ESTIMATING EMISSIONS FROM SHIPS/MARINE VESSELS

Summary

Base Year: 2008

Because of lack of recent, representative and reliable activity datasets, atmospheric emissions from shipping and marine vessels for the 2008 base year were not estimated; they were simply assumed to be the same as those in the LAEI 2006 (LAEI 2004). In the LAEI 2004, improved and up-to-date information on marine vessel characteristics and activities within the LAEI area were obtained from the Lloyd's Maritime Intelligence Unit (LMIU) and the Port of London Authority (PLA), including the number and types of vessels, ship size, destination, approximate time of arrival and departure, distance travelled, engine type and number for the calendar year 2004. Improved emission factors and the up-to-date marine vessel activity datasets were used to estimate emissions in the LAEI 2006.

Projection Years: 2011 and 2015

Because of lack of recent, representative and reliable activity datasets for the 2008 base year, projections of atmospheric emissions from shipping and marine vessels to 2011 and 2015 were not undertaken; instead projections of atmospheric emissions from shipping and marine vessels to 2011 and 2015 were basically assumed to be the same as those in the LAEI 2006 (using 2010 projection).

2008 emission estimation methodology: Same as the LAEI 2006 methodology

Below is a synopsis of the methodological approach used in the LAEI 2006 to quantify vessel emissions:

1. Delineation of the geographical scope of the study area and the composition of a digital representation of the River Thames, the Port of London and its terminal and ports.

2. Identification and classification of vessels and their characterisation (e.g., the number and types of vessels, ship size, destination, approximate time of arrival and departure, distance travelled, engine type and number) from the databases supplied by both the LMIU and the PLA.

3. Analysis of the duration various vessel categories spend navigating "at sea" and operating "in port" from the average speeds of the various vessel categories, vessel activity databases and the estimated distances (km) travelled along the Thames.

4. Analysis and designation of average vessel power to each vessel category and the adjustment of the average vessel power (kW) by load factors for "at sea" and "in port" operations to obtain rated average vessel power (kW) for each vessel category.

5. Calculation of the average energy consumption (kWh) by vessel type from the rated average vessel power (kW) and duration for "at sea" and "in port" modes.

6. Estimation of the amount of pollutant (expressed as tonnes) emitted by a vessel type in each mode as a function of the average energy consumption (kWh) by vessel category in each mode, an emission factor (g/kWh), the number of vessel trips to ports and a unit conversion factor (Equation 1).

Equation 1

$$E_k = VC_{port} * EF_k * EC_{avg,k} * 10^{-6}$$

Where:

E_k =Emissions from vessel category *k* (tonnes)

VC_{port} =Number of vessel calls at ports

EF_k =Emission factor for vessel category *k* (g/kWh)

$EC_{avg.k}$ =Average energy consumption for vessel category *k* (kWh)

10^{-6} =Unit conversion factor, grammes to tonne

7. Spatial representation and mapping of the "at sea" emissions as channel segment (lines) and "in port" emissions as points along the Thames in a GIS layer. Apportionment of the "in port" emissions and "at sea" emissions (using the linear referencing functionality in ArcGIS) to the appropriate ports and the navigational route on the Thames respectively.

8. Overlaying of the appropriate ports and the navigational route with a digital layer of the generic 1km^2 grid cells. Apportionment of the combined "at sea" and "in port" emissions to the generic 1km^2 grid cells of the LAEI area were they intersected using the "proportion summed" algorithm in GIS.

9. Presentation of the emission results at the 1km^2 resolution.

For the purpose of estimating emissions from marine vessels in this study, only the 33 ports and terminals (see Table 1) on the Thames and within the LAEI area were considered - starting from the breakwater at the M25 Motorway eastern boundary and then 43 km westward along the River Thames towards Teddington.

