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Aether

Port of London Emissions Inventory 2016

Report to Port of London Authority and Transport for London

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PORT OF LONDON AUTHORITY

TRANSPORT FOR LONDON

Report Details

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Executive summary

The impacts of poor air quality on human and environmental health are of increasing concern in the UK and Europe, particularly in urban areas such as London. Use of the Thames can offer an effective way to reduce pollution exposure by carrying freight by water, where a load carried by multiple lorries can be taken by one vessel which also moves the emissions away from congested roads and vulnerable receptors. However, shipping can also be a significant source of air pollutant emissions.

Aether and TNO were commissioned by the Port of London Authority (PLA) and Transport for London (TfL) to prepare an inventory of emissions to air from shipping on the Thames and other navigable waterways in the Port of London. This inventory provides a baseline against which policy scenarios can be tested to show their impact on pollution emissions along the Thames. It will also support an update to the London Atmospheric Emissions Inventory (LAEI), providing more detailed and accurate emissions estimates for shipping.

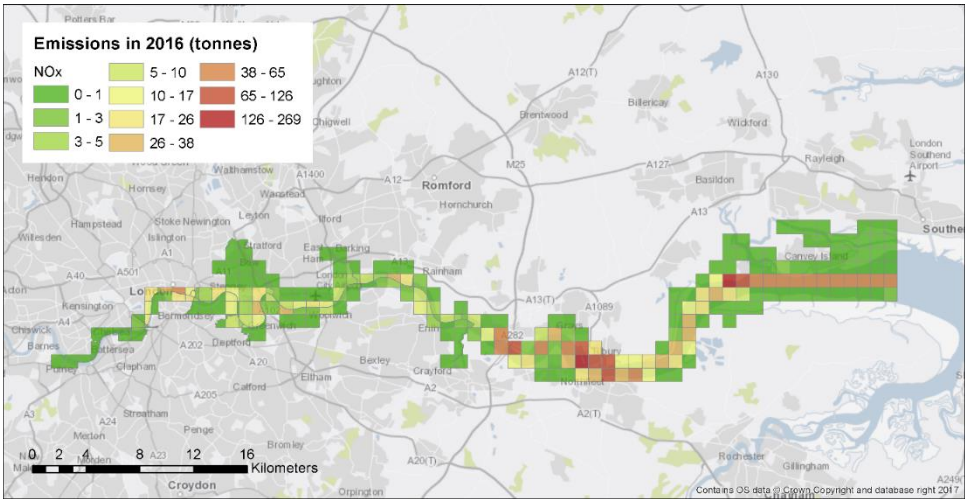
This study provides a higher level of detail than previous emissions estimates for shipping in the Thames, as well as covering a larger area. The 2013 update of the LAEI used passenger ferry schedules and information on ships at berth, to produce data on ship movements. Information on individual ships available from Lloyds List Intelligence (LLI) were used to produce straight line shipping tracks and time at berth for cargo vessels. Emissions factors for nine cargo vessel types and one for passenger ferries were then used to produce the inventory[1].

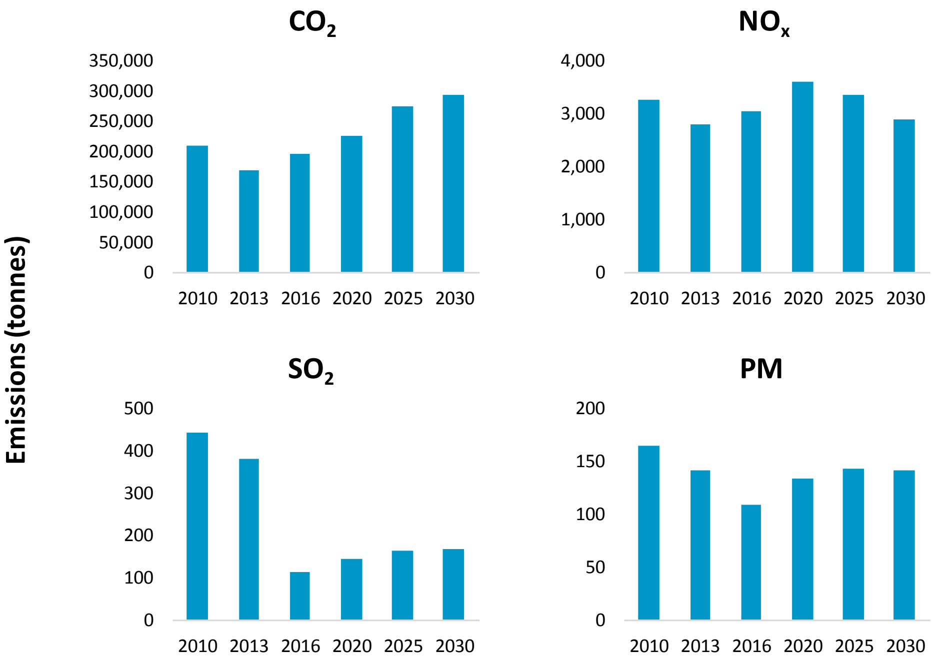
The methodology for this study used more detailed data on ships and their movements available through the Automatic Identification System (AIS), alongside the LLI database. Using AIS, individual ship tracks can be plotted and emissions calculated for each using detailed emissions factors for a wide variety of ship types, corrected to take account of engine use and power required for each journey. The totals have been aggregated for categories of ship type. AIS also provides geographical information which allows emissions to be assigned to specific locations and, again, aggregated into the grid cells used in the LAEI. The result is a comprehensive and detailed shipping emission inventory which can be used flexibly to assess the impact of policies and measures.

The geographical scope of this project comprises the Port of London, i.e. the Thames, its tributaries and connected waterways, between Teddington and Southend. For administrative purposes, i.e. to ensure data is compatible with the LAEI, study area is split into the Thames between the eastern M25 crossing at Dartford and Southend and the area covered by the LAEI which roughly equates to the Thames between the two M25 river crossings. This provides, for the first time, a geographically distributed emissions inventory for the whole of the Port of London.

The base year for this inventory is 2016. The inventory shows that the majority of the shipping emissions occur to the east of the M25. Carbon dioxide (CO_2) emissions correlate well with total fuel used by shipping and is thus a useful proxy for shipping activity. 66% of the total CO_2 emissions in 2016 are to the east of the M25, rising to 70% in 2030. For oxides of nitrogen (NO_x) the east of M25 area accounts for 71% of the total in 2016 and 75% for particulate matter, reflecting the higher sulphur fuels generally used by sea going vessels. This is illustrated by the map, below, which shows emissions for NO_x, although other pollutants follow a very similar pattern.

[1] The full methodology is described within the supporting documentation for the LAEI: https://data.london.gov.uk/dataset/london-atmospheric-emissions-inventory-2013





Shipping emissions have been projected forwards to 2020, 2025 and 2030 and "back calculated" for 2010 and 2013. Back calculations use ship movement data for previous years alongside policies and trends impacting on the shipping fleet, such as the North Sea SO_X control Area (SECA). The basis for the projections has been the evidence base which supports the PLA's Thames Vision project[2]. This work forecasts a substantial increase in container and roll on-roll off (RoRo) traffic using the Port facilities, as well as a doubling of commuter and tourist passenger numbers by 2035. These forecasts have been set against other long-term influences on emissions, including the North Sea NO_X Emission Control Area (NECA) (including the transition to Tier III engines under MARPOL[3] Annex VI), control of fuel quality for inland vessels, transition to Stage V engines for inland waterway vessels and changes in global shipping trends towards larger, more efficient vessels. The chart above illustrates the changes in emissions over time for four key pollutants.

[2] http://www.pla.co.uk/About-Us/The-Thames-Vision

[3] The International Convention for the Prevention of Pollution from Ships

Glossary of abbreviations

AIS	Automatic Identification System
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CRT	Canal and River Trust
EA	Environment Agency
GIS	Geographic Information System
GLA	Greater London Authority
IMO	International Maritime Organisation
LAEI	London Atmospheric Emissions Inventory
LEGGI	London Energy and Greenhouse Gas Inventory
LEZ	Low Emission Zone
LLI	Lloyds List Intelligence
MMSI	Maritime Mobile Service Identification
NECA	NO_X Emission Control Area
NMVOC	Non-methane volatile organic compounds
N_2O	Nitrous oxide
NO_x	Oxides of Nitrogen
PLA	Port of London Authority
PM	Particulate matter
PM_{10}	Particulate matter with an aerodynamic size of less than 10 micrometres
$PM_{2.5}$	Particulate matter with an aerodynamic size of less than 2.5 micrometres
RoRo	Roll on, Roll off
TfL	Transport for London
SECA	SO_X Emission Control Area
SO_2	Sulphur dioxide
SO_X	Oxides of Sulphur
ULEZ	Ultra-Low Emission Zone
VOCs	Volatile organic compound

Contents

1 Introduction

The impacts of poor air quality on human and environmental health are of increasing concern in the UK and Europe, particularly in urban areas such as London. The Thames is one of the UK's major ports, handling some 53.4 million tonnes of cargo in 2016. Use of the Thames can offer an effective way to reduce pollution exposure by carrying freight by water, where a load carried by multiple lorries can be taken by one vessel; 3 million tonnes of freight were carried in this way in 2016. It is also a major transport route, carrying almost 10 million passenger journeys. This has the potential to move air pollution emissions away from congested roads and vulnerable receptors. However, traffic on the river can still be a significant source of air pollutant emissions.

As emission controls on land based sources, especially road vehicles, become more stringent, emissions from shipping are receiving greater attention. However, data has not previously been available to accurately evaluate policies and measures to reduce emissions from inland vessels.

The Port of London Authority (PLA) is developing a port-wide air quality strategy and is undertaking data collection activities to support this work. The Port Wide Emissions Inventory exercise was commissioned as part of this programme of work by the PLA, in partnership with Transport for London (TfL), from Aether and TNO, and is the first port wide inventory developed for the Port of London. It will also be used to support an update to the London Atmospheric Emissions Inventory (LAEI).

An emissions inventory is an account of pollution releases to the environment from a set of sources. This is used to track changes in emissions over time and to prioritise sources of pollution for potential reductions. This inventory for the Port of London Authority and Transport for London is an inventory of air pollution emissions from the ships that visit and use the whole of the Port of London area.

The GLA and TfL maintain two emissions inventories for London; the LAEI and the London Energy and Greenhouse Gas Inventory (LEGGI). The Mayor supports the continued improvement to the LAEI and LEGGI to ensure that boroughs and other organisations have access to accurate emissions information to help develop effective policies. The inventories are critical to the development, implementation and monitoring of the London Environment Strategy (currently in draft form[4]) and schemes such as London's Low Emission Zone (LEZ) and the Ultra-Low Emission Zone (ULEZ).

The current LAEI[5] includes emissions data for the 'base year' 2013, back calculations for 2008, 2010 and projections for years 2020, 2025 and 2030. The current LEGGI is 2013 with an interim update for 2014. The emissions estimates produced through this study will feed into future updates of the LAEI and LEGGI. However, the LAEI does not cover the whole of the area considered in this study and so results have been calculated for the LAEI area and the remainder of the PLA jurisdiction.

[4] https://www.london.gov.uk/sites/default/files/london_environment_strategy-_draft_for_public_consultation.pdf

[5] http://data.london.gov.uk/dataset/london-atmospheric-emissions-inventory-2013

The basic process for calculating any emissions inventory is to combine data inputs by multiplying Activity data with Emission Factors for specific sources to calculate emissions. These separate emissions estimates are then aggregated into categories for reporting. Activity data can be sourced from a wide range of different types of datasets, for example could be the amount of fuel consumed by a particular fleet of ships, or the average distance travelled in a year by a type of ship. Emission factors are derived from emissions modelling or emissions measurements and are usually reported in terms of the amount of pollutant emitted per quantity of fuel consumed or per distance travelled. The level of detail chosen for the definition of a sources depends on the amount of detail available in the activity data and emission factors.

In many cases in the compilation of an emission inventory there are additional factors that must be taken into account when calculating emissions. Correction factors are therefore applied to the basic function of activity data multiplied by emission factors. For example: fuel quality varies over time and also by location, the size and number of engines in a ship varies within a group of ships. Gaps in data often need to be filled using expert judgement.

This study provides a higher level of detail that previous emissions estimates for shipping in the Thames, in addition to covering a larger area. The 2013 update of the LAEI used passenger ferry schedules and information on ships at berth, to produce data on ship movements. Using information on individual ships available from Lloyds List Intelligence (LLI), these were used to produce straight line shipping tracks and time at berth for cargo vessels. Emissions factors for nine cargo vessel types and one for passenger ferries were then used to produce the inventory[6].

