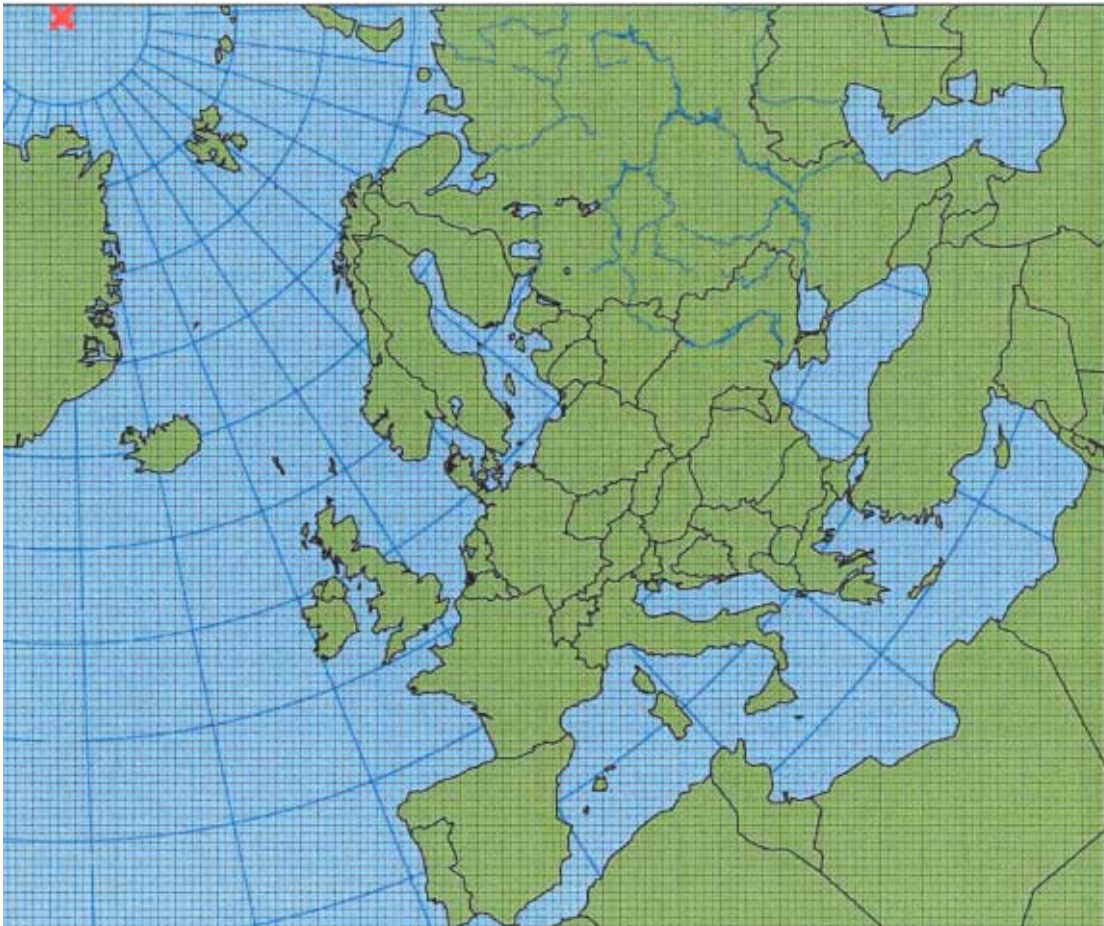

2. Quantification of ship emissions

2.1 Sea Areas within the Scope of this Study

The sea areas within which shipping movements were considered in this study coincide with the EMEP (European Monitoring and Evaluation Programme) area and this is depicted in Figure 2.1 below. The EMEP area is defined in a polar conical projection and is approximately the area East of 40 deg W, West of 60 deg E and North of 30 deg N. The relevant EMEP grid has a 50km x 50km resolution and represents the full geographical extent of EMEP, comprising some 132 x 111 points.

Figure 2.1 EMEP Geographical Area



2.2 Ship Movement Analysis

2.2.1 Details of database used in ship movement analysis

The primary source of information in terms of ship movements was a comprehensive database provided by Lloyds Marine Intelligence Unit (LMIU). This is the only commercial database of all ship movements world-wide (over 46,000 merchant vessels calling at over 6000 ports). It comprises up-to-date data resolved to a daily timeframe and over 3 million movements are processed annually.

The data was structured to identify:

- The Vessel;
- Vessel Type;
- Engine Type;
- Vessel Size;
- Flag;
- Port/Place details including: Arrival/Departure Port/Place, Previous Port/Place, Next Port/Place, Arrival/Departure Dates or Estimates, Port/Place Reference Id, Port/Place Name, Country, Area, Place Type, Latitude/Longitude; and
- Movement Type Identifier and Unique Reference ID for each Movement.

The database covers all ships greater than 500 gross tonnes. Daily monitoring activity includes vessel callings at over 700 EU ports covering all of the EU littoral member states plus data relevant to accession countries. Clearly, vessels of less than 500 gross tonnes have not been included in this estimation of emissions from ship movements. Vessels in this category would include research ships, oil industry service vessels and others. In addition, no account has been taken of river shipping movements.

The most up-to-date ship movements available at the time of this study (year 2000) were utilised in the transit analysis component of the emissions study. Due to the large number of vessel movements world-wide on an annual basis; the complexities of the data analysis and level of disaggregation required for this project; a sample of the data was supplied. The data was for four discrete months to reflect seasonal variations in shipping activity. The months selected were January, April, July, October 2000, to represent movements representative of winter, spring, summer and autumn. The final emissions values were then multiplied by three, to give annual emissions estimates.

LMIU has confirmed that there were 1,831,838 shipping movements in the area of interest during 2000 and that, in their experience, there is little variation between annualised quarterly projections and yearly actual movements. In particular, there were 608,942 vessel movements in the 4-month period of data selected which, when annualised, produces a yearly estimate of 1,826,826. Thus, the estimate is within 1% of the actual figure for 2000.

2.2.2 Key assumptions used in ship movement analysis

In General

Vessels take the shortest straight line route between two ports. When land prohibits this assumption, the vessels take the shortest route around the land towards the destination port.

Ferry Movements

The movements database does not detail all ferry movements. i.e. where a ferry makes multiple callings at the same port in one day, only the first movement of that vessel is likely to be recorded. Therefore, all ferries were removed from the initial analysis and investigated separately.

Ferry movements were analysed by identifying the maximum number of crossings possible in 24 hours, based on the distance between two ports and the average vessel speed. Ratios were determined for seasonal movements and a comparison of derived movements was compared against a sample of published timetable information. These movements were then fed back into the movements database and applied to days when ferry departures or arrivals were identified in the database.

Fishing Vessels

Many fishing vessels may not be covered by the LMIU database, although the majority will be included in the characteristics database. A separate analysis of emissions from these vessels has therefore been undertaken.

A map showing the main fishing areas in and around EC waters was obtained. This contained details of the fishing quotas for 2001 for all those areas for which quotas are set. For each species of fish, the quotas are shown in terms of the total annual tonnage of that fish which may be caught by each country, and in which fishing areas. This data was summarised to show the total tonnage of fish which may be caught by each country in each fishing area. Where the quotas for a certain fish type and a certain country were divided across more than one fishing area, it was assumed that the total tonnage was divided equally.

No publicly available information could be located which gave the total fuel used by each country's fishing fleet, although the data was available for the UK fleet. The total used in 2000 was 114,000 tonnes per annum of gas oil/marine diesel oil. This figure was provided by the Department of Trade and Industry. The total tonnage of fish caught by each country was compared to the total for the UK, and the resulting factor was multiplied by the UK fishing fleet's total fuel consumption. This provided an estimate of the total annual fuel usage by the fishing fleet of each country.

The percentage of the total fish tonnage caught by each country in each of the fishing areas was calculated, and this was multiplied by the estimated total fuel consumption by that country's fishing fleet. This resulted in an estimate of the total fuel consumed by each country in each fishing area.

It was assumed that all the fuel used by the fishing fleets was expended in the fishing zone itself, rather than in the journey there and back, as there was not sufficient information available to include an assessment of the journeys to and from the fishing areas. These figures were added together to give the total estimated fuel consumption by all fishing vessels in each of the fishing areas identified on the map.

The Mediterranean is not subject to fishing quotas, therefore separate data was sought for this region. A database run by the Food and Agriculture Organisation of the United Nations (FAO) was queried to find the total fish catch by FAO Member Countries in 1999, which was the latest year for which totals were available. This total was again compared to the total tonnage caught by the UK and the resulting factor multiplied by the UK fishing fleet's total fuel consumption, to provide an estimate of total annual fuel usage by fishing fleets operating in the Mediterranean. As can be seen in Table 2.1, this is much larger than that for the other fishing areas, which are all relatively small in comparison with the Mediterranean.

There is obviously considerable uncertainty involved in this estimation of emissions from fishing vessels. However, it is evident, from the estimates derived, that the contribution to overall emissions in European waters is small and the influence upon air quality factors will be correspondingly low.

The figures for total fuel usage in each fishing area and in the Mediterranean were multiplied by the emissions factors for fishing vessels and the data was then included in the GIS for mapping. A map of the fishing zones is included in Appendix A.

Table 2.1 Estimated total fuel consumption by fishing fleets in each Fishing Zone in Europe

Fishing Zone	Estimated Total Fuel Consumed (tonnes marine gas oil/diesel oil per annum)
I	10,845
IIa	141,442
IIb	7,766
IIIa	39,821
IIIb	50,828
IIIc	42,730
IIId	49,465
Iva	13,304
Ivb	149,874
Ivc	109,644
Va	3,160
Vb	41,699
Via	17,755
Vib	16,428
VIIa	6,031
VIIb	4,874
VIIc	4,874
VIIId	8,747

Fishing Zone	Estimated Total Fuel Consumed (tonnes marine gas oil/diesel oil per annum)
VIIe	5,839
VII f	4,256
VII g	5,069
VII h	5,020
VII j	5,020
VII k	5,020
VIII a	15,204
VIII b	15,204
VIII c	13,141
VIII d	14,738
VIII e	14,738
IX	12,913
X	7,187
XII	28,411
XIV	26,080
Atlantic	15,954
CEFAF	7,914
Other	23,445
Subtotal	944,441
Mediterranean and Black Sea	330,986
TOTAL	1,275,427

2.3 Ship characteristics analysis

2.3.1 Details of database used in ship characteristics analysis

A detailed database of vessel characteristics and performance from the latest full year of data (2000) was supplied by Lloyd's Register - Fairplay. Lloyd's Register is the principal authoritative source of vessel characteristics covering all 87,000 vessels of the world's merchant fleet over 100 gross tonnes. This includes data as to the size and engine type of individual ships combined with such information as fuel consumption.

The vessel characteristics database links with the movements database through the Lloyd's Registration Number, making it possible to identify the characteristics for all vessels recorded within the 4 discrete months of the movements database.

These characteristics data formed the platform for the development of the vessel emissions factors.

2.3.2 Key assumptions used in ship characteristics analysis

In the development of the emission factors, vessel characteristics were analysed for the vessels for which movements were logged world-wide in January, April, July, October 2000. The vessels were categorised on the basis of the LMIU database as shown below. Not all fields for each vessel in the database were complete and, where assumptions could not be made based on other characteristics of the vessel, that particular vessel was excluded from further analysis. The number of vessels excluded on this basis account for 3.2 percent of the total. Average service speeds for each vessel category were determined from the database.

Further assumptions are detailed in Section 2.5 of this report.

Table 2.2 Ship categories used in emissions analysis

Ship Type	LMIU Code	Ship Count	Ships Excluded ²	Average Speed (km/hr)
Liquefied Gas	A11	781	11	31.2
Chemical	A12	1712	19	25.3
Oil	A13	3706	77	26.0
Other Liquids	A14	124	0	24.0
Bulk Dry	A21	4617	19	26.5
Bulk Dry / Oil	A22	186	0	25.0
Self-Discharging Bulk Dry	A23	79	0	25.7
Other Bulk Dry	A24	373	6	23.9
General Cargo	A31	9702	410	22.8
Passenger/General Cargo	A32	42	3	27.0
Container	A33	2503	22	35.7
Refrigerated Cargo	A34	1094	37	31.4
Ro-Ro Cargo	A35	1274	16	28.6
Passenger/Ro-Ro Cargo	A36	496	17	28.4
Passenger	A37	386	27	38.5
Other Dry Cargo	A38	197	6	25.1
Fish Catching	B11	1024	109	25.7
Other Fishing	B12	185	5	24.7
Offshore Supply	B21	577	22	24.6

² Vessels were excluded on the basis of incomplete database records, as discussed in Section 2.2..

Ship Type	LMIU Code	Ship Count	Ships Excluded ²	Average Speed (km/hr)
Other Offshore	B22	165	38	23.1
Research	B31	217	25	25.1
Towing / Pushing	B32	777	53	23.8
Dredging	B33	164	13	21.2
Other Activities	B34	266	36	25.2
Other Activities	W11	11	0	18.1
Other Activities	W12	7	2	15.1
Other Activities	W13	2	1	22.2
TOTAL	27	30667	974	-

2.4 In-port emissions quantification

2.4.1 Development of assumptions

Questionnaires were sent to over 100 port operators asking for details concerning ship activities in port. Of the 100+ ports approached in the survey, useful data responses were received from 14. The information received is summarised in Appendix B. For each category of vessel, the operator was asked to complete the time in hours that a vessel was manoeuvring, loading & unloading and hotelling. These were reviewed and a median for each vessel type drawn up. Emission factors were then applied to each of these activities and duration for each port within the EMEP domain.

To avoid the doubling counting of in-port emissions, the movements database was queried based on the 'To Place ID' field. The LMIU data records only the dates when vessels arrive at and depart from ports. Clearly, arrival and departure times would have assisted greatly in estimating durations of in-port activity times.