Table 1. Ports and terminal within the LAEI area

Ports	Approximate distance (km) from the LAEI boundary*
Thames Europort	0.5
Vopak Terminal London	0.5
Thurrock Marine Jetty/Lafarge Jetty	0.7
Civil & Marine/Purfleet Aggregates	1.4
Jurgens	1.9
Purfleet Thames Terminal	2.2

European Metal Recycling	7
British Gypsum	7.5
ADM Erith Ltd	8.2
Pioneer	8.5
Mulberry Wharf	9.2
Fords	10.8
Hanson Aggregates	11.3
No.1 Western Extension	12.1
TDG European Chemicals	12.4
RMC Dagenham	12.7
Docklands Wharf	14.5
Kierbeck	16
Welbeck	16.3
Pinns	16.4
Thames Refinery	19.3
Tay Wharf	19.6
Riverside Wharf	20.3
Murphy's Wharf	21.8
Angersteins	22.4
Thames Wharf	22.8
Brunswick Wharf	23
Delta	24.1
Victoria Deep	24.9
Brewery	26.6
RMC Vauxhall	38.6
Cringle Wharf	39.4
RMC Fulham	42.7

Source: GLA 2005

* Distance along the River Thames, starting from the breakwater at the M25 Motorway eastern boundary and then westward along the River Thames.

Vessel characteristics and movement

The primary source of information in terms of vessel characteristics and movements was a comprehensive database[1] maintained by LMIU. The database maintains information about ship details, including owner, operator, ship name, ship type, registry number, cargo handling equipment, flag of registry and, significantly, ship engine details such as maximum horsepower and sometimes number of auxiliary engines. The LMIU provided a spreadsheet of vessel characteristics and vessel movements to and from the Port of London for the full calendar year 2004. Due to the large number of vessel types and vessel movements to and from the Port of London on an annual basis and the complexities of data analysis required for this project, all vessels were classified and limited to the following categories:

- Liquified Gas Carrier - *Liquefied natural gas/Liquified petroleum gas*

[1] This database is the only commercial database of all vessel movements worldwide with up-to-date data resolved to a daily timeframe and over 3 million vessel movements are processed annually.

- Specialised Cargo - *Chemical tank, chemical/oil carrier*

- Tanker - *Acid tanker, asphalt tanker, bunkering tanker, crude oil tanker, edible oil tanker, fruit juice tanker, fish oil tanker, floating production, floating storage, molasses tanker, naval auxiliary, product tanker, non specific tanker, wine tank, water tanker*

- Bulk Carrier - *Bulk, cement, aggregates, ore, wood-chip*
- General Cargo - *Cargo/training, general cargo, barge carrier, container/unitised carrier*

- Pallet Carrier - *Container, barge carrier, vehicles*

- Ro-Ro Cargo - *Ro/Ro, container Ro/Ro, Passenger Ro/Ro*

- Tug/Dredger - *Tugs/dredgers*

Table 2. Vessel characteristics: average speed, power and tonnage

Type of Vessel	Average Speed km/h	Average Vessel Power kW	Average Vessel Tonnage tonnes
Bulk Carrier	26	5,464	15,125
Pallet Carrier	30	7,803	7,943
General Cargo	20	1,362	2,709
Specialised Cargo	24	1,982	2,679
Tug/Dredger	22	2,544	2,395
Liquified Gas Carrier	24	1,982	4,755
Tanker	22	3,116	10,135
Ro/Ro	20	5,411	12,973

Source: LMIU, 2004

The Port of London Authority (PLA) provided information on the number of vessels calling at each port within the Port of London in the LAEI area for the year 2004.

Table 3. Vessel movements: number and types of vessels and vessel calls in 2004

Ports of Arrival and Departure	Number of Vessels	Type of Vessel	Number of Vessel Calls
ADM Erith Ltd	99	General Cargo	163
ADM Erith Ltd	16	Tanker	32
Angersteins	5	Dredger	93
Brewery	6	General Cargo	249
British Gypsum	9	General Cargo	59
Brunswick Wharf	9	Tanker	72
Civil & Marine/Purfleet Aggregates	11	Dredger	57
Civil & Marine/Purfleet Aggregates	4	General Cargo	108
Cringle Wharf	7	General Cargo	13
Cringle Wharf	1	Tug	1