The methodology for this study used detailed information on ships and their movements available through the Automatic Identification System (AIS), alongside the LLI database. Using AIS, individual ship tracks can be plotted and emissions calculated for each using detailed emissions factors for a wide variety of ship types, corrected to take account of engine use and power required for each journey. The totals have been aggregated for categories of ship type. AIS also provides geographical information which allows emissions to be assigned to specific locations and, again, aggregated into the grid cells used in the LAEI. The result is a comprehensive and detailed shipping emission inventory which can be used flexibly to assess the impact of policies and measures.

This report provides a summary of the scope of the study and the methodology used to develop the inventory. It then provides output information for oxides of nitrogen (NO_X), particulate matter (PM), sulphur dioxide (SO_2), carbon dioxide (CO_2), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOC), as well as analysing the trends in emissions over time.

[6] The full methodology is described within the supporting documentation for the LAEI: https://data.london.gov.uk/dataset/london-atmospheric-emissions-inventory-2013

2 Scope

The scope of this port wide inventory comprises the whole of the Port of London, i.e. the Thames, its tributaries and connected waterways, between Teddington and Southend. For administrative purposes, i.e. to ensure data is compatible with the LAEI, the area is split into two main sections. The first is the area currently covered by the LAEI[7], which approximately equates to the river Thames between the two M25 river crossings. Previous studies have estimated shipping emissions from this part of the Thames, although none have used the detailed methodology described in this report. Shipping emissions within this area will be used as part of a forthcoming update to the LAEI, managed by Transport for London.

The second is the area of the remainder of the PLA jurisdiction covering the main port activities for which PLA are responsible, including Tilbury Docks and the London Gateway facility. This area extends east from the M25 orbital motorway crossing at Dartford up to a line extending south from Crow Stone (near Southend) to Yantlet Creek. It excludes activity within the Medway Estuary. Due to the large volume of seagoing ships concentrated in this area, this eastern section accounts for the majority of emissions within the inventory. The geographical extent of the inventory is shown in Figure 2.1.

Emissions estimates (tonnes per annum) have been calculated for all relevant pollutants: NO_X, SO_2, PM_{10}, CO, CO_2, VOC, NMVOC, CH_4 and some heavy metals. Other pollutants which are covered by the LAEI and LEGGI, e.g. fluorinated gaseous compounds (HFCs, PFCs, SF6), N_2O, and POPs have not been included as shipping is not a significant source.

These emissions estimates have been provided in disaggregate form in order to show:

- Emissions in each grid square for the study area (and thus totals for the three sectors)
- Emissions by vessel type
- Emissions by activity, i.e. whether sailing/manoeuvring or at berth.

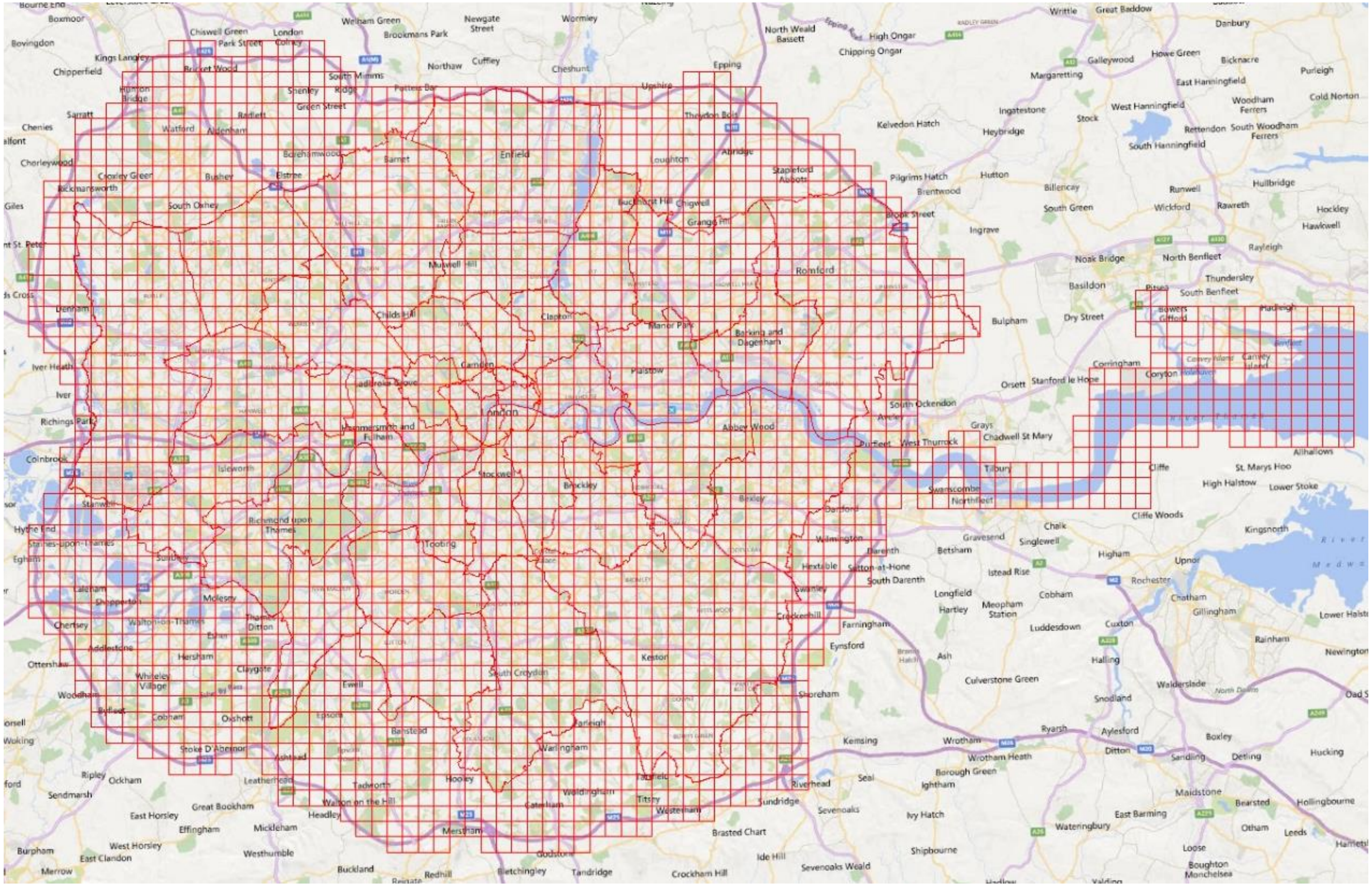
The base year for this inventory is 2016. Back calculations for 2010 and 2013 have been made based on aggregated activity data on ship movements within the Thames Estuary, including some AIS data for 2013, combined with adjustments to emission factors based on changes in fuel quality and other sectoral trends.

Forward projections for 2020, 2025 and 2030 have been made based on:

- Estimated trends in activity, e.g. cargo tonnages or passenger trips, using data provided by PLA
- Current policy measures, such as changes in fuel quality required in the North Sea SO_X Emissions Control Area (SECA) and NO_x Emissions Control Area (NECA)
- Intelligence on global shipping trends, such as changes in seagoing vessel size and efficiency
- Data gathered from operators, such as expected technology changes, use of shore power, other abatement technologies, fleet sizes, etc.

[7] http://data.london.gov.uk/dataset/london-atmospheric-emissions-inventory-2013

Figure 2.1: Geographical extent of the Port Wide Inventory



3 Methodology and data sources

This section provides a summary of the methodology and data sources used to produce the emissions estimates presented in section 4 of this report. A more complete explanation of the methodology is provided in the accompanying methodology report.

3.1 Data sources

Several key datasets were obtained in order to build the overall activity dataset for 2016, which, alongside the emission factors, form the basis for emissions calculation. The main data sources were:

- AIS data on individual ship movements, supplied by PLA; AIS transponders are carried by almost all commercial vessels using the Thames
- Ship berth arrival and departure data, supplied by PLA
- Lloyds List Intelligence (LLI) data on ships for which AIS messages were recorded
- Information gains through a survey of operators
- Projections of port cargo handling and passenger numbers, supplied by PLA[8]
- Locations of berths, wharfs and moorings in GIS format, supplied by PLA
- Data on recreational craft movements, supplied by PLA (including data from the Thames Barrier), Canal and River Trust (CRT) and the Environment Agency (EA).

At its most basic level, data was required on the number and location of vessels operating within the study area. For the great majority of larger vessels, and a significant number of small ones, this was provided by the network of shore based AIS receivers which pick up signals from transponders fitted to vessels.

AIS messages provide a significant amount of information about individual vessels, particularly when allied with shipping intelligence data, which in this study was obtained through LLI. Each AIS message provides the location, speed and direction of the ship at a given point in time, as well as its name and standard identification numbers. These can be matched to the LLI database to provide details on the ship type, dimensions, engine type, number and power, fuel use, year of build, etc. All of these parameters have a significant impact on the emissions produced by that ship.

In more detail:

- Ship dimensions: the larger a ship is, the more power is needed to move it at a given speed and thus the greater the emissions will tend to be. The relationship between the different dimensions, e.g. length, width, draught, is also an important factor
- Engine type: each engine type – reciprocating diesel, gas turbine, steam turbine – will have different emission characteristics and different power profiles
- Engine number: some ships are fitted with multiple engines and, depending on how these are used, this will also affect the emissions profile

[8] http://www.pla.co.uk/assets/forecasts-consultationdocumentv11december-1.pdf

- Auxiliary power: larger ships, typically seagoing ships, will have smaller auxiliary power units fitted to provide power, e.g. for onboard services and system, when the ship is at berth
- Fuel use: different fuel grades and types are available, e.g. Marine Diesel, Heavy Fuel Oil, and these can have a profound impact on the type and composition of the ship's emissions. Legislation is in place to control the quality of fuel used in UK inland waterways and in the North Sea
- Ship and engine age: generally, the emissions from an engine increase with age as control systems wear and power output drops. The age of an engine will also affect the level of emission control fitted to it when new. Note that ships can be re-engined and so the ship age does not necessarily equate with engine age.

Data from AIS and LLI were supplemented by a survey sent out to vessel operators using the Port. This provided important information both on vessels not fitted with AIS transponders and on the fuel consumption for those that are; fuel consumption can be calculated but reported figures are an important correlation factor.

The location of berths, wharfs and moorings was supplied by PLA. This provides information both to validate the split between "at berth" and "sailing" calculated from the AIS data and to provide indications of ship movements for non-AIS movements.

In addition to estimating emissions for 2016, the project required both back-cast emissions for 2010 and 2013 and emission projections for the years 2020, 2025 and 2030. The process for estimating these, including the data used, is explained in section 3.2.2, below.

3.2 Methodology

Figure 3.1, below, provides an outline summary of the process used in this study. The method is further explained in the following sections. A more detailed explanation is provided in the accompanying Methodology Report[9].

3.2.1 Calculation of emissions

Previous attempts to estimate shipping emissions for the UK have tended to use either surrogate statistics, e.g. fuel sales, or have used generic factors for ship types, i.e. they have started at an aggregated level. This study uses a more complex process for vessels carrying AIS transponders. Standard emissions factors are adjusted according to ship and movement characteristics to produce near unique factors for each individual AIS message. The outputs from these calculations are then aggregated according to vessel type. This allows a far more detailed inventory to be produced, although it also places greater demands in terms of data needs.