Table 2.3 Assumptions for the duration (hours) of in-port activities, based on port surveys

Vessel Class	Vessel Category	Manoeuvring Time	Loading & Un-loading Time	Hotelling Time*	Total Time
Liquefied Gas	A11	1.0	12.0	12.0	25
Chemical	A12	0.8	8.0	10.0	18.8
Oil	A13	1.5	19.8	18.0	39.3
Other Liquids	A14	1.0	22	24.0	47
Bulk Dry	A21	1.0	30	22.0	53
Bulk Dry / Oil	A22	1.0	84	6.5	91.5
Self-Discharging Bulk Dry	A23	1.0	6	6.5	13.5
Other Bulk Dry	A24	1.0	12	9.5	22.5
General Cargo	A31	1.0	17	21.5	39.5
Passenger/General Cargo	A32	0.8	9.6	4.0	14.4
Container	A33	1.0	9.0	5.3	15.3
Refrigerated Cargo	A34	1.0	14.2	9.7	24.9
Ro-Ro Cargo	A35	1.0	7.0	8.3	16.3
Passenger/Ro-Ro Cargo	A36	1.0	6.0	4.0	11
Passenger	A37	0.8	9.6	4.0	14.4
Other Dry Cargo	A38	1.1	36.4	4.0	41.5
Fish Catching	B11	0.7	12.0	48.0	60.7
Other Fishing	B12	0.7	12.0	48.0	60.7
Offshore Supply	B21	2.0	22.0	24.0	48
Other Offshore	B22	0.5	22.0	24.0	46.5
Research	B31	0.9	0.0	7.3	8.2
Towing / Pushing	B32	1.7	25.0	8.0	34.7
Dredging	B33	3.0	113.2	26.3	142.5
Other Activities	B34	1.1	25.0	26.3	52.4
Other Activities	W11	0.5	0.6	26.3	27.4
Other Activities	W12	0.5	0.6	26.3	27.4
Other Activities	W13	0.5	0.6	26.3	27.4

* Hotelling denotes the time a vessel spends in port that is neither loading or unloading time, at berth and consuming minimum power.

2.5 Ship Emission Factors

2.5.1 Proposed Vessel Emission Factors

This section of the report contains a summary of the approach adopted and the emission factors derived. A more detailed account can be found in Appendix C.

General overview of methodology

Based on the published sources (mostly IVL and Lloyds Register Engineering Services data), a new marine emission database (“dataset A”) was compiled. By sorting and filtering the data, emission factors (NO_x, SO₂, HC, PM and CO₂) for 5 different engine types and 3 different fuel types, where possible, were derived. This was repeated for 3 different activities or operating modes of the ships; (i) “at sea” (or cruising), (ii) “in port” (includes time spent hotelling, loading and unloading) and (iii) “manoeuvring”.

Irrespective of ship category (container, passenger ferry etc.), the installed engine type on board a ship and the fuel used largely dictates the ship’s emission. In order to present universal emission factors, which represent a given vessel category, information regarding the typical engine types used and fuel used for this category is necessary. Thus Entec UK Ltd has examined the LMIS database for the ships entering the EU study area and provided such data (“dataset B”).

Finally, by combining the underlying datasets A and B, weighted emission factors for each specific vessel type can be derived for each of the three activities.

Emission factor comparisons

In generating the proposed emission factors comparisons have been made between IVL, Lloyds and other sources. A comparison for main engine emissions operating at 70 - 100% MCR is presented in Table 2.4 below. These in turn can be compared with Marintek and Germanischer Lloyd’s data represented in Table C.12 of Appendix C. Also included in Table 2.4, for simple comparative purposes, are the corresponding emission factors for a typical European new heavy goods road vehicle and those for a large coal-fired power station.

Table 2.4. A comparison of IVL and selected Lloyds Register Engineering Services data for main engine marine emission factors and specific fuel consumption (sfc) in g/kWh at steady state engine loads of 70 - 100% MCR, as well as indicative values for trucks and large combustion plants.

Mean values	IVL ^a slow speed	Lloyds ^a slow speed	IVL ^b med. speed	Lloyds ^b med. speed	HGV, Euro III Standard	Large Combustion Plant ^c
NO _x	17.4	18.7	13.6	13.7	5.0	2.6
CO	0.52	2.0	0.71	1.59	2.1	0.4
HC	-	0.63	0.12	0.65	0.66	0.01
PM	-	1.23	0.42	1.25	0.1	0.1
sfc	194	223	209	226		

^a Based on 8 (IVL) and 11 (Lloyds) measurements for NO_x.

^b Based on 25 (IVL) and 28 (Lloyds) measurements for NO_x.

^c Based upon a coal fired power station fitted with FGD.

In general, a smaller variation in the emissions was observed within the IVL data in comparison to the Lloyds data. Since the differences in CO, HC, PM and fuel consumption are most probably due to the differences in the sampled engines (notably engine age) and not systematic measurement differences, both IVL and Lloyds data were combined in obtaining the most representative emission factors possible. The few other emission data sources in the literature were useful for comparison purposes, but these were not easily combined with the IVL and Lloyds dataset.

Activity descriptions and engine operation

For each of the three different activities for ship operation, several assumptions regarding engine load operation were necessary in order to calculate corresponding, weighted emission factors (i.e. for AE and ME combined). These assumptions are presented in Table 2.5 and are based on approaches reported in other marine emission inventory work, (e.g. Alexandersson et al., 1993; European Commission 1999a, Flodström, 1997), contact with engine manufacturers (e.g. MAN B&W, 2002) and IVL experience gained during measurement campaigns on board ships. It should be noted, however, that some of these engine load assumptions have considerable uncertainty and can influence the calculated emissions significantly. This is especially so regarding main engine use in port. In contrast, the operation of auxiliary engines at sea and the fraction of ships equipped with shaft generators, have a relatively small effect on the emissions at sea, which are dominated by emissions from the main engines.

Table 2.5. Assumptions regarding engine operation for the different activities.

	% load of MCR for ME operation	% of time all MEs operating	% of electric power from shaft generators	% load of MCR for AE operation
at sea	80	100	50	30
in port (tankers-using pumps ^{a)})	20	100	0	60
in port	20	5	0	40
manoeuvring ^{b)}	20	100	0	50

^{a)} For sea vessel categories A11 Liquefied gas, A12 Chemical, A13 Oil, and A14 Other liquid. The tanker, in port ME characteristics can possibly be interpreted from the table as “all tankers operate at 20% MCR all the time in port”. In reality this is not correct, since some tankers (especially those not using diesel electric propulsion) will not run MEs in port but rely on AE power, and others will operate in port but with engine loads > 20%. The assumed characteristics have thus been chosen in an attempt bring the results to a “reasonable approximation” within the constraints of the project.

^{b)} “Manoeuvring” associated with arrival at and departure from a port, i.e. when a ship decreases ME load at the end of a period “at sea”, up to the point when the ship is stationary “in port” and vice versa.

Engine / fuel type profiles for ship categories

Engine / fuel type profiles have been obtained from the LMIS dataset by Entec UK Ltd for 30,665 ships (GRT > 100 tonnes) split into 26 different vessel categories. An example of the results for oil tankers is provided in Table 2.6. It should be noted that in some areas, the LMIS data was incomplete. For example, some fuels were classified as “unknown” and some engines could not be fully identified (speed rpm data lacking). In these cases, the unknowns were assumed to follow the same proportions as the known data. An additional issue, which could not be resolved, was for ships using dual fuels, where it was uncertain which fuel was used for which engine and for which activity. In this case where two fuels were possible, the data for the residual fuel was assumed, which could possibly lead to an overestimate regarding sulphur emissions. Profiles for the other vessel categories are contained in Appendix D.

Table 2.6. Example of profile for vessel type A13 "Oil Tanker" regarding engine / fuel profile for MEs and AEs. SSD = slow speed diesel, MSD = medium speed diesel, HSD = high speed diesel, GT = gas turbine, ST = steam turbine, MGO = marine gas oil, MDO = marine diesel oil, RO = residual oil.

A13 OIL TANKER	% of total installed	% of total installed
Engine type / Fuel type	ME power	AE power
SSD / MGO	0.2	0
SSD / MDO	0	0
SSD / RO	75.9	0
MSD / MGO	0.1	0.1
MSD / MDO	0	0
MSD / RO	4.9	57.9
HSD / MGO	0	0
HSD / MDO	0	0
HSD / RO	0.1	42.0
GT / MGO	0	0
GT / MDO	0	0
GT / RO	0	0
ST / MGO	0	0
ST / MDO	0	0
ST / RO	18.7	0
Total	99.9	100

Emission factors in terms of engine / fuel type

Emission factors (as g/kWh) in terms of engine / fuel type are presented in Tables 2.8–2.10 and are valid for the year 2000. Note that emission factors in kg/tonne fuel can be obtained by taking the g/kWh factor and dividing by the specific fuel consumption x 0,001 (e.g. NO_x factor for a slow speed ME operating on residual oil for a ship at sea; 18,1 / [195 x 0,001] = 92,8 kg/tonne fuel).

Some important issues to note in assessing the emission factors are:

- The emission factors for CO₂ and SO₂ have been derived assuming that all fuel carbon and sulphur present in the fuel is burnt to CO₂ and SO₂. Fuel sulphur contents have been based on data provided to the International Maritime Organisation's Marine Environment Protection Committee (IMO MEPC) (2001) and are shown in Table 2.7.

Table 2.7 Sulphur and Carbon Contents of Fuels

FUEL	MGO	MDO	RO
Assumed Contents			
Sulphur (%)	0,5	1,0	2,7
Carbon (%) ^{a)}	86,7	86,7	86,7

a) This corresponds to a CO₂ emission of 3179 kg/tonne fuel (i.e. 1000 x 0,867 x 44/12 = 3179).

- Initially it was suspected that emission factors could even be assigned for different engine sizes within the same type of engine / fuel category. After sorting the data in three different engine size categories (Small < 1500 kW, Medium 1500 - 4000 kW and Large > 4000 kW) possible correlations were examined (see for example Figure C.1 in Appendix C concerning NO_x emissions from medium speed main engines). Since the spread of data was in general considerable and the size of the datasets quite limited however, assignment of "engine size" emission factors with any great significance was doubtful. Consequently the emission factors were only derived for engine / fuel types and valid for all engine sizes.
- For specific NO_x emission factors and fuel consumption, a single factor was first assigned for each engine type. Thereafter an adjustment was made to account for the higher N content and lower heating value of RO fuel. Thus specific NO_x emissions from distillate fuels (MGO/MDO) were assumed as being ca. 6% lower, and specific fuel consumptions ca. 5% higher than for RO fuel. One should note however, the relatively large standard deviations present with the data e.g. ca. 23 relative % associated with the NO_x data for RO and MDO/MGO. Despite this uncertainty, the applied differentiation for NO_x for different fuels is intended to aid future policy decision making.

-
- Emission factors for main engines “at sea” (assumed to be operating at 80% MCR) were obtained by averaging all emission measurements in the data set made at 70 - 100% MCR engine load. Similarly, factors for auxiliary engines for all three activities were obtained by averaging all emission measurements in the data set made at 40 - 80% MCR engine load.
 - For some factors, e.g. HC and PM from slow speed engines, the proposed emission data is biased towards to Lloyds measurements since these emission measurements are lacking in the IVL data set.
 - Emission factors for main engines during “manoeuvring” and “in port” (assumed to be operating at 20% MCR) were based largely on professional judgement due to a lack of data. Consideration has however been given to IVL’s so-called real-world studies which cover whole journeys (e.g. Cooper, 2001) and the transient/passage and steady state/passage ratios reported in Lloyds Register Engineering Services (1993a). In addition, mean emission factors from main engines operating at steady-state low engine loads (< 40 % MCR) were evaluated from the IVL/Lloyds database and assessed. The approach adopted was to multiply “at sea” main engine emission factors (derived from steady state loads 70 - 100%) by 0,8 for NO_x, 3,0 for HC and 3,0 for PM for all diesel engines and steam turbines. For gas turbines the corresponding factors were taken as 0,5 for NO_x, 5,0 for HC and 5,0 for PM. In addition, the specific fuel consumption (and thereby specific SO₂ and CO₂ emissions) has been assumed to increase by 10% for engine operation at these low loads. Clearly this approach unfortunately introduces significant uncertainty and provides an area to be targeted for future emission factors studies.
 - It is important to note that the “manoeuvring” and “in port” emission factors will have an increased uncertainty compared to emission factors “at sea”, for two reasons. Firstly, some main engine operation will be from starts with a cold engine, which will give significantly different emissions (especially HC and PM), compared to starts with relatively warm engines. Secondly since engine loads can change rapidly during manoeuvring operations, the variability in emissions is increased.
 - Emission factor measurement data relating to gas turbines and steam turbines are scarce in comparison to diesel engines and thus a greater uncertainty is associated with these factors. For steam turbines, all recent marine emission inventory studies have relied on US data from the early 1980s (US EPA, 1985 and Scott Environmental Technology Inc., 1981). Since no new data has been found in the literature and steam engines are in general being phased out, the same emission factors are proposed here. For gas turbines more recent data on board sea vessels from IVL and Lloyds has been used.
 - There is no information currently available with regard to the size distribution of particles emitted from ship engine exhaust, although work is underway at IVL in Sweden and initial results may be available in 2003. However, in common with most large diesel engines, it is anticipated that greater than 80% of emitted particulate matter will be PM₁₀ or less.

Table 2.8. Emission factors in g/kWh regarding engine / fuel type for MEs "at sea". SSD = slow speed diesel, MSD = medium speed diesel, HSD = high speed diesel, GT = gas turbine, ST = steam turbine, MGO = marine gas oil, MDO = marine diesel oil, RO = residual oil.

MEs AT SEA	NO_x	SO₂	CO₂	HC	specific fuel consumption
Engine type / Fuel type					
SSD / MGO	17.0	0.9	588	0.6	185
SSD / MDO	17.0	3.7	588	0.6	185
SSD / RO	18.1	10.5	620	0.6	195
MSD / MGO	13.2	1.0	645	0.5	203
MSD / MDO	13.2	4.1	645	0.5	203
MSD / RO	14.0	11.5	677	0.5	213
HSD / MGO	12.0	1.0	645	0.2	203
HSD / MDO	12.0	4.1	645	0.2	203
HSD / RO	12.7	11.5	677	0.2	213
GT / MGO	5.7	1.5	922	0.1	290
GT / MDO	5.7	5.8	922	0.1	290
GT / RO	6.1	16.5	970	0.1	305
ST / MGO	2.0	1.5	922	0.1	290
ST / MDO	2.0	5.8	922	0.1	290
ST / RO	2.1	16.5	970	0.1	305

Table 2.9 Emission factors in g/kWh regarding engine / fuel type for MEs “in port” and “manoeuvring”. SSD = slow speed diesel, MSD = medium speed diesel, HSD = high speed diesel, GT = gas turbine, ST = steam turbine, MGO = marine gas oil, MDO = marine diesel oil, RO = residual oil.

