors of medium/high speed engines (MS) at berth, (g/kg fuel)

Year of build	NOx	PM	PM	PM	HC	CO
Fuel	all	HFO	MDO	MGO/ULMF	all	all
1900 – 1973	53	2.8	2.2	1.4	2.7	13
1974 – 1979	65	2.9	2.3	1.5	2.8	14
1980 – 1984	73	3.1	2.4	1.6	2.9	15
1985 – 1989	82	3.3	2.6	1.8	3.1	13
1990 – 1994	74	3.0	2.1	1.3	2.6	11
1995 – 1999	59	2.6	1.6	0.8	2.2	11
2000 – 2010	54[1]/49[2]	2.5	1.6	0.8	1.6	11

[1] HFO; [2] MDO or MGO/ULMF

Table 5-20 Emission factors of slow speed engines (SP) at berth, (g/kg fuel)

Year of build	NOx	PM	PM	PM	HC	CO
Fuel	all	HFO	MDO	MGO/ULMF	all	all
1900 – 1973	76	4.9	2.4	1.6	2.9	14
1974 – 1979	90	5.2	2.5	1.7	3.0	15
1980 – 1984	100	5.4	2.6	1.8	3.2	16
1985 - 1989	111	5.7	2.8	2.0	3.3	14
1990 - 1994	103	5.6	2.3	1.5	2.9	11
1995 - 1999	88	4.9	1.8	1.0	2.4	12
2000 - 2010	75[1]/71.4[2]	5.0	1.8	1.0	1.8	12

[1] HFO; [2] MDO or MGO/ULMF

Table 5-21 Emission factors of boilers of boilers at berth, (g/kg fuel)

Fuel	NOx	PM	HC	CO
HFO	1.6	2	0.8	4.1
MDO	1.6	0.7	0.8	3.5
MGO/ULMF	1.6	0.7	0.8	3.5

Table 5-22 Emission factors of all engines and apparatus, (g/kg fuel)

Fuel	SO_2	CO_2
HFO	30	3170
MDO	16	3150
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.

6 EMISSIONS IN THE NCS

In the final emission calculation, the emission per grid cell is divided over moving and non-moving ships and over EU and non-EU flags and over inside and outside 12 miles zone. Non-moving in the NCS means in most cases that the ship is located in the anchorage area. There are also some anchorage areas in the Western Scheldt. Non-moving in a port means that the ship is berthed. The distinction into EU-flag and zone can help to estimate the effect of measures.

The emissions are delivered as a database that can be used for additional emission calculations.

Since the figures with the spatial distribution of the emissions are all rather similar, only the spatial distribution of CO_2 is presented in this report. But before the results are illustrated, the observed number of ships with AIS is compared to the number of ships calculated with the SAMSON traffic database for 2008, to get some feeling about the accuracy of the AIS data and/or SAMSON. The SAMSON traffic database was used for the emission calculations until now.

6.1 Comparison of AIS with SAMSON for moving ships in the NCS

The most complete database of sea shipping traffic is the database of the SAMSON model based on the reconstruction of all journeys crossing the North Sea. This database is used for sea shipping safety studies and other sea shipping related projects. Until the introduction of AIS, this database was verified with observations from aeroplanes, which was a very time consuming and expensive method. For example the last verification has taken place from 1998-2001 during which so called 350 VONOVI-flights were carried out. During the flights each part of the North Sea was observed 28 times divided over the day of the week and the season. The verification was executed with particular attention to the routes taken by the ships. The number of ship movements based on the voyage records of one year of LMIU was much more accurate than based on VONOVI-observations, However, the densities of non-route-bound traffic, as fishing vessels and work vessels, are still based on these VONOVI-flights.
With the introduction of AIS, a much better knowledge could be built up of the shipping traffic on the North Sea. A better verification of the SAMSON database can be achieved in areas where AIS data is available. AIS data is more and more used in ship related studies, under which the calculation of emissions.
In this study, the AIS data is used for the calculation of emissions in the NCS. For the part of the North Sea in the OSPAR-region outside the NCS, the traffic database of SAMSON will still be used. This is because AIS data is not available for the entire area outside the NCS. It is not acquired by the Netherlands Coastguard because the base station belongs to another country, or not received by any base station in the middle of the North Sea. A base station receives all AIS in its vicinity, being a range of about 30 nautical miles.

To enlarge the insight in the quality of the AIS data and the quality of the SAMSON traffic database, the numbers of observed moving ships derived from the AIS data are compared with the ones derived from the SAMSON database. The ships at anchor (not moving) in the anchorage areas are not included because they are described by a separate database in SAMSON, based on the aerial observations.

Figure 6-1 contains the average number of ships in the cells belonging to the NCS, derived from the SAMSON traffic database of 2008. Table 6-1 contains the number of ships in the NCS spread over the ship type and ship size classes. On average nearly 148 (is 147697*0.001) ships are in the NCS.

An average number of ships in an area, for example 25, means that when taking a large number of photos of the area, on average you will find 25 ships on a photo.

The same table is composed from the AIS data. This result is given in Table 6-2. The same ship types are used, but Table 6-2 contains a different ship size class, namely the EMS-size class. In EMS, the lowest size class runs from 100-1600 GT, corresponding with the two lowest size classes of SAMSON. Within EMS the SAMSON size class 3 is divided into a size class from 1600-3000GT and one from 3000-5000 GT. For this reason the comparison between SAMSON and AIS could only be done for seven size classes. The comparison is presented in Table 6-3, in which the average based on the AIS count is presented as percentage of the average, determined with SAMSON. Only those cells are filled of which the SAMSON value was above 20.
The largest deviations can be observed for the ship types “Miscellaneous” and “Unknown/supply”. That was expected because movements of these ships are not included in the database with journeys collected by LMIU. Summarizing all values without these two ship types delivers 142.1 with SAMSON and 139.9 with AIS. With reference to the percentages presented in Table 6-3 it can be concluded that:

- The AIS data can be used for calculating the emissions and their spatial distribution in the NCS;
- The SAMSON traffic database of 2008 can be used for the OSPAR region for which no AIS data is available.

The number of ships calculated with SAMSON is calculated from the journeys assuming an average speed of 90% of the service speed (the same speed as used until now for the calculation of the emission factors). However, the average speed observed from the AIS data for 2008 is less than 90% of the service speed. This means that the average number of ships in the NCS derived from the SAMSON database is somewhat higher than reported in Table 6-1, increasing the difference between numbers derived from SAMSON and numbers derived from the AIS data. On the other hand, the numbers derived from the AIS data are underestimated because the AIS signals of some areas are not covered for the full 100% of the time due to the distance to the nearest base station. It is very difficult to give the spatial distribution of the quality or coverage of the AIS. That is only possible by a detailed comparison of the journeys generated by SAMSON and the real routes found in AIS, and next how long the ship is covered by the AIS. Such a detailed comparison was outside the scope of the project. But the conclusions made above about the applicability of AIS for the NCS and SAMSON for the remaining North Sea remain valid.

Table 6-4 contains the number of non-moving ships. Nearly all of them are at anchor in one of the anchorage areas on the North Sea. The average number of ships is 69. This is considerably compared to the 163 moving ships in Table 6-1. However, the emission of a ship at anchor is limited, the total emission of non-moving ships is only a few percent of the total emission.

