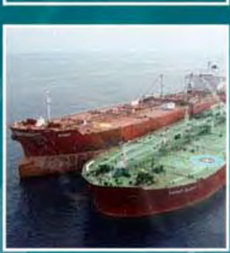
Defra

UK Ship Emissions Inventory

Final Report

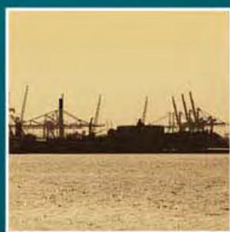
November 2010









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Document Revisions

No.	Details	Date
1	Interim Emissions Inventory Report	05 June 2008
2	Draft Final Emissions Inventory Report	31 July 2008
3	Final Emissions Inventory Report	24 October 2008
4	Technical Note: Revision of Emissions Inventory to incorporate MARPOL Annex VI amendments	12 March 2009
5	Draft chapters of back-casting and sensitivity analysis for client comment	17 November 2009
6	Draft Final Consolidated Report for Consultation	1 November 2010
7	Final report (taking into account peer review comments)	29 November 2010

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Entec UK Limited

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Glossary

AE	Auxiliary Engine
AIS	Automatic Identification System
CLRTAP	Convention on Long-range Transboundary Air Pollution
CO_2	Carbon Dioxide
DECC	Department of Energy and Climate Change
DfT	Department for Transport
DUKES	Digest of UK Energy Statistics
DWT	Deadweight Tonnes - a measure of how much mass or weight of cargo or burden a ship can safely carry
ECA	Emission Control Area
EMEP	European Monitoring and Evaluation Programme
EU	European Union
GIS	Geographical Information System
GGI	Greenhouse Gas Inventory
GRT	Gross Registered Tonnes
GT	Gas Turbine
HC	Hydrocarbon
HFO	Heavy Fuel Oil (Residual Oil)
HSD	High Speed Diesel
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
kT	Kilotons
kW	Kilowatt
LMIU	Lloyd's Marine Intelligence Unit (now known as Lloyd's List Intelligence)
LRF	Lloyd's Register Fairplay
MCA	Maritime and Coastguard Agency
MCR	Maximum Continuous Rating
MD	Marine Distillates (MDO and/or MGO)
MDO	Marine Diesel Oil (a blend of Marine Gas Oil and Heavy Fuel Oil)
ME	Main Engine
MEPC	Marine Environment Protection Committee
MGO	Marine Gas Oil (Distillate Fuel)
MSD	Medium Speed Diesel

NAEI	National Atmospheric Emissions Inventory
NECD	National Emission Ceilings Directive
NH_3	Ammonia
NMVOC	Non Methane Volatile Organic Compounds
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
NTUA	National Technical University of Athens
PM	Particulate Matter
PM_{10}	Fine particulate matter with an aerodynamic diameter of less than 10 µm
$PM_{2.5}$	Fine particulate matter with an aerodynamic diameter of less than 2.5 µm
RO	Residual Oil (Heavy Fuel Oil)
RPM	Revolutions per Minute
RSZ	Reduced Speed Zone
S	Sulphur
SECA	Sulphur Emission Control Area
sfc	Specific Fuel Consumption
SO_2	Sulphur dioxide
SO_X	Sulphur oxides
SSD	Slow Speed Diesel
ST	Steam Turbine
SWS	Sea Water Scrubbing
TREMOVE	A policy assessment model, designed to study the effects of different transport and environment policies on the emissions of the transport sector
UNECA	United Nations Economic Commission for Europe
US EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds

Executive Summary

Background

Entec UK Limited (Entec) has been appointed by the Department for Environment, Food and Rural Affairs (Defra) to develop a gridded atmospheric emissions inventory from ship movements within waters surrounding the UK, including the North Sea, English Channel, Irish Sea and Northeast Atlantic.[1] The inventory was based on year 2007 ship movements.

Following this study that was completed in October 2008, Defra commissioned Entec to undertake a series of additional related studies that aimed to further quantify and account for underlying uncertainties in the development of the inventory and assess the potential effects of emerging legislation. These additional tasks included:

- Use of Department for Transport (DfT) statistics to estimate potential emissions from vessel movements that were unlikely to be included in the movements data used to compile the original emissions inventory. The outputs from this sensitivity analysis were revised estimates of fuel consumption and emissions for domestic (UK to UK) movements and UK International movements. The inventory was uplifted to take these additional emissions into account;
- Update of emission projections to achieve consistency with assumptions in the UK Carbon Budgets and Department for Transport (DfT) and Maritime and Coastguard Agency (MCA) studies;
- An update to the 2020 projections of the emissions inventory to take into account the amendments to the MARPOL Annex VI regulations and the Nitrogen oxide (NO_X) Technical Code adopted by the International Maritime Organization (IMO) in October 2008 that entered into force in July 2010;
- Back-casting of fuel consumption and emissions were required to 1990. Entec used proxy-data for growth from 1990 to produce a consistent time-series for shipping fuel consumption and emissions that considered changes in vessel emission factors and movement / activity trends. The same approach was used to provide interim forecasts for 2008 and 2009; and
- The NAEI and the Greenhouse Gas Inventory (GGI) have historically reported emissions from domestic and international shipping based on fuel consumption data from the Digest of UK Energy Statistics (DUKES) for marine bunkers (for international shipping) and national navigation (for domestic shipping and fishing). Entec has provided technical support to Defra, the Department of Energy and Climate Change (DECC) and the National Atmospheric Emissions Inventory (NAEI) team in updating the approach for estimating fuel consumption and emissions from shipping that will be applied to the 2009 inventory compilation to be published in December 2010.

This report represents a consolidation of the reports and technical notes issued by Entec from 2008 to 2010 in relation to the above studies.

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[1] The study area is 200 nautical miles from the UK coastline, extended eastwards for more complete North Sea coverage.

Approach

Fuel combustion related emissions from ships can make a significant contribution to air pollution which can lead to acidification and eutrophication as well as the formation of ground level ozone and particulate matter (PM).

The pollutant species for consideration in the assessment include:

- Oxides of Sulphur (SO_X);
- Oxides of Nitrogen (NO_X);
- Non Methane Volatile Organic Compounds (NMVOC) derived as 99% of total hydrocarbons;
- Primary PM_{10} derived as 95% of total particulate matter;
- Primary $PM_{2.5}$ derived as 90% of total particulate matter; and
- Carbon Dioxide (CO_2).

This report provides a detailed analysis of ship emissions resolved to a 5km x 5km grid, including emissions from vessels at sea, manoeuvring and at berth.

Underpinning the emissions inventory are individual vessel movements and characteristics data provided by Lloyds Marine Intelligence Unit (LMIU) for the year 2007. To ensure more complete coverage of vessel movements and time of arrival and departure, particularly for passenger vessels, LMIU has provided supplementary Automatic Identification System (AIS) data that is transmitted by vessels to shore stations and includes information about a ship's position and course. These vessel movements data have been used in the development of a detailed Geographic Information System (GIS) based route network across the study area, which utilised route distances from Shipping Marine Distance Tables. In addition to the ship movements, engine emission factors and engine load factors have been assigned to each vessel, based on a vessel's engine type, installed power and fuel type. When combined, the above data enable the calculation of emissions from each vessel and their spatial disaggregation across the study area.

The primary focus of the emission inventory was the 2007 baseline, although emission projections have been developed to 2020. In the initial inventory developed in 2008, the projections were based on annual ship movement growth rates of 2%, 3% and 4%, but were updated in 2009 to provide an additional scenario of 1% annual growth to reflect the changing global economic situation at that time and to achieve consistency with other work undertaken since the initial Defra inventory compilation by the DfT and the MCA.

These projections include the current provisions of the Sulphur Content of Marine Fuels Directive (SCMFD) (European Parliament and Council, 2005), which came into force on 6th July 2005, which is linked to MARPOL Annex VI, thus setting maximum permissible sulphur content of marine fuels used in Sulphur Emission Control Areas (Sulphur ECAs, or 'SECA') of the Baltic Sea (from August 2006), and the North Sea and English Channel (from August 2007) and also sulphur limits for passenger vessels between EU Ports (from August 2006), and for all vessels at berth in EU ports (from January 2010). MARPOL Annex VI also includes limits on NO_X emissions for post year 2000 marine engines, which are considered in this assessment.

The amendments to the MARPOL Annex VI regulations, which were adopted in October 2008 and came into force on 1 July 2010, were not included in the initial emissions inventory which was completed before the amendments were agreed. The revised Annex VI allows for an ECA to be designated to limit emissions from ships of SO_X, particulate matter or NO_X, or all three pollutants. It also introduced more stringent general requirements for the sulphur content of fuel oil to be used on ships and it introduced tighter regulations for fuel oil sulphur content within ECAs, but it also permits operators to use other compliance methods that are at least as effective in terms of emission reductions. More stringent limits also came into force in relation to emissions of NO_X.

Owing to these regulatory changes, under a separate work package, Entec was commissioned by Defra to update the emission projections to 2020 to take account of the MARPOL Annex VI amendments. On the basis of the timescales for developing revised emission projections, Entec applied broad assumptions, primarily in terms of fuel type, fuel switching and the assumed uptake rates of abatement technology to determine appropriate weighted emission adjustment factors from which the revised projections were based. Recommendations were presented in terms of further work that could be undertaken to refine these emission estimates at a later stage.

Outputs

Outputs of this study will be used to update the NAEI[2] with regards to emissions from UK shipping, which have historically been estimated from fuel consumption data, based on UK fuel sales, published by DECC.[3] Subsequent regional modelling will be undertaken using the data in the NAEI to assess the impact of emissions from shipping on the UK in terms of effects on human health and ecosystems.

The total emission estimates for each pollutant and for fuel consumption for the 2007 baseline are presented below in Table i and 2020 projections in Table ii, with further disaggregated emissions presented in Section 12 and Appendices C and D. The 2020 estimates show increases in NO_X, CO_2 and VOC emissions and fuel consumption compared to 2007 (although NO_X emission increases are more marginal) which are due to growth. The estimates show that the impact of fuel sulphur content reductions results in significantly lower SO_2 emissions and lower PM emissions in 2020 compared to 2007.

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[2] The UK National Atmospheric Emissions Inventory (NAEI). The NAEI is funded by Defra, The National Assembly for Wales, The Scottish Executive and The Department of Environment, Northern Ireland. The NAEI compiles estimates of emissions to the atmosphere from UK sources such as cars, trucks, power stations and industrial plant. These emissions are estimated to help to find ways of reducing the impact of human activities on the environment and our health.

[3] Digest of UK Energy Statistics (DUKES).

Mapped SO_2 emission estimates in 2007 and 2020 (assuming 1 % growth) are presented alongside each other for visual comparison of the estimates in Figure i. Figure i clearly shows the impact of the assumptions for 2020 compared to 2007. The most notable difference (which is also apparent for PM emissions in Appendix E, but to a lesser degree) is that emissions in 2020 are noticeably lower than in 2007, and furthermore, that the benefit of the additional fuel sulphur reductions in the SECAs compared to outside the SECAs is clear. SO_2 emissions outside the SECAs (for example, in the Irish Sea) also reduce between 2007 and 2020 due to the assumed reduction in global fuel sulphur content. Further comparison of mapped emission estimates presented in Appendix E do not show shifts in geographical distributions of emission estimates in 2020 compared to 2007 for remaining pollutants.

Emission and fuel consumption estimates within the UK 12 nautical mile zone are approximately 11% of the total estimates for UK waters as defined in this study. Domestic movements contribute around 4% to total estimates, whilst UK international movements are responsible for approximately 38% of total estimates. The remaining emissions are attributed to passing vessels through the study area (i.e. not calling at any ports within the study area). Emissions should be viewed in the context of the key areas of uncertainty summarised in Section 14.

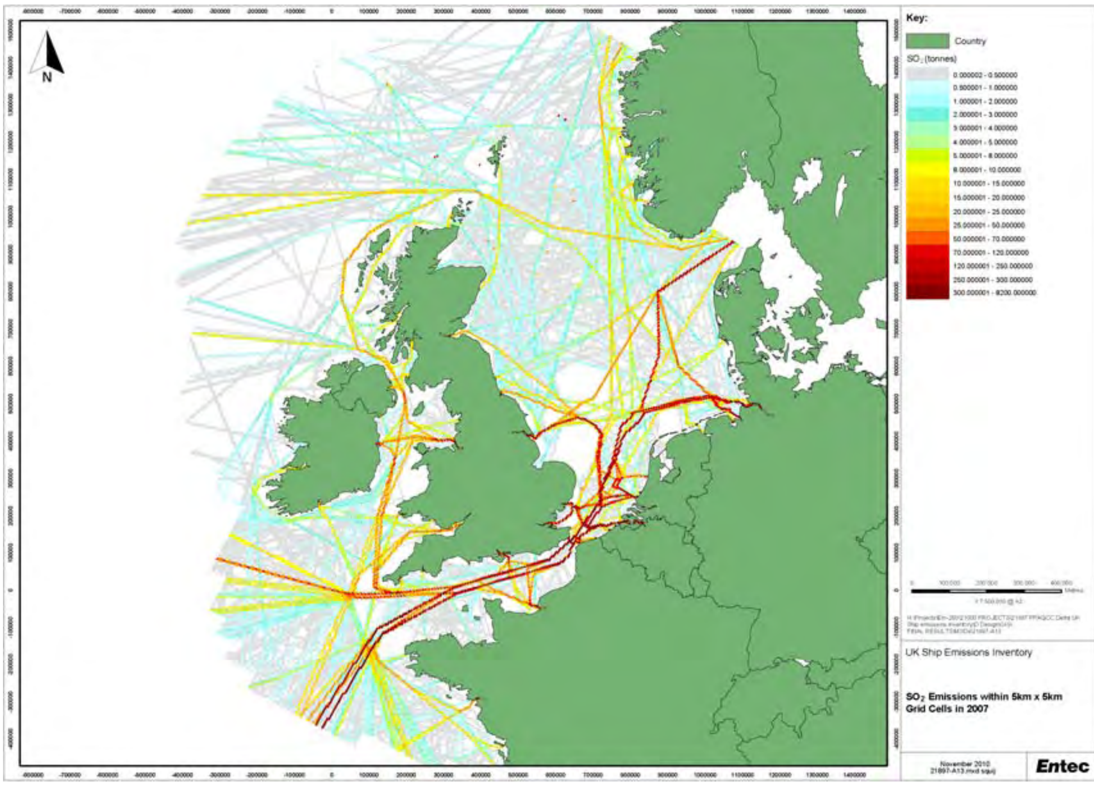
Table i Emission and Fuel Consumption Estimates (kT) in 2007 in 'UK waters' as defined in this study

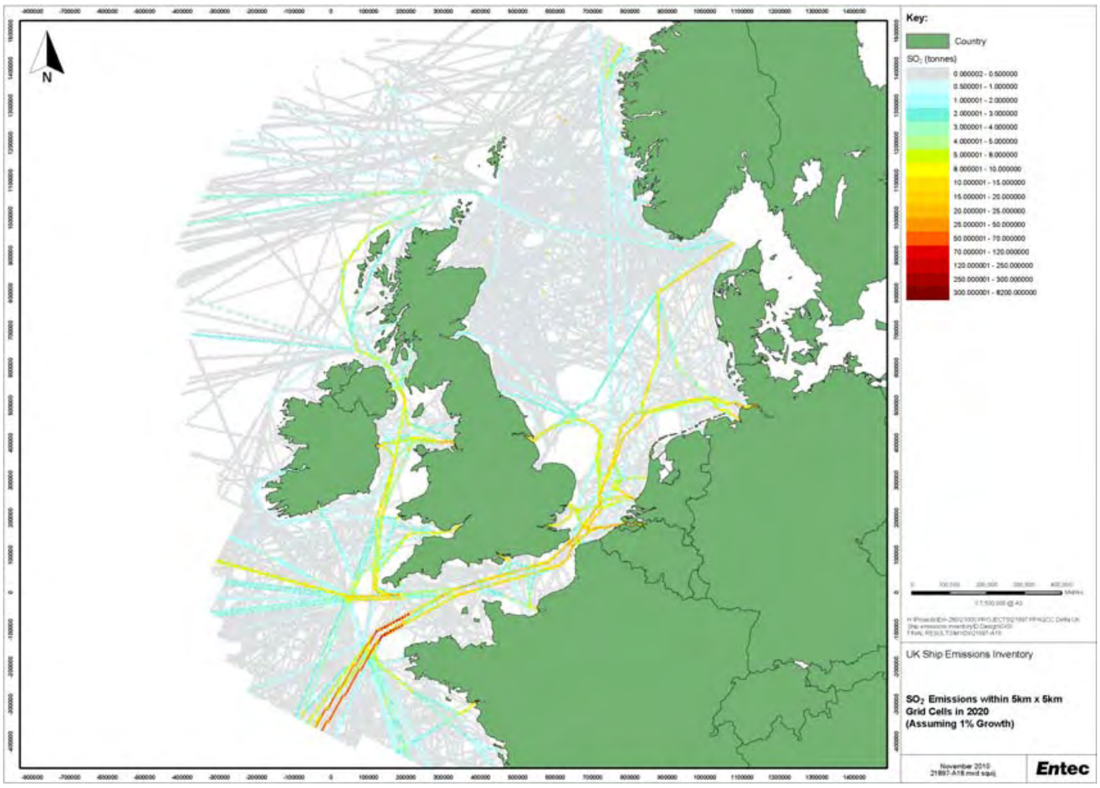
	NO_X	SO_2	CO_2	VOCs	$PM_{2.5}$	PM_{10}	Fuel Consumption
At sea	811	355	34,049	30.0	28.7	30.3	10,712
Manoeuvring	10	5	557	0.8	0.6	0.7	175
At berth	108	37	5,795	5.5	4.3	4.6	1,823
TOTAL	**929**	**397**	**40,401**	**36.4**	**33.7**	**35.6**	**12,711**

Table ii Emission and Fuel Consumption Estimates (kT) in 2020 in 'UK waters' as defined in this study, expressed as ranges that represent annual growth rates of 1% to 4% from 2007.

	NO_X	SO_2	CO_2	VOCs	$PM_{2.5}$	PM_{10}	Fuel Consumption
At sea	839 - 1,227	44 - 65	38,443 - 56,243	34 - 50	13 - 20	14 - 21	12,095 - 17,696
Manoeuvring	10 - 15	0.6 - 0.8	633 - 926	1.0 - 1.4	0.4 - 0.7	0.5 - 0.7	199 - 291
At berth	107 - 157	5.2 - 7.6	6,586 - 9,636	6.3 - 9.2	3.3 - 4.8	3.4 - 5.0	2,072 - 3,031
TOTAL	**956 - 1,399**	**50 - 73**	**45,662 - 66,805**	**41 - 61**	**17 - 25**	**18 - 26**	**14,366 - 21,019**

Figure i **Annual SO_2 Emissions within 5km x 5km Grid Cells. Top: in 2007: bottom: in 2020 (1% growth)**





Contents

1. Introduction

1.1 Purpose of this Report

The primary objective of Entec's contract with Defra was to develop a detailed ship emission dataset (primarily for the baseline year, i.e. 2007) that could be used to inform future UK policies that target shipping emissions. This information was then to be used to inform discussions with the European Commission and the IMO regarding the future direction of marine emissions reduction policy, as well as informing UK policy.

Following completion of the initial inventory study in October 2008, Entec was commissioned to undertake a series of additional related tasks. This document represents a consolidation of the reports and technical notes issued by Entec to Defra from 2008 to 2010 in relation atmospheric emissions from shipping in UK waters. The additional tasks included:

- Use of DfT statistics to estimate potential emissions from vessel movements that were unlikely to be included in the movements data used to compile the original emissions inventory. The outputs from this sensitivity analysis were revised estimates of fuel consumption and emissions for passenger vessels, smaller vessels, domestic (UK to UK) movements and UK International movements. The inventory was uplifted to take these additional emissions into account;

- Update of emission projections to achieve consistency with assumptions in the UK Carbon Budgets and more recent studies undertaken by the DfT and the MCA;

- An update to the projections of the emissions inventory to take into account the amendments to the MARPOL Annex VI regulations and the NO_X Technical Code adopted by the IMO in October 2008 that entered into force in July 2010;

- Back-casting of fuel consumption and emissions were required to 1990. Entec used proxy-data for growth from 1990 to produce a consistent time-series for shipping fuel consumption and emissions that considered changes in vessel emission factors and movement / activity trends. The same approach was used to provide interim forecasts for 2008 and 2009; and

- The NAEI and the GGI have historically reported emissions from domestic and international shipping based on fuel consumption data from the DUKES for marine bunkers (for international shipping) and national navigation (for domestic shipping and fishing). Entec has provided technical support to Defra, the DECC and the NAEI team at AEA Energy and Environment in updating the approach for estimating fuel consumption and emissions from shipping that will be applied to the 2009 inventory compilation to be published in December 2010.

This document presents the work undertaken in the development of the UK ship emissions inventory and projections, including the key data sources, assumptions and the resulting emission estimates from shipping in 'UK waters' as defined in this study.

1.2 Ship Emission Inventories

Several studies provide information regarding emissions from shipping activity across the area of the European Monitoring and Evaluation Programme (EMEP)[4] unified domain. However, none of these studies focus specifically on the UK, and the ones that cover the EMEP domain have a broad spatial resolution (50km by 50km grid cells).

The NAEI historically provides UK emission estimates for coastal shipping, international shipping and naval shipping based on fuel consumption data provided in the DUKES publication. However, such emission estimates have uncertainties associated with the quality, completeness and coverage of the fuel consumption data and are based on the refiners' best estimate of the split of the fuel data between different activities (e.g. domestic or international shipping). More specifically, for shipping, these emission estimates are based on UK fuel sales, so vessels bunkering outside the UK are not included in the emission estimates, although these vessels may also be operating within UK waters. Further complexities are introduced when assigning a geographical distribution to the fuel consumption statistics and the associated emissions.

1.3 Aims and Objectives

The overall objective of this study was to develop a gridded ship emissions inventory for UK waters, defined as 200 miles from the UK coastline, as shown in Figure 1.1. To include more complete coverage of the North Sea, the extent of the study area was extended further east to include the Danish coastline and part of the Skagerrak Strait that runs between Norway and the southwest coast of Sweden and the Jutland peninsula of Denmark, connecting the North Sea and the Kattegat Strait, which leads to the Baltic Sea.

Fuel consumption and the following fuel combustion-based pollutants have been considered in the emissions inventory:

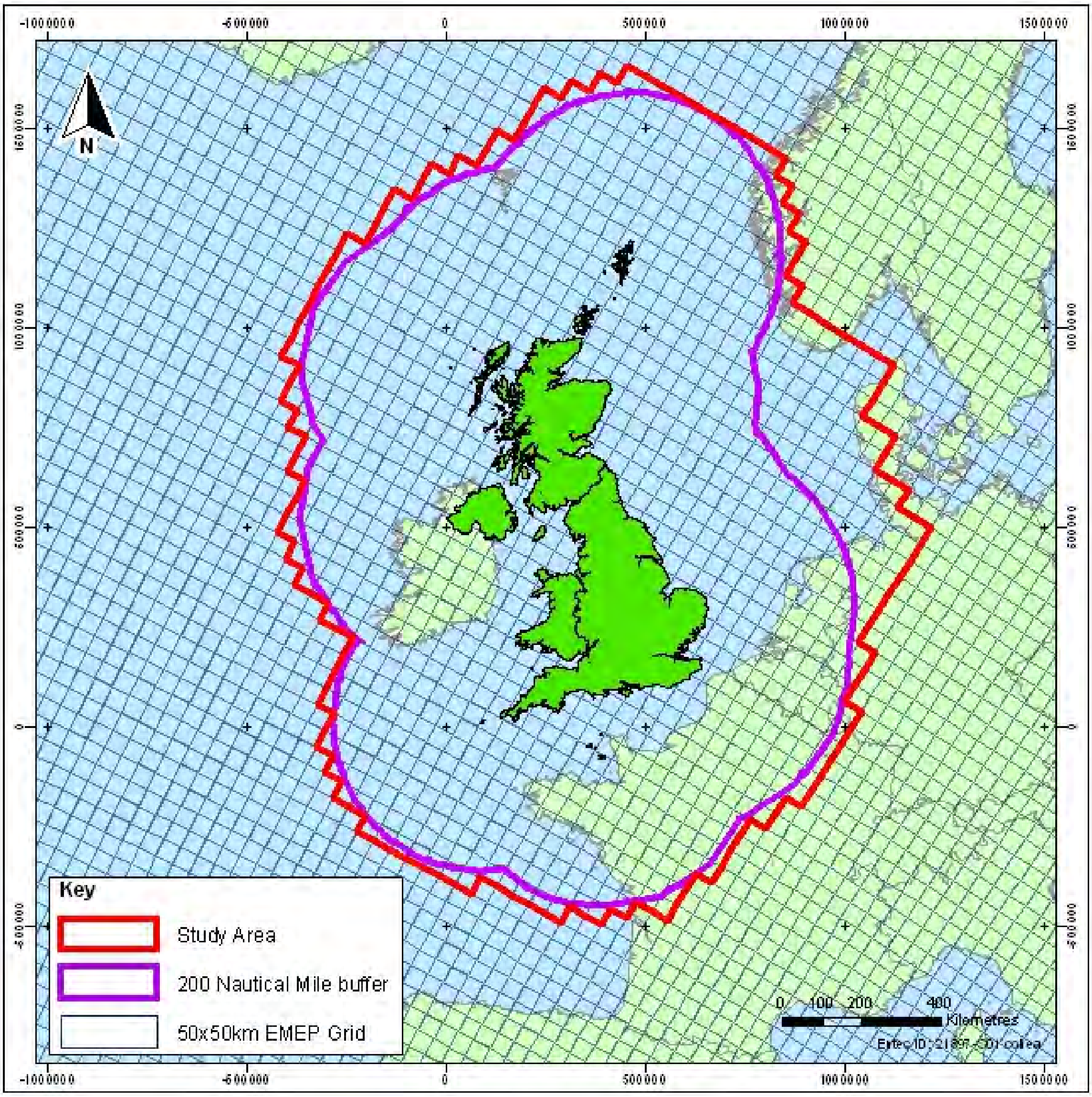
- Sulphur Dioxide (SO_2);
- Oxides of Nitrogen (NO_X);
- $PM_{2.5}$ and PM_{10} (derived as a fraction of Total PM);
- Non Methane Volatile Organic Compounds (derived as a fraction of HC); and
- Carbon Dioxide (CO_2).

[4] EMEP is a programme under the Convention on Long-range Transboundary Air Pollution.

The primary focus of the emission inventory was the 2007 baseline, although emission projections have been developed for 2010 and 2020. Emission projections were then updated to take into account the amendments to the MARPOL Annex VI regulations (described in Section 2).

The outputs of this study will be used to update the NAEI with regards to shipping emissions in UK waters. The requirements for inclusion of the ship emissions inventory in the NAEI and for the subsequent impact assessment modelling are important considerations in terms of the spatial resolution of the inventory. Therefore, the EMEP unified domain that has a spatial resolution defined by grid cells of a 50km by 50km has been used, although the resolution has been refined to grid cells of 5km by 5km.

Figure 1.1 UK Waters as defined in this study (200 nm buffer including additional area in North Sea)



1.4 Structure of this Report

This report is structured around the following main sections:

- Section 2 describes the policy background;
- Section 3 provides a general overview of the methodology employed to undertake this work;
- The following sections, i.e. Section 4 to Section 11, present the methodology in more detail, including key parameters used to undertake the work and assumptions employed to populate missing data. More specifically:
  - Section 4 covers ship movements and port callings, with the methodology adopted for addressing issues with incomplete coverage of movement records;
  - Section 5 presents additional work undertaken in 2009 to compare LMIU port arrival statistics with those produced by the DfT, with the aim of uplifting the emissions inventory to account for missing movements;
  - Section 6 describes vessel characteristics;
  - Section 7 describes engine characteristics;
  - Section 8 describes the development of emission factors for the year 2007 inventory;
  - Section 9 describes the approach to assess the implications of the MARPOL Annex VI amendments;
  - Section 10 describes vessel routings; and
  - Section 11 provides a general discussion regarding economic factors that affect growth in shipping and describes the assumptions used to project emissions in future years.
- Section 12 presents the emission and fuel consumption estimates from shipping in UK waters;
- Section 13 presents additional work undertaken in 2009 to back-cast emissions to 1990 and forecast emissions to 2009 for integration with the NAEI;
- Section 14 summarise the uncertainties associated with the emission estimates; and
- Section 15 presents the conclusions and recommendations.

2. Policy Background

Fuel combustion related emissions from ships can make a significant contribution to air pollution, as demonstrated by previous studies of emissions estimates for ship movements in Europe. In particular, they are major sources of SO_2 and NO_x, which lead to acidification and eutrophication as well as the formation of ground level ozone and particulate matter (PM).

Shipping is unlike industrial emission sources and domestic transportation since emissions are, for the most part, outside of UK control but impact on human health and the environment within the UK. As land-based emissions of SO_2, NO_x and PM are being reduced, those from shipping are expected to increase. At an EU-level, according to the Impact Assessment accompanying the Thematic Strategy on Air Pollution, unless further action is taken, emissions of SO_2 and NO_x from the maritime sector could surpass total emissions from land-based sources by 2020.[5] Not only may this negate improvements achieved within the UK, but a reduction of shipping emissions could be far more cost-effective than taking further action to reduce UK land-based emissions.

The European Commission is already committed to achieving significant reductions in land-based emissions of these pollutants, for example, through the directives on Large Combustion Plants (2001/80/EC) and National Emissions Ceilings (NEC) (2001/81/EC). To address the health and environmental impacts of ship emissions, in 2002 the European Commission adopted a strategy to reduce atmospheric emissions from seagoing ships. The strategy reports on the magnitude and impact of ship emissions in the EU and sets out a number of actions to reduce the contribution of shipping to acidification, ground-level ozone, eutrophication, health, climate change and ozone depletion.[6] The IMO is the UN body that has responsibility for addressing maritime emissions of these pollutants.

This chapter sets out the international policy context in Section 2.1, and the European policy context in Section 2.2.

2.1 International policy context

2.1.1 MARPOL Annex VI Regulations

The IMO Regulations for the Prevention of Air Pollution from Ships were adopted in the 1997 Protocol to MARPOL 73/78 and are included in Annex VI of the Convention, which entered into force in May 2005. MARPOL Annex VI sets limits on SO_X and NO_X emissions from ship exhausts. It included a global cap of 4.5% by mass on the sulphur content of fuel oil and also set provisions allowing for Sulphur Emission Control Areas

[5] http://ec.europa.eu/environment/air/cafe/pdf/ia_report_en050921_final.pdf

[6] http://ec.europa.eu/environment/air/transport.htm

(SO_X ECAs, 'SECAs') where either the sulphur content of fuel oil used on board ships must not exceed 1.5% m/m, or ships must fit technologies to achieve equivalent SO_X emissions. Limits on emissions of NO_X from diesel engines were also set. The Baltic Sea is designated as a SECA in the Protocol and the North Sea was adopted as a SECA in July 2005 (the North Sea SECA entered into force on 21st November 2006, to be fully implemented 12 months later, on 22nd November 2007).

2.1.2 Amendments to Annex VI and the NO_X Technical Code

In April 2008, the IMO's Marine Environment Protection Committee (MEPC) approved proposed amendments to the MARPOL Annex VI Regulations to reduce harmful emissions from ships. MEPC unanimously adopted the amendments to Annex VI and the NO_x Technical Code[7] when it met for its 58th session in October 2008.[8] These amendments set more stringent limits on SO_x and NO_x emissions from ship exhausts than the existing Annex VI.

The revised MARPOL Annex VI Regulations entered into force on 1st July 2010. Relevant key provisions include:

- A reduction in the global limit of sulphur content in fuel to 3.5% by mass (from the current 4.5%) effective from 1st January 2012; then to 0.5%, effective from 1st January 2020 subject to a feasibility review to be completed no later than 2018);
- A reduction in sulphur limits for fuels in SO_X ECAs to 1%, beginning on 1 July 2010 (from the current 1.5%); being further reduced to 0.1%, effective from 1st January 2015;
- As with the existing MARPOL Annex VI, the revised regulations allow for the use of suitable abatement equipment as an alternative to the fuel switching requirements described above on the basis that equivalent SO_X emissions are achieved on a continuous basis; and
- Tiered reductions in NO_x emissions from marine engines (with the most stringent controls on 'Tier III' engines, i.e. those installed on ships constructed on or after 1st January 2016, operating in ECAs).

These provisions are discussed in more detail in the relevant sections below.

Sulphur Oxides (SO_X) and Particulate Matter

The 2008 Annex VI revision stipulated time-limited sulphur content limits in Regulation 14, with the aim to reduce emissions of SO_X and particulate matter. Key provisions are presented in Box 2.1 below and the time-limited sulphur content limits are represented graphically in Figure 2.1.

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[7] The NO_X Technical Code was first adopted at the same time as the original Annex VI was added to MARPOL 73/78. The aim of the NO_X Technical Code was to establish mandatory procedures for the testing, survey and certification of marine diesel engines, in order to enable engine manufacturers, ship-owners and Administrations to ensure that all applicable marine diesel engines comply with the regulation.

[8] http://www.imo.org/Newsroom/mainframe.asp?topic_id=1709&doc_id=10262

Box 2.1 Revised MARPOL Annex VI - Regulation 14: Sulphur Oxides (SO_X) and Particulate Matter

General Requirements

1. The sulphur content of any fuel oil used on board ships shall not exceed the following limits:
   1 4.50% m/m prior to 1 January 2012;
   2 3.50% m/m on and after 1 January 2012; and
   3 0.50% m/m on and after 1 January 2020.

Requirements within Emission Control Areas

3. For the purpose of this regulation, Emission Control Areas shall include:
   1 the Baltic Sea area as defined in regulation 1.11.2 of Annex I, the North Sea as defined in regulation 5(1)(f) of Annex V; and
   2 any other sea area, including port areas, designated by the Organization in accordance with criteria and procedures set forth in appendix III to this Annex.

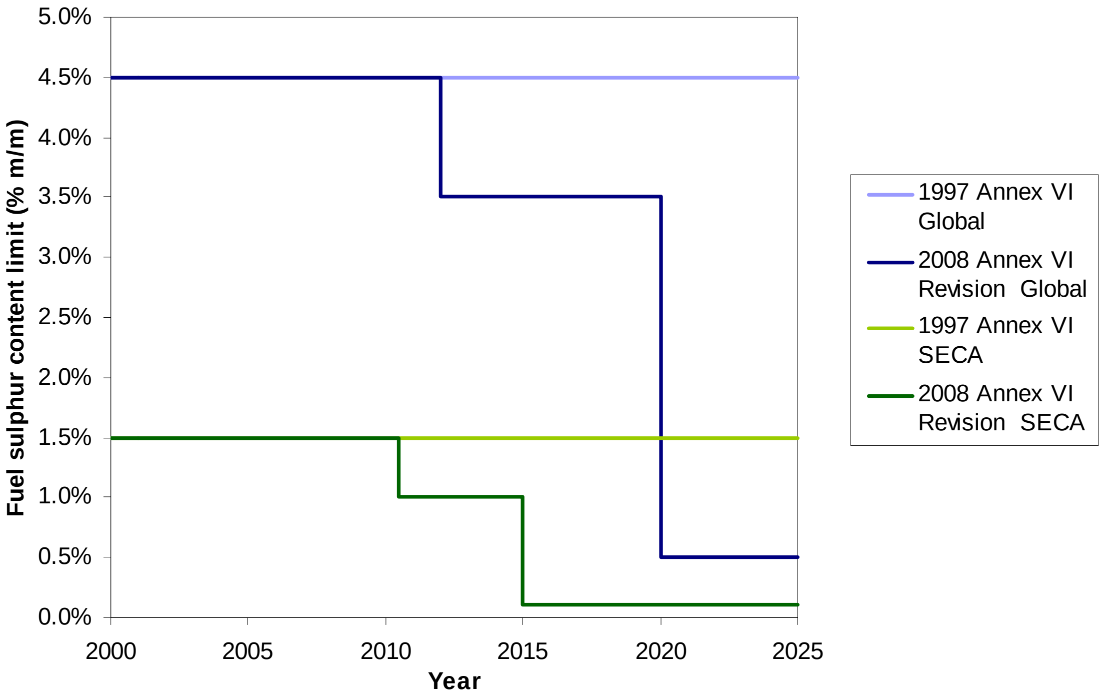
4. While ships are operating within an Emission Control Area, the sulphur content of fuel oil used on board ships shall not exceed the following limits:
   1 1.50% m/m prior to 1 July 2010;
   2 1.00% m/m on and after 1 July 2010; and
   3 0.10% m/m on and after 1 January 2015.

Review Provision

8. A review of the standard set forth in subparagraph 1.3 of this regulation shall be completed by 2018 to determine the availability of fuel oil to comply with the fuel oil standard set forth in that paragraph (…).

10. The Parties, based on the information developed by the group of experts, may decide whether it is possible for ships to comply with the date in paragraph 1.3 of this regulation. If a decision is taken that it is not possible for ships to comply, then the standard in that subparagraph shall become effective on 1 January 2025.

Figure 2.1 Revised MARPOL Annex VI - Fuel Sulphur Limits



The revised Annex VI will also allow for ECAs to be designated to limit emissions of SO_X, PM or NO_X, or all three pollutant species, from ships subject to a proposal from a Party or Parties to the Annex which would be considered for adoption by the IMO if supported by a demonstrated need to prevent, reduce and control one or all three of those types of emissions from ships.

The revised Annex VI Regulation 14 does not make any reference to the alternative of exhaust gas cleaning systems, as was the case in the previous Regulation 14. Instead, this provision for using end of pipe exhaust cleaning is given in Regulation 4 (Equivalents); see Box 2.2.

Box 2.2 Revised MARPOL Annex VI - Regulation 4: Equivalents

1. The Administration of a Party may allow any fitting, material, appliance or apparatus to be fitted in a ship or other procedures, alternative fuel oils, or compliance methods used as an alternative to that required by this Annex if such fitting, material, appliance or apparatus or other procedures, alternative fuel oils, or compliance methods are at least as effective in terms of emissions reductions as that required by this Annex, including any of the standards set forth in regulations 13 and 14.

Nitrogen Oxides (NO_X)

The IMO NO_X emission standards are referred to as Tier I, II and III standards. The Tier I standards were defined in the 1997 version of Annex VI, while the Tier II / III standards and a standard for ships constructed before 2000 (for the purposes of this note this is referred to as 'Tier 0') were introduced by the Annex VI amendments adopted in 2008 (Regulation 13), as follows:

- 'Tier 0' (Revised Annex VI, came into force July 2010) – applies to engines with power output >5,000kW and a per cylinder displacement >=90 litres installed on a ship constructed between 1/1/1990 and 31/12/1999, subject to availability of approved engine upgrade kit;
- Tier I (1997 Protocol, in force[9]) – applies to each engine greater than 130 kW installed on ships constructed between 1/1/2000 and 31/12/2010, or which undergo a major conversion between these dates;
- Tier II (Revised Annex VI, came into force July 2010) – applies to each engine greater than 130 kW installed on ships constructed between 1/1/2011 and 31/12/2015, or which undergo a major conversion between these dates; and
- Tier III (Revised Annex VI, came into force July 2010) – applies to each engine greater than 130 kW installed on ships constructed on or after 1/1/2016, or which undergo a major conversion on or after this date. Only applies to ships operating in an ECA. Does not apply to craft of length <24m designed and used for recreational purposes.

[9] The 'in force' refers to the obligation to meet Tier I for new engines installed after 1/1/2000. The Revised Annex VI introduces new Tier II which would place a limit on Tier I applicability of 31/12/2010.

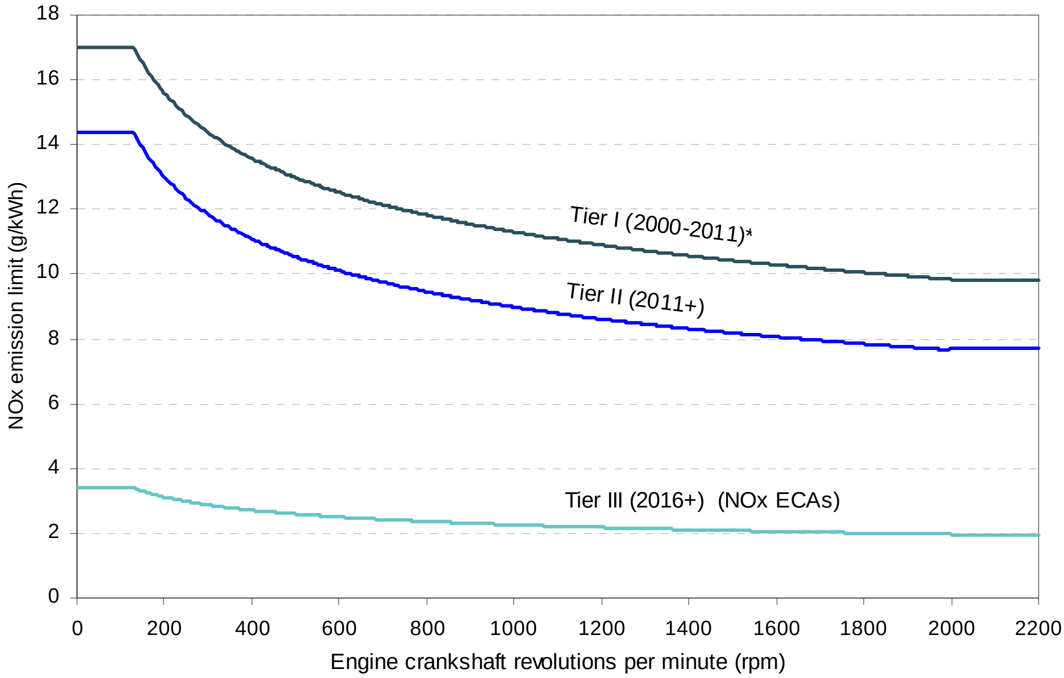
The NO_X emission limits are set for diesel engines depending on the rated engine speed (crankshaft revolutions per minute (rpm)), as shown in Table 2.1 and presented graphically in Figure 2.2. 'Tier 0', Tier I and Tier II limits are global, while the Tier III standards apply only in NO_X ECAs (there are currently no NO_X ECAs designated in European waters).

Table 2.1 Revised MARPOL Annex VI - NO_X Emission Limits (n = rated engine speed, rpm) for New Engines, and, for Tiers I, II and III, for Engines Undergoing Major Conversions

Tier	Date	NO_X emission limit, g/kWh		
		n < 130	130 ≤ n < 2000	n ≥ 2000
'Tier 0'	1990-2000	17.0	$45 \times n^{-0.2}$	9.8
Tier I	2000 - 2011	17.0	$45 \times n^{-0.2}$	9.8
Tier II	2011+	14.4	$44 \times n^{-0.23}$	7.7
Tier III	2016+ (Note 1)	3.4	$9 \times n^{-0.2}$	1.96

Note 1: In NO_X ECAs (Tier II standards apply outside ECAs).