MEs IN PORT / MANOEUV.	NO_x	SO₂	CO₂	HC	PM	specific fuel consumption
Engine type / Fuel type						
SSD / MGO	13.6	1.0	647	1.8	0.9	204
SSD / MDO	13.6	4.1	647	1.8	0.9	204
SSD / RO	14.5	11.6	682	1.8	2.4	215
MSD / MGO	10.6	1.1	710	1.5	0.9	223
MSD / MDO	10.6	4.5	710	1.5	0.9	223
MSD / RO	11.2	12.7	745	1.5	2.4	234
HSD / MGO	9.6	1.1	710	0.6	0.9	223
HSD / MDO	9.6	4.5	710	0.6	0.9	223
HSD / RO	10.2	12.7	745	0.6	2.4	234
GT / MGO	2.9	1.6	1014	0.5	0.5	319
GT / MDO	2.9	6.4	1014	0.5	0.5	319
GT / RO	3.1	18.1	1067	0.5	1.5	336
ST / MGO	1.6	1.6	1014	0.3	0.9	319
ST / MDO	1.6	6.4	1014	0.3	0.9	319
ST / RO	1.7	18.1	1067	0.3	2.4	336

Table 2.10. Emission factors in g/kWh regarding engine / fuel type for AEs (all three activities). MSD = medium speed diesel, HSD = high speed diesel, MGO = marine gas oil, MDO = marine diesel oil, RO = residual oil. Note none of the AEs in the LMIS dataset were of slow speed diesel, gas turbine nor steam turbine engine types

AEs	NO_x	SO₂	CO₂	HC	PM	specific fuel consumption
Engine type / Fuel type / Size						
MSD / MGO	13.9	1.1	690	0.4	0.3	217
MSD / MDO	13.9	4.3	690	0.4	0.3	217
MSD / RO	14.7	12.3	722	0.4	0.8	227
HSD / MGO	10.9	1.1	690	0.4	0.3	217
HSD / MDO	10.9	4.3	690	0.4	0.3	217
HSD / RO	11.6	12.3	722	0.4	0.8	227

Emission factors in terms of ship category

By combining the underlying datasets, weighted emission factors (“Actual year 2000”) for each specific ship category can be derived for each of the three ship operation activities (Tables 2.11-2.13).

Table 2.11. Emission factors for “at sea” operation regarding ship type.

AT SEA	NO _x	SO ₂	CO ₂	HC	sfc	NO _x	SO ₂	CO ₂	HC
	<u>in g/kWh</u>					<u>in kg/tonne fuel</u>			
A11 Liquefied Gas	8.5	12.4	822	0.3	258	41	49	3179	1.4
A12 Chemical	16.5	11.0	645	0.6	203	83	54	3179	2.8
A13 Oil	14.9	11.7	689	0.5	217	75	54	3179	2.5
A14 Other liquid	16.6	10.9	641	0.6	202	83	54	3179	2.8
A21 Bulk dry	17.9	10.6	624	0.6	196	92	54	3179	3.0
A22 Bulk dry/oil	16.8	10.3	643	0.6	202	86	52	3179	2.9
A23 Self-discharging bulk dry	14.3	11.5	695	0.5	218	71	53	3179	2.4
A24 Other bulk dry	17.4	10.6	631	0.6	198	88	53	3179	2.9
A31 General cargo	16.3	10.9	644	0.6	203	81	54	3179	2.7
A32 Passenger/general cargo	15.8	11.1	653	0.5	205	77	54	3179	2.7
A33 Container	17.5	10.7	631	0.6	199	89	54	3179	3.0
A34 Refrigerated cargo	17.4	10.7	631	0.6	198	88	54	3179	2.9
A35 Roro cargo	15.6	11.2	659	0.5	207	76	54	3179	2.6
A36 Passenger/Roro cargo	13.3	9.8	686	0.4	216	63	46	3179	2.0
A37 Passenger	13.2	11.7	696	0.5	219	62	54	3179	2.2
A38 Other dry cargo	11.1	12.9	757	0.4	238	53	54	3179	1.9
B11 Fish catching	13.9	11.5	685	0.5	215	65	53	3179	2.1
B12 Other fishing	13.3	12.3	722	0.5	227	66	54	3179	2.2
B21 Offshore supply	14.0	11.0	675	0.5	212	66	52	3179	2.3
B22 Other offshore	13.5	11.1	682	0.4	215	63	52	3179	2.1
B31 Research	14.2	11.4	673	0.5	212	67	54	3179	2.3
B32 Towing/Pushing	13.7	10.8	673	0.4	212	65	51	3179	2.0
B33 Dredging	14.1	11.4	674	0.5	212	67	54	3179	2.3
B34 other activities	12.5	10.7	705	0.4	222	59	48	3179	2.0
W11 Other activities	14.0	11.5	678	0.5	213	66	54	3179	2.3
W12 Other activities	12.7	11.5	677	0.2	213	60	54	3179	0.9

Table 2.12. Emission factors for “in port” operation regarding ship type.

IN PORT	NO _x	SO ₂	CO ₂	HC	PM	sfc	NO _x	SO ₂	CO ₂	HC	PM
	<u>in g/kWh</u>						<u>in kg/tonne fuel</u>				
A11 Liquefied Gas	7.5	13.4	884	0.9	2.1	278	33	49	3179	3.7	7.8
A12 Chemical	13.3	12.1	710	1.5	2.2	223	60	54	3179	6.7	9.7
A13 Oil	12.1	12.8	754	1.4	2.2	237	55	54	3179	6.3	9.6
A14 Other liquid	13.3	12.0	707	1.5	2.2	222	60	54	3179	7.0	10.0
A21 Bulk dry	13.8	12.0	706	1.0	1.5	222	62	54	3179	4.5	6.8
A22 Bulk dry/oil	13.4	11.9	715	0.9	1.4	225	60	53	3179	4.3	6.5
A23 Self-discharging bulk dry	13.1	12.3	727	0.5	1.0	229	58	54	3179	2.4	4.4
A24 Other bulk dry	13.6	12.0	709	1.0	1.5	223	61	54	3179	4.6	6.9
A31 General cargo	13.3	12.1	716	0.9	1.5	225	59	54	3179	4.1	6.5
A32 Passenger/general cargo	13.2	12.2	721	0.6	1.1	227	59	54	3179	2.9	5.0
A33 Container	13.7	12.1	710	1.0	1.5	223	62	54	3179	4.4	6.7
A34 Refrigerated cargo	13.5	12.1	714	0.7	1.2	225	60	54	3179	3.4	5.5
A35 Roro cargo	13.0	12.3	723	0.9	1.4	227	58	54	3179	3.9	6.3
A36 Passenger/Roro cargo	11.3	11.2	746	1.0	1.8	235	49	48	3179	4.4	7.6
A37 Passenger	11.6	12.6	750	1.0	1.8	236	50	54	3179	4.4	7.7
A38 Other dry cargo	11.8	12.9	761	0.7	1.4	239	52	54	3179	2.9	5.6
B11 Fish catching	13.4	12.2	722	0.4	0.8	227	59	54	3179	1.8	3.6
B12 Other fishing	11.3	13.2	776	1.1	2.0	244	51	54	3179	5.1	8.4
B21 Offshore supply	12.0	11.9	734	1.1	1.7	231	52	52	3179	4.6	7.5
B22 Other offshore	12.0	12.2	737	0.9	1.6	232	52	53	3179	3.8	6.9
B31 Research	11.8	12.5	736	1.2	2.0	232	51	54	3179	5.2	8.7
B32 Towing/Pushing	11.8	12.0	734	1.0	1.8	231	51	52	3179	4.2	7.7
B33 Dredging	11.9	12.4	736	1.2	2.0	232	51	54	3179	5.1	8.4
B34 other activities	11.1	11.5	756	1.0	1.7	238	48	48	3179	4.2	7.2
W11 Other activities	12.7	12.4	729	0.8	1.3	229	55	54	3179	3.2	5.7
W12 Other activities	11.2	12.5	738	0.5	1.9	232	48	54	3179	2.3	8.2

Table 2.13. Emission factors for “manoeuvring” operation regarding ship type.

MANOEUVRING	NO _x	SO ₂	CO ₂	HC	PM	sfc	NO _x	SO ₂	CO ₂	HC	PM	
	<u>in g/kWh</u>						<u>in kg/tonne fuel</u>					
A11 Liquefied Gas	7.4	13.5	887	0.9	2.1	279	32	49	3179	3.7	7.8	
A12 Chemical	13.3	12.1	710	1.5	2.2	223	60	54	3179	6.9	9.9	
A13 Oil	12.0	12.8	754	1.4	2.3	237	55	54	3179	6.4	9.7	
A14 Other liquid	13.3	12.0	706	1.6	2.3	222	60	54	3179	7.1	10.2	
A21 Bulk dry	14.3	11.7	688	1.7	2.3	217	66	54	3179	7.8	10.6	
A22 Bulk dry/oil	13.5	11.4	708	1.6	2.2	223	62	52	3179	7.3	10.1	
A23 Self-discharging bulk dry	12.0	12.5	751	1.1	1.9	236	54	53	3179	5.2	8.2	
A24 Other bulk dry	13.9	11.6	695	1.6	2.3	219	64	53	3179	7.6	10.4	
A31 General cargo	13.1	12.0	709	1.6	2.3	223	59	54	3179	7.0	10.2	
A32 Passenger/general cargo	12.8	12.2	718	1.4	2.1	226	57	54	3179	6.2	9.2	
A33 Container	14.0	11.8	696	1.6	2.3	219	65	54	3179	7.6	10.4	
A34 Refrigerated cargo	13.9	11.8	697	1.5	2.2	219	63	54	3179	7.1	9.9	
A35 Roro cargo	12.5	12.3	724	1.5	2.3	228	56	54	3179	6.7	10.0	
A36 Passenger/Roro cargo	10.6	10.8	754	1.3	2.1	237	46	46	3179	5.4	9.0	
A37 Passenger	10.7	12.9	764	1.4	2.3	240	46	54	3179	5.8	9.8	
A38 Other dry cargo	9.3	14.0	821	1.1	2.2	258	40	54	3179	4.7	8.9	
B11 Fish catching	13.0	12.2	725	0.6	1.1	228	57	54	3179	2.6	4.8	
B12 Other fishing	10.7	13.5	792	1.3	2.4	249	49	54	3179	6.0	9.9	
B21 Offshore supply	11.2	12.1	742	1.4	2.3	233	48	52	3179	6.1	9.7	
B22 Other offshore	10.9	12.2	749	1.3	2.2	236	47	52	3179	5.4	9.5	
B31 Research	11.4	12.6	740	1.4	2.4	233	49	54	3179	6.2	10.2	
B32 Towing/Pushing	11.0	11.8	740	1.2	2.3	233	48	51	3179	5.3	9.7	
B33 Dredging	11.4	12.5	741	1.4	2.4	233	49	54	3179	6.2	10.1	
B34 other activities	10.1	11.8	774	1.2	2.2	243	43	48	3179	5.3	9.0	
W11 Other activities	11.5	12.6	742	1.4	2.2	233	49	54	3179	5.9	9.5	
W12 Other activities	10.2	12.6	744	0.6	2.4	234	44	54	3179	2.5	10.1	

Uncertainty

In addition to the actual values assigned as emission factors, it is of equal importance to assess the level of uncertainty associated with the factors. This uncertainty arises primarily from:

- the number and representativity of the measurements used in deriving the emission factors in comparison to the total number and types of marine engines in use;
- measurement uncertainties within the emission factor data set which vary for different measurement techniques and thus pollutants, and even activities;
- assumptions made in assigning the factors for a given activity, e.g. main engine operation in port; and
- the applicability of a universal factor for a given ship category (i.e. uncertainty will increase for inventories covering a smaller number of ships).

By considering the above and bearing in mind uncertainty calculations for accredited marine emission measurement methods, an attempt has been made to determine uncertainty levels for the presented emission factors (Table 2.14). Following guidelines presented in Eurochem 2000, uncertainty is expressed as a relative percent at the 95% confidence interval. It should be noted that these uncertainties are for consideration of a large shipping fleet. On a much smaller scale, for example a minor port with only a few ships hotelling, considerably greater uncertainty can be expected arising mainly from ships having machinery and fuel atypical of the ship category in general and their main engine use in port (both time in operation and load).

Table 2.14. Estimated uncertainties at the 95% confidence interval given as relative percent of the emission factors (in g/kWh or kg/tonne fuel). For example, the NO_x emission factor at sea has a 20 relative % uncertainty assigned, which means that 95% of ships' emissions will lie within + or – 20% of the assigned factors. Thus, the NO_x emission factor range expected for a Chemical tanker A12 would be 13,2 - 19,8 g/kWh (i.e. uncertainty margin calculated from 16,5 g/kWh in Table 2.11 multiplied by 0,20).

	at sea	manoeuvring	in port
NO _x	± 20%	± 40%	± 30%
SO ₂	± 10%	± 30%	± 20%
CO ₂	± 10%	± 30%	± 20%
HC	± 25%	± 50%	± 40%
PM	± 25%	± 50%	± 40%
sfc	± 10%	± 30%	± 20%

Emission factors for future policy scenarios

The EC intends to propose legislation aimed to reduce marine emissions, and it is possible to speculate on the influence of this legislation on the assigned “Actual” emission factors for year 2000. Obviously further uncertainty is introduced in calculating the emission factors for different policy scenarios, but the results aid in evaluating important policy making decisions. To this end, four new scenarios are envisaged for year 2006 and five for the year 2008 (Table 2.15), together with one for 2010. Annual growth in shipping movements for future years were taken from a recent publication (IMO, 2000), which estimated between 1.5% and 3% growth per annum in vessel movements for the period 2000 – 2010. Calculations have been carried out for both 1.5% and 3% growth, applied to all vessels except ferries and fishing vessels (for which no growth was assumed).