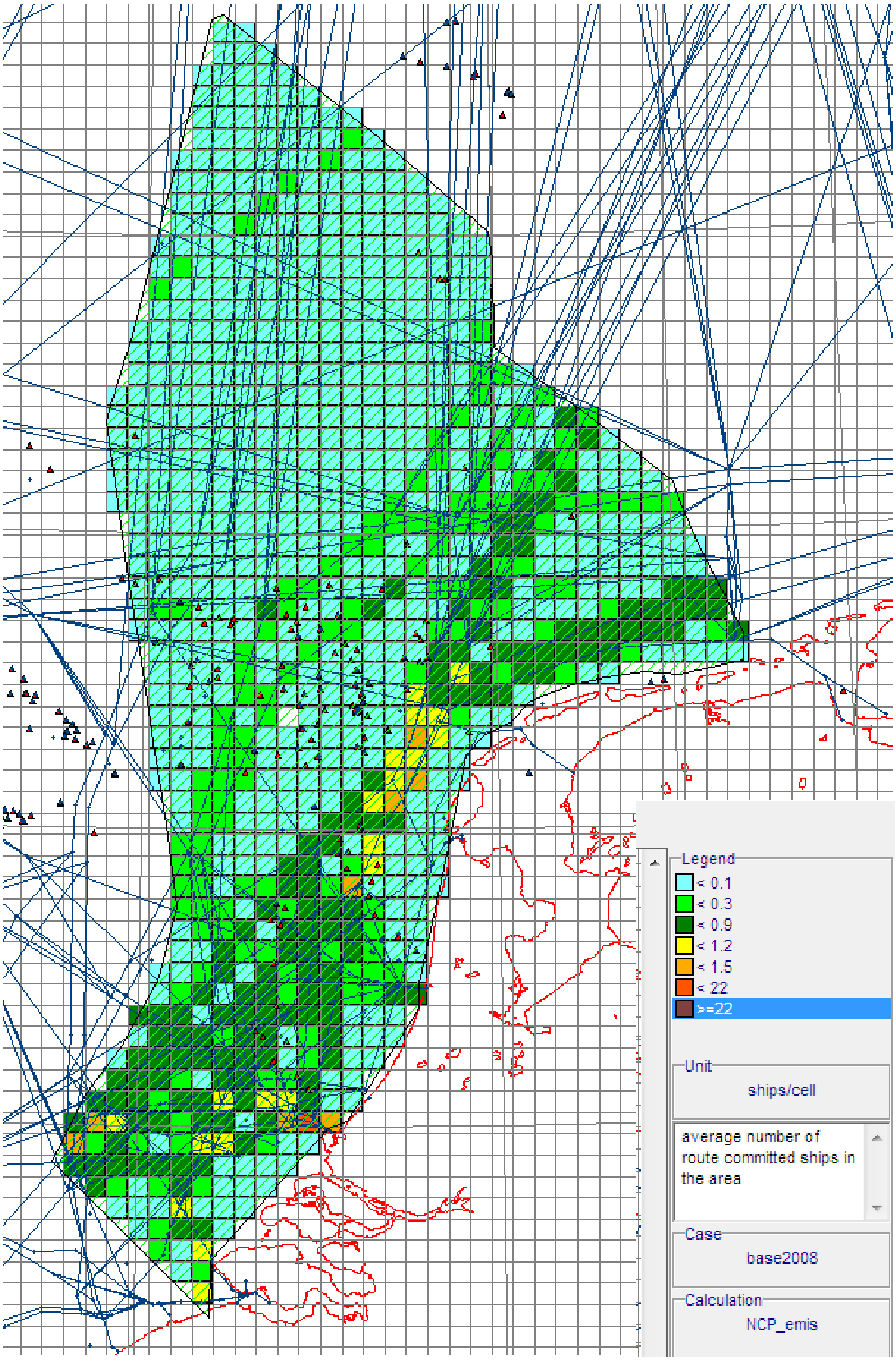

Figure 6-1 Average number of moving ships per 5x5 km grid cell, based on the SAMSON traffic database of 2008, assuming a sailing speed of 90% of the service speed.

Table 6-1 Average number of moving ships in the Netherlands Continental Shelf, derived from the SAMSON traffic database of 2008, assuming a sailing speed of 90% of the service speed (unit =0.001)

Ship type	Gross Tonnage (GT) size classes								total
	-100 <1000	-1000 <1600	-1600 <5000	-5000 <10000	-10000 <30000	-30000 <60000	-60000 <100000	-100000	
OBO	42	0	3	52	0	14	0	2	113
OBO DH	0	0	6	0	0	86	48	0	140
CHEM IMO 1	0	0	61	66	46	0	0	0	173
CHEM IMO 1 DH	0	0	8	347	380	0	0	0	734
CHEM IMO 2	47	179	1634	526	424	0	0	0	2810
CHEM IMO 2 DH	2	51	6178	3447	4448	55	0	0	14180
CHEM IMO 3	0	46	342	1	206	11	0	0	606
CHEM IMO 3 DH	0	1	106	112	2265	247	0	0	2731
CHEM	9	2	28	0	6	0	0	0	45
CHEM DH	0	17	129	589	105	0	0	0	840
CHEM WWR	136	42	124	7	16	0	0	0	325
CHEM WWR DH	2	29	101	0	0	9	0	0	141
OIL crude oil	0	0	2	0	8	3	56	10	79
OIL crude oil DH	0	0	39	5	83	1532	1940	127	3726
OIL product	25	15	298	20	178	13	0	0	548
OIL product DH	1	79	723	493	1467	581	71	0	3415
OIL remaining	11	3	17	3	14	1	0	0	48
OIL remaining DH	0	8	136	0	37	38	43	0	262
LNG	0	0	0	0	0	0	5	24	29
LPG refrigered	0	0	0	0	226	67	0	0	293
LPG semi pressured	0	92	1460	431	395	0	0	0	2379
LPG pressured	0	36	1336	55	0	0	0	0	1427
LPG remaining	0	1	441	65	74	28	0	0	609
BULKERS	24	94	1192	430	5381	2652	733	152	10658
UNITISED container	0	33	2619	5425	4116	3259	2681	492	18626
UNITISED roro	9	4	434	1604	6418	1254	2	0	9725
UNITISED vehicle	0	0	38	1035	890	2133	386	0	4482
GDC dry cargo	1391	3092	8541	1151	145	11	0	0	14332
GDC dry c/container	310	5275	30956	4700	1368	144	0	0	42753
GDC reefer	45	29	687	1291	1074	0	0	0	3126
Passenger	31	2	26	41	256	130	164	30	680
Passeng.roro	5	0	9	10	1074	941	0	0	2039
Ferries	16	0	7	0	0	1	0	0	25
HSF	7	0	0	0	0	0	0	0	7
Miscellaneous	1554	442	1205	495	217	46	2	24	3984
Unknown / Supply	1594	0	0	10	0	0	0	0	1604
Total	5260	9572	58888	22410	31319	13256	6130	861	147697

Table 6-2 Average number of moving ships in the Netherlands Continental Shelf, derived from the AIS data of 2008 (unit =0.001)

Ship type	Gross Tonnage (GT) size classes								total
	-100 <1600	-1600 <3000	-3000 <5000	-5000 <10000	-10000 <30000	-30000 <60000	-60000 <100000	-100000	
OBO	33	0	0	41	0	16	0	5	95
OBO DH	0	0	2	0	0	79	60	0	141
CHEM IMO 1	0	10	39	73	42	0	0	0	164
CHEM IMO 1 DH	0	0	7	338	414	0	0	0	759
CHEM IMO 2	223	1018	650	496	556	0	0	0	2944
CHEM IMO 2 DH	49	3451	2850	3172	4801	92	0	0	14416
CHEM IMO 3	48	134	201	4	214	16	0	0	617
CHEM IMO 3 DH	0	72	47	119	2315	288	0	0	2841
CHEM	9	31	0	0	6	0	0	0	47
CHEM DH	0	70	95	605	133	0	0	0	903
CHEM WWR	138	108	0	8	16	0	0	0	271
CHEM WWR DH	37	123	0	0	0	11	0	0	171
OIL crude oil	0	0	0	0	16	3	69	11	98
OIL crude oil DH	0	0	37	5	78	1690	2052	184	4047
OIL product	39	116	166	21	238	13	0	0	593
OIL product DH	99	285	384	514	1688	673	67	0	3710
OIL remaining	5	0	11	0	22	0	0	0	38
OIL remaining DH	5	7	95	0	39	34	34	0	214
LNG	0	0	0	0	0	0	11	16	27
LPG refrigered	0	0	0	0	217	60	0	0	278
LPG semi pressured	132	315	1048	368	396	0	0	0	2259
LPG pressured	42	454	811	50	0	0	0	0	1356
LPG remaining	0	133	349	55	60	28	0	0	624
BULKERS	106	451	677	430	5157	2551	979	235	10586
UNITISED container	43	1178	1310	5026	4093	3478	3075	581	18785
UNITISED roro	3	210	192	1426	5701	1191	2	0	8723
UNITISED vehicle	0	0	55	951	856	2137	387	0	4386
GDC dry cargo	4072	6708	1517	1043	155	8	0	0	13505
GDC dry c/container	5340	20679	9514	4372	1290	123	0	0	41318
GDC reefer	186	214	461	1283	1184	0	0	0	3327
Passenger	38	17	14	35	270	131	153	28	684
Passeng.roro	0	3	0	13	959	1023	0	0	1999
Ferries	14	2	0	0	0	1	0	0	17
HSF	4	0	0	0	0	0	0	0	4
Miscellaneous	4763	2066	916	1144	426	78	8	4	9405
Unknown / Supply	8842	4754	144	34	0	0	0	0	13775
Total	24272	42610	21591	21624	31342	13725	6896	1065	163127

Table 6-3 Average number of ships in Netherlands Continental Shelf, based on AIS data, expressed as % of the average number derived from the SAMSON traffic database