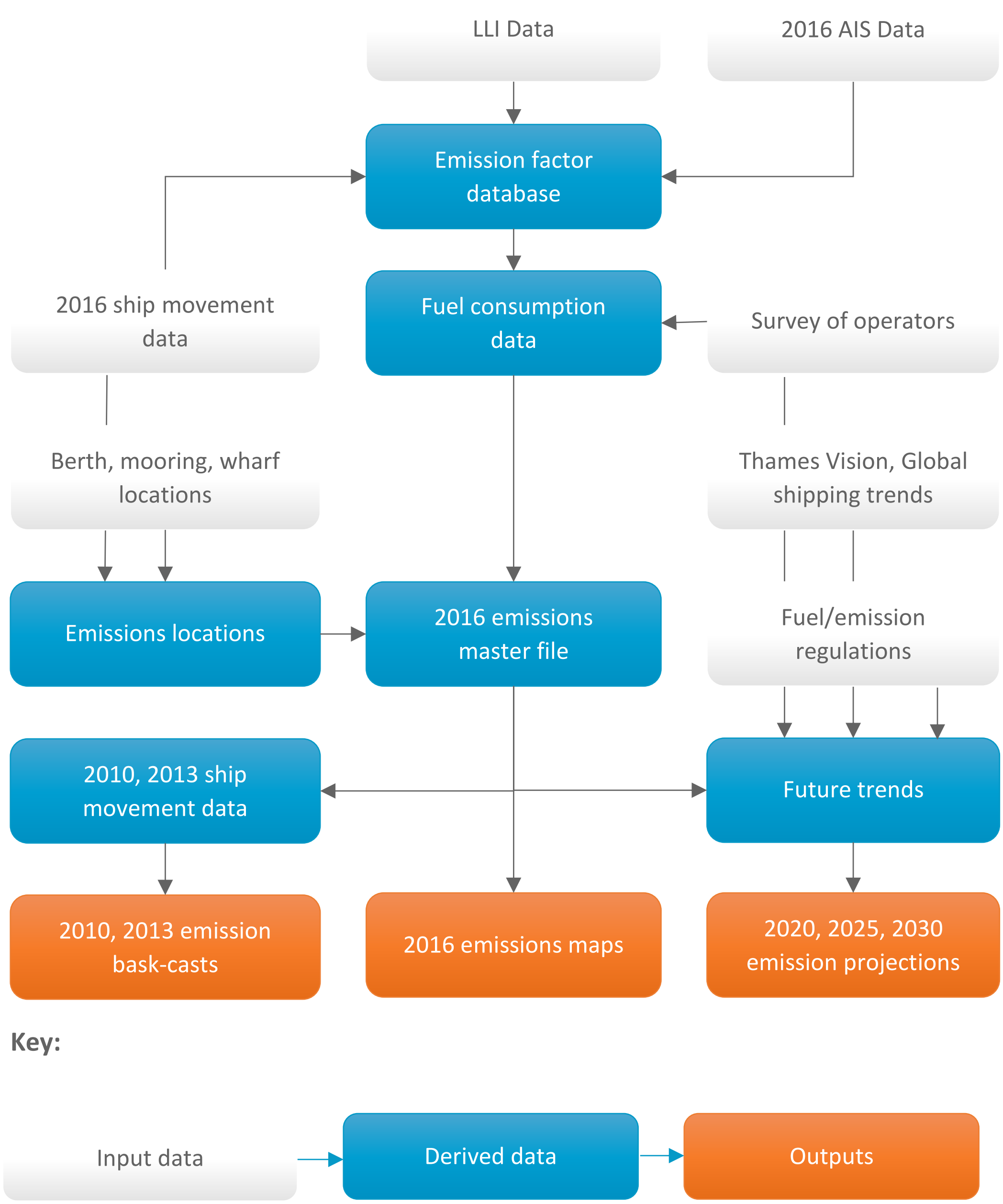
The initial step is to split activity, as represented by AIS messages, into "sailing and manoeuvring" and "at berth". Vessels with a speed of less than 0.5 knots over a continuous period of over 15 minutes were assumed to be at berth.

Emissions from manoeuvring

[9] PLA Port Wide Inventory Methodology Report

For sailing and manoeuvring, AIS data is used to calculate the speed of each ship and, from this, the amount of power required to move the ship at that speed. Calculations were based on key parameters obtained from AIS and LLI data sources. Both speed and power use are key variables in the emission calculation. A correction to the assumed engine load is made based on the number of main propulsion engines fitted to the ship. Multiple engines tend to result in more optimal (i.e. higher) load at low speeds compared to single engine vessels because one or more engines can be switched off at very low speeds.

Figure 3.1: Outline methodology for producing the Port Wide Emissions Inventory



As a result, an emission is calculated using the emission factor to produce the power required to attain the actual speed, using a correction factor corresponding with the power rating on each engine for each ship as it moves through the Port of London. This is then aggregated by ship type to give emissions for that type for the specific year. Ship types are based on information contained in the LLI. Further aggregation to a smaller set of ship types has been undertaken to give the aggregated outputs shown in this report.

Emissions at berth

For ships at berth, where auxiliary engines and boilers are used, emissions factors based on survey work undertaken within the Clean North Sea Shipping (CNSS) project, adopted by the Dutch national inventory, were used. These vary according to ship type and volume (gross tonnage), both of which have a bearing on the amount of work auxiliary engines are required to undertake. For example, for tankers, fuel usage and thus emissions at berth tend to be high relative to other ship types because they need to power cargo pumps and produce inert gas.

Data resulting from a survey of operators was used to validate the outputs and, where necessary, make further corrections.

Ship movement data, including time at berth or mooring, was multiplied against the calculated emission factors to produce emission totals for each ship track. These were aggregated by ship type to give emission totals for each type and each pollution for the year 2016. QA/QC checks against other data sources were undertaken to ensure consistency and identify any outlying results.

3.2.2 Mapping, back-casting and projecting emissions

The calculated emissions were assigned geographical locations, based on AIS messages or known ship tracks, and those locations were matched to grid cells taken from the LAEI as illustrated in Figure 2.1. The emissions for each grid cell were then aggregated to give a total for that cell for each vessel type, which were further aggregated to give total shipping emissions for each pollutant. The results of this aggregation process were then used to produce the tables and charts shown in Section 4, below, and were also exported into a GIS programme to produce the emission maps.

Emissions for 2016 are then used as a baseline from which to “back cast” emissions for previous years and to project forwards to estimate future emissions. A range of different factors affect emissions over time and these need to be accounted for in producing back casts and projections. These include:

- Increases or decreases in the number of ships operating in the area
- Changes to the composition of the fleet
- Changes in the locations where ships operate, e.g. shoreside operations opening or closing
- Changes in the size of ship, influences by global shipping trends
- Tighter controls on fuel quality, including the phase out of “bunker” fuels
- Technological trends, e.g. in ship engines or ship design.

To back cast to 2010 and 2013, PLA provided records of arrivals and departures at the berths, wharfs and moorings within the study area. These included vessel IMO numbers which allowed further information on ship characteristics (size, type, engine capacity, etc.) to be obtained. These were used to scale the baseline results for 2016, with corrections made for changes in available fuel quality and including the impact of the North Sea SECA. Where movement data was not available, flat movement profiles were assumed, with corrections made for available fuel quality.

Projections require further assumptions to be made. Projections for ship movements were made based on trade forecasts produced by The Stamford Research Group to support the PLA's Thames Vision project[10]. These allowed forecasts of the total number of ship movements to be made, alongside changes in the composition of the fleet, corrected against global trends in shipping towards larger, more efficient vessels. Passenger numbers were assumed to increase to 20 million commuter and tourist journeys on the river per year, over the period to 2035, in line with the Thames Vision goals[11]. Proposed changes in fuel quality and in the control of emissions in the North Sea NECA were also accounted for in the projections. The geographical location of emissions was assumed to remain constant over the period as this was not possible to quantify within an acceptable level of certainty.

3.2.3 Assumptions and Uncertainties

As with any study of this type, there are uncertainties and assumptions in the estimation process which could impact on the final outputs. The table below summarises the key uncertainties alongside the potential impact they could have on the final emission estimates.

Table 3.1: Key assumptions and uncertainties

Assumption or uncertainty		Potential impact on emission totals
AIS data	AIS data does not provide complete coverage for all ship journeys. Interference with transponder messages may result in either messages not being received by shore stations or being assigned incorrect locations. This issue was far more significant for vessels in the central London area, notably passenger vessels. A tested methodology was used to fill in gaps in reported journeys but there is the possibility of under-reporting for certain vessel types.	Small overall, potentially larger for certain ship types such as passenger vessels
Non-AIS vessels	For vessels without AIS transponders, less accurate movement data was used, e.g. reported movements through control points, e.g. locks or the Thames Barrier.	Small as non-AIS vessels tend to be much smaller and non-commercial craft
Fuel consumption	Fuel consumption is a key correcting factor for the emission factors. For some vessel classes, notably passenger vessels, reported fuel consumption was significantly different from the calculated fuel consumption based on AIS data. Expert judgment was used to define a realistic figure.	Small overall, potentially larger for certain ship types such as passenger vessels

[10] http://www.pla.co.uk/assets/forecasts-consultationdocumentv11december-1.pdf

[11] http://www.pla.co.uk/About-Us/The-Thames-Vision/The-Thames-Vision-Goals

Assumption or uncertainty		Potential impact on emission totals
Auxiliary engines	Emissions at berth are the result of auxiliary engines being used to power on-board activities and services_and a ship moving less than 0.5 knots for more than 15 minutes was assumed to be at berth and making use of the auxiliary engine. However, information on the auxiliary engines fitted to specific ships is incomplete, even within high quality data sources such as LLI. The assumptions used in this study are based on an internationally recognised methodology[12], which included extensive surveys of ship emissions at berth (see more details in section 4.4 of the Methodology report). Using this methodology, individual vessel time-based emission factors were derived dependent on vessel type, year of build and size expressed in gross tonnes. While it is conceivable that ships in the Port of London differ significantly from those in other ports, any such differences are likely to be minor.	Small to medium
Sulphur content of fuel	Emissions of SO_2 are closely related to the amount of sulphur in the fuel used. The sulphur content of fuels is controlled by EU and UK law. In the North Sea and English Channel, fuel not exceeding 0.1% must be used as from 2015 (previously 1%). The same limit applies to ships at berth. Vessels on inland waterways and leisure craft must use fuel not exceeding 0.001% sulphur. In this study, 100% compliance with the relevant standards at sea and for inland navigation has been assumed. However, surveys in the Netherlands, undertaken since the fuel quality regulations were introduced (including SECA), have shown that ships at berth are, on average, 90% compliant. Therefore, it has been assumed that 10% of seagoing ships at berth use 1% sulphur fuel for their auxiliary operations.	Medium to large for sea-going vessels at berth, increasing sulphur emissions by around 50%. However, no evidence on compliance levels of ships in the survey area was available at the time of the study.
Future trends	In projecting emissions to future years, the study relied on the forecasts of several other organisations and studies. Each of these contain uncertainties and often include ranges, whereas this study has only used a central estimate. Some of the future trends, such as the increase in ferry passenger numbers are based on expert stakeholder input. While this remains a valid method of information gathering, it is more difficult to analyse for uncertainty. In addition, intelligence on future trends which could not be quantified has not been taken into account.	Small in the short term but increasing over time.

[12] Hulskotte J.H.J, H.A.C. Denier van der Gon, Emissions From Seagoing Ships At Berth Derived From An On-Board Survey; Atmospheric Environment, Doi: 10.1016/j.atmosenv.2009.10.018, 2009

4 Inventory outputs

This section provides a summary of the emissions calculated during this project, for the years 2010, 2013, 2016, 2020, 2025 and 2030. For each pollutant, a table of emissions split by vessel type and further split between emissions at berth and when under way (sailing or manoeuvring) is given for each of the years. These results are further illustrated which charts showing emissions by ship type, split between at berth and sailing emissions, for 2016 and a chart showing the change in emissions over time. The geographical distribution of emissions for 2016 is also provided in map form. Finally, a commentary on the key features of the results is provided. The full set of results has been provided to PLA and TfL in spreadsheet form.