Figure 2.2 Revised MARPOL Annex VI - NO_X Emission Limits



* Also applicable to certain engines 1990-2000 'Tier 0'.

2.1.3 Greenhouse gases

In July 2009 the MEPC published the Second IMO GHG Study (IMO, 2009). IMO (2009) assessed the GHGs emitted by ships, and put into context of total global anthropogenic CO_2 emissions the GHG emissions from international shipping. IMO (2009) identified the potential reductions of GHG emissions that could be achieved through technical and operational measures. In March 2010 the MEPC began consideration of making the technical and operational measures mandatory for all ships irrespective of flag and ownership; this is expected to be completed by July 2011.[10]

2.2 Sulphur Content of Marine Fuels Directive 2005/33/EC

One result of the European Commission's strategy on emission reductions from ships was the Sulphur Content of Marine Fuels Directive (SCMFD) (European Parliament and Council, 2005), which came into force on 6th July 2005, amending the existing Sulphur Content of Liquid Fuels Directive (SCLFD) (European Council, 1999). The SCMFD is linked to MARPOL Annex VI, as MARPOL Annex VI was used as the determinant of the maximum permissible sulphur content of marine fuels used in SECAs. The main elements of the Directive include:

i. A 1.5% sulphur limit for fuels used by all ships in the SECAs of the Baltic Sea, from 11th August 2006, and the North Sea and English Channel, from either 11th August 2007 or 12 months after the entry into force of the International Maritime Organisation designation, whichever is the earlier;

ii. A 1.5% sulphur limit for fuels used by passenger vessels on regular services between EU ports, from 11th August 2006; and

iii. A 0.1% sulphur limit[11] on fuel used by inland waterway vessels and by seagoing ships at berth in EU ports, from 1st January 2010.

As an alternative to the use of low sulphur marine fuels to comply with Articles 4a and 4b of the Directive, Member States can '*(…) allow ships to use an approved emission abatement technology, provided that these ships continuously achieve emission reductions which are at least equivalent to those which would be achieved through the limits on sulphur in fuel specified in this Directive*' (Article 4c, paragraph 4).

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[10] http://www.imo.org/OurWork/Environment/PollutionPrevention/AirPollution/Pages/GHG-Emissions.aspx

[11] The 0.1% sulphur limit on fuels used by inland waterway vessels and ships at berth does not apply to:

a) Ships due to be at berth for less than two hours according to published timetables.

b) Inland waterway vessels that carry a certificate proving conformity with the International Convention for the Safety of Life at Sea, 1974, as amended, while those vessels are at sea.

c) Ships which switch off all engines and use shoreside electricity while at berth in ports.

In addition to the requirements described above, the European Parliament negotiated a stronger review of the Directive in 2008 requiring the Commission to consider a second phase limit of 0.5% (dependent upon progress at the IMO). The Commission has brought forward its review of the Directive, and is (as of November 2010) currently consulting on revisions to the Directive, and is foreseeing initial proposals for revising the Directive to be published in Spring 2011. Such proposals are expected to consider the designation of additional ECAs or alternative or complementary measures.

Creating the environment for business

3. Overview of Inventory Methodology

This section outlines the overall methodology employed in the development of the emissions inventory.

The adopted approach enables detailed data on ship movements and vessel engine characteristics to be combined with emission factors to quantify atmospheric emissions from shipping sources in UK waters in accordance with the project objectives.

The approach is consistent with the methodology for quantifying ship emissions in the EMEP/EEA (2009) air pollutant emission inventory guidebook and relies on the following information, that largely dictate the emissions from a vessel:

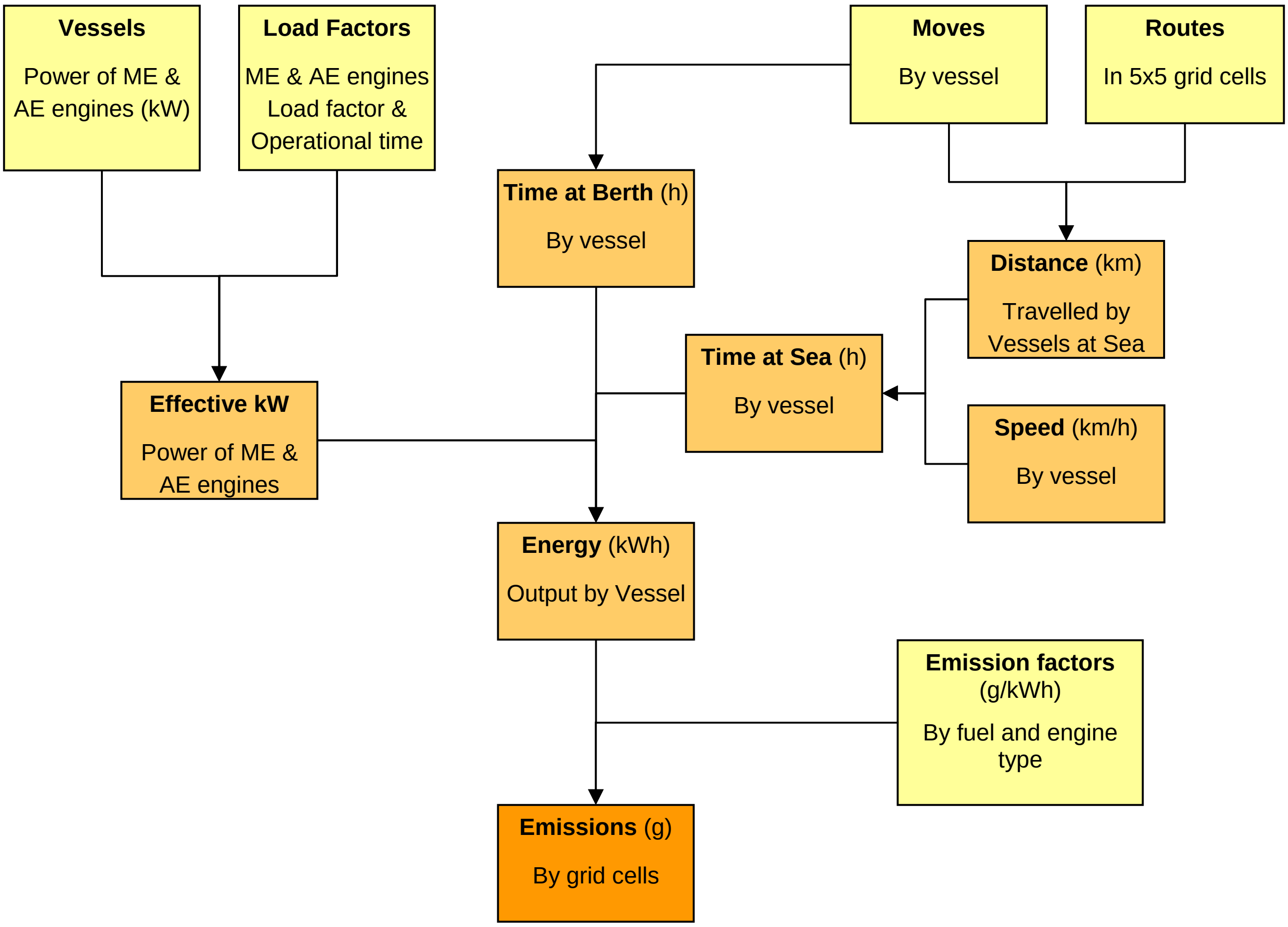
- Installed engine power;
- Type of fuel consumed;
- Vessel speed and the distance travelled (or the time spent travelling at sea);
- Time spent in port; and
- Installed emission abatement technologies.

Emissions and fuel consumption in each 5km x 5km grid cell have been calculated as the sum of ‘at sea’ emissions, ‘at berth’ emissions and ‘manoeuvring’ emissions of each vessel. Figure 3.1 presents a flow chart showing how the available data, including vessel movements, routing information, vessel characteristics, load factors and emission factors, have been combined to calculate emissions and distribute these in the appropriate grid cells within the study area.

Sections 4 to 11 present the key parameters and methodology in more detail, including assumptions and approaches to populate missing data. It should be noted that this study has a UK focus and therefore, in some cases assumptions employed are likely to be more representative for the UK than for other countries within the study area.

Section 3 presents the initial work undertaken that aimed to quantify emissions from vessel movements that were not included in the database. Section 4 presents the findings of an additional task that was undertaken following the initial development of the emissions inventory that compares vessel movements data from Lloyd’s MIU and those from the DfT; the output of these tasks was an approach, that was subsequently applied, to uplift the emissions inventory to account for missing movements.

Figure 3.1 Summary of Methodology for Estimating Emissions



3.1 At Sea Emissions

For each ship movement, without the adjustments described in Section 5, the emissions in a certain grid cell have been calculated as follows:

Formula 1

$$E_{At\ sea}(g) = \frac{\mathrm{D\,(km)}}{\mathrm{v\,(km/h)}} \cdot \left[\left(\mathrm{ME(kW)} \cdot \mathrm{LF_{ME}}\ (\%) \right) \cdot \mathrm{EF\,(g/kWh)} + \left(\mathrm{AE(kW)} \cdot \mathrm{LF_{AE}}\ (\%) \right) \cdot \mathrm{EF\,(g/kWh)} \right]$$

Where:

D: Distance a ship travels in, estimated based on port of departure/arrival and assumed route.

V: Average speed of a ship.

ME: Installed main engine power.

LF_{ME}: Average load factor of main engine at sea.

AE: Installed auxiliary engine power.

LF_{AE}: Average load factor of auxiliary engine at sea.

EF: Emission factors assigned to each vessel for ‘at sea’ depending on each fuel type and engine speed.

3.2 Port Emissions

For each ship calling in a port, without the adjustments described in Section 5, the emissions for at berth and manoeuvring activities have been calculated as follows:

Formula 2

$$E_{\text{in port}}(g) = \text{T(h)} \cdot \left[\left(\text{ME(kW)} \cdot \text{LF}_{\text{ME}}\,(\%)\right) \cdot \text{EF}\,(\text{g/kWh}) + \left(\text{AE(kW)} \cdot \text{LF}_{\text{AE}}\,(\%)\right) \cdot \text{EF}\,(\text{g/kWh})\right]$$

Where:

T: Average time spent at berth or manoeuvring per calling for a certain ship category.

ME: Installed main engine power.

LF_{ME}: Average load factor of main engine at berth/manoeuvring.

AE: Installed auxiliary engine power.

LF_{AE}: Average load factor of auxiliary engine at berth/manoeuvring.

EF: Emission factors assigned to each vessel for at berth/manoeuvring depending on each fuel type and engine speed.

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4. Ship Movements and Port Callings

4.1 Introduction

The primary source of ship movements data was the Lloyds Marine Intelligence Unit (Lloyd's MIU) database. This is the only commercial database of all ship movements world-wide with over 3.6 million movements recorded annually.

Lloyd's MIU vessel movements for the full 2007 calendar year have been used for this study. The full 2007 data have been used to ensure that the inventory is as contemporary as possible and that issues relating to seasonal movements, which may be significant when using less than one full year of data, are taken into account. It should be noted that the Lloyd's MIU dataset used for this study has been split between:

- Transits (i.e. any movement within the study area, including passing vessels that do not call at any port in the UK or any other country within the study area) that have been used to estimate emissions 'at sea'; and
- Port callings (i.e. only the transits that call at a port within the study area) that have been used to estimate emissions 'at berth' and 'manoeuvring'.

These datasets are described separately in this section, along with a detailed analysis of the dataset and the vessel movement records in order to identify the extent of its coverage and the potential emissions from vessels not included. Section 5 develops this discussion further and presents a more detailed analysis of missing port calling records and establishes a methodology for uplifting emissions estimates to account for these missing movements. It is this uplifted inventory that forms the final output of this study and the inputs to the NAEI.

4.1.1 Movement coverage

Lloyd's MIU has extracted all transits by commercial vessels sailing within the study area during the year 2007. More specifically, Lloyd's MIU extracted transits:

- Between ports in the area;
- From ports outside the area to ports inside the area;
- From ports inside the area to ports outside the area; and
- Through the area without calling at a port in the area.

Lloyd's MIU does not normally capture individual arrivals or departures of vessels which call at a port more than once a day, for example, cross channel passenger vessels. The Lloyd's MIU movements database provides basic entries concerning passenger vessel port callings and is therefore unlikely to include multiple arrivals/departures by one passenger vessel in a 24-hour period at one port. Clearly, for some UK ports a higher proportion of ship traffic, particularly in the summer, will be passenger vessels. To ensure more complete data capture of vessel movements Lloyd's MIU has also provided Automatic Identification System (AIS)[12] data for 2007 that have been used to populate the daily movements of vessels operating on short, frequent transits, such as cross channel passenger vessels.

AIS is a safety device that automatically transmits information – including the ship's identity, type, position, course, speed, navigational status (for example 'at anchor' or 'moving with engines running') and other safety-related information – to appropriately equipped shore stations, other ships and aircraft. The International Convention for the Safety of Life at Sea (SOLAS) requires an AIS transponder to be fitted aboard all ships of 300 gross tonnage (GT) and upwards engaged on international voyages, cargo ships of 500 GT and upwards not engaged on international voyages and all passenger ships irrespective of size. The requirement became effective for all ships as of 31 December 2004. Ships fitted with AIS are to maintain AIS in operation at all times except where international agreements, rules or standards provide for the protection of navigational information.

4.1.2 Vessel coverage

Lloyd's MIU "*aims to cover all merchant vessels over 100 GT engaged in international trade*", although it is expected that in many cases domestically trading vessels are also captured. The main exceptions to this, as far as UK waters are concerned, are vessels employed in supply, dredging or dumping at sea and regular small domestic ferries crossing estuaries over a distance of less than 2 kilometres. Lloyd's MIU does not normally provide coverage of yachts and small fishing vessels.[13] The majority of military movements are also excluded.

4.2 Movement Numbers and Comparison with other Data Sources

In order to corroborate the movement data used in this study, year 2007 port callings at UK ports have been extracted from the Lloyd's MIU database and compared to data held by the DfT.

The statistics from DfT are derived from primary data supplied by Lloyd's MIU in combination with estimates from MDS-Transmodal for the frequent sailings missing from LMIU data (DfT, 2008). DfT then publish the resulting annual totals by port and ship type in the Maritime Statistics report. The arrivals recorded relate to movements of all sea-going vessels of 100 GT and over, involved in the movement of goods or passengers. The following vessels are excluded:

[12] AIS (Automatic Identification System) provides the means for ships to electronically exchange ship data including: identification, position, course, and speed, with other nearby ships and Vessel Traffic Services stations.

[13] Personal communication with Lloyd's MIU on 22/05/08

- Vessels arriving at safe anchorages (e.g. because of bad weather);
- Vessels moving within a port or an estuary;
- Tugs and other vessels employed within the limit of the port or estuary;
- Other dredgers, supply and support ships, and research vessels;
- Fishing vessels, pleasure yachts; and
- Vessels entering a port to land sick or injured crew members.

Table 4.1 includes a comparison of the DfT published statistics and the port arrivals data used in this study, in terms of the UK ports with the highest number of annual port callings.

For the purposes of comparison with DfT data, two sets of figures are presented from this study:

- Number of port callings of all vessels; and
- Number of port callings of all vessels except dredgers, tugs, research vessels and fishing vessels.

Table 4.1 Comparison of Annual Ship Arrivals at UK Ports (Number of Vessels in 2007)

Port	DfT (Number of ship arrivals)	LMIU (No. of port callings, all vessels)	LMIU (No. of port callings, all vessels except dredgers, tugs, research and fishing vessels)
Dover	23,003	9,943	9,943
London[1]	9,680	11,100	9,664
Grimsby and Immingham[2]	8,302	8,479	8,439
Belfast	6,058	2,630	2,628
Liverpool[3]	6,758	5,118	5,091
Southampton[4]	5,320	6,777	5,975
Tees and Hartlepool[5]	5,845	5,508	5,412
Felixstowe	4,025	4,053	4,053
Larne	4,218	1,718	1,718
Forth[6]	3,430	3,587	3,564
All above ports	**76,639**	**58,913**	**56,487**
Selected others			
Aberdeen	1,584	7,344	7,220
Hull[7]	3,034	3,237	3,142
All ports of United Kingdom	**139,662**	**123,383**	**118,127**

[1] For comparison with the DfT reporting of the port of London, the port callings at London, Canvey Island, Cliffe, Coryton, Shell Haven, Southend and Tilbury have been combined The DfT reporting port includes 15 further ports that have not been identified in the Lloyd's MIU database.

[2] For comparison with the DfT reporting of the port of Grimsby and Immingham, the port callings at Grimsby, Immingham, North Killingholme, South Killingholme and Killingholme have been combined.

[3] For comparison with the DfT reporting of the port of Liverpool, the port callings at Liverpool and Bromborough have been combined. The DfT reporting port includes 3 more ports that have not been identified in the Lloyd's MIU database.

[4] For comparison with the DfT reporting of the port of Southampton, the port callings at Southampton, Fawley and Hamble have been combined.

[5] For comparison with the DfT reporting of the port of Tees and Hartlepool, the port callings at Tees, Hartlepool and Tees Bay have been combined. The DfT reporting port includes 5 more ports that have not been identified in the Lloyd's MIU database.

[6] For comparison with the DfT reporting of the port of Forth, the port callings at Braefoot Bay, Burntisland, Grangemouth, Hound Point, Leith, Methil and Rosyth have been combined. The DfT reporting port includes 4 more ports that have not been identified in the Lloyd's MIU database.

[7] For comparison with the DfT reporting of the port of Hull, the port callings at Hull and Salt End have been combined.

As discussed above, the two data sources are not expected to be in complete agreement as the DfT Maritime Statistics are supplemented with additional data. Therefore, it is acceptable that the total number of arrivals reported by DfT is higher than that reported by Lloyd's MIU (the Lloyd's MIU data, when dredgers, tugs, research and fishing vessels are excluded represent approximately 85% of the DfT Maritime Statistics data).

The table above suggests that in most cases, on a port to port basis, the Lloyd's MIU database is in reasonable agreement with the DfT Maritime statistics. However, the Lloyd's MIU dataset underestimates port arrivals, especially for at the ports of Dover, Belfast and Larne. Lloyd's MIU has highlighted that AIS data have been provided to supplement the movements data where AIS data offered better coverage for an individual passenger vessel. However, cargo vessels are only required to install AIS if they are larger than 300GT, so vessels below this size have not been captured by AIS.[14] It is therefore likely that discrepancies in total numbers for these ports are due to movements of vessels smaller than 300 GT with multiple callings per day.

There are also instances in which the DfT port arrivals are significantly lower than the Lloyd's MIU database, for example for the port of Aberdeen. For this particular instance, the differences are primarily due to supply and support vessels.

As part of the comparison between the DfT Maritime Statistics and the Lloyd's MIU database, the port of Stranraer has been identified as only having one port calling in the Lloyd's MIU data, whilst the DfT Maritime Statistics report 2,219 port arrivals. Lloyd's MIU has stated that they do not receive conventional movement reports from this port, potentially because the majority are domestic moves within the UK, and although this port is now covered by AIS it was not in 2007.[14] Therefore, it is likely that there are more ports like Stranraer, that have not been included in the main analysis for compiling the shipping emission inventory, thus leading to under-estimates in total emission estimates.

4.3 Analysis of Ship Movements Data

As described above, Lloyd's MIU has provided data on transits that include any movement within the study area. These have been used to estimate emissions 'at sea'. However, it is expected that Lloyd's MIU does not capture all transits within the study area and may therefore exclude transits of vessels smaller than 100 GT, yachts and small fishing vessels, or multiple transits of the same vessel on the same day. This is likely to be the case for vessels other than passenger vessels, where AIS data have not been used to supplement the standard movements database. In addition, in some cases, data reported cannot be included in the main analysis as these are considered problematic. Movements that would fall under this category would include transits with an unknown destination.

This section summarises the main findings from analysing the movement data provided by Lloyd's MIU and the main assumptions that have been used to estimate emissions from missing or problematic data entries.

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[14] Personal communication with Lloyd's MIU on 02/09/08

4.3.1 Consideration of Vessels <500 Tonnes, Fishing Vessels and Military Movements

Fishing vessels generally operate from one port and if the port callings are recorded in the Lloyd's MIU database they may be logged as a departure from and arrival to the same port. This leads to uncertainty concerning the route taken by the vessel and the sea area that it has been operating within.

Movements relating to Naval and other military activity are generally unavailable as these data are usually classified. For operational reasons the vessels may spend prolonged periods at sea and as with the fishing vessels, there is uncertainty concerning the route taken by the vessel and the sea area that it has been operating within.

As described above, the Lloyd's MIU database aims to include detailed movements records for merchant vessels above 100 GT, engaged in international trade, and does not normally provide coverage of yachts and small fishing vessels. Table 4.2 below, presents the number of movements and the number of vessels, subdivided by vessel size.

Table 4.2 Number of Movements Recorded and Number of Vessels of Different Vessel Sizes

Vessel Category	> 500 GT		100 – 500 GT		≤ 100 GT	
	Number of vessels	Number of Moves	Number of vessels	Number of Moves	Number of vessels	Number of Moves
Bulk Carrier	2461	19,660	-	-	-	-
Container Ship	1288	52,307	-	-	-	-
Fishing	396	1,160	357	791	26	15
General Cargo	3539	120,408	109	2215	7	15
Passenger	293	54,308	65	122	13	-
Ro – Ro cargo	757	55,401	11	16	-	-
Tanker	2802	73,588	27	724	1	-
Others	1152	14,209	712	3576	138	409
TOTAL	**12,688**	**391,041**	**1,281**	**7,444**	**185**	**439**

In the Lloyd's MIU database for the study area the total number of moves that can be used in the analysis (i.e. departure and destination port are both populated and are not the same port) is 399,070 and the total number of vessels is 14,255.

From the table above it can be concluded that although there are approximately 1% of vessels less than 100 GT, this represents about 0.1% of total movements recorded. Furthermore, there are approximately 10% of vessels with between 100 GT and 500 GT that represent approximately 2% of total movements recorded. Therefore, it is considered likely that port calling data of smaller vessels and fishing vessels are not well covered by the movements database.

There is little published information available concerning the contribution that smaller vessels make to total fuel consumption or overall emissions. Some research has indicated that the fuel consumption for vessels in the range 100-500 GT is estimated at <8% of the total fuel consumption (Endresen, 2003).

A further study on ships emissions (NTUA, 2008) has considered the contribution of vessels smaller than 400 GT to total CO_2 emission estimates and bunker fuel consumption in 2007. The study concluded that "*the contribution of the small vessel group to total emissions is negligible (order of 1%). If alternative assumptions are made, it is speculated that the percentage will not change that much*".

Data provided by DfT[15], more specifically the returns from ports on vessel traffic, indicate that vessels with a size <500 GT are responsible for 2% of total transits in 2007. The data are thought to cover all seagoing vessels involved in the movement of goods or passengers, excluding those under 100 GT. Therefore, the relevant contribution of vessels between 100-500 GT to total movements is in agreement with the statistics obtained by the Lloyd's MIU database.

As the Lloyd's MIU database has movements recorded for smaller vessels, fishing vessels and naval vessels, although considered limited, a top-down estimate of emissions from these vessels may result in double counting of emissions. Due to limited published information, the approach adopted for estimating emissions from these sources was to assume that the fuel consumption for vessels in the range 100-500 GT was approximately 5% of the total fuel consumption (as Endresen, 2003 indicates that this is <8% and it has been assumed that the main emission estimates include to some extent movements from smaller vessels, fishing vessels and naval vessels). Therefore, in Section 12.6 emission estimates for smaller vessels, fishing vessels and naval vessels have been approximated. It is important to note that these estimates are highly uncertain.

4.3.2 Consideration of problematic/miscellaneous movements data

The supplied Lloyd's MIU database includes a number of movements which need to be considered separately and in some cases cannot be considered in the gridded inventory. This section presents these types of movements and explains the methodologies and assumptions adopted to estimate total emissions from these movements, which are presented in Section 12.6. The movements considered are:

- Movements from and to the same port;
- Movements to places without geographic coordinates:
  - Where places are known ports for which coordinates can be sourced;
  - Where places are generic places; and

[15] Personal communication with DfT on 17/10/08

- Where movements have unknown destinations.

Movements from and to the same port

The movements data provided by Lloyd's MIU include movements by vessels that start and end at the same place (such movements include movements extracted from the AIS network, when the port of destination/arrival is not covered by the AIS network).[16] For these movements, the route taken by the vessel is unknown.

In order to show the significance of this type of movement, Table 4.3 below lists the ten ports with the highest number of movements to and from the same port; these ten ports represent 50% of the movements. The number of ports with movements to and from the same port is 266; the number of movements this represents is 35,851.

Table 4.3 Top Ten Ports in Lloyd's Database with most Number of Movements which Start and End at the Port (i.e. Movements with Unknown Routes)

Port	Number of movements with same from and to port	Average estimated duration of movement (hours)
Aberdeen	**3257**	**17**
Bergen	3186	269
Den Helder	2729	85
Dublin	1689	13
Dover	**1619**	**7**
Rotterdam	1310	112
Larne	**1183**	**14**
Busum	960	47
London	**924**	**31**
Cherbourg	924	25
…	…	…
266 Ports	**Total movements = 35,851**	

A modified methodology has been developed to estimate the total emissions from movements originating and arriving at the same port. This estimate has not been assigned geographically because the routes taken by each vessel are unknown. The methodology is similar to that presented in Section 3, but the distance/speed component of Formula 1 is replaced with the time taken, such that the following formula is used:

[16] Personal communication with Lloyd's MIU on 02/09/08

Formula 3

$$E_{unknown\ route\ at\ sea}(g) = \mathrm{t\ (h)} \cdot \left[\mathrm{ME(kW)} \cdot \mathrm{LF_{ME}}(\%) \cdot \mathrm{EF(g/kWh)} + \mathrm{AE(kW)} \cdot \mathrm{LF_{AE}}(\%) \cdot \mathrm{EF(g/kWh)}\right]$$

Where:

- t: Duration of movement (in hours).
- ME: Installed main engine power.
- LF_{ME}: Average load factor of main engine at sea.
- AE: Installed auxiliary engine power.
- LF_{AE}: Average load factor of auxiliary engine at sea.
- EF: Emission factors assigned to each vessel for ‘at sea’ depending on each fuel type and engine speed.

The Lloyd’s database has provided some fields of data which allow the duration of vessel movements to be derived. The fields of data used for this purpose include:

- The date (100% of records populated) and time (86.5% coverage) the vessel previously arrived in the port from which the movement departs;
- The date (100% coverage) and time (82.0% coverage) the vessel sails from the port; and
- The date (100% coverage) when the vessel arrives at its destination.

The time when the vessel arrives at the destination has been in-filled according to the following order of preference:

i. If the vessel movement is immediately prior to a subsequent movement for which the field ‘time the vessel previously arrived in the port’ *is* populated, this time is assumed as the arrival time;

ii. If the date the vessel sails from the port and the date the vessel arrives at its destination are the same, *and* the time the vessel sails from the port is populated, then the time of arrival is set as half way between the time the vessel sails from the port and midnight; and

iii. For movements where the date the vessel sails from the port and date the vessel arrives at its destination are not the same, the time of arrival is set as midday.

Combining these assumptions populates 87.7% of the 35,851 movements with arrival times, resulting in 82.1% of the movements having both departure time and arrival time populated.

The trip duration is automatically calculated for these 82.1% of movements from the time difference between the sailed date and time, and the arrival date and time.

Of the remaining 17.9% of movements:

- 5.7% have arrival time populated, but sailed time not populated. For these movements, the trip duration is estimated by assuming the sailed time is half way between midnight and the arrival time; and

- The remaining 12.3% have neither departure time nor sailed time populated. For these movements, if the arrival date is the same as the departure date, the trip duration is assumed to be 12 hours. If the movement arrives on a different day (after) it departs, the trip duration is assumed to be the number of days difference between the two dates (i.e. not plus additional hours).

For those moves without populated departure and arrival times, because the dates of departure and arrival are 100% populated, the uncertainty in trip duration is only significant for movements lasting one day or less.

141 movements (0.39% of 35,851 movements) are listed by Lloyd's MIU as having either:

- The arrival time before the departure time (if departure and arrival are on the same date); or

- As having the arrival date before the departure date.

These movements have not been excluded from this analysis. Instead, their trip durations have been assumed to be 12 hours in case (i), or in case (ii) the median trip duration (26.25 hours).

Movements to ports without geographic coordinates

2.2% of all movements in the Lloyd's MIU movements database are to or from places listed in the database without geographic coordinates. These places fall into three categories:

i. Known ports without coordinates, for which coordinates can be found (0.85%);

ii. Generic places, e.g. 'Continental Shelf', or 'Scotland' (1.14%); and

iii. Unknown places – i.e. the movement record has a null destination field (0.25%).

Known ports without coordinates, for which coordinates can be found

For the first category, where ports without coordinates are outside the study area, an entry/exit point to the study area has been assigned based on the country where the ports are located. Therefore, these ports are included in the main analysis, and it is only necessary to consider those ports without coordinates that are located in countries which lie either close to the study area, or partially or entirely within the study area. After excluding known ports outside the study area, the number of ports which need to be considered was 76, which comprise 3,758 movements. The ten ports with the highest number of movements are shown in Table 4.4 below.

Table 4.4 The Number of Movements to & from Ports that are Missing Coordinates in Countries within the Study Area

Place	Total number of movements from or to place
Shannon Estuary	1348
Halling	223
Tor Bay	186
Ursfjord	167
Aasgard Field	156
Holy Loch	149
Reydharfjordur	146
Blacktoft Anch.	119
Schiehallion Field	108
Faroes	98
…	…
Total number: 76	**Sum: 3,758**

A literature search[17] was conducted to geocode ports that were missing coordinates in countries either partially or entirely in the study area. This search was prioritised on ports that had ten or more movements from or to them; this search geocoded 39 ports. After this search, 96% of the movements had been geocoded; i.e. 118 movements from or to 37 ports are not included in the gridded inventory due to time constraints of identifying their coordinates.

For these 118 movements the same methodology as assumed by Formula 3 (page 25) was adopted. Thus the trip duration (in hours) for each movement was either calculated (if for departure and arrival, both the date and time fields were populated) or estimated (if only departure and arrival dates were populated). The assumptions adopted for this were:

- If the date the vessel sails from the port and the date the vessel arrives at its destination were the same, *and* the time the vessel sails from the port were populated, then the time of arrival was set as half way between the time the vessel sails from the port and midnight;

- For vessel movements arriving the same day they depart, but for which departure and arrival times were missing, the trip duration was assumed to be 12 hours;

- For vessel movements arriving on a day after the day they depart, and for which departure and arrival times were missing, the trip duration was estimated from the number of whole days sailing; and

[17] Sources included Reeds Nautical Almanac 2008 (publ. Adlard Coles Nautical), worldportsource.com and other internet resources.

- A fraction of movements (8 of 118) were listed by Lloyd's MIU as having the arrival date before the departure date. For these movements the trip durations have been assumed to be the median trip duration (12 hours) for all those movements with populated departure and arrival times is assumed.

Generic places

For the second category, generic places were included in Lloyd's database if the precise destination of the vessel was unknown. For those generic places entirely outside the study area, it was not necessary to consider them further because they would be subsequently assigned to entry points of the study area. It was only necessary to consider them if they were entirely or partially within the study area (or close to it, if that would affect the assignment of the entry point into the study area).

Table 4.5 lists the 18 generic places used in the Lloyd's MIU movements database, and the number of movements from, to, plus from and to these places. The comments column has been included to indicate the results of the analysis of vessel movements to and from the specified place, which was undertaken for places with ten or more movements.

Table 4.5 Generic Places used as the from or to Port in Lloyd's Movements Database (Places with 10 or Fewer Movements Not Detailed)

Place	Number of movements from and to generic ports	Comments	Geocoded
Continental Shelf	4,512	A range of vessels and routes. This place is assigned principally to fishing vessels, supply vessels, patrol vessels which have returned to port from operations in the North Sea.	No
North Sea	212	A range of vessels and routes. Could be any port that borders the North Sea.	No
North Europe	97	A range of vessels and routes. Could be anywhere along the coastline from Brest (FR) to Brunsbuttel (DE).	No
Norway	42	A range of vessels.	No
Scotland	34	The majority of vessel movements in the database from/to 'Scotland' are regular passenger vessels coming from/going to Torshavn (Faroe Islands). Research suggests that these movements represent the ferry service between Torshavn and Scrabster, Scotland.	Assigned the coordinates of Scrabster.
Iceland	34	The majority of vessel movements in the database from/to 'Iceland' are regular passenger vessels coming from/going to Torshavn (Faroe Islands). Research suggests that these movements represent the ferry service between Torshavn and Seydisfjordur, Iceland.	Assigned the coordinates of Seydisfjordur.
Denmark	30	75% of vessel movements in the database from/to 'Denmark' are cargo/passenger vessels coming from/going to Torshavn (Faroe Islands). Research suggests that these movements represent the service between Torshavn and Hanstholm, Denmark.	Assigned the coordinates of Hanstholm.
U.K.	19	A range of vessels and routes.	
…	…		
TOTAL	**5,016**		

A literature search was conducted to geocode those generic places with ten or more movements; if research suggested that movements to a generic place were likely to be travelling to a specific port then that generic place was assigned the coordinates of the specific port. The literature search geocoded three generic places: Scotland, Iceland and Denmark (see Table 4.5 for details). As can be seen from Table 4.5, these three generic places represent 98 movements (2%) of 5,016. Therefore 4,918 movements remain which are not included in the gridded inventory.

For these 4,918 movements the same methodology as assumed by Formula 3 (page 25) is adopted. Thus the trip duration (in hours) for each movement is either calculated (if for departure and arrival both the date and time fields are populated) or estimated (if only departure and arrival dates are populated). The assumptions adopted for this are:

- If the date the vessel sails from the port and the date the vessel arrives at its destination are the same, *and* the time the vessel sails from the port is populated, then the time of arrival is set as half way between the time the vessel sails from the port and midnight;
- For vessel movements arriving the same day they depart, but for which departure and arrival times are missing, the trip duration is assumed to be 12 hours;
- For vessel movements arriving on a day after the day they depart, and for which departure and arrival times are missing, the trip duration is estimated from the number of whole days sailing;
- Again, a fraction of movements (172, 3.5%) are listed by Lloyd's MIU as having the arrival date before the departure date. For these movements the trip durations have been assumed to be the median trip duration (6.25 hours) for all those movements with populated departure and arrival times is assumed; and
- For vessel movements with a departure date before 1 January 2007, the departure date is set to 1 January 2007.

Movements with unknown destination

The Lloyd's MIU movements database included 1,106 movements without a specified destination. Of the total 440,494 movements, this represents 0.25%. The 1,106 movements are shown split by vessel category in the table below.

Table 4.6 Movements with Unknown Destinations, Split by Vessel Category

	Bulk Carrier	Container Ship	Fishing	General Cargo	Others	Passenger	Ro-Ro cargo	Tanker	TOTAL
Number of movements	2	4	262	83	612	83	12	48	**1,106**

For these movements, fuel consumption and emissions are estimated by assuming that the missing 0.25% movements represent 0.25% of total fuel consumed.

4.4 Analysis of Port Callings Data & Generation of Port Database

Previous studies have identified that a significant proportion of emissions from ships occur within the port area, during manoeuvring, hotelling alongside or at anchor and during loading and unloading. Furthermore, emissions closer to land are likely to have a more significant impact on local air quality and therefore, port emissions are an important consideration.

The Lloyd's MIU movements database identifies port callings. The entries typically include the date of arrival in port and the departure date. For 56% of the port callings in the 2007 data obtained for this study[18], the time of arrival and departure are also recorded and is shown in Table 4.7. However, it should be noted that from the time of arrival and departure recorded, 4.7% of these entries were zero or negative and have therefore been excluded from the analysis.

For the port callings where the time of arrival and departure were not available, an estimated number of hours in port has been assigned to each port calling, based on the number of days spent in port as presented in Table 4.7. When departure and arrival dates were not available it has been assumed that the vessel stays in port for less than one day. In the Lloyd's MIU database, a total of 5% of callings are shown to be longer than 4 days, therefore a maximum number of 4 days has been assumed as the upper limit of time spent at berth with engines operational.

For manoeuvring, time-in-mode varies depending on the location of and the approach to the destination terminal and turning requirements of each vessel. It has been assumed that, for all ports and vessels, manoeuvring time is 1 hour on entry and 1 hour on exit to port, based on 14 European port responses received from a survey of port operators (Entec, 2002).

[18] Total number of ship callings with populated times are 248,136 out of 351,869 in the database, representing 71% of total ship callings

Table 4.7 Median Days Spent at Berth by Vessel Type and Number

	Bulk		Container		Fishing		General Cargo		Passenger		Ro-Ro Cargo		Tankers		Others	
Days	Median days	Count	Median days	Count	Median days	Count	Median days	Count	Median days	Count	Median days	Count	Median days	Count	Median days	Count
0-1	0.63	1,156	0.62	18,616	0.36	1,516	0.56	21,505	0.06	45,937	0.33	34,518	0.67	17,678	0.34	10,973
1-2	1.52	1,704	1.33	11,475	1.37	318	1.37	16,063	1.32	662	1.37	4,186	1.32	12,604	1.4	2,738
2-3	2.48	1,466	2.28	1,968	2.46	205	2.35	7,080	2.47	165	2.35	850	2.37	3,364	2.4	1,384
3-4	3.47	965	3.34	382	3.48	123	3.38	3,238	3.5	57	3.42	308	3.41	1,327	3.44	799
4-5	4.45	632	4.37	122	4.38	90	4.38	1,586	4.55	61	4.44	106	4.42	677	4.41	462
5-6	5.47	311	5.5	83	5.43	69	5.4	820	5.42	33	5.5	91	5.41	365	5.49	308
6-7	6.4	226	6.42	39	6.43	38	6.42	401	6.26	37	6.37	48	6.38	220	6.49	259
7-8	7.42	132	7.32	29	7.15	17	7.45	207	7.54	15	7.39	25	7.41	126	7.45	159
8-9	8.52	93	8.49	34	8.36	11	8.48	130	8.33	11	8.36	24	8.38	92	8.43	111
9-10	9.5	51	9.4	18	9.5	23	9.41	101	9.2	12	9.56	12	9.4	90	9.57	129
>10	12.54	170	14.91	123	19.64	189	15.03	454	17.82	132	16.46	157	15.07	346	19.45	943

Count – This is the number of ship callings used to calculate the average time. Negative and zero values have been excluded from the analysis (a total of 236,580 ship callings have been used out of 248,136 that have the time field populated).

4.4.1 Consideration of problematic/miscellaneous movements data

As discussed above, the supplied Lloyd's MIU database of movements includes a number of movements which are considered problematic/miscellaneous. For estimating emissions 'at berth' and 'manoeuvring' the methodology employed is consistent with the methodology employed for estimating emissions 'at berth' and 'manoeuvring' in Section 3.2, although emission estimates are reported separately. However, it should be noted that movements from and to the same port and movements with an unknown destination have been included in the main analysis for estimating emissions 'at berth' and 'manoeuvring' (i.e. the port where the vessels have called is known) therefore, these have been included in the gridded inventory and have not been reported separately.

4.5 Summary

On the basis of the findings of the sensitivity analysis presented in Section 4 above, Defra commissioned a further more detailed comparison of movements data available from Lloyd's MIU and DfT, with the aim of developing a methodology to account for under-reporting of movements.

The following section presents the approach taken to uplift the gridded emissions inventory to take account of movements that were missing from the Lloyd's MIU database, based on a more detailed comparison undertaken with port calling data provided by the DfT.

5. Detailed Port Calling Analysis

5.1 Overview

As part of a separate work package commissioned in the autumn of 2009, Entec revisited the underlying movements database, as provided by LMIU, and undertook a more detailed comparison of port arrival statistics with those produced by the DfT. The objective for undertaking this additional analysis was to try to reconcile the differences in fuel consumption estimates produced by Entec with those published by DECC in the DUKES publication[3], with a focus on domestic movements, in order to provide better integration with the NAEI.

The approach for revisiting the underlying movements data involved a comparison of Entec's Lloyd's MIU derived port calling statistics with those produced by the DfT. Section 4.2 already concluded that the LMIU database underestimates port arrivals for certain ports, with discrepancies for certain ports most likely from missing movements of vessels smaller than 300 GT with multiple callings per day. The comparison (in much more detail than that presented in section 4.2) enables an assessment of which movements are missing from the Entec LMIU database and thus derive an estimate of the missing fuel consumption and emissions that could be incorporated into the final gridded inventory to reduce uncertainty in the overall emissions estimates.

5.2 Methodology

The DfT publishes an annual compendium of marine statistics in which numbers of vessel arrivals per port, split by cargo vessel category and by vessel deadweight are listed in Table 3.6 of that compendium.[19] The DfT's shipping database is, similarly to Entec, derived from primary data supplied by Lloyd's MIU, and to this extent one would expect similarity between Entec's and DfT's databases. However, where the database held by Entec has been supplemented by AIS data to account for missing high frequency movements, the DfT has instead combined the LMIU data with estimates from MDS-Transmodal. The MDS-Transmodal data that the DfT use to supplement the LMIU database also aims to improve the data capture of regular services with greater than one arrival per day. Of the DfT port arrivals data, just over one third of the arrivals are from data supplemented by MDS-Transmodal.

Consultation with the DfT has resulted in the DfT providing to Entec port arrival statistics tailored to this sensitivity analysis, which enables like-for-like comparison with the LMIU movements database utilised by Entec but which also diverges slightly from the published statistics. The statistics provided to Entec[20] differ from the published statistics in the following ways:

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[19] The report detailing 2007 statistics (i.e. relevant to the present work) is Maritime Statistics 2007, available at http://www.dft.gov.uk/pgr/statistics/datatablespublications/maritime/compendium/maritimestatistics2007

[20] Personal communication with Jeremy Grove, DfT 7/10/2009, 9/10/2009 and 3/11/2009.

- The number of vessel categories were expanded to include passenger vessels, and to aid re-classification, were subdivided into the eight vessel categories used in the present work;

- Vessel size was determined by gross tonnage rather than by deadweight tonnage (to be in-line with Entec's existing approach) and subdivided into the three size bands used in the present work (<5,000 GT, 5,000-25,000 GT and >25,000 GT);

- All vessel movements were included, regardless of whether the deadweight tonnage (or gross tonnage) was missing from the DfT database; and

- The arrivals were split by whether the movement was domestic or international. The assessment of whether the movement was classed as domestic or international was undertaken on the basis of the country of the previous *place* of call.