Ship type	Gross Tonnage (GT) size classes								Total
		-100 <1600	-1600 <5000	-5000 <10000	-10000 <30000	-30000 <60000	-60000 <100000	-100000	
OBO		79%		78%					84%
OBO DH						91%	126%		101%
CHEM IMO 1			81%	110%	92%				95%
CHEM IMO 1 DH				97%	109%				103%
CHEM IMO 2		99%	102%	94%	131%				105%
CHEM IMO 2 DH		92%	102%	92%	108%	168%			102%
CHEM IMO 3		105%	98%		104%				102%
CHEM IMO 3 DH			112%	107%	102%	117%			104%
CHEM			112%						105%
CHEM DH			128%	103%	127%				107%
CHEM WWR		78%	87%						84%
CHEM WWR DH		120%	122%						121%
OIL crude oil							123%		125%
OIL crude oil DH			95%		94%	110%	106%	145%	109%
OIL product		99%	95%		133%				108%
OIL product DH		123%	93%	104%	115%	116%	94%		109%
OIL remaining									79%
OIL remaining DH			75%		105%	91%	79%		82%
LNG								67%	93%
LPG refrigered					96%	90%			95%
LPG semi pressured		143%	93%	85%	100%				95%
LPG pressured		116%	95%	91%					95%
LPG remaining			109%	84%	81%	100%			103%
BULKERS		90%	95%	100%	96%	96%	134%	155%	99%
UNITISED container		132%	95%	93%	99%	107%	115%	118%	101%
UNITISED roro			92%	89%	89%	95%			90%
UNITISED vehicle			146%	92%	96%	100%	100%		98%
GDC dry cargo		91%	96%	91%	107%				94%
GDC dry c/container		96%	98%	93%	94%	86%			97%
GDC reefer		251%	98%	99%	110%				106%
Passenger		115%	120%	84%	105%	100%	93%	93%	101%
Passeng.roro					89%	109%			98%
Ferries									69%
HSF									
Miscellaneous		239%	247%	231%	196%	171%		17%	236%
Unknown / Supply		555%							859%
Total		164%	109%	96%	100%	104%	112%	124%	110%

Table 6-4 Average ships not moving (at anchor) in Netherlands Continental Shelf from the AIS data of 2008 (unit =0.001)

Ship type	Gross Tonnage (GT) size classes								total
	-100 <1600	-1600 <3000	-3000 <5000	-5000 <10000	-10000 <30000	-30000 <60000	-60000 <100000	-100000	
OBO	38	0	0	2	0	9	0	20	69
OBO DH	0	0	0	0	0	11	61	0	72
CHEM IMO 1	0	26	12	78	98	0	0	0	215
CHEM IMO 1 DH	0	0	1	139	297	0	0	0	437
CHEM IMO 2	57	791	510	282	733	0	0	0	2374
CHEM IMO 2 DH	52	2544	2410	3831	6340	179	0	0	15358
CHEM IMO 3	1	108	21	18	248	17	0	0	414
CHEM IMO 3 DH	0	125	19	150	3175	414	0	0	3883
CHEM	0	2	0	0	1	0	0	0	3
CHEM DH	0	65	70	1021	280	0	0	0	1436
CHEM WWR	0	0	0	0	3	0	0	0	3
CHEM WWR DH	55	95	0	0	0	0	0	0	150
OIL crude oil	0	0	0	0	36	4	55	1	97
OIL crude oil DH	0	0	46	18	103	1778	1020	326	3291
OIL product	1	140	127	25	600	13	0	0	907
OIL product DH	8	284	385	905	3084	1055	92	0	5814
OIL remaining	0	0	17	0	37	0	0	0	54
OIL remaining DH	12	8	182	0	84	39	20	0	345
LNG	0	0	0	0	0	0	0	0	0
LPG refrigered	0	0	0	0	81	6	0	0	86
LPG semi pressured	293	454	851	422	192	0	0	0	2213
LPG pressured	21	260	909	61	0	0	0	0	1252
LPG remaining	0	70	242	38	3	0	0	0	353
BULKERS	0	9	105	140	1729	1742	2090	695	6509
UNITISED container	5	109	503	1945	1394	641	629	111	5337
UNITISED roro	0	44	3	44	32	23	0	0	146
UNITISED vehicle	0	0	20	7	21	132	9	0	190
GDC dry cargo	283	549	145	91	78	0	0	0	1147
GDC dry c/container	367	1956	1068	541	156	8	0	0	4095
GDC reefer	4	10	173	205	127	0	0	0	519
Passenger	0	0	0	0	48	0	1	0	50
Passeng.roro	0	0	0	0	1	2	0	0	3
Ferries	0	0	0	0	0	0	0	0	78
HSF	0	0	0	0	0	0	0	0	0
Miscellaneous	1370	382	658	1353	93	21	0	0	5279
Unknown / Supply	3662	2455	266	38	0	0	0	0	6443
Total	6231	10489	8746	11355	19074	6094	3975	1154	68621

6.2 The spatial distribution of the emissions

All substances show more or less the same spatial distribution because there is a strong relation with the shipping routes. Therefore only the emission distribution of CO_2 is presented for the NCS and the four port areas in the next figures.