4.1 Oxides of Nitrogen (NO_x)

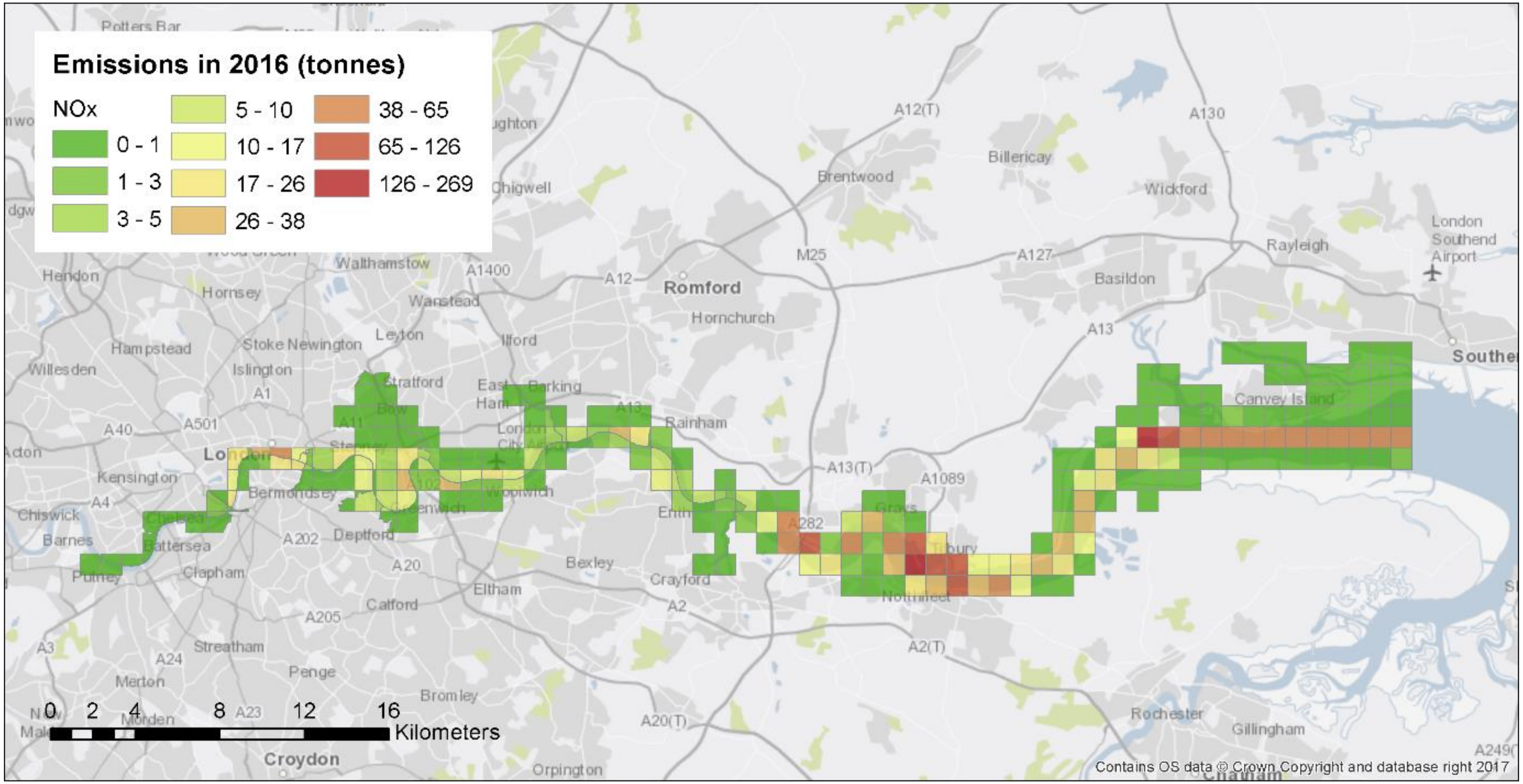


Figure 4.1.1: NO_x emissions from shipping in 2016

Figure 4.1.2: NO_x emissions by ship type in 2016

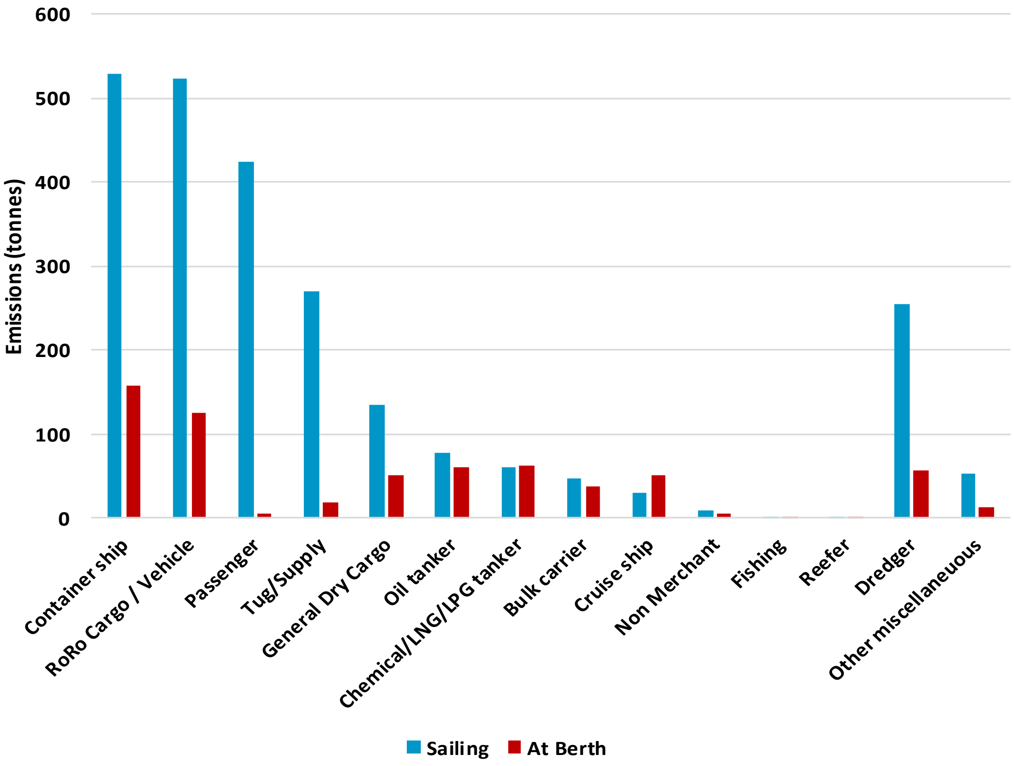


Figure 4.1.3: Trends in NO_x emissions from shipping over time

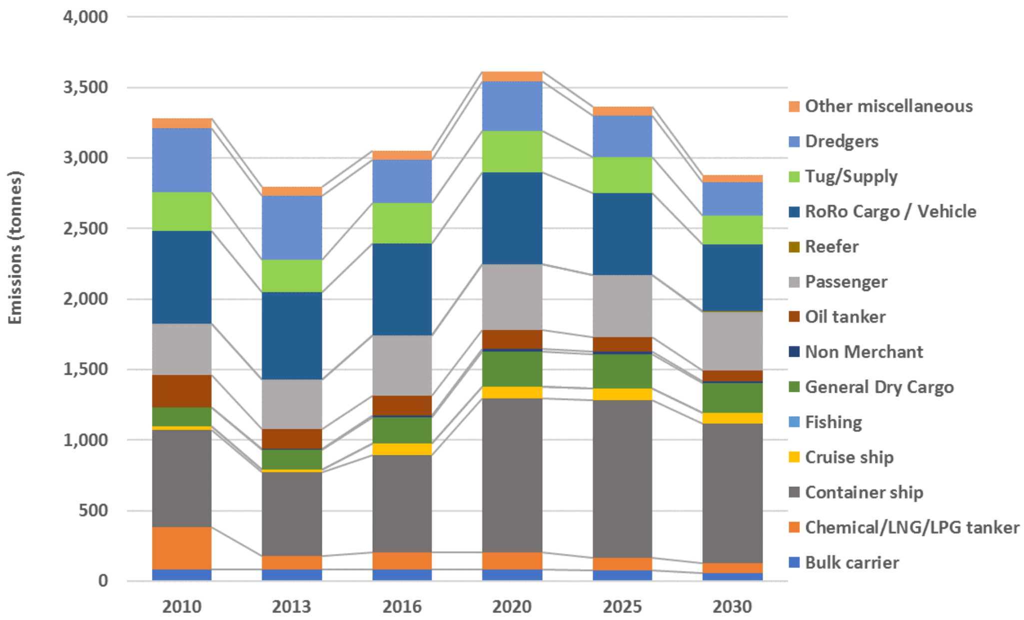


Table 4.1.1: NO_x emissions from shipping for all years and ship types

Ship type	Emissions (tonnes)					
	2010	2013	2016	2020	2025	2030
Bulk carrier	82	80	84	86	74	58
Chemical/LNG/LPG tanker	301	97	123	120	93	68
Container ship	692	597	686	1,088	1,116	987
Cruise ship	23	20	80	86	82	78
Fishing	1	1	1	1	1	1
General Dry Cargo	131	138	186	249	245	212
Non Merchant	5	5	14	15	14	13
Oil tanker	228	138	138	135	103	76
Passenger	360	356	429	465	443	418
Reefer	2	1	1	1	1	0
RoRo Cargo/Vehicle	660	615	649	652	580	477
Tug/Supply	271	230	287	295	254	201
Dredgers	455	455	311	350	298	240
Other miscellaneous	72	65	64	73	62	50
All Vessels	**3,282**	**2,797**	**3,053**	**3,614**	**3,364**	**2,880**