After a first analysis of the data it became apparent that the DfT database classifies approximately 11,500 movements that are listed in the LMIU database as arriving from the Dover Strait as domestic movements. The LMIU database used by Entec lists a similar number of movements as *passing through* the Dover Strait but distinguishes this from the original departure port, which enables the assessment of whether the movement should be classified as domestic or international. Of these approximately 11,500 movements, Entec's LMIU database lists 20% of them as domestic movements and 80% as international. Thus for the purposes of a like-for-like comparison between the Entec and DfT statistics, both the DfT and the Entec port calling statistics have been tailored to exclude arrivals that arrive from/pass through the Dover Strait respectively.[21]

The analysis of the statistics post these revisions was aggregated at a port level to establish differences between the two datasets, and then aggregated by movement type, then by vessel category (e.g. domestic Bulk Carriers).

The methodology for adjustment of the 2007 emissions inventory was to obtain the relative differences in numbers of arrivals per vessel category, per movement type (domestic, international) and by vessel size, and scale up/down the emissions inventory that was identically split. The arrivals data was based on arrivals at the UK ports listed in Table 3.6 of the DfT's Maritime Statistics 2007 publication. Where a 'port group' exists which constitutes a number of separately listed arrivals places, then Entec has grouped its arrivals identically to the DfT.[22]

For the purposes of this adjustment, it has been assumed that fuel consumption and emissions were directly proportional to the number of port callings within each vessel category and size category.

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[21] In a similar fashion, but with much reduced impact (24 movements instead of 11,500), the UK port of Brixham is listed by LMIU as a passing place, such that arrivals listed by DfT as arriving 'from' Brixham may just have been passing through such that the movement is not necessarily a domestic movement. As such, for the purposes of the statistics comparison, movements from/via Brixham have also been excluded.

[22] Port groups provided by DfT via Personal Communication, 19th October 2009.

It was not within the scope of this task to assess international port callings and movements that pass through the study area, such that it is assumed the emissions from these movements remain fixed. It is worth noting that, as reported in Table 12.4, passing vessels constitute nearly two thirds of the emissions from the total in the study.

5.3 Results and Discussion

The comparison of statistics from the two datasets yielded the following results listed in Table 5.1. It is to be noted that the numbers listed in this table exclude movements arriving from the Dover Strait and from Brixham, and movements arriving at UK places which are not listed among the UK ports/port groups in DfT's Maritime Statistics 2007 Table 3.6.

Table 5.1 Comparison of UK Port Arrival Statistics as Listed by DfT and by Entec, Split by Movement Type and by Vessel Size

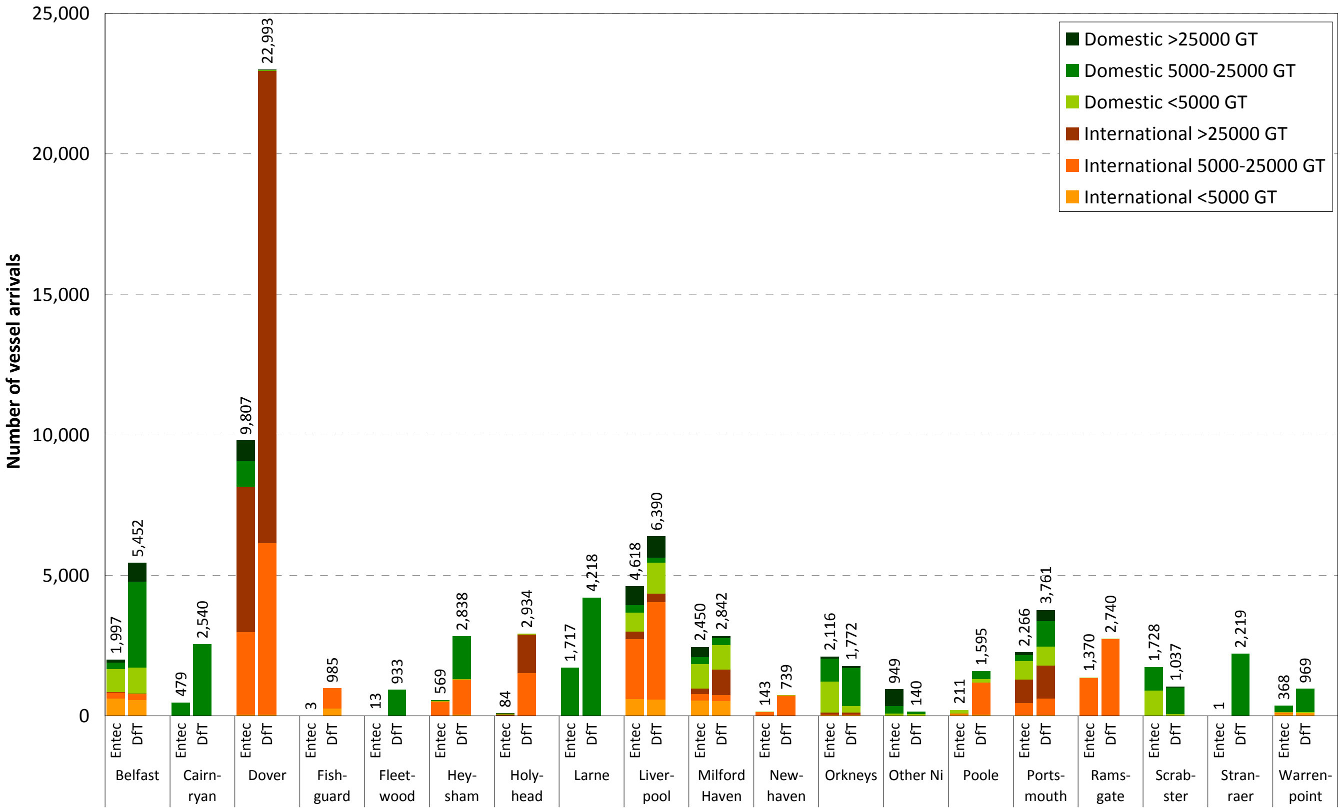
Movement	Gross tonnage:	0-5,000	5,000-25,000	>25,000	Total	0-5,000	5,000-25,000	>25,000	Total
		DfT number of arrivals				**Entec number of arrivals**			
Domestic		30,199	24,887	2,795	57,881	31,802	11,880	3,515	47,197
International		19,499	37,105	28,812	85,416	19,516	25,827	14,347	59,690
Total		49,698	61,992	31,607	**143,297**	51,318	37,707	17,862	**106,887**
		Difference of Entec from DfT				**Percentage difference of Entec from DfT**			
Domestic		1,603	-13,007	720	-10,684	5%	-52%	26%	-18%
International		17	-11,278	-14,465	-25,726	0%	-30%	-50%	-30%
Total		1,620	-24,285	-13,745	**-36,410**	3%	-39%	-43%	**-25%**

Note the numbers listed in this table exclude certain movements: (1) movements arriving from the Dover Strait and from Brixham, Entec total 11,713, DfT total 11,397 which are classified differently by Entec and by DfT; (2) movements arriving at UK places which are not listed among the UK ports/port groups in DfT's Maritime Statistics 2007 Table 3.6: Entec total 4,594.

Table 5.1 shows that overall Entec's arrivals data lists approximately only three quarters of the arrivals listed by the DfT. The split by vessel size indicates that there is good agreement for the smallest vessel size category, but for the larger two categories Entec's arrivals data are significantly under those reported by the DfT by 38,000 movements. However, there is insufficient detail at this level to draw further conclusions except to suggest that MDS-Transmodal were better at accounting for the missing movements than the methodology of using 2007 AIS data. Section 4.2 confirmed that not all ports were covered by the AIS data network, such that future years of AIS may provide more complete coverage.

Section 4.2 suggested that the discrepancies were at particular ports where movements by vessels with frequent (greater than one per day) calls were not recorded. Thus an analysis was undertaken at a port level to understand these differences further. For each port/port group, the arrivals from both datasets were compared and split by movement type and vessel size. There were 98 ports/port groups, but the majority of these showed no major discrepancies between the two datasets. However 19 of those ports covered nearly 95% of the absolute differences in arrival numbers. The differences for these 19 ports are shown in more detail in Figure 5.1 below.

Figure 5.1 Total Arrivals per Port as listed by Entec and DfT, Split by Movement Type and Vessel Size



The results by port in Figure 5.1 show that there were particular areas where movements were missing. For example, for the port of Belfast, both Entec and DfT list similar numbers of international arrivals and domestic arrivals <5,000GT, but Entec is missing nearly 3,500 domestic arrivals of vessels >5,000GT. As a second example, Figure 5.1 shows that for Dover, Entec is missing in total just over 13,000 arrivals, mostly from large international vessel movements. Further analysis of the data indicates that in this particular example, the movements differ due to missing roll-on-roll-off (Ro-Ro) cross-channel movements, despite the attempt to account for such movements by the use of AIS data to supplement the standard Lloyd's MIU data.

However, due to the nature of the inventory, it was not possible to make adjustments on the basis of differences at individual ports, because the emissions were spread over the route of the vessel. The alternative is to make adjustments at an aggregated level, but split by vessel type, vessel size and movement type, assuming that the geographical distribution of missing movements is the same as those movements captured by the database. (The supplied DfT data do not list the departure place for each movement such that distance travelled and emissions cannot be determined and compared to Entec estimates).

Such an analysis has been undertaken and is presented in Table 5.2. This analysis has identified one inconsistency between Entec's and the DfT's classification in terms of passenger Ro-Ro vessels. Owing to this difference in classification, the analysis has combined the numbers for these two categories together.

The analysis shows that there were certain movements that were particularly under/over-represented in Entec's database, namely (taking into account both absolute and relative differences):

- Bulk carriers:
  - domestic <5,000 GT and 5,000-25,000 GT;
  - international 5,000-25,000 GT and >25,000 GT.
- Container ships:
  - domestic <5,000 GT and 5,000-25,000 GT;
  - international <5,000 GT and 5,000-25,000 GT.
- General cargo:
  - international 5,000-25,000 GT.
- Passenger and Ro-Ro cargo:
  - all domestic and international movements.

Table 5.2 Comparison of UK Port Arrivals listed by DfT and Entec, Split by Movement and Vessel Category and Size

Movement	Gross tonnage:	0-5000	5-25000	>25000	Total	0-5000	5-25000	>25000	Total
	Vessel Category	DfT number of arrivals				Entec number of arrivals			
Domestic	Bulk Carrier	245	519	214	978	102	374	171	647
	Container Ship	1,006	523	27	1,556	760	453	27	1,240
	Fishing	847	0	0	847	885	0	0	885
	General Cargo	8,861	200	6	9,067	9,141	236	5	9,382
	Others	11,017	978	8	12,003	11,528	1,026	8	12,562
	Passenger & Ro-Ro cargo	935	21,338	1,824	24,097	2,257	8,476	2,571	13,304
	Tanker	7,288	1,329	716	9,333	7,129	1,315	733	9,177
International	Bulk Carrier	284	2,298	1,293	3,875	263	901	606	1,770
	Container Ship	1,693	2,415	2,230	6,338	1,204	2,173	2,174	5,551
	Fishing	150	1	0	151	125	2	0	127
	General Cargo	11,054	1,220	50	12,324	11,856	1,414	92	13,362
	Others	1,105	236	3	1,344	1,080	251	2	1,333
	Passenger, Ro-Ro cargo	592	28,361	23,922	52,875	280	18,502	10,140	28,922
	Tanker	4,621	2,574	1,314	8,509	4,708	2,584	1,333	8,625
Domestic	Bulk Carrier	-143	-145	-43	-331	-58%	-28%	-20%	-34%
	Container Ship	-246	-70	0	-316	-24%	-13%	0%	-20%
	Fishing	38	0	0	38	4%	0%	0%	4%
	General Cargo	280	36	-1	315	3%	18%	-17%	3%
	Others	511	48	0	559	5%	5%	0%	5%
	Passenger & Ro-Ro cargo	1,322	-12,862	747	-10,793	141%	-60%	41%	-45%
	Tanker	-159	-14	17	-156	-2%	-1%	2%	-2%
International	Bulk Carrier	-21	-1,397	-687	-2,105	-7%	-61%	-53%	-54%
	Container Ship	-489	-242	-56	-787	-29%	-10%	-3%	-12%
	Fishing	-25	1	0	-24	-17%	100%	0%	-16%
	General Cargo	802	194	42	1,038	7%	16%	84%	8%
	Others	-25	15	-1	-11	-2%	6%	-33%	-1%
	Passenger & Ro-Ro cargo	-312	-9,859	-13,782	-23,953	-53%	-35%	-58%	-45%
	Tanker	87	10	19	116	2%	0%	1%	1%

5.4 Outcome of Analysis

Following the analysis presented above, consultation with Defra, DECC, DfT and AEA in July 2010 concluded that the inventory was to be uplifted by the factors presented in Table 5.2 above. The proposed approach was to scale up/down the relevant emissions and fuel consumption from each sub-category by the percentage differences in arrival numbers. Such an approach assumes that, in light of a lack of better alternatives, the routes of the missing movements are similar in length to the routes of the existing movements for that sub-category and that the number of port callings are therefore directly proportional to the total emissions. For the gridded inventory, this also assumes (at the level of disaggregation that the uplift was applied) that the geographical distribution of missing movements is the same as those movements captured by the database.

As no analysis for the potential for other missing movements from the database has been undertaken (i.e. movements that pass within the study area, but do not call at the UK) the fuel consumption and emissions from such passing movements is assumed to remain unchanged. This may not however be a valid assumption since it may be assumed that if Entec's LMIU database is deficient for moves calling at the UK, then it may well also be deficient in recording movements that do not call at the UK. However, the scope of work has not included for the assessment of foreign port callings.

6. Vessel Characteristics

6.1 Introduction

Lloyd's MIU has provided data on vessel characteristics, including vessel types and vessel speeds. The vessel types are mainly used as a proxy to assign missing data such as fuel type, engine characteristics and vessels speeds to a specific vessel. Vessel speeds, when combined with the distance travelled by each vessel, are used to determine the time spent 'at sea' by each vessel.

This section summarises the main findings from analysing the vessel characteristics data provided by Lloyd's MIU and the main assumptions that have been used to populate missing vessel characteristics data.

6.2 Vessel Categories

Missing characteristics data fields have been populated on the basis of the following eight primary vessel categories (the assignment of vessels categories is presented in Appendix A):

- Bulk Carrier;
- Container Ship;
- General Cargo;
- Passenger;
- Ro-Ro Cargo;
- Tanker;
- Fishing; and
- Others.

This differentiation is required because there are often variances in engine or vessel operation between different vessel types. The type of vessel, along with its overall size, are often indicators of the likely fuel use in terms of residual oil versus marine distillates; average service speeds of vessels also vary according to the vessel type. These issues are discussed further throughout this section and Section 7.

6.3 Service Speed of each Vessel Category

Lloyd's MIU vessel characteristics database includes a field for vessel service speed in knots. The vessels table in the database has approximately 85% coverage of this field for the 14,255 vessels.

Statistics can be drawn from the list of vessels in the database, to show the median, mean and standard deviation of vessel service speeds for each vessel category. These have been derived and are shown in Table 6.1. Alongside the service speeds are the number of vessels from which the statistics are derived, and the fraction of the vessels in each category which have the service speed field populated. These statistics represent the service speeds used by all the vessels in the database, regardless of the distance travelled by the vessels.

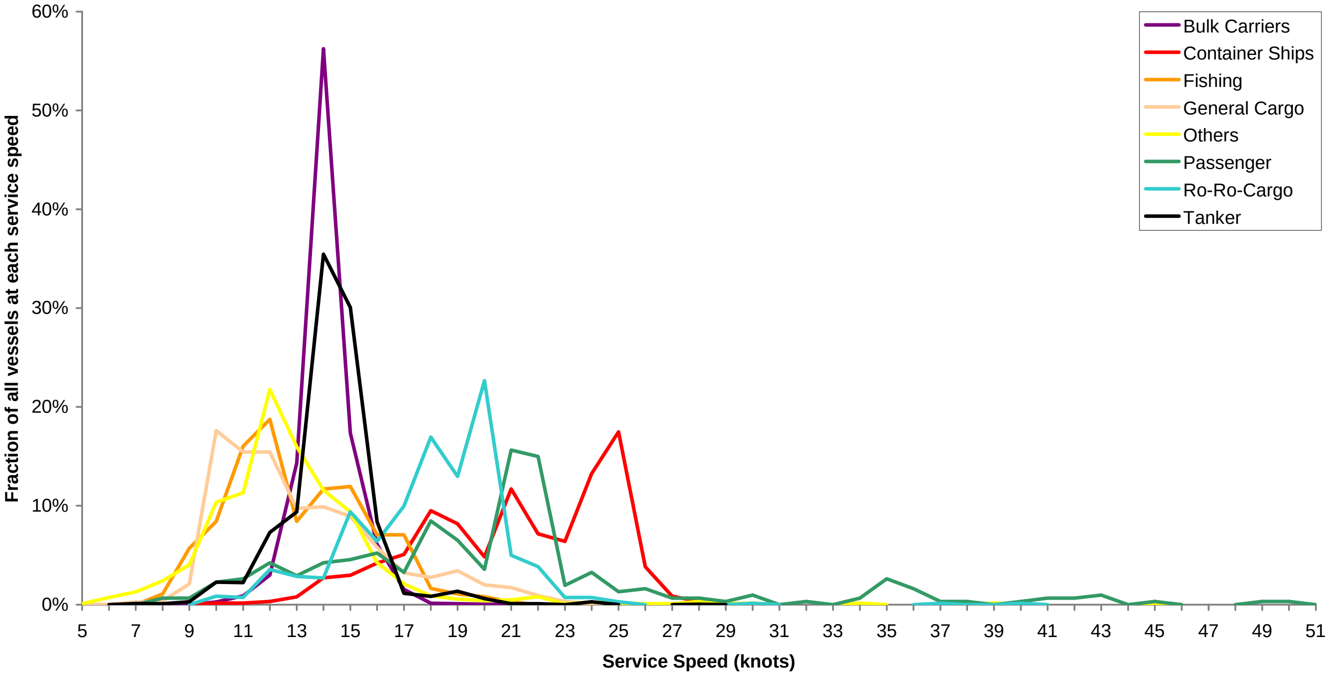
Table 6.1 Statistical Analysis of Service Speeds from Lloyd's Database of Vessels for each Vessel Category

Vessel category	Number of vessels	Coverage	Median service speed (knots)	Mean service speed (knots)	Standard deviation of service speed (knots)
Bulk Carrier	2,306	93.7%	14	14.1	1.0
Container Ship	1,282	99.5%	21	21.2	3.5
Fishing	368	46.1%	12.5	13.0	2.6
General Cargo	3,486	95.0%	12	13.2	3.1
Others	1,245	60.6%	12	12.8	3.4
Passenger	307	81.6%	21	20.6	7.3
Ro-Ro cargo	702	91.4%	18	18.0	2.9
Tanker	2,434	85.7%	14	14.3	1.7
TOTAL	**12,130**	**85.1%**			

As shown in Table 6.1, the coverage of the service speed in the Lloyd's MIU dataset depends on the vessel category. For instance, for bulk carriers, data on service speed are almost complete, whilst for fishing vessels and other vessels missing data are significant. It is worth mentioning that missing data for fishing vessels and other vessels will have a smaller impact on total emission estimates, for example movements of 'Other' vessels comprise <8% of total movements (and less in terms of installed kW).

The mean and median figures presented in Table 6.1 show close correlation for Bulk Carriers, Container Ships, Passenger, Ro-Ro cargo and Tankers, whilst larger discrepancies exist for Fishing, General Cargo and Others. The standard deviation of service speed for each vessel category gives an indication of how much the service speed varies within each vessel category from the mean service speed. The analysis shows that for passenger vessels there is wide variability of service speeds, whilst for bulk carriers and tankers the standard deviation is much lower. Figure 6.1 confirms this trend as it presents the distribution of percentage of vessels across each vessel service speeds for each vessel category.

Figure 6.1 Service Speed Distribution among Vessel Categories, from Vessels in Lloyd's Database



Vessel speed provided in the Lloyd's MIU database is the service speed. An inspection of ship specifications indicates that the quoted service speed of a vessel is normally provided for a certain percentage, between 80 and 90%, of MCR.[23] The 'at sea' emission factors have been measured at an engine operating load of 70-100% MCR, and so it is consistent to use the service speed, without any adjustment, as the vessel's speed at sea. Discussions with operators and articles in the shipping press suggest there is an increasing trend for operators to operate ships at lower speeds in order to reduce fuel consumption. Consequently this could result in a slight over estimation of emissions in this study, as vessels travelling more slowly consume less fuel for the equivalent journey.

6.3.1 Other sources of information on vessel speeds

In order to confirm that the service speeds assumed are realistic, other data sources were consulted. Details of each source are included below. A summary of all sources, including statistics derived above on service speeds of the vessels in the Lloyd's MIU database, are shown in Table 6.2.

[23] MCR is the maximum continuous rating, which is the standard means of quoting engine power.

Table 6.2 Summary of Different Sources on Vessel Speeds (knots)

Vessel category	Lloyd's database (this study)	Cosco	US EPA	Maes et al., EMEP / Entec	NTUA LMT	Operator consultation
Bulk Carrier	14.1	10 – 13	17.6	14 /14.3	13	14.1 (Note 1)
Container Ship	21.2	19.8 – 22.5	21.3	20/ 19.3	15.5	18.4 – 20.0 (worldwide – UK)[2]
Fishing	13.0					
General Cargo	13.2	10 – 13	14.7	14 /12.3		
Others	12.8	10 – 13 (specialist vessel)	9.4 – 14.1 (tug - miscellaneous)			
Passenger	20.6		18.1	20/ 20.8		
Ro-Ro cargo	18.0	10 – 13 (car carriers)	13.8 – 13.9 (auto carrier - RoRo)	18 /15.4	14 – 23.5 (RoRo - RoPax)	
Tanker	14.3	10 – 13	13.6	14/ 14.0	12 – 17 (Crude - LNG tanker)	14.5 – 15.0 (laden – unladen)[3]
Reefer			18.9	20/ 16.9	17.5	

[1] Personal Communication, Zodiac Maritime, 4th August.
[2] Personal Communication, Maersk, 7th August 2008.
[3] Personal Communication, Shell, 4th August 2008.

Cosco

As reported in Lloyd's List on 20 June 2008,[24] the average speed of China Ocean Shipping Company (Cosco) container ships is reported as 22-25 knots, but these speeds were to be cut by 10% as a fuel saving measure. The mean container ship service speed in Table 6.1 is 21.2 knots, which is lower than the mean speed of Cosco's container ships. The same article suggests a blanket average service speed for bulk carriers, tankers, general cargo, heavylift, car carriers and specialist vessels (i.e. not passenger vessels) of 10-13 knots (speeds which Cosco do not intend to reduce by 10%). This compares favourably with figures presented in Table 6.1, except for Ro-Ro cargo, although the vessel categories 'car carriers' and 'Ro-Ro Cargo' may not be equivalent and comparable.

US EPA

The US EPA (2006) consider service speeds listed in Lloyd's Data to be maximum service speeds, and assumes that '*cruise speed is generally taken as 94 percent of the maximum service speed*'. As such, they provide average cruise speeds for each vessel type for the Port of Los Angeles, which have been included in Table 6.2. These cruise speeds do not closely match the statistics extracted from Lloyd's MIU database in Table 6.1 across all categories:

[24] http://www.lloydslist.com/ll/news/cosco-puts-brakes-on-speed-cut-programme/1213803909025.htm

the vessel categories Bulk Carrier, Container Ship and General Cargo are all higher than the Lloyd's MIU statistics, whilst for the categories Passenger, Ro-Ro and Tanker the US EPA speeds are lower than the Lloyd's MIU statistics. These cruise speeds have not been adopted in this study for the following reasons:

- The ship types used by the US EPA are different to this study;
- The vessel types and their speeds may be different in and around the Port of Los Angeles compared to in and around the UK; and
- Adopting a blanket assumption that all vessel service speeds should be reduced by 6% may lead to increased discrepancies in some cases between the US EPA and Lloyd's MIU vessel speeds.

Maes et al. (2006)

In their study of ship emissions in the Belgian part of the North Sea, Maes et al. (2006) quote average speeds per ship type (using different ship types from this study) from EMEP (dated 2004) and Entec (dated 2002), where both sources base their quoted speeds on statistical analyses of Lloyd's Register characteristics data. These speeds, which are similar to the statistics derived for this study, are included in Table 6.2 for the vessel categories used in the present study.

NTUA LMT

The vessel speeds that were used in the National Technical University of Athens' (NTUA) Laboratory for Maritime Transport's (LMT) ship emissions study[25] are included in Table 6.2. The NTUA LMT speeds have not been adopted in preference for the speeds listed in Table 6.1 because the vessel categories used by NTUA LMT do not provide complete coverage against the vessel categories used in this study – i.e. additional sources would be need to be used for vessel categories which would include Passenger or Fishing vessels.

Operators

In order to corroborate the assumed service speeds, a selection of vessel operators have been contacted. The results of this consultation are also included in Table 6.2.

6.3.2 Assigning service speeds to vessels with null speed

For the remaining 15% of vessels in the Lloyd's MIU database (which comprise 8% of UK transits) without an assigned vessel service speed, missing data have been populated using the figures presented in Table 6.1, based on the category of the vessel.

[25] http://www.martrans.org/emis/

6.3.3 Vessel speeds when approaching ports

Vessel speeds may vary during a movement, particularly when vessels approach a port, where they slow down. Vessels that reduce their speed when approaching a port need more time to reach the port and this may therefore, result in higher emissions. However, it is more likely that a reduction in speed will reduce fuel consumption, which will result in lower emissions.

A literature review on the application of varying speeds on approach to ports was undertaken. Corbett and Köehler (2003) refer to the use of four vessel speeds when undertaking a sensitivity analysis – full cruise, slow cruise, precautionary speed and manoeuvring – the penultimate of which could be assumed to be when approaching port.

The US EPA (2006) also refers to a speed used to traverse distances within a waterway leading to a port as a Reduced Speed Zone (RSZ). It states that pilots generally can report average ship speeds for a precautionary or reduced speed zone. The US EPA (2006) also notes that vessel speeds in the RSZ may well be lower than the maximum RSZ speed (e.g. in the Port of Los Angeles where the precautionary zone speed is 12 knots or less, auto carriers, container ships, and cruise ships averaged 11 knots while other ship types averaged 9 knots in the RSZ), but that compliance with RSZ speeds should be questioned.

Due to the limited amount of information available, and the uncertainties associated with the degree to which vessels decrease their speed, this study does not include speed reductions. In order to understand speed reductions it would also be necessary to identify the distance from the port when vessels start to reduce their speed and the impact that speed reductions are likely to have on engines loads and emission factors. Any assumption that could be employed to take into account vessels slowing down when approaching a port, or gathering speed when exiting a port, will be very uncertain. In addition, all of the above would vary greatly according to the port geography and infrastructure, and any generic assumption may, in reality, be reasonable for only a fraction of the ports considered. A detailed analysis of vessel speeds when approaching or exiting ports, on a port by port basis, would be required in order to be able to apply robust assumptions. For this regional emission inventory, vessel speeds have not been further assessed.

7. Engine Characteristics & Fuel Type

7.1 Introduction

Lloyd's MIU has provided data on engine characteristics for vessels that have transits recorded in the study in 2007. Engine characteristics such as the engine size, engine type and fuel type of a specific vessel, together with other factors not included in the database, such as installed abatement technology, determine likely emissions. This section summarises the main findings from analysing the data provided by Lloyd's MIU and the main assumptions that have been used to populate missing engine characteristics data.

7.2 Main Engine Power

Main Engines (ME) are almost entirely diesel engines (99% of engines in the Lloyd's MIU dataset) and are mostly medium speed 4-stroke or slow speed 2-stroke (48% and 41% respectively).

The ME power (kW) is required to calculate the ME contribution to the vessel emissions. The Lloyd's MIU dataset contains the ME power for around 96% of vessels. Table 7.1 presents a summary of ME power by vessel category.

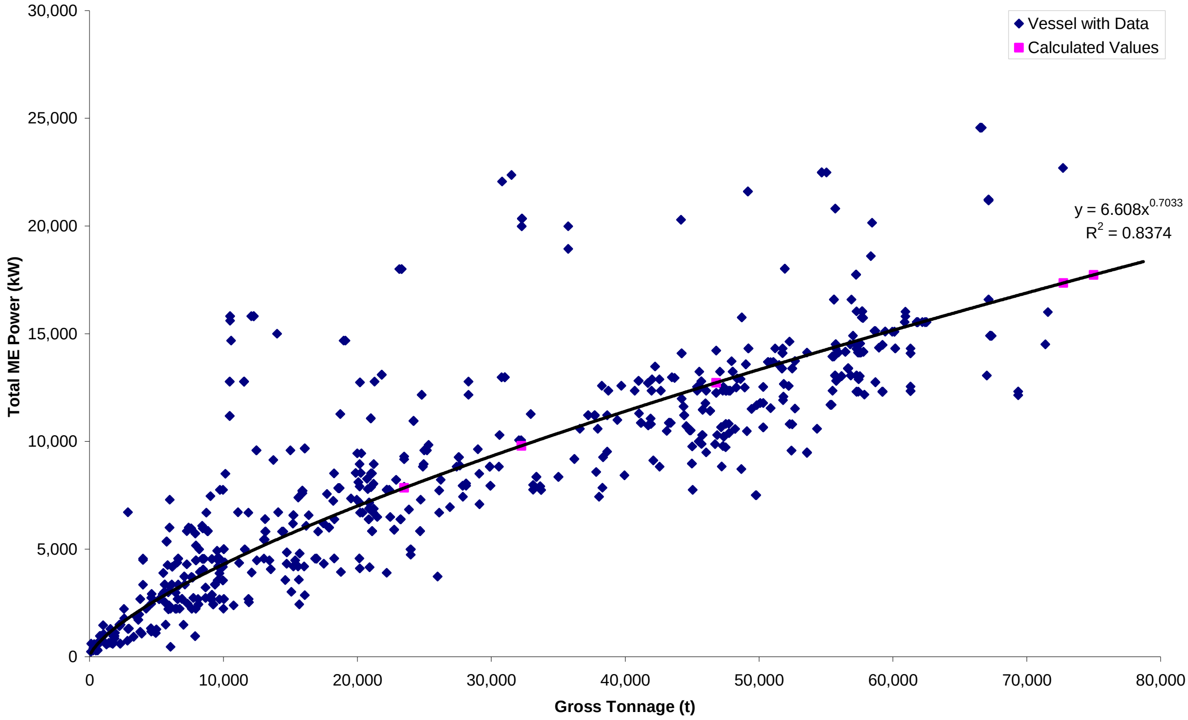
Table 7.1 Percentage of Vessels without Main Engine Power Data

Vessel Category	Percentage of vessels with ME power data
Bulk Carrier	100%
Container Ship	99.8%
Fishing	85.3%
General Cargo	98.9%
Passenger	92.3%
Ro – Ro Cargo	99.1%
Tanker	98.9%
Others	80.1%

As shown in Table 7.1 the coverage of the main engine power data in the Lloyd's MIU dataset depends on the vessel category. For instance, for bulk carriers, main engine power data for all vessels are available, whilst for fishing vessels and other vessels, missing data are more than in other categories. It is worth noting that missing data for fishing vessels and other vessels will have a smaller impact on total emission estimates, for example movements of 'Other' vessels comprise <8% of total movements (and less in terms of installed kW).

In order to obtain assumed values for ME power where entries are not included in the dataset, trends have been identified within each vessel category. For each vessel for which there are complete data, the total installed ME power has been plotted against the gross tonnage. For the vessels with missing data, the power law equation from each trend line developed for the different vessel categories is applied to calculate the total ME power of the vessel using its entry in the database for gross tonnage. Figure 7.1, shows this comparison for Ro – Ro Cargo.

Figure 7.1 Ro – Ro Cargo – Gross Tonnage against Total Main Engine Power (kW)



Literature identifying trends in certain vessel categories contain similar graphs, but the deadweight tonnage[26] has been used instead.[27] For this study it is less appropriate to use deadweight tonnage since there are many more omissions in this category than for gross tonnage (1% of vessels do not have a gross tonnage whereas over 9% of vessels do not have a deadweight tonnage).

There are 91 vessels for which neither gross tonnage nor ME power is known (0.6% of total). For these vessels the gross tonnage has been assumed as being the average for the respective vessel category and then the ME power calculated as above. Although this introduces uncertainty, these 91 vessels account for an insignificant percentage of the whole vessel fleet operating in sea areas around the UK.

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[26] Deadweight tonnage is a measure of how much mass or weight of cargo or burden a ship can safely carry.

[27] http://www.manbw.com/category_000246.html

7.3 Auxiliary Engine Power

Auxiliary Engines (AE) are diesel engines that are usually either high speed 4-stroke or medium speed 4-stroke, that drive a generator unit. The speed refers to engine speed at the crankshaft in terms of number of revolutions per minute (RPM).

The AE power is required to calculate the AE contribution to the vessel emissions. The Lloyd's MIU dataset contains the AE power (for all engines) for around 36% of vessels.[28] Using the vessels for which there are complete data, the ratio between ME and AE power[29] has been calculated for each vessel (excluding vessels with a total AE kW>ME kW, which is approximately 5% of vessels), and the average AE/ME ratio is presented in Table 7.2, along with the total AE and ME power per vessel category, and the ratio of these two. In order to complete the dataset, each unknown AE power is calculated by multiplying the vessel's ME power with the appropriate category ratio. The ratio of total AE/total ME power has been applied for this study.

Table 7.2 Total Main Engine Power and Auxiliary Engine Power per Vessel Type

Vessel Category	Number of vessels	AE Total Power (kW)	ME Total Power (kW)	Ratio of Total AE/Total ME	Average of ratio of AE/ME per vessel
Bulk Carrier	846	1,627,555	7,595,982	0.23	0.21
Container Ship	521	2,822,373	12,611,795	0.28	0.22
Fishing	86	105,685	165,481	0.57	0.64
General Cargo	1,811	1,777,232	5,467,977	0.37	0.33
Others	250	152,445	522,972	0.31	0.29
Passenger	37	58,431	166,526	0.45	0.35
Ro – Ro cargo	211	532,972	1,765,660	0.34	0.30
Tanker	1,118	2,736,512	10,115,796	0.35	0.27

The total number of vessels in the dataset is 14,255.

[28] Lloyd's MIU has identified that uncertainty concerning Auxiliary Engine data is higher than for main engines as the sources and structure of the data prevent thorough auditing of the dataset.

[29] In the LMIU database the rated power values for AE are given under the title 'Generators', either in kVA or kW units. LMIU define an Auxiliary Engine as an "engine other than for propulsion purpose; usually refers to electrical power generating diesel engine". It is therefore assumed that the kW units given are for electrical power (kWe) for consistency with the kVA units. The kW (shaft) values are therefore calculated as follows; kW (shaft) = kWe / 0.9, where kWe = kVA x 0.8

7.4 Main Engine Speed

Statistics for main engine speed by vessel type and gross tonnage have been determined from the available database. The RPM value, available for approximately 68% of the main engines, has been used to determine if the engine is high speed diesel (HSD), medium (MSD) or slow (SSD) speed. Consistent with earlier studies (Entec, 2002), high speed diesel engines were defined as engines with an RPM>1000, medium speed engines were defined as engines with an RPM≤1000 and RPM>300, and slow speed engines were defined as engines with an RPM≤300. For three vessel size ranges the number of vessels with high, medium and low speed diesel engines has been identified, as shown in Table 7.3.

Table 7.3 Number of Vessels Disaggregated by Gross Tonnage and Engine Speed

Vessel Category	≤ 5,000 GT			5,000 – 25,000 GT			>25,000 GT		
	High	Medium	Slow	High	Medium	Slow	High	Medium	Slow
Bulk Carrier	-	44	4	-	29	633	1	11	1094
Container Ship	-	67	-	1	233	161	-	2	634
Fishing	27	256	4	-	8	1	-	-	-
General Cargo	129	1494	121	-	298	510	-	-	82
Tanker	28	348	91	5	238	558	3	12	901
Passenger	37	28	5	8	60	8	1	41	14
Ro – Ro cargo	8	31	2	2	154	38	-	22	286
Others	295	546	23	5	90	7	-	1	6

The dominant speed for the relevant category and size of ship has been applied to each vessel in the database where an entry for ME engine speed is not present (highlighted orange, for example bulk carriers of ≤ 5,000 GT are assigned medium speed engines).

7.5 Auxiliary Engine Speed

An emission factor has been developed for AEs assuming an even distribution between medium and high speed diesel engines. Since a shortage of data has required a common emission factor to be developed, it is not necessary to specify whether the AEs on a specific vessel are MSD or HSD.

7.6 Fuel Type Assumptions for 2007

Worldwide, the main fuel currently used for propulsion is Residual Oil (RO), also referred to as Heavy Fuel Oil (HFO), while Marine Diesel Oil (MDO) and Marine Gas Oil (MGO), collectively referred to as Marine Distillates (MD), are more commonly used for auxiliary power generation.

The data from Lloyd's MIU include a fuel type field for Main Engines (that defines the type of fuel suitable for the engine) and this is populated for approximately 95% of the engines with an entry of MDO fuel. Fuel consumption data is available for some vessels (approximately 35%), in various formats (as a text field), but this has not been included in the assessment owing to low data capture and inconsistency in the reporting format.

There is uncertainty over the interpretation of the fuel type field and based on other studies[30] assuming that 95% of engines consume MDO is thought to be unrealistic, therefore the approach proposed for determining the fuel type of the vessels is more generic and is described below.

For Vessels at Berth:

- For all port callings, for the baseline year the fuel type assumptions are as per the fuel type assumptions for the movements (i.e. as outlined below for vessel movements outside and within SECAs);

- For all port callings for the projections, with the exception of passenger vessels, main and auxiliary engines are assumed to be using MGO in order to comply with the 0.1% sulphur limit of the SCMF Directive on fuel used by inland waterway vessels and by seagoing ships at berth in EU ports. The limitation of this would be that some vessels, in the future, may be using shore-side electricity, therefore, this could result in an overestimation of SO_2 and other pollutant emissions, but it is expected that the number of vessels using shore-side electricity will be limited; and

- For all port callings for the projections, main and auxiliary engines for passenger vessels are assumed to be using MDO (with the exception of passenger vessels with a kW power greater than 4 times the deadweight of the vessel that are assumed to be using MGO). This assumption is based on the fact that the 0.1% sulphur limit on fuel used by inland waterway vessels and by seagoing ships at berth in EU ports of the SCMF Directive does not apply to ships due to be at berth for less than two hours according to published timetables.

For vessel movements, fuel types have been assigned depending on whether the vessel is travelling within or outside a SECA, as shown in Figure 7.2. The area defined as a SECA for this study is consistent with that of the SCMF Directive.

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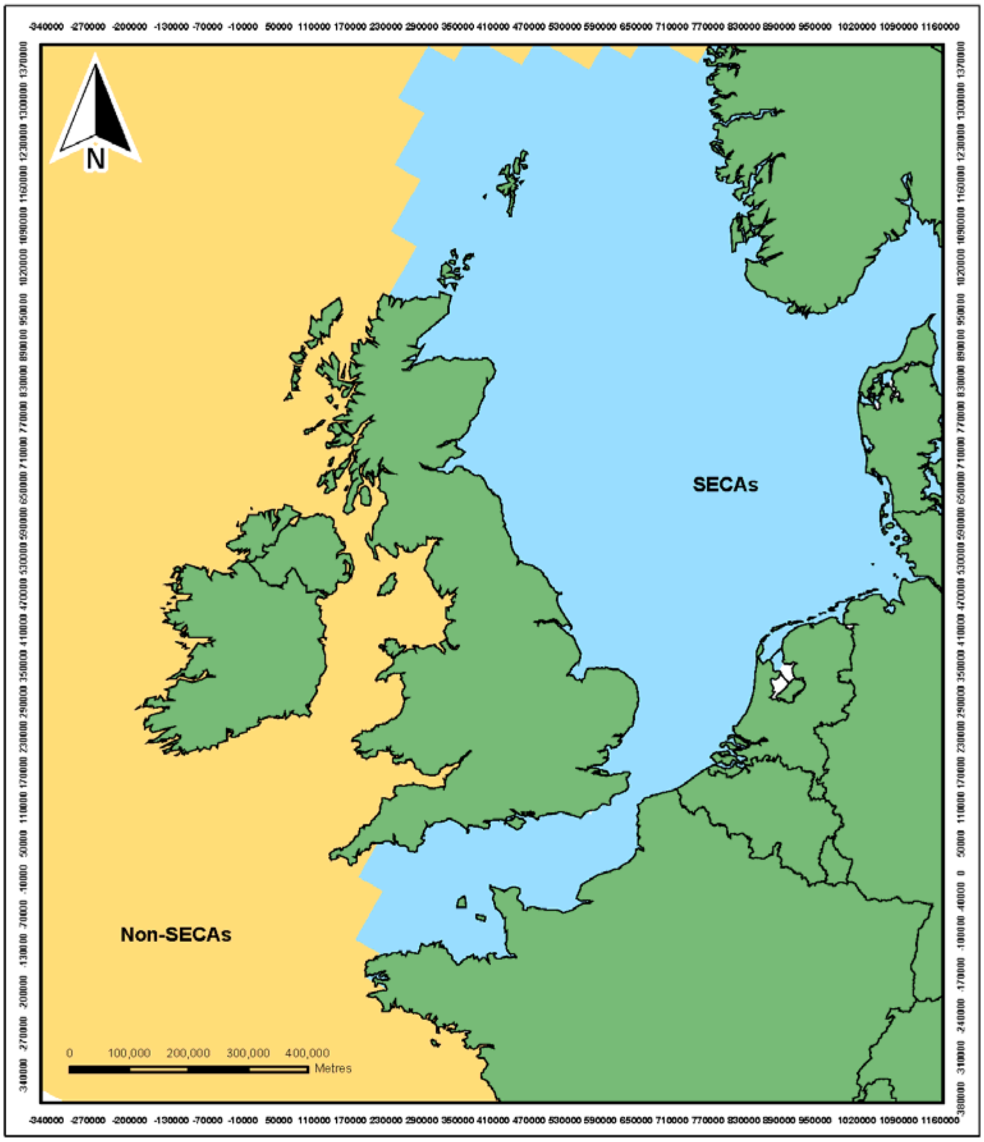
[30] Following IMO's expert group advice, a study assessing the environmental impact of proposed SO_2 and PM control options has assumed that the fuel split is 84% RO, 5% MDO and 11% MGO, http://www.endseuropedaily.com/docs/80213b.pdf

Figure 7.2 Geographical Representation of the SECAs within the 'UK waters' Study Area



For Vessel movements within SECAs:

- The SCMF Directive includes a 1.5% sulphur limit for fuels used by all ships in the SECAs of the Baltic Sea, from 11th August 2006, and the North Sea and English Channel, from 11th August 2007. Lloyd's MIU vessel movements for the full 2007 calendar year have been used for this study to estimate emissions in 2007, i.e. baseline emissions. Therefore, for the purposes of this study it has been assumed that the sulphur limit for fuels used by all ships in the SECAs of the North Sea and English Channel is in place for the full 2007 calendar year.