Delta	6	Dredger	70
Delta	1	Tug	1
Docklands Wharf	30	General Cargo	49
Docklands Wharf	1	Specialised Cargo	2
European Metal Recycling	9	General Cargo	9
European Metal Recycling	1	Ro/Ro	1
Fords	10	Ro/Ro	693
Fords	1	Tug	1
Hanson Aggregates	4	Dredger	184
Jurgens	1	Specialised Vessels	1
Jurgens	23	Tanker	129
Kierbeck	28	General Cargo	32
Mulberry Wharf	18	General Cargo	24
Murphy's Wharf	9	Dredger	304
Murphy's Wharf	5	General Cargo	125
Murphy's Wharf	1	Specialised Cargo	11
Murphy's Wharf	1	Tanker	1
No.1 Western Extension	44	General Cargo	124
Pinns	39	General Cargo	52
Pioneer	4	Dredger	57
Purfleet Thames Terminal	23	Ro/Ro	1,369
Riverside Wharf	19	General Cargo	50
RMC Dagenham	1	Dredger	1
RMC Dagenham	87	General Cargo	193
RMC Dagenham	1	Specialised Cargo	11
RMC Fulham	3	General Cargo	192
RMC Vauxhall	6	General Cargo	306
Tay Wharf	1	General Cargo	1
TDG European Chemicals	77	Tanker	125
Thames Europort	11	Ro/Ro	1,681
Thames Europort	1	Tug	1
Thames Refinery	16	Bulk Carrier	16
Thames Refinery	15	General Cargo	20
Thames Refinery	1	Pallet Carrier	25
Thames Wharf	16	General Cargo	19
Thurrock Marine Jetty/Lafarge Jetty	2	Bulk Carrier	2
Thurrock Marine Jetty/Lafarge Jetty	9	Dredger	80
Thurrock Marine Jetty/Lafarge Jetty	10	General Cargo	15
Victoria Deep	1	Dredger	1
Victoria Deep	23	General Cargo	37
Victoria Deep	1	Specialised Cargo	1
Vopak Terminal London	2	Liquified Gas Carriers	80
Vopak Terminal London	1	Tanker	4
Welbeck	21	General Cargo	94

Source: Port of London Authority, 2004

The vessel characteristics and movement information from both the LMIU and the PLA were combined with the following information to estimate emissions from ships:

- Information on the times that each type of vessel spent "at sea" and "in port";
- A GIS representation of the ports and terminals within the Port of London; and
- Emission factors for the air pollutants: oxides of nitrogen (NO_X), sulphur dioxide (SO_2), hydrocarbons (HC), carbon dioxide (CO_2) and particulate matters (PM_{10}) form the Entec Report (Entec UK Ltd, 2000).

Durations of vessel operations "in port" and "at sea"

The LMIU and PLA databases recorded only the dates when vessels arrived at and departed from the Port of London. Undoubtedly, actual arrival and departure times to and from each port would have assisted greatly in estimating durations of "in port" activities with confidence. "In port" activities include time spent manoeuvring, hotelling, loading, and unloading. Hotelling denotes the time a vessel spends in port that is neither loading nor unloading time, at berth and consuming minimum power. Manoeuvring is associated with arrival at and departure from a port, i.e. when a ship decreases main engine load at the end of a period "at sea", up to the point when the ship is stationary in port and vice versa.

In the absence of reliable arrival and departure times to and from each port in the Port of London, the average time (in hours) spent "in port" per call by each vessel type was estimated from the LMIU and PLA ship activity datasets and augmented by information gained through personal conversations with port operators. For example, a typical tanker can take 24 to 40 hours to unload, with the vessel using its own pumps to unload liquid material. Due to various conditions on vessel movements in the Port of London, after loading, a vessel may stay an additional 12-18 hours at berth. Discharge rates for product ships vary considerably with the loading rate dependent on the diameter of the pipeline, the distance to the tank, pump used, and capacity.