4.2 Particulate Matter (PM_{10})

Figure 4.2.1: PM_{10} emissions from shipping in 2016

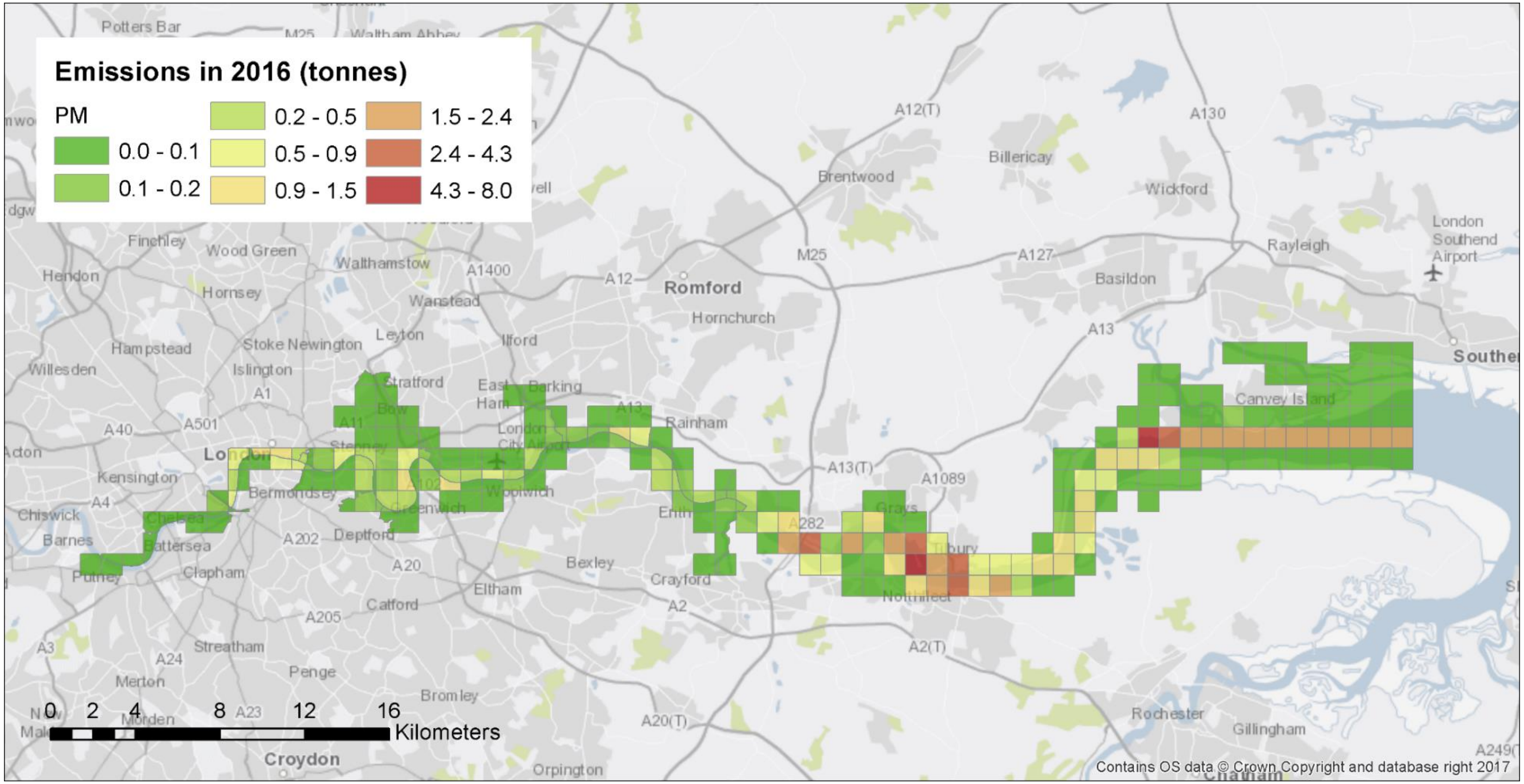


Figure 4.2.2: PM_{10} emissions by ship type in 2016

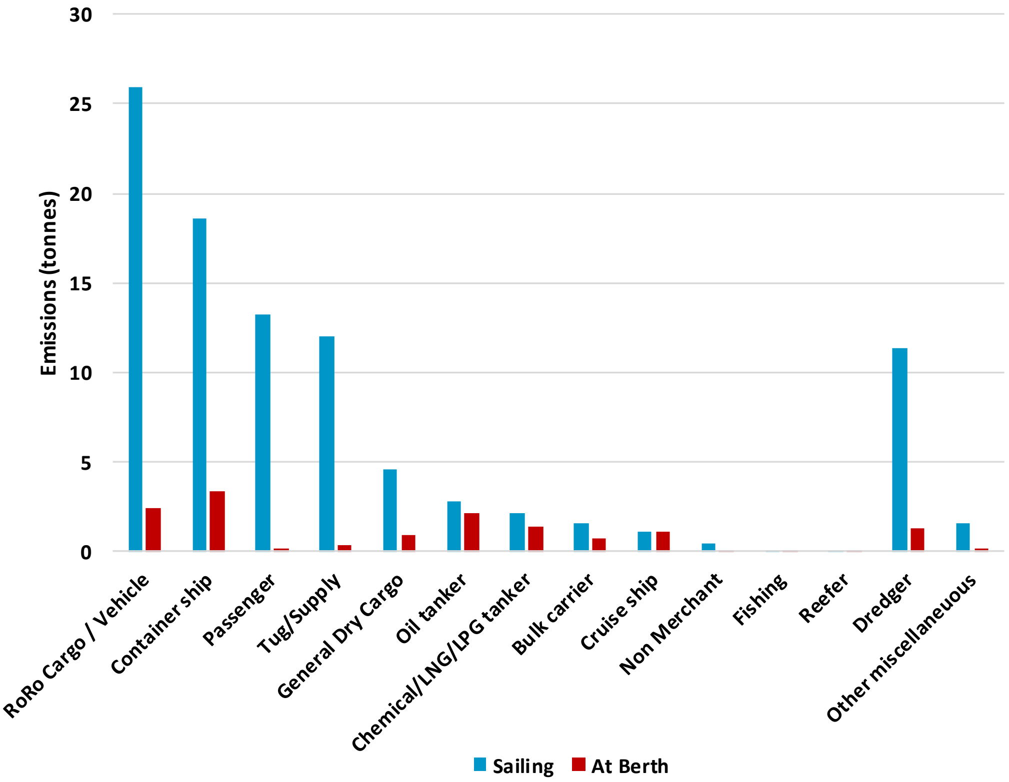


Figure 4.2.3: Trends in PM_{10} emissions from shipping over time

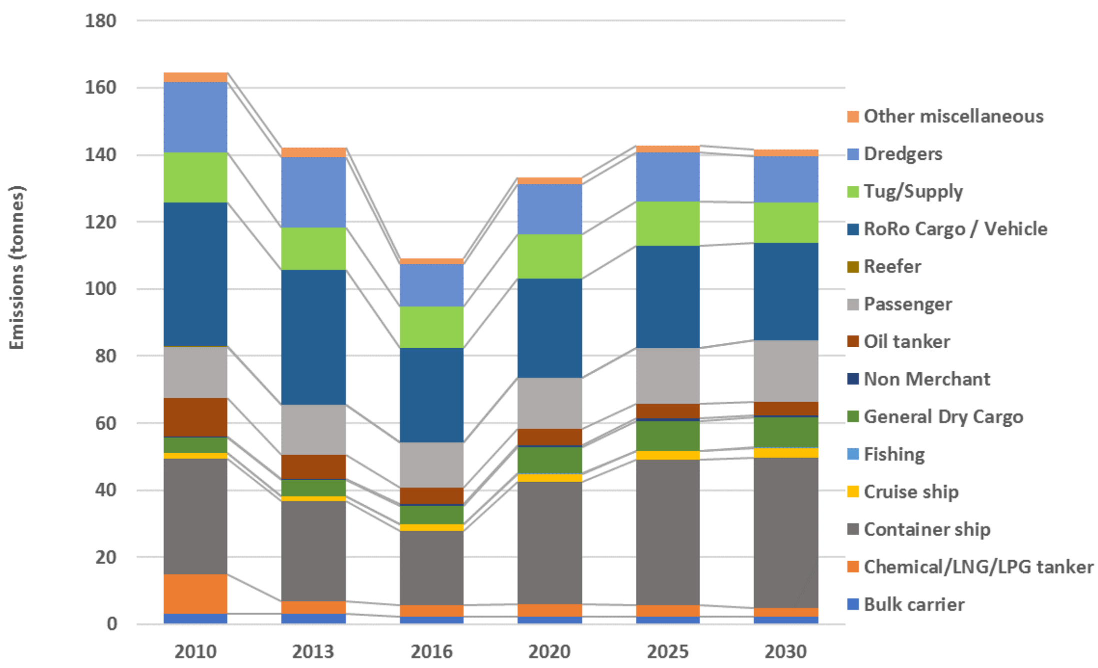


Table 4.2.1: PM_{10} emissions from shipping for all years and ship types

Ship type	Emissions (tonnes)					
	2010	2013	2016	2020	2025	2030
Bulk carrier	3	3	2	2	2	2
Chemical/LNG/LPG tanker	12	4	4	4	3	3
Container ship	34	30	22	36	43	45
Cruise ship	2	1	2	2	3	3
Fishing	0	0	0	0	0	0
General Dry Cargo	5	5	5	8	9	9
Non Merchant	0	0	1	1	1	1
Oil tanker	12	7	5	5	4	4
Passenger	15	15	13	15	17	18
Reefer	0	0	0	0	0	0
RoRo Cargo/Vehicle	43	40	28	30	30	29
Tug/Supply	15	13	12	13	13	12
Dredgers	21	21	13	15	15	14
Other miscellaneous	3	3	2	2	2	2
All Vessels	**165**	**142**	**109**	**133**	**143**	**142**