- For all movements that are geographically located within the English Channel and the North Sea area, main and auxiliary engines are assumed to be using various fuel types, depending on their assigned vessel type, as presented in Table 7.4, for all years including the baseline, except where compliance with the revision to MARPOL Annex VI may lead to a fuel switch (Section 9.1.2).

Table 7.4 Fuel Type used per Vessel and Engine Type in SECAs (MDO = Marine Diesel Oil, MGO = Marine Gas Oil)[5]

Vessel Type	ME Fuel Type	AE Fuel Type
Bulk Carrier	MDO	MGO
Container Ship	MDO	MDO
General Cargo	MDO	MGO
Passenger[1]	MDO	MDO
Ro – Ro cargo[2]	MDO	MDO
Tanker	MDO	MGO
Others[3]	MGO	MGO
Fishing[4]	MGO	MGO

[1] For Passenger vessels with a kW Power greater than 4 times the deadweight of the vessel, it is assumed that the ME fuel type is MGO and the AE fuel type is MGO.

[2] For smaller Ro-Ro Cargo vessels it is assumed that the AE fuel type is MGO.

[3] For larger 'Other' vessels it is assumed that the ME fuel type is MDO.

[4] For larger Fishing vessels it is assumed that the ME fuel type is MDO.

[5] This table was originally used in Entec (2007) and was based on expert advice from the CONCAWE project steering group. The original table only presented RO and MD, however the % S content of MD was assumed to be 0.2%. Thus, for the purpose of this study it has been assumed that MD is MGO, and RO has been assumed to be MDO in order for vessels in SECAs to comply with the 1.5% sulphur limit of the SCMF Directive.

Note – Small vessels are defined as vessels with a Gross Tonnage of <5,000 and large vessels are defined as vessels with a Gross Tonnage of >25,000

For Vessel movements outside SECAs:

- For all other movements (i.e. these are not geographically located within the English Channel and the North Sea area) main and auxiliary engines are assumed to be using various fuel types, depending on their assigned vessel type, as presented in Table 7.5. The fuel type assumptions presented in Table 7.5 are based on expert advice from the CONCAWE project steering group (Entec, 2007).

Table 7.5 Fuel Type used per Vessel and Engine Type outside SECAs (RO = Residual Oil, MGO = Marine Gas Oil)[5]

Vessel Type	ME Fuel Type	AE Fuel Type
Bulk Carrier	RO	MGO
Container Ship	RO	RO
General Cargo	RO	MGO
Passenger[1]	MDO	MDO
Ro – Ro cargo[2]	RO	RO
Tanker	RO	MGO
Others[3]	MGO	MGO
Fishing[4]	MGO	MGO

[1] Passenger vessels are assumed to be using MDO, in order to comply with the 1.5% sulphur limit of the SCMF Directive for fuels used by used by passenger vessels on regular services between EU ports. For Passenger vessels with a kW Power greater than 4 times the deadweight of the vessel, it is assumed that the ME fuel type is MGO and the AE fuel type is MGO.

[2] For smaller Ro-Ro Cargo vessels it is assumed that the AE fuel type is MGO.

[3] For larger 'Other' vessels it is assumed that the ME fuel type is RO.

[4] For larger Fishing vessels it is assumed that the ME fuel type is RO.

[5] The table used in Entec (2007) only presented RO and MD, however the % S content of MD was assumed to be 0.2%. Thus, for this study it has been assumed that MD would be MGO.

Note – Small vessels are defined as vessels with a Gross Tonnage of <5,000 and large vessels are defined as vessels with a Gross Tonnage of >25,000

7.6.1 Limitations of this approach

The approach for assigning fuel types implies that vessels that pass through SECAs, with movements originating or terminating outside the SECAs will be assumed to be using two different fuels on the same journey in these two areas. Hence, this approach considers 100% compliance with the SCMF Directive. However, it is considered unlikely that all vessels passing through SECAs, with movements originating or terminating outside the SECAs, will be switching from RO to MDO on the same journey.

Therefore, the limitation of the approach used to assign fuel types to vessels would be that some vessels with movements originating or terminating outside the SECAs that pass through the SECAs, may comply with the SCMF Directive requirements throughout the transit, or may not comply with the SCMF Directive requirements at all. This may therefore lead to an overestimation of emissions outside the SECAs, as it may be the case that these vessels comply with the SECAs requirements even when travelling outside the SECAs, or to the contrary, this may lead to an underestimation of emissions within the SECAs due to non-compliance.

A further limitation may be that some vessels may be using RO and have an abatement technology in place, such as Sea Water Scrubbing (SWS), in order to comply with the 1.5% sulphur limit of the SCMF Directive. This could result in an underestimation of other pollutant emissions, such as NO_X within the SECAs.

It is also recognised that one of the main assumptions made for assigning fuel types is that ships that are required to meet the 1.5% sulphur limit of the SCMF Directive will switch from using RO to MDO. The production of RO with 1.5% sulphur is possible, via a process of desulphurisation of the residual oil. This process increases the hydrogen content of the fuel, which results in a lower CO_2 emission factor, and converts some of the nitrogen in the fuel to ammonia therefore reducing the NO_X emission factor (CONCAWE, 1993). Desulphurised RO emission factors have not been calculated due to scarcity of information and the fact that such a process is unlikely to occur on a commercial scale. A study by CONCAWE (2006) shows that the cost of desulphurisation is high but has little increase in value of the final product, whereas the alternative process, which is further distillation of the RO to produce a range of distillates, has a slightly higher cost but results in a large increase in the value of the end products. For this reason it can be assumed that the majority of refineries will opt for the latter option, and therefore desulphurised RO is less likely to become commercially available.

8. Emission Factors for Year 2007 Inventory

8.1 Overview of Published Emission Factors

Two Entec studies for the European Commission (2002 and 2005) include emission factors for ships operating in the EU. This section of the report summarises the data available from these earlier ship emissions studies and the methodology to update them for this study.

Year 2000 Emissions and Key Assumptions

The year 2000 baseline emission factors reviewed in this study were compiled on behalf of the European Commission to represent a cross section of new and old engines across the fleet, based on measured emissions data from IVL and Lloyds Register Engineering Services. The Lloyds dataset was compiled in 1990-1995 and covers the international shipping fleet, whereas the IVL primary data only focused on the Swedish fleet. However, the IVL measurements are more recent and provide an indication of how the Lloyds data could be updated.

Some of the emission factors, such as PM for slow speed engines, remain biased towards the Lloyds data since the IVL measurements covered fewer variables. Where there were shortages in the data the emission factors have been mainly based upon professional judgement. The ME ‘manoeuvring’ emission factors were formed from IVL’s experience in whole journey studies (e.g. Cooper, 2001) and transient/passage and steady state/passage ratios reported in Lloyds Register Engineering Services (1993a). Further literature containing emissions data provided sources for comparison, but was not suitable to be combined with the IVL and Lloyds datasets.

These specific emission factors were for NO_x, SO_2, CO_2, PM and VOC and have been derived for five engine types, using three different fuels. Diesel engines with speeds between 60 and 300 RPM are classed as slow speed, 300 to 1000 RPM as medium speed and 1000 to 3000 RPM as high speed, where speed refers to engine speed at the crankshaft in terms of number of revolutions per minute (RPM). Generally, for diesel engines, MEs are slow or medium speed two or four-stroke engines whilst AEs are medium or high speed four-stroke engines. The remaining two engine types are gas turbines and steam turbines, which are not categorised by speed.

Although the actual mass flow rate of each emission increases as the engine power output increases, the specific emissions vary across the power curve. SO_2 and CO_2 specific emissions are directly related to specific fuel consumption and therefore remain fairly constant, with a minimum at the design operating load where fuel efficiency is optimum. PM specific emissions are higher at low engine loads, particularly at start-up when engines are cold and incomplete combustion occurs. For NO_x there is no apparent trend. Accordingly, ship operations have been categorised as “at sea” for cruising, “at berth” when stationary in port for hotelling, loading and unloading, and “manoeuvring” for the period of variable engine load entering and leaving the port.

Entec (2002) identifies that assumptions for engine load, shown in Table 8.1, under each activity were based upon other marine emission studies, (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. These assumptions have been used in the current study.

Table 8.1 Assumptions Regarding Engine Operation for the Different Activities (Entec, 2002)

	% 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
Manoeuvring	20	100	0	50
At berth[1]	20	0	0	40

[1] Tankers at berth have been assumed to operate main engines at berth. This can possibly be interpreted as "all tankers operate at 20% MCR (Maximum Continuous Rating) all the time at berth". 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 to bring the results to a "reasonable approximation" within the constraints of the project.

8.2 Development of an Updated Emission Factor Dataset

The year 2000 baseline emission factors used in Entec (2002 and 2005) have been reviewed and updated for the year 2007. This section of the report details the approach taken for each pollutant, in updating the emission factors to 2007, which are presented in Table 8.3 to Table 8.5. The method for adjusting the 2007 baseline emission factors for future years is also included. Section 9 describes the more simplified top-down approach to developing weighted emission factor adjustments to provide estimates in terms of the likely effect of the revised MARPOL Annex VI regulations.

8.2.1 Nitrogen Oxides (NO_X)

Emissions of NO_x are the result of high engine temperatures activating oxidation of nitrogen in the air passing through the engine as well as the potential formation of NO_X from nitrogen compounds in the fuel. Consequently, the emission level is dependent on the combustion process in different engine types. Slow speed engines operate for a longer period at higher temperatures, resulting in improved combustion efficiency but also higher NO_X emissions. The NO_X:NO_2 ratio can vary between 0.05 and 0.10 (i.e. NO_2 is 5-10% of total NO_X (Entec, 2002), hence primary NO_2 is usually assumed to be around 8% of total NO_X. [31]

[31] The nitrogen oxides (NO_X) formed during combustion comprise predominantly of nitric oxide (NO), with a small percentage of primary NO_2. In the atmosphere the NO oxidises to NO_2 which is considered as secondary NO_2.

In developing the emission factors, IVL first assigned a single factor for each engine type. To account for the higher nitrogen content and lower heating value of RO fuel (40.96 MJ/kg) an adjustment was made resulting in the specific NO_x emissions for MDO/MGO being 6% lower than for RO (Entec, 2002).

Technical NO_X Code

Engines installed on ships constructed on or after 1 January 2000, or engines which undergo a major conversion on or after 1 January 2000, are required to meet the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines (NO_x Technical Code). The maximum NO_x emission limits for marine diesel engines permitted under the NO_x Technical Code are directly related to the rated speed of the engine. To meet the requirements existing engines may need one of a variety of modifications, dependent on the engine speed and age. In Entec's study for the European Commission (2005) it was assumed that a new engine meeting the requirements of the NO_X Technical Code had approximately 17% lower NO_x emissions than a pre-2000 engine.

The age of the engine is identified in the Lloyd's dataset for approximately 79% of main engines, and therefore three sets of NO_x emission factors have been calculated when updating the 2000 emission factors for 2007. For engines installed prior to 2000 (~62% of engines) the NO_x emission factor is assumed to remain the same, whereas for engines installed during or after 2000 (~17% of engines) it has been reduced by 17%.[32] For the 21% of engines for which the age is not known a third emission factor is applied. This third emission factor is calculated as the average emission factor for the engines of known age. For the purpose of projecting forward from 2007, the approximate life cycle for a marine engine is assumed to be 25 years, which is equivalent to an annual replacement rate of 4% on the basis that the overall fleet size remains constant. Therefore it has been assumed that the average fleet NO_x emission factor reduces by 0.68%[33] per year. The age of auxiliary engines is not included in the dataset, therefore the assumption taken is that the auxiliary engine age and the main engine age are the same for a particular vessel. Thus, the approach described above for main engines is applied to auxiliary engines when allocating which NO_x emission factor is to be used.

8.2.2 Sulphur Dioxide (SO_2)

The SO_2 emission levels are directly dependent on the sulphur content of the fuel, since it is reasonable to assume that all sulphur in the fuel is converted to SO_2 on combustion. For the purpose of this study it is assumed that no SO_2 abatement technology is fitted to ships operating in UK waters in 2007.

The composition of fuel sold in a certain region is not necessarily the same as that of the fuel used in the region. The IVL measurements focus on Swedish ships and, therefore, to provide a more accurate representative of the EU fleet as a whole, IVL developed the emission factor using the value of 2.7% sulphur for RO as reported to IMO for

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[32] 16 vessels in the Lloyd's MIU database include both engines installed prior to and after 2000. For these vessels it has been assumed that the engines have been installed prior to 2000, as a worst case scenario.

[33] In each year 4% of the fleet has new engines (17% lower NO_X): 4% x 17% = 0.68%

the year 2000 (IMO MEPC, 2001). The emission factors derived by IVL assumed a sulphur content of 0.25% for MGO, 1.0% for MDO and 2.7% for RO. For the 2007 baseline emission factors the average sulphur content of MGO is assumed to be 0.2%, therefore a 20% reduction to the MGO SO_X emission factors was made to account for the reduction. Similarly, a 50% increase to the MDO SO_x emission factors has been applied for 2007 as the MDO sulphur content is assumed to be 1.5% (i.e. assuming that vessels will not consume fuel with a lower % S content than that required to comply with the SCMF Directive). The RO SO_X emission factors are unchanged.

A summary of these assumptions is included in Table 8.2.

Table 8.2 Sulphur Contents of Fuel Assumptions for the 2007 Inventory and Medium Term Projections

Fuel	Assumed sulphur content		
	2007	2010-2020 non-SECA	2010-2020 SECA
Marine Gas Oil (MGO)	0.2%	0.1%	0.1%
Marine Diesel Oil (MDO)	1.5%	1.5%	1.5%
Residual Oil (RO)	2.7%	2.7%	n/a

From 2010, it is assumed that the sulphur content of MGO reduces to 0.1% in order to meet the requirements of the SCMF Directive for use in ports. The associated SO_x emission factors are reduced in direct proportion (i.e. 50%). The assumptions used in the projections are discussed in more detail in Section 13.

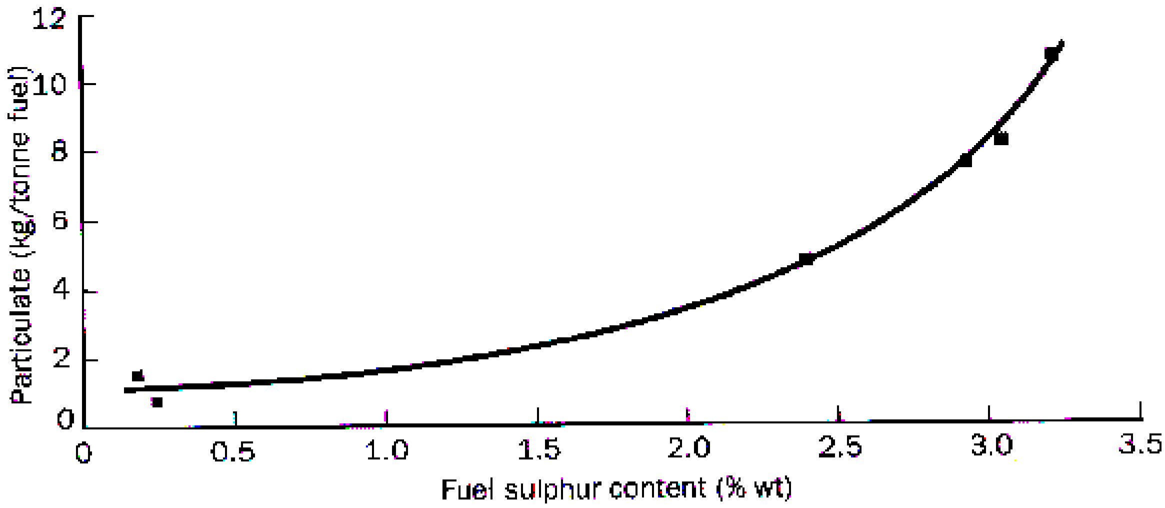
8.2.3 Particulate Matter (PM)

Particulate matter is made up of unburned fuel, soot and incombustible elements in the fuel. It is assumed for the purpose of this assessment that primary $PM_{2.5}$ is equivalent to 90% of total PM, and PM_{10} is 95% of total PM (Cofala *et al*., 2007). The PM emission factors are for total PM emissions and adjustments have been made to the results from the model for $PM_{2.5}$ and PM_{10}. It is however, important to note that the Total PM emission factors are based on the standard monitoring techniques involving the measurement of diluted cooled exhaust on a filter. The application of this dilution method, in addition to primary PM, will also include the measurement of secondary sulphate particles, the mass of which will be dependent on the sulphur content of the fuel.

The European Commission (Entec, 2005) 'at sea' PM emission factors for MSD and HSD engines were approximated from those for auxiliary engines, since the same engine models are used for auxiliary engines as for MSD or HSD main engines. For SSD the 'at sea' factor is taken from Endresen and Sorgard (2003) and this single figure is assumed to represent emissions from engines using RO, since the fraction of MD used in ships at present is minimal. The emission factor for 'at sea' SSD using MD has been calculated as 85% of this emission factor for SSD using RO. Emission factors for turbine machinery have been taken from IVL's revised data for European Commission (Entec, 2005).

For reductions in sulphur content the PM emission factor can be assumed to decrease in line with the graph in Figure 8.1. SO_2 abatement technologies also reduce PM emissions but it is assumed such technologies have not been introduced in 2007. The increase in sulphur content for MDO has resulted in an increase in the baseline MDO PM emission factors of 35%, whilst the MGO and RO baseline PM emission factors are assumed to be the same as in 2000. From 2010 onwards the sulphur content of MGO is assumed to reduce by 50%; this is a reduction from 0.2% to 0.1% and is assumed to decrease the PM emission factor by 4%.

Figure 8.1 Relationship between Sulphur Content of Fuel and PM Emissions



Source: Lloyd's Register, Marine Exhaust Emissions Research Programme (1995)

8.2.4 Carbon Dioxide (CO_2)

It is assumed that during combustion all of the carbon in the fuel is converted into CO_2 and that therefore, the emission factor is dependent on the carbon content of the fuel. This assumption is reasonable since the carbon content emitted as PM and VOCs is minimal.

The IVL emission factors are based upon the carbon content of the fuel being 86.7% for all marine fuels (IMO MEPC, 2001). This corresponds to a CO_2 emission of 3,179 kg/tonne fuel. This is comparable to 86.5% used for the Lloyds Register CO_2 emission factor of 3,170 kg CO_2/tonne fuel or 660 g/kWh (Lloyds Register Engineering Services, 1995) which has been used in most marine emissions inventories to date (Entec, 2002). Recent IMO (2005) guidance lists the carbon content of marine fuels as 86.2%. The NAEI uses the following carbon factors for UK shipping: fuel oil: 879 Kt/Mt fuel; gas oil: 870 Kt/Mt fuel. The IVL emission factor, which is for all marine fuels, equates to 3179 x (12/44) = 867 kT C/Mt fuel. Due to the small variation it is assumed that the fuel composition is the same as in 2000 and the emission factor is unchanged for 2007 or past/future years.

8.2.5 Non-Methane Volatile Organic Compounds (NMVOC)

In this study it is assumed that NMVOC comprise 99% of total hydrocarbon (HC) emissions.[34] Endresen et al. (2003) use a split of 11.36% of CH_4 and 88.64% of NMVOC. HC emissions arise from unburned fuel in the engine exhaust and from fugitive emissions of evaporated fuel. This study excludes evaporative losses from fuel and cargos, which could be significant for crude tankers. The VOC emission factors for 2007 and future years are assumed to remain the same as the 2000 VOC emission factors used in Entec (2005).

8.2.6 Specific Fuel Consumption (sfc)

The specific fuel consumption is a measure of the amount (grams) of fuel consumed relative to the engine kWh produced. The emission factors are given as grams of pollutant per engine kWh and the specific fuel consumption is used in order to convert the emission factor to kilograms of pollutant per tonne of fuel consumed, as indicated in the following equation:

$$\text{kg/tonne of fuel} = \text{g/kWh}/(\text{sfc} \times 0.001)$$

As discussed in Entec's report for the European Commission (2002), the specific fuel consumption is dependent on the fuel heating value and engine technology. This remains mainly constant across the engine power range, with a minimum at the design operating load and an increase of 10% for engine operation at low engine loads. As with NO_x emission factors, a single factor was assigned for each engine type, then an adjustment was made for the lower heating value of RO fuel (40.96 MJ/kg, compared to 42.19 MJ/kg from MDO and 42.65 MJ/kg for MGO), resulting in MD specific fuel consumption being 5% higher than for RO.

It is assumed that the sfc of new engines is the same as for existing engine types and fuel combinations, as there have been no major changes in fuel composition or engine technology between 2000 and 2007. Projected sfc factors are also assumed to remain the same as the 2000 values as no significant engine developments are anticipated by 2020; gradual improvements in engine efficiency will lead to a small decrease in sfc and for long term projections (i.e. 2050) the 2000 sfc will be an over-estimate, although this cannot be quantified due to uncertainty in such long term technology development and energy efficiency measures.

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[34] Cooper (2001) states that based on six measurements undertaken on three HSD engines, approximately 2% of the Total VOC consists of CH_4. To provide a conservative assessment a figure of 1% has been used in this study.

8.3 Revised Emission Factors for Year 2007

The year 2000 baseline emission factors used in Entec (2002 and 2005) have been reviewed and updated for the year 2007. These revised emission factors are presented in Table 8.3 to Table 8.5.

Table 8.3 ME emission factors (g/kWh) for 'at sea' 2007

Engine type	/	Fuel type	NO_X pre-2000 engine	NO_X post-2000 engine	NO_X fleet average	SO_2	CO_2	VOC	PM	sfc
						(g/kWh)				
SSD	/	MGO	17.0	14.1	16.0	0.7	588	0.6	0.3	185
SSD	/	MDO	17.0	14.1	16.0	5.6	588	0.6	0.3	185
SSD	/	RO	18.1	15.0	17.0	10.5	620	0.6	1.7	195
MSD	/	MGO	13.2	11.0	12.4	0.8	645	0.5	0.3	203
MSD	/	MDO	13.2	11.0	12.4	6.2	645	0.5	0.4	203
MSD	/	RO	14.0	11.6	13.1	11.5	677	0.5	0.8	213
HSD	/	MGO	12.0	10.0	11.3	0.8	645	0.2	0.3	203
HSD	/	MDO	12.0	10.0	11.3	6.2	645	0.2	0.4	203
HSD	/	RO	12.7	10.5	11.9	11.5	677	0.2	0.8	213
GT	/	MGO	5.7	4.7	5.3	1.2	922	0.1	0.0	290
GT	/	MDO	5.7	4.7	5.3	8.7	922	0.1	0.0	290
GT	/	RO	6.1	5.1	5.7	16.5	970	0.1	0.1	305
ST	/	MGO	2.0	1.7	1.9	1.2	922	0.1	0.3	290
ST	/	MDO	2.0	1.7	1.9	8.7	922	0.1	0.4	290
ST	/	RO	2.1	1.7	2.0	16.5	970	0.1	0.8	305

Table 8.4 ME emission factors (g/kWh) for 'manoeuvring' and 'at berth' 2007

Engine type	/	Fuel type	NO_X pre-2000 engine	NO_X post-2000 engine	NO_X fleet average	SO_2	CO_2	VOC	PM	sfc
			(g/kWh)							
SSD	/	MGO	13.6	11.3	12.8	0.8	647	1.8	0.9	204
SSD	/	MDO	13.6	11.3	12.8	6.2	647	1.8	1.2	204
SSD	/	RO	14.5	12.0	13.6	11.6	682	1.8	2.4	215
MSD	/	MGO	10.6	8.8	9.9	0.9	710	1.5	0.9	223
MSD	/	MDO	10.6	8.8	9.9	6.8	710	1.5	1.2	223
MSD	/	RO	11.2	9.3	10.5	12.7	745	1.5	2.4	234
HSD	/	MGO	9.6	8.0	9.0	0.9	710	0.6	0.9	223
HSD	/	MDO	9.6	8.0	9.0	6.8	710	0.6	1.2	223
HSD	/	RO	10.2	8.5	9.6	12.7	745	0.6	2.4	234
GT	/	MGO	2.9	2.4	2.7	1.3	1014	0.5	0.5	319
GT	/	MDO	2.9	2.4	2.7	9.6	1014	0.5	0.7	319
GT	/	RO	3.1	2.6	2.9	18.1	1067	0.5	1.5	336
ST	/	MGO	1.6	1.3	1.5	1.3	1014	0.3	0.9	319
ST	/	MDO	1.6	1.3	1.5	9.6	1014	0.3	1.2	319
ST	/	RO	1.7	1.4	1.6	18.1	1067	0.3	2.4	336

The vessel database used for this study does not specify the engine type for the AE. Reviewing manufacturers' catalogues indicates that that AE are either MSD or HSD. For this study it is assumed that there is an even distribution of medium and high speed engines in the fleet and, therefore, the emission factor is weighted accordingly. This assumption has been developed from Entec (2002) in which the split of 58% MSD and 42% HSD was based upon information from IVL (2002), since data obtained from LRF was too incomplete to draw useful assumptions and is unlikely to have significantly increased capture since. The IVL assumption came from a study of a small sample and therefore has high associated uncertainty, so it is reasonable to approximate to 50:50. These AE emission factors are presented in Table 8.5 below.

Table 8.5 AE Emission Factors for 'at sea', 'manoeuvring' and 'at berth' 2007

Engine type	/	Fuel type	NO_X pre-2000 engine	NO_X post-2000 engine	NO_X fleet average	SO_2	CO_2	VOC	PM	sfc
			(g/kWh)							
M/H SD	/	MGO	13.9	11.5	13.0	0.9	690	0.4	0.3	217
M/H SD	/	MDO	13.9	11.5	13.0	6.5	690	0.4	0.4	217
M/H SD	/	RO	14.7	12.2	13.8	12.3	722	0.4	0.8	227

8.4 Uncertainty in Emission Factors

When deriving the emission factors for Entec (2002) IVL acknowledged a number of factors which contribute to the final uncertainties in the figures, including:

- The number and representativeness 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; and
- Assumptions made in assigning the factors for a given activity, e.g. main engine operation in port.

The accuracy of the primary data is affected by the measurement uncertainties for different techniques and emission types, based upon uncertainty calculations for accredited marine emission measurement methods. The size and dispersion of the sample on which the IVL and Lloyds measurements were made and how representative this is of the UK fleet is a further contributor.

In the manipulation of the data there is considerable uncertainty in some of the engine load assumptions made. Variations in main engine use in port could increase the calculated emissions significantly. Additionally, when manoeuvring, the performance of cold started engines and the unpredictable nature of engine loads required and will lead to variations in emissions. The uncertainty in AE use at sea is a lesser concern as the contribution of these emissions is minor in comparison to those from the ME.

Table 8.6 expresses the IVL uncertainties as a relative percentage at the 95% confidence interval, as advised in Eurochem (2000). A large fleet operates in EU waters and therefore the average actual emission factors should approximate to the values used in the Entec studies (2002 and 2005). However, when applied to a smaller fleet operating around the UK, the error between the assigned emission factor and the average fleet value will be greater.

Table 8.6 Estimated Uncertainties at the 95% Confidence Interval given as Relative Percent of the Emission Factors (in g/kWh or kg/tonne fuel) (Entec, 2002)

Pollutant	At sea	Manoeuvring	At berth
NO_X	±20%	±40%	±30%
SO_2	±10%	±30%	±20%
CO_2	±10%	±30%	±20%
VOC	±25%	±50%	±40%
PM	±25%	±50%	±40%
Sfc	±10%	±30%	±20%

It should be noted that the use of a combined emission factor for HSD and MSD Auxiliary Engines will increase the uncertainty for NO_x emissions at berth by approximately ±10%, although it is difficult to determine the overall uncertainty introduced without knowledge of the actual split in engine types in use. The other emissions are not dependent on engine design speed.

8.5 Comparison with Other Published Emission Factors

A literature review of other shipping emission studies published since 2005 has been undertaken and comparisons made between the emission factors.

Table 8.7 Comparison of Emission Factors (for Residual Oil) with other Studies; TexAQS II - Williams *et al* (2007) and ERG (2007)

	This study	TexAQS II	Percentage difference from Entec EFs	ERG	Percentage difference from Entec EFs
Year	2007	2007		2007	
S content	2.7 (RO)	1-5% (RO)			
Engine type	SSD manoeuvring	SSD		SSD	
	kg/tonne	**kg/tonne**		**kg/tonne**	
NO_X	67.4		-9.7%[1]		-9.7%[1]
NO_2		74		74	
SO_2	54.0	28	48.1%	8	85.2%

[1] Comparison of NO_X against NO_2. Explanation of why EFs in this study are presented as NO_X is given in Section 8.2.1. For TexAQS II and ERG the EFs are reported as NO_2 and have therefore been represented here as such; presumably all NO_X emissions are reported as NO_2 in this case but that is not explicitly stated in the referenced documents..

Table 8.8 Comparison of Emission Factors (for Marine Distillates) with other Studies; TexAQS II - Williams *et al* (2007) and ERG (2007)

	This study	TexAQS II	Percentage difference from Entec EFs	ERG	Percentage difference from Entec EFs
Year	2007	2007		2007	
S content	Average of 0.2-1.5% (MGO & MDO)	0.1-1% (MDO)			
Engine type	H/MSD manoeuvring	MSD		H/MSD	
	kg/tonne	**kg/tonne**		**kg/tonne**	
NO_X	47.5		-26.2%[1]		-13.6%[1]
NO_2		60		54	
SO_2	17.1	9	47.4%	5	70.8%

[1] Comparison of NO_X against NO_2. Explanation of why EFs in this study are presented as NO_X is given in Section 8.2.1. For TexAQS II and ERG the EFs are reported as NO_2 and have therefore been represented here as such; presumably all NO_X emissions are reported as NO_2 in this case but that is not explicitly stated in the referenced documents..

Table 8.9 Comparison of Emission Factors with other Studies; Eyring *et al* (2005)

	This study	Eyring (2005)	Percentage less than Entec EFs
Year	2000	2001	
S content	2.7 (RO)	2.4 (RO)	11.1%
Engine type	SSD/MSD average at sea	Fleet average	
	kg/tonne	**kg/tonne**	
NO_X	79.3	76.4	3.6%
SO_2	53.9	43.0	20.2%
CO_2	3179	2905	8.6%
HC		7.0	-158.1%[1]
VOC	2.7		
PM	6.2	6.0	2.6%

[1] Comparison of HC against VOCs

California Air Resources Board (2006)

> *"ARB staff developed an alternative PM emission factor for auxiliary engines using heavy fuel oil. Instead of the Starcrest/Entec emission factor for PM of 0.8 g/kWh for auxiliary engine using heavy fuel oil, ARB*

staff used a PM emission factor of 1.5 g/kWh. ARB staff believes the Starcrest/Entec emission factor was too low based on a re-analysis of available data.

Main Engine emission factors for manoeuvring have been adjusted, using methodology described in the Starcrest report, for low speeds. As a result of the revisions, the manoeuvring emission factors decreased by about 22% for diesel PM, 9% for SO_X *and 60% for ROG. The emission factors for* NO_X *more than quadruple for container ships, nearly triple for passenger ships and increased by 63% for tankers."*

As can be seen there is significant variation between sources for emission factors. This can in part be explained by differences in the pollutants for which the emission factors are for, namely HC rather than VOC. Furthermore, differences for SO_2 and PM emissions can partially be attributed to different assumed sulphur content of fuel. It is important to consider the differences between the emission factors used in this study and those presented in other reports, along with the uncertainties stated in 8.4. This may result significant uncertainty in the final emission inventory results, however, there has not been a comprehensive international monitoring regime from which to calculate emission factors and this study is limited to the best data available.

9. Adjustments to Emission Factors for MARPOL Annex VI Revision

9.1 Overview

This section describes the analysis undertaken and the assumptions made in order to develop emission projections for 2020 to take into account the MARPOL Annex VI amendments that were adopted by the IMO in October 2008.

The primary focus of the emission inventory was the 2007 base year and on the basis of Defra' timescales for developing revised emission projections based on the Annex VI amendments, Entec applied broad assumptions to determine appropriate weighted emission factor adjustments from which the revised projections were based. Revised emission estimates were not produced for 2010, although with the introduction of the MARPOL Annex VI amendments from 1 July 2010, it is likely that annual emissions for 2010 would be affected by these more stringent regulations.

Supporting information for the development of weighted NO_X emission factors is included in Appendix B. The adjustments applied to the 2007 emission factors are also presented in Appendix B.

The emissions and fuel consumption estimates for 2020 are presented in Section 12.4.

9.1.1 Projecting emissions into the future

A general discussion concerning the economic drivers for growth in world shipping is included in Section 11. The sections below include specific considerations around growth in demand and what this means in terms of the future vessel fleet and assigned emission factors.

Fleet renewal

For the purpose of projecting forward from 2007, the approximate life cycle for a marine main engine is assumed to be 25 years, which is equivalent to an annual replacement rate of 4% on the basis that the overall fleet size remains constant. Therefore a 4% per annum fleet replacement rate has been assumed when calculating the number of vessels' main engines in each age group (pre-1990, 1990-2000, 2000-2011 and post 2011), for which different NO_X emission limits apply. The ages of main diesel engines have been taken from the 2007 fleet database provided by Lloyd's MIU. This lists 9,442 vessels with 10,926 engines (i.e. this excludes vessels with missing data, e.g. with missing information on the main engine type). Not all vessel records have the date that the main engine was installed; coverage of this field is limited to 80% of engines.

Key assumptions for projecting fleet size through the application of a 4% annual replacement are:

- The fleet size is projected through numbers of main engines. One reason for using this approach is that the NO_X emission limit values apply to engines, not to vessels;
- Main engines listed in the database without a date installed are assumed to be distributed among all age categories as per the distribution of those with main engine installed dates. This may not necessarily be the case due to the possibility that engines without dates may be for older vessels;
- The oldest engines among the fleet are replaced first. For example, the size of the fleet that are of date category 1990-2000 is assumed to stay constant from 2007 to 2011, whilst the number of engines in category 2000-2011 is assumed to increase by the same number that the category of pre-1990 decreases;
- New engines which replace old engines from 2011 are in the category post 2011; and
- The fraction of engines in each age category which do not meet the criteria for applying the NO_X emission limits (two criteria for 'Tier 0', one criterion for Tiers I and II) grows or is replaced at the same rate as the fraction that do meet the criteria for applying the NO_X emission limits. For growth, this has been assumed because it is anticipated that new engines are introduced on the basis of the installed power required for the purpose of the vessel, rather than to be exempt from NO_X emission limits. For replacement, this has been assumed due to lack of additional information.

Applying the above assumptions (without growth) to the 2007 engine fleet gives the fleet distribution in 2020 as shown below in Table 9.1.

Table 9.1 Main Engine Fleet by Age Category and Applicable NO_X Emission Limits

Age category	Applicable NO_X emission limit category	Main engine fleet in 2007	Main engine fleet in 2020
pre-1990	(none)	39.9%	0%
1990-2000	'Tier 0'	18.2%	12.4%
	Exempt from 'Tier 0'	19.4%	13.2%
2000-2011	Tier I	22.4%	34.3%
	Exempt from Tier I	0.1%	0.1%
post-2011	Tier II	0%	39.8%
	Exempt from Tier II	0%	0.1%

Fleet growth

One of the key assumptions when projecting emissions to a future year is the assumed growth rate as discussed further in Section 11. Given the wide range of published growth rates and the high range of uncertainties associated with each, for the purposes of the initial inventory study a low, medium and high estimate of growth was applied to future emission forecasts (2%, 3% and 4% respectively). For the development of the revised emission estimates that take into account the MARPOL Annex VI amendments a growth of 1% was also assumed. This growth rate accounts for both an increase in the size of the fleet and an increase in the number of movements of existing vessels (as it is applied on emissions/fuel consumption).

9.1.2 Considering the revised Fuel Sulphur Limits

Introduction

Prior to the adoption by the IMO of the MARPOL Annex VI amendments, the assumed sulphur contents of fuels incorporated into the emissions inventory were those as shown in Table 9.2. The options for meeting the revised Annex VI regulations are discusses in this section and the assumptions made in terms of fuel type and sulphur content are presented in Table 9.3.

Table 9.2 Entec (2008) Assumed Sulphur Contents of Fuel

Fuel	Assumed sulphur content		
	2007	2010 - 2020 non-SECA	2010 - 2020 SECA
Marine Gas Oil (MGO) (Note 1)	0.2%	0.1%	0.1%
Marine Diesel Oil (MDO) (Note 2)	1.5%	1.5%	1.5%
Residual Oil/Heavy Fuel Oil (RO)	2.7%	2.7%	n/a (i.e. will need to fuel switch)

Note 1 – From 2010, MGO sulphur content assumed to reduce to 0.1% to meet SCMF Directive requirements for use in ports.
Note 2 – MDO is a blend of RO and MGO

In order to determine how the revised MARPOL Annex VI requirements can be met, there is a need to understand:

- The sulphur contents of the different fuels available on the international market;
- The feasibility and/or difficulties associated with switching fuels; and
- The feasibility and/or difficulties associated with SWS.

Sulphur contents of the different fuels available on the international market

Bunkerworld[35] presents the sulphur contents of fuels available on the international market over a selected period of time. For North and West Europe, the following fuel sulphur contents were available in 2008/9:

- MGO: annual average 0.13% S content; range from 0.00% to 1.24%; and
- MDO: annual average 0.96% S content; range from 0.04% to 1.53%.

This suggests that in 2008/9, MDO has rarely been available with a sulphur content of <0.1%, and that although it has been available with a sulphur content of <0.5% this is not very common (the average sulphur content was ~1%). Therefore, for the purposes of this study it has been assumed that a 0.1% sulphur limit in fuels can only be met by MGO and/or MDO combined with SWS, because given that the sulphur content of RO is 2.7% a SWS abatement efficiency of more than 96% would be required to meet the 0.1% S limit value, which is beyond 95% efficiency, often recognised as a limit for SWS.

Fuel switching

It is considered technically feasible for operators to switch fuels, for instance, from RO to MDO, if the vessel already has a dual-tank system that uses low sulphur fuel. *"Fuel switching from RO to a low sulphur fuel like MDO requires certain ship requirements to be in place before fuel switching can be considered. The ship must have dual fuel systems. Each system must have sufficient storage tanks, transfer pumps, separate piping, fuel treating equipment, and measurement equipment. The auxiliaries and boilers must have adjustable equipment so the different fuels will ignite and burn to provide power necessary to safely operate the ship. In addition, ship's personnel must be trained to safely complete the fuel switch operation".* [36]

Although fuel switching from MDO to MGO could be considered easier than switching from RO to MDO (e.g. the latter would require the entire system to be slowly and steadily brought down in temperature, from a high temperature to burn RO, ~165°C, to the lowest temperature, ~38°C, required for burning MGO or MDO) some of the abovementioned requirements are also valid for fuel switching from MDO to MGO, for instance that ships must have dual fuel systems.

Intertanko (the International Association of Independent Tanker Owners) has produced a document with key questions and responses on whether a mandatory global low sulphur cap could work.[37] Key comments that have been useful for deriving assumptions for use in this study include:

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[35] http://www.bunkerworld.com/quality/

[36] Port of Los Angeles, Marine Terminal Berth 408 Project, http://www.pacificenergypier400.com/index2.php? id=58

[37] http://www.intertanko.com/upload/Key%20questions-responses.doc

- All existing engines can safely use low sulphur distillate fuel/DMB grade;
- Switching from RO to MDO (permanently) would need only minor modifications, all of which are in Intertanko's opinion easily manageable. In principle, the main changes would be to the fuel pumps and fuel injection systems;
- Boilers can use low sulphur marine distillate fuels/DMB grade fuel but would need to change injection pumps and burner nozzles; and
- Modifications to existing engines for MDO use therefore do incur a cost.

From the above, it can be concluded that fuel switching is a valid option for operators to consider for meeting the requirements of the revised MARPOL Annex VI (within SECAs and outside of SECAs).

Sea Water Scrubbing (SWS)

SWS is an alternative to the fuel switching option for operators/ship owners to consider for meeting the requirements of the revised MARPOL Annex VI. Key points to note for this are:

- Each engine on board operating on high sulphur fuel will have to be fitted with a separate scrubber unit; [38]
- Retro-fitting abatement equipment in existing ships may not be straightforward due to space, weight and stability constraints because of the additional amount of equipment and water in the funnel area high in the ship; and
- If NO_X ECAs are designated, resulting in Tier III NO_X standards being in place, it is more likely for the fuel sulphur limits to be met by switching fuels, to allow NO_X abatement to be put in place such as SCR (Selective Catalytic Reduction). This is due to two issues: (1) there may be an adverse effect on stability (both are to be mounted in ship exhaust gas systems), and (2) since the exhaust gas temperature from the SWS is about 50°C, substantial reheating to a minimum of 300°C will be required if reduced sulphur gas emissions are to be additionally subjected to NO_X abatement through SCR technology.

Summary of assumptions for fuel switching and uptake of abatement technology

Based on the above brief consideration of both fuel switching and SWS, both are technically feasible to comply with the revised MARPOL Annex VI. It is expected that operators will choose the most suitable option, for each vessel, for meeting these requirements.

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[38] Confidential IMO Annex BLG 12/6/1, 'Report on the Outcome of the Comprehensive Study Undertaken by the Informal Cross Government/Industry Scientific Group of Experts Established to Evaluate the Effects of the Different Fuel Options Proposed under the Revision of MARPOL Annex VI'.

Table 9.3 summarises the potential options available to operators assumed by the present work, for operators to meet the requirements of the revised MARPOL Annex VI (requirements described in Section 2.1.2 and the remainder of Section 9), and the assumed sulphur contents of fuels. Taking an example from the table, given an original fuel type of RO, there are two options to comply outside a SECA; either continue using RO and fit SWS or switch to use MDO at or below 0.5% sulphur. For a vessel originally using RO, fuel switching will be necessary in a SECA; either using MDO at 1.5% and fitting SWS or using MGO which is compliant with 0.1% sulphur.