The average time (in hours) spent "in port" per call by each vessel type was estimated using Equation 2:

Equation 2

$$AvgT_{in-port,vc,j} = \frac{T_{PL}}{VC_{port,j}}$$

Where:

$AvgT_{in-port,vc,j}$ =Average time "in port" per vessel call *vc* by vessel type *j, (hours)*

T_{PL} = Total time in Port of London, (hours)

$VC_{port,j}$ =Number of vessel call *vc* to Port of London by vessel type *j*

Table 4. Estimates of durations of vessel "in port" in Port of London

Type of Vessel	Vessel Count	Number of Vessel Calls	Time in Port (Days)	Time in Port (h)	Average Time "in port" (h)
Bulk Carrier	85	204	480	11,520	**56.5**
Pallet Carrier	6	6	6	144	**24.0**
General Cargo	469	1,971	3,034	72,816	**36.9**
Specialised Cargo	19	122	137	3,288	**27.0**
Tug/Dredger	52	1,271	1,455	34,920	**27.5**
Liquefied Gas Carrier	7	31	31	744	**24.0**
Tanker	75	563	714	17,136	**30.4**
Ro/Ro	39	3,505	3,557	85,368	**24.4**

Source: LMIU 2004

The average travelling time (in hours) "at sea" by each vessel type was estimated using Equation 3.

Equation 3

$$AvgT_{at-sea,vc,j} = \frac{D_{PL}}{AvgS_{PL,j}}$$

Where:

$AvgT_{at-sea,vc,j}$ =Average time "at sea" per vessel call *vc* by vessel type *j*, *(hours)*

D_{PL} = Distance from breakwater to a port in the Port of London, (km)

$AvgS_{PL,j}$ =Average speed of vessel type *j* in the Port of London, (km/hour)

Table 5. Durations (in hours) of vessel "at sea" in Port of London

Port	Distance km	Vessel Type	Average Speed km/h	Average Time "at sea" hours
Thames Europort	0.5	Ro/Ro	30	0.02
Thames Europort	0.5	Tug	22	0.02
Vopak Terminal London	0.5	Liquified Gas Carriers	24	0.02
Vopak Terminal London	0.5	Tanker	22	0.02
Thurrock Marine/Lafarge Jetty	0.7	Bulk Carrier	26	0.03
Thurrock Marine/Lafarge Jetty	0.7	Dredger	22	0.03
Thurrock Marine/Lafarge Jetty	0.7	General Cargo	20	0.04
Civil & Marine/Purfleet Aggregates	1.4	Dredger	22	0.06
Civil & Marine/Purfleet Aggregates	1.4	General Cargo	20	0.07
Jurgens	1.9	Specialised Vessels	24	0.08
Jurgens	1.9	Tanker	22	0.09
Purfleet Thames Terminal	2.2	Ro/Ro	30	0.07
European Metal Recycling	7	General Cargo	20	0.35
European Metal Recycling	7	Ro/Ro	30	0.23
British Gypsum	7.5	General Cargo	20	0.38