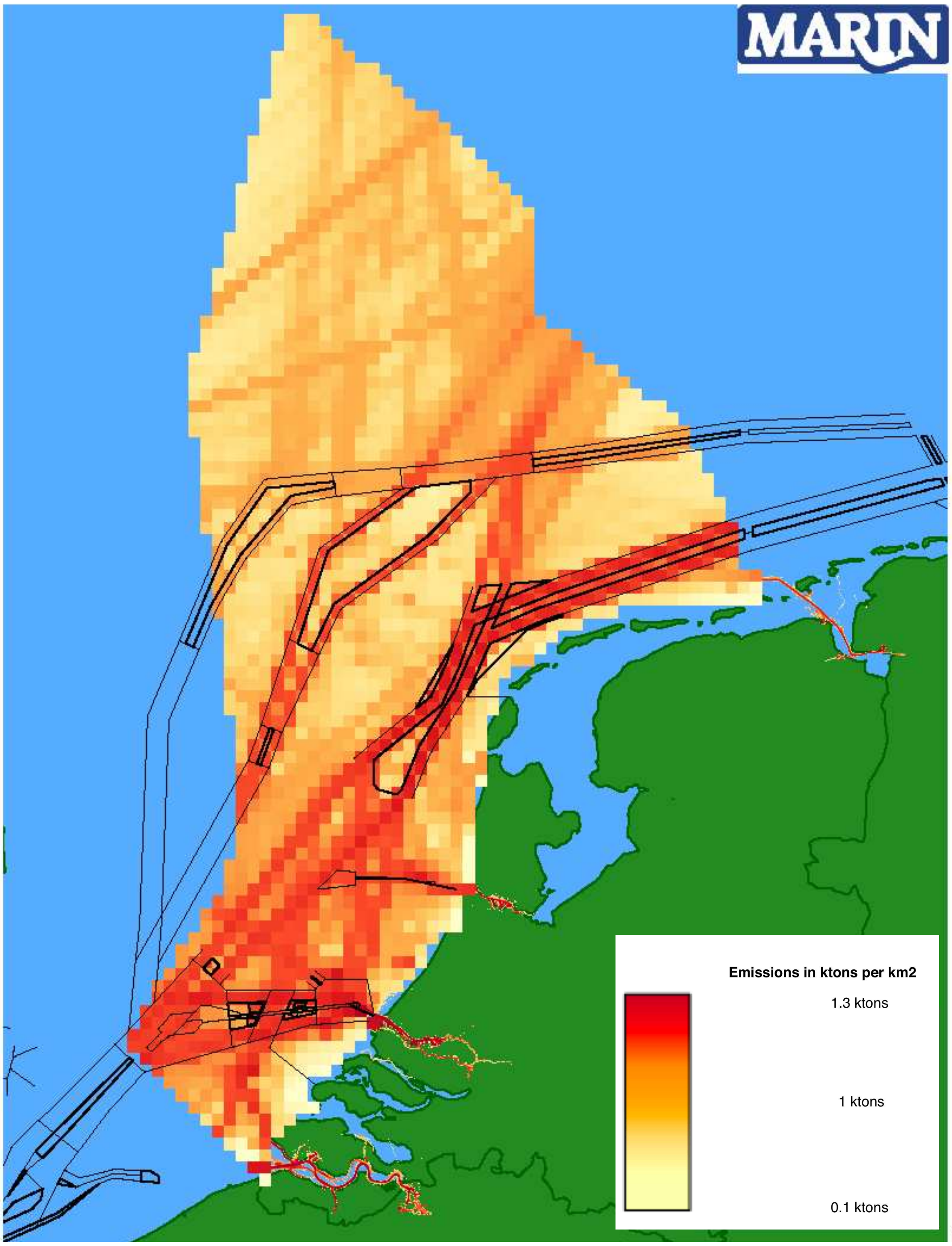

Figure 6-2 CO_2 emissions in the NCS by ships with AIS in 2008

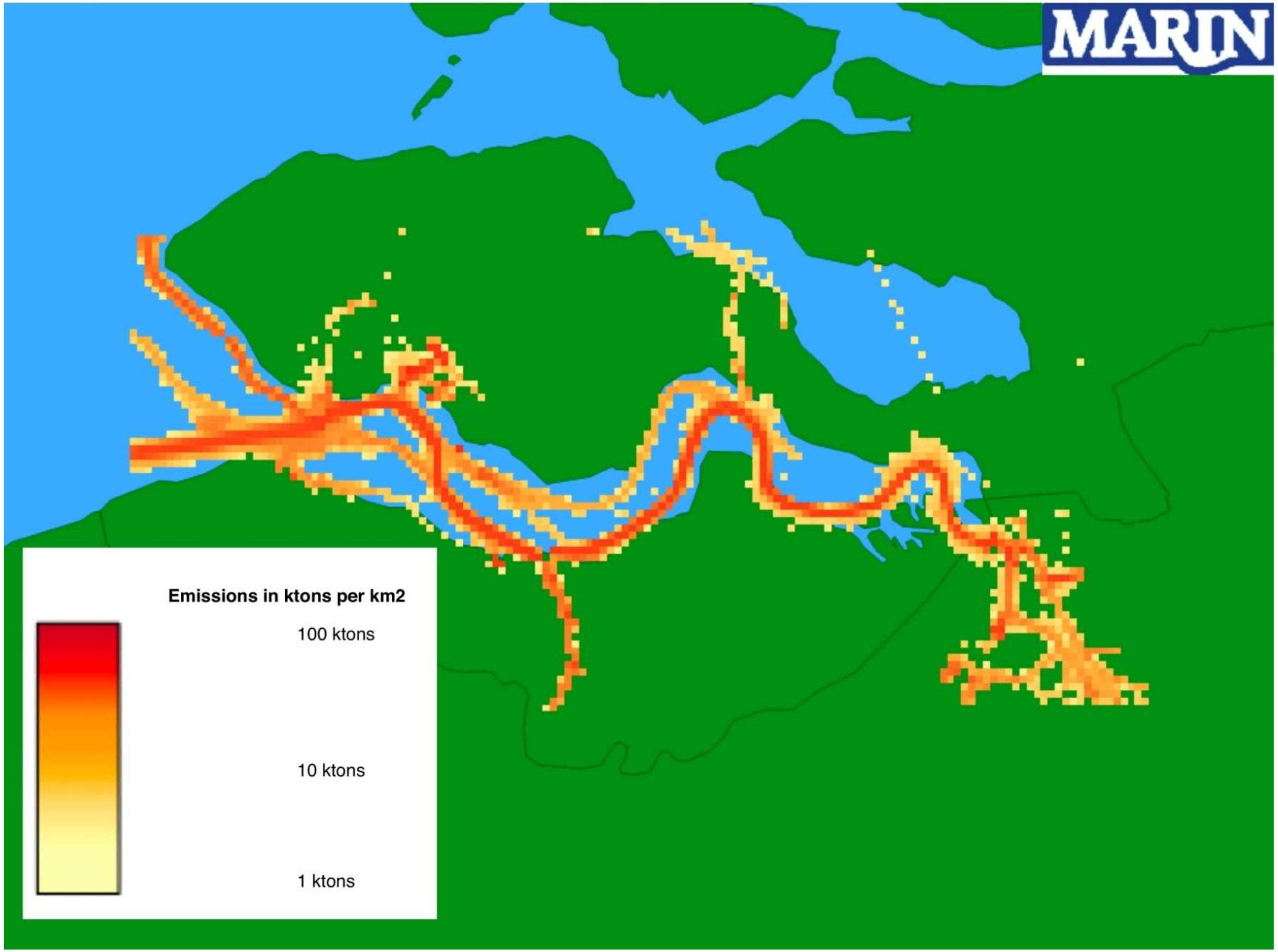

Figure 6-3 CO_2 emission in the Western Scheldt by ships with AIS in 2008

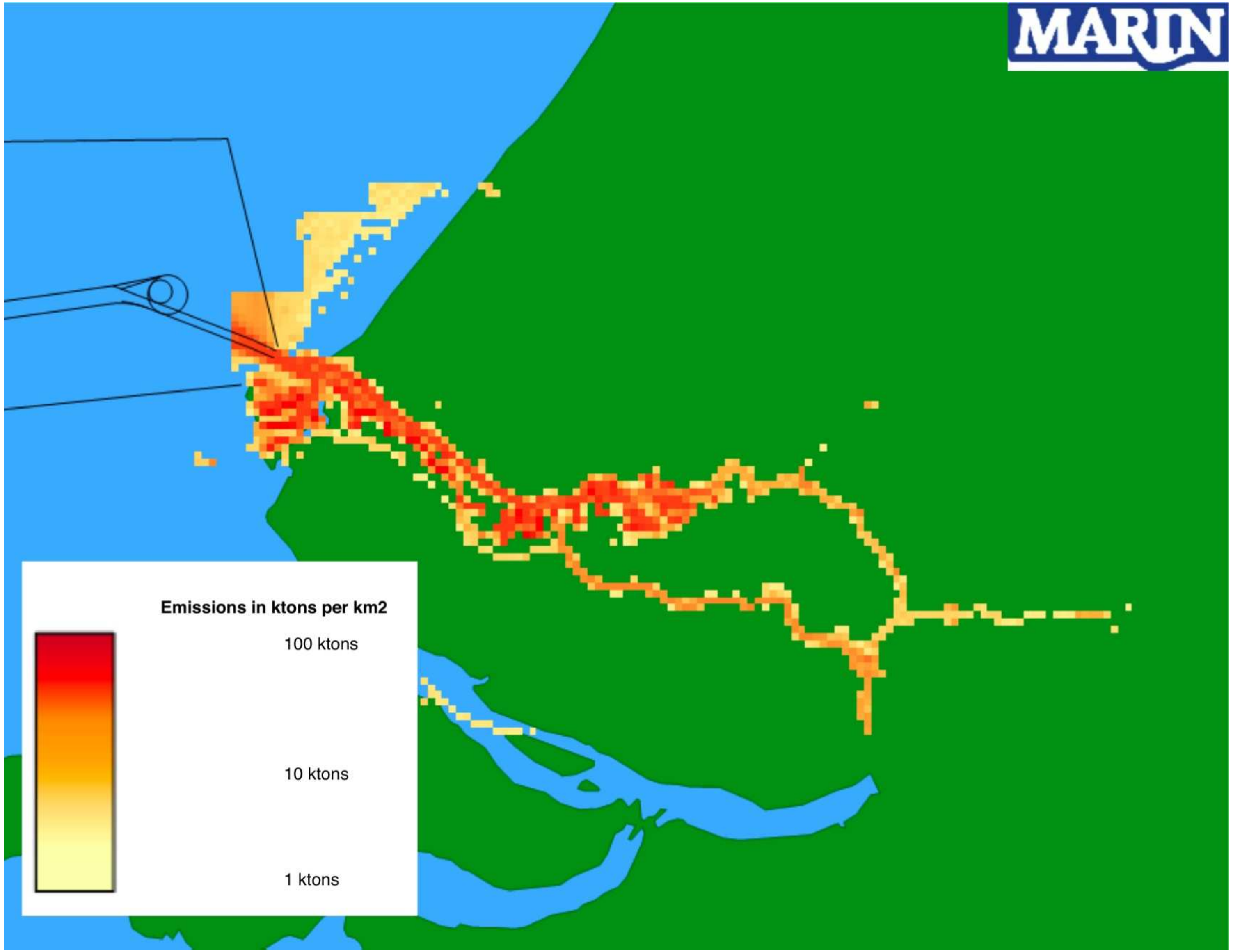

Figure 6-4 CO_2 emissions in the port area of Rotterdam by ships with AIS in 2008