Table 9.3 Options for Meeting the Requirements of the Revised MARPOL Annex VI (and Assumed Sulphur Contents of Fuels)

Original fuel type	Compliance in Non-SECA	Compliance in SECA
RO	RO (2.7%S)+SWS	MDO (1.5 S%) + SWS
	MDO (0.5% S)	MGO (0.1 S%)
MDO	MDO (0.5% S)	MDO (1.5 S%) + SWS
		MGO (0.1 S%)
MGO	MGO (0.1% S)	MGO (0.1% S)

The following assumptions conclude the approach adopted in the present work:

- 10% of vessels are assumed to fit abatement equipment, i.e. SWS, and the remainder to fuel switch. This was based on published information[39], where a 10% market penetration of SWS has been assumed. Assumptions on the uptake of other potential abatement measures, i.e. switch to LNG (liquefied natural gas) have not been identified and have therefore not been considered for this work (note - it is expected that this will be considered in future revisions of the projections);

- In SECAs in 2020: the 0.1% fuel sulphur limit (or equivalent abatement by SWS) applies, therefore vessels have been assumed to burn either MGO or, if SWS is installed, MDO;

- Outside SECAs in 2020: the 0.5% fuel sulphur limit (or equivalent abatement by SWS) applies, therefore vessels have been assumed to burn either MDO or, if SWS is installed, RO; and

- Other pollutants have been affected by the choice of abatement versus fuel switching:

  - Fuel switching to fuel of lower sulphur content reduces PM emissions, and to a smaller extent when switching from RO to MDO or MGO, CO_2 emissions and fuel consumption are reduced; and

[39] IMO (2008), Revision of MARPOL ANNEX VI and the NO_X Technical code, Input from the four subgroups and individual experts to the final report of the Informal Cross Government/Industry Scientific Group of Experts Note by the Secretariat, Sub-committee on bulk liquids and gases, 12th session, Agenda item 6, 28 December 2007 http://www.endseurope.com/docs/80213b.pdf

- SWS has been applied in order to reduce the SO_2 emissions in accordance with the Annex VI limits. The use of SWS also affects other emission levels, and these have been scaled accordingly, as shown in Table 9.4.

Table 9.4 SWS Assumed Abatement Efficiency

Fuel Type	NO_X	SO_2	CO_2	VOC	PM	sfc
Marine Diesel Oil	-6.5%	-93.3%	+1.9%	0%	-88.7%	+1.9%
Residual Oil	-5.7%	-81.5%	+1.6%	0%	-77.4%	+1.6%

9.1.3 Considering the revised NO_X Limit values

The revised MARPOL Annex VI sets different NO_X limit values for engines depending on their age, power and revolutions per minute (RPM). Due to differences between the RPM classifications used by the revised MARPOL Annex VI and the initial 2007 inventory, the distribution of RPM among the diesel main engines in the 2007 fleet is used to derive a weighted emission factor that can be applied to Entec's RPM categories. The RPM classifications used in revised MARPOL Annex VI are shown in Appendix B; Entec's classifications are slow speed diesel (SSD, $RPM \leq 300$), medium speed diesel (MSD, $300 < RPM \leq 1000$) and high speed diesel (HSD, $RPM > 1000$).

The method to derive such a weighted emission factor is as follows:

i. For each Entec RPM category, the RPM of main engines in the fleet were collated. For 'Tier 0', main engines that did not meet the criteria of age, power and cylinder displacement were discarded from the analysis. For Tiers, II and III, due to their future applicability, no engines were discarded for age restrictions and it was assumed that RPM distribution among future engines would be the same as current RPM distribution. Engines of less than 130 kW make up less than 0.1% of the fleet by number, and were ignored;

ii. A histogram analysis was performed, counting the numbers of engines in defined RPM bins;

iii. The NO_X emission factors ('Tier 0', Tiers II and III) for the midpoint of each bin were calculated; and

iv. A weighted emission factor for that RPM category is found from the sum of (for each bin) the multiplication of the fraction of engines in that bin by the applicable emission factor for that bin.

For example, for 24 engines with RPM in a bin of 230-240 RPM, the applicable Tier II NO_X emission limit value is 12.53 g/kWh (this is based on the emission limit defined in the revised MARPOL Annex VI for this category of $44 \times n^{-0.23} = 44 \times 235^{-0.23}$). Out of the total of 5081 SSD engines, 24 represents 0.47%. The partial factor for this bin is 12.53 g/kWh×0.47%. The weighted emission factor is the sum of the partial factors for each bin.

The histograms that show the distribution of RPM among main engines that was used for Tier II and Tier III weighted NO_X emission limit values are shown in Appendix B.

The results of this histogram analysis were the following emission factors:

- For all engines built between 1/1/1990 – 31/12/1999 (inclusive) that are >5 MW and with per cylinder displacement >=90 *l* the following weighted emission factors (based on 'Tier 0') have been applied in instances when these limits are more stringent than the emission factors for scenarios that do not consider the Annex VI amendment:
  - For SSDs: an emission factor of 16.82 g/kWh;
  - For MSDs: an emission factor of 13.16 g/kWh;
  - For HSDs: an emission factor of 10.05 g/kWh;
- For all engines built 1/1/2000 – 31/12/2010 (inclusive) that are >130 kW the existing NO_X emission factors remain unchanged;
- For all engines built on or after 1/1/2011 that are >130 kW, the following weighted emission factors (based on Tier II) have been applied in instances when these limits are more stringent than the emission factors used for scenarios that do not consider the Annex VI amendment:
  - For SSDs: an emission factor of 14.14 g/kWh;
  - For MSDs: an emission factor of 9.94 g/kWh if lower than existing emission factor;
  - For HSDs: an emission factor of 8.06 g/kWh.

Currently, there are no designated NO_X emission control areas in European waters, thus the Tier III standards have not been considered further. The weighted emission factors for Tier III have however been calculated and are shown in Appendix B.

10. Vessel Routings

As discussed in Section 3, the methodology adopted for this assessment is consistent with past work for the EC that involves the application of a 'ship movement' emissions inventory development approach. This approach enables detailed data on ship movements and engine characteristics to be combined with emission factors to quantify fuel consumption and exhaust emissions from ship movements. Integral to the approach is the development of a detailed route network to enable the determination of port to port distances from which total emissions can be calculated, and determination of the route taken by a vessel to enable the spatial disaggregation of the emissions across the study area.

The movements data provided by Lloyd's MIU have been interrogated to provide individual port to port movements from the arrival and departure port details in the database. The paired ports for each movement are assigned a unique reference ID.

AtoBviaC provides BP Shipping Marine Distance Tables that includes routings between over 2,650 of the world's most frequently visited ports. The Distance Tables fully respect all mandatory and recommended traffic separation schemes and as a result the distance between ports A and B is not necessarily the same as from B to A. All the routes within these tables have been chosen by experienced Master Mariners, rather than being computer generated. The algorithms for calculating the distances for Rhumb, Mercator and Great Circles are all industry approved standards. Whilst the early releases of these tables had a bias towards tanker ports, they now include comprehensive coverage of general and bulk cargo, gas and container ports.[40] Approximately 70% of the routes identified for this study, based on the Lloyd's MIU movements data, have been provided by AtoBviaC Plc as it has been considered the most up to date and accurate shipping routing information available at the outset of this study.

Approximately 28 routes have been identified in this study (0.05% of the total routes) which represent 4% of the total movements in the Lloyd's MIU dataset, which are excluded from the data provided by AtoBviaC. These routes have therefore been selected and manually digitised on basis of the most likely navigable route that the vessel will have taken through the study area.

For the remaining routes, a GIS route network has been developed on the basis of the departure and arrival information. The GIS route network has assumed the shortest and most direct sea route between each port (avoiding land and sea areas identified as un-navigable), across a network of nodes aligned to the 5x5 km grid. A method of distance calculation, which assumes a spherical Earth, has been used within the GIS system to measure the distance between two ports and to calculate the distance travelled on each route within each grid cell. Where populated, the 'passing place' field in that database has been used to assist in assigning the correct route for each journey, particularly where alternative routes exist, for instance when a passing place of 'Brunsbuttel' is present the

[40] http://www.atobviaconline.com/public/default.aspx

vessel is assumed to travel through the Kiel Canal instead of Skagerrak Strait. Ports outside the study area have been assigned an entry/exit point to the study area which has been used for the development of the route network for such movements. Entry and exit points have been selected on a 50 km buffer that has been created around the study area (for the purpose of the route network development only), to ensure that there are no artificial hotspots on the study area boundaries (study are boundaries are shown in Figure 1.1).

For all vessel routings, the length of each route has been calculated for each 5x5 km grid cell, in order to distribute emission estimates geographically. A 12 nautical mile zone buffer has been created and grid cells have been assigned outside/inside the 12 nautical mile zones on the basis of whether the centre of the grid is located outside/inside the buffer.

Changes in vessel routes

The extent of summer Arctic sea ice has been retreating in recent years due to global warming, and climate models project this retreat to continue (IPCC, 2007). This has the potential to open new shipping routes through passages that were previously either seasonally or permanently ice-bound.

The Northern Sea Route (or North East Passage) is a seasonally sea ice-covered shipping passage along the Russian arctic coast. This route is 40% shorter than voyages from Northern Europe to north-eastern Asia and north-western North America, compared to southerly routes via the Suez or Panama Canals. The navigation season is projected to increase by between two and four months (UNEP, 2007). The North West Passage through the Canadian Arctic may also become navigable through the summer months as a commercial sea route.[41]

In addition to increased cargo shipping, the opening of such passages will probably increase the number of tourist cruises and passenger vessels in Arctic waters. The retreat of summer arctic sea ice extent may therefore affect some vessel routes through UK waters, if only during some months of the year. It could affect the location of future emissions in UK waters, and could also affect growth rates.

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[41] http://www.guardian.co.uk/environment/2007/sep/16/climatechange

11. Growth in Shipping to Year 2020

11.1 Introduction

The increase in fuel consumption associated with future growth in seaborne trade has the potential, without policy intervention, to lead to an increase in atmospheric emissions from the shipping sector. The main driver for growth in shipping is the world economy, which has a direct effect upon global ship traffic demand and emissions.

A number of studies identify proxies that can be used to estimate future total emissions, often at a global level, and include:

- Economic activity (GDP and value of imports and exports);
- Trade activity (tonnes and tonne/kilometres);
- Fuel usage (sales and estimates); and
- Installed engine power.

For the development of the UK ship emissions inventory, and in other similar regional studies, the growth in ship movements and associated emissions will not occur uniformly across the spatial extent of the inventory; some regions and even some ports, particularly containerised ports, will exhibit more growth than others. Uncertainties in emission inventories are therefore increased significantly when projecting emissions to future years, partly on the basis of the uncertainties about the magnitude of future growth and the reliability of proxies, but also owing to uncertainties in the geographical distribution of this estimated growth.

This section provides a discussion of the detailed bottom-up approach that is sometimes undertaken, predominantly in global ship emission studies, to determine appropriate growth rates. These approaches are compared to other studies where future emissions have been determined on the basis of standard annual growth rates applied to the baseline emissions.

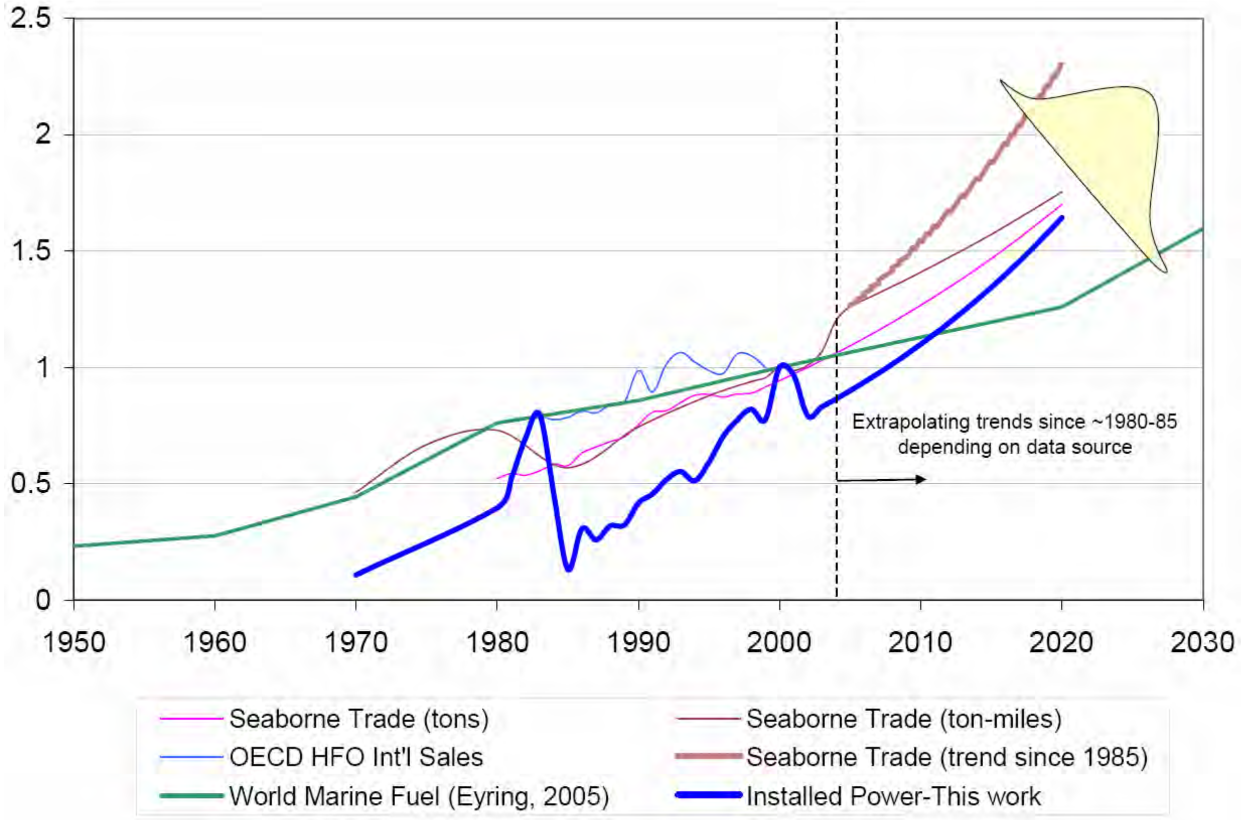
11.2 Growth Rates - Worldwide

Figure 11.1 illustrates this variability in future demand and emissions, comparing historical data (extrapolated to 2030) in energy use/fuel sales, trade-based data (tonnes and tonne-miles) and installed power (derived from average power by year of build). The range of business-as-usual (BAU) trends presented show that world shipping activity and energy use may double from 2002 to about 2030 or for World Marine fuel to about 2050.

Eyring *et al.* (2005) have shown a good correlation between the total volume of seaborne trade and world real GDP; a higher economic growth results in higher total seaborne trade, which in turn affects the number of ships, the total installed power and therefore the total fuel consumption and emissions.

Corbett et al. (2007) identifies that growth rates in shipping are not likely to be reduced without significant changes in freight transportation behaviour and/or changes in shipboard technology.

Figure 11.1 Global Indices for Seaborne Trade, Ship Energy/Fuel Demand, Installed Power (Corbett *et al*., 2007)



11.2.1 Growth in Economic and Trade Activity

As identified by Eyring *et al*. (2005), for the development of future emission scenarios one of the key assumptions in the annual growth is the world's real GDP and in the case of shipping, the most important underlying driver is international trade. Increase in total seaborne trade affects the number of ships, the total installed power, the fuel consumption and the emissions.

Historically, a constant annual growth in GDP did not necessary lead to the same magnitude of increase in seaborne trade. Data reported by Eyring et al. (2005) indicates that World seaborne trade since 1985 has on average increased by 3.3% per annum in terms of volumes and 3.6% in terms of tonne-miles while during this period real GDP grew by an annual average of approximately 2.8%.

From the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) (IPCC, 2000) SRES storylines, several global studies have developed a correlation between the different future demand scenarios driven by future GDP and the total volume of seaborne trade. The SRES scenarios, which are widely used in climate change research, identify four different scenario families that correspond to different assumptions on economic, technical, environmental and social development: A1, A2, B1, and B2. The 'A' scenarios place more emphasis on economic growth, the 'B' scenarios on environmental protection; the '1' scenarios assume higher rates of globalisation, and the '2' scenarios more regionalisation.

In line with these SRES scenarios, Eyring *et al*. (2005) defined the annual growth in World GDP as Medium (2.3% and 2.8%), high (3.1%) and very high (3.6%). These rates of GDP growth were then shown to result in annual increases in total seaborne trade of 2.6%, 3.1%, 3.4% and 4.0%. These derived future volumes of seaborne trade were then used to estimate the required number of vessels, which were then correlated with the future total installed engine power to determine future total fuel consumption and future total emissions.

Based on the historic correlation between global GDP and sea transport demand[42] the IMO has more recently derived estimates for future tonne-mile demand and shipping, and seaborne trade, within the same possible futures outlined by IPCC SRES scenarios. The driving factors of the economy, transport efficiency and energy were identified as affecting different categories of vessels in different ways. When determining future tonne-mile projections, GDP projections in the SRES scenarios were the primary consideration. In total, the report for the IMO evaluated 162 growth scenarios for each year (2020 and 2050), based on three levels of demand growth, three levels of transport efficiency and three levels of speed reduction impacts for each of the 6 SRES scenarios. The number of scenarios considered by the IMO reflects the uncertainties in determining likely future growth in shipping and the associated increase in emissions.

11.2.2 Growth in Vessel Numbers, Installed kW and Fuel Consumption

As discussed above, a forecast increase in seaborne trade influences the required number of vessels and the future total installed engine power. The number of vessels and their total installed power then determines future total fuel consumption and future total emissions.

Eyring *et al*. (2005) identified that from 1970 to 2001 the world-merchant fleet increased rapidly in terms of ship numbers (by 70%), with a corresponding increase in total fuel consumption. They also identified that between 1985 and 2001 the number of ships in the world fleet increased by only 0.3% per year, fuel consumption increased by 2.6% per year, as on average, the installed engine power per ship was higher in 2001 (3.2 MW) than in 1995 (2.81 MW).

Corbett *et al*. (2007) identified that the observed increase in average installed power by year-of-build since 2005 was 10.7% per year, more than twice the rate of world seaborne trade growth, driven by increases in containership

[42] Eyring, V., H. W. Köhler, A. Lauer, and B. Lemper (2005), Emissions from international shipping: 2. Impact of future technologies on scenarios until 2050, J. Geophys. Res., 110, D17306, doi:10.1029/2004JD005620

power which grew at more than 16% annually over this period. It has been identified that during the past 20 years, container transport has grown nearly 10% annually.[43]

As identified in a report for the IMO (2008), this trend cannot be assumed to continue to 2050 since container transport would then in itself exceed the projected tonne-mile levels for world seaborne trade. Instead it was assumed in the study for the IMO that the average growth of containerised transport was 2% higher than other cargo types.

11.3 Growth Rates for UK and Europe

The complex issues around determining future emissions estimates for the shipping sector are borne out in section 11.2 above. Emission inventory studies undertaken on a European scale, where detailed desegregations of emissions are often for impact assessment modelling tend to adopt top-down estimates of growth in emissions, rather than developing estimates of underlying growth on the basis of economic projections and the complex interactions with transport demand, vessel numbers, fleet mix, installed power, fuel consumption and emissions.

Published annual growth factors for European studies show that annual increases in ship movements/emissions have been assumed to range from 1% to 3.9%; these are listed below:

- Entec (2002), applied annual growth rates in emissions of 1.5% and 3% between 2000 and 2010, for all vessels except ferries and fishing vessels. This was justified on the basis of IMO (2000) where the growth in the decade 1990-2000 was of the order 2.5%;
- Derwent *et al*. (2005) used an annual growth rate of 1.25%;
- Entec (2005), on the advice of the EC, applied an annual growth factor of 2.6% for all vessels;
- A study undertaken by Entec (2006) that was part of the development of a Regulatory Impact Assessment for the UK for the SCMFD, used a vessel movement growth factor of 2.6% per annum for cargo vessels, and zero growth for passenger vessels. Data were adjusted from an original specification of 2.6% growth for all vessels;
- Based on the TREMOVE model, Cofala *et al*. (2007) used annual growth rates of 2.5% for cargo vessels and 3.9% for passenger vessels;
- Dore *et al*. (2007) assumed a growth rate for all vessels of 2.5% per annum;
- IMO (2009) included a range of growth scenarios. Based on growth in tonne-miles, the study included assumptions equivalent to annual average growth rates for container ships of 1.9% to 8.0%, and for all other ships, of 0.5% to 3.3%; and

43 Review of Maritime Transport, United Nations Conference on Trade and Development (UNCTAD) 2007

- Entec (2009) in a report for the Maritime and Coastguard Agency regarding the impact assessment of the revised MARPOL Annex VI assumed as a central case an annual growth factor of 1% in fuel consumed.

11.4 Growth Rates for the UK Inventory

Entec has liaised with DECC and DfT regarding long-term trends in fuel consumption and ship callings, with a view to refining estimates of growth for use in this study. The DECC energy trend data are focused primarily on the UK marine bunker market which does not necessarily translate to fuel consumption within UK waters or world bunker supply. The DfT (2006) report provides a range of datasets from which it is possible draw conclusions relating to likely growth in UK imports and exports, freight traffic, port callings and worldwide statistics regarding new vessel registrations. Data for world fleets between 1997 and 2006 provides an average annual increase in new registrations of 3.1% in terms of DWT which fits within the estimates of growth adopted in other published studies.

Given the wide range of growth rates presented in the above literature review, and the high range of uncertainties associated with each, for the purposes of this study, low, medium and high estimates of growth have been applied to future emission forecasts, based on growth rates of 2%, 3% and 4% respectively. In addition, a 1% annual growth rate was added to achieve consistency with other studies commissioned by the DfT and MCA.

The emission factors estimated for each future assessment year have therefore been combined with these estimates of growth in emissions. These growth rates have been used to estimate business as usual emissions for each future year, where baseline emissions in each grid cell are simply increased by the appropriate percentage. The growth rates have therefore been applied uniformly across the study area and a range of future estimates of emissions provided.

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12. Results – Emission and Fuel Consumption Estimates

12.1 Overview

This chapter presents the output of the estimates of fuel consumption and emissions relating to shipping within UK waters.

Initially, Section 12.2 presents the results of the analysis of port calling data presented in Section 5 and specifically what the analysis of LMIU and DfT port calling data meant in terms of adjustment of the base-year inventory to take account of vessel movements that were potentially missing from the dataset used to compile the inventory.

Section 12.3 presents emissions and fuel consumption data for the 2007 base-year of the inventory that includes adjustments based on the port calling analysis discussed in Section 5.

Section 12.6 presents estimates of emissions from incomplete and other problematic movement records within the database. These data are presented to further inform the analysis of uncertainties associated with the development of the emission inventory, but have not been included in the spatially disaggregated inventory where geographical information concerning the location of emissions is unavailable.

Emission and fuel consumption projections, based on the 2007 inventory and incorporating the emission factor adjustments related to the MARPOL Annex VI amendments, are then presented in Section 12.4 for the year 2020.

12.2 Effects of Adjustments of Port Callings

The detailed analysis of port calling data presented in Section 5 has led to the adjustment fuel consumption and emission estimates based on the under-reporting of port callings in the LMIU dataset when compared to statistics available from the DfT.

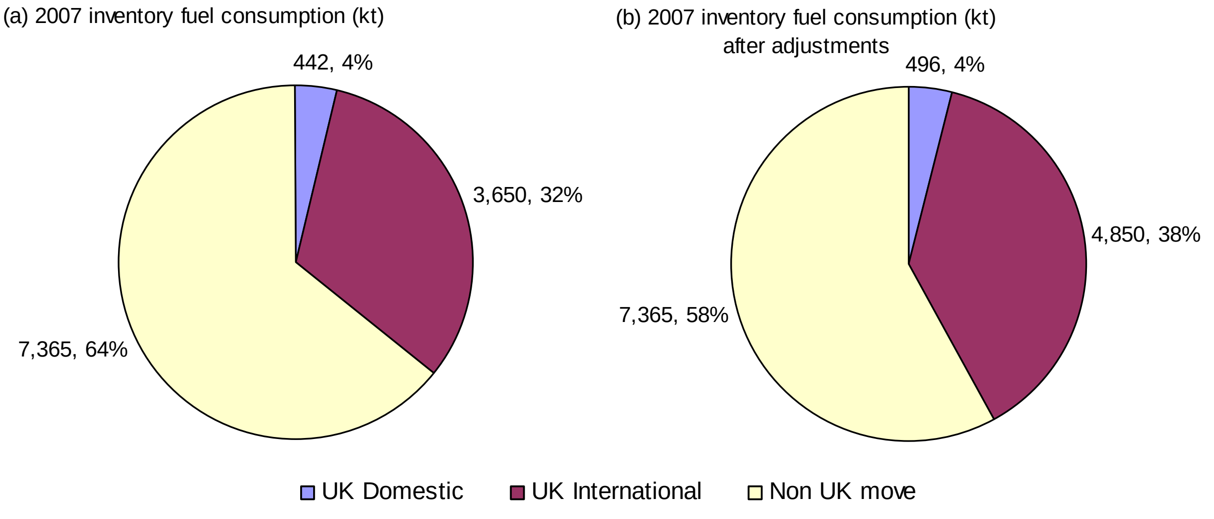
The results in Table 12.1 show, compared to the unadjusted results, that the adjustments following the statistics comparison increase the emissions and fuel consumption by approximately 10% overall. Given that the emissions and fuel consumption within the inventory of non-UK movements remain unchanged, the overall increase for the total of UK domestic and UK international movements is approximately 30%. Furthermore, the UK domestic and UK international have been uplifted by different amounts; the UK domestic estimates are on average adjusted upwards by 11%, whilst the UK international are increased by 33% on average. Since the estimates for UK international movements increase by a greater fraction than the domestic, the split of domestic: international thus shifts further to international: from 11%:89% to 9%:91%.

Table 12.1 Revised Emission and Fuel Consumption Estimates (kT) in 2007 in 'UK waters' as Defined in this Study – Split by Movement and Fuel Type

Movement type	Fuel Type	NO_X	SO_2	CO_2	VOCs	$PM_{2.5}$	PM_{10}	Fuel Consumption
UK Domestic	RO	7	6	328	0.4	0.6	0.7	103
UK Domestic	MDO	17	8	797	0.8	0.5	0.6	251
UK Domestic	MGO	9	1	450	0.3	0.2	0.2	141
UK International	RO	70	49	2,862	2.6	5.8	6.1	900
UK International	MDO	244	103	10,881	9.8	6.3	6.6	3,424
UK International	MGO	32	2	1,673	1.0	0.7	0.7	526
Non UK move	RO	110	75	4,421	4.0	9.2	9.7	1,391
Non UK move	MDO	383	151	15,952	15.6	9.2	9.7	5,019
Non UK move	MGO	58	4	3,037	1.8	1.2	1.3	955
ADJUSTED TOTAL		**929**	**397**	**40,401**	**36.4**	**33.7**	**35.6**	**12,711**
UNADJUSTED TOTAL		**841**	**356**	**36,416**	**33.1**	**30.5**	**32.1**	**11,457**

In terms of fuel consumption, for the purposes of comparison with the DUKES estimates, the total fuel consumption of UK domestic increases from 0.44 Mt to 0.50 Mt (excluding miscellaneous estimates discussed in Section 4.3.2), which remains much less than the 2007 National Navigation total in DUKES of 1.5 Mt, which itself has unknown uncertainties associated with it. The split among movement type of total fuel consumption of the 2007 inventory pre- and post-adjustments are shown in Figure 12.1.

Figure 12.1 2007 Fuel Consumption Split by Movement Type, (a) as Listed in the Original 2007 Inventory, and (b) in 2007 after Adjustments Arising from the Comparison with DfT Statistics.



12.3 Emission and Fuel Consumption Estimates for 2007

Emission estimates for SO_2, NO_X, CO_2, VOCs, $PM_{2.5}$ and PM_{10} as well as fuel consumption for the baseline year (2007) are presented in Table 12.2. Table 12.3 presents emission estimates within the UK 12 nautical mile zone (including the Crown Dependencies within the study area, i.e. Isle of Man, Jersey and Guernsey). Emissions are presented separately for 'at sea', 'manoeuvring' and 'at berth'.[44] It should be noted that $PM_{2.5}$ and PM_{10} are derived as a fraction of total particulate matter, and VOCs are derived as a fraction of total hydrocarbons.

Table 12.2 Emission and fuel consumption estimates (kT) in 2007 in 'UK waters' as defined in this study

	NO_X	SO_2	CO_2	VOCs	$PM_{2.5}$	PM_{10}	Fuel Consumption
At sea	811	355	34,049	30.0	28.7	30.3	10,712
Manoeuvring	10	5	557	0.8	0.6	0.7	175
At berth	108	37	5,795	5.5	4.3	4.6	1,823
TOTAL	**929**	**397**	**40,401**	**36.4**	**33.7**	**35.6**	**12,711**

Table 12.3 Emission and fuel consumption estimates (kT) in 2007 within the UK 12 nm zone

	NO_X	SO_2	CO_2	VOCs	$PM_{2.5}$	PM_{10}	Fuel Consumption
At sea	62	28	2,677	2.3	2.3	2.4	842
Manoeuvring	4	2	229	0.3	0.3	0.3	72
At berth	35	13	1,839	1.7	1.4	1.5	578
TOTAL	**100**	**43**	**4,745**	**4.3**	**4.0**	**4.2**	**1,493**

Table 12.4 presents emission and fuel consumption estimates subdivided by movement type and fuel type. This enables direct comparison with emission estimates for shipping reported in the NAEI presented in Section 12.5.

Emission and fuel consumption estimates for 2007 are further disaggregated in Appendix C and Appendix D, whilst emission estimates are mapped in Appendix E.

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[44] 11% of the total transits recorded in the Lloyd's MIU database cannot be included in the main analysis for estimating emissions, as these transits have an unknown route (i.e. for 'at sea' estimates, vessels that depart and arrive at the same port) or involve a transit to or from a port that cannot be geocoded (e.g. generic places recorded instead of actual ports). These types of movements have been described in more detail in Section 4 and emissions from these are estimated in Section 12.6. Furthermore, emission estimates in land areas (based on the EMEP domain definition) have been excluded from this analysis.

Table 12.4 Emission and fuel consumption estimates (kT) in 2007 in 'UK waters' as defined in this study - split by movement and fuel type

Movement type	Fuel Type	NO_X	SO_2	CO_2	VOCs	$PM_{2.5}$	PM_{10}	Fuel Consumption
UK Domestic	RO	7	6	328	0.4	0.6	0.7	103
UK Domestic	MDO	17	8	797	0.8	0.5	0.6	251
UK Domestic	MGO	9	1	450	0.3	0.2	0.2	141
UK International	RO	70	49	2,862	2.6	5.8	6.1	900
UK International	MDO	244	103	10,881	9.8	6.3	6.6	3,424
UK International	MGO	32	2	1,673	1.0	0.7	0.7	526
Non UK move	RO	110	75	4,421	4.0	9.2	9.7	1,391
Non UK move	MDO	383	151	15,952	15.6	9.2	9.7	5,019
Non UK move	MGO	58	4	3,037	1.8	1.2	1.3	955
TOTAL		**929**	**397**	**40,401**	**36.4**	**33.7**	**35.6**	**12,711**

The mapped estimates for 2007 clearly show, from the 5km by 5km grid resolution, the shipping lanes assumed around the UK, and those grid cells for which emissions are estimated to be higher (i.e. major shipping lanes are coloured red).

12.4 Emission and Fuel Consumption Projections

Emission and fuel consumption estimates have been projected to 2020 and are presented in Table 12.5. It is important to note that the 2010 projections do not take into account the recent amendments to the MARPOL Annex VI and the NO_X Technical Code, which potentially may have had an effect on emissions from 1 July 2010 onwards. These projections for 2010 and 2020 assume annual growth rates (of 1% to 4%) from 2007, and are therefore based on different assumptions to the 2008 and 2009 forecasts presented in Section 13.

Emission and fuel consumption estimates for 2020 are further disaggregated in Appendix C and Appendix D, whilst the spatially disaggregated emission estimates assuming a 1% growth are mapped in Appendix E.

Comparison of the 2020 mapped emission estimates with 2007 maps for each pollutant shows the impact of the different assumptions for 2020 compared to 2007. The most notable different is for the maps of SO_2 emissions (and to a lesser degree the PM emissions), for which emissions in 2020 per grid cell are noticeably lower than in 2007, and furthermore, that the benefit of additional fuel sulphur reductions in the SECAs compared to outside the SECAs is clear (see, for example, the change in emission intensity – i.e. in colour – of the two major pairs of lanes in the English Channel between the SW tip of Cornwall and the NW tip of Brittany). SO_2 emissions outside the SECAs (for example, in the Irish Sea) also reduce between 2007 and 2020 due to the assumed reduction in global fuel sulphur content.

Table 12.5 Emission and Fuel Consumption Projections (kT) in 'UK Waters' as defined in this study

	NO_X				SO_2				CO_2			
Growth:	**1%**	**2%**	**3%**	**4%**	**1%**	**2%**	**3%**	**4%**	**1%**	**2%**	**3%**	**4%**
2010 – MARPOL Annex VI Revision not taken into account												
At sea	836	861	886	912	366	377	388	399	35,081	36,133	37,207	38,301
Manoeuvring	10	10	11	11	5	5	5	5	574	591	609	627
At berth	112	115	118	122	38	39	40	42	5,971	6,150	6,332	6,519
TOTAL	**957**	**986**	**1,015**	**1,045**	**409**	**421**	**434**	**446**	**41,626**	**42,874**	**44,148**	**45,446**
BAU - 2020 - 1% annual growth, MARPOL Annex VI Revision taken into account												
At sea	839	953	1,082	1,227	44	51	57	65	38,443	43,696	49,604	56,243
Manoeuvring	10	12	13	15	1	1	1	1	633	720	817	926
At berth	107	122	138	157	5	6	7	8	6,586	7,486	8,498	9,636
TOTAL	**956**	**1,087**	**1,234**	**1,399**	**50**	**57**	**65**	**73**	**45,662**	**51,901**	**58,920**	**66,805**

Table 12.5 (continued) Emission and Fuel Consumption Projections (kT) in 'UK Waters' as defined in this study

	VOCs				$PM_{2.5}$				Fuel Consumption			
Growth:	**1%**	**2%**	**3%**	**4%**	**1%**	**2%**	**3%**	**4%**	**1%**	**2%**	**3%**	**4%**
2010 – MARPOL Annex VI Revision not taken into account												
At sea	30.9	31.8	32.8	33.7	29.6	30.5	31.4	32.3	11,037	11,368	11,706	12,050
Manoeuvring	0.9	0.9	0.9	1.0	0.7	0.7	0.7	0.7	181	186	192	197
At berth	5.7	5.9	6.1	6.2	4.5	4.6	4.7	4.9	1,878	1,935	1,992	2,051
TOTAL	**37**	**39**	**40**	**41**	**35**	**36**	**37**	**38**	**13,096**	**13,489**	**13,889**	**14,298**
BAU - 2020 - 1% annual growth, MARPOL Annex VI Revision taken into account												
At sea	34.1	38.8	44.0	49.9	13.4	15.2	17.2	19.5	12,095	13,748	15,607	17,696
Manoeuvring	1.0	1.1	1.2	1.4	0.4	0.5	0.6	0.7	199	226	257	291
At berth	6.3	7.2	8.1	9.2	3.3	3.7	4.2	4.8	2,072	2,355	2,673	3,031
TOTAL	**41**	**47**	**53**	**61**	**17**	**19**	**22**	**25**	**14,366**	**16,330**	**18,538**	**21,019**

12.5 Comparison of Emission Estimates with Other Studies

IIASA study (2006)

At the time of developing the 2007 inventory, the most recent report published on shipping emissions that also included estimates for the sea area considered in this study, was the 2006 Final Report to the European Commission, “Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive” undertaken by IIASA, the Norwegian Meteorological Institute and Entec. In said study the emissions inventory calculated emissions in a ‘bottom-up’ way on the basis of kilometres travelled by individual vessels and uses weighted emission factors for each vessel type. It is based on the inventory developed in an earlier study undertaken by Entec on behalf of the European Commission (2002).

Emission estimates from the IIASA study for the ‘UK waters’ as defined in this study have been extracted from the underlying datasets and are presented in Table 12.6.

Table 12.6 IIASA Emission and Fuel Consumption Estimates (kT) in ‘UK waters’

Year: 2000	**NO_X**	**SO_2**	**CO_2**	**VOC**	**$PM_{2.5}$**
At sea	764	527	31,535	25	58
Manoeuvring	8	7	422	1	1
At berth	75	71	4,210	4	6
TOTAL	**846**	**605**	**36,167**	**30**	**65**
Year: 2010	**NO_X**	**SO_2**	**CO_2**	**VOC**	**$PM_{2.5}$**
At sea	914	429	40,559	32	63
Manoeuvring	9	5	543	1	1
At berth	85	27	5,219	5	6
TOTAL	**1,008**	**462**	**46,320**	**38**	**70**

When comparing the results from the current study (Table 12.2) to the results above from previous work, differences would be expected for the following reasons:

- The underlying movements and characteristics data are based on different years. The IIASA study has used Lloyd’s MIU data for 2000 – for European waters, whilst this study has used Lloyd’s MIU data for 2007 – for ‘UK waters’, supplemented by AIS data;
- This study has used a different method for assigning a fuel type, resulting in a higher assumed use of marine distillates compared to residual oil. This would primarily affect SO_2 and PM emissions;

- This study has refined the route network model significantly – primarily by using routes provided by AtoBviaC Plc that are considered the most up to date and accurate shipping routing information currently available;

- A different method has been used to estimate emissions 'at berth' and 'manoeuvring' in the two studies. This study has used departure and arrival dates and times for each calling (data provided by Lloyd's MIU) and has in-filled missing data, whilst the IIASA study used a more generic approach, i.e. assigning an average time 'at berth' and 'manoeuvring' per vessel category, based on data collected from port authorities;

- Emission projections are based on different growth rate assumptions. This study estimates emissions in future years assuming a 1% to 4% growth, whilst the IIASA study presents estimates of emissions in future years based on growth rates consistent with those used in the TREMOVE model, i.e. 2.5% growth for cargo vessels and 3.9% growth for passenger vessels; and

- When comparing the baseline years, this study assumes that all vessels within a SECA comply with the requirements of the SCMF Directive, whilst the IIASA study only considers the SCMF Directive for the projections. For future years both studies take into account the requirements of SCMF Directive, but for the IIASA study a growth is assumed between 2000 and 2010, whilst this study assumes a growth between 2007 and 2010.

Overall, when comparing the results from the current study to the results from the IIASA study, there seems to be a good agreement for the NO_X, CO_2 and VOC emission estimates, although one would expect that for some pollutants (where the fuel type used does not affect significantly emission estimates) the estimates from this study would be significantly higher due to the growth in the shipping sector (the IIASA study would have assumed a 2.5% / 3.9% growth between 2000 and 2007. In practice this level of growth does not appear to have been realised. Without undertaking a very detailed analysis and comparison of the movements data used for this study with the LMIU 2000 movements data, any conclusions on growth cannot be made.

NAEI estimates

The UK NAEI provides UK emission estimates for coastal shipping, UK international shipping and naval shipping based on fuel consumption data provided in the DUKES publication. Emissions are assigned to port areas and coastal zones according to ship arrival data provided by DfT. The port area emissions are mapped on the approximate port locations. Emissions from ships 'at sea' are assigned to the area of the coastline nearest to the relevant port and within 12km of the shore, based on an inverse distance weighting method.[45] Table 12.7 presents the 2006 NAEI emission estimates for coastal shipping for 2006 and 2010, whilst Table 12.8 presents the NAEI emission estimates for UK international shipping and naval shipping for 2006. Table 12.9 presents the fuel consumption data that are the basis of the 2006 NAEI ship emission estimates (fuel consumption for naval shipping provided by the MoD is subtracted out of the fuel totals in DUKES). The 2006 NAEI figures were based on DECC energy projections that were valid at the time the projections were compiled in 2008.

[45] Personal communication with AEA Energy & Environment on 29/07/08

Table 12.7 NAEI Emission Estimates (kT) for Coastal Shipping [46]

Year : 2006	Activity	NO_X	SO_2	CO_2	VOC	$PM_{2.5}$	PM_{10}
Shipping – coastal	Fuel oil	36.4	26.7	1,625	1.8	3.7	3.9
Shipping – coastal	Gas oil	85.7	23.2	3,780	4.1	4.1	4.4
TOTAL		**122.1**	**49.9**	**5,405**	**5.9**	**7.8**	**8.3**
Year : 2010	**Activity**	**NO_X**	**SO_2**	**CO_2**	**VOC**	**$PM_{2.5}$**	**PM_{10}**
Shipping – coastal	Fuel oil	9.5	4.0	-	0.5	1.0	1.0
Shipping – coastal	Gas oil	66.5	18.0	-	3.2	3.2	3.4
TOTAL		**76.0**	**22.0**	-	**3.7**	**4.2**	**4.4**

Table 12.8 NAEI Emission Estimates (kT) for other Shipping Sources for 2006[46]

Source Name	Activity	NO_X	SO_2	CO_2	VOC	$PM_{2.5}$
Shipping – naval	Gas oil	16.5	4.5	198	0.79	0.8
Shipping – international (Note 1)	Fuel oil	19.0	13.9	223.2	0.9	1.9
Shipping – international (Note 1)	Gas oil	17.5	4.7	207.5	0.8	0.8
TOTAL – international (Note 1)		**36.5**	**18.6**	**430.7**	**1.8**	**2.8**

Note 1: International shipping estimates presented are not as per the IPCC definition

Table 12.9 Fuel Consumption (Mt) in 2006 by the Shipping Sector According to DUKES[46]

	Fuel oil	Gas oil
Domestic	0.5041	1.1851
International (Note 1)	1.3127	0.80718

Note 1: For air quality modelling purposes the NAEI assumes that emissions from international shipping emitted in close proximity to the UK are a proportion of the international bunker fuel sales presented in this table (30% of the fuel oil and 20% of the gas oil).

[46] Personal communication with AEA Energy & Environment on 19/08/08 and 29/07/08

Overall, when comparing the results from the current study to the existing NAEI estimates for 2006, it can be concluded that;

- The NAEI estimates are significantly higher for UK domestic movements; and
- The NAEI estimates are significantly lower for UK international movements. This also applies when comparing the NAEI estimates based on the IPCC definition (not presented in this report).

The differences described above are expected, as the current study uses an activity based bottom-up approach to estimate emissions, whilst the NAEI estimates emissions based on UK fuel sales that do not necessarily reflect the fuel consumed by ships in UK waters, e.g. vessels bunkering outside the UK are not included in the emission estimates, whilst vessels bunkering within the UK may be using this fuel outside of UK waters.

12.6 Estimates from Problematic/Miscellaneous Moves - 2007

As described in Section 4.3.2 there are various problematic/miscellaneous movements data provided by Lloyd's MIU. Emission estimates for these movements have not been estimated in the sections above, as this leads to an increased uncertainty, but have been presented for 2007 in the following sections in order to establish the potential significance of these emissions. An uplift was made to the inventory, as discussed in Section 5, to partially account for some of these problematic/miscellaneous movements as well as port callings that were missing from the Lloyd's MIU movements database. It is important to note that the emission and fuel consumption estimates presented in the following sections may be partially located outside the 'UK waters' area as defined in this study.