It should be noted that the proposed scenarios are primarily aimed for evaluating effects on SO₂ emissions through legislation capping fuel sulphur content and restriction of fuel type use (Robinson, 2002). Besides lowering of SO₂ emission factors, lower PM emission factors were anticipated and taken into account. NO_x, HC, and CO₂ emissions, however, will only be slightly altered through restrictions on fuel type legislation, as a result of the higher specific energy (and, therefore, lower specific fuel consumption) of lower sulphur fuels. Future and more significant changes in NO_x, HC, and PM emissions following legislation of regulation 13 of Annex VI MARPOL 73/78 which sets NO_x limits for marine diesel engines following an engine speed curve (IMO Technical NO_x Code, 1997) was outside the scope of this investigation. Future scenario emission factors are contained in Appendix E.

Table 2.15. Envisaged future scenarios and their influence on “Actual 2000” emission factors

Scenario No. / Year	Sulphur in fuel and fuel type legislation	NO_x, PM, HC and CO₂
1. 2006 BAU*	as in assigned emission factors for year 2000 (“Actual 2000”)	as in “Actual 2000”
2. 2006	1,5% in RO for North Sea/Baltic	as in “Actual 2000” + lower PM
3. 2006	1,5% in RO for North Sea/Baltic + 0,2% in MGO in port for AEs only	as in “Actual 2000” + lower PM + NO _x , CO ₂ reductions due to increase in MGO use (lower sfc)
4. 2006	1,5% in RO for North Sea/Baltic + 0,2% in MGO in port and manoeuvring for both AEs and MEs	as in “Actual 2000” + lower PM + NO _x , CO ₂ reductions due to increase in MGO use (lower sfc)
5. 2008 BAU	as in “Actual 2000”	as in “Actual 2000”
6. 2008	1,5% in RO for North Sea/Baltic	As in “Actual 2000” + lower PM
7. 2008	1,5% in RO for North Sea/Baltic + 0,1% in MGO in port for AEs only	as in “Actual 2000” + lower PM + NO _x , CO ₂ reductions due to increase in MGO use (lower sfc)
8. 2008	1,5% in RO for North Sea/Baltic + 0,1% in MGO in port and manoeuvring for both AEs and MEs	as in “Actual 2000” + lower PM + NO _x , CO ₂ reductions due to increase in MGO use (lower sfc)
9. 2008	1,5% in RO for North Sea/Baltic and all territorial waters + 0,1% in MGO in port and manoeuvring for both AEs and MEs	as in “Actual 2000” + lower PM + NO _x , CO ₂ reductions due to increase in MGO use (lower sfc)
10. 2010 BAU	As in “Actual 2000”	As in “Actual 2000”

* BAU – Business as Usual

2.6 Results

2.6.1 Quantification of emissions

The results of the quantification of emissions are presented in tabular format in this report. Emissions estimates are for annual emissions for the year 2000, and are expressed in kilotonnes.

In accordance with our methodology, emissions estimates have been developed separately for:

- vessels excluding ferries and fishing vessels;
- ferries; and
- fishing vessels.

In addition, the emissions are subdivided by port of origin and destination (EU-15, Accession Candidate Countries (ACC) or Non-EU/ACC (NON)) and by the flag status of vessels. The following sections present the results. Tables 2.16 to 2.22 contain the pollutant emissions during 2000 from vessels at sea, in-port and manoeuvring subdivided by origin and destination port and

by vessel flag status. Tables 2.23 to 2.26 contain a breakdown of vessel movements during the four months selected data period on the following basis:

- EU-15 Country to EU-15 Country movements.
- EU-15 Country to Accession Candidate Country movements;
- Accession Candidate Country to EU-15 Country movements;
- Accession Candidate Country to Accession Candidate Country movements; and
- All movements involving Non-EU/ACC ports of origin and/or departure.

Emissions for 2000 by Origin and Destination Port Status and by Vessel Flag.

Table 2.16 Emission of Pollutants during 2000 from Vessels at Sea subdivided by Origin & Destination Port and by Flag Status (excludes Ferries & Fishing Vessels), Kilotonnes

AT SEA		NO _x				SO ₂				CO ₂				HC			
FROM	TO	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total
EU-15	EU-15	107.6	456.8	456.3	1020.6	72.9	326.6	320.4	719.9	4337.6	19946.3	19045.9	43329.8	3.7	15.5	15.9	35.1
EU-15	NON	89.5	93.0	294.3	476.8	57.9	63.2	197.0	318.1	3416.1	3756.9	11751.3	18924.3	3.1	3.2	10.1	16.4
NON	EU-15	81.9	70.2	256.6	408.7	53.7	48.7	174.2	276.6	3170.8	2906.3	10401.5	16478.6	2.8	2.4	8.9	14.1
NON	NON	42.3	36.2	173.0	251.4	27.6	23.9	115.7	167.1	1628.4	1412.4	6869.0	9909.8	1.4	1.2	6.0	8.6
ACC	ACC	42.6	8.7	56.2	107.5	30.2	6.6	39.4	76.2	1784.5	391.7	2338.2	4514.5	1.5	0.3	2.0	3.8
ACC	EU-15	64.7	39.8	129.9	234.4	45.1	28.7	91.1	164.9	2712.3	1703.2	5426.1	9841.6	2.2	1.4	4.6	8.2
EU-15	ACC	55.9	38.1	118.8	212.8	38.7	27.7	83.1	149.5	2298.7	1649.9	4951.8	8900.5	1.9	1.3	4.2	7.5
NON	ACC	37.2	11.5	65.0	113.6	25.5	8.2	45.1	78.8	1516.3	486.5	2679.6	4682.4	1.3	0.4	2.3	4.0
ACC	NON	46.8	14.3	83.7	144.8	31.8	10.4	58.9	101.0	1887.6	615.2	3513.4	6016.2	1.6	0.5	2.9	5.1
Sub-total		568.5	768.6	1633.8	2970.6	383.4	544	1124.9	2052.1	22752.3	32868.4	66976.8	122597.7	19.5	26.2	56.9	102.8
% of total		15.7	21.2	45.2	82.1	14.9	21.1	43.6	79.6	14.5	20.9	42.6	77.9	14.6	19.6	42.5	76.7

Table 2.17 Emission of Pollutants during 2000 from Vessels in Port and Manoeuvring subdivided by Origin & Destination Port and by Flag Status (excludes Ferries & Fishing Vessels)

IN PORT + MAN		NO _x				SO ₂				CO ₂				HC				PM IN PORT			
FROM	TO	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total
EU-15	EU-15	9.6	39.2	31.1	79.8	9.5	40.3	31.9	81.7	559.3	2408.0	1911.9	4879.3	1.0	4.2	3.1	8.3	1.2	5.4	4.0	10.6
EU-15	NON	3.2	2.2	6.0	11.4	3.2	2.3	6.2	11.7	191.1	136.5	374.2	701.8	0.3	0.2	0.6	1.2	0.4	0.3	0.8	1.5
NON	EU-15	4.4	2.8	8.6	15.8	4.4	2.9	8.9	16.2	257.2	174.1	533.7	965.0	0.5	0.3	0.8	1.6	0.6	0.4	1.1	2.1
NON	NON	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
ACC	ACC	9.1	1.1	3.8	13.9	9.3	1.1	3.7	14.1	550.1	68.1	219.8	837.9	1.0	0.1	0.4	1.5	1.2	0.1	0.4	1.8
ACC	EU-15	2.8	2.0	3.9	8.7	2.8	2.1	3.9	8.9	167.8	125.3	234.9	528.1	0.3	0.2	0.4	0.9	0.3	0.3	0.4	1.1
EU-15	ACC	3.2	2.2	4.4	9.8	3.3	2.2	4.5	10.0	194.0	133.2	267.8	595.0	0.3	0.2	0.4	1.0	0.4	0.3	0.6	1.3
NON	ACC	2.8	0.8	2.8	6.3	2.8	0.8	2.8	6.4	168.7	47.0	167.0	382.6	0.3	0.1	0.3	0.6	0.4	0.1	0.3	0.8
ACC	NON	3.1	0.7	2.8	6.6	3.1	0.8	2.9	6.8	184.9	46.3	170.6	401.8	0.3	0.1	0.3	0.7	0.4	0.1	0.4	0.9
Sub-total		38.2	51	63.4	152.3	38.4	52.5	64.8	155.8	2273.1	3138.5	3879.9	9291.5	4	5.4	6.3	15.8	4.9	7	8	20.1
% of total		1.1	1.4	1.8	4.2	1.5	2.0	2.5	6.0	1.4	2.0	2.5	5.9	3.0	4.0	4.7	11.7	23.3	33.3	38.1	94.7

Table 2.18 Total (at Sea, In-Port plus Manoeuvring) Pollutant Emissions during 2000 from Vessels subdivided by Origin & Destination Port and by Flag Status (Excludes Ferries & Fishing Vessels)

TOTAL		NO _x				SO ₂				CO ₂				HC			PM IN PORT				
FROM	TO	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total
EU-15	EU-15	117.1	496.0	487.3	1100.4	82.4	366.9	352.4	801.7	4897.0	22354.3	20957.8	48209.1	4.7	19.7	19.0	43.4	1.2	5.4	4.0	10.6
EU-15	NON	92.8	95.2	300.2	488.2	61.1	65.4	203.3	329.8	3607.2	3893.4	12125.5	19626.1	3.4	3.4	10.7	17.6	0.4	0.3	0.8	1.5
NON	EU-15	86.3	73.0	265.2	424.5	58.0	51.6	183.1	292.7	3428.0	3080.5	10935.2	17443.7	3.3	2.7	9.7	15.7	0.6	0.4	1.1	2.1
NON	NON	42.3	36.2	173.0	251.4	27.6	23.9	115.7	167.1	1628.4	1412.4	6869.0	9909.8	1.4	1.2	6.0	8.6	0	0	0	0
ACC	ACC	51.6	9.8	60.0	121.4	39.5	7.7	43.1	90.3	2334.6	459.8	2558.0	5352.4	2.5	0.4	2.3	5.2	1.2	0.1	0.4	1.8
ACC	EU-15	67.5	41.8	133.8	243.1	47.9	30.8	95.0	173.7	2880.1	1828.5	5661.0	10369.6	2.5	1.6	5.0	9.1	0.4	0.3	0.4	1.1
EU-15	ACC	59.1	40.3	123.3	222.7	41.9	30.0	87.6	159.5	2492.7	1783.2	5219.6	9495.5	2.3	1.6	4.6	8.5	0.4	0.3	0.6	1.3
NON	ACC	39.9	12.2	67.7	119.9	28.4	9.0	47.9	85.2	1685.0	533.5	2846.6	5065.0	1.6	0.5	2.6	4.6	0.4	0.1	0.3	0.8
ACC	NON	49.8	15.1	86.5	151.4	34.9	11.1	61.7	107.8	2072.4	661.6	3684.0	6418.0	1.9	0.6	3.2	5.7	0.4	0.1	0.4	0.9
Sub-total		606.4	819.6	1697	3123	421.7	596.4	1189.8	2207.8	25025.4	36007.2	70856.7	131889.2	23.6	31.7	63.1	118.4	5	7	8	20.1
% of total		16.8	22.7	46.9	86.4	16.4	23.1	46.2	85.7	15.9	22.9	45.0	83.8	17.6	23.7	47.1	88.4	23.8	33.3	38.1	95.7

Table 2.19 Pollutant Emissions during 2000 from Ferries at Sea subdivided by Origin & destination Port and by Flag Status

AT SEA FERRIES		NO _x				SO ₂				CO ₂				HC			
FROM	TO	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total
EU-15	EU-15	20.3	227.1	40.9	288.4	15.0	167.9	30.2	213.0	1046.9	11718.8	2111.9	14877.6	0.6	6.9	1.2	8.7
EU-15	NON	7.8	10.5	14.4	32.8	6.1	7.9	10.6	24.6	406.1	544.5	744.2	1694.8	0.3	0.3	0.4	1.0
NON	EU-15	6.1	11.8	18.3	36.2	4.8	8.9	13.5	27.2	317.4	608.2	945.5	1871.1	0.2	0.4	0.6	1.1
NON	NON	1.4	0.2	4.6	6.2	1.1	0.2	3.5	4.7	73.7	10.0	237.5	321.2	0.0	0.0	0.1	0.2
ACC	ACC	4.3	0.1	0.8	5.2	3.2	0.0	0.6	3.8	221.0	2.9	42.6	266.4	0.1	0.0	0.0	0.2
ACC	EU-15	5.8	0.9	6.4	13.1	4.2	0.7	4.7	9.7	297.4	49.0	329.9	676.2	0.2	0.0	0.2	0.4
EU-15	ACC	6.2	1.5	6.9	14.6	4.6	1.2	5.1	10.8	319.1	78.3	357.3	754.8	0.2	0.0	0.2	0.4
NON	ACC	2.0	0.1	2.7	4.8	1.5	0.1	2.0	3.7	105.8	6.1	138.4	250.2	0.1	0.0	0.1	0.1
ACC	NON	2.2	0.0	2.6	4.8	1.7	0.0	1.9	3.6	114.0	0.0	133.0	247.1	0.1	0.0	0.1	0.1
Sub-total		56.1	252.2	97.6	406.1	42.2	186.9	72.1	301.1	2901.4	13017.8	5040.3	20959.4	1.8	7.6	2.9	12.2
% of total		1.6	6.9	2.7	11.2	1.6	7.2	2.8	11.6	1.8	8.3	3.2	13.3	1.3	5.6	2.2	9.1

Table 2.20 Pollutant Emissions during 2000 from Ferries Manoeuvring subdivided by Origin & Destination Port and by Flag Status