ADM Erith Ltd	8.2	General Cargo	20	0.41
ADM Erith Ltd	8.2	Tanker	22	0.37
Pioneer	8.5	Dredger	22	0.39
Mulberry Wharf	9.2	General Cargo	20	0.46
Fords	10.8	Ro/Ro	30	0.36
Fords	10.8	Tug	22	0.49
Hanson Aggregates	11.3	Dredger	22	0.51
No.1 Western Extension	12.1	General Cargo	20	0.61
TDG European Chemicals	12.4	Tanker	22	0.56
RMC Dagenham	12.7	Dredger	22	0.58
RMC Dagenham	12.7	General Cargo	20	0.63
RMC Dagenham	12.7	Specialised Cargo	24	0.53
Docklands Wharf	14.5	General Cargo	20	0.73
Docklands Wharf	14.5	Specialised Cargo	24	0.60
Kierbeck	16	General Cargo	20	0.80
Welbeck	16.3	General Cargo	20	0.81
Pinns	16.4	General Cargo	20	0.82
Thames Refinery	19.3	Bulk Carrier	26	0.74
Thames Refinery	19.3	General Cargo	20	0.96
Thames Refinery	19.3	Pallet Carrier	30	0.64
Tay Wharf	19.6	General Cargo	20	0.98
Riverside Wharf	20.3	General Cargo	20	1.01
Murphy's Wharf	21.8	Dredger	22	0.99
Murphy's Wharf	21.8	General Cargo	20	1.09
Murphy's Wharf	21.8	Specialised Cargo	24	0.91
Murphy's Wharf	21.8	Tanker	22	0.99
Angersteins	22.4	Dredger	22	1.02
Thames Wharf	22.8	General Cargo	20	1.14
Brunswick Wharf	23	Tanker	22	1.05
Delta	24.1	Dredger	22	1.10
Delta	24.1	Tug	22	1.10
Victoria Deep	24.9	Dredger	22	1.13
Victoria Deep	24.9	General Cargo	20	1.25
Victoria Deep	24.9	Specialised Cargo	24	1.04
Brewery	26.6	General Cargo	20	1.33
RMC Vauxhall	38.6	General Cargo	20	1.93
Cringle Wharf	39.4	General Cargo	20	1.97
Cringle Wharf	39.4	Tug	22	1.79
RMC Fulham	42.7	General Cargo	20	2.13

Key assumptions used in the analysis of durations of vessels "in port" and "at sea" in the Port of London.

1. Where a vessel arrived and departed on the next day, the time in port (see Table 4) were assumed to be one day or 24 hours. Where arrival and/or departure dates were estimated from the LMIU databases, times “in port” were assumed to be two days or 48 hours.

2. The average speeds of vessel types are averages of the vessels' characteristics. They are not weighted by calls or associated with the calls themselves.

3. Vessels took the shortest straight-line route between ports. Where land mass prohibited this assumption, the vessels took the shortest route around the land towards the destination port.

4. The Average Time "at sea" in Table 5 is considered the time taken to travel to the designated port (in one direction only) after entering the breakwater (entrance at the Port of London at the LAEI boundary).

Undoubtedly, some of these assumptions unfortunately introduce significant uncertainty in this study but they provide an area to be improved on in future estimation of emissions from ships in the LAEI.

Average and rated average vessel (engine) power

Analysing average engine power and energy consumption for vessels is a complicated task because vessels can have various combinations of main and auxiliary engines. Vessels are self sufficient in terms of energy supply, apart from a very few exceptions where power from land sources are used on board in ports. Main engines are used primarily for ship propulsion and are normally shut down in ports; exception is for some tankers, which can use main engines for unloading and loading operations in port. Main engines are almost entirely diesel engines; mostly medium speed 4-stroke or slow 2-stroke. Auxiliary engines are used mainly for electric power generation on board for lighting, ventilation, cranes, pumps etc and they are normally shut down at sea. Rather than size, main and auxiliary engines are normally sub-divided according to their engine speed at the crankshaft as: high speed, medium speed and slow speed. Slow and medium speed engines are more abundant than high-speed engines for main engines; for auxiliary engines, high and medium speed engines dominate.

The LMIU database did not hold data for auxiliary engines on vessels so a decision was taken to use only the average vessel power (kW) of the main engine power (see Table 6) based on the assumption that most of the emissions "at sea" and "in port" come from the main engine, which realistically is not true and introduces significant uncertainty. The greatest contribution to uncertainty arises from the estimation of emissions from vessels whilst undertaking "in port" operations, as the exact engine power and load levels are subject to an unknown degree of variation. Nonetheless, this assumption provides a "rational estimate" within the context and constraints of this study.

Information on the average vessel power of various types of vessels entering the Port of London was obtained from the LMIU and used in calculations.

Table 6. Average vessel power (kW) by vessel type

Type of Vessel	Average Vessel Power ,kW[2]
Bulk Carrier	5,464

[2] The averages vessel powers are averages of populated fields, e.g. where the power of a particular vessel was unknown, this vessel was excluded from the average power calculation.