12.6.1 Movements from and to the same port (at sea emissions)

The database provided by Lloyd's MIU includes movements by vessels that start and end at the same place. For these movements, the route taken by the vessel is unknown. The estimated total emissions from these 40,318 movements are shown in Table 12.10 below.

Table 12.10 Estimated Emissions and Fuel Consumption (kT) from Movements that Depart from and Return to the Same Port in 2007 within the Study Area

Region of Departure	NO_X	SO_2	CO_2	VOCs	$PM_{2.5}$	PM_{10}	Fuel Consumption
EU (Note 1)	40	9	1,944	1.5	0.9	1.0	612
Non EU	24	4	1,167	0.9	0.5	0.6	367
UK	36	7	1,798	1.3	0.9	1.0	566
TOTAL	**100**	**20**	**4,909**	**3.7**	**2.4**	**2.5**	**1,545**

Note 1: Excluding UK

It should be noted that emission estimates 'at berth' and 'manoeuvring' presented in Section 12.3 include estimates for movements that depart from and return to the same port. Therefore, such emissions have not been included in this section. The data presented in this section represent 'at sea' emissions only.

It is worth noting that these emissions estimated for movements from and to the same port may include a significant fraction within 12nm of the coastline. However, these movements may also constitute omissions from the movements database of destination details such that a greater proportion of the emissions may lie outside the 12nm zone. This is therefore an uncertainty inherent in the data set.

12.6.2 Movements to ports without geographic coordinates

The Lloyd's MIU movements database includes movements to places for which there are no geographic coordinates. These places fall into three categories;

i. Known ports without coordinates;

ii. Generic places, e.g. 'Continental Shelf', or 'Scotland'; and

iii. Unknown places – i.e. the movement entry has no record of the destination.

Known ports without coordinates

As described in Section 4.3.2, 120 movements from or to 37 ports have not been included in the gridded inventory, as their location is unknown. The estimated total emissions and fuel consumption 'at sea', 'manoeuvring' and 'at berth' from these 120 movements are shown in Table 12.11 below and are considered highly uncertain. It is unknown whether these 120 movements are within a SECA, thus, emission estimates have been presented as a range, the lowest one assumes that all vessels are required to comply with the SCMF Directive requirements, whilst the highest one assumes that vessels are not required to comply with the SCMF Directive requirements.

Table 12.11 Estimated Emissions and Fuel Consumption (kT) from Movements from or to Ports without Coordinates in 2007

	NO_X	SO_2	CO_2	VOCs	$PM_{2.5}$	PM_{10}	Fuel Consumption
TOTAL	0.4 - 0.5	0.1 - 0.2	17.9 - 18.5	0.02	0.01	0.01	5.6 - 5.8

Generic places

As described in Section 4.3.2, 4,918 movements from or to 15 generic places have not been included in the gridded inventory. The estimated total emissions and fuel consumption from these 4,918 movements are shown in Table 12.12. It is unknown whether these movements are within a SECA, thus, emission estimates have been presented

as a range, the lowest one assumes that all vessels are required to comply with the SCMF Directive requirements, whilst the highest one assumes that vessels are not required to comply with the SCMF Directive requirements.

Table 12.12 Estimated Emissions and Fuel Consumption (kT) from Movements from or to Generic Ports in 2007

	NO_X	SO_2	CO_2	VOC	$PM_{2.5}$	PM_{10}	Fuel Consumption
Belgium	0	0	0.2	0	0	0	0.1
continental shelf	0.9	0.1	47.6	0.04	0.02	0.02	15.0
France	0	0	0.4	0	0	0	0.1
Germany	0	0	0.0	0	0	0	0
Netherlands	0	0	0.1	0	0	0	0
North Europe	0.7	0.2 - 0.4	24.9 - 26	0.02	0.01 - 0.05	0.01 - 0.06	7.8 - 8.2
North Sea	0.6	0.2 - 0.3	22.1 - 23	0.02	0.01 - 0.05	0.01 - 0.05	6.9 - 7.2
Norway	0.1	0	3.1 - 3.2	0	0 - 0.01	0 - 0.01	1
U.K.	0	0	0.2	0	0	0	0.1
TOTAL	**2.3**	**0.5 - 0.8**	**98.6 - 100.7**	**0.08**	**0.04 - 0.13**	**0.04 - 0.14**	**31 - 31.7**

Movements with unknown destination

As described in Section 4.3.2, there are 1,106 movements without a specified destination, representing 0.25% of the total number of movements recorded in the Lloyd's MIU database. For these movements, fuel consumption and emissions have been estimated by assuming that the missing 0.25% movements represent 0.25% of total fuel consumed 'at sea'. Therefore, as discussed in Section 12.3, it is highly likely that the emissions and fuel consumption presented are an over-estimate.

Table 12.13 Estimated Emissions and Fuel Consumption (kT) from Movements from with an Unknown Destination in 2007

	NO_X	SO_2	CO_2	VOCs	$PM_{2.5}$	PM_{10}	Fuel Consumption
At sea	1.8	0.8	76.6	0.07	0.06	0.07	24.1

12.6.3 Estimates from smaller vessels and fishing vessels - 2007

As described in Section 4.3.1, due to limited published information, the approach adopted for estimating emissions from these sources is to assume that the fuel consumption for vessels in the range 100-500 GT is approximately 5% of the total fuel consumption. It is important to note that these estimates are highly uncertain and most probably an overestimate as these smaller vessels may be primarily consuming marine distillates.

Table 12.14 Estimated Emissions and Fuel Consumption (kT) from Smaller Vessels (Typically <500 GT) and Fishing Vessels in 2007

	NO_X	SO_2	CO_2	VOCs	$PM_{2.5}$	PM_{10}	Fuel Consumption
At sea	36.7	16.0	1532	1.35	1.29	1.37	482
Manoeuvring	0.4	0.2	22	0.03	0.03	0.03	7
At berth	5.0	1.7	267	0.26	0.20	0.22	84
TOTAL	**42.1**	**17.8**	**1821**	**1.65**	**1.52**	**1.61**	**573**

12.7 Summary of Total Emission and Fuel Consumption Estimates (Including Miscellaneous Moves) - 2007

Total emission estimates for SO_2, NO_X, CO_2, VOCs, $PM_{2.5}$, PM_{10} and for fuel consumption for the baseline year for 'UK waters' as defined in this study are presented in Table 12.15.

Table 12.15 Total Emissions and Fuel Consumption (kT) Including Miscellaneous Moves in 'UK waters' as Defined in this Study

	NO_X	SO_2	CO_2	VOC	$PM_{2.5}$	PM_{10}	Fuel Consumption
Spatially disaggregated estimates							
At sea	811	355	34,049	30.0	28.7	30.3	10,712
Manoeuvring	10	5	557	0.8	0.6	0.7	175
At berth	108	37	5,795	5.5	4.3	4.6	1,823
Sub – TOTAL (in MT)	**0.93**	**0.40**	**40.4**	**0.04**	**0.03**	**0.04**	**12.7**
Miscellaneous estimates (not spatially disaggregated)							
From port = To port	100	20	4,909	3.67	2.38	2.51	1,545
No coordinates	0.4 - 0.5	0.1 - 0.2	17.9 - 18.5	0.02	0.01	0.01	5.6 - 5.8
Generic ports	2.3	0.5 - 0.8	98.6 - 100.7	0.08	0.04 - 0.13	0.04 - 0.14	31 - 31.7
Unknown destination	1.8	0.8	76.6	0.1	0.1	0.1	24.1
Vessels <500GT	42.1	17.8	1820.8	1.7	1.5	1.6	572.8
Sub – TOTAL (in MT)	**0.1**	**0**	**6.9**	**0**	**0**	**0**	**2.2**
TOTAL (in MT)	**1.0**	**0.40**	**47.3**	**0.04**	**0.03**	**0.04**	**14.9**

Overall, miscellaneous estimates represent approximately 10-15% (depending on the pollutant) of total spatially disaggregated estimates, although it should be noted that miscellaneous estimates are highly uncertain. The results also suggest that from the miscellaneous estimates the most considerable are the emission estimates for movements that start and end at the same port. For these movements, the route taken by the vessel is unknown, thus the geographical location of the emissions is uncertain.

At the time of writing, it is envisaged that a part of the emissions estimated in this study will be incorporated into the NAEI to be published in December 2010. In order to retain consistency with the spatially resolved inventory, only the spatially disaggregated estimates form the basis of the emissions that are to be incorporated into the NAEI. For reporting emissions to UNFCCC and UNECE / CLRTAP, and as agreed with Defra, DECC and DfT, the NAEI and GHGI will report domestic emissions using the Entec figures, but emissions from international shipping will be reported as a Memo item based on the residual fuel assumed to be from international bunkering in order to be consistent with the total fuel consumption data from national energy statistics as given in DUKES.

13. Estimating Annual Emissions for 1990 to 2009

13.1 Introduction

As part of a separate work package begun in autumn 2009, Entec has explored the back-casting of the 2007 inventory annually to 1990, and projecting forward to 2008 and 2009 for the purposes of providing data for the NAEI. Emissions are back-casted to 1990 as this is the reference year for reporting emissions under the Gothenburg Protocol.

Previously, the NAEI has considered using annual DUKES fuel consumption data as a proxy for assessing annual shipping fuel consumption and emissions estimates. However, given the high variability of annual DUKES data, such an application would lead to significant and, perhaps, unlikely annual estimates.

This section explores the use of alternative proxies for back-casting and forecasting fuel consumption and emission estimates, and to produce back-casted annual inventories to 1990 and forecasted inventories for 2008 and 2009 using top-down adjustments from the 2007 inventory. It was not within the scope of the assessment to undertake detailed bottom-up adjustments to the 2007 inventory.

13.2 Methodology

A methodology has been developed to improve upon the application of DUKES fuel consumption data. This methodology attempts to incorporate a number of proxies to adjust the 2007 inventory top-down (but at varying levels of aggregation). Variables that have been considered include:

- Trends in activity – changes in vessel movements over time, which is affected by changes in the number of vessels, and their size (e.g. a trend of increasingly large container ships);
- Trends in fuel types in use over time – the 2007 inventory includes assumptions to separately consider fuels used by vessels operating within and outside of SECAs, which would need to be adjusted for previous years; and
- Emission factor trends – the 2007 inventory includes assumptions about the rate of progress of NO_X emission reductions from main engines from the year 2000. Also, the sulphur content of fuels over the period is considered.

These factors are considered in turn.

13.2.1 Activity changes over time

The DfT's annually published Maritime Statistics compendium includes a number of statistical time series which can potentially be used as proxies for activity rate changes, which are indicators of fuel consumption and thus emissions. Copies of past compendia can be used to complete the 1990-2009 annual time series, although care must be taken to ensure there are no discontinuities in the scope of the statistics. The published statistical time series include:

i. All ports freight traffic, disaggregated by domestic [47] and international (Table 1.1 in 2009 publication). This series is available annually 1990-2009, is based on tonnes of cargo;

ii. All ports main unitised traffic (statistics recorded as numbers of units), which includes conventional containers lifted on/off and those rolled on/off (Ro-Ro), disaggregated by domestic and international (Table 2.2 in 2009 publication). This time series is available from 1990 to 2009;

iii. International and domestic sea passenger movements (Tables 3.1 and 3.3 in 2009 publication). The international movements are compiled from statistics collected monthly from cruise and ferry operators, and include drivers of lorries, coaches and other vehicles. The 1997 and 1998 datasets are missing information on cruise passengers, but as the 1999 figures comprise 1% of total passenger numbers, this data gap is considered insignificant. The domestic passenger movements are compiled from monthly returns to DfT by domestic ferry operators and supplemented by annual surveys of other operators conducted by DfT and the Scottish Executive. Both the international and domestic series are publicly available from 1993 to 2009 – the years 1990-1992 have been extrapolated from 1993-2007 linear trends; and

iv. Arrivals at UK ports as number of vessels (Table 3.7 in 2009 publication). The published data do not differentiate by vessel category and have not been considered further in the analysis.

As can be seen, ranges of time series trends exist that apply to specific vessel categories. As such different proxies were applied to each vessel type. Similarly, where the proxies differentiated between domestic and international movements, separate proxies were considered for each movement type. Passing movements were assumed to follow international trends, and therefore the international proxy was applied.

Trend (i) has been applied to Entec’s vessel categories of Bulk Carrier, General Cargo and Tanker, trend (ii) has been applied to Container Ship and Ro-Ro cargo, and trend (iii) to Passenger. The category of ‘Others’ will have trend (i) applied but not disaggregated by domestic/international (i.e. the total trend) because many of the vessel types included in the category of ‘Others’ are vessels such as tugs and dredgers (among others), which service both international and domestic traffic.

Not included in the above discussion are fishing vessels. A separate publication of statistical time series was sourced for this vessel category, namely the United Kingdom Sea Fisheries Statistics which is produced by the Marine Management Organisation.[48] Table 3.3 of the 2009 publication lists total quantity (in tonnes) of fish landed

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[47] Domestic is the combined total of ‘coastwise’ and ‘one-port’ traffic.

[48] Available online at http://marinemanagement.org.uk/fisheries/statistics/annual.htm

in the UK, by UK and foreign vessels as an entire time series 1990-2009, which was then applied as both a domestic and international proxy (trend (iv)).

As a note about the continuity of the statistical series, the DfT has expressed confidence about the continuity of the collected freight and passenger traffic statistics series.[49] It is worth noting that the collection systems changed in 1995 and 2000 for freight statistics (passenger statistics were unaffected), but in the DfT's opinion this would not have had much effect on the series continuity, which is backed up by the lack of obvious discontinuities in the series. More caution would have been necessary had any of the statistical series of 'Major ports' been used as proxies, as the threshold for designation as a 'Major Port' halved.

A summary of the proxies used is presented in Table 13.1 and their indexed trends 1990-2009 displayed in Figure 13.1, indexed to the year 2007. The application of the proxy to the 2007 follows the equation below:

$$\left|\text{Backcasted inventory}\right|_{Year} = \left[\text{2007 inventory}\right] \times \left|\text{Proxy index}\right|_{Year}$$

Table 13.1 Summary of Historical Statistics Trends Applied as Proxies of Activity Data

Source	Trend		Trend sub-category	Trend applied as activity proxy to			
				Vessel Category	D	I	P
DfT Maritime Statistics	(i)	All ports traffic (thousand tonnes)	All foreign and domestic traffic	Others	X	X	X
			Domestic traffic	Bulk Carrier, General Cargo, Tanker	X		
			Foreign traffic			X	X
	(ii)	All ports, main freight units (thousand units)	Coastwise traffic	Container Ship, Ro-Ro Cargo	X		
			Foreign traffic			X	X
	(iii)	UK international sea passenger movements (number)	N/A	Passenger		X	X
		UK domestic waterborne passenger movements (number)	N/A	Passenger	X		
MFA UK Sea Fisheries Statistics	(iv)	Landings into the UK by UK and foreign vessels (thousand tonnes)	N/A	Fishing	X	X	X

'Trend applied as activity proxy to': D = UK domestic, I = UK international and P = passing movement

[49] Personal communication with DfT, 23rd October 2009.

Figure 13.1 Summary of Historical Statistics Trends Applied as Proxies of Activity Data

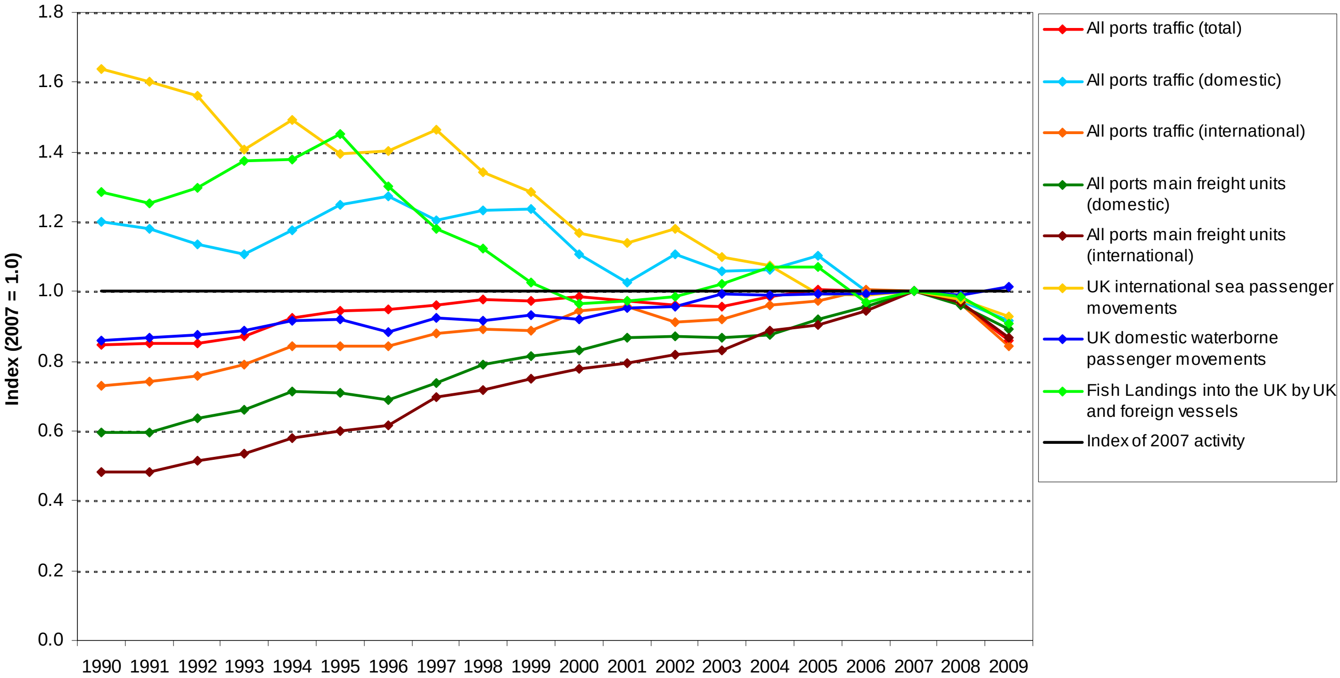


Figure 13.1 shows that five of the eight trends show increasing activity over the 1990-2007 period: traffic (total and international), unitised traffic (total, domestic and international) and domestic passenger numbers. The remaining three trends of domestic traffic, international passenger numbers and fish landings show declining activity over the period 1990 to 2007. The unitised traffic trends demonstrate the highest rates of increase; international unitised traffic more than doubles over the period (107% increase), whilst domestic unitised traffic increases by two thirds (68%). Total traffic, international traffic and domestic passenger numbers increase by smaller amounts over the period: increases of 18%, 37% and 19% respectively. The fastest rate of decline is from international passenger numbers which fall by over 60% between 1990 and 2007 (with some annual variability). Domestic traffic and fish landings fall by 20% and 30% respectively over the period, although with considerable annual variation in trends. Almost all the trends show decreasing activity in the period 2007-2009.

13.2.2 Fuel type changes over time

Section 7.6 described the year 2007 assumptions for the fuel types used by each vessel category, separately for main and auxiliary engines. There were separate assumptions used depending on whether the movement (or part-movement) was within a SECA. As described in Section 2, the two SECAs of relevance to the 2007 inventory – the Baltic Sea and the North Sea & English Channel SECAs; imposed fuel sulphur content limits from mid 2006 and mid 2007 respectively, such that the 2007 inventory assumed that the North Sea SECA was in force for the whole 2007 calendar year. This assumption resulted in increased use of distillates compared to residual oil.

A second assumption relating to the fuel used by passenger vessels outside of SECAs (listed in Table 7.5) was that passenger vessels were assumed to be using MDO in order to comply with the SCMF Directive. This assumption was changed for the main engine category as the SCMF Directive 2005/33/EC did not apply 1990-2006, which agrees with information gathered from the MCA that passenger vessels were likely to be using residual oil in the period before 2007.[50]

The assumptions for the back-casted inventories 1990 to 2006 will therefore follow the assumptions for fuel types used outside SECAs. These are listed in Table 13.2.

Table 13.2 Assumed Fuel Types used per Vessel Category for both Main Engines and Auxiliary Engines

Vessel Category	2007 Inventory and 2008-2009 forecasted inventories				1990-2006 back-casted inventories	
	In SECA		Outside SECA			
	ME	AE	ME	AE	ME	AE
Bulk Carrier	MDO	MGO	RO	MGO	RO	MGO
Container Ship	MDO	MDO	RO	RO	RO	RO
General Cargo	MDO	MGO	RO	MGO	RO	MGO
Passenger (Note 1)	MDO	MDO	MDO	MDO	RO	MDO
Ro – Ro cargo (Note 2)	MDO	MDO	RO	RO	RO	RO
Tanker	MDO	MGO	RO	MGO	RO	MGO
Others (Note 3)	MGO	MGO	MGO	MGO	MGO	MGO
Fishing (Note 4)	MGO	MGO	MGO	MGO	MGO	MGO

Note 1: For Passenger vessels with a kW Power greater than 4 times the deadweight of the vessel, it is assumed that the ME fuel type is MGO and the AE fuel type is MGO.

Note 2: For Ro-Ro Cargo vessels of gross tonnage <5,000 GT it is assumed that the AE fuel type is MGO.

Note 3: For 'Other' vessels of gross tonnage >25,000 GT it is assumed that the ME fuel type is MDO.

Note 4: For Fishing vessels of gross tonnage >25,000 GT it is assumed that the ME fuel type is MDO.

[50] Personal communication with the MCA, 9th November 2009.

13.2.3 Emission factor changes over time

NO_X

As stated in Section 8.2.1, engines installed on ships from 1st January 2000 must comply with the NO_X Technical Code. As such, the NO_X emission factor assumed in the 2007 inventory was based on the assessment of engine age distribution among the 2007 fleet from the Lloyds database, (in which the age of 79% of the vessels was listed) in order to appropriately weight the average of post- and pre-2000 emission factors. Thus the same methodology as that used to derive 2007 NO_X emission factors has been employed to calculate emission factors for previous years.

In order to do this, it was assumed that the age profile of the unknown vessels was in the same ratio. The engine distribution was back-calculated to 1999 on the basis that there must be 0% post-2000 engines and 100% pre-2000 engines in 1999; this was equivalent to an annual replacement rate of 4.5%. Previously, engine replacement rates of 4% were assumed. The discrepancy indicates that, in the vessels of unknown age, there was likely to be a higher proportion of pre-2000 engines than in the ratio of known engines. The emission factors 1990-1999 remained constant.

SO_2

Data sources for assumptions on fuel sulphur content to supplement the assumptions in the 2007 inventory include:

- Entec (2005) for assumptions on MDO and RO sulphur contents for the year 2000;
- CONCAWE (1994) for assumptions on MDO and RO sulphur contents for the year 1992; and
- CONCAWE (1993) for assumptions on MGO and RO sulphur contents for the year 1990.

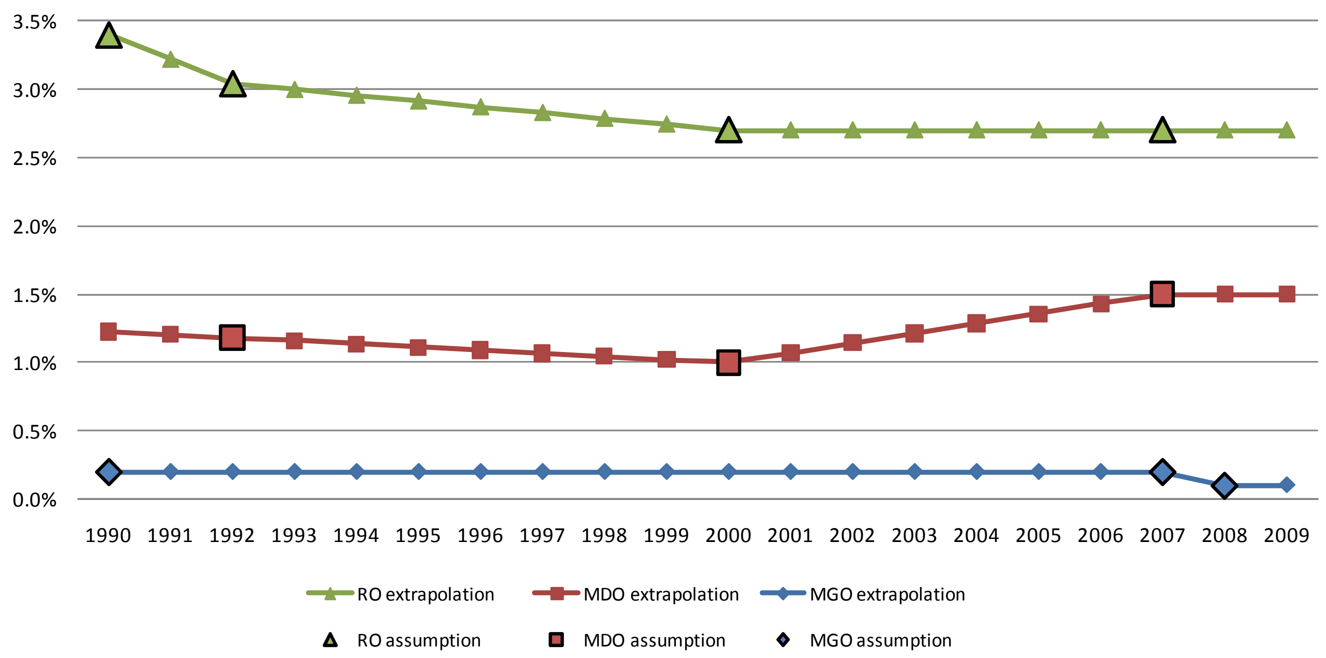
Sulphur contents of fuels for intervening years have been calculated assuming a linear trend between the known figures. Uptake of SWS is assumed to be 0% as there are only a limited number of vessels fitted with this abatement technology. A summary of the fuel sulphur content assumptions are shown in Table 13.3, and a plot of the inter-year extrapolations is shown in Figure 13.3. The sulphur content of MGO has been assumed to be 0.1% from 2008.

Table 13.3 Assumptions on Fuel Sulphur Contents in 1990, 1992, 2000 and 2007

Fuel type	Fuel sulphur content (%)				
	1990	1992	2000	2007	2008/9
Marine gas oil (MGO)	0.2%	-	-	0.2%	0.1%
Marine Diesel Oil (MDO)	-	1.18%	1%	1.5%	1.5%
Residual Oil (RO)	3.40%	3.04%	2.7%	2.7%	2.7%

Note: Intermediate year sulphur contents calculated assuming linear trend between the data points.

Figure 13.2 Assumed Fuel Sulphur Contents 1990 to 2007 (Extrapolations are based on Linear Trends between Data Points)



PM, CO_2 and VOC

PM emission factors will change due to the difference in sulphur content, however no other changes in PM (e.g. due to fuel quality) are expected in this period. Similarly no changes are expected in the emission factors for CO_2 or VOCs.[51]

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[51] Personal communication with UKPIA, 30th September 2009.

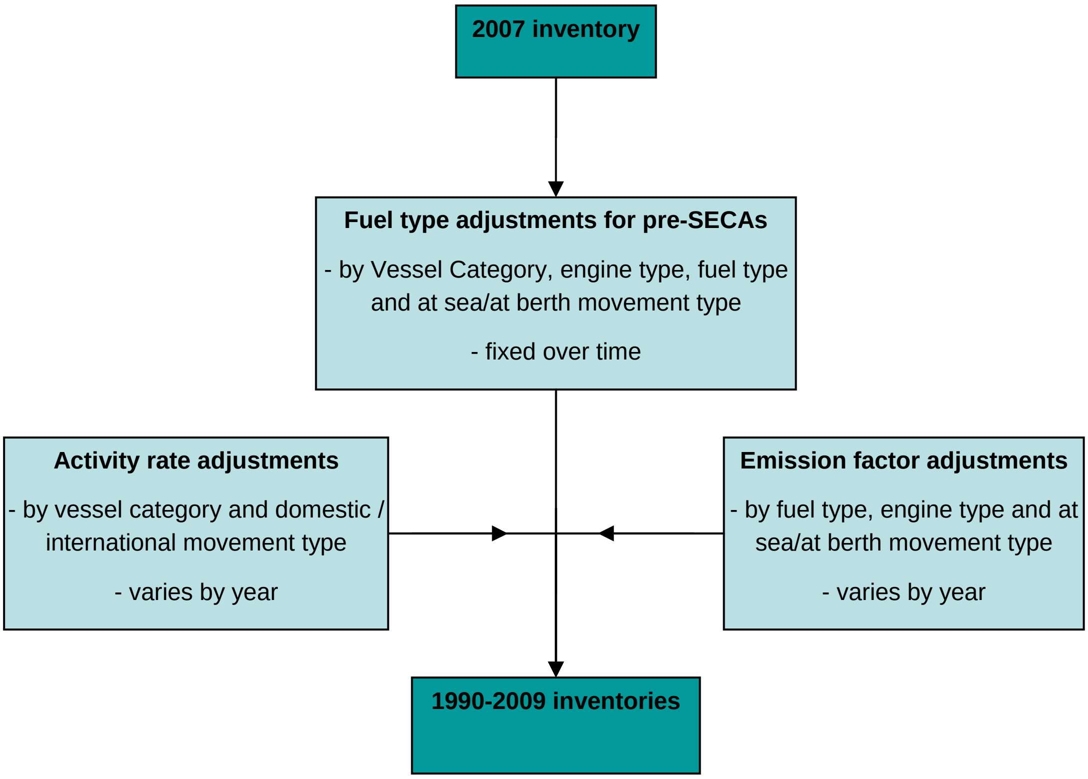
Specific fuel consumption

MARPOL Annex VI was drafted in the mid-1990s using a specific fuel consumption (sfc) figure of 200 g/kWh. This is in-line with the values used to develop the 2000 emission factors and the 2007 baseline; therefore no adjustment is made to sfc.

13.2.4 Overview of the methodology

To summarise the top-down adjustment methodology that back-casts and forecasts the 2007 inventory to produce annual inventories 1990-2006 and 2008-2009, described in the above sections, Figure 13.3 shows the stages involved in the adjustment. The first stage applies adjustment factors (split by vessel category, engine type, fuel type and at sea/at berth) to the 2007 inventory to alter the fuel type assumptions used therein to those applicable for the period 1990-2006 (this is not applicable to 2008/9 forecasts). As these assumptions do not change over time this produces a revised 2007 inventory using fuel types from the period 1990-2006. The second stage uses two additional sets of adjustment factors, one to adjust for activity rate changes using the historical statistics time series (these factors are disaggregated by vessel category, and by domestic/international/passing movement type), and a second for changes in the emission factors over time (disaggregated by fuel type engine type and at sea/at berth).

Figure 13.3 Overview of Top-down Adjustment Methodology for Producing 1990-2009 Inventories



13.3 Results

The annual total back-casted emission and fuel consumption inventories for the period 1990 to 2009 are shown in Table 13.4. These results are plotted indexed to the 2007 inventory below in Figure 13.4.

Table 13.4 Summary of Emission and Fuel Consumption Estimates (kT) for Each Year 1990-2009 in 'UK waters' as Defined by this Study

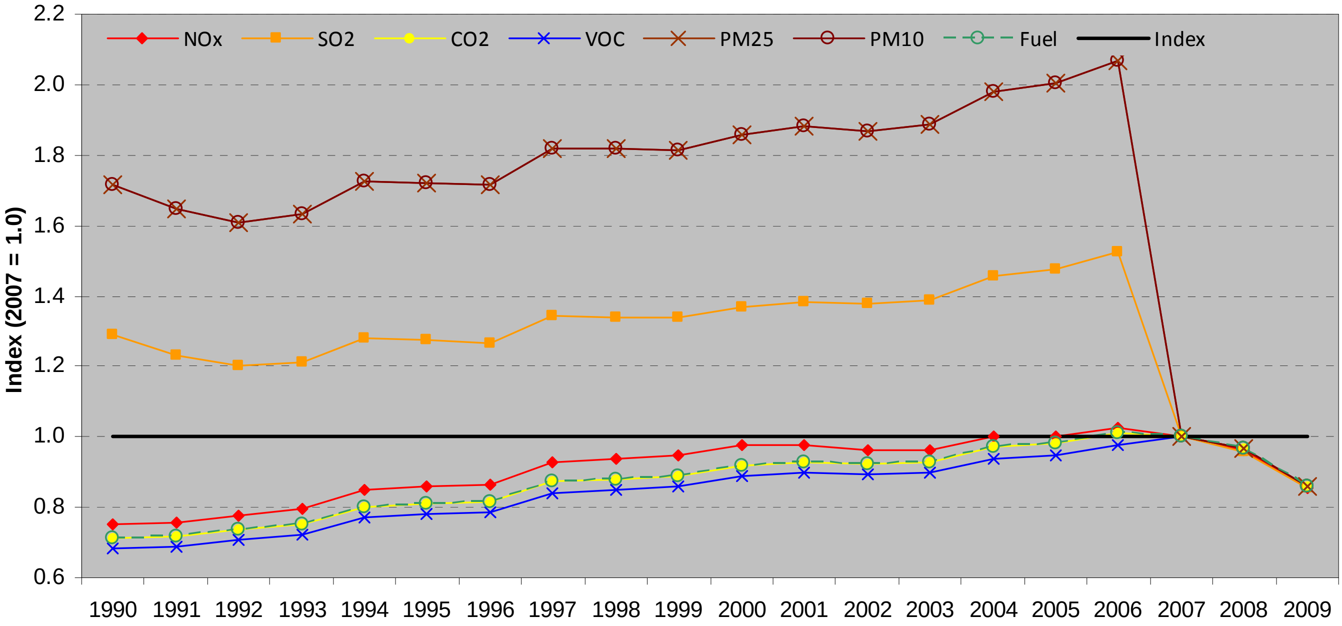
Year	NO_X (kT)	SO_2 (kT)	CO_2 (kT)	VOC (kT)	$PM_{2.5}$ (kT)	PM_{10} (kT)	Fuel consumption (kT)
1990	698	512	28,798	24.9	57.9	61.1	9,058
1991	703	489	28,976	25.1	55.5	58.6	9,114
1992	723	477	29,754	25.8	54.3	57.3	9,359
1993	739	481	30,358	26.4	55.1	58.1	9,549
1994	790	507	32,412	28.1	58.1	61.3	10,195
1995	797	505	32,673	28.4	58.0	61.2	10,277
1996	804	503	32,948	28.6	57.8	61.0	10,364
1997	863	534	35,285	30.6	61.2	64.7	11,099
1998	872	532	35,597	30.9	61.2	64.6	11,197
1999	880	531	35,908	31.2	61.1	64.5	11,295
2000	906	542	37,150	32.4	62.7	66.1	11,686
2001	908	549	37,509	32.7	63.4	66.9	11,798
2002	896	547	37,293	32.4	63.0	66.5	11,730
2003	894	551	37,474	32.6	63.5	67.0	11,787
2004	929	579	39,209	34.1	66.7	70.4	12,333
2005	932	586	39,614	34.5	67.5	71.3	12,460
2006	953	605	40,796	35.5	69.7	73.6	12,832
2007	929	397	40,401	36.4	33.7	35.6	12,711
2008	895	381	39,079	35.2	32.5	34.3	12,295
2009	796	339	34,804	31.3	28.9	30.5	10,950

The indexed estimates in Figure 13.4 show more clearly the trends in the inventories over the period 1990-2009. NO_X, CO_2, VOC emissions and fuel consumption all increase every year 1990-2006 except in 2002, whilst SO_2 and PM emissions show decreases (compared to the previous years) for the years of 1991, 1992, 1996, 1999 and 2002.

All pollutants (except VOCs) emissions and fuel consumption decrease between 2006 and 2007 as the assumptions regarding the inventory shift to take into account the introduction of the North Sea and English Channel SECA.

SO_2 and PM emissions show sharp declines to 2007, whilst NO_X, CO_2 and fuel consumption show minor declines. Decreases continue in 2008 and 2009 for all pollutants and fuel consumption.

Figure 13.4 Emission and Fuel Consumption Estimates for Each Year 1990-2007 in 'UK waters' as Defined by this Study, Indexed to Year 2007



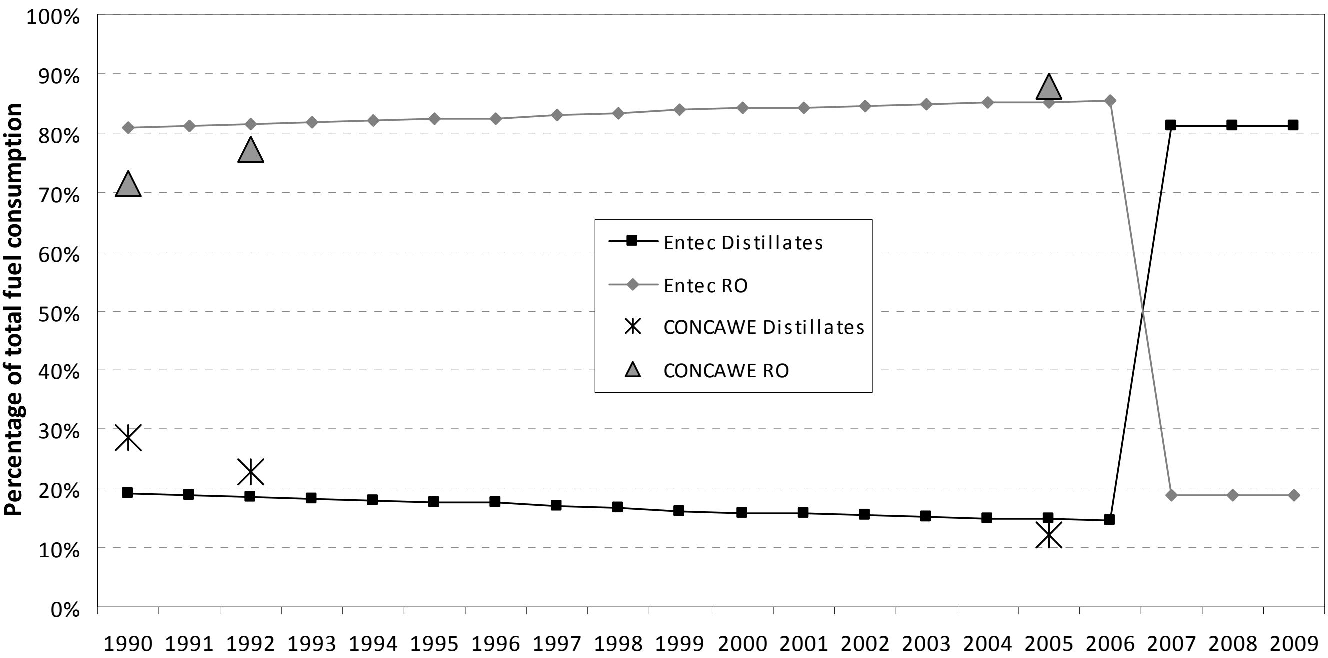
13.3.1 Comparison of results with other sources

The back-casted inventory results of the ratio of distillate fuel use to residual oil use has been compared to figures available in the following published reports:

- CONCAWE (1993) – year of data is 1990; scope is total international and national world bunker demand;
- CONCAWE (1994) – year of data is 1992; study area is the English Channel and the southern North Sea; and
- CONCAWE (2006) – year of data is 2005; scope is EU-27 demand.

The comparison is shown in Figure 13.5. The plot shows a trend of increasing use of residual oil over the period 1990 to 2006, which is both consistent with the trend shown by the CONCAWE data points and with the trend over the same period of increasing fuel prices which pushes marine fuel demand towards greater residual oil use. This trend was supported by consultation with the MCA. The plot also shows a shift in the split between residual and distillate fuel use between 2006 and 2007 – this is due to the assumptions regarding the introduction of the North Sea SECA, and the relevant fuel type assumptions that accompany this policy step change.

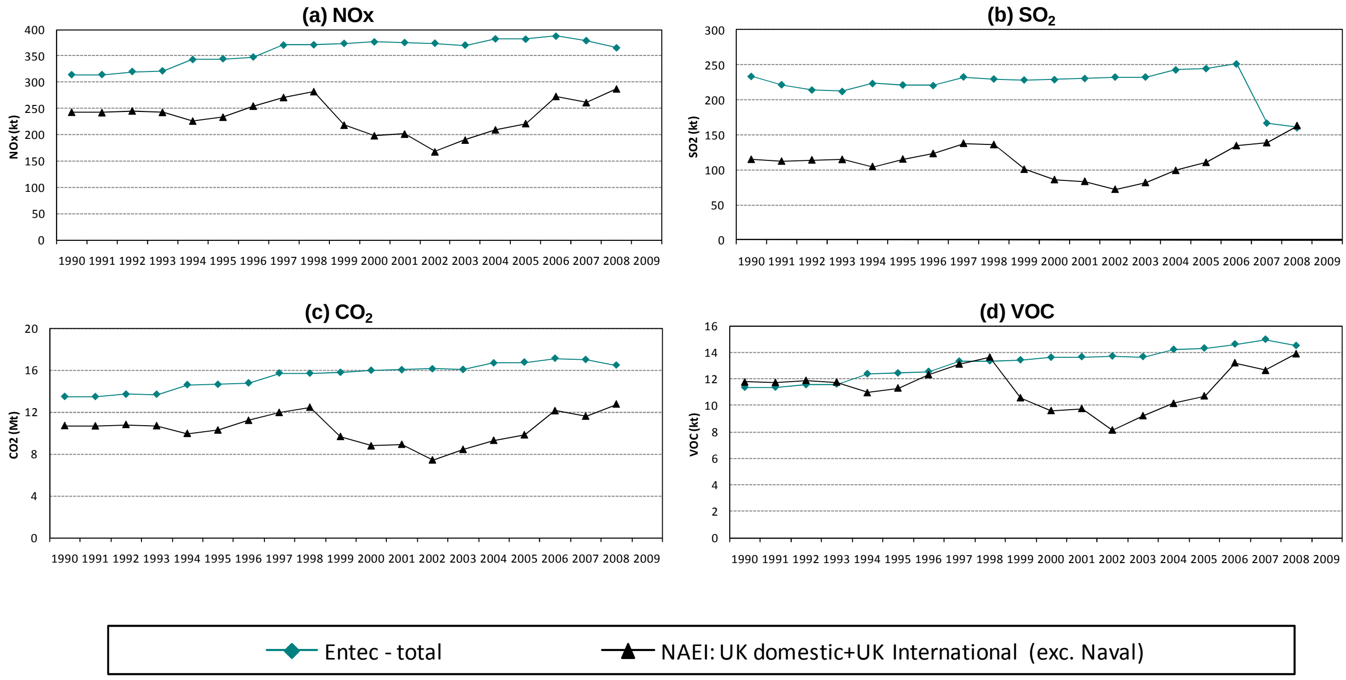
Figure 13.5 Residual Oil (RO) and Distillates (MGO and MDO) as a Percentage of Total Fuel Consumption



CONCAWE figures are combined from multiple sources: CONCAWE (1993), CONCAWE (1994) and CONCAWE (2006).