4.3 Sulphur Dioxide (SO_2)

Figure 4.3.1: SO_2 emissions from shipping in 2016

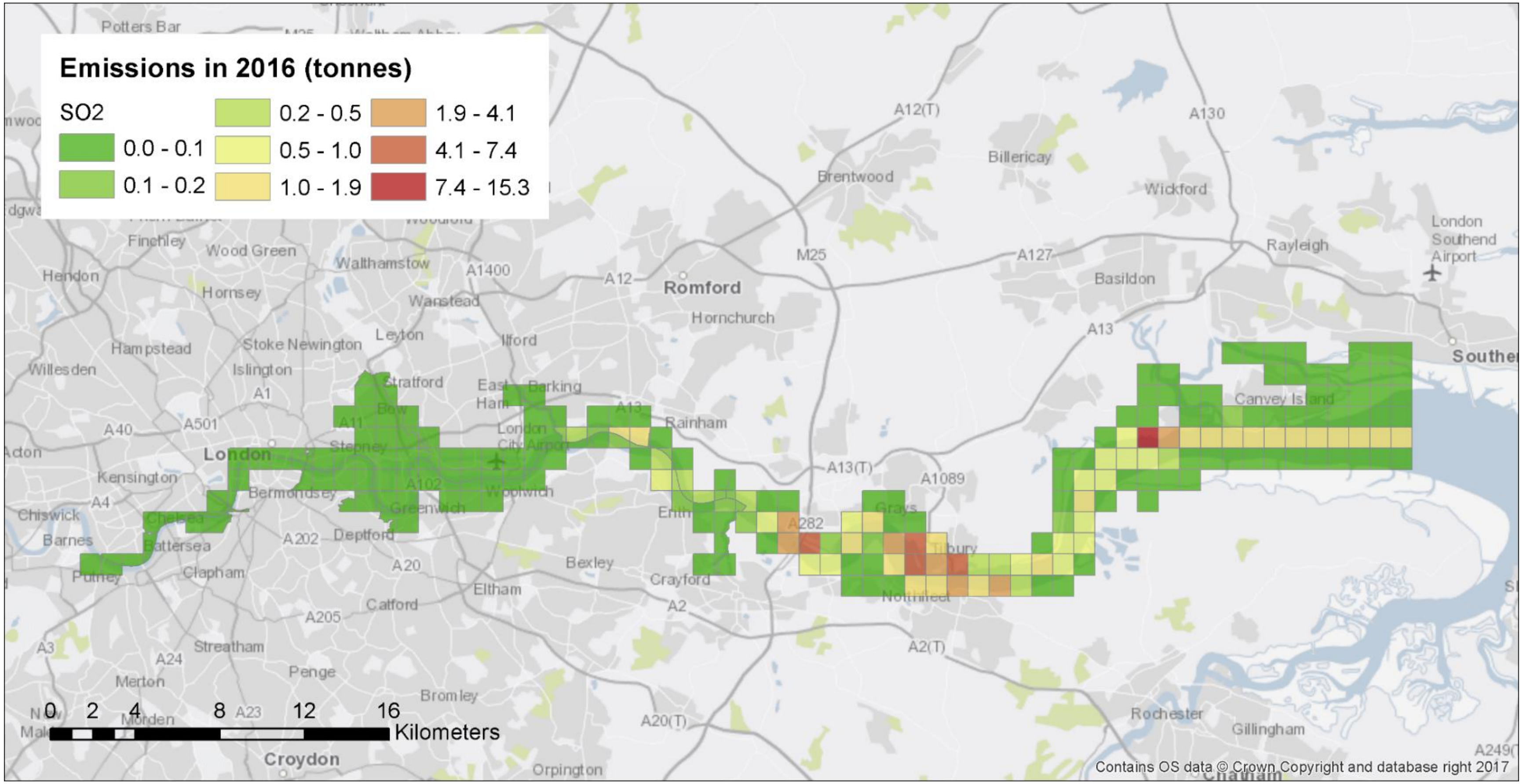


Figure 4.3.2: SO_2 emissions by ship type in 2016

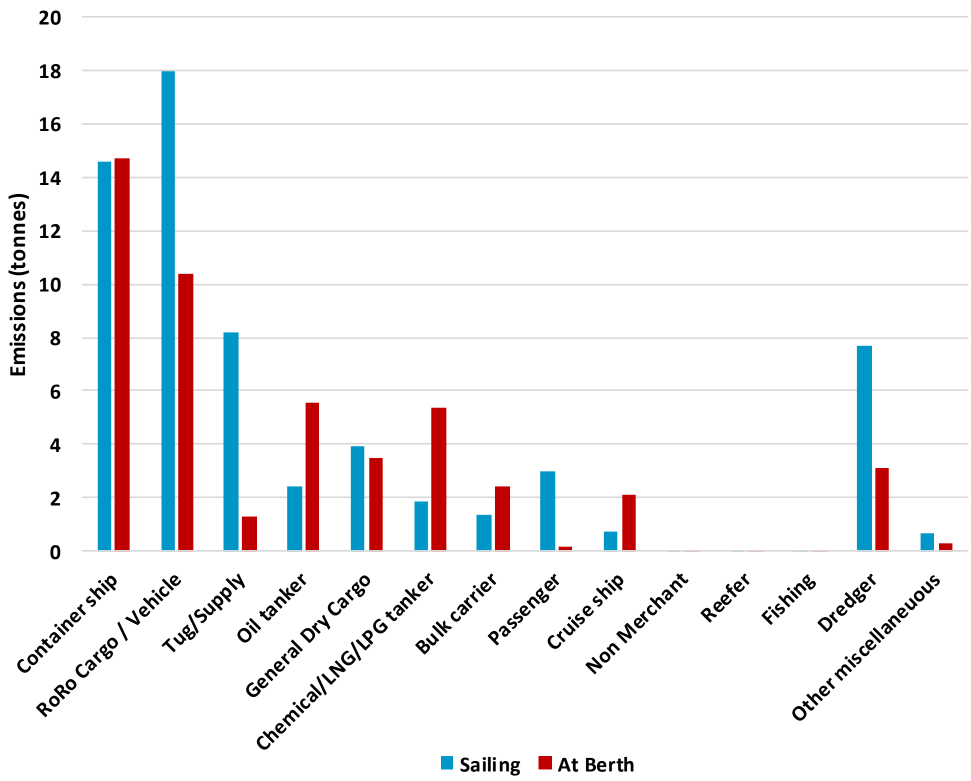


Figure 4.3.3: Trends in SO_2 emissions from shipping over time

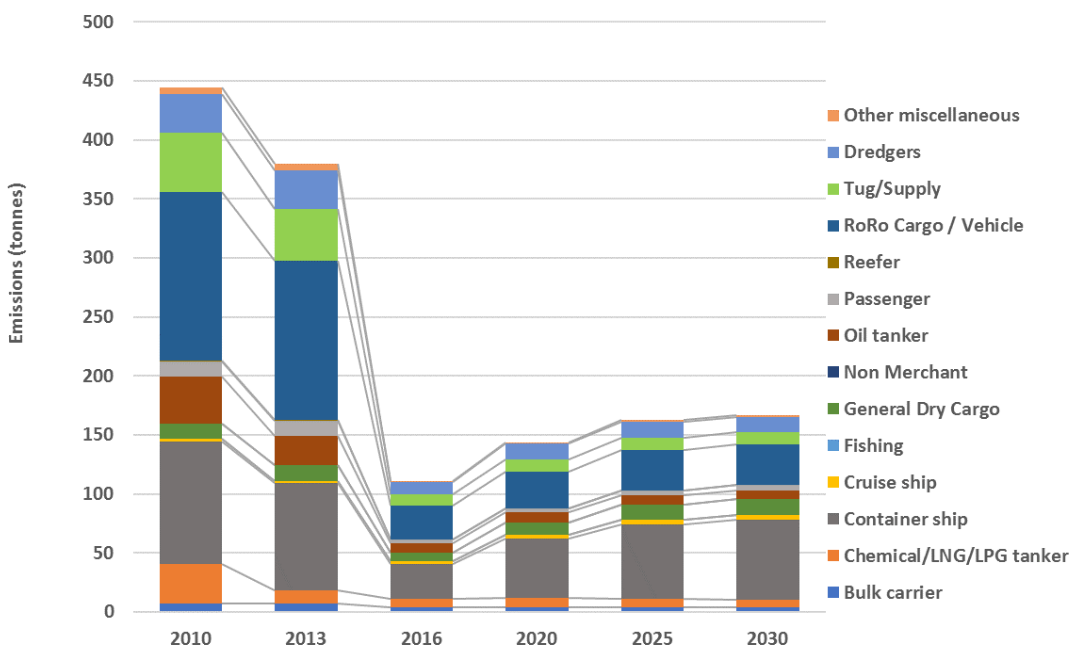


Table 4.3.1: SO_2 emissions from shipping for all years and ship types

Ship type	Emissions (tonnes)					
	2010	2013	2016	2020	2025	2030
Bulk carrier	8	7	4	4	4	4
Chemical/LNG/LPG tanker	33	11	7	8	7	6
Container ship	104	91	29	50	63	67
Cruise ship	2	2	3	3	4	4
Fishing	0	0	0	0	0	0
General Dry Cargo	13	14	7	11	13	14
Non Merchant	0	0	0	0	0	0
Oil tanker	40	25	8	8	8	7
Passenger	13	13	3	4	4	5
Reefer	0	0	0	0	0	0
RoRo Cargo/Vehicle	143	136	28	31	34	34
Tug/Supply	50	43	9	10	11	11
Dredgers	33	33	11	13	14	13
Other miscellaneous	5	5	1	1	1	1
All Vessels	**444**	**379**	**111**	**144**	**162**	**167**

4.4 Carbon Dioxide (CO_2)

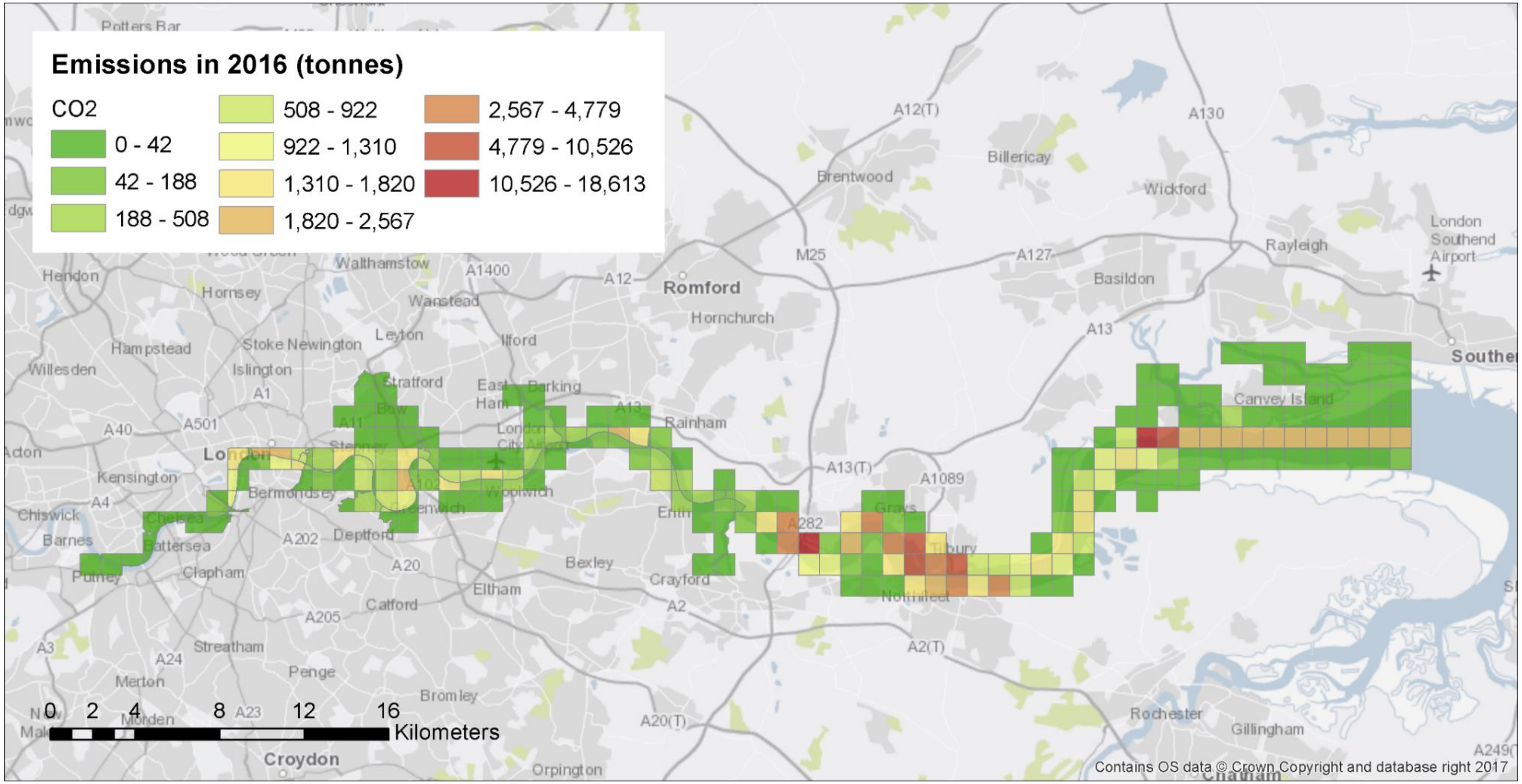


Figure 4.4.1: CO_2 emissions from shipping in 2016

Figure 4.4.2: CO_2 emissions by ship type in 2016

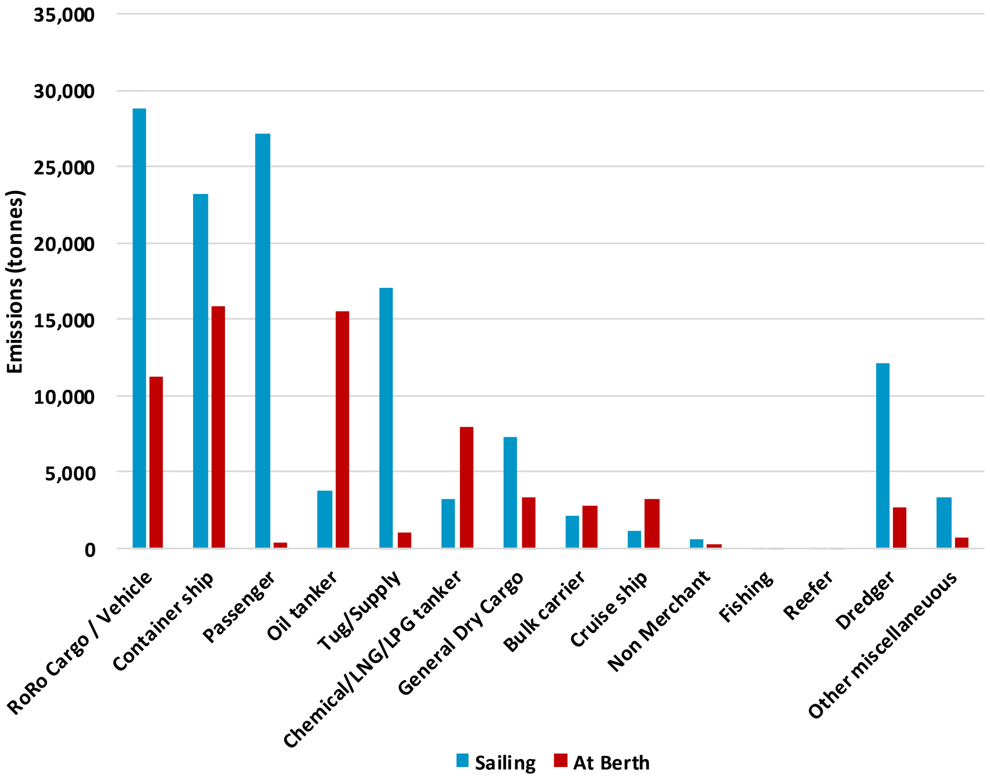


Figure 4.4.3: Trends in CO_2 emissions from shipping over time

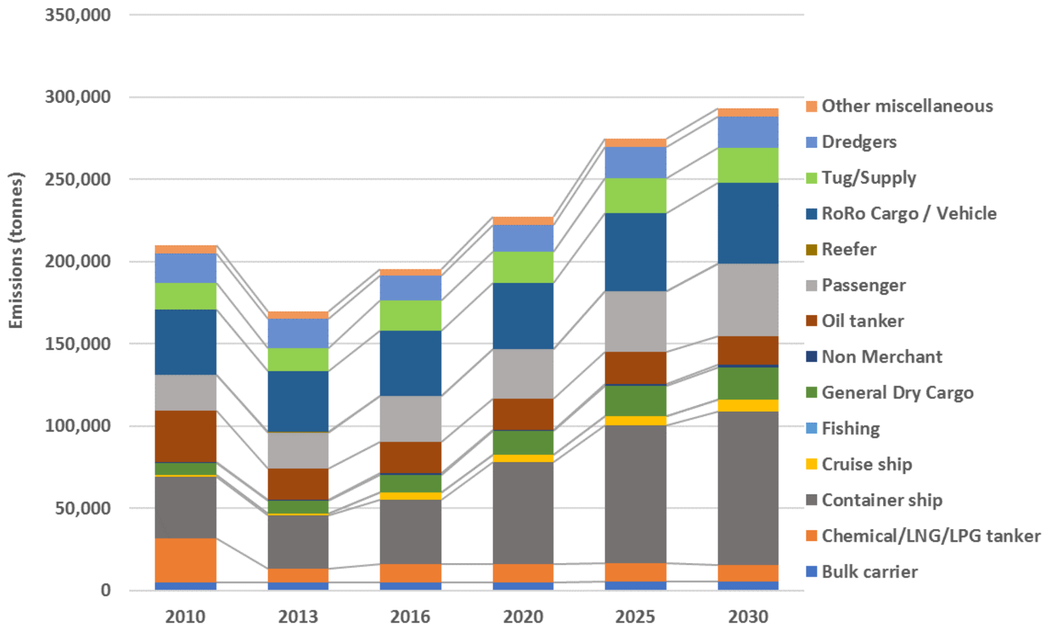


Table 4.4.1: CO_2 emissions from shipping for all years and ship types

Ship type	Emissions (tonnes)					
	2010	2013	2016	2020	2025	2030
Bulk carrier	4,970	4,900	4,993	5,110	5,787	5,745
Chemical/LNG/LPG tanker	26,859	8,712	11,142	10,878	10,989	10,134
Container ship	37,226	32,357	39,101	61,939	83,490	92,824
Cruise ship	1,136	969	4,467	4,832	6,050	7,169
Fishing	47	47	48	45	51	52
General Dry Cargo	7,465	7,932	10,589	14,159	18,275	19,905
Non Merchant	343	340	866	937	1,173	1,390
Oil tanker	31,177	18,993	19,431	18,986	19,114	17,572
Passenger	22,188	22,038	27,502	29,748	37,249	44,136
Reefer	80	30	31	29	33	34
RoRo Cargo/Vehicle	39,327	36,925	40,145	40,515	47,515	49,202
Tug/Supply	16,292	13,918	18,200	18,675	21,137	20,995
Dredgers	18,002	18,002	14,794	16,678	18,611	18,843
Other miscellaneous	4,633	4,480	4,042	4,546	5,078	5,161
All Vessels	**209,743**	**169,643**	**195,350**	**227,075**	**274,553**	**293,162**