MAN FERRIES		NO _x				SO ₂				CO ₂				HC				PM IN PORT			
FROM	TO	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total
EU-15	EU-15	0.3	2.3	0.5	3.0	0.3	2.3	0.5	3.1	18.5	160.3	37.1	215.9	0.0	0.3	0.1	0.4	0.0	0.4	0.1	0.5
EU-15	NON	0.1	0.2	0.2	0.5	0.1	0.2	0.2	0.5	7.0	11.6	13.6	32.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
NON	EU-15	0.1	0.2	0.2	0.5	0.1	0.2	0.2	0.5	7.2	11.7	15.2	34.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
NON	NON	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1	1.0	0.6	5.4	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ACC	ACC	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.1	4.8	0.1	0.5	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ACC	EU-15	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1	1.9	0.5	6.5	8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EU-15	ACC	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1	1.9	0.6	6.3	8.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NON	ACC	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	2.4	0.1	1.7	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ACC	NON	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	2.4	0.0	1.6	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sub-total		0.6	2.7	1.2	4.6	0.6	2.7	1.2	4.7	47.1	185.5	87.9	320.2	0.0	0.3	0.1	0.6	0.0	0.4	0.1	0.7
% of total		0.02	0.07	0.03	0.13	0.02	0.10	0.04	0.16	0.03	0.12	0.06	0.21	0	0.22	0.07	0.44	0	1.9	0.5	3.3

Table 2.21 Pollutant Emissions during 2000 from Ferries In-Port subdivided by Origin & Destination Port and by Flag Status

IN PORT FERRIES		NO _x				SO ₂				CO ₂				HC				PM IN PORT			
FROM	TO	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total
EU-15	EU-15	0.1	0.6	0.1	0.8	0.1	0.6	0.1	0.7	4.2	36.9	8.4	49.5	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1
EU-15	NON	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	1.7	2.7	3.1	7.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NON	EU-15	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1	1.8	2.7	3.5	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NON	NON	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	1.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ACC	ACC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.1	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ACC	EU-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1	1.5	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EU-15	ACC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1	1.4	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NON	ACC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.4	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ACC	NON	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.4	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sub-total		0.1	0.6	0.2	1	0.1	0.6	0.2	0.9	11	42.6	20	73.9	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1
% of total		<0.01	0.02	<0.01	0.02	<0.01	0.02	<0.01	0.02	<0.01	0.03	0.01	0.05	0	0	0	0.07	0	0.48	0	0.48

Table 2.22 Grand Emission Totals during 2000 for all Vessels subdivided by origin & Destination Port and by Flag Status

GRAND TOTAL		NO _x				SO ₂				CO ₂				HC				PM IN PORT			
FROM	TO	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total	ACC Flag	EU Flag	NON Flag	Total
EU-15	EU-15	137.7	725.9	528.9	1392.6	97.7	537.7	383.2	1018.5	5966.6	34270.3	23115.2	63352.1	5.3	26.9	20.3	52.6	1.3	5.8	4.1	11.2
EU-15	NON	100.7	106.0	314.9	521.6	67.3	73.5	214.1	355.0	4022.2	4452.2	12886.3	21360.7	3.7	3.8	11.2	18.6	0.4	0.3	0.8	1.6
NON	EU-15	92.5	85.0	283.8	461.3	63.0	60.7	196.8	320.5	3754.4	3703.1	11899.3	19356.8	3.5	3.1	10.3	16.9	0.6	0.4	1.1	2.1
NON	NON	43.7	36.4	177.7	257.8	28.6	24.0	119.3	172.0	1703.4	1423.1	7113.2	10239.7	1.5	1.2	6.1	8.9	0.0	0.0	0.0	0.0
ACC	ACC	56.0	9.9	60.8	126.7	42.8	7.8	43.7	94.2	2561.5	462.8	2601.1	5625.4	2.6	0.4	2.4	5.4	1.3	0.2	0.5	1.9
ACC	EU-15	73.3	42.7	140.3	256.4	52.2	31.5	99.8	183.6	3179.9	1878.1	5998.8	11056.8	2.7	1.6	5.2	9.5	0.4	0.3	0.5	1.2
EU-15	ACC	65.3	41.8	130.3	237.4	46.5	31.1	92.8	170.5	2814.2	1862.1	5584.6	10261.0	2.5	1.6	4.9	8.9	0.4	0.3	0.6	1.3
NON	ACC	42.0	12.3	70.4	124.8	29.9	9.1	49.9	89.0	1793.7	539.6	2987.0	5320.4	1.7	0.5	2.6	4.8	0.4	0.1	0.4	0.8
ACC	NON	52.1	15.1	89.1	156.3	36.7	11.1	63.7	111.5	2189.5	661.6	3819.0	6670.0	2.0	0.6	3.3	5.9	0.4	0.1	0.4	0.9
TOTAL		663	1075	1796	3535	465	787	1263	2515	2798	49253	76005	153243	25	40	66	131	5.2	7.5	8.4	21
										5											
FISHING					82				63				4055				3				
GRAND TOTAL					3617				2578				157298				134				21

Table 2.16 demonstrates that approximately 80% of the total emissions of NO_x, SO₂, CO₂ and HC arise from vessels at sea, other than ferries and fishing boats. The approximate breakdown of this 80% is ~15% contributed by ACC flagged vessels, ~20% by EU flagged vessels, and ~45% by NON (EU or ACC) flagged vessels. The greatest proportion of this 80% is contributed by vessel movements between EU-15 ports (34%), with almost 90% of that proportion contributed by EU-flagged and NON-flagged vessels.

In Table 2.17, it is clear that, for in-port and manoeuvring activity, vessels other than ferries and fishing boats contribute between 4.2% (NO_x) and 11.7% (HC) of pollutant emissions. Approximately 50% of the emissions originate from EU-15 to EU-15 movements, with almost 90% of this proportion split equally between EU-flagged and NON-flagged vessels.

The pattern of Table 2.16 is repeated in Table 2.18, where total (at sea and in-port) emissions from vessel movements (excluding ferries and fishing vessels) is reported.

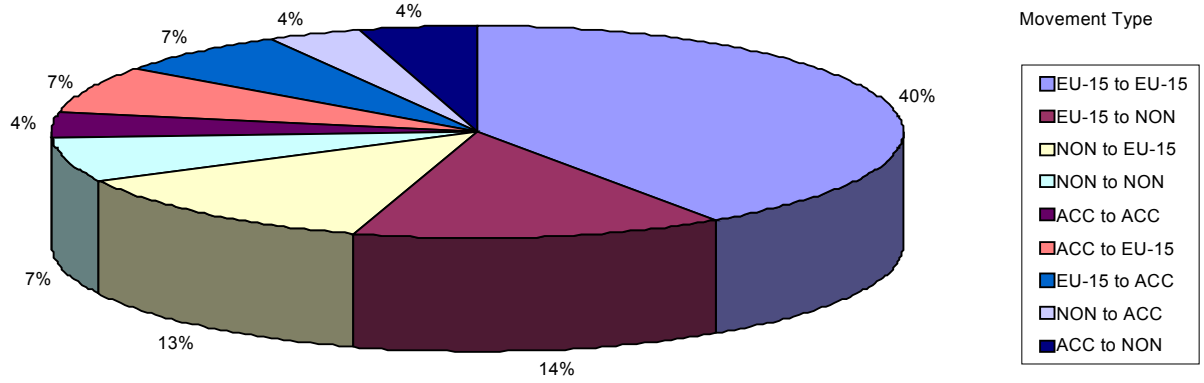
Emissions from Ferries at sea are laid out in Table 2.19, from where it is evident that between 9.1% (HC) and 13.3% (CO₂) of total emissions arise from these sources. Of this proportion, emissions from EU-15 to EU-15 ferry movements make up the majority share (~70%) and approximately 60% of the total is contributed by EU-flagged ferries.

Tables 2.20 and 2.21 include a break-down of manoeuvring and in-port emissions for ferries respectively and, unsurprisingly, a similar pattern to that in Table 2.19 is apparent. Overall, ferry manoeuvring and in-port emissions contribute fractional percentage contributions to overall pollutant emissions.

Table 2.22 contains a grand summary of total emissions from all vessels (excluding fishing boats, which are totalled separately in the penultimate row of the table) at sea and in-port. The general features that can be drawn out of these results can be summarised thus:

- Of the total 2000 emissions, only approximately 2.5% are contributed by fishing vessel movements;
- Approximately 40% of pollutant emissions originate from vessel movements between ports within the EU (EU-15 to EU-15), 14% from EU-15 to NON movements, 12% from NON to EU-15 movements and the remaining 34% split between other movements (see Figure 2.2 below for SO₂);
- In terms of emissions from differently-flagged vessels, approximately 49% arise from NON-flagged vessels, 31% from EU-flagged vessels and 18% from ACC-flagged vessels;
- For particles emitted in-port, just over 50% arises from EU-15 to EU-15 vessel movements, with the remainder spread almost equally among the other categories. The majority (40%) were contributed by NON-flagged vessels, followed by 36% from EU-flagged and 24% from ACC-flagged vessels.

Figure 2.2. Total SO₂ Emissions Breakdown by Movement



Analysis of Vessel Movements

Tables 2.23 to 2.27 contain a break-down of vessel movements between countries by movement category for the four months of 2000 considered in this study.

Table 2.23 EU(15) to EU(15) ship movements for 4 months in 2000 (excluding ferries)

Departure Country	Arrival Country - number of vessels arriving																
	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	United Kingdom	Totals	
	AUT	BEL	DNK	FIN	FRA	DEU	GRC	IRL	ITA	LUX	NLD	PRT	ESP	SWE	GBR		
Austria	AUT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Belgium	BEL	0	566	52	59	282	571	0	50	0	0	957	4	52	202	2488	5283
Denmark	DNK	0	154	2736	509	48	709	0	19	0	0	362	5	28	1734	580	6884
Finland	FIN	0	91	264	1469	20	552	0	9	1	0	74	0	8	452	184	3124
France	FRA	0	338	26	34	2216	180	116	173	885	0	617	62	947	26	1209	6829
Germany	DEU	0	908	1031	1327	174	4946	1	31	2	0	1619	6	68	1354	1789	13256
Greece	GRC	0	2	0	0	66	0	3669	1	738	0	1	2	136	1	0	4616
Ireland	IRL	0	139	15	2	211	55	0	512	0	0	222	6	64	32	1188	2446
Italy	ITA	0	1	0	0	937	0	1122	0	9393	0	3	4	1148	0	0	12608
Luxembourg	LUX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Netherlands	NLD	0	930	183	127	362	1322	1	124	2	0	2882	12	103	402	4150	10600
Portugal	PRT	0	16	1	1	51	16	3	5	4	0	32	1365	281	3	60	1838
Spain	ESP	0	756	57	66	2615	378	318	263	1744	0	1268	1814	8861	105	1375	19620
Sweden	SWE	0	230	1081	615	27	623	0	22	0	0	263	0	18	2512	505	5896
United Kingdom	GBR	0	2911	284	149	1122	1378	1	1073	1	0	4930	36	391	426	7452	20154
Totals		0	7042	5730	4358	8131	10730	5231	2282	12770	0	13230	3316	12105	7249	20980	113154

Table 2.24 EU(15) to Accession Country ship movements for 4 months in 2000 (excluding ferries)

Departure Country	Arrival Country - number of vessels arriving																
	Bulgaria	Cyprus	Czech Republic	Estonia	Hungary	Iceland	Latvia	Lithuania	Malta	Norway	Poland	Romania	Slovakia	Slovenia	Turkey	Totals	
	BGR	CYP	CZE	EST	HUN	ISL	LVA	LTU	MLT	NOR	POL	ROM	SVK	SVN	TUR		
Austria	AUT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Belgium	BEL	0	0	0	30	0	3	38	24	0	232	32	0	0	0	0	359
Denmark	DNK	0	0	0	282	0	26	313	242	0	974	543	0	0	0	1	2381
Finland	FIN	0	0	0	373	0	0	127	27	0	62	164	0	0	0	0	753
France	FRA	1	8	0	14	0	2	13	8	20	96	22	0	0	1	38	223
Germany	DEU	0	0	0	306	0	8	340	255	0	763	793	0	0	0	0	2465
Greece	GRC	12	261	0	0	0	0	0	0	47	0	0	6	0	41	553	920
Ireland	IRL	0	0	0	4	0	1	7	1	0	51	12	0	0	0	0	76
Italy	ITA	7	67	0	0	0	0	0	0	403	0	0	5	0	195	365	1042
Luxembourg	LUX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Netherlands	NLD	0	0	0	62	0	28	73	26	0	844	98	0	0	1	0	1132
Portugal	PRT	0	0	0	1	0	2	0	0	0	1	3	1	0	0	0	8
Spain	ESP	1	38	0	12	0	15	21	14	134	148	43	2	0	17	192	637
Sweden	SWE	0	0	0	473	0	7	513	165	0	589	363	0	0	0	0	2110
United Kingdom	GBR	0	0	0	57	0	39	116	39	0	871	70	0	0	0	0	1192
Totals		21	374	0	1614	0	131	1561	801	604	4631	2143	14	0	255	1149	13298

Table 2.25 Accession Country to Accession Country ship movements for 4 months in 2000 (excluding ferries)

Departure Country	Arrival Country - number of vessels arriving																
	Bulgaria	Cyprus	Czech Republic	Estonia	Hungary	Iceland	Latvia	Lithuania	Malta	Norway	Poland	Romania	Slovakia	Slovenia	Turkey	Totals	
	BGR	CYP	CZE	EST	HUN	ISL	LVA	LTU	MLT	NOR	POL	ROM	SVK	SVN	TUR		
Bulgaria	BGR	48	1	0	0	0	0	0	7	0	0	64	0	0	110	230	
Cyprus	CYP	0	79	0	0	0	0	0	11	0	0	0	0	6	275	371	
Czech Republic	CZE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Estonia	EST	0	0	0	65	0	6	73	12	0	102	36	0	0	0	294	
Hungary	HUN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Iceland	ISL	0	0	0	0	0	64	0	2	0	50	2	0	0	0	118	
Latvia	LVA	0	0	0	70	0	5	139	39	0	48	36	0	0	0	337	
Lithuania	LTU	0	0	0	32	0	1	70	32	0	40	110	0	0	0	285	
Malta	MLT	0	3	0	0	0	0	0	0	200	0	0	2	0	11	15	231
Norway	NOR	0	0	0	57	0	58	41	56	0	7374	135	0	0	0	1	7722
Poland	POL	0	0	0	82	0	3	120	136	0	148	336	0	0	0	0	825
Romania	ROM	102	1	0	0	0	0	0	0	0	1	0	484	0	0	204	792
Slovakia	SVK	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Slovenia	SVN	1	3	0	0	0	0	0	0	8	0	0	0	0	6	10	28
Turkey	TUR	608	372	0	0	0	0	0	0	122	0	0	990	0	51	3973	6116
Totals		759	459	0	306	0	137	443	277	348	7763	655	1541	0	74	4588	17350