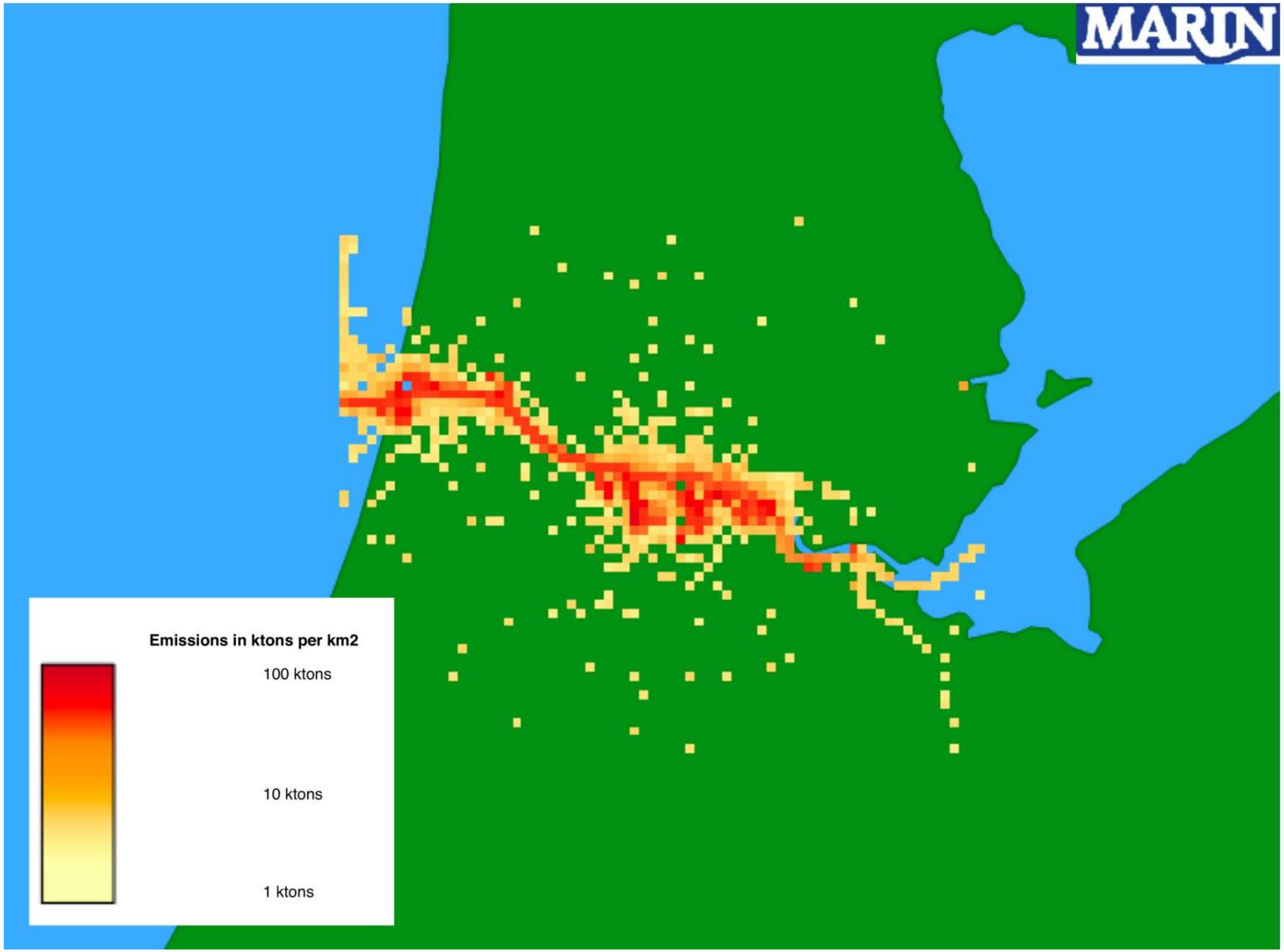

Figure 6-5 CO_2 emissions in the port area of Amsterdam by ships with AIS in 2008

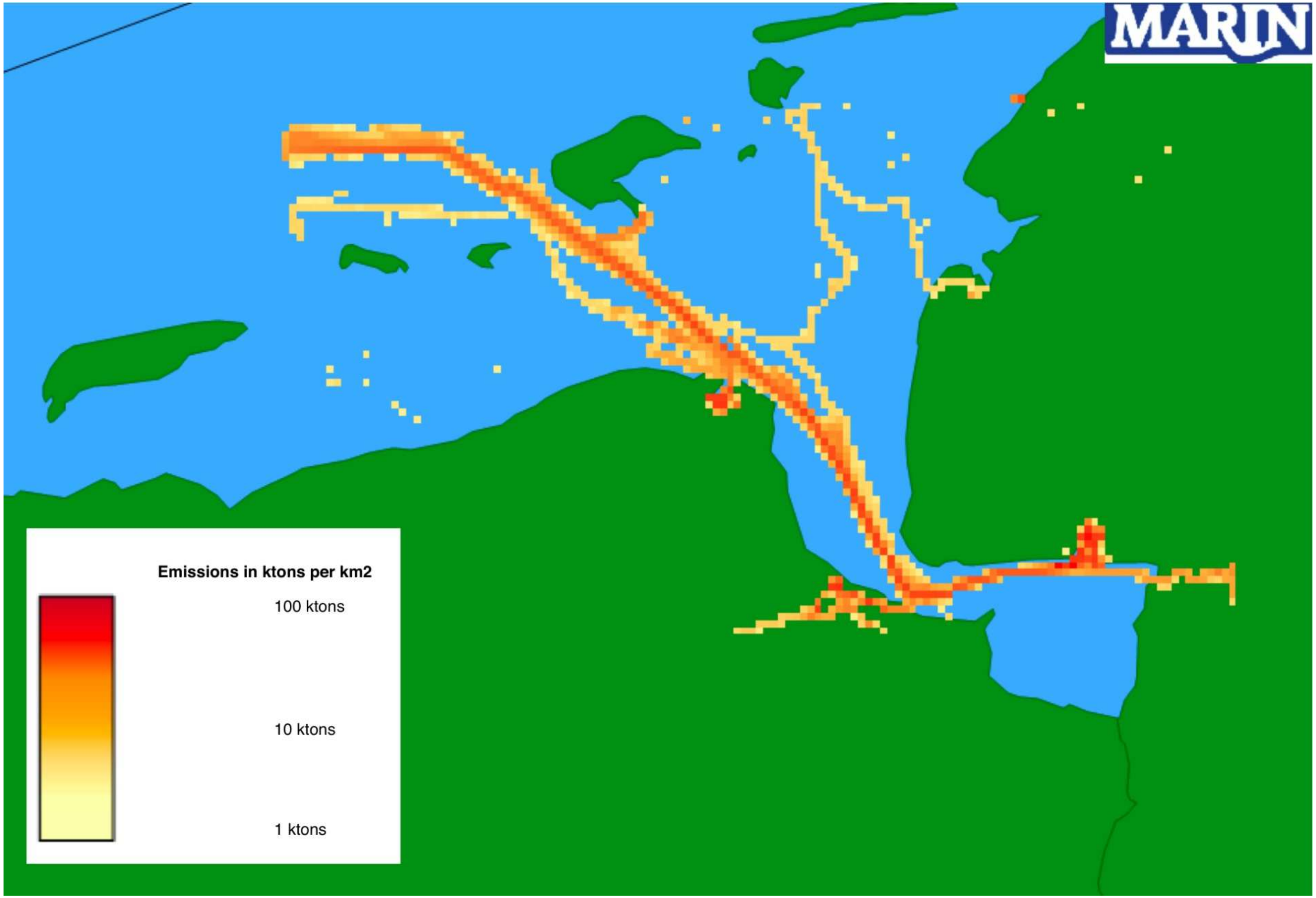

Figure 6-6 CO_2 emissions in the Eems area by ships with AIS in 2008

6.3 Emissions in port areas

Some results of the emissions in the port areas are presented in this chapter. The results are completely based on the AIS data.
It is assumed that the AIS data in the western part of the Western Scheldt is covered quite well by the base station in Westkapelle. It is not known how well the eastern part of the Western Scheldt is covered. It can be expected that the AIS signals of ships in the port of Antwerpen are not always received, but this does not affect the results for the area within the Netherlands. Of course this can be analyzed in detail, but this time consuming task was not part of this study. It is assumed that the Dutch ports along the Western Scheldt are covered quite well because the distance from these ports to the base station is less than 30 nautical miles. The delivered dataset can be used to calculate the emissions for a smaller area, for example the Sloehaven. The user can define the emission for each area by summarizing the emissions of all grid cells within the specified area.

The area of Rotterdam is covered reasonably well, as analyzed in the 2008 pilot study [1], but the coverage decreases when going eastwards. It is assumed that the same coverage pattern will occur in Amsterdam and the Eems, thus a decreasing coverage when going further inland. Because most sea ships visit a port area close to the entrance the emissions can be considered as complete.

Table 6-5 contains the number of ships, moving and berthed, divided over EU and non-EU flag. It shows that the non-EU flag has the largest share.