The 1990-2007 back-casted inventories and the forecasts for 2008 and 2009 have also been plotted against the 2008 NAEI estimates (published in 2010) for the sum of UK domestic and UK international (excluding naval vessels); this is compared to Entec estimates of domestic and international in order that a like-for-like comparison between the two datasets can be made. This comparison is shown below in Figure 13.6 for four pollutants NO_X, SO_2, CO_2 and VOC and shows in all cases, with the exception of VOCs in the earliest part of the time-series, that the back-casted Entec estimates are much higher than the current NAEI estimates. The plots show marked differences between the two inventories in both absolute terms and in the apparent trends. The absolute differences are likely to be due to differences in scope between the two; the Entec estimate is for emissions in UK waters as defined in this study. The trend differences may be due to the proxies used by the two methods; the NAEI uses DUKES fuel consumption data to extrapolate emission estimates.

Figure 13.6 Comparison of 1990-2008 (a) NO_X), (b) SO_2, (c) CO_2 and (d) VOC emission estimates in 'UK Waters' as defined by in study and the 2008 NAEI total for UK domestic and UK international (excluding naval).



13.3.2 Uncertainty

The back-casted inventories and forward projections to 2009 estimated and presented in this section are understandably subject to high levels of uncertainty. A discussion of the contributing factors is included in the Uncertainty Analysis in Section 14.

14. Uncertainty Analysis

Due to the fact that a number of data are combined to estimate total emissions, each with an uncertainty attached, the uncertainty in the total emission estimates involves a combination of the contributing uncertainties. In addition, there are the limitations present in the Lloyd's MIU database from which these estimates are derived; both limitations in data capture and limitations due to coverage.

14.1 Summary of Contributing Uncertainties

A qualitative discussion of the likely uncertainties is presented in Table 14.1. In the right-hand column of the table, the uncertainty magnitude of the component is grouped into low (0-10%), medium (10-30%) and high (>30%). The direction of the uncertainty is identified as 'decrease', 'increase' or decrease/increase', indicating which direction the results could move, taking into account the uncertainty.

Table 14.1 List of Uncertainties Identified (not Ordered by Significance)

Origin of uncertainty	Subcategory	Description	Magnitude and direction of uncertainty of component[1]
Ship movements and port callings	Movements that the database aims to cover	The source of vessel movements data is the Lloyd's MIU database. This database aims to cover all merchant vessels over 100 GT engaged in international trade, although in many cases this may also include details of domestically trading vessels. Although Lloyd's MIU market themselves as the "only organisation that systematically collects global ship movements information via (…) port-based (…) network [of agents]", they do not guarantee the database's coverage to be 100%.[52] There exist few official or commercial sources at a global or national level there that can be used for benchmarking the actual level of coverage. The database is unlikely to include 100% coverage of the vessel movements which it aims to cover. The number of movements that took place in UK waters during 2007 but have not been recorded in the database is unknown. For UK port callings, as described in Section 4.2, the total number of callings captured by the Lloyd's MIU dataset is approximately 85% from that reported by DfT Maritime Statistics. The inventory had therefore been uplifted to account for these missing movements (Section 5). This approach should therefore have reduced uncertainty in the final emissions and fuel consumption estimates.	Small/Medium; Increase

[52] Personal communication with Lloyd's MIU on 22/05/08.

Table 14.1 (continued) List of Uncertainties Identified (not Ordered by Significance)

Origin of uncertainty	Subcategory	Description	Magnitude and direction of uncertainty of component[1]
	Movements specifically excluded from the database	The main exceptions to this (i.e. specifically excluded from the database) as far as UK waters are concerned are: • vessels employed in supply, dredging or dumping at sea; • some movements between Scotland's Western Isles; • regular small domestic ferries crossing estuaries over a distance of less than 2 kilometres; and • most yachts and small fishing vessels.	Small/Medium; Increase
	AIS movements	For this study, in order to improve coverage of vessels which call at port more than once a day (e.g. cross-channel ferries), the standard Lloyd's MIU database has been supplemented with Automated Identification System (AIS)[53] data for 2007 to populate the daily movements of vessels operating on short, frequent transits, such as cross channel ferries. Clearly, for some UK ports a higher proportion of ship traffic, particularly in the summer, will be ferries. The number of movements from vessels where AIS data has been provided, that travelled in UK waters during 2007 but have not been included in the database is unknown, although it is considered insignificant.	Small; Increase
Time spent at berth	Movements with known time of arrival and departure (56%)	The Lloyd's MIU database lists, in addition to the departure and arrival dates, the time of arrival and departure for 56% of the movements. For this 56%, there are both known and unknown uncertainties inherent in the data already included in the database:	
		• The known uncertainty is for those movements where the departure dates and/or times are after the arrival dates and/or times. This is not the case when AIS data have been used, although some AIS data have records where departure dates and times are the same as arrival dates and times. For all these movements (approximately 5% of movements with dates/times populated), time at berth is assumed to be less than one day.	Small, Increase/ Decrease
		• There is an unknown uncertainty about the remainder of movements (from e.g. human error in data entry).	Small/Medium; Increase/Decrease
	Movements without known time of arrival and departure (44%)	For the movements where the time of arrival and departure is not available, time in port was assigned based on median values from those movements with populated data. Each assigned time (split by vessel category and number of days docked in port; see Table 4.7) will have an uncertainty associated with it.	Magnitude varies depending on vessel category and days in port; increase/ decrease
		For those movements without departure and arrival dates (0.1% of total port callings), another uncertainty is introduced through the assumption that the vessel stays in port for less than one day.	Insignificant; Increase/ Decrease

[53] AIS is a system that provides the means for ships to electronically exchange ship data including: identification, position, course, and speed, with other nearby ships and Vessel Traffic Services stations. The AIS data have been chosen wherever they provide greater coverage than the standard movements database.

Table 14.1 (continued) List of Uncertainties Identified (not Ordered by Significance)

Origin of uncertainty	Subcategory	Description	Magnitude and direction of uncertainty of component[1]
		A further uncertainty was introduced with the assumption that the upper limit of time spent at berth with engines operational was 4 days (see 4.4). Approximately 5% of callings are shown to be longer than 4 days. It has been assumed that these vessels are inactive and turn off their engines after this time period. The relevance of this assumption is that about 50% of these calling are for longer than 10 days (about ¼ are more than 20 days), with some vessels being at berth for 200 days. Therefore it is considered inappropriate to assume that such vessels have their engines operational for the entire duration at berth.	Small; increase
Average time spent manoeuvring		It has been assumed that the time spent manoeuvring is one hour for all vessel types and ports. In reality this varies depending on the location of the destination terminal and the approach and turning requirements of each vessel. The uncertainty associated with this assumption is unknown, although the impact to total emission estimates is considered to be low.	Small; increase/ decrease
Vessel service speeds		The largest uncertainty in vessel speed is that the service speed included in the database is not the actual speed at which a vessel travels. This is unknown and may vary depending on currents, weather conditions, fuel prices, traffic in busy channels and changing delivery schedules.	Unknown
	Vessels with data on vessel service speed (85%)	The Lloyd's MIU database contains the service speed for approximately 85% of the 14,255 vessels. For this 85%, there are two sources of uncertainty:	
		• An unknown uncertainty inherent in the data already included in the database (from e.g. human error in data entry); and	Small; increase/ decrease
		• There could also be error associated with outliers of this field.	Zero or small; increase/decrease
	Vessels without data on vessel service speed (15%) (assigned mean of vessel category)	For the 15% of vessels that have been assigned a service speed based on the vessel category mean, the error in assigned service speed for each assigned vessel is the standard deviation from the mean for that vessel category. These were given in Table 6.1. The standard deviation is therefore different for each vessel category, but has much lower variability than other vessel characteristics such as main engine power; the vessel category with lowest coefficient of variation (i.e. standard deviation divided by the mean) is Bulk Carriers (7%) and the highest is Passenger vessels (35%).	Magnitude depends on vessel category (low for Bulk Carriers, rising to High for Passenger Vessels); increase/ decrease
Installed main engine power	Vessels with data on ME power (96%)	The Lloyd's MIU dataset contains the ME power for around 96% of vessels. For this 96%, there is an unknown uncertainty inherent in the data already included in the database (from e.g. human error in data entry). A small number of outliers identified (e.g. a vessel with a size of 23,000GT and a main engine power of 4kW) have been manually corrected. The frequency of such errors is unknown.	Small; increase/ decrease
	Vessels without data on ME power (4%) (assigned mean of vessel category)	For the 4% of vessels which have ME power assigned from vessel category mean, the error in ME power for each assigned vessel is the standard deviation from the mean for that vessel category. The standard deviation is therefore different for each vessel category; excluding bulk carriers for which 100% of vessels had ME Power populated, the vessel category with lowest coefficient of variation is Ro-Ro cargo (59%) and the highest is Passenger vessels (138%).	Magnitude depends on vessel category, but in all cases is High; increase/decrease

Table 14.1 (continued) List of Uncertainties Identified (not Ordered by Significance)

Origin of uncertainty	Subcategory	Description	Magnitude and direction of uncertainty of component[1]
Installed auxiliary engine power	Vessels with data on AE power (36%)	The Lloyd's MIU dataset contains the AE power for around 36% of vessels. It is worth noting that Lloyd's MIU has identified that uncertainty concerning Auxiliary Engine data is higher than for Main Engines as the sources and structure of the data prevent thorough auditing of the dataset.	
		• For these 36% of vessels, there is an unknown uncertainty inherent in the power kW values reported in the database (including the number of engines), and this is likely to be higher than for ME.	Medium; increase/ decrease
		• There could also be error associated with outliers of this field.	Small; ; increase/ decrease
	Vessels without data on AE power (64%) (assigned mean of vessel category)	For the 64% of vessels which have had AE power assigned based on a vessel category ratio of Total AE/Total ME, the error in AE power for each assigned vessel is the standard deviation of the ratio for that vessel category. The standard deviation is therefore different for each vessel category, and as per ME, it exhibits high levels of uncertainty. In addition to the above, when estimating the ratio between ME and AE power, vessels with a total AE kW>ME kW, have been excluded (approximately 5% of vessels). However, in a few occasions this may be true in practice, for instance a high speed passenger vessel may have a total AE power greater than its total ME power.	Magnitude depends on vessel category, but in all cases is High; increase/decrease
Emission factors		Uncertainty in emission factors is described in detail in Section 8.4. This discussion lists three factors which contribute to the final uncertainties in the emission factors: • The number and representativeness 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; and • Assumptions made in assigning the factors for a given activity, e.g. main engine operation in port.	Magnitude depends on pollutant, but in general: at sea: Medium; manoeuvring: High; at berth: Medium-High. Direction: increase/ decrease.
Routes/km travelled	Geographic assignment of emissions into grid cells	The route network model for vessel movements used in this study is based on two sources: the majority are routes provided by AtoBviaC. These routes utilise route distances from Shipping Marine Distance Tables and which have been considered to be the most up-to-date and accurate shipping route information available. The remaining routes have been created using a combination of manual and automated GIS route digitisation. The optimal route network developed will still differ from the actual routes taken by vessels. There is uncertainty associated with the optimal route developed/used in this study and whether this will differ to the actual route taken by a vessel. The movements for which this error may be larger are those movements which change course/destination during a movement. For example, ownership of bulk goods (e.g. coal) may change hands whilst the vessel is at sea and the new owner may wish to redirect the vessel.	Small/Medium; increase/decrease
		The differences between the actual curvature of the Earth where the movement is and the approximations for the Earth's curvature assumed in the analysis (see Section 10). This is less important over the dimensions of the study area.	Small; increase/ decrease

Table 14.1 (continued) List of Uncertainties Identified (not Ordered by Significance)

Origin of uncertainty	Subcategory	Description	Magnitude and direction of uncertainty of component[1]
Fuel types		There is uncertainty associated with the method employed to assign fuel types to vessels. The uncertainties associated with the fuel type assignment can only be quantified by sensitivity analysis. On a per-vessel basis, an example can be given for the maximum error possible in SO_2 emissions if an incorrect fuel type is assigned: if a vessel actually used 2.7%S RO but was assumed to use 0.1%S MGO, the SO_2 emissions for this vessel will be underestimated as 27 times lower than reality.	Unknown
		Variations in fuel quality exist (with respect to sulphur dioxide and particulate matter emissions).	Small; increase/ decrease
Miscellaneous movements		For the movements described in Section 4.3.2 there are much larger uncertainties in addition to an unknown uncertainty inherent in the data. For example, calculating the trip duration of a movement involved a number of assumptions, and involved reliance on departure and arrival times, which were fields that were not well populated. The associated errors will vary depending on whether the trip duration was calculated from departure/arrival times, or if the trip duration was estimated based on in-filled departure/arrival times, or if the median trip duration was assigned to movements without departure/arrival times.	High; increase/ decrease
Business as usual Assumptions		There is an uncertainty associated with the abatement technologies fitted on vessels, for example sea water scrubbing, or other abatement measures that may be in place, such as shore side electricity. For the baseline year this is insignificant, however, when projecting to future years the business as usual assumptions may become more significant, and will also depend on the pollutant under consideration.	Small; increase/ decrease
Emission estimates derived as a fraction		There is an uncertainty associated with the assumptions employed for deriving VOC emissions from HC and $PM_{2.5}$ and PM_{10} from PM emissions.	Small; increase/ decrease
Projections and back-casting		As described in Section 11 there is uncertainty associated with the growth of the shipping sector in future years. Furthermore, this study applies the growth according to the distribution of the baseline movements, (i.e. equal distribution of growth in each grid cell, so for instance growth due to the development/expansion of a port will not be reflected at that location and moves from and to that location). The approach to back-casting emissions for 1990 and forecasting to 2009 is subject to a high degree of uncertainty.	High; increase/ decrease

[1] Magnitude is approximately grouped into low (0-10%), medium (10-30%) and high (>30%). Direction is 'decrease', 'increase' or decrease/increase', indicating which direction the results could move taking into account the uncertainty.

14.2 Overall Uncertainty of Emission Estimates

The overall uncertainty associated with the estimated emissions can be derived from the errors associated with each component. Such a calculation relies on each individual component having been quantitatively assessed. It has not been possible, within the timescales of this study, to quantify with confidence the uncertainty associated with all the individual components described qualitatively above. More specifically, the uncertainty related to the fuel type assignment can best quantified by sensitivity analysis.

15. Conclusions

This study has developed a gridded ship emissions inventory for UK waters, defined as 200 miles from the UK coastline for the 2007 baseline. In addition to fuel consumption, the following pollutants have been considered in the emissions inventory:

- Sulphur Dioxide (SO_2);
- Oxides of Nitrogen (NO_X);
- $PM_{2.5}$ and PM_{10} (derived as a fraction of Total PM);
- Non Methane Volatile Organic Compounds (derived as a fraction of HC); and
- Carbon Dioxide (CO_2).

The methodology and key assumptions for this work have been outlined in Section 3 and presented in more detail in Sections 4 to 11. As discussed in these sections, this current study has taken into account advances in data quality and data capture to make refinements, where possible, in order to reduce the overall uncertainty in the emissions estimates. This includes the use of AIS data to populate port callings and time of arrival and departure for passenger vessels operating within the study area. The route network has also be refined, in part to reflect the more detailed 5km x 5km grid resolution required for the UK inventory, but also to take advantage of the latest GIS datasets and analysis techniques.

Emission and fuel consumption estimates for 2007 for 'UK waters' have been presented in Section 12. Emission and fuel consumption estimates are further disaggregated in Appendix C and Appendix D, whilst emission estimates are mapped in Appendix E. Emission and fuel consumption estimates have also been projected to 2020.

A comparison of the 2020 mapped emission estimates with 2007 maps for each pollutant shows the impact of the assumptions for 2020 compared to 2007. The most notable difference is for mapped SO_2 emissions (and to a lesser degree PM emissions), for which emissions in 2020 are noticeably lower than in 2007, and furthermore, that the benefit of additional fuel sulphur reductions in the SECAs compared to outside the SECAs is clear. SO_2 emissions outside the SECAs (for example, in the Irish Sea) also reduce between 2007 and 2020 due to the assumed reduction in global fuel sulphur content. For emissions of NO_X, there is no obvious change in the distribution of emission estimates, whilst emissions of CO_2 and VOC increase between 2007 and 2020 due to growth but without any geographical bias.

15.1 Recommendations

The 2007 inventory and the projections are based on datasets that are continually improving in terms of their data capture and accuracy. The use in this study of AIS data to supplement the standard Lloyd's MIU movements database has itself led to improvements in the methodology of ship emission inventory development; data capture is increasing and future inventories should be less dependent on the need to uplift emissions based on the sensitivity analysis of missing and incomplete movements. This study has included a top-down uplift to emission estimates to try to take account of possible incomplete datasets, but that not all emission estimates of so-called miscellaneous movements have been included in domestic figures provided for the NAEI (and which are spatially disaggregated) due to the need, for this study, to spatially resolve the emissions. It is hoped that future bottom-up inventories can rely on improved datasets.

With these issues in mind, and the comprehensive understanding of data capture from the comparisons and sensitivity analyses conducted as part of this study, it is recommended that a full bottom-up update of the UK ship emissions inventory is conducted using year 2010 vessel movement and characteristics data. Assuming the bottom-up inventory is updated on the basis of year 2010 movements data, it would be recommended that this should be repeated on a 5 year cycle. In interim years, for the purpose of integration with the NAEI and other policy analysis, top-down inventories could be developed, adopting a similar approach as that described in Section 13 where the back-casting to 1990 and forecasting to 2009 are presented.

Although the current inventory has made initial estimates of the effect of the amendments to MARPOL Annex VI on emissions and fuel consumption, this was undertaken in a top-down manner that has the potential to lead to increased levels of uncertainty in the outputs. When a full bottom-up revision to the UK inventory is undertaken, the implications of the MARPOL Annex VI amendments should be considered in more detail. At the time the inventory is updated there will also be a period of practical application of these more stringent regulations and the inventory can incorporate data regarding the industry’s response in terms of fuel switching and the take-up of abatement technology such as sea water scrubbing.

Prior to the next full bottom-up revision of the emission inventory, the emission factors should be reviewed and updated where appropriate. Such a review may also extend to a more detailed appraisal of fuel types and fuel sulphur content, particularly in the context of the MARPOL Annex VI revision and the shift in demand for lower sulphur fuels and the uptake of abatement technology, particularly within Emission Control Areas.

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Appendix A
Vessel Categories

Table A.1 Assignment of Vessel Categories

LIMIU General Type	LIMIU Sub Type	Lloyd's MIU Vessel Type Decode	Vessel categories for this study
B	BU	bulk carrier	Bulk Carrier
B	CB	bulk carrier with container capacity	Bulk Carrier
B	CE	bulk cement carrier	Bulk Carrier
B	OR	bulk ore carrier	Bulk Carrier
B	WC	wood-chip carrier	Bulk Carrier
C	BO	combined bulk and oil carrier	Bulk Carrier
C	OO	combined ore and oil carrier	Bulk Carrier
D	CS	cutter suction dredger	Others
D	DR	dredger	Others
D	GD	grab dredger	Others
D	GH	grab hopper dredger	Others
D	HD	hopper dredger	Others
D	SD	suction dredger	Others
D	SH	suction hopper dredger	Others
D	SS	sand suction dredger	Others
D	TD	trailing suction dredger	Others
D	TS	trailing suction hopper dredger	Others
F	FC	fish carrier	Fishing
F	FF	fish factory	Fishing
F	FP	fishery protection	Fishing
F	FS	fishing (general)	Fishing
F	TR	trawler (All types)	Fishing
G	CT	cargo/training	General Cargo
G	GC	general cargo	General Cargo
G	PC	general cargo with container capacity	General Cargo
G	RF	reefer	General Cargo
L	NG	Liquid Natural Gas Carrier	Tanker
L	NP	Combined LNG and LPG Gas Carrier	Tanker

Table A.1 (continued) Assignment of Vessel Categories

LIMIU General Type	LIMIU Sub Type	Lloyd's MIU Vessel Type Decode	Vessel categories for this study
L	PG	Liquid Petroleum Gas Carrier	Tanker
M	LV	livestock	General Cargo
M	PR	passenger (cruise)	Passenger
M	VE	vehicle carrier	Ro – Ro cargo
N	AV	Naval Vessel	Others
N	AX	Naval Auxiliary Vessel	Others
O	BA	barge	Others
O	BY	buoy ship	Others
O	CL	cable ship	Others
O	CP	cable pontoon	Others
O	CS	crane ship	Others
O	CX	crane barge	Others
O	DS	diving support	Others
O	ES	exhibition ship	Others
O	FL	floating crane	Others
O	FY	ferry	Passenger
O	HB	hopper barge	Others
O	HF	hydrofoil	Others
O	HL	semi-sub HL vessel	Others
O	HS	hospital ship	Others
O	IB	icebreaker	Others
O	IS	icebreaker/supply	Others
O	LC	landing craft	Others
O	LT	lighthouse tender	Others
O	MS	mission ship	Others
O	MT	maintenance	Others
O	OS	offshore safety	Others
O	PA	patrol ship	Others
O	PC	pollution control vessel	Others
O	PI	pilot ship	Others
O	PL	pipe layer	Others
O	PO	pontoon	Others

Table A.1 (continued) Assignment of Vessel Categories

LIMIU General Type	LIMIU Sub Type	Lloyd's MIU Vessel Type Decode	Vessel categories for this study
O	RD	radio ship	Others
O	RP	repair ship	Others
O	SC	sludge carrier	Others
O	SP	semi-sub pontoon	Others
O	SU	support	Others
O	SV	salvage	Others
O	SY	supply	Others
O	SZ	standby safety vessel	Others
O	TB	tank barge	Others
O	TN	tender	Others
O	TR	training	Others
O	WA	waste ship	Others
O	WO	work ship	Others
O	YT	yacht	Others
P	RR	passenger ro/ro	Passenger
R	HR	hydrographic research	Others
R	OR	oceanographic research	Others
R	RE	research	Others
R	RS	research/supply ship	Others
R	SR	seismographic research	Others
T	AS	asphalt tanker	Tanker
T	BK	bunkering tanker	Tanker
T	CH	chemical tanker	Tanker
T	CO	Combined chemical and oil tanker	Tanker
T	CR	crude oil tanker	Tanker
T	EO	edible oil tanker	Tanker
T	FJ	fruit juice tanker	Tanker
T	FP	floating production tanker	Tanker
T	MO	molasses tanker	Tanker
T	NA	naval auxiliary tanker	Tanker
T	PD	product tanker	Tanker
T	TA	Tanker (unspecified)	Tanker

Table A.1 (continued) **Assignment of Vessel Categories**

LIMIU General Type	LIMIU Sub Type	Lloyd's MIU Vessel Type Decode	Vessel categories for this study
T	WN	wine tanker	Tanker
T	WT	water tanker	Tanker
U	BC	barge container carrier	Container Ship
U	BG	barge carrier	Container Ship
U	CC	fully cellular containership	Container Ship
U	CR	fully cellular refrigerated	Container Ship
U	RC	roll on roll off with container capacity	Ro – Ro cargo
U	RR	Roll On Roll Off	Ro – Ro cargo
X	AA	anchor handling salvage tug	Others
X	AF	anchor handling fire fighting tug/supply	Others
X	AG	anchor handling fire fighting tug	Others
X	AH	anchor handling tug/supply	Others
X	AT	anchor handling tug	Others
X	FF	fire fighting tug	Others
X	FS	fire fighting tug/supply	Others
X	FT	fire fighting tractor tug	Others
X	PT	pusher tug	Others
X	ST	salvage tug	Others
X	TG	tug	Others
X	TI	tug/icebreaker	Others
X	TR	tractor tug	Others
X	TS	tug/supply	Others
Y	DP	drill platform	Others
Y	DS	drill ship	Others
Z	ZZ	Vessel Type (unspecified)	Others

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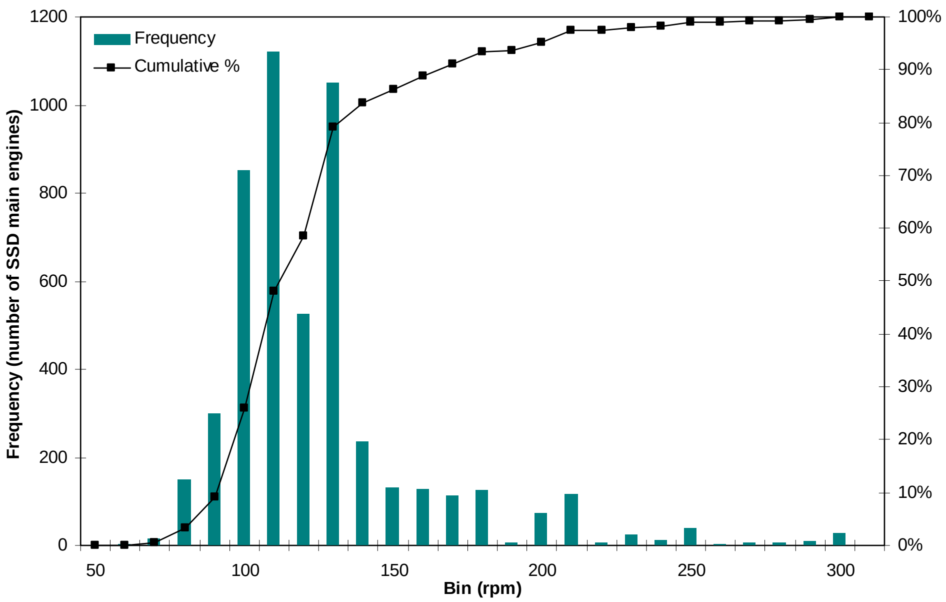
Appendix B
Adjustments for MARPOL Annex VI Amendments – Supporting Information

Distribution of RPM among main engines and weighted Tier III NO_X emission limit values

Slow speed diesel engines (SSD)

5081 diesel main engines have been assigned as SSD engines in Entec (2008), with the distribution of rpm shown in the histogram below (Figure B.1).

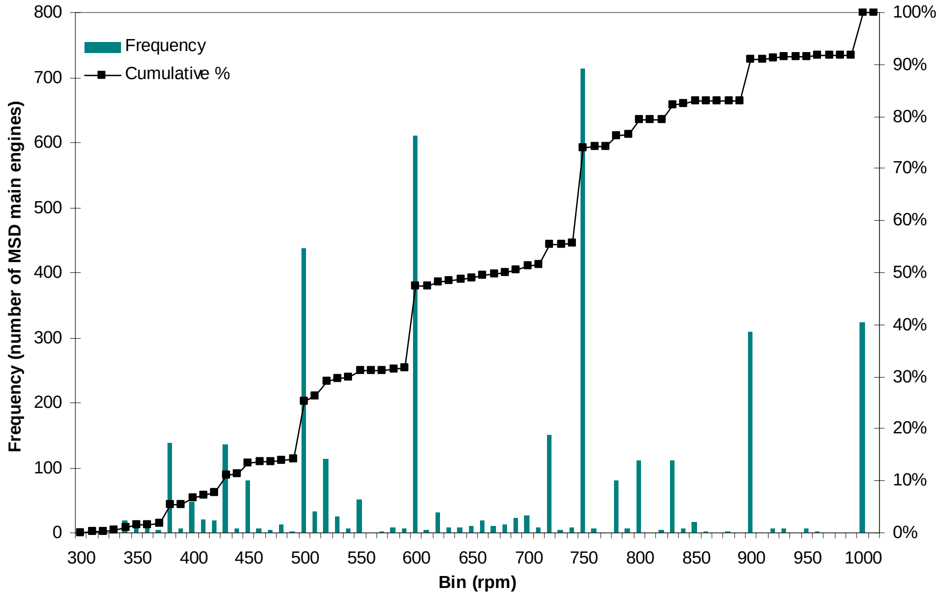
Figure B.1 Histogram of Entec-Assigned SSD



Medium speed diesel engines (MSD)

For medium speed diesel main engines the distribution is much less skewed, and is distributed across the range of rpm, as shown in Figure B.2 below.

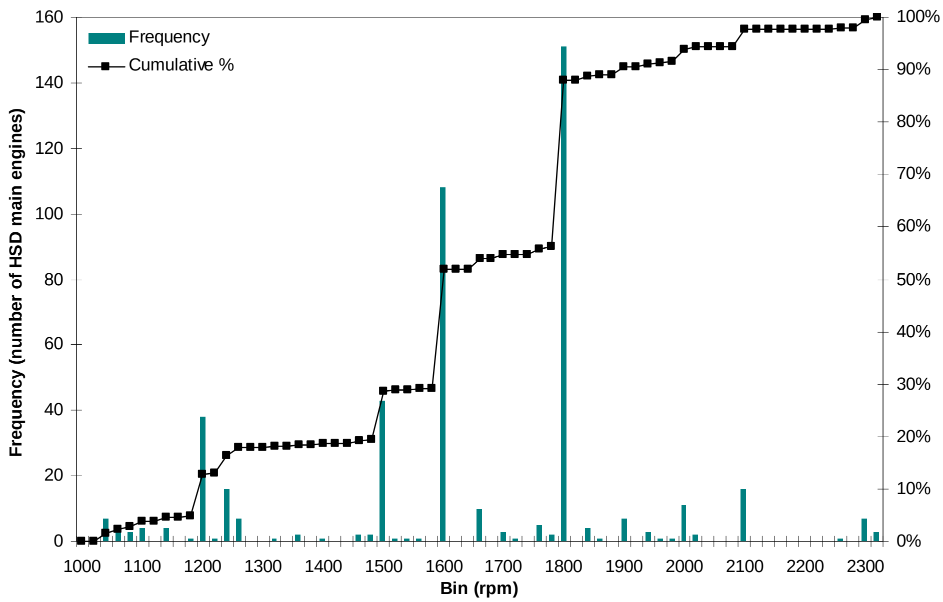
Figure B.2 Histogram of Entec-Assigned MSD



High speed diesel engines (HSD)

Surprisingly, there are only 40 main engines in the IMO category of >2000rpm (compared with 2968 engines in the category <130rpm and 6434 in the category 130<rpm<2000). Similarly to the Entec MSD category, the Entec HSD category includes engines with a broad distribution of rpm, as shown in Figure B.3 below.

Figure B.3 Histogram of Entec-Assigned HSD



Weighted NO_X emission limit values for Tier III

As described in section 9.1.3, there are no NO_X ECAs currently in place, and hence no Tier III NO_X emission limit values have been assumed in this study. Nevertheless, suitable weighted Tier III NO_X emission limit values for each Entec RPM category were calculated as the following:

- A Tier III NO_X emission limit value of 3.35g/kWh for SSDs (<300rpm);
- A Tier III NO_X emission limit value of 2.47g/kWh for MSDs (300-1000rpm); and
- A Tier III NO_X emission limit value of 2.05g/kWh for HSDs (>1000rpm).

Adjustments made to the 2007 emission factors in order to develop revised projections

The following tables summarise the adjustments applied to the 2007 emission factors in order to develop emission projections that take into account the revised MARPOL Annex VI requirements.

Table B.1 Adjustments for Main Engines – at Sea

Engine type	2007 Fuel type	Non SECA						SECA					
		NO_X	SO_2	CO_2	VOC	PM	sfc	NO_X	SO_2	CO_2	VOC	PM	sfc
SSD	MGO	95%	50%	100%	100%	96%	100%	95%	50%	100%	100%	96%	100%
SSD	MDO	95%	33%	100%	100%	62%	100%	95%	7%	100%	100%	65%	100%
SSD	RO	90%	18%	96%	100%	14%	96%	89%	3%	95%	100%	13%	95%
MSD	MGO	92%	50%	100%	100%	96%	100%	92%	50%	100%	100%	96%	100%
MSD	MDO	92%	33%	100%	100%	62%	100%	92%	7%	100%	100%	65%	100%
MSD	RO	87%	18%	96%	100%	30%	96%	86%	3%	95%	100%	33%	95%
HSD	MGO	87%	50%	100%	100%	96%	100%	87%	50%	100%	100%	96%	100%
HSD	MDO	87%	33%	100%	100%	62%	100%	87%	7%	100%	100%	65%	100%
HSD	RO	82%	18%	96%	100%	30%	96%	82%	3%	95%	100%	33%	95%
GT	MGO	100%	50%	100%	100%	96%	100%	100%	50%	100%	100%	96%	100%
GT	MDO	100%	33%	100%	100%	62%	100%	99%	7%	100%	100%	65%	100%
GT	RO	94%	18%	96%	100%	17%	96%	93%	4%	95%	100%	18%	95%
ST	MGO	100%	50%	100%	100%	96%	100%	100%	50%	100%	100%	96%	100%
ST	MDO	100%	33%	100%	100%	62%	100%	99%	7%	100%	100%	65%	100%
ST	RO	95%	18%	96%	100%	30%	96%	95%	4%	95%	100%	33%	95%

Table B.2 Adjustments for Main Engines – Manoeuvring

Engine type	2007 Fuel type	Non SECA						SECA					
		NO_X	SO_2	CO_2	VOC	PM	sfc	NO_X	SO_2	CO_2	VOC	PM	sfc
SSD	MGO	100%	50%	100%	100%	96%	100%	100%	50%	100%	100%	96%	100%
SSD	MDO	100%	33%	100%	100%	62%	100%	99%	7%	100%	100%	65%	100%
SSD	RO	94%	18%	96%	100%	30%	96%	93%	3%	95%	100%	33%	95%
MSD	MGO	100%	50%	100%	100%	96%	100%	100%	50%	100%	100%	96%	100%
MSD	MDO	100%	33%	100%	100%	62%	100%	99%	7%	100%	100%	65%	100%
MSD	RO	94%	18%	96%	100%	30%	96%	94%	3%	95%	100%	33%	95%
HSD	MGO	96%	50%	100%	100%	96%	100%	96%	50%	100%	100%	96%	100%
HSD	MDO	96%	33%	100%	100%	62%	100%	95%	7%	100%	100%	65%	100%
HSD	RO	90%	18%	96%	100%	30%	96%	90%	3%	95%	100%	33%	95%
GT	MGO	100%	50%	100%	100%	96%	100%	100%	50%	100%	100%	96%	100%
GT	MDO	100%	33%	100%	100%	62%	100%	99%	7%	100%	100%	65%	100%
GT	RO	94%	18%	96%	100%	27%	96%	93%	4%	95%	100%	29%	95%
ST	MGO	100%	50%	100%	100%	96%	100%	100%	50%	100%	100%	96%	100%
ST	MDO	100%	33%	100%	100%	62%	100%	99%	7%	100%	100%	65%	100%
ST	RO	94%	18%	96%	100%	30%	96%	94%	4%	95%	100%	33%	95%

Table B.3 Adjustments for Auxiliary Engines – All Activities

Engine type	2007 Fuel type	Non SECA						SECA					
		NO_X	SO_2	CO_2	VOC	PM	sfc	NO_X	SO_2	CO_2	VOC	PM	sfc
SSD	MGO	86%	50%	100%	100%	96%	100%	86%	50%	100%	100%	96%	100%
SSD	MDO	86%	33%	100%	100%	62%	100%	86%	7%	100%	100%	65%	100%
SSD	RO	82%	18%	96%	100%	30%	96%	81%	4%	96%	100%	33%	96%

Appendix C
Total Emission Estimates splits

This Appendix presents emission estimates split by flag, vessel, movement and fuel type, as well as whether emissions are located within the UK 12 nautical mile zone.

Emission estimates for PM_{10} have not been presented here as splits would be similar with $PM_{2.5}$ estimates. Total PM_{10} emission estimates are presented in Section 12.

For the emission projections, only estimates based on a 1% growth have been presented. Disaggregated emissions would be similar for any additional projections based on alternative growth assumptions presented in the main report. Total emission projections for different growth assumptions are presented in Section 12.4. The same applies for emission projections for different years i.e. for 2020.

Table C.1 Emissions and Fuel Consumption Split by Flag Type (kT)

Flag Type	NO_X			SO_2			CO_2			VOCs			$PM_{2.5}$			Fuel Consumption		
	Sea	Man	Berth	Sea	Man	Berth	Sea	Man	Berth	Sea	Man	Berth	Sea	Man	Berth	Sea	Man	Berth
Baseline - 2007																		
UK Flag	43	1.8	7.5	19	1.0	2.7	1,958	109	397	1.6	0.1	0.3	1.4	0.1	0.3	616	34	125
Other EU flags	282	3.5	36	125	1.8	13	12,103	202	1,956	10	0.3	1.8	10	0.2	1.4	3,808	63	615
Non EU flags	487	4.5	65	211	2.0	21	19,988	246	3,443	18	0.4	3.4	18	0.3	2.6	6,288	77	1,083
TOTAL	**811**	**10**	**108**	**355**	**5**	**37**	**34,049**	**557**	**5,795**	**30**	**0.8**	**5.5**	**29**	**0.6**	**4.3**	**10,712**	**175**	**1,823**
BAU - 2020 (1% growth)																		
UK Flag	44	1.9	7.4	2	0.1	0.4	2,219	125	451	1.8	0.2	0.4	0.8	0.1	0.2	698	39	142
Other EU flags	291	3.7	35	15	0.2	1.8	13,683	229	2,222	11.9	0.3	2.0	4.8	0.2	1.1	4,305	72	699
Non EU flags	504	4.6	64	27	0.3	3.0	22,541	279	3,913	20.4	0.4	3.9	7.8	0.2	2.0	7,092	88	1,231
TOTAL	**839**	**10**	**107**	**44**	**0.6**	**5.2**	**38,443**	**633**	**6,586**	**34.1**	**1.0**	**6.3**	**13.4**	**0.4**	**3.3**	**12,095**	**199**	**2,072**

Table C.2 Emissions and Fuel Consumption Split by Vessel Type (kT)

Vessel Type	NO_X	SO_2	CO_2	VOCs	$PM_{2.5}$	Fuel Consumption
Baseline - 2007						
Passenger	51	22	2,628	2.0	1.5	827
All other vessels	879	375	37,774	34	32	11,884
TOTAL	**929**	**397**	**40,401**	**36**	**34**	**12,711**
BAU - 2020 (1% growth)						
Passenger	51	2.8	2,995	2.2	1.1	942
All other vessels	905	47	42,667	39	16	13,424
TOTAL	**956**	**50**	**45,662**	**41**	**17**	**14,366**

Table C.3 Emissions and Fuel Consumption Split by Movement Type (kT)

Movement Type	NO_X			SO_2			CO_2			VOCs			$PM_{2.5}$			Fuel Consumption		
	Sea	Man	Berth	Sea	Man	Berth	Sea	Man	Berth	Sea	Man	Berth	Sea	Man	Berth	Sea	Man	Berth
Baseline – 2007																		
UK Domestic move	22	1.1	10	10	0.5	3.1	981	64	531	0.8	0.1	0.6	0.8	0.1	0.5	309	20	167
UK International move	299	5.1	42	135	2.7	16	12,894	293	2,230	11	0.4	2.0	11	0.3	1.6	4,057	92	702
Non UK move	490	3.7	56	210	1.6	18	20,175	201	3,034	18	0.3	3.0	17	0.2	2.2	6,347	63	955
TOTAL	**811**	**10**	**108**	**355**	**4.8**	**37**	**34,049**	**557**	**5,795**	**30**	**0.8**	**5.5**	**29**	**0.6**	**4.3**	**10,712**	**175**	**1,823**
BAU - 2020 (1% growth)																		
UK Domestic move	22	1.1	10	1.5	0.1	0.6	1,105	72	601	0.9	0.1	0.6	0.4	0.0	0.3	348	23	189
UK International move	308	5.3	41	17	0.3	2.1	14,561	332	2,534	13	0.5	2.2	5.1	0.2	1.2	4,582	105	797
Non UK move	509	3.8	56	26	0.2	2.5	22,777	228	3,451	21	0.4	3.4	7.9	0.2	1.8	7,166	72	1,086
TOTAL	**839**	**10**	**107**	**44**	**0.6**	**5.2**	**38,443**	**633**	**6,586**	**34**	**1.0**	**6.3**	**13**	**0.4**	**3.3**	**12,095**	**199**	**2,072**

Table C.4 Emissions and Fuel Consumption Split by whether these are Located within the UK 12 nm zone (kT)

Type	NO_X	SO_2	CO_2	VOCs	$PM_{2.5}$	PM_{10}	Fuel Consumption
Baseline - 2007							
Within UK 12 mile zone	100	43	4,745	4.3	4.0	4.2	1,493
Other	829	354	35,656	32	30	31	11,218
TOTAL	**929**	**397**	**40,401**	**36**	**34**	**36**	**12,711**
BAU - 2020 (1% growth)							
Within UK 12 mile zone	102	6	5,365	4.9	2.2	2.4	1,688
Other	855	44	40,297	37	15	16	12,679
TOTAL	**956**	**50**	**45,662**	**41**	**17**	**18**	**14,366**

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Appendix C

Appendix D
UK 12 nm Emission Estimates Splits

This Appendix presents emission estimates within the UK 12 nautical mile zone split by vessel, movement and fuel type.

Emission estimates for PM_{10} have not been presented here as splits would be similar with $PM_{2.5}$ estimates. Total PM_{10} emission estimates are presented in Section 12.

For the emission projections, only estimates based on a 1% growth have been presented. Disaggregated emissions would be similar for any additional projections based on alternative growth assumptions presented in the main report. Total emission projections for different growth assumptions are presented in Section 12.4. The same applies for emission projections for different years i.e. for 2020.