Table 2.26 Accession Country to EU(15) ship movements for 4 months in 2000 (excluding ferries)

Departure Country	Arrival Country - number of vessels arriving																
	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	United Kingdom	Totals	
	AUT	BEL	DNK	FIN	FRA	DEU	GRC	IRL	ITA	LUX	NLD	PRT	ESP	SWE	GBR		
Bulgaria	BGR	0	0	0	0	0	18	0	23	0	0	0	6	0	0	47	
Cyprus	CYP	0	0	0	0	6	0	185	0	111	0	0	28	0	0	330	
Czech Republic	CZE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Estonia	EST	0	41	94	338	8	101	0	4	0	0	72	0	5	424	80	1167
Hungary	HUN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iceland	ISL	0	0	16	2	1	5	0	2	0	0	22	0	0	5	73	126
Latvia	LVA	0	25	106	89	6	80	0	10	0	0	77	0	2	448	226	1069
Lithuania	LTU	0	23	118	24	7	104	1	2	1	0	35	0	5	133	40	493
Malta	MLT	0	0	0	0	10	0	125	0	395	0	1	1	48	0	0	580
Norway	NOR	0	201	741	91	48	946	1	40	1	0	770	2	19	572	753	4185
Poland	POL	0	30	356	180	15	215	0	11	0	0	27	0	2	321	113	1270
Romania	ROM	0	0	0	0	1	0	22	0	33	0	3	0	11	0	0	70
Slovakia	SVK	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slovenia	SVN	0	0	0	0	4	0	32	0	234	0	0	0	9	0	0	279
Turkey	TUR	0	0	0	0	137	0	1349	0	1547	0	0	3	305	1	0	3342
Totals		0	320	1431	724	243	1451	1733	69	2345	0	1007	6	440	1904	1285	12958

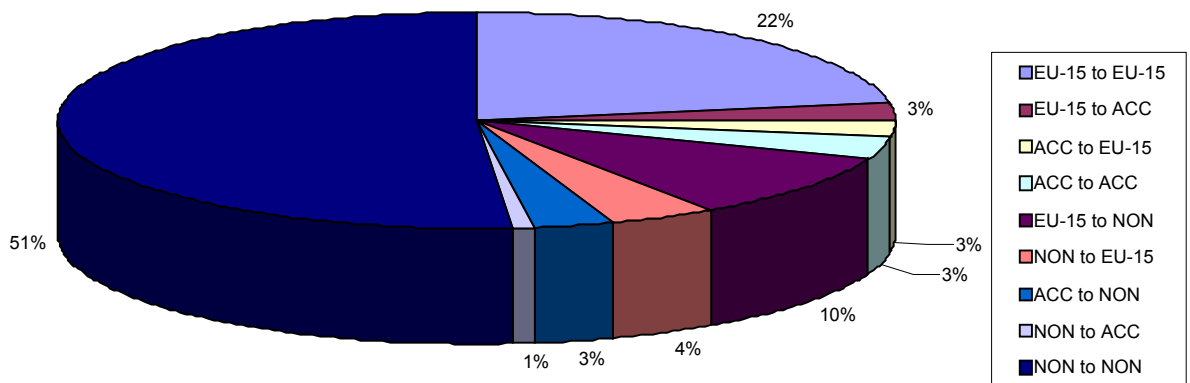
Table 2.27 Summary of other ship movements for 4 months in 2000 (excluding ferries)

Departure	Arrival	Count
EU	NON	49218
NON	EU	20641
ACC	NON	15412
NON	ACC	4545
NON	NON	261019

The data contained in the tables show that total intra-EU movements for the period were 113,154, total EU-15 to ACC movements were 13,298, ACC to EU-15 were 12,958 and ACC to ACC movements were 17,350. Other categories of movements, as included in Table 2.27 (EU-15 to NON, NON to EU-15, ACC to NON, NON to ACC and NON to NON) totalled 350,835.

A summary of the breakdown is included in Figure 2.3 below.

Figure 2.3. Breakdown of Vessel Movements by Origin and Destination State



2.6.2 Discussion of Emission Results

Total Emissions

Table 2.28 below contains a simplified summary of the emission results from this exercise, together with an assessment of the likely uncertainty envelope, derived by application of the estimated uncertainty factors, contained in Table 2.14, to the individual component emissions. No uncertainty factors have been applied to the estimated fishing emissions, as the level of confidence in the results reported here cannot be determined.

Table 2.28 Summary of Total Pollutant Emissions during 2000

Source	NO _x	SO ₂	CO ₂	HC	PM (in port)
	Kte/annum	Kte/annum	Kte/annum	Kte/annum	Kte/annum
Vessels+ferries	3,535	2,515	153,243	131	21
Fishing	82	63	4,055	2.8	-*
TOTAL	3,617	2,578	157,298	134	21
Uncertainty Margins (High and Low)					
Totals-low	2,868	2,293	139,906	97	12
Totals-high	4,366	2,863	174,690	171	30

* Not calculated

In overall terms, therefore, the percentage uncertainties around the above estimates are plus and minus 21% for NO_x, 11% for SO₂, 11% for CO₂, 28% for HC and 45% for PM.

The greatest contribution to uncertainty arises from the estimation of emissions from vessels whilst undertaking in-port operations, as the exact engine load levels and durations in particular operational modes are subject to an unknown degree of variation. Additional sources of imprecision in calculating these annual emissions will include:

- Assumptions made in the GIS analysis with regard to actual vessel routings through European waters;
- Accuracy and completeness of the vessel movements database;
- Variations in fuel quality (with respect to sulphur dioxide and particulate matter emissions);
- Variations in use profiles of main and auxiliary engines and associated fuel type use and;
- Exclusion of smaller (<500 tonnes) vessels from the analysis.

Geographical Differences

As a part of the work reported below on future projections of shipping emissions, incorporating limitations on the sulphur content of residual oil for vessels operating in the North Sea and Baltic areas, a subdivision of 2000 emission estimates between the North Sea/Baltic and other areas was made. The results of this are included in Table 2.29 below.

Table 2.29 Subdivision of Emission estimates for 2000 between North Sea/Baltic and Other Areas

Area	NO _x	SO ₂	CO ₂	HC	PM (in port)
	Kte / annum	Kte / annum	Kte / annum	Kte / annum	Kte / annum
North Sea/Baltic	1,074	763	40,849	39	6
Other Areas	2,543	1,815	116,449	95	15
Total	3,617	2,578	157,298	134	21

It is difficult to place these results in perspective in relation to estimates from previous studies, owing to differences in the areas studied, variation in vessel movements numbers used, non-inclusion of in-port emissions and use of different fuel sulphur contents.

In-Port Emissions

Table 2.30 below contains a summary of the in-port emission estimates, subdivided into ferries and other vessels, excluding fishing vessels for which no estimates are available, together with the total 2000 emissions for comparative purposes.

Table 2.30 Pollutant Emission Estimates in 2000 for In-Port (includes manoeuvring, loading/unloading and hotelling)

	NO_x	SO₂	CO₂	HC	PM (in port)
Category	Kte/annum	Kte/annum	Kte/annum	Kte/annum	Kte/annum
All Vessels (excludes fishing vessels)	158	161	9,686	17	21
Ferries	5.6	5.6	394	0.7	0.8
Total Emissions	3,617	2,578	157,298	134	21
In-Port emissions as % of total	4.5%	6.2%	6.2%	13%	100%*

* only In-Port emissions considered

From the above figures, it can be appreciated that total estimated in-port emissions make up a small percentage of the overall estimated emissions during 2000 (from 4.4% for NO_x emissions to 13% for HC emissions), with ferries contributing between 3% and 4% of total in-port emissions. These are further disaggregated in detail in the Tables comprising Appendix E. Whilst additional disaggregation into the discrete activities (manoeuvring, loading, unloading, hotelling) may be desirable, it is considered that the uncertainties inherent in the estimates obtained in this study regarding “times in mode” for these activities are such as to produce an incomplete picture.

A detailed breakdown of emissions at each of the ports considered in this study was compiled and, as an example, the ten highest emitting ports in the EU are shown in Table 2.31.

Table 2.31 Ports in the EU ranked by estimated annual emissions of NO_x in 2000.

Rank	Port Name	Country Code	NO_x (kT)	SO₂ (kT)	CO₂ (kT)	HC (kT)	PM (kT)
1	Rotterdam	NLD	3.8	3.7	219.9	0.4	0.6
2	Antwerp	BEL	2.2	2.2	134.0	0.2	0.3
3	Milford Haven	GBR	2.0	2.2	130.4	0.2	0.4
4	Hamburg	DEU	2.0	1.9	115.5	0.2	0.3
5	Augusta	ITA	1.8	2.0	121.4	0.2	0.3
6	Agioi Theodoroi	GRC	1.7	1.8	107.0	0.2	0.3
7	Piraeus	GRC	1.6	1.6	93.9	0.2	0.3
8	Eleusis	GRC	1.5	1.6	95.1	0.2	0.3
9	Göteborg	SWE	1.5	1.5	91.1	0.2	0.3
10	Immingham	GBR	1.3	1.4	82.0	0.1	0.2

Previous and Potential Future Emissions

In a previous study into greenhouse gas emissions from world-wide shipping movements, growth indices derived from GDP increases world-wide over the period 1971 to 1995 (3.2% per annum) and over a 20 year period (1.5-2.5% per annum) were investigated. It was concluded that growth in the decade 1990-2000 was of the order 2.5% per annum (IMO, 2000). For an estimation of corresponding 1990 emissions, it has been assumed, as above, that the overall annual growth factor in the period 1990 – 2000 was 2.5%. For the future period 2000-2010, a shipping movement growth envelope of 1.5% to 3.0% per annum was selected, and we apply these figures here to all vessels except ferries and fishing vessels (for which no growth is assumed) for our consideration of future emissions to 2010 from vessel movements.

Table 2.32 below contains these projections, using these annual growth factors, of pollutant emissions from shipping movements in 1990, factored from the calculated 2000 emissions, and for 2010.

Table 2.32 Past and Future Estimated Shipping Emissions

Scenario	NO _x	SO ₂	CO ₂	HC	PM (in port)
	Kte / annum	Kte / annum	Kte/ annum	Kte/annum	Kte/annum
1990	2,808	2,001	122,115	104	16
2000	3,617	2,578	157,298	134	21
2010-Low	4,015	2,845	172,791	147	24
2010-High	4,649	3,294	200,105	171	28

A previous study of shipping emissions in European waters (BMT, 2000), derived emission tonnages for SO₂ and NO_x for 2001, roughly corresponding to the study area for this current investigation, but excluding the Black Sea and Caspian sea and with no consideration of in-port emissions. These estimates are compared in Table 2.33 below with the 2000 estimates from the current study.

Table 2.33 Comparison of emission estimates for 2000 with a previous study

Study	NO_x	SO₂
	Mte / annum	Mte / annum
This Study 2000	3.6	2.6
BMT 2001	2.3	1.9

It is evident that the 2001 BMT estimates are significantly lower than those derived for 2000 in this current study.

Future Detailed Scenarios

As described earlier in this report and in Table 2.15, a range of potential future emission scenarios was developed jointly by Entec and the European Commission, incorporating the provisions of MARPOL Annex VI. These dealt with reductions in the sulphur content of residual oil (RO) in the North Sea and Baltic waters, reductions in marine gas oil (MGO) sulphur contents for use by vessels in port and restrictions upon RO sulphur content in territorial waters to 1.5%. Vessels operating in areas outside the Baltic and North Sea were assumed to use RO with a sulphur content of 2.7%.

Table 2.34 Future emission scenarios

Scenario No. / Year	Sulphur in fuel and fuel type legislation	NO _x , PM, HC and CO ₂
1. 2006 BAU*	as in assigned emission factors for year 2000 ("Actual 2000")	as in "Actual 2000"
2. 2006	1,5% in RO for North Sea/Baltic	as in "Actual 2000" + lower PM
3. 2006	1,5% in RO for North Sea/Baltic + 0,2% in MGO in port for AEs only	as in "Actual 2000" + lower PM + NO _x , CO ₂ reductions due to increase in MGO use (lower sfc)
4. 2006	1,5% in RO for North Sea/Baltic + 0,2% in MGO in port and manoeuvring for both AEs and MEs	as in "Actual 2000" + lower PM + NO _x , CO ₂ reductions due to increase in MGO use (lower sfc)
5. 2008 BAU	as in "Actual 2000"	as in "Actual 2000"
6. 2008	1,5% in RO for North Sea/Baltic	As in "Actual 2000" + lower PM
7. 2008	1,5% in RO for North Sea/Baltic + 0,1% in MGO in port for AEs only	as in "Actual 2000" + lower PM + NO _x , CO ₂ reductions due to increase in MGO use (lower sfc)
8. 2008	1,5% in RO for North Sea/Baltic + 0,1% in MGO in port and manoeuvring for both AEs and MEs	as in "Actual 2000" + lower PM + NO _x , CO ₂ reductions due to increase in MGO use (lower sfc)
9. 2008	1,5% in RO for North Sea/Baltic and all territorial waters + 0,1% in MGO in port and manoeuvring for both AEs and MEs	as in "Actual 2000" + lower PM + NO _x , CO ₂ reductions due to increase in MGO use (lower sfc)
10. 2010 BAU	As in "Actual 2000"	As in "Actual 2000"

* BAU – Business as Usual

Annual growth rates for vessel movements were selected as 1.5% per annum and 3.0% per annum after IMO (2000). The resultant projections for the 1.5% per annum growth rate are contained in Table 2.35 below. A more detailed breakdown of the scenario calculations is contained in Appendix F, together with the summarised results for the 3% per annum growth factor.