Table 6-5 Average number of AIS-ships in the port areas in 2008

Port area	Not moving (berthed)			Moving			Total
	Non EU flag	EU	All	Non EU flag	EU	All	
Western Scheldt	25.76	24.23	49.99	12.30	9.83	22.13	72.12
Rotterdam	93.64	64.23	157.87	13.91	11.24	25.15	183.02
Amsterdam	34.88	29.56	64.45	3.02	4.08	7.09	71.54
Eems	18.99	21.65	40.63	2.12	3.69	5.81	46.45
Grand Total	173.27	139.67	312.94	31.35	28.83	60.18	373.12

Table 6-6 contains the emissions calculated for ships berthed, and for the main and auxiliary engines during the journeys within the port area.

Table 6-6 The total emissions in ton in each area for 2008 based on the AIS data

Substance	source	Wester-schelde	Rotter-dam	Amster-Dam	Eems	Totaal
1237 NMVOC	Berthed	45	255	68	13	380
	Sailing: Main engine	238	149	34	22	443
	Sailing: Auxiliary engines	37	29	7	4	78
	Total	***320***	***433***	***110***	***38***	***901***
4001 SO_2	Berthed	486	2,843	670	108	4,108
	Sailing: Main engine	2,503	1,334	238	203	4,278
	Sailing: Auxiliary engines	465	388	84	36	973
	Total	***3,454***	***4,565***	***993***	***347***	***9,358***
4013 NO_x	Berthed	1,042	5,561	1,537	300	8,438
	Sailing: Main engine	7,308	3,753	715	588	12,365
	Sailing: Auxiliary engines	1,080	866	213	110	2,270
	Total	***9,430***	***10,180***	***2,465***	***997***	***23,072***
4031 CO	Berthed	203	1,139	300	61	1,704
	Sailing: Main engine	1,500	1,023	231	120	2,874
	Sailing: Auxiliary engines	202	165	40	21	428
	Total	***1,905***	***2,327***	***572***	***202***	***5,006***
4032 CO_2	Berthed	88,425	603,152	144,952	22,403	858,933
	Sailing: Main engine	272,321	149,730	27,406	24,037	473,494
	Sailing: Auxiliary engines	55,670	46,424	10,908	5,499	118,501
	Total	***416,417***	***799,306***	***183,266***	***51,940***	***1,450,928***
6598 PM10 and PM2.5	Berthed	50	325	80	12	467
	Sailing: Main engine	408	215	40	31	695
	Sailing: Auxiliary engines	60	49	11	5	124
	Total	***518***	***590***	***131***	***47***	***1,286***

6.4 Comparison of emissions in Rotterdam with the emissions of 2007

The emissions in the four port areas are calculated based on the AIS data. The port area of Rotterdam in this study is larger than the port area in the AIS Rijnmond study of 2007 [1]. For comparing the results of 2008 with 2007, the emissions are also calculated for an area “2007” that is equal to the area used in [1]. The comparison is carried out for moving ships and ships at berth. Table 6-7 shows the emissions of 2007 (from [1]) and 2008 for the same area for both the main engine and the auxiliary engines of moving ships. Table 6-8 contains the total emissions for moving ships of Table 6-7 together with the emissions of the berthed ships.

Table 6-7 Emissions in ton of moving ships in the Rijnmond area

Sub-stance nr	Substance	2007			2008			2008/ 2007
		Main Engine	Auxiliary Engine	Total	Main Engine	Auxiliary Engine	Total	
1237	NMVOC	116	26	142	131	26	157	110%
4001	SO_2	891	211	1,101	1,123	347	1,470	134%
4013	NO_x	2,559	737	3,296	3,190	775	3,965	120%
4031	CO	805	148	953	903	147	1,051	110%
4032	CO_2	99,899	41,479	141,378	126,750	41,570	168,320	119%
6598	PM10/PM2.5	149	23	173	183	44	227	131%

Table 6-8 Emissions in ton for moving and berthed ships in Rijnmond

Sub-Stance nr	2007			2008			2008 / 2007		
	Moving	Berth	Total	Moving	Berth	Total	Moving	Berth	Total
1237	142	209	351	157	247	404	110%	118%	115%
4001	1,101	2,339	3,440	1,470	2,763	4,233	134%	118%	123%
4013	3,296	4,551	7,847	3,965	5,389	9,354	120%	118%	119%
4031	953	925	1,878	1,051	1,105	2,156	110%	119%	115%
4032	141,378	490,837	632,215	168,320	586,594	754,914	119%	120%	119%
6598	173	266	439	227	316	543	131%	119%	124%

Both Table 6-7 and Table 6-8 show a significant increase of the emissions. It is important to find the cause of this increase. The cause can be:

- The growth of the number of ships;
- Relatively more larger ships;
- Effect of changes in emission factors;
- Improved quality of AIS data;

or any combination of these facts.

A more detailed analysis is required to find the cause. For this purpose Table 6-9 is composed with the number of GThours in 2007 and 2008 for each EMS-ship type. In [1] the EMS-type “Passenger” was not available. This type was presumably classified as a

Ro/Ro type. For this reason the percentage 2008/2007 for Ro/Ro is based on the sum of the ship types “RoRo Cargo / Vehicle” and “Passenger”. There is an increase for nearly all ship types, with the exception of “Reefer”. The 234% for the “Other” ships is far above the average, because more and more smaller ships, that fall in this category, use AIS. The extra calculated emission by these smaller ships is limited, because they produce relatively low emissions.

Table 6-9 Number of GThours, base for the emissions at berth

typenr	Ship type	2007	2008	2008 as % of 2007
1	Oil tanker	3,333,113,931	3,623,401,847	108.7%
2	Chemical/LNG/LPG tanker	2,234,631,672	2,737,595,014	122.5%
3	Bulk carrier	4,616,753,221	5,572,886,460	120.7%
4	Container ship	5,045,537,884	5,471,691,271	108.4%
5	General Dry Cargo	838,029,258	939,499,296	112.1%
6	RoRo Cargo / Vehicle	1,557,328,741	976,883,156	107.2%
7	Reefer	113,443,696	94,556,961	83.4%
8	Passenger		782,115,905	(in 2007 under RoRo)
9	Other	295,569,004	692,424,386	234.3%
	Total	18,034,407,408	20,891,054,295	115.8%

Table 6-10 Number of observations used from the AIS data (unit is 1000)

EMS size	GT	2007	2008			2008/ 2007
			At berth	Moving	Total	
0	unknown. or <100	2,785	6,632	1,458	8,090	290.5%
1	100-1,600	9,380	6,360	1,636	7,996	85.2%
2	1,600-3,000	6,111	4,666	745	5,411	88.5%
3	3,000-5,000	4,864	4,088	584	4,673	96.1%
4	5,000-10,000	6,136	5,051	670	5,721	93.2%
5	10,000-30,000	7,411	7,463	677	8,140	109.8%
6	30,000-60,000	2,823	2,888	210	3,098	109.8%
7	60,000-100,000	2,499	2,292	140	2,431	97.3%
8	>100,000	654	779	39	818	125.0%
0-8	all	42,662	40,219	6,158	46,377	108.7%
1-8	>100	39,877	33,587	4,701	38,287	96.0%

Table 6-10 contains the number of observations derived from the AIS data. These are very large numbers because an observation is counted every 2 minutes. The number of observations has increased from 42.7 million in 2007 to 46.4 million in 2008, meaning an increase of 8.7%. The GT class lower than 100 GT shows the largest increase of which the cause has already been mentioned. In case size class 0 is excluded, the number of observations has even decreased. The table shows larger increases in the higher size classes thus for ships with higher emissions.

Conclusion
The emissions calculated with AIS for the port of Rotterdam for 2007 and 2008 differ substantially. The emissions in 2008 are about 20% higher. In spite of additional calculations the cause could not be traced. The main reason seems to be that more AIS ships have been observed as shown in Table 6-10, but the largest difference is found in the size class 0, which means that the ship is not found or is very small (<100GT). For the other size classes the same table shows an increase of the observations in the higher size classes and a decrease in the lower size classes. This effect can explain part of the increase in emissions. Furthermore, the year 2008 cannot be considered as an average year due to the economic crisis. A longer stay in the harbour due to lack of cargo could be an additional explanation for the increase in the emissions.

The difference in observed ships in the AIS data can only be explained when the results of the AIS observations are checked with a second source with detailed shipping data. The only second source that fulfils the requirements, is the complete dataset collected by the Port of Rotterdam of all visiting merchant vessels with time of arrival and departure. When these datasets become available for 2007 and 2008, it can be researched where the differences come from. Such a detailed analysis is beyond the scope of this study.