Table D.1 UK 12 nm Zone NO_X Emissions Split by Vessel and Movement Type (kT)

Vessel Type	Movement type	At Sea		Manoeuvring		At Berth	
		2007	2020	2007	2020	2007	2020
Passenger	UK Domestic	1.4	1.4	0.5	0.5	1.1	1.0
Passenger	UK International	6.0	6.1	1.1	1.1	3.1	3.0
Passenger	Non UK move	0.0	0.0	0.0	0.0	0.0	0.0
All other vessels	UK Domestic	7.0	7.1	0.6	0.6	8.1	8.1
All other vessels	UK International	33.8	34.7	1.8	1.9	22.3	21.9
All other vessels	Non UK move	13.4	14.0	0.0	0.0	0.0	0.0
TOTAL		**61.6**	**63.4**	**4.0**	**4.1**	**34.6**	**34.0**

Table D.2 UK 12 nm Zone SO_2 Emissions Split by Vessel and Movement Type kT)

Vessel Type	Movement type	At Sea		Manoeuvring		At Berth	
		2007	2020	2007	2020	2007	2020
Passenger	UK Domestic	0.6	0.1	0.2	0.1	0.5	0.1
Passenger	UK International	2.7	0.3	0.6	0.1	1.4	0.1
Passenger	Non UK move	0.0	0.0	0.0	0.0	0.0	0.0
All other vessels	UK Domestic	3.5	0.5	0.3	0.1	2.4	0.5
All other vessels	UK International	16.2	2.2	0.9	0.1	8.4	1.2
All other vessels	Non UK move	5.3	0.6	0.0	0.0	0.0	0.0
TOTAL		**28.4**	**3.8**	**2.1**	**0.3**	**12.6**	**1.9**

Table D.3 UK 12 nm Zone CO_2 Emissions Split by Vessel and Movement Type (kT)

Vessel Type	Movement type	At Sea		Manoeuvring		At Berth	
		2007	2020	2007	2020	2007	2020
Passenger	UK Domestic	72	82	27	31	58	66
Passenger	UK International	310	353	66	76	162	184
Passenger	Non UK move	1.8	2.0	0.0	0.0	0.8	0.9
All other vessels	UK Domestic	315	353	36	40	430	487
All other vessels	UK International	1,434	1,612	100	113	1,187	1,347
All other vessels	Non UK move	545	618	0.1	0.1	1.1	1.3
TOTAL		**2,677**	**3,019**	**229**	**260**	**1,839**	**2,086**

Table D.4 UK 12 nm Zone VOC Emissions Split by Vessel and Movement Type (kT)

Vessel Type	Movement type	At Sea		Manoeuvring		At Berth	
		2007	2020	2007	2020	2007	2020
Passenger	UK Domestic	0.1	0.1	0.0	0.0	0.0	0.0
Passenger	UK International	0.2	0.3	0.1	0.1	0.1	0.1
Passenger	Non UK move	0.0	0.0	0.0	0.0	0.0	0.0
All other vessels	UK Domestic	0.3	0.3	0.1	0.1	0.5	0.5
All other vessels	UK International	1.2	1.4	0.2	0.2	1.1	1.2
All other vessels	Non UK move	0.5	0.6	0.0	0.0	0.0	0.0
TOTAL		**2.3**	**2.6**	**0.3**	**0.4**	**1.7**	**1.9**

Table D.5 UK 12 nm Zone $PM_{2.5}$ Emissions Split by Vessel and Movement Type (kT)

Vessel Type	Movement type	At Sea		Manoeuvring		At Berth	
		2007	2020	2007	2020	2007	2020
Passenger	UK Domestic	0.0	0.0	0.0	0.0	0.0	0.0
Passenger	UK International	0.2	0.1	0.1	0.0	0.1	0.1
Passenger	Non UK move	0.0	0.0	0.0	0.0	0.0	0.0
All other vessels	UK Domestic	0.3	0.1	0.0	0.0	0.4	0.3
All other vessels	UK International	1.4	0.6	0.1	0.1	0.9	0.6
All other vessels	Non UK move	0.4	0.2	0.0	0.0	0.0	0.0
TOTAL		**2.3**	**1.1**	**0.3**	**0.2**	**1.4**	**1.0**

Table D.6 UK 12 nm Zone Fuel Consumption Split by Vessel and Movement Type (kT)

Vessel Type	Movement type	At Sea		Manoeuvring		At Berth	
		2007	2020	2007	2020	2007	2020
Passenger	UK Domestic	23	26	9	10	18	21
Passenger	UK International	97	111	21	24	51	58
Passenger	Non UK move	0.6	0.6	0.0	0.0	0.2	0.3
All other vessels	UK Domestic	99	111	11	13	135	153
All other vessels	UK International	451	507	31	36	374	424
All other vessels	Non UK move	171	194	0.0	0.0	0.4	0.4
TOTAL		**842**	**950**	**72**	**82**	**578**	**656**

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Appendix E
Mapped Emission Estimates

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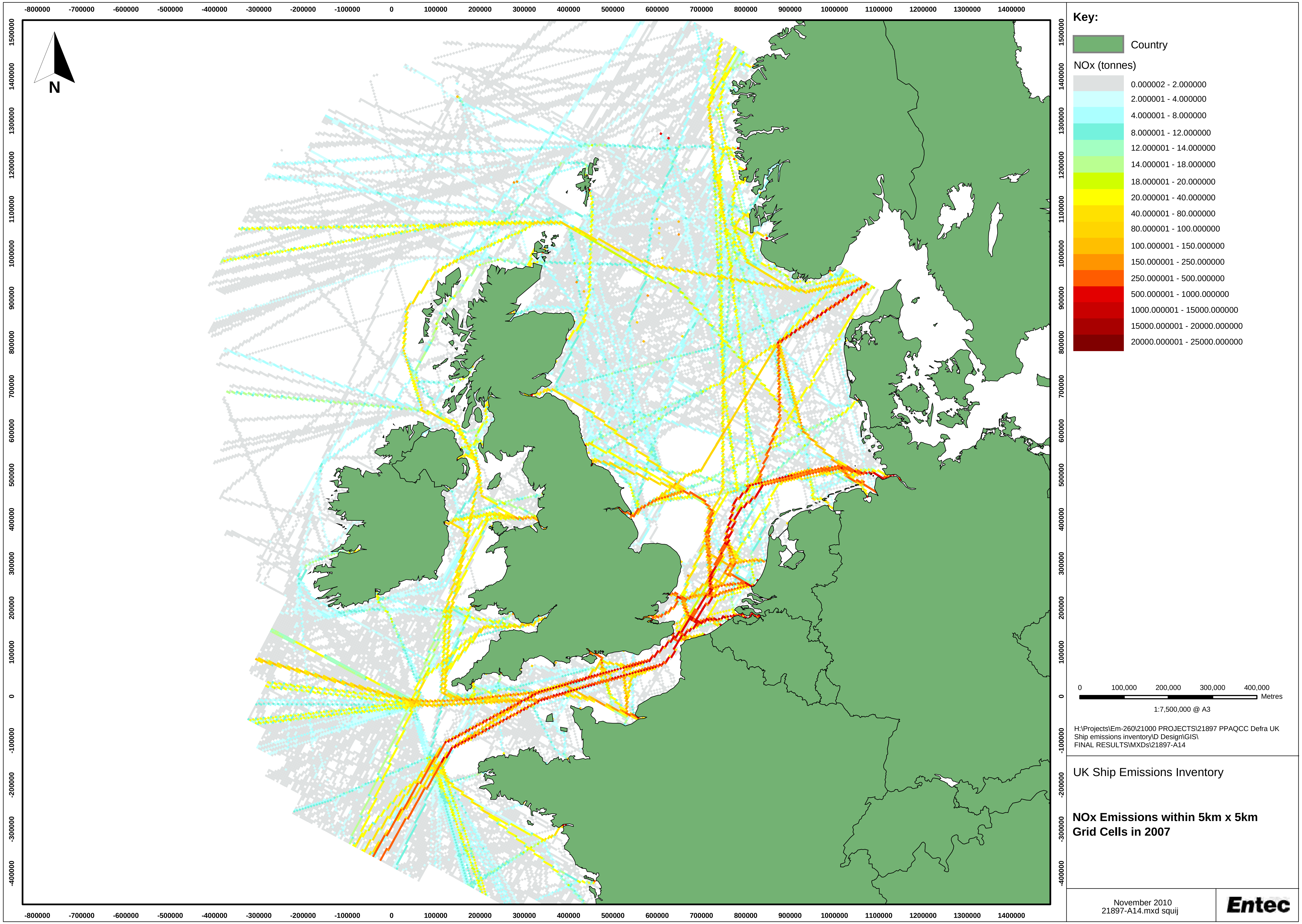
Appendix E



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UK Ship Emissions Inventory
NOx Emissions within 5km x 5km Grid Cells in 2007
November 2010
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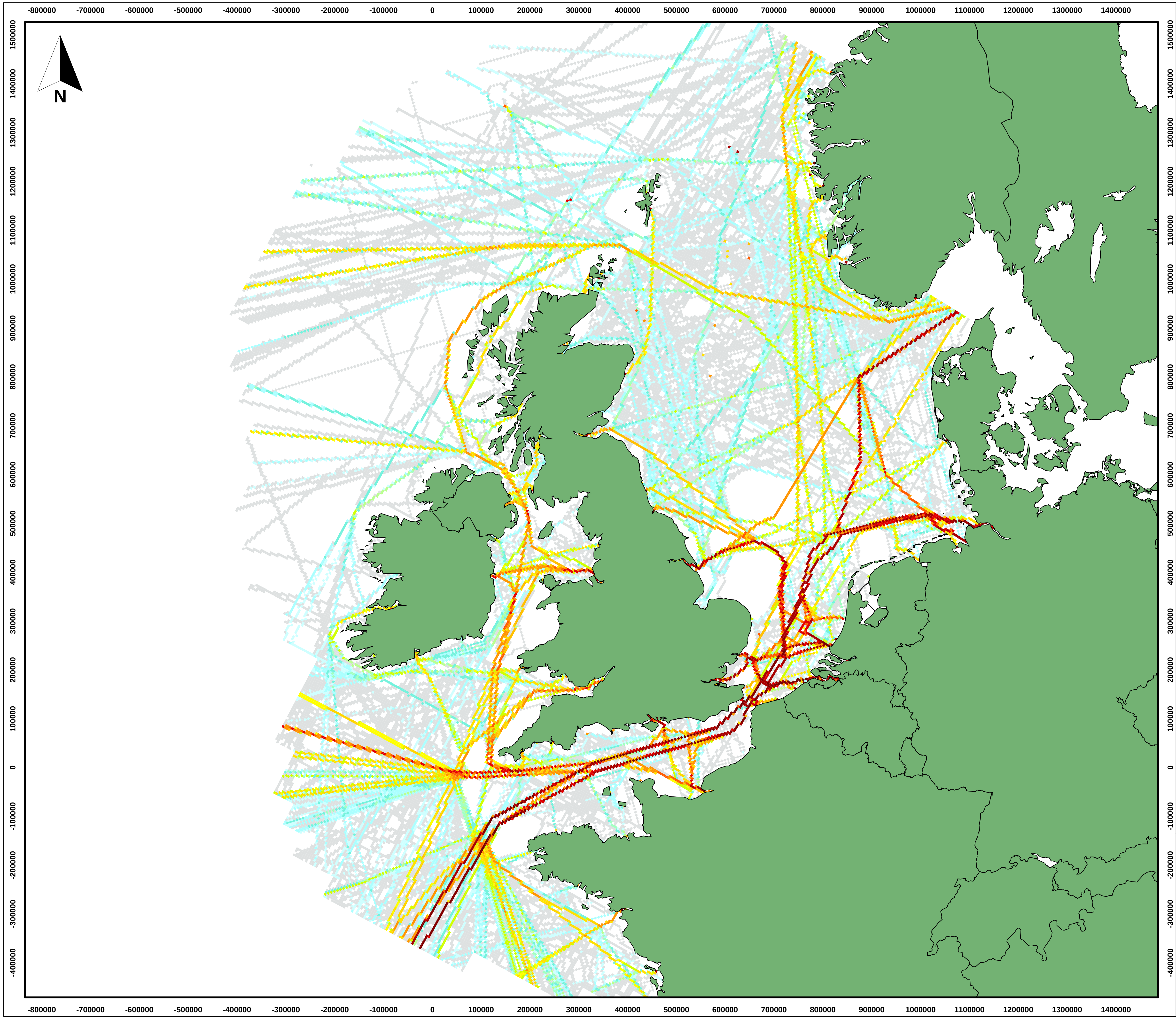

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UK Ship Emissions Inventory

SO_2 Emissions within 5km x 5km Grid Cells in 2007

November 2010
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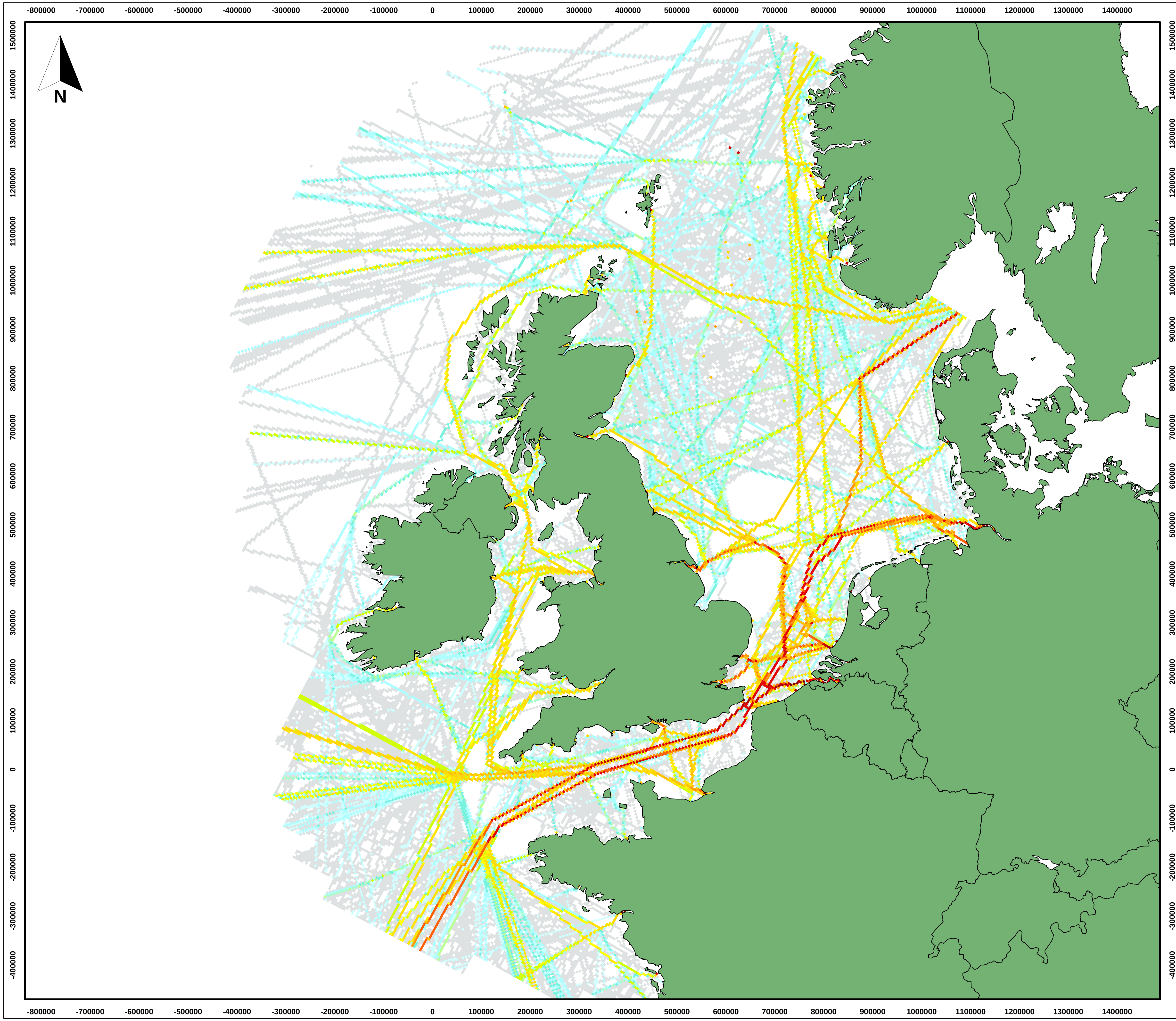

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UK Ship Emissions Inventory

CO_2 Emissions within 5km x 5km Grid Cells in 2007

November 2010
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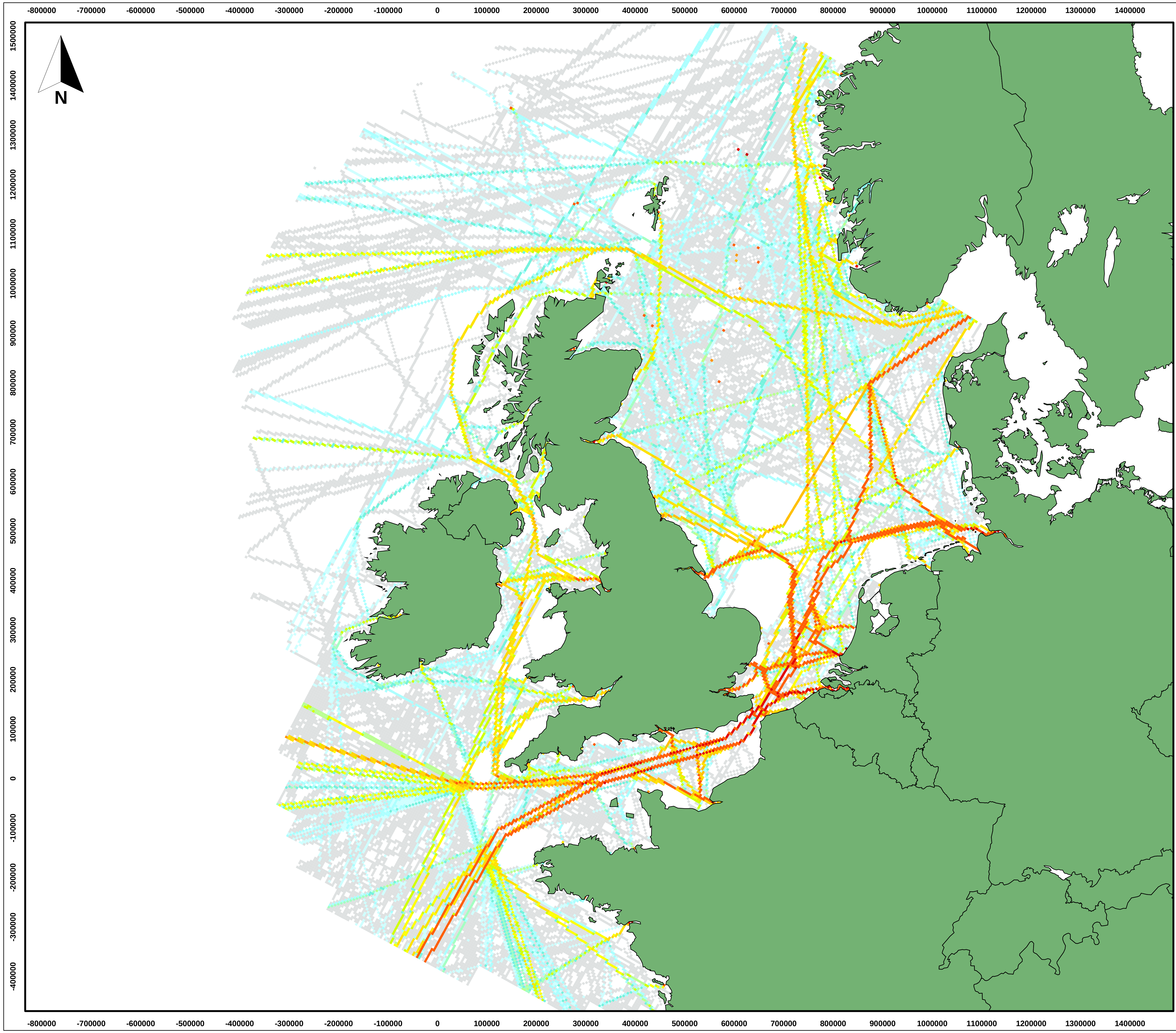

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UK Ship Emissions Inventory

NMVOC Emissions within 5km x 5km Grid Cells in 2007

November 2010
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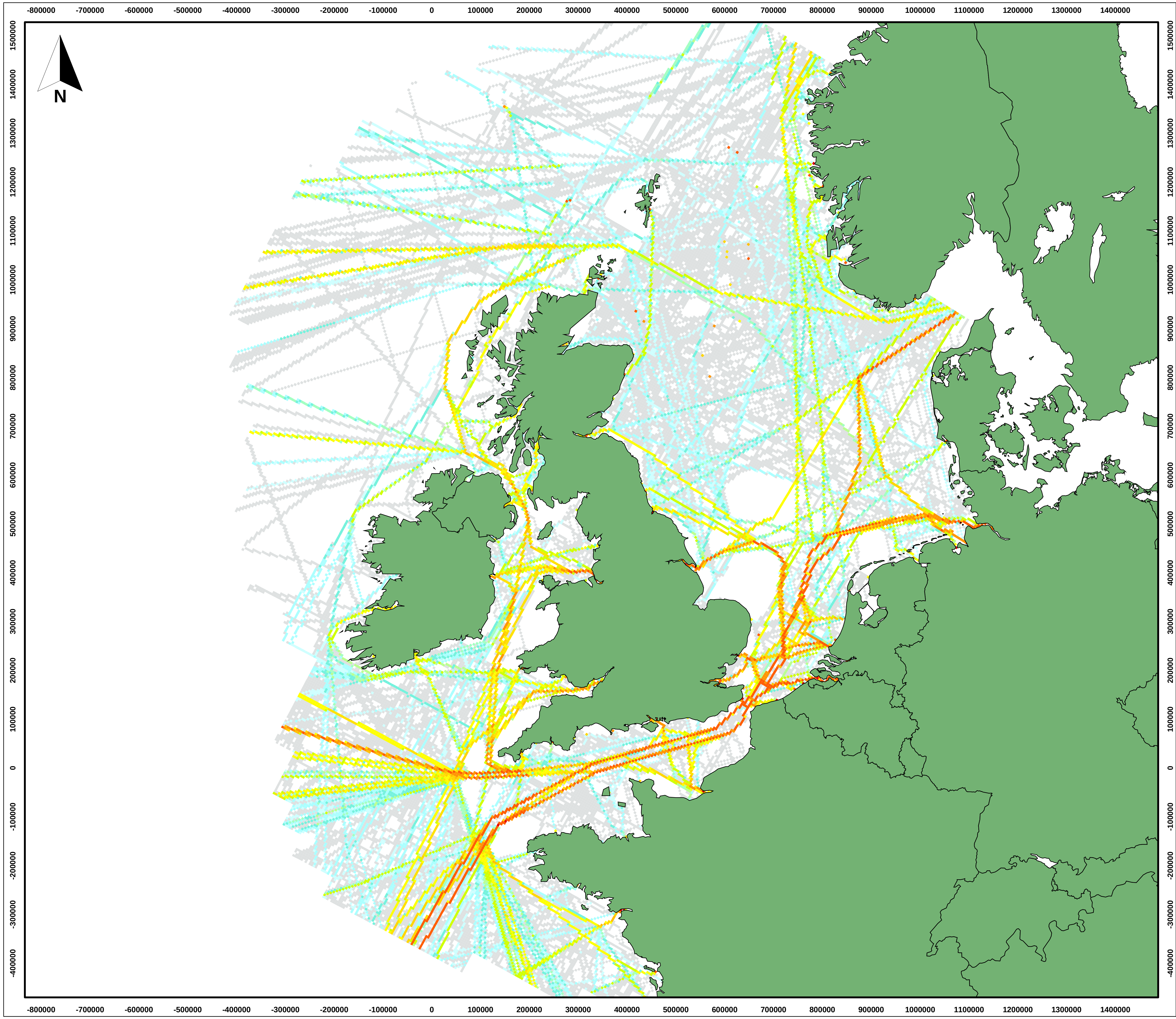
Entec



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UK Ship Emissions Inventory

PM2.5 Emissions within 5km x 5km Grid Cells in 2007

November 2010
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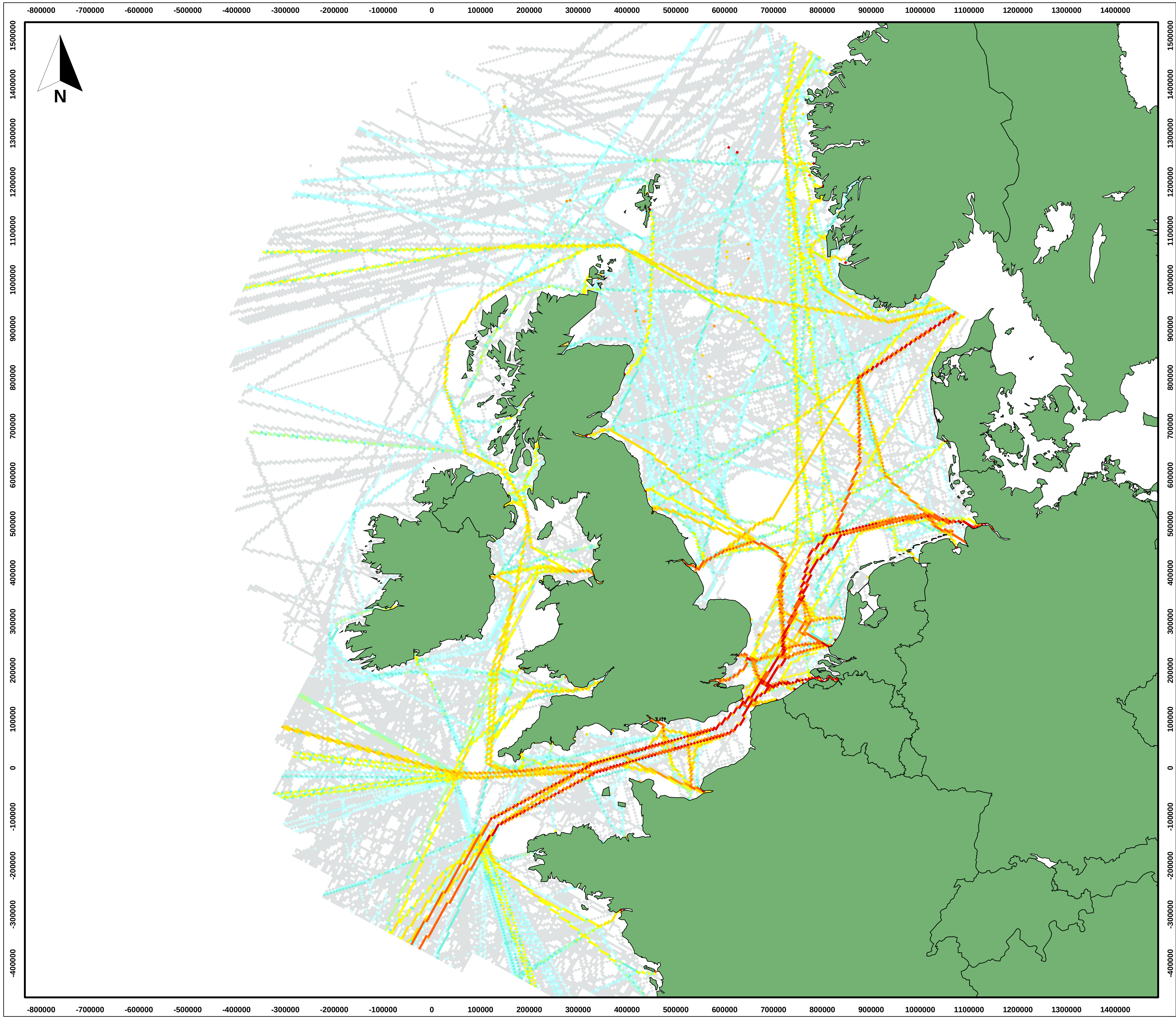

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UK Ship Emissions Inventory

NOx Emissions within 5km x 5km Grid Cells in 2020 (Assuming 1% Growth)

November 2010
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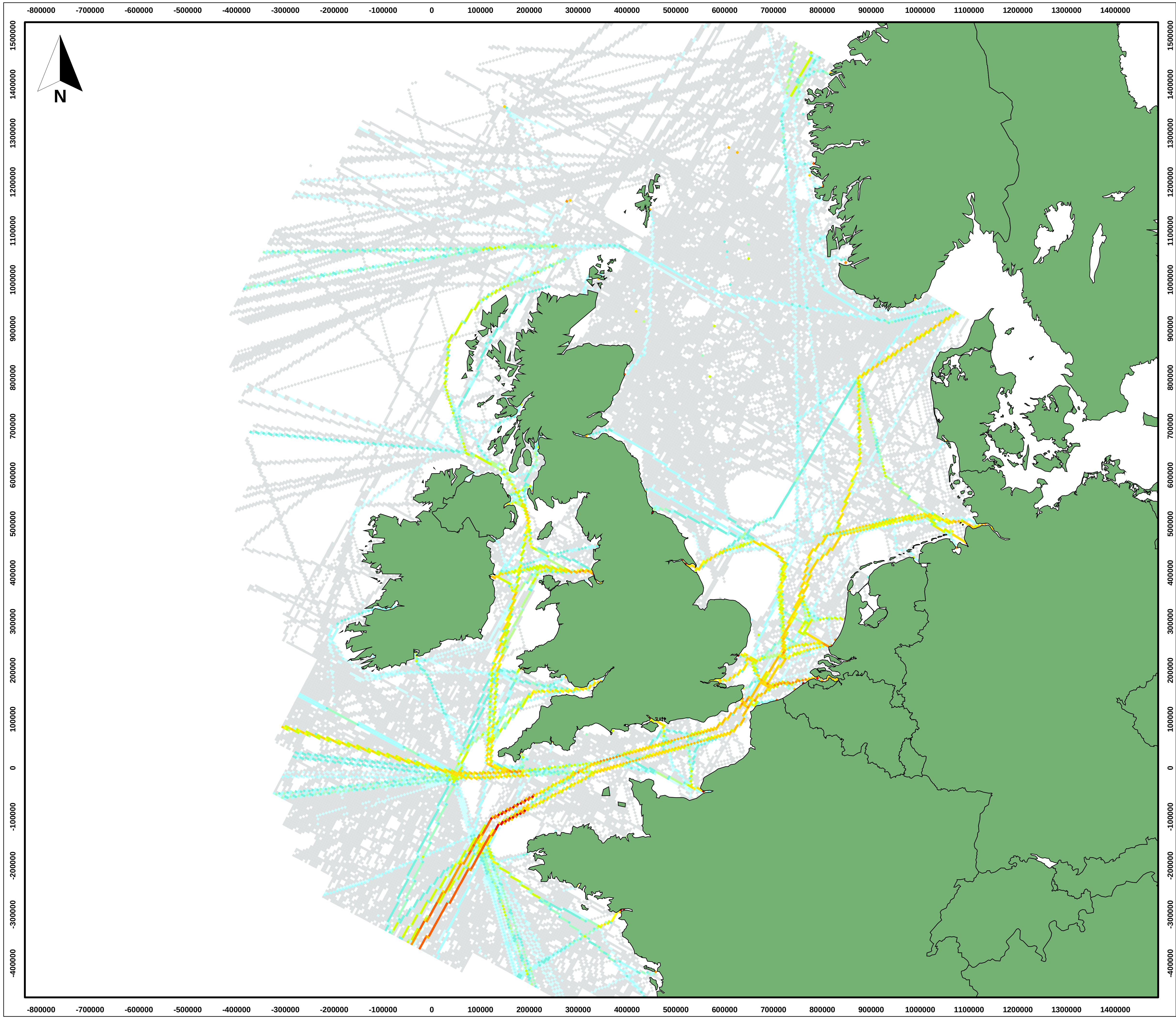

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UK Ship Emissions Inventory

SO_2 Emissions within 5km x 5km Grid Cells in 2020 (Assuming 1% Growth)

November 2010
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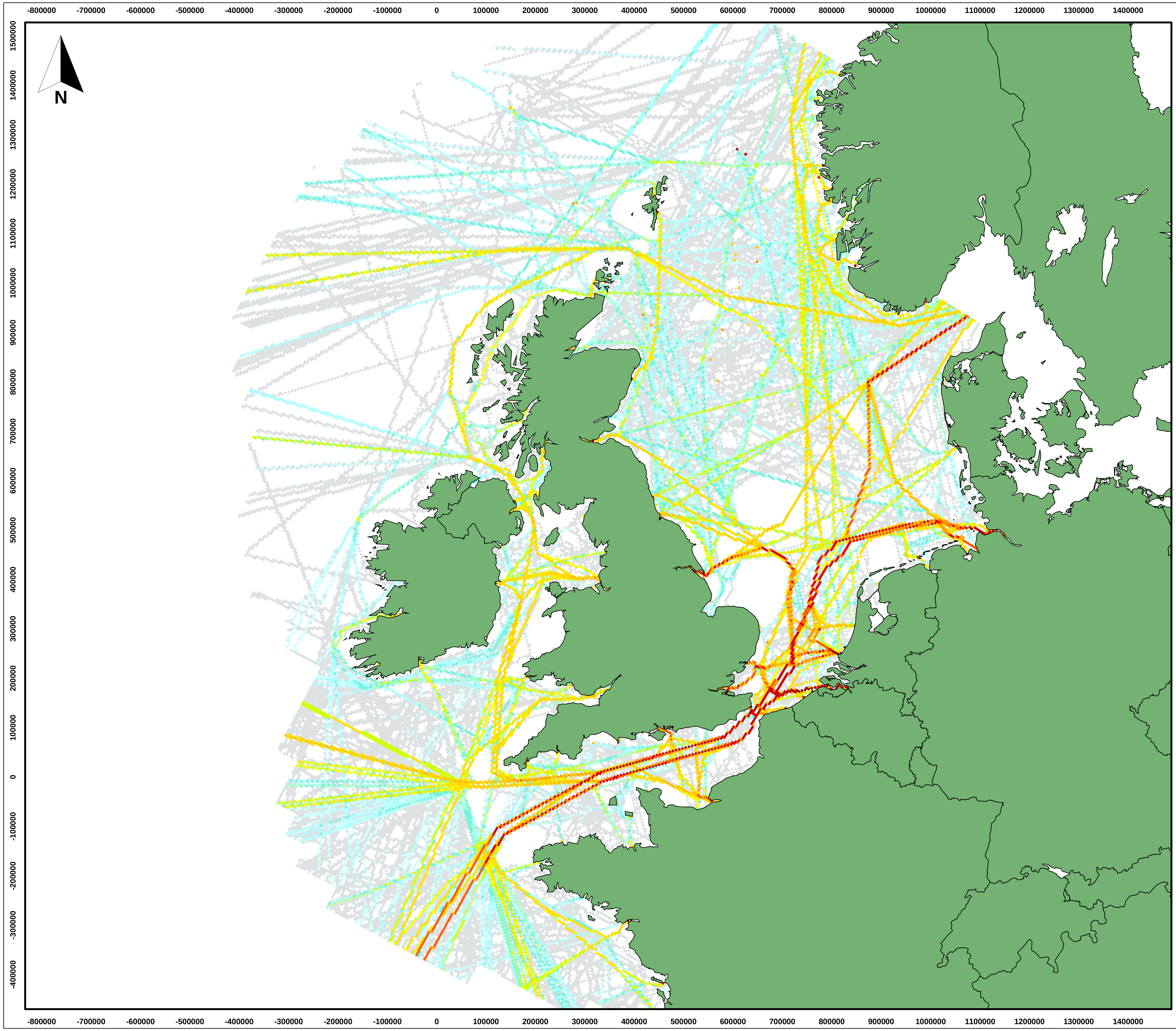

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UK Ship Emissions Inventory

CO_2 Emissions within 5km x 5km Grid Cells in 2020 (Assuming 1% Growth)

November 2010
21897-A20.mxd squij

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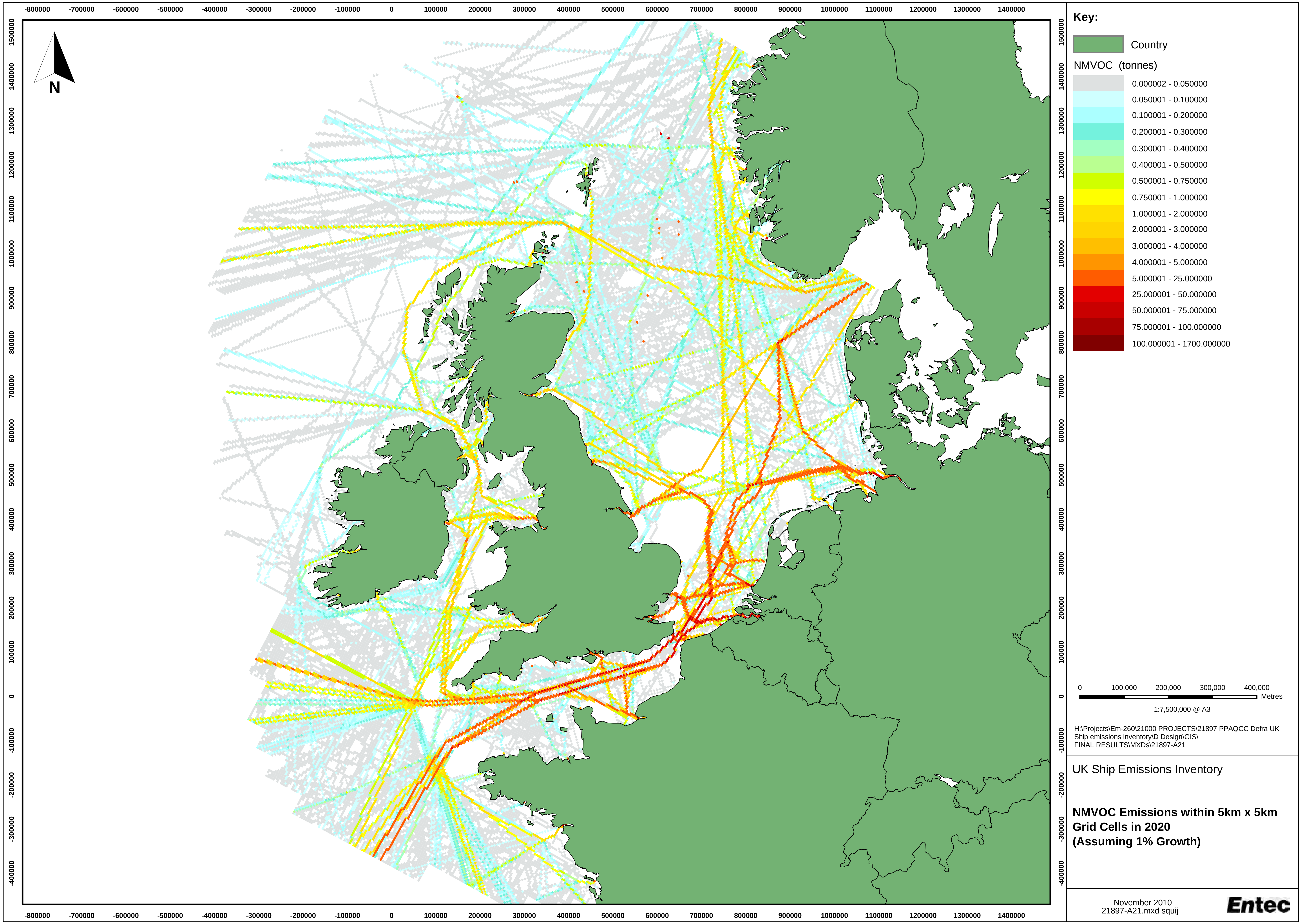
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UK Ship Emissions Inventory
NMVOC Emissions within 5km x 5km Grid Cells in 2020 (Assuming 1% Growth)
November 2010
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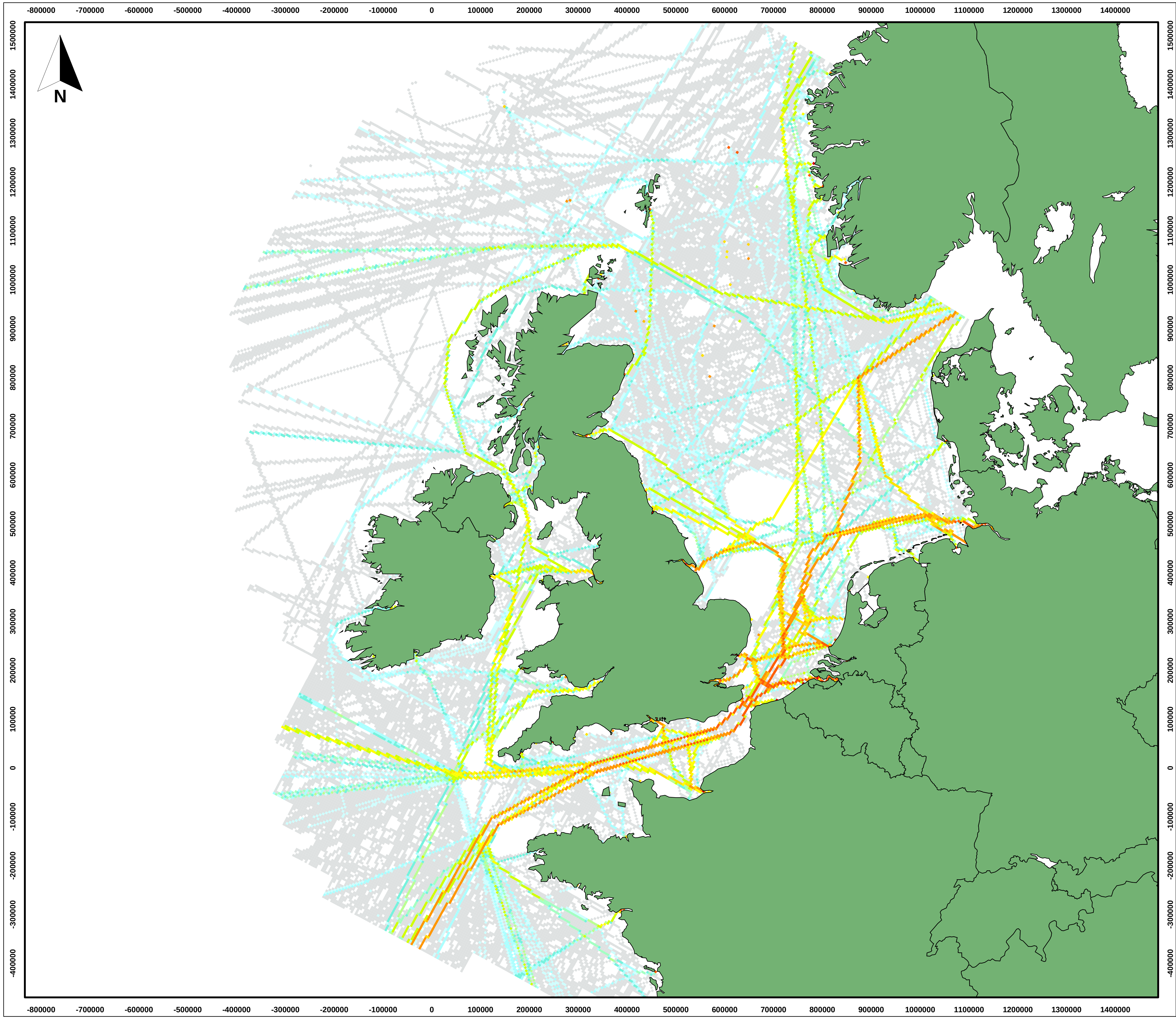
Entec



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UK Ship Emissions Inventory

PM2.5 Emissions within 5km x 5km Grid Cells in 2020 (Assuming 1% Growth)

November 2010
21897-A22.mxd squij

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