Pallet Carrier	7,803
General Cargo	1,362
Specialised Cargo	1,982
Tug/Dredger	2,544
Liquified Gas Carrier	1,982
Tanker	3,116
Ro/Ro	5,411

Source: LMIU 2004

The load on the main engine during navigation "at sea" and during "in port" activities vary greatly, depending on the type of vessel. Hence it was imperative to establish the load factor (fraction of main engine power) for both "at sea" and "in port" activities. Load factor is defined as actual power divided by maximum continuous rated (MCR) power, and typically can be between 20% and 80% (Entec UK, 2000). MCR power is the full throttle available to the engine that would result in a full cruise speed.

For the purpose of this study, the load on the main engines during navigation "at sea" and "in port" was assumed to be 80% and 20% of the main engine respectively, irrespective of the vessel type. This assumption has been made as an attempt to obtain a "reasonable approximation" of emissions from ships within the constraints of this study. The assumed load factors and the average vessel power (average power of the main engine) by vessel type were used to calculate the **rated average engine power** (kW) by mode ("at sea" and "in port") and vessel type according to Equation 4.

Equation 4

$$REP_{avg.k.sea,port} = LF_{sea,port} * 0.01 * AVP_{avg.k}$$

Where:

$REP_{avg.k.sea,port}$ =Rated average engine power "at sea"/"in port" for vessel category k, (kW)
$LF_{sea,port}$ = Load factor, fraction of average vessel power "at sea" or "in port", (%)
$AVP_{avg.k}$ =Average vessel power for vessel category k, (kW)
0.01 =Conversion factor

Table 7. Rated average vessel power (kW)

Type of Ship	"At sea" 80% of average vessel power, kW	"In port" 20% of average vessel power, kW
Bulk Carrier	4,371	1,093
Pallet Carrier	6,242	1,561
General Cargo	1,090	272

Specialised Cargo	1,586	396
Tug/Dredger	2,035	509
Liquified Gas Carrier	1,586	396
Tanker	2,493	623
Ro/Ro	4,329	1,082

Average Energy Consumption

The average energy consumption (kWh) by each vessel category was calculated as a function of the total time spent (expressed in hours) "at sea" (Equation 5) or "in port" (Equation 6) and the rated average engine power for each vessel category.

Average energy consumption (kWh) "at sea"

Equation 5

$$EC_{avg.k.sea} = 2 * T_{sea} * REP_{avg.k.sea}$$

Where:

$EC_{avg.k.sea}$ =Average energy consumption for vessel category *k* "at sea", kWh

$2 * T_{sea}$ =Total time "at sea" during arrival at and departure from a port, h

$REP_{avg.k.sea}$ =Rated average engine power "at sea" for vessel category *k*, kW

Average energy consumption (kWh) "in port"

Equation 6

$$EC_{avg.k.port} = T_{port} * REP_{avg.k.port}$$

Where:

$EC_{avg.k.port}$ =Average energy consumption for vessel category *k* "in port", kWh

T_{port} =Total time "in port", h

$REP_{avg.k.port}$ =Rated average engine power "in port" for vessel category *k*, kW

Emission factors

The installed engine type on board a vessel and the fuel used largely dictates the ship's emissions. Since the emission factors for individual engines on vessels in this study were not known, a decision was taken to use the emission factors from the Entec UK Ltd 2000 Report. While the Entec UK Ltd 2000 study was geared towards estimating emissions for the European Union, it provides an insightful analysis of the worldwide commercial marine vessel fleet, even including a statistical analysis of variance in emission factors. The Entec UK Ltd 2000 study estimated emission factors for NO_X, HC, CO and PM_{10} and SO_2 for "at sea" and "in port" activities as shown in Table 8 and Table 9[3]. The emission factors for main engines "at sea" and "in port" were assumed to be operating at 80% and 20% maximum continuous rating respectively

Entec UK Ltd used the LMIS database for the ships entering the EU study area to derive weighted emission factors for each vessel type for "at sea" and "in port" activities. Assignment of "engine size" emission factors with any great significance was doubtful. Consequently the emission factors were only derived for engine types and valid for all engine sizes.