6.5 Emissions in the NCS

The emissions of the ships in the NCS are calculated for moving ships and non-moving ships. Ships are counted as non-moving when the speed is less than 1 knot. Most of the ships having this speed are at anchor in one of the anchorage areas. But there will be some ships having 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 is calculated for the main engine and auxiliary engines.
The calculated emissions for 2008 are summarized in Table 6-11. The emissions of moving ships are compared with the emissions determined for 2007 according to the EMS-approach that was followed until 2007. It turns out that the calculated emissions in 2008 are about 30% less than in 2007. For SO_2 it is even more, but that is due to the reduction of the percentage sulphur in the fuel. The reduction is mainly due to the lower speed observed within the AIS data, than assumed within the emission calculations until 2007. The lower speed is an effect of the economic crisis, to save in fuel costs, that forms a substantial part of the operational costs of a ship. When assuming that emissions are related with the third power of the speed, than the emissions per nautical mile travelled are related with the second power of the speed, Thus sailing with 80% of the speed instead of 90% means that the emissions per hour will reduce to 70%, and the emissions per nautical mile travelled will reduce to 79%. Also the number of shipping movements is slightly reduced by the crisis.
Furthermore a different approach will lead to new results that cannot always be compared with results of other approaches. It is expected that the speed will increase again after the crisis.

The column with emissions of the, on average, 70 ships at anchor (nearly 30% of the total number of ships) could not be compared with results from 2007, because emissions for this group were not taken into account in EMS. However, the emission of ships at anchor is very limited: less than 3%.

Table 6-11 Emissions of ships in ton in NCS for 2008 and 2007

Nr	Substance	EMS	Emission in ton in 2008			2008 as % of 2007	at anchor 2008
		NCS 2007	Main Engine	Auxiliary Engine	Total		
1237	NMVOC	3,347	2,199	236	2,434	72.7%	66
4001	SO_2	58,600	28,298	2,935	31,233	53.3%	830
4013	NO_x	117,000	79,352	6,838	86,190	73.7%	1,950
4031	CO	17,860	12,874	1,292	14,165	79.3%	371
4032	CO_2	4,600,000	3,055,508	357,384	3,412,891	74.2%	103,447
6598	PM10 and PM2.5	7,109	4,407	375	4,782	67.3%	105
	Ships		172	172	172		70

7 EMISSIONS IN OSPAR REGION II, THE GREATER NORTH SEA

7.1 Approach

The OSPAR region II, called the Greater North Sea, is the area between 48° and 62° N and 5°W and 13°E. MARIN has no access to AIS data f or this whole area. For the estimation of the emissions in the Greater North Sea an extrapolation has been performed based on the traffic database of SAMSON. Figure 7-1 shows all traffic links defined within the traffic database of 2008.

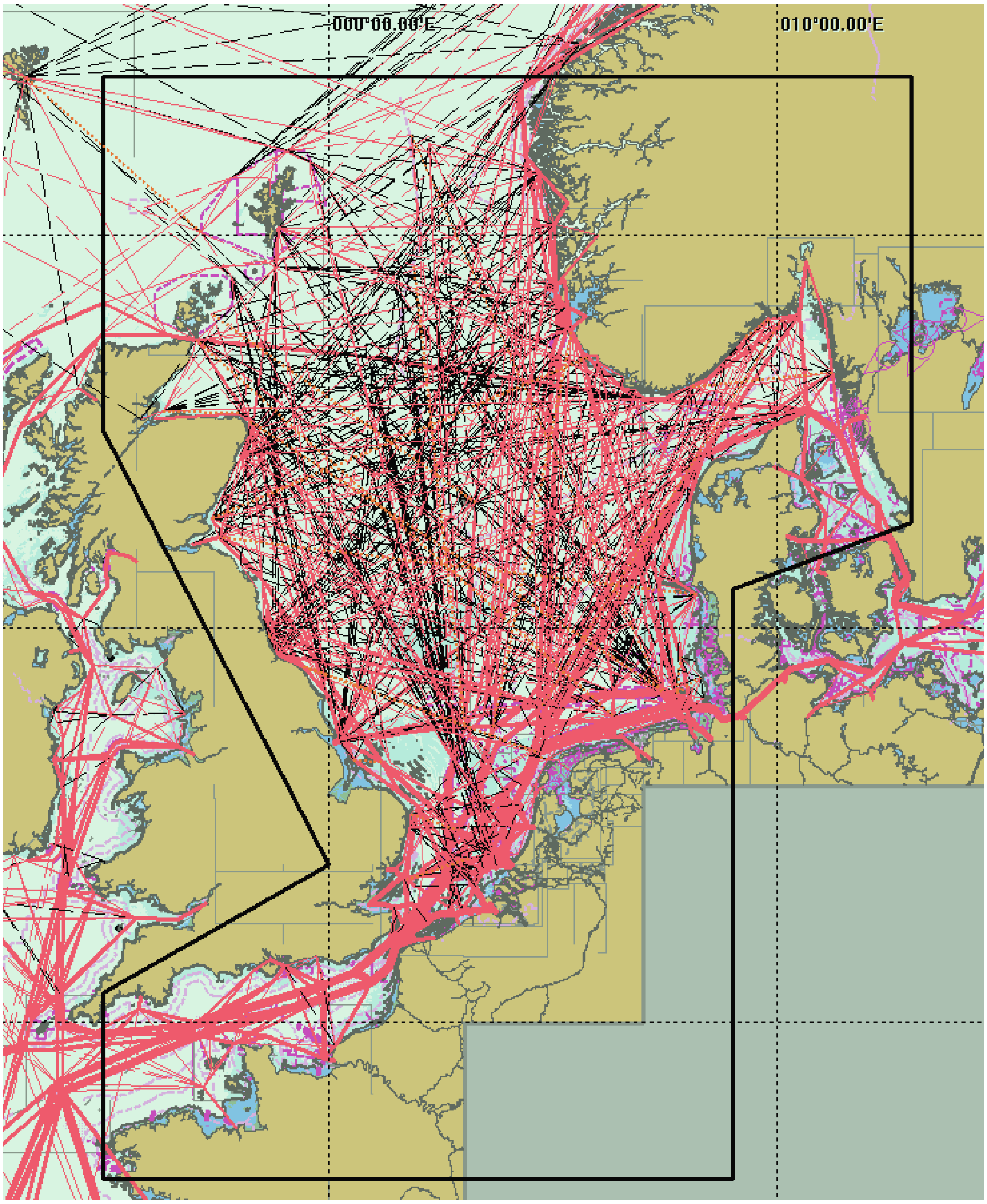

Figure 7-1 Traffic links in OSPAR region II (thick black frame). The width indicates the intensity of ships on the link (red represents a higher intensity than black).

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 base, the number of movements per years. The traffic links in Dover Strait represent about 40,000 movements in one direction per year.

The traffic database of SAMSON contains for each traffic link the number of ship movements per year spread over 36 ship types and 8 ship size classes. Further the database contains the lateral distribution of each traffic link, thus how the ship movements are divided over a crossing line. All safety calculations with SAMSON use the traffic database. One model calculates the average number of ships in each grid cell. In this typical calculation the lateral distribution is not used. It is assumed that all ships sail over the centre line of the traffic link. The average number of ships of type i and class j in grid cell c is

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

Herein is:

n_{ijk} the number of ship movements of type i and size j over link k per year divided by the number of hours in one year, thus movements/(24x366) in 2008;

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.

Based on analyses in the past, SAMSON uses for v_{ij} 90% of the service speed. The AIS data has made it possible to enlarge the knowledge about the speed at sea. The AIS data of 2008 has learnt that the average speed in 2008 was significantly lower. On average 80% of the service speed instead of the 90% assumed in SAMSON. The main reason for this phenomenon is the credit crisis, that has led to a decrease in transport freight, thus indirectly to more idle time. This “idle time” is used by sailing with reduced speed, which delivers a considerable saving of fuel costs.

Therefore it is better to base the emissions in the OSPAR region on the number of shipping miles sailed in each grid cell, because this does not depend not on the speed of the vessels. The average number of ship miles per ship type and size class is multiplied with the average emission per mile in the Netherlands Continental Shelf based on the AIS data of 2008. The emission of ships type i and size j in grid cell c can be calculated with:

$$Emission_{cij} = n_{ijk} \cdot L_k \cdot \frac{Emission_{NCS_{ij}}}{D_{NCS_{ij}}}$$

Herein is:

Emission_NCS$_{ij}$	total emission in the NCS for ship type i and size j
D_NCS$_{ij}$	total distance in nautical miles sailed by ships type i size j in the NCS.