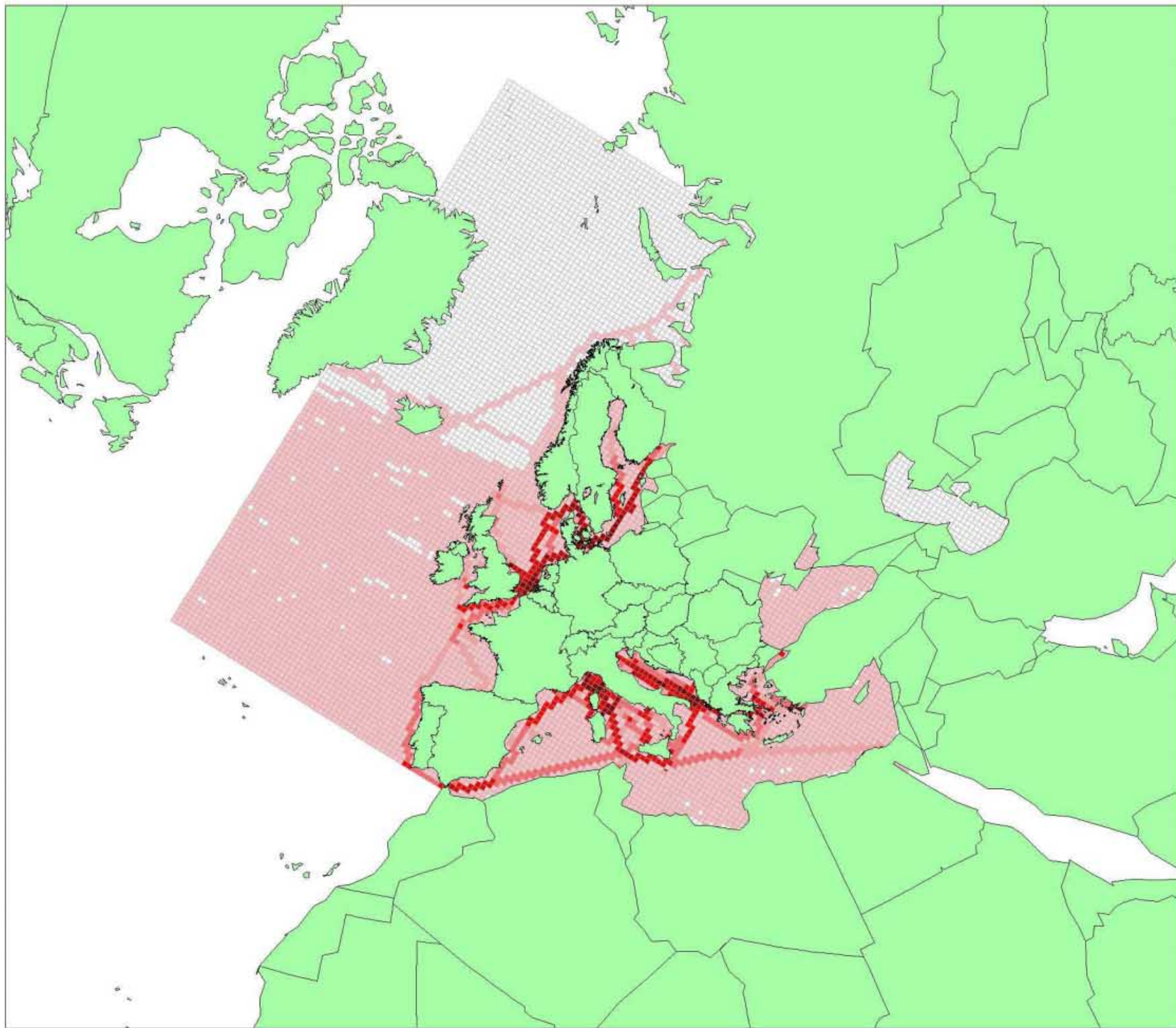
Table 2.35 Emissions estimates for Future Scenarios

Scenario	NO _x	SO ₂	CO ₂	HC	PM (in port)
	Kte / annum	Kte / annum	Kte/ annum	Kte/annum	Kte/annum
2000 BAU	3,617	2,578	157,298	134	21
1 2006 BAU	3,833	2,718	165,412	140	23
2	3,833	2,381	165,412	140	20
3	3,831	2,301	165,222	140	12
4	3,826	2,268	165,026	140	9
5 2008 BAU	3,922	2,780	169,024	144	23
6	3,922	2,435	169,024	144	21
7	3,919	2,350	168,828	144	13
8	3,915	2,314	168,628	144	9
9	3,915	1,999	168,628	144	9
10 2010 BAU	4,015	2,845	172,791	147	24

Spatial Representation of Emissions

The distribution of shipping emissions over the EMEP domain on an individual 50 km x 50 km grid square resolution for the year 2000 is represented in Figures 2.4 to 2.16, organised on the following basis:

- Figures 2.4 to 2.8 – Total emissions (excluding fishing vessels) of the five pollutants considered (SO₂, NO_x, PM, HC, CO₂);
- Figures 2.9 to 2.11 – Emissions of SO₂ by vessel flag status (EU-15, ACC or NON);
- Figures 2.12 to 2.13 – Emissions of SO₂ from fishing boats and ferries, respectively;
- Figures 2.14 to 2.16 – Emissions of SO₂ by origin and destination state.



Key:

Total Annual SO₂ Emission (Kilo Tonnes)

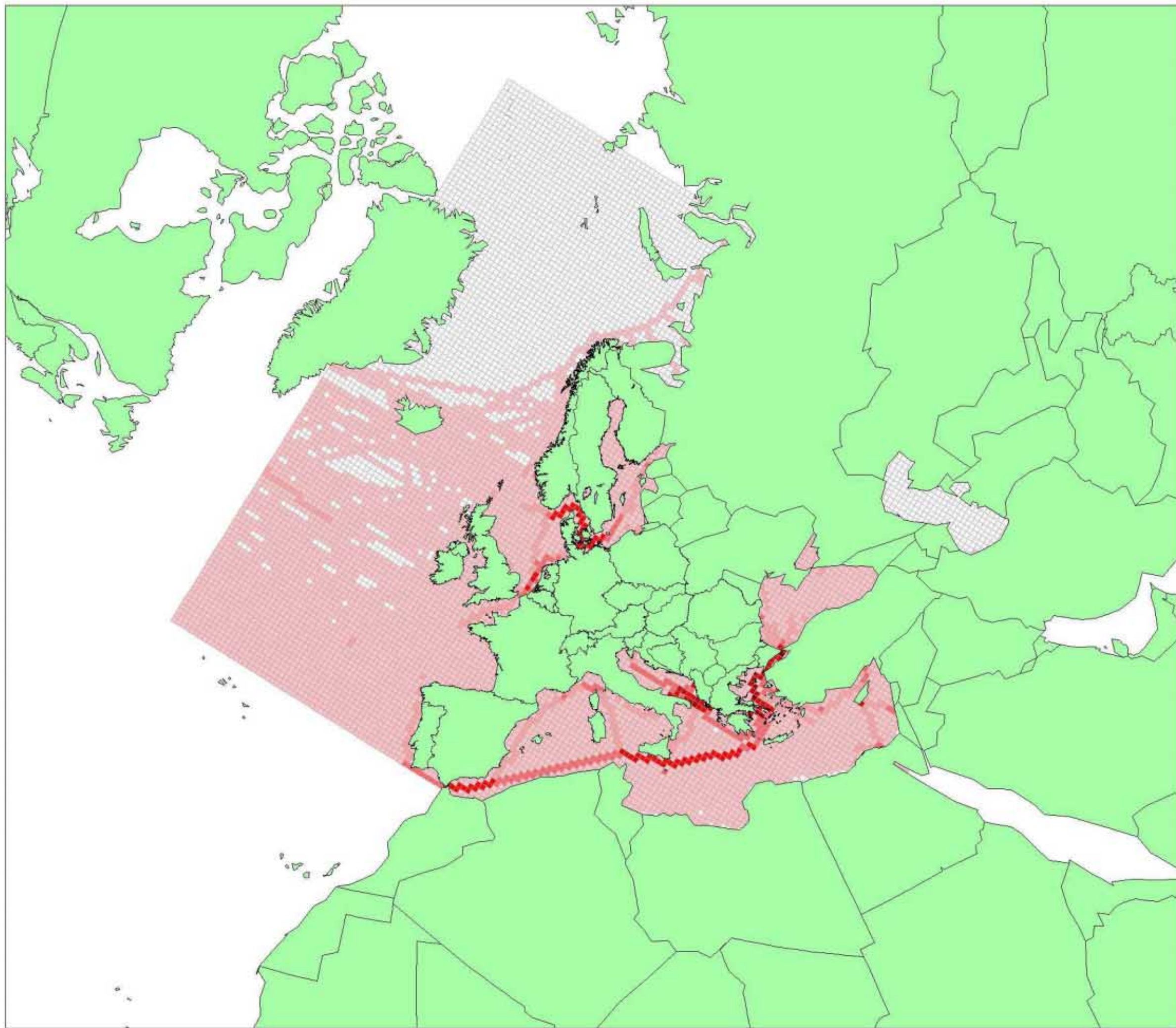
- No Emission
- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 5.0
- 5.0+

0 600 1200 1800 Kilometers

0195026 3108 04941701642 1284417701641 03030203032 AIR

Quantification of emissions from ships associated with ship movements between ports in the European community

Figure 2.9
EU Flag registered - SO₂



Key:

Total Annual SO₂ Emission (Kilo Tonnes)

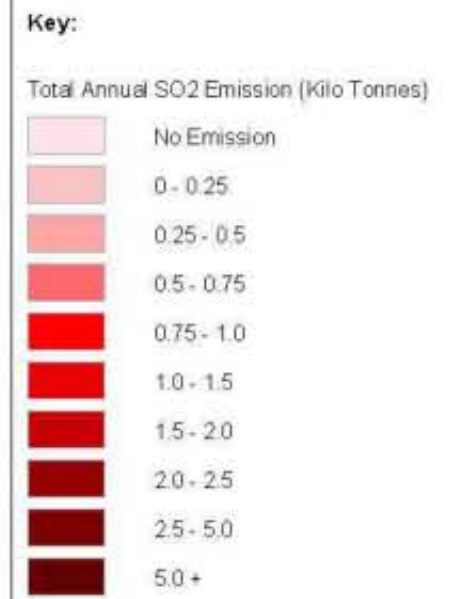
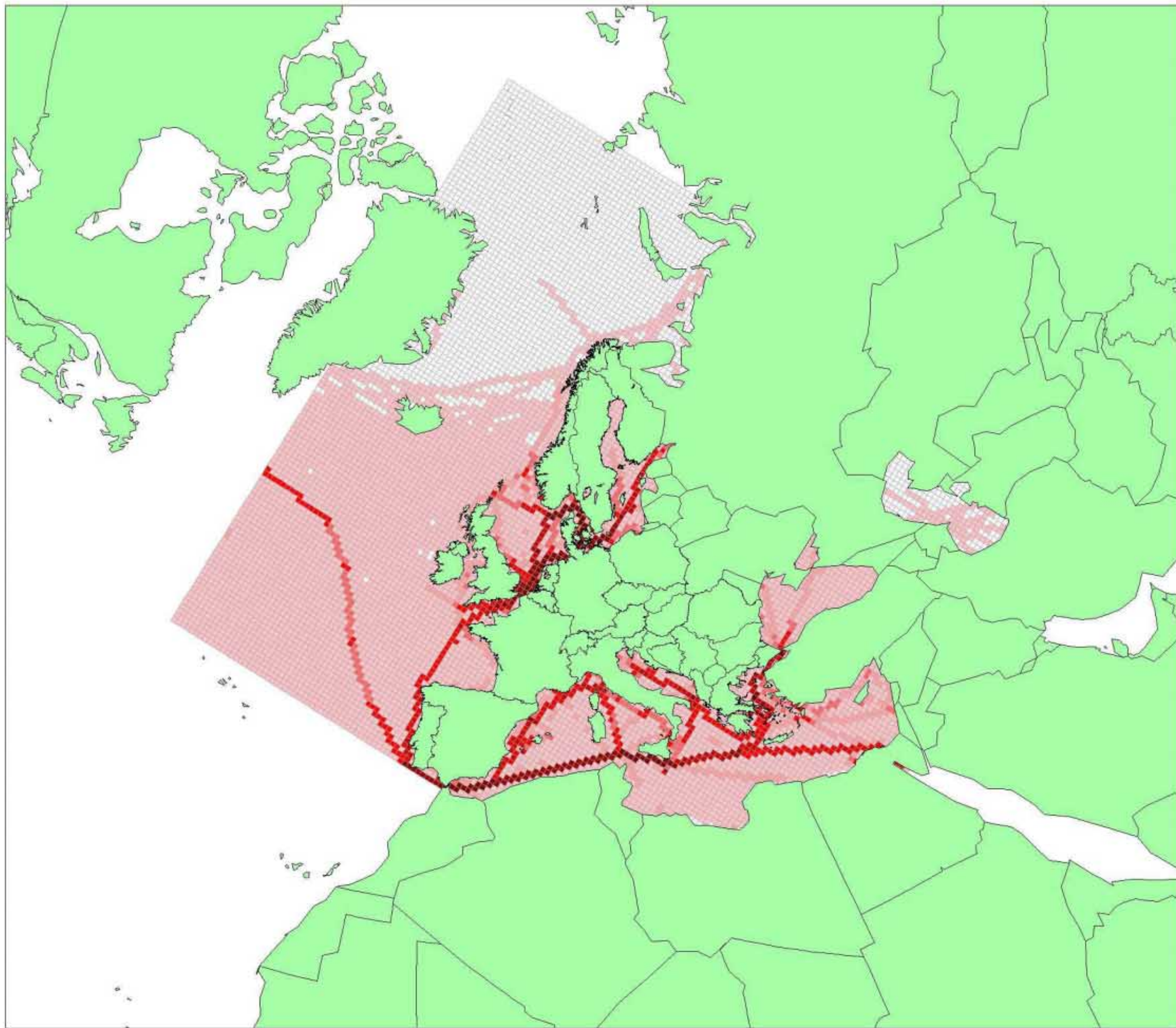
- No Emission
- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 5.0
- 5.0+