4.5 Non-methane Volatile Organic Compounds (NMVOC)

Figure 4.5.1: NMVOC emissions from shipping in 2016

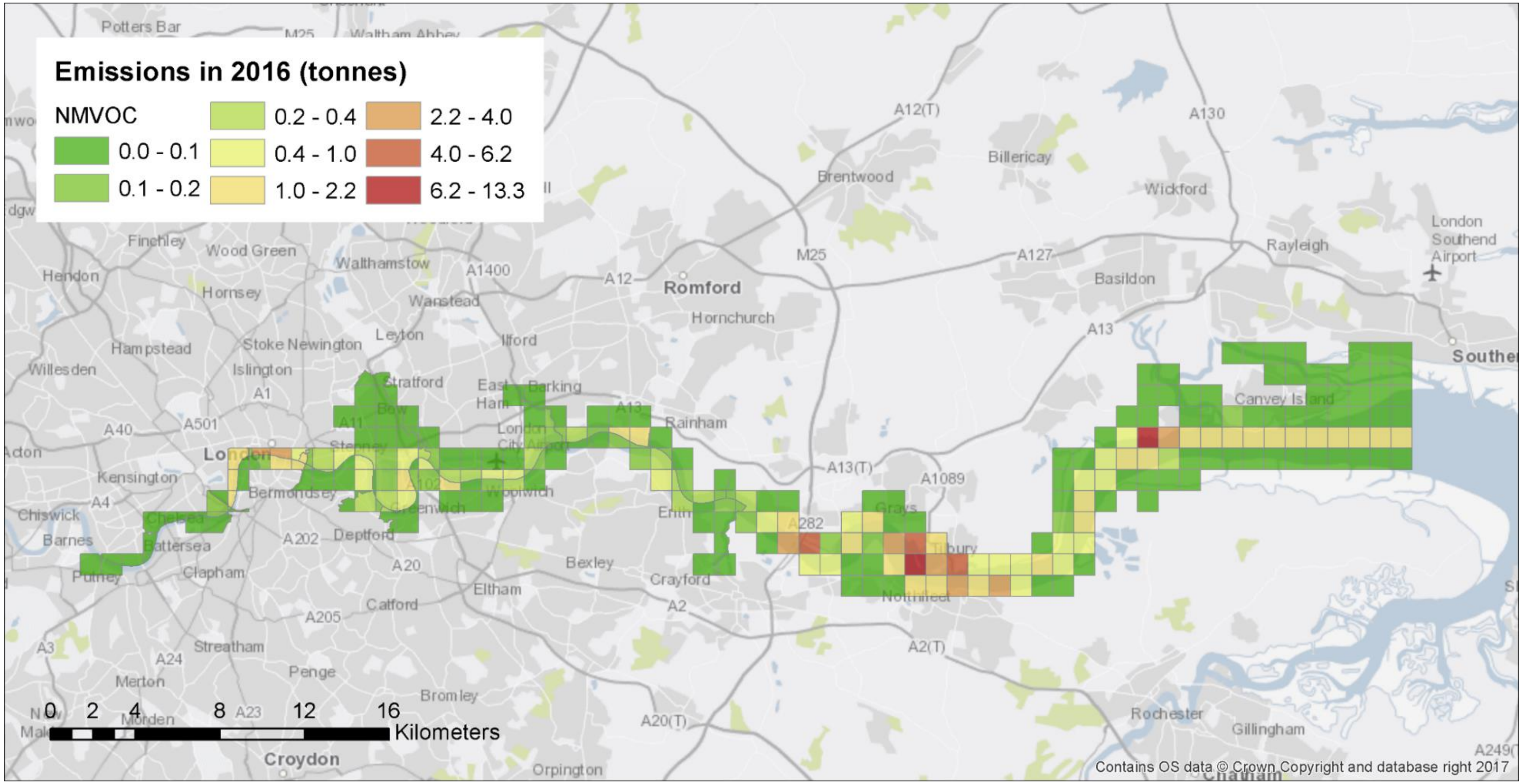


Figure 4.5.2: NMVOC emissions by ship type in 2016

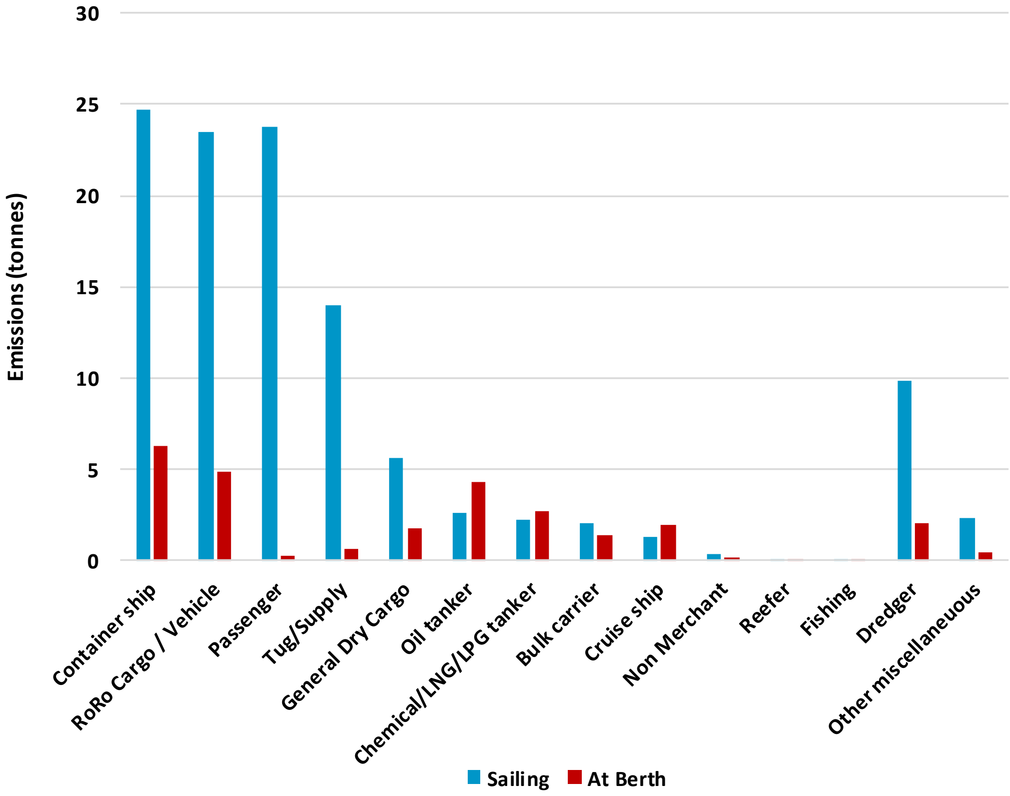


Figure 4.5.3: Trends in NMVOC emissions from shipping over time

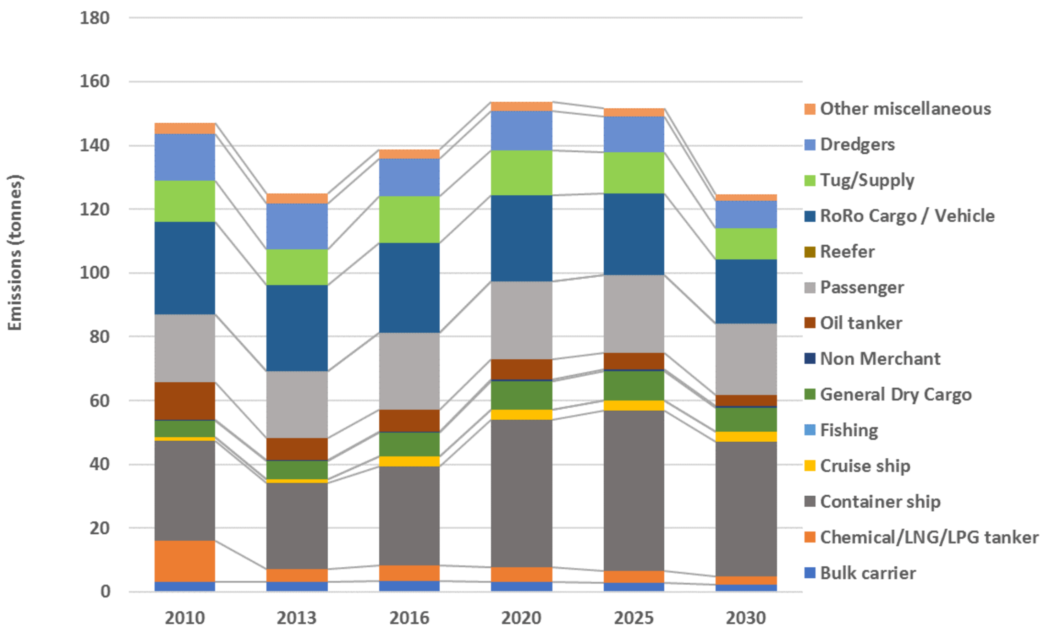


Table 4.5.1: NMVOC emissions from shipping for all years and ship types

Ship type	Emissions (tonnes)					
	2010	2013	2016	2020	2025	2030
Bulk carrier	3	3	3	3	3	2
Chemical/LNG/LPG tanker	13	4	5	5	4	3
Container ship	31	27	31	46	50	42
Cruise ship	1	1	3	3	3	3
Fishing	0	0	0	0	0	0
General Dry Cargo	5	6	7	9	9	8
Non Merchant	0	0	1	1	1	0
Oil tanker	12	7	7	6	5	4
Passenger	21	21	24	24	25	22
Reefer	0	0	0	0	0	0
RoRo Cargo/Vehicle	29	27	28	27	26	20
Tug/Supply	13	11	15	14	13	10
Dredgers	15	15	12	12	11	9
Other miscellaneous	3	3	3	3	3	2
All Vessels	**147**	**125**	**139**	**154**	**152**	**125**