Table 8. Emission factors for "at sea" operation regarding vessel type, 2004

Type of Ship	Emission Factors (g/kWh)			
	NO_X	SO_2	CO_2	HC
Bulk Carrier	17.9	10.6	624	0.6
Tanker	16.5	11	645	0.6
Pallet Carrier	17.5	10.7	631	0.6
General Cargo	16.3	10.9	644	0.6
Specialised Cargo	8.5	12.4	822	0.3
Liquified Gas Carrier	8.5	12.4	822	0.3
Dredge/Tug	12.5	10.7	705	0.4
Ro-Ro Cargo	15.6	11.2	659	0.5

Source: Entec UK Ltd, 2000

Table 9. Emission factors for "in port" operation regarding vessel type, 2004

Type of Ship	Emission Factors (g/kWh)				
	NO_X	SO_2	CO_2	PM_{10}	HC
Bulk Carrier	13.8	12	706	1.5	1
Tanker	13.3	12.1	710	2.2	1.5
Pallet Carrier	13.7	12.1	710	1.5	1
General Cargo	13.3	12.1	716	1.5	0.9
Specialised Cargo	7.5	13.4	884	2.1	0.9
Liquified Gas Carrier	7.5	13.4	884	2.1	0.9
Dredge/Tug	12.7	12.4	729	1.3	0.8
Ro-Ro Cargo	13	12.3	723	1.4	0.9

[3] In some cases, the emission factors vary slightly due to the differences in vessel categorisation; where averaged emission factors were applied.

Source: Entec UK Ltd, 2000

The emission factors for CO_2 and SO_2 were derived assuming that all fuel carbon and sulphur present in the fuel are burnt to CO_2 and SO_2 respectively.

Table 10. Estimated uncertainties at the 95% confidence interval

Pollutant	At sea	In port
NO_X	±20%	±30%
SO_2	±10%	±20%
CO_2	±10%	±20%
HC	±25%	±40%
PM	±25%	±40%
Specific Fuel Consumption	±10%	±20%

Source: Entec UK Ltd, 2000

Estimated uncertainties at the 95% confidence interval given as relative percent of the emission factors (g/kWh).

As can be noted form Table 10, the "in port" emission factors have an increased uncertainty compared to emission factors "at sea", for two reasons. Firstly, some main engine operation will be from starts with a cold engine, which will give significantly different emissions (especially HC and PM), compared to starts with relatively warm engines. Secondly, because engine loads can change rapidly during "in port" operations, the variability in emissions are increased.

Estimating emissions

As stated previously, the average energy consumption (expressed as kWh) method was used to estimate emissions, as opposed to using the fuel sales methods. The average energy consumption (kWh) by vessel type in each mode was multiplied by the appropriate emission factor (g/kWh), the number of vessel trips to ports and a unit conversion factor to obtain the amount of pollutant (in tonnes) emitted by a vessel type in each mode.

Below are the equations that were used in estimating ship emissions "at sea" and "in port":

"At sea" emission calculation

Equation 7

$$E_{k,sea} = VC_{port} * EF_{k,sea} * EC_{avg,k,sea} * 10^{-6}$$

Where:

$E_{k,sea}$ =Emissions from vessel category *k* "at sea", tonnes

VC_{port} =Number of vessel calls at port

$EF_{k,sea}$ =Emission factor for vessel category *k* "at sea", g/kWh

$EC_{avg.k,sea}$ =Average energy consumption for vessel category *k* "at sea", kWh

10^{-6} =Unit conversion factor from grammes to tonne

"In port" emission calculation

Equation 8

$$E_{k,port} = VC_{port} * EF_{k,port} * EC_{avg,k,port} * 10^{-6}$$

Where:

$E_{k,port}$ =Emissions from vessel category *k* "at sea", tonnes

VC_{port} =Number of vessel calls at port

$EF_{k,port}$ =Emission factor for vessel category *k* "at sea", g/kWh

$EC_{avg.k,port}$ =Average energy consumption for vessel category *k* "at sea", kWh

10^{-6} =Unit conversion factor from grammes to tonne

A GIS presentation of the study area and a large spreadsheet were constructed to apportion and spatially represent "at sea" and "in port" emissions for each vessel type. "At sea" emissions were uniformly and linearly represented as channel segments (lines) along the River Thames using the linear referencing functionality in ArcGIS. "In port" emissions were allocated to the appropriate ports as point features. Both the "at sea" and "in port" emissions, represented as channel segments and points respectively, were overlaid with a digital layer of the generic LAEI 1km^2 grid cells and their corresponding emission values "proportion summed" to the 1km^2 grid cell that they intersected.

2011 emission projection

In the future, it is expected that there will be changes in the atmospheric emissions from marine vessels operating in the Port of London as a result of legal requirements regarding ship engines and the fuel they use, improved technologies and emission control systems. The European Union intends to propose legislation aimed to reduce marine emissions, especially legislation capping fuel sulphur content[4] and restriction of fuel type use. Consequently, a high degree of uncertainty will be introduced in any future projections (specifically, 2011 projections) of atmospheric emissions from marine vessels operating in the Port of London.

[4] In 1997, the European Commission made a proposal to amend Directive 93/12/EEC to include a limit of 1% for the sulphur content of fuel oils.

Though a steady course of investment and expansion is set to create a number of high-profile new facilities[5], which will confirm London's status as the major gateway to UK market, most of these expansions lie outside the LAEI area. Quantitative estimates of future emissions have been based on a review of literature on ship transport and emissions. Annual growth in number of vessel calls to the Port of London (that lies within the LAEI area) for future years was estimated from the "Port of London Handbook 2004" and "PLA Annual Review 2003", which was assumed at 1% growth per annum in number of vessel calls for the period 2003 – 2010. To project 2011 and 2015 emissions, the estimated emission factors for future scenarios (i.e., 2008) for "at sea" and "in port" activities (shown in Table 11 and Table 12) were derived from the Entec UK Ltd Report. Entec's estimated emission factors for 2008 years have been used to project 2011 and 2015 emissions in this study.

Table 11. Emission factors for "at sea" operation regarding vessel type, 2011and 2015

Type of Ship	Emission Factors (g/kWh)			
	NO_X	SO_2	CO_2	HC
Bulk Carrier	13.4	5.2	688	1.0
Tanker	13.1	10.2	706	1.5
Pallet Carrier	13.2	5.2	691	1.0
General Cargo	12.8	5.2	698	0.9
Specialised Cargo	7.4	12.1	881	0.9
Liquified Gas Carrier	7.4	12.1	881	0.9
Dredge/Tug	12.2	4.4	707	1.0
Ro-Ro Cargo	12.6	5.1	7.3	0.9

Table 12. Emission factors for "in port" operation regarding vessel type, 2010 and 2015

Type of Ship	Emission Factors (g/kWh)				
	NO_X	SO_2	CO_2	PM_{10}	HC
Bulk Carrier	13.4	3.0	688	0.8	1.0
Tanker	13.1	5.7	706	1.3	1.5
Pallet Carrier	13.2	3.0	691	0.8	1.0
General Cargo	12.8	3.0	698	0.8	0.9
Specialised Cargo	7.4	6.8	881	1.3	0.9
Liquified Gas Carrier	7.4	6.8	881	1.3	0.9
Dredge/Tug	10.9	4.5	747	1.1	1.0
Ro-Ro Cargo	12.6	2.9	703	0.8	0.9

Source: Entec UK Ltd, 2000

References

Entec UK Ltd (2000) Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community. Prepared for the European Commission. Final report, July 2003.

[5] P&O is planning to invest £650 million in its "London Gateway" port development at Shell Haven, in a project that will significantly boost volumes through the Port of London in 2007. Shell Haven is outside the LAEI area.

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