0 600 1200 1800 Kilometers

0195081210810494177016A2102994177016A1_03POLIT000002.APR

Quantification of emissions from ships associated with ship movements between ports in the European community

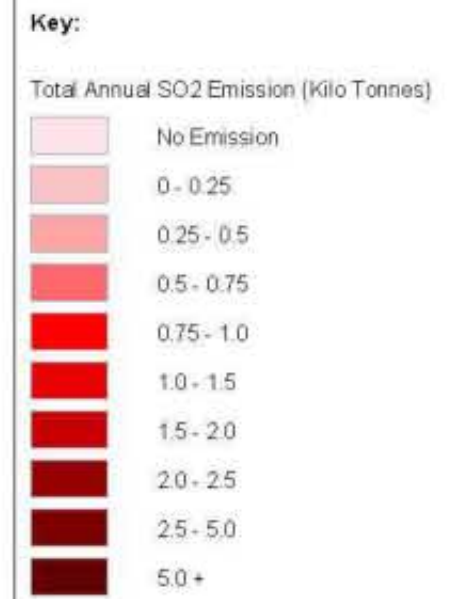
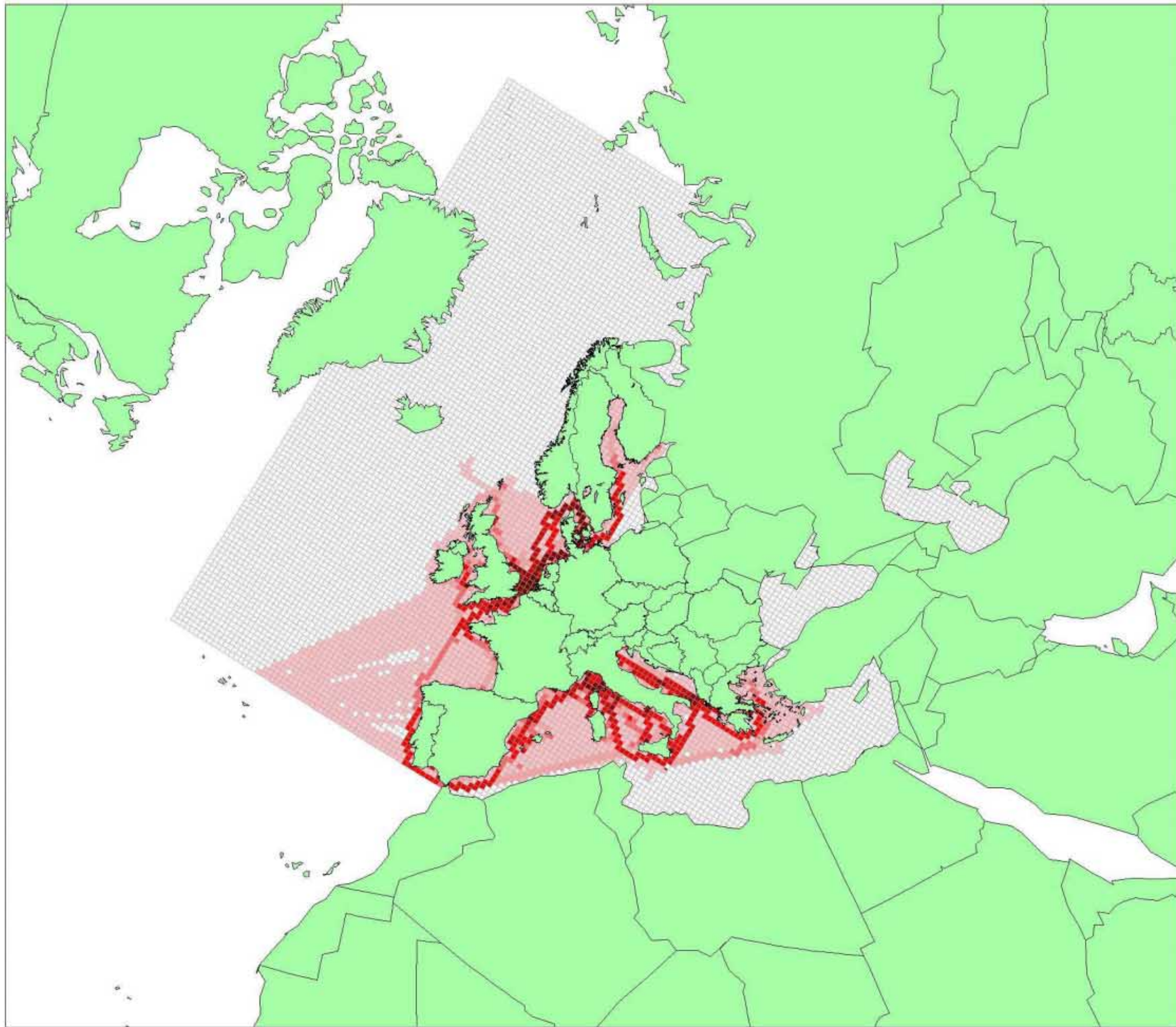
Figure 2.10
ACC Flag registered - SO₂



01950812 1108 0494 0701FA02 V02 W44 0700A1_03POL0100002.APR

Quantification of emissions from ships associated with ship movements between ports in the European community

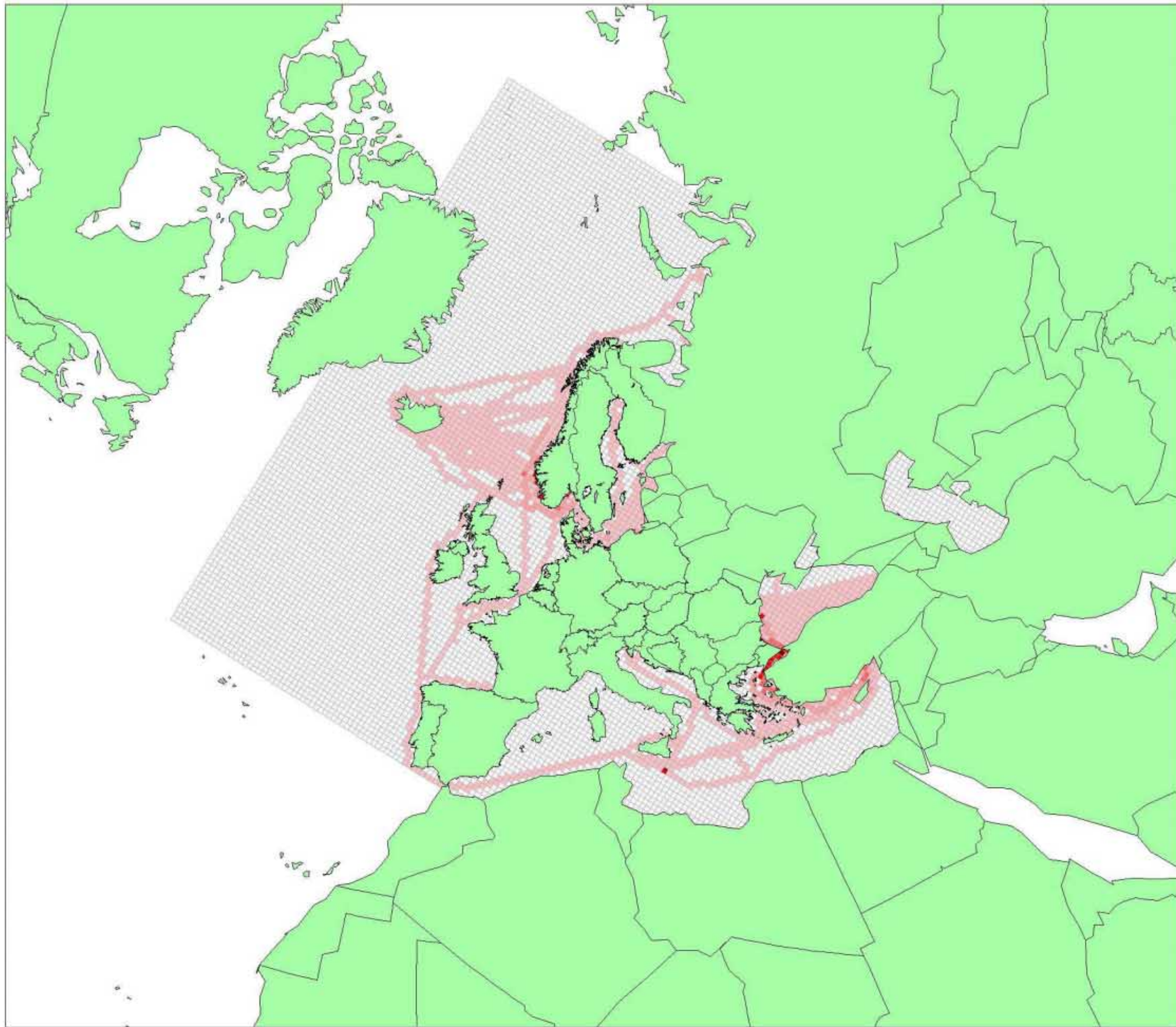
Figure 2.11
NON Flag registered - SO₂



01950261 2102 049417701642 12874417701641 0701641_030102030203 AIR

Quantification of emissions from ships associated with ship movements between ports in the European community

Figure 2.14
Total SO₂ emissions - Group - EU - EU



Key:

Total Annual SO₂ Emission (Kilo Tonnes)

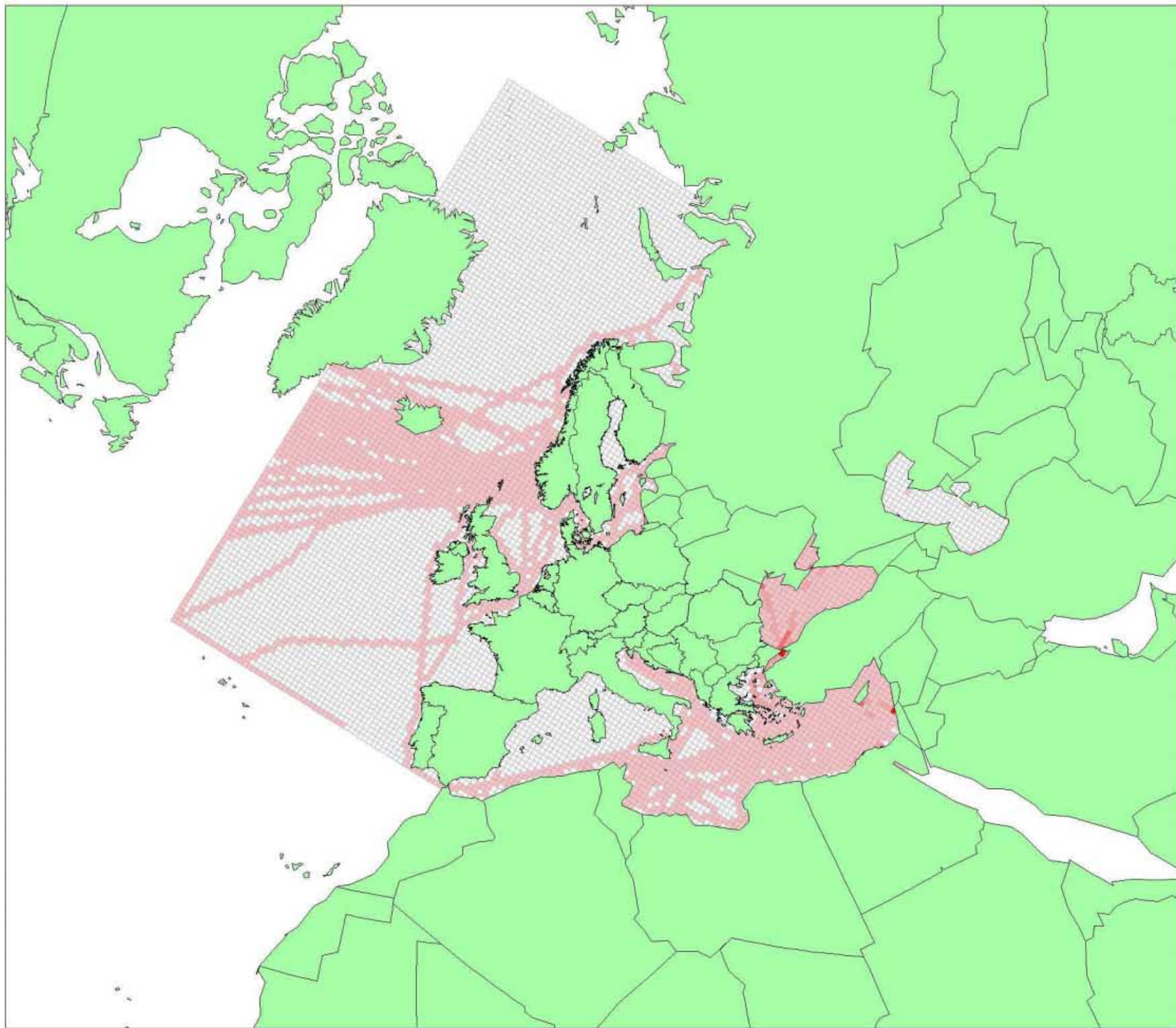
- No Emission
- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 5.0
- 5.0+

0 600 1200 1800 Kilometers

0195026 31026 049417701642 1287441 7701641_3301026 020822 2002

Quantification of emissions from ships associated with ship movements between ports in the European Community

Figure 2.15
Total SO₂ emissions - Group - ACC - ACC



Key:

Total Annual SO₂ Emission (Kilo Tonnes)

- No Emission
- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 5.0
- 5.0+

0 600 1200 1800 Kilometers

0195026 2102 04941701642 1284417701641 0195026 2102 04941701641

Quantification of emissions from ships associated with ship movements between ports in the European community

Figure 2.16
Total SO₂ emissions - Group - NON EU - ACC