4.6 Carbon Monoxide (CO)

Figure 4.6.1: CO emissions from shipping in 2016

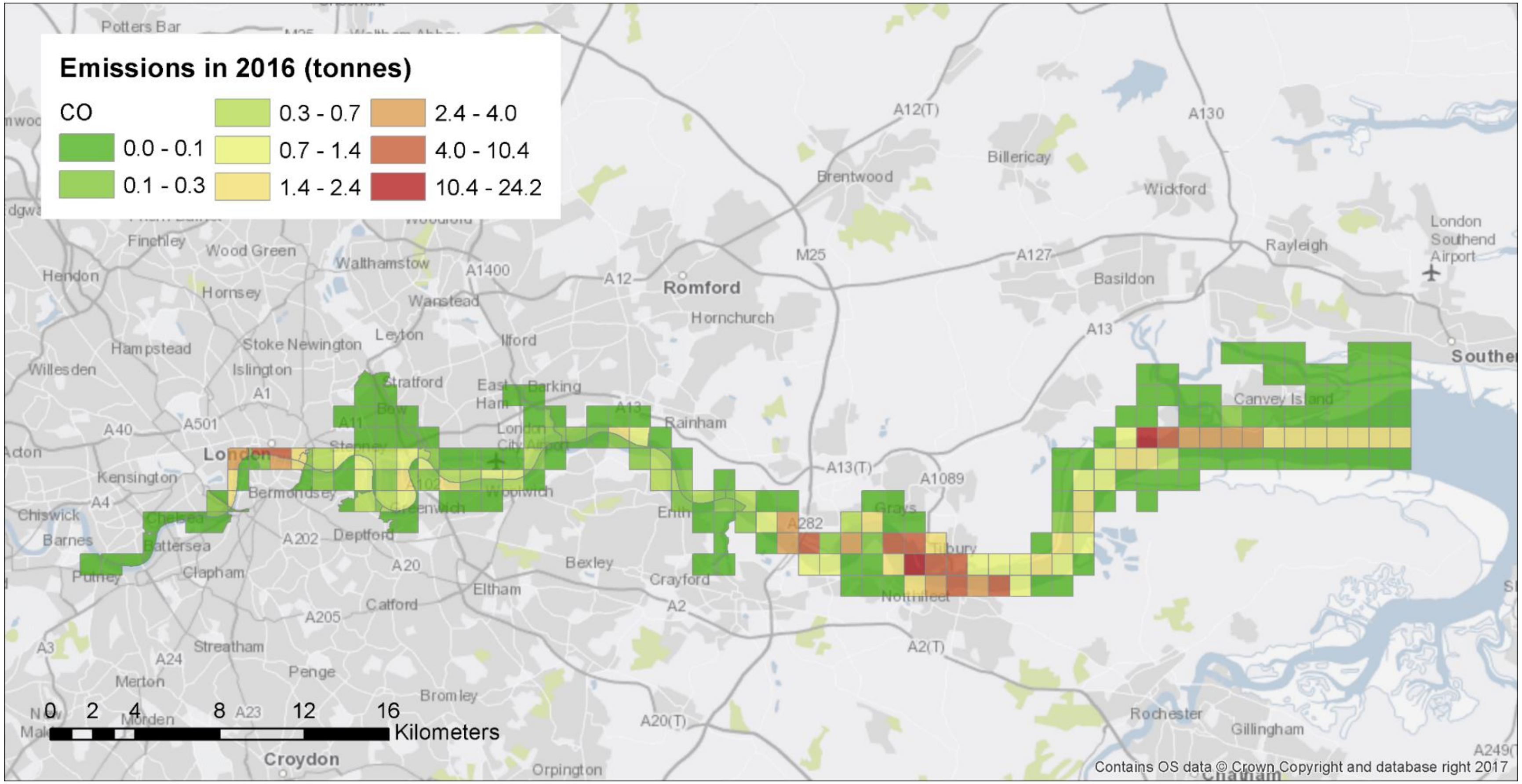


Figure 4.6.2: CO emissions by ship type in 2016

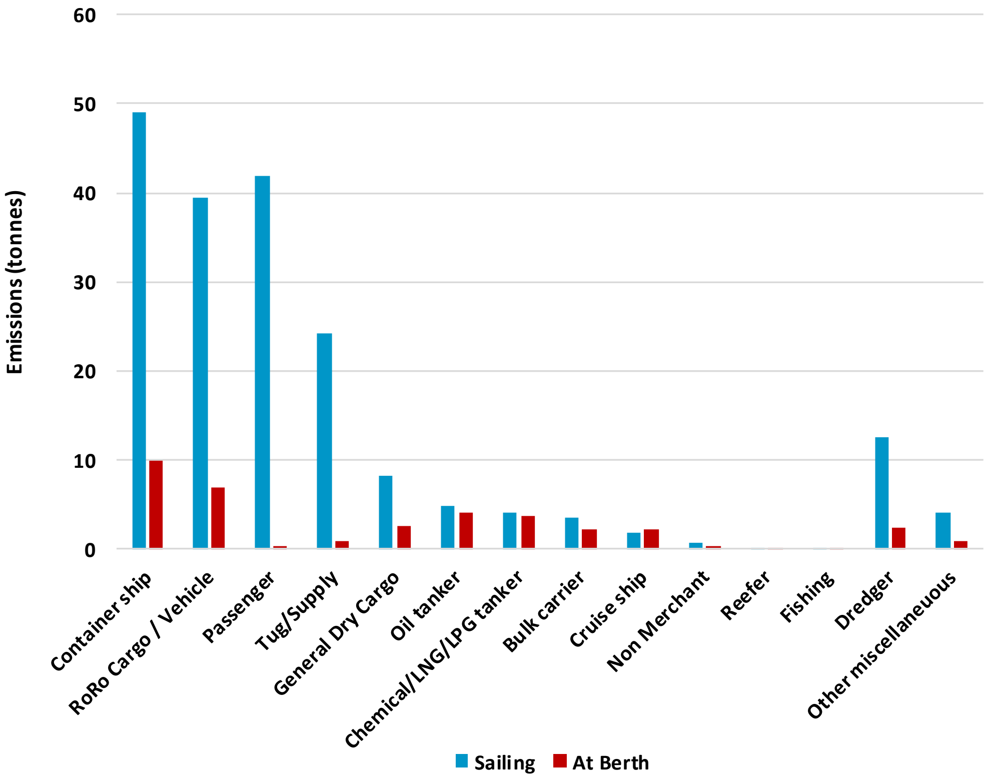


Figure 4.6.3: Trends in CO emissions from shipping over time

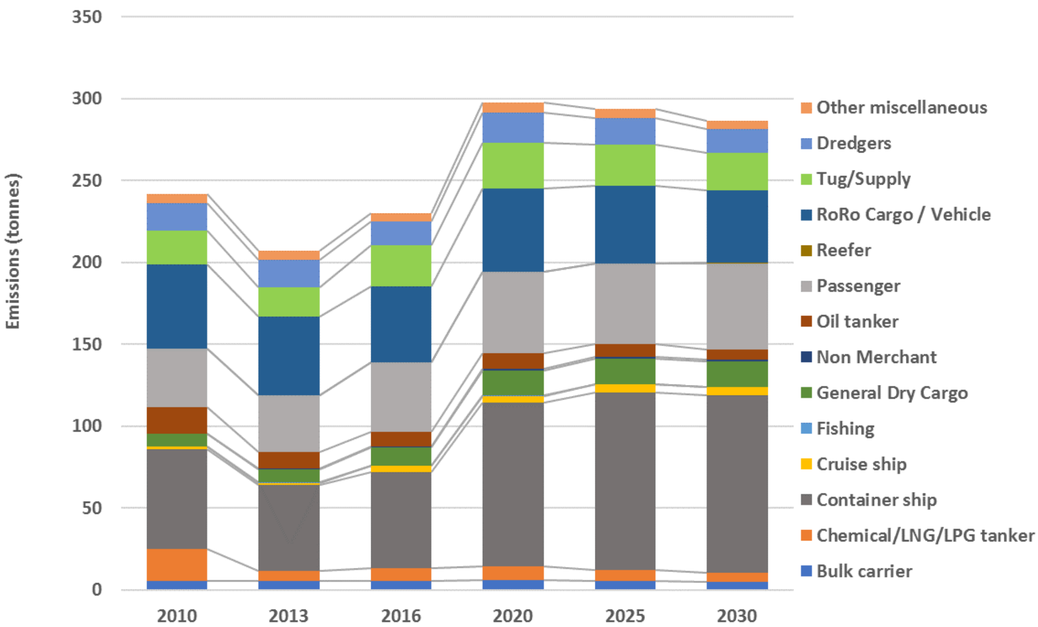


Table 4.6.1: CO emissions from shipping for all years and ship types

Ship type	Emissions (tonnes)					
	2010	2013	2016	2020	2025	2030
Bulk carrier	5	5	6	6	6	5
Chemical/LNG/LPG tanker	20	6	8	8	7	6
Container ship	61	52	59	100	108	109
Cruise ship	2	1	4	4	5	5
Fishing	0	0	0	0	0	0
General Dry Cargo	8	8	11	15	16	16
Non Merchant	0	0	1	1	1	1
Oil tanker	16	10	9	9	8	6
Passenger	35	35	42	50	49	53
Reefer	0	0	0	0	0	0
RoRo Cargo/Vehicle	51	48	46	51	48	45
Tug/Supply	21	18	25	28	25	23
Dredgers	17	17	15	18	16	15
Other miscellaneous	6	6	5	6	5	5
All Vessels	**242**	**207**	**230**	**298**	**294**	**286**

5 Conclusions

5.1 Emissions in 2016

In broad terms, the largest sources of emissions for most pollutants are container and RoRo vessels, and passenger vessels. Tug/supply vessels and dredgers are also important sources. For most vessel types and pollutants, emissions from sailing and manoeuvring greatly exceed those at berth. However, for certain ship types, namely tankers, bulk carriers and cruise ships, emissions at berth are higher, due to the high load on auxiliary engines, through cargo handling or operating onboard systems used when the ship is moored.

As noted in Table 3.1, assumptions around the level of compliance with the sulphur in fuels regulations will have a significant impact on SO_2 emissions. The assumed 10% non-compliance for sea-going vessels at berth shows clearly in the proportion of SO_2 emissions at berth and sailing for several vessel types, notably container ships, tankers, general dry cargo, bulk carriers and cruise ships. Tugs, passenger vessels and dredgers do not show this feature as they are, mainly, inland vessels and thus use 10ppm sulphur fuels where 100% compliance has been assumed.

5.2 Emissions trends

Figure 5.2.1, below, shows the trends in shipping emissions over time for CO_2, NO_x, SO_2 and PM_{10}. The trends for CO and NMVOC are similar to NO_x.

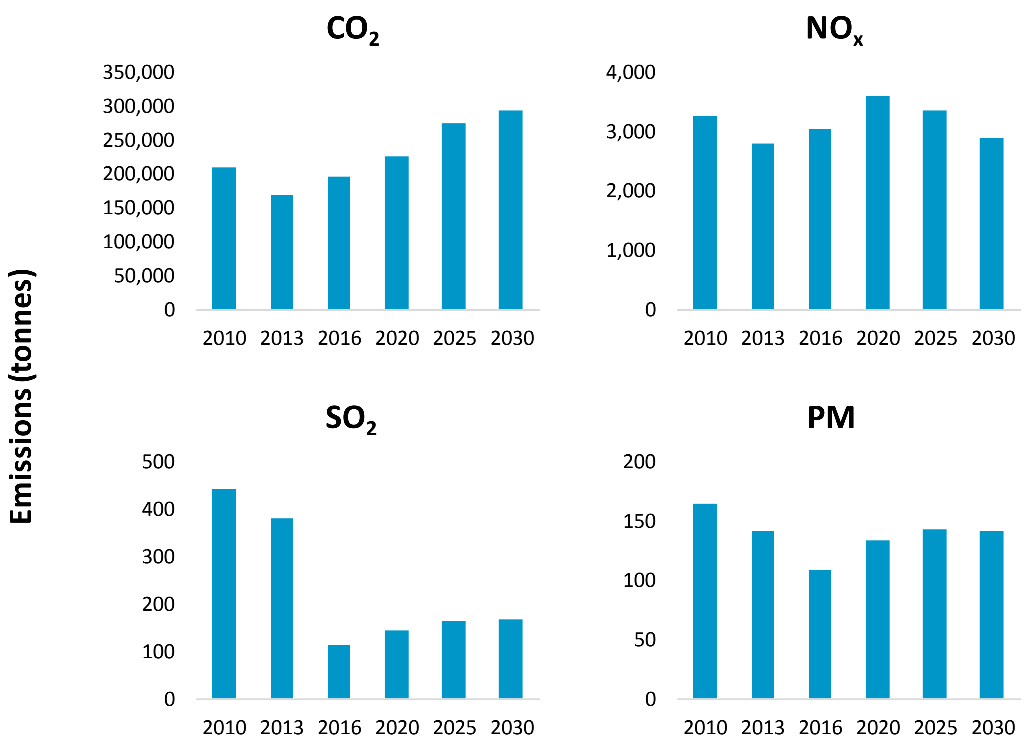


Figure 5.2.1: Shipping emission trends for selected pollutants, 2010-2030

The predominant influence on emissions from 2010 to 2016 is the improvement in ship fuel quality, in particular the shift to lower sulphur fuels. This shift has been driven by the North Sea SECA which was adopted in 2005 and introduced a phased reduction in the level of sulphur allowed in marine fuels (1% in 2010, 0.1% in 2015), and the control of sulphur in fuels used for inland vessels (0.001% or 10ppm as from 2011). This is most clearly seen in the SO_2 emissions trend but is also in the PM emissions trend as high sulphur fuels produce higher PM emissions than low sulphur fuels.

The reduction in the number of chemical, LNG, LPG and oil tanker movements between 2010 and 2013 also has a marked influence. The effect of lower sulphur fuels continues into future years although their impact is much reduced as the majority of ships will have moved to the cleaner fuels.

In future years, container vessels become a more important source of pollutants, in line with the freight forecasts prepared for the Thames Vision project.

The North Sea NECA applies to the engines of new ships and so takes longer to have an impact on NO_x emissions as new ships and engines are introduced to the fleet. However, the impact on emissions is clearly seen from 2020 onwards. The introduction of cleaner ship engines also has an impact on NMVOC and CO emissions.

Over the whole period, the process of upgrading to newer ships and engines will generally exert a downward trend on emissions, as will the global trend towards larger, more efficient sea-going ships. However, these influences are generally outweighed by the increase in freight being handled through the port and the increase in passenger numbers forecast through the Thames Vision project. This is particularly prevalent for container ships and passenger vessels, with emissions of CO_2 from each more than doubling over the period. The rate of increase in CO_2 emissions slows between 2025 and 2030 as a result of the introduction of more fuel-efficient ships. Note that these forecasts do not take into account any measures proposed through the IMO Oceans and Climate Change agenda[13],nor measures that may be planned in the future to encourage fuel-efficient practices, due to the uncertainty of the timescales for adoption.

[13] http://www.imo.org/en/MediaCentre/PressBriefings/Pages/17-MEPC-71.aspx

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