The average emissions per ship type and class per mile, calculated from the AIS data, contains implicitly the effect of the reduced speed. The time the ship is in a grid cell is proportional to 1/speed and the produced emissions per hour is proportional to speed^3. Thus the emission in the grid cell and each other area is proportional to speed^2.

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

7.2 Results for OSPAR Region

The emissions for the total OSPAR region are calculated for each substance separately and summarized in Table 7-1. The average number of ships at sea in the OSPAR region amounts to 767.2. This is the number calculated with SAMSON corrected for the difference between the assumed speed in SAMSON and the speed in reality as found in the AIS data of the NCS.

Table 7-1 Emissions at sea in ton in the OSPAR region II

Nr	Substance	SAMSON emissions in 2008		
		Main Engine	Auxiliary Engine	Total
1237	NMVOC	9,329	1,017	10,346
4001	SO_2	119,418	12,615	132,033
4013	NO_x	334,056	29,469	363,524
4031	CO	53,866	5,563	59,429
4032	CO_2	12,932,130	1,539,223	14,471,353
6598	PM10 and PM2.5	18,519	1,609	20,128
	Ships	767.2	767.2	767.2

Table 7-2 contains the emissions for the NCS based on either the SAMSON traffic database of 2008 or the AIS observations of 2008. The results are very close to each other, which means that the method with SAMSON seems to be very 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 is used within the calculation of the emissions from the database of SAMSON. Thus the nice fit of the results means that the SAMSON traffic database fits well with the reality described by the AIS data.

Table 7-3 shows the nice fit by dividing the result of both approaches on each other. The worst fit is found for the average number of ships in the area. With AIS more ships are observed. The main reason is the number of ships as pilot tenders, tugs and other service ships that are operating in the port approaches. These ships are not described in the SAMSON traffic database, because they do not follow a route over sea. These ships have AIS thus are counted, but these smaller ships produce relatively very low emissions. This explains the larger number of observed ships based on AIS that have a negligible effect on the total emissions.

The average number of ships at sea in the OSPAR region is with 767.2 a factor 4.64 larger than the average number of 165.2 ships in the NCS. The emissions in the OSPAR region are between a factor 4.33 and 4.42 higher than in the NCS. The difference in the factor means that the average ship in the NCS is larger than the average ship in the OSPAR region.

Table 7-2 Emissions at sea in ton in 2008 in the NCS, based on AIS and SAMSON

Nr	Substance	AIS based emission in ton in 2008			SAMSON emission in ton in 2008		
		Main Engine	Auxiliary Engine	Total	Main Engine	Auxiliary Engine	Total
1237	NMVOC	2,199	236	2,434	2,202	230	2,433
4001	SO_2	28,298	2,935	31,233	28,538	2,909	31,447
4013	NO_x	79,352	6,838	86,190	80,063	6,708	86,772
4031	CO	12,874	1,292	14,165	12,862	1,267	14,129
4032	CO_2	3,055,508	357,384	3,412,891	3,080,231	351,697	3,431,928
6598	PM10 and PM2.5	4,407	375	4,782	4,442	371	4,813
	Ships	176.3	176.3	176.3	165.2	165.2	165.2

Table 7-3 The emissions at sea in 2008 in the NCS, based on SAMSON divided by the emissions based on the AIS data

Nr	Substance	SAMSON emissions / AIS emissions in 2008		
		Main Engine	Auxiliary Engine	Total
1237	NMVOC	99.8%	102.3%	100.1%
4001	SO_2	99.2%	100.9%	99.3%
4013	NO_x	99.1%	101.9%	99.3%
4031	CO	100.1%	102.0%	100.3%
4032	CO_2	99.2%	101.6%	99.4%
6598	PM10 and PM2.5	99.2%	101.0%	99.4%
	Ships	93.7%	93.7%	93.7%

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The conclusions of this study are:

- The AIS data is very useful for the calculation of both the level and the spatial distribution of the emissions in the Netherlands Continental Shelf. There is doubt concerning the applicability for determining the level of emissions in port areas. However, the application for determining the spatial distribution is fine.
- The average speed on the NCS derived from the 2008 AIS data turns out to be significantly lower than assumed until now. A plausible explanation is the credit crisis, This results in significantly lower emissions then calculated before with SAMSON.
- The distinction into non-moving and moving and EU and non-EU flag could be added;
- The grid size of 5000 x 5000 m for the Netherlands Continental Shelf and 500 x 500 m for the other areas can be dealt with;
- The average number of ships on the NCS based on AIS corresponds very well with the number based on SAMSON;

Conclusions from comparison of emissions:

- The emissions for the NCS calculated with AIS fit very well with the emissions calculated with SAMSON.
- The emissions of ships at anchor are very limited, less than 3% in the NCS while nearly 30% of all ships in the NCS are at anchor.
  The emissions calculated with AIS in the port of Rotterdam for 2007 and 2008 differ substantially. The emissions in 2008 are about 20% higher. In spite of additional calculations the cause could not be traced. The main reason seems to be that more AIS ships have been observed. The largest difference is found in the size class 0, which means that the ship is unknown (not found in the shipping database) or is very small (<100GT). For the other size classes an increase of the observations is found in the higher size classes and a decrease in the lower size classes. This effect can explain part of the increase in emissions. Furthermore, the year 2008 cannot be considered as an average year due to the economic crisis. The crisis has possibly led to a different behaviour that can have an impact on the emissions.

8.2 Recommendations

The increase in observed ships in the AIS data of 2008 can only be explained when the results of the AIS observations are checked with a second source with detailed shipping data. The only second source that fulfils the requirements, is the complete dataset collected by the Port of Rotterdam of all visiting merchant vessels with time of arrival and departure. When these datasets become available for 2007 and 2008, it can be researched where the differences come from. Such a comparison seems necessary for getting confidence in the AIS data.

The process followed in this study can be repeated each year. This delivers variations in the emissions by the behaviour of the ships. For example, the general view is that ships have used less power in 2008, thus less speed and less emissions compared with other years. The reason for this was that the economic crisis has reduced the transport volume, making it possible to sail with reduced speed. Also the number of port arrivals in the last two months of 2008 has decreased. This can be checked next year. The AIS data contains much more details that can be used in studies.
It is expected that the sailing speed will increase after the crisis, but it is questionable whether it will completely return to the old level.

In case of a yearly calculation, a new shipping database (about GBP 3,000) has to be purchased each year, because otherwise the ships built in the last year cannot be coupled. Further, the emission factors have to be determined for the new database by TNO. Thereafter MARIN can produce the emissions per grid cell. The total yearly costs for the emission calculation based on AIS, including the purchase of the new shipping database and the work of TNO, will amount to € 50,000 per year.

Until now the SAMSON database is updated once in four years with new voyage data (costs € 30,000), or, in the meantime, if the traffic patterns in the North Sea change due to for example a change in a traffic separation scheme or a new offshore wind farm.

The emissions in the OSPAR Region II can be updated each year with SAMSON based on the developments of shipping in the NCS, expressed in the new emissions in the NCS based on real AIS-data of that year. This approach can be offered for an addition € 10,000.

9 FOLLOW UP WORK

The significant difference in the figures for Rotterdam between 2007 and 2008 has made a further research activity to the cause of this difference absolutely necessary. Therefore, the first recommendation is followed up. The IVS (Informatie Verwerkende Systeem) data of the VTS (Vessel traffic Service) of the Port of Rotterdam is requested. This data contains all shipping movements of sea going ships in the port area and is built up for safety and logistic purposes during the visit of a ship to Rotterdam. With this data the movements of AIS could be checked for both 2007 and 2008. This approach has resulted in discovering the shortcoming of the AIS data of 2007. The shortcoming is that during three months the AIS data of the eastern part of the port area was not included in the dataset used. The reason why is unknown, but presumably an error somewhere in the development process of the introduction, use and archiving of AIS data.

The follow up work started after the finalizing of the study. The follow up work is described in a memo (in Dutch), see [8]. After applying correction factors for the emissions of 2007, there was a good correspondence in the emissions of 2007 and 2008. The shortcoming does not affect the emissions at sea and in the OSPAR region.

The memo describes also how such a shortcoming can be signalised in future. However, it is expected that it will not occur anymore, because the process of AIS data acquisition is stabilized. The AIS dataset of 2009 contains 526,578 files with the AIS data of one minute. This means that only 22 files (22 minutes of the 60 x 24 x 265 = 526,600 minutes in 2009) are missing. Thus spread over 2009, only a 22 minutes are missing, while in 2007 and 2008 some periods of several days were missing. However, it remains possible that data of a longer period within a certain region (as in 2007) is missing, because that cannot be derived from the number of files. This means that global completeness checks remain essentially in